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AUTHORS & EDITORS

Initials	Name	Organisation	Project Role
OP, CK	Oliver Philipp, Christian Kinas	Panasonic Business Support, Europe GmbH	Main Contact in ePIcenter
RL	Ruihua Lu	Stena Line	Main Contact in ePicenter
CR	Cayetana, Ruiz de Almiron	Aker Arctic	Main Contact in ePicenter
FL	Frédéric Lasserre	Laval University	Main Contact in ePicenter
KG	Kate Gormley	Heriot-Watt University	Main Contact in ePicenter
LM	Lauren McWhinnie	Victoria University	Main Contact in ePicenter
SS	Sami Saarinen	Aker Arctic	Main Contact in ePicenter
ZZ	Zhihua Zhang	Shandong University	Main Contact in ePicenter

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List of Acronyms

Abbreviation/acronym	*Description*
AIS	Automatic identification system
AMAP	Arctic Assessment and Monitoring Programme
APM	Associated Protective Measures
ATBA	Areas To Be Avoided
CAFF	Conservation of Arctic Flora and Fauna
CCAMLR	Conservation of Antarctic Marine Living Resources
CHNL	Center for High North Logistics
COP26	26th United Nations Climate Change conference
CSL	Coastal Shipping Limited
DAS	Double Acting Ship
ECHO	Enhancing Cetacean Habitat and Observation
EEZ	Exclusive Economic Zone
GHG	Greenhouse Gas
GPS	Global Positioning System
GIS	Geographical Information System
HFO	Heavy-Duty Fuel Oil
IACS	International Association of Classification Societies
IMO	International Maritime Organization
IUCN	International Union for Conservation of Nature
LNG	Liquefied Natural Gas
MEPC 80	80^{th} session of the IMO’s Marine Environment Protection Committee
MMO	Marine Mammal Observer
MPA	Marine Protected Area
MTS	Marine Transportation Services
NEP	Northeast Passage
NGO	Non-Governmental Organisations
NORDREG	Nordic energy regulators
NSR	Northern Sea Route
NSRA	Northern Sea Route Administration
NTCL	Northern Transportation Company Limited
NWP	Northwest Passage
NWT	Northwest Territories
OSPAR	Oslo-Paris Commission
PA	Protected Area
PC	Polar Class
PSSA	Particularly Sensitive Sea Areas
SAR	Search and Rescue
SPRI	Scott Polar Research Institute
TEU	Twenty-foot equivalent unit
TPR	Transpolar Route
UNCLOS	United Nations Convention on the Law of the Sea
VTS	Vessel Traffic Services
WPSD	World Protected Sites Database
WWF/CCU	World Wildlife Fund and Circumpolar Conservation Union

Executive Summary

This paper describes opportunities of Arctic shipping. Focus is in wildlife, geo-economic and societal as well as in technical and economic aspects. Executive summaries of these aspects are presented below.

Wildlife

Rapid reduction in sea ice is facilitating an increase in commercial shipping traffic on the currently designated Arctic routes. This has mostly been driven by commercial interests in developing a viable alternative to the current routes between Asia and Europe and the potential opportunities associated with natural resource extraction e.g., fisheries and oil and gas exploration. However, there are significant concerns that increasing commercial traffic will impose considerable risks to Arctic environments and wildlife through possible events such vessel groundings, spills and collisions. The subsequent risk of environmental impacts from such incidents are further magnified due to the remoteness, lack of support systems, untested search and rescue infrastructure, lack of ports as sites of refuge, data poor regions (lack of accurate hydrographic charts in some regions) and shortages of experience crews, which all serve to amplify the risks associated with Arctic navigation. Analysis within this report has shown that shipping is not yet being considered within the Arctic protected areas, nor have the IMO yet designated any areas protected from shipping within the Arctic, highlighting the importance for management and protection measures to be implemented at the early stage for Arctic shipping.

Another significant consideration for commercial ship owners is the financial cost that are/will be associated with operating in Arctic waters. Currently vessels transiting the NSR must meet the NSRA permit fee and companies must ensure their vessels meet the criteria specified by the NSRA and marine insurance underwriters (for example winterization and structural considerations that aim to improve the safety of vessel and crew). The Polar Code has been developed by the IMO to manage the risks of Arctic shipping by setting standards and operational prerequisites related to vessel structural integrity, emergency and life saving protocols, personnel safety and training, navigational planning and enhanced environmental regulations. To realize the full potential of Arctic shipping routes its essential that stakeholders have an in-depth knowledge of the risks and hazards associated with Arctic voyage, the implications of different management measures and vessel operations, and that there is commitment to taking a proactive approach to ensuring shipping operations in the Arctic are conducted in a safe and sustainable manner. For the time being, whilst further understanding and data is collected (made accessible and communicated to mariners) it is important that appropriate routing measures are implemented (e.g., seasonal ATBAs) in areas of known environmental importance (e.g., marine mammal foraging and breeding areas) and that speed restriction are considered for areas where wildlife and vessels may unavoidably (due to navigational safety) overlap.

Geo-economic and societal

Traffic is expanding in the Arctic, but it is mainly destinational shipping, ships going to the Arctic to perform an economic activity, then heading back. Transit traffic, however in expansion, remains very moderate for structural reasons. Traffic is mainly driven by community resupply and natural resources extraction, fishing, mining and oil and gas, especially in Siberia where the Russian State is actively pushing for both the expansion of shipping and the development of minerals and oil & gas fields.

Technical and economic

The key technical and economic opportunities of arctic shipping can be concluded as follows:

Utilization of satellites and other state of the art remote sensing means to identify ice conditions and plan & optimize routes in advance to minimize costs and maximize safety and environmental friendliness.

High-quality design of the ships for the intended ice conditions (sea regions, navigational seasons) to minimize operational costs and risks associated to shipping in ice waters.

Utilization of high-tech products and services associated to the data recording, monitoring, analysing and storing for later use to increase understanding of artic shipping.

Co-operation with other ship owners, governmental bodies, etc. to share experiences and general information as well as up-to-date route-specific information to increase general understanding of arctic shipping and route-specific information.

Utilization of appropriate training to prepare ship crews to work and navigate in remote arctic environment safely and efficiently.

Co-operation with environmental bodies to minimize environmental impacts caused by arctic shipping.

This paper is a natural continuation of ePIcenter report D1.3 "Arctic & New Trade Routes Challenges" (1), which focus on challenges of arctic shipping.

IMPORTANT NOTE: this report has been prepared before the start of the terrible events in Ukraine. These events will have impacts on the future utilization of the Northern Sea Route in Arctic shipping, which has been considered in this report as one of the key shipping routes in Arctic. It should be therefore emphasized, that the content of this report applies in general level to all possible Arctic shipping routes, not only Northern Sea Route.

1 Introduction

The opportunities associated to future Arctic shipping are considered in this report. To provide context and background to these opportunities, the status of the Arctic shipping activities and related challenges today, are considered in Section 2. Detailed focus to Arctic wildlife, geo-socio-economic and technical opportunities is then given in Sections 3 - 5. At the end, conclusions summarizing the key findings and learnings, are presented.

The current status and challenges associated to the Arctic Shipping are enlightened in the ePIcenter Report D1.3 "Arctic & New Trade Routes Challenges" (1). This report is a logical continuation of the Report D1.3 focusing to the future opportunities associated to the Arctic Shipping.

This report is divided into three fundamental parts. These parts and the respective key authors are listed below.

Part 1: Opportunities associated to Arctic marine wildlife

This part is prepared by Dr. Lauren McWhinnie and Dr. Kate Gormley from Heriot-Watt University (Scotland, UK).

Part 2: Geo-economic & societal opportunities

This part is prepared by Prof. Frédéric Lasserre from Laval University (Canada).

Part 3: Technical and economic opportunities

This part is prepared by Sami Saarinen, Sabina Idrissova and Cayetana Ruiz de Almiron from Aker Arctic Technology Inc (Finland).

In addition, important contribution to the report contents have also been given by:

- Ruihua Lu from Stena Rederi A/S. His input is in Appendix C.
- Professor Zhihua Zhang from Shandong University (China). His input is in Appendix D.

Acknowledgements to all authors.

2 Arctic Shipping - General

The Arctic is changing. Temperatures in the region are increasing causing a range of physical and environmental changes. Arctic sea ice is thinning and receding (Figure 2-1, (2)). Today the autumn sea ice extend is approximately only 50% of what it was at 1980s. As these changes expose potential opportunities and because the Arctic Sea provides shorter routes for global shipping, the international interest in the Arctic has increased. The growth of international interest towards commercial utilization of Arctic Seas is inevitable.

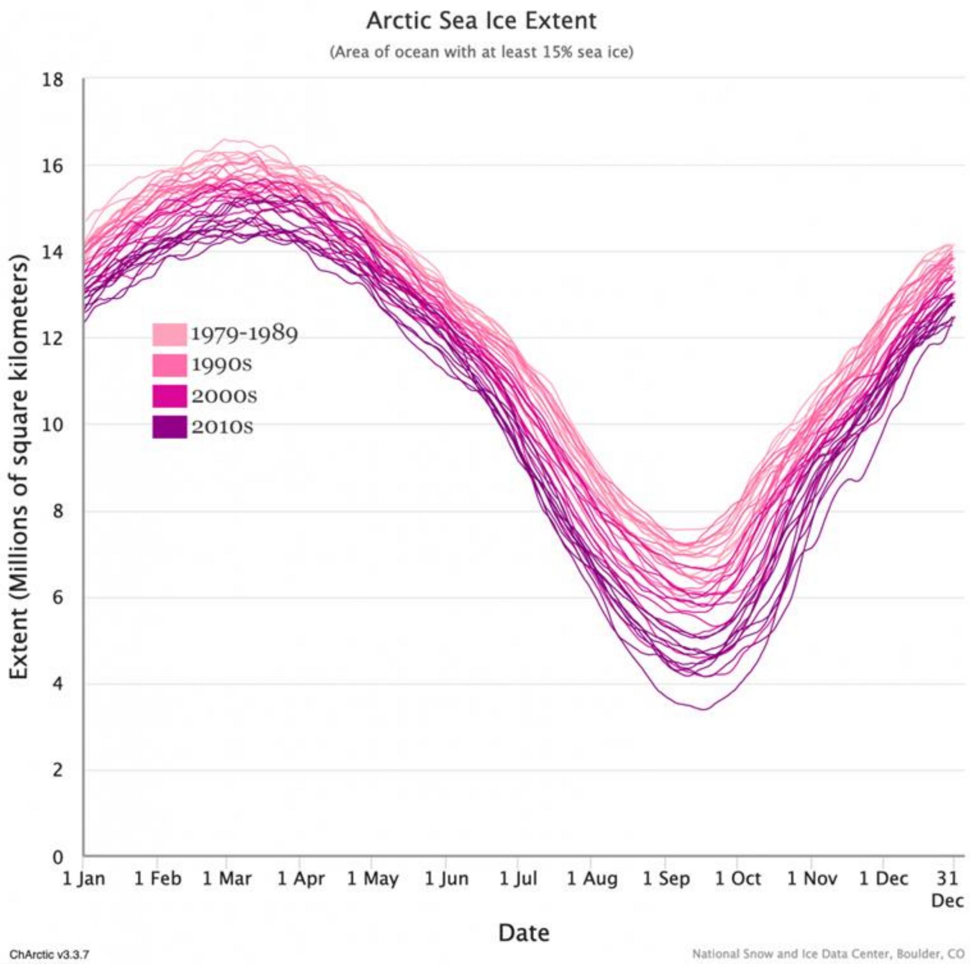

Figure 2-1. Monthly arctic sea ice extent during 1980s – 2010s.

The traffic in the Northern Sea Route is continuously growing. Gas related mega-projects, located in the Russian Arctic, as well as governmental cooperative actions of the Russia and China to build the "Ice Silk Road", will boost the near-future marine activities and shipping in the Northern Sea Route (NSR, Figure 2-2). On the other hand, commercial utilization of other trans-Arctic routes, like Northwest Passage (NWP) and Transpolar Route (TPR, Figure 2-2) is still practically zero. This is because in most of the time, the ice conditions are still too difficult in these areas for the economical shipping. The chart of shipping development at the NSR is presented in Figure 2-3 (3).

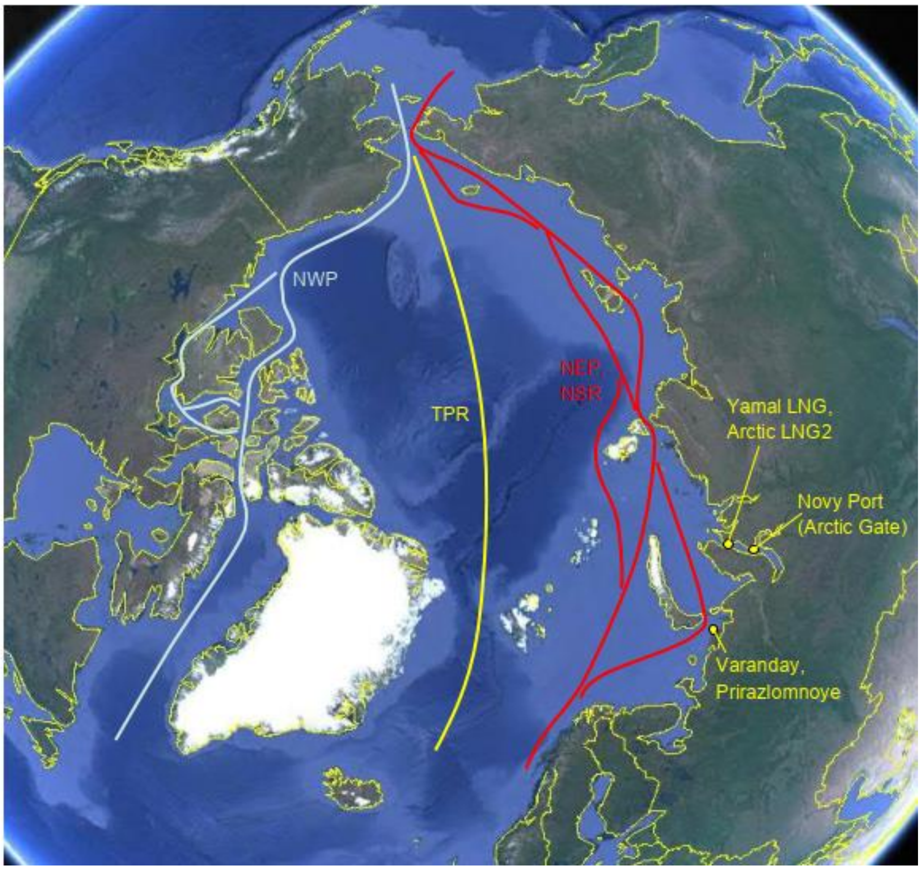

Figure 2-2 Main transit routes in the Arctic and key locations of current activities aside the Northern Sea Route.

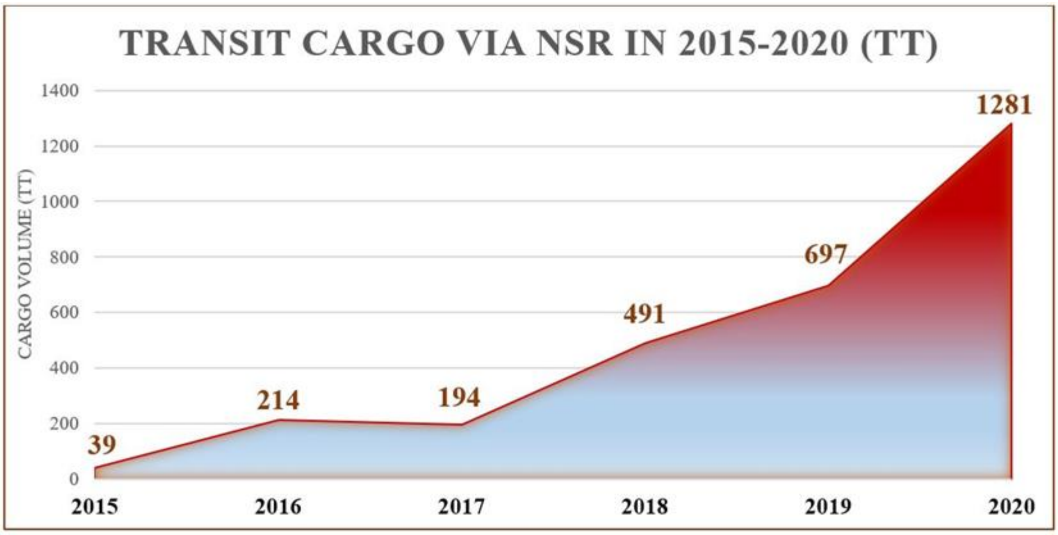

Figure 2-3. Shipping development in the Northern Sea Route (NSR)

Arctic shipping presents not only opportunities, but also challenges and threats (1). Sea ice, even if it is thinning, still creates major challenges for economically feasible shipping. Ice features, such as multi-year (icebergs, etc.) and compressive ice, which generate threats and hampers shipping, may exist in the encountered ice regime. The vessels operating in the Arctic regions should be appropriately strengthened and the ships should be designed economical ice navigation. In addition, marine and coastal infrastructure, which is inappropriate today, should be set up to enable safe navigation and reasonably quick respond times for possible hazards and their prevention in advance.

Arctic environment is vulnerable. To enable utilization of Arctic routes in an environmental-friendly manner it is important to study the effects of shipping on the Arctic nature. An understanding of Arctic environment, together with findings and learnings from anticipated future studies, can be utilised to plan and execute shipping so that the environmental impacts are minimized. In addition, these studies would improve the design of “greener ships” and enables the development of the services for “greener navigation” practices. Appropriate services, together with appropriate ships, ensure that Arctic shipping practices are conducted in the most environmentally friendly and sustainable manner in the future.

3 Part 1: Shipping Impact Mitigation, Conservation Management and Marine Mammals

3.1 Introduction

Shipping within the Arctic marine area means the potential to transit into six different international waters (Arctic nations: Canada, Kingdom of Denmark (Greenland & The Faroe Islands), Iceland, Norway, Russia, and USA. Finland and Sweden, although Arctic nations, do not have a coastline in the Arctic marine area, defined below, and will not be considered further in this report). To add to the complexity, within the Arctic marine area, a coherent and binding policy with regards to shipping is lacking; with each Arctic country and indigenous community potentially having sovereign legally binding statutes in their own authority (McWhinnie et al. 2018 (4)).

Therefore, management of shipping activities, especially within protected or sensitive areas, will vary from country to country, with the use of the International Maritime Organisation's (IMO) Polar Code (mandatory code of conduct; IMO, 2016 (5)) as the best bridging mechanism at present to harmonize and upgrade vessel operating standards within international Arctic waters (McWhinnie et al. 2018 (4)). However, the management of these protected areas will still require additional input from national governments, stakeholders (including industry), and indigenous communities to ensure their success.

This report provides an overview of marine environmental management measures that could be explored to minimise the potential damage to the Arctic marine environment from shipping activities. There are several strategies (including those still in proposal stages) that are used globally to help reduce environmental impacts associated with shipping. However, these strategies are usually developed at an international or country level, therefore impact mitigation measures should be required at the industry/company and individual ship/port level too (see Section 3.2 and 0).

For the purposes of this report the associated study area has been defined as a combination of the Arctic Assessment and Monitoring Programme (AMAP) working group of the Arctic council area and the Arctic Biodiversity Assessment (CAFF) Arctic area (Figure 3-1), known herein as the 'Arctic marine area'; sub divided into sub-Arctic, low Arctic and high Arctic regions (Figure 3-1).

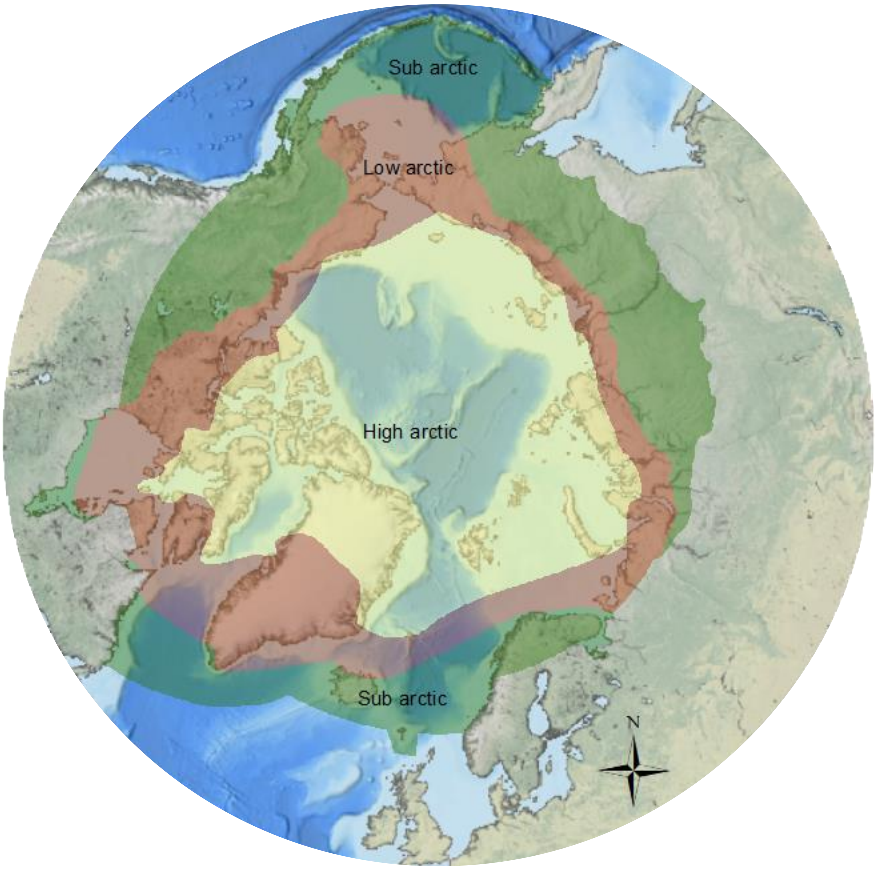

Figure 3-1. Arctic marine Region

3.2 Environmental Management Measures

3.2.1 IMO Measures

The International Maritime Organisation (IMO) is the United Nations agency responsible for the safety and security of international shipping and in the prevention of marine pollution from vessel activities (6). To fulfil their objectives the IMO create and implement an authoritative and universally applicable regulatory framework for international shipping. Through their comprehensive body of international conventions, the IMO has developed numerous measures, both recommendatory and mandatory, that can be used to help protect the Arctic marine environment from negative effects caused by international shipping activities, these include:

- Particularly Sensitive Sea Areas (see below)
- Navigational aids
    - Ship Routing Systems
        - Areas to be Avoided (ATBA)
        - No-Anchoring Areas
        - Traffic Separation Scheme
        - Traffic Lane
        - Recommended Route
        - Recommended Track
        - Two-Way Route
        - Inshore Traffic Zone
        - Roundabout
        - Precautionary Area
        - Deep Water Route

- Ship Reporting Systems
- Discharge Restrictions
    - Special Areas
    - Emission Control Areas
- Speed Recommendations

One component of the IMO's purview is the designation of various marine protected areas (MPA's) around the world specifically to mitigate the effects of shipping, these include Particularly Sensitive Sea Areas (PSSA's), which offer a specific type of protection.

A PSSA is "*an area that needs special protection through action by IMO because of its significance for recognized ecological, socio-economic, or scientific attributes where such attributes may be vulnerable to damage by international shipping activities. At the time of designation of a PSSA, an associated protective measure, which meets the requirements of the appropriate legal instrument establishing such measure, must have been approved or adopted by IMO to prevent, reduce, or eliminate the threat or identified vulnerability*." (7).

Therefore, PSSA's are provided with an international legal status that allows countries to promote regulations (such as those previously listed associated protective measures APM's), for all vessels in their waters, not just those vessels carrying their own countries flag or visiting their ports and includes vessels in 'international waters' such as narrow straits that are separating the jurisdiction of different countries for example the Bering Strait. Notably, PSSA's are the only tool of the IMO that allows for local cultural and ecological resources, (as opposed to vessel or mariner safety), to be the justification for environmental protections through the regulation of international vessel traffic.

When ships are within the PSSAs, the PSSAs can be protected via any of the measures listed above e.g., routing measures, strict application of MARPOL discharge and equipment requirements, installation of for example, Vessel Traffic Services (VTS) (7)). The intention is that each of these measures is linked to specific marine ecosystem services, with the goal of the APM sustaining those services when presented with pressures or threats from vessel traffic.

At present, there are no designated PSSAs within the Arctic marine area or any PSSAs specifically designated for marine mammals.

3.2.2 Oil Spill response

Since the IMO placed a ban on the use and carriage for use of heavy-duty fuel oil (HFO) for ships operating in Antarctic waters in 2011, there has been significant international debate on whether to adopt a similar standard for ships operating in Arctic waters (8). The most severe threat from HFO's in Arctic shipping is an oil spill. Navigational and operational measures could help reduce the risks associated with vessel source oil pollution. Some of the potential measures that could be introduced via the IMO include ship routeing measures (such as areas to be avoided) and Particularly Sensitive Sea Areas (PSSA's). For instance, IMO approved the Bering Strait and Sea ship routeing measures proposed by the United States and Russian Federation. These had six, 2-way routes and six precautionary areas that have been in effect since December 2018. These measures were the first IMO approved ship routeing measures to be put in place within Polar Code waters with the intention that they would play a precautionary role and mitigate the risks caused by an HFO spill from Arctic shipping through increasing maritime safety. Additionally, under Article 211(6) of UNCLOS, Arctic states may seek IMO assistance in adopting a special mandatory measure with respect to HFOs in the Arctic (9).

In terms of dealing with actual spill incidents, there are a range of response techniques that have been developed in laboratories and in controlled experiments in Arctic conditions. However, they are yet to be tested on full-scale spill events. In real-world terms the remoteness, lack of infrastructure and extreme environmental conditions in the Arctic all mean that there are significant logistical and operational challenges that have yet to be overcome. Equipment, vessels and personnel would all need to be mobilised over vast ranges to contain a potential spill. Teams would need to be trained to not only to respond to spills but also to survive and administer first aid in extreme environments. Considerable planning would be required to ensure the safety of oil spill responders in Arctic conditions, that, depending on the time of year may also mean 24hrs of darkness, extremely low temperatures and exposure to dangerous wildlife.

Incident management and communications related to spill response will also prove further challenges. Clean-up sites may be very remote and ultimately this could lead to clean-up operations taking several months. Additionally, the storage, transportation and disposal of oily waste can be another difficult issue to deal with, and also very costly, but this an important issue that has to be considered in remote regions with little infrastructure.

Ultimately, there may be instances that make it impossible to respond to an oil spill, such as, location and time of year (environmental conditions). When responses are possible, risks associated with response deployment will also likely need to be evaluated. From our review it seems that there is a discrepancy between the research and development that has been and continues to be undertaken, and the response technology that is commercially available. To date Arctic response techniques have mostly centred around dealing with crude oils, mainly driven by the increase in exploration and production activities. In recent years there have also been increasing incidents of bunker fuel spills (from non-tankers) which emphasises the risk of spills occurring from shipping activities more generally.

3.2.3 Green Shipping Corridors and Zero-Emissions Shipping

Plans for the decarbonisation of the shipping industry was a highlight for the industry at COP26, November 2021, with the discussions focussing on “green shipping corridors” and “zero-emission shipping”. Twenty-two countries became signatories of the “Clydebank Declaration for green shipping corridors” (10). The signatories of the Declaration, among other statements...

“*Emphasise the importance of pursuing efforts to limit the increase in the global average temperature to 1.5°C above pre-industrial levels....... Recognise the benefits of pursuing synergies between decarbonisation and clean air policies in shipping, and building on existing measures related to the reduction of pollution from ships....... recognise that a rapid transition in the coming decade to clean maritime fuels, zero-emission vessels, alternative propulsion systems, and the global availability of landside infrastructure to support these, is imperative for the transition to clean shipping*.”

The Declaration mission statement states that....

“*The signatories of the Declaration are to support the establishment of green shipping corridors – zero-emission maritime routes between 2 (or more) ports. It is our collective aim to support the establishment of at least 6 green corridors by the middle of this decade, while aiming to scale activity up in the following years, by inter alia supporting the establishment of more routes, longer routes and/or having more ships on the same routes. It is our aspiration to see many more corridors in operation by 2030. We will assess these goals by the middle of this decade, with a view to increasing the number of green corridors*.”

It is the intention that these first “green corridors” will be used to test and prove the “zero-emissions” technology across the whole value chain (including: ports, energy providers, ship owners, customers, investors etc.). The goal is for ships capable of running on zero-emissions fuels to make up at least 5% of the global fleet by 2030 (11).

At the IMO’s Maritime Environmental Protection Committee 77th meeting immediately following COP26 (22nd-26th November 2021), delegates agreed to initiate the revision of the Initial IMO Strategy on Reduction of GHG emissions from ships, with a view for this to be adopted by MEPC 80 in 2023, showing the IMO’s commitment to the decarbonisation of the global shipping industry, in line with discussions at COP26 (12).

It is unclear however, whether the “green shipping corridors” would only be focussing on GHG emissions, or whether other environmental impact mitigation measures (such as protected/sensitive areas and the associated shipping management tools, see section 0) would also be implemented within these corridors to maximise wildlife and environment protection, only time will tell.

3.2.4 Voluntary Measures

Voluntary management measures for shipping are also in use internationally. An example of a voluntary environmental management measure is presented in case study 1 (Table 3-1).

Table 3-1. Case Study 1: Green Marine

Case Study 1: Green Marine
Green Marine (https://green-marine.org/) is a voluntary environmental certification program for the marine industry. Addressing key environmental issues through 14 performance indicators: Aquatic invasive species; cargo residues, community impacts, community relations, dry bulk handling and storage, environmental leadership, greenhouse gas emissions, oily discharge, pollutant air emissions: NOx, SOx, PM; spill prevention and stormwater management, ship recycling, underwater noise, waste management. Participants of the program include: shipowners, ports, terminals, Seaway corporations and shipyards. The program encourages its participants to reduce their environmental footprint by taking concrete actions. To receive their certification, participants must benchmark their annual environmental performance through Green Marine environmental program's exhaustive self-evaluation guides. They also need to have their results verified by an accredited external verifier and agree to publication of their individual results.

3.2.5 Marine Protected Areas

The IUCN define Marine Protected Areas (MPAs) as "areas of the ocean set aside for long-term conservation aims – are the only mainstream conservation-focussed, area-based measure to increase the quality and extent of ocean protection. MPAs and their network offer nature-based solution to support global efforts towards climate change adaptation and mitigation." Selection, spatial extent and management measures for MPAs are the responsibility of individual countries (within their EEZ) and various commissions and organisations in international waters (e.g., Commission for the Conservation of Antarctic Marine Living Resources, CCAMLR; Oslo-Paris Commission, OSPAR.

Data taken from the World Protected Sites Database (13) reports there are 572 (154 marine and 418 coastal) protected area designations within the Arctic marine area. Note: designations are classed as individual designations, and not the number of protected sites as some sites/areas may have multiple designations, for all or part of the area. It should be noted that this database is not complete, and a number of protected areas are not yet included. An additional 19 MPAs have been identified within the Arctic marine area, but no spatial data was available for those sites for inclusion in any further analysis (14).

The Sub Arctic has most of the designations (80%; Table 3-2), the High Arctic has 11%, with the Low Arctic having the fewest (9%) designations. Note: some of these protected areas may overlap more than one Arctic region (Figure 3-2).

Table 3-2. Number of Marine and Coastal protected area designations in the Arctic marine region

Region	*Marine Designations*	*Coastal Designations*	*Total No. Designations*
Sub Arctic	115	344	459
Low Arctic	16	34	50
High Arctic	23	40	63

Within the Arctic marine area, there are currently 57 designation types (Appendix A. Protected Area Designation by Arctic Country) across 7 nations (UK, although not an Arctic nation, has two designations that extend into the Arctic marine area between the Faroes and Shetland Islands). These designations are either at an international, regional, or national level. Each of these designation types will have different requirements from a management plan, reporting and allowance of activity perspective, and will vary between countries – highlighting the complexity of environmental protection, conservation, and management in the Arctic marine area.

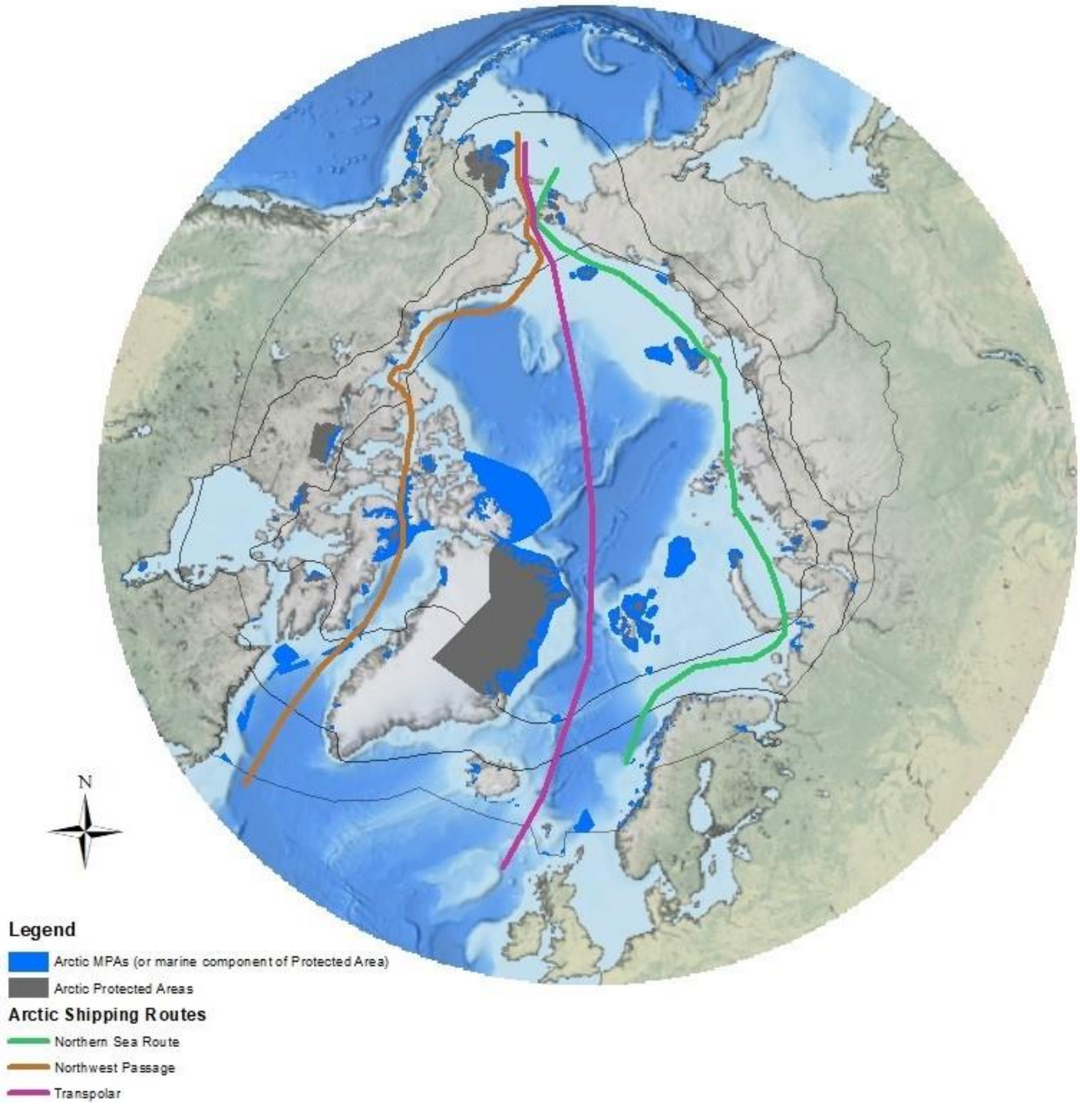

Figure 3-2. Marine Protected Areas within the Arctic marine Region

3.3 Arctic Shipping and Protected Areas

To understand the potential impact of shipping on Arctic wildlife (in particular, marine mammals) and marine protected areas, it is important to understand the type of protected areas within the vicinity of the three identified "shipping routes": Northern Sea route, Northwest Passage and Transpolar route (Figure 3-3). Here, shipping "corridors" were created representing a 14, 25, 50 and 100km buffer around each of the shipping routes. Analysis was carried out using ArcGIS 10.7 to determine which MPAs fell within each of the shipping corridors.

Results show that a total of 14 marine (MPA) and coastal (PA) protected areas fall within the 14, 25, 50, 100 km shipping corridors (Table 3-3). Of these 14 protected areas, 9 have been designated for marine mammals, of the remaining 5, three protected areas note that marine mammals are present within the area but are designated for other reasons such as seabirds or seabed features (e.g., coral); and 2 do not mention marine mammals (Table 3-4).

Of the 14 protected areas located within proximity to/or within a currently designated shipping corridor, only one protected area highlights increased shipping as a potential threat, however, no specific shipping management measures have been named within the management plan. Of the remaining 13 protected areas, either no management plan was available, navigation was not listed within the management plan, or measures are applicable to fisheries only.

Table 3-3. Number of Marine and Coastal protected areas within the Arctic shipping route "corridors"

Route	*Corridor (km)*	*No. MPA designations*	*Area (Km^2)*	*No. Coastal PAs designations*	*Area (Km^2)*	*Total No. Coastal PAs/ MPAs*	*Total MPA Area Intersection (km^2)*	*No. of available Management Plans*
Transpolar	**14**	0	n/a	0	n/a	0	n/a	n/a
	25	0	n/a	0	n/a	0	n/a	n/a
	50	0	n/a	0	n/a	0	n/a	n/a
	100	0	n/a	1	231	1	231	0
Northwest Passage	**14**	3	14,727	1	1	4	14,728	4
	25	4	26,224	2	76	6	26,299	6
	50	4	50,690	4	306	8	50,996	6
	100	6	83,301	8	1,790	14	85,091	10
Northern Sea Route	**14**	0	n/a	1	89	1	89	0
	25	0	n/a	3	338	3	338	0
	50	0	n/a	3	1,712	3	1,712	0
	100	1	79	4	7,976	5	8,055	1

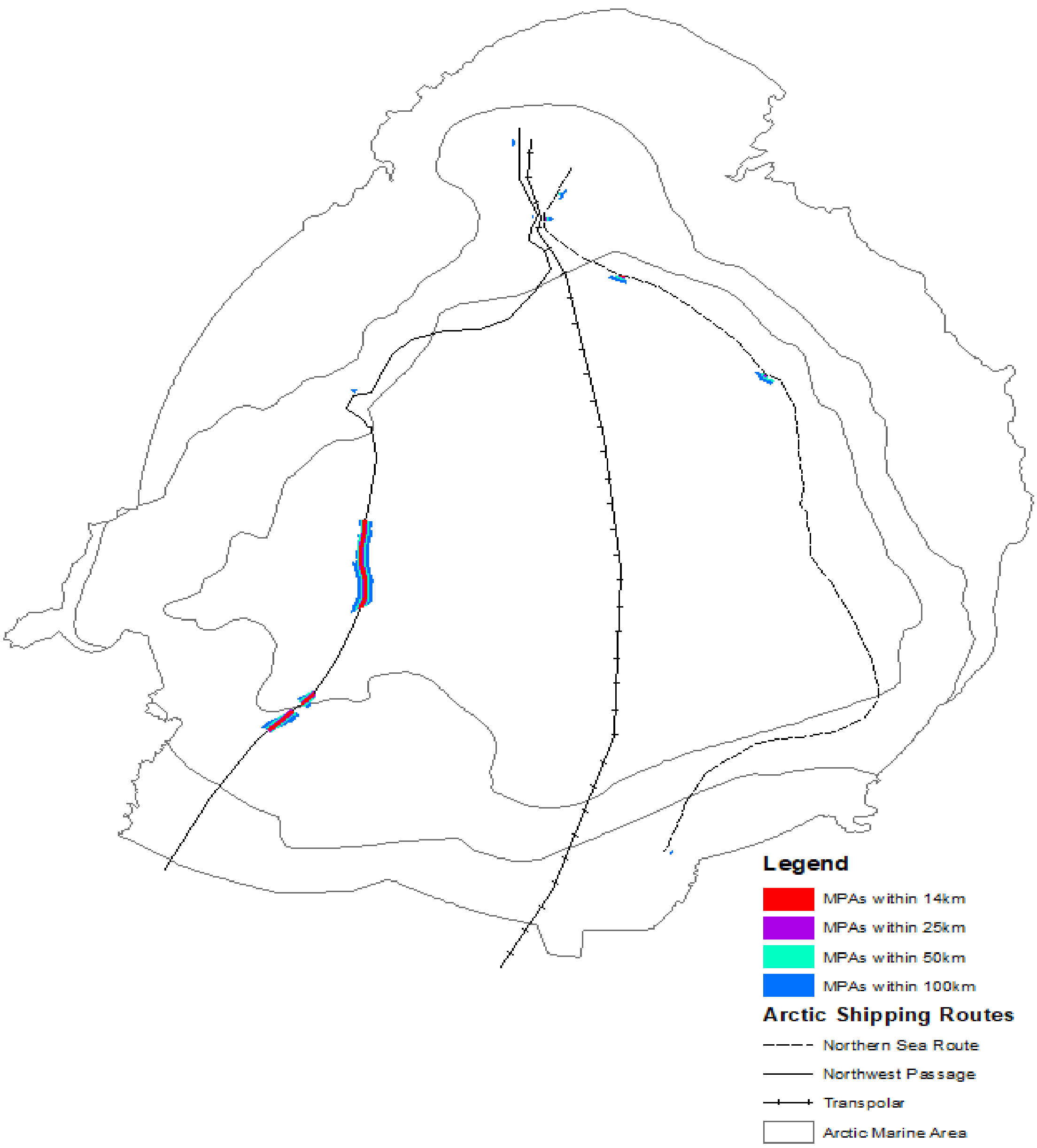

Figure 3-3. Marine and coastal protected areas which fall within the "shipping corridors"

Table 3-4. Arctic marine and costal protected areas within the shipping corridors and their associated designation and management plan information regarding shipping

Name	***Designated for Marine Mammals?***	***Shipping Mentioned in Management Plan?***
Alaska Maritime	Beluga, Blue, Gray, Bowhead, Humpback, northern fur seals, harbour seal, otters, Steller sea lion, walrus, polar bear	No - navigation to not be impeded under the Alaska National Interest Lands Conservation Act
Alaska Maritime National Wildlife Refuge		No - navigation to not be impeded under the Alaska National Interest Lands Conservation Act
Anguniaqvia Niqiqyuam Marine Protected Area	beluga whales, ringed and bearded seals	Increased shipping is identified as a threat, however navigation can still occur in the MPA, under Canada Shipping Act, 2001, no other specific shipping management measures are in place.
Disko Fan Conservation Area (portion closed to all bottom-contact fishing)	Narwhal (and corals)	No - fisheries management measures only mentioned to preserve corals
Natural System of Wrangel Island Reserve	Walrus and Gray whale	No information
Novosibirskie ostrova	Walrus, Beluga, and bearded seal	No information
Yukon Delta	Polar bear, walrus, spotted seal, harbor seal, ringed seal, bearded seal, ribbon seal, northern fur seal, Steller's sea lion, beluga, minke, gray, bowhead, killer whales	
Yukon Delta National Wildlife Refuge		No - navigation to not be impeded under the Alaska National Interest Lands Conservation Act
Tallurutiup Imanga	bowhead and beluga whales, narwhal, walrus and polar bear	Navigation is listed in the agreement - but no management strategies specifically mentioned - more to do with the communication and discussion of navigation matters with the local community
Prince Leopold Island Bird Sanctuary	No - but marine mammals are listed in the area, but protection for seabirds specifically (Nunavut beneficiaries do not require a permit to carry out activities related to subsistence harvesting in this sanctuary)	No - permits relate directly to access to reserve and disturbance to seabirds - doesn't imply that the access permit is required for the marine component.
Røstrevet	No - Lophelia pertusa (cold water coral)	No specific management plan available
Beringiy	No - but marine mammals present in area	No information
Bylot Island Bird Sanctuary	No - but marine mammals are listed in the area, but protection for seabirds specifically (Nunavut beneficiaries do not require a permit to carry out activities related to subsistence harvesting in this sanctuary)	No - permits relate directly to access to reserve and disturbance to seabirds - doesn't imply that the access permit is required for the marine component.
Davis Strait Conservation Area	no - corals, seapens and sponges	No - bottom trawling prohibited to preserve corals

3.4 Addressing Shipping Impacts: Tools, Challenges and Opportunities

As seen in Section 3.2 and 3.3, the inclusion of shipping management measures is currently lacking from the MPAs identified within the shipping corridors; this will need to be addressed to ensure adequate protection. For the Arctic marine area therefore, best practice from international shipping case studies is a good place to start, to ensure good management techniques are deployed at the early development of Arctic shipping.

(15) examined and reviewed 10 global shipping management case studies, including: management plans, shipping areas, shipping straits, key routes and management programs. Their review focused on 6 themes:

1. Shipping operations
2. Economic opportunities
3. Marine safety
4. Training
5. Marine environmental protection
6. Technology and information

Each of those themes were further broken down for analysis, into:

1. Key findings and strengths
2. Areas of improvement

In summary, common key findings and areas for improvement that were noted for the case study areas are presented in Table 4. The full table of case studies and analysis is presented in Appendix B. Marine Management Case Studies (based on (15)).

Table 3-5. Global shipping management case studies Case study key findings

Key Findings and Strengths	***Areas for improvement***
• Use of traffic lanes, voluntary routing measures and shipping corridors; • Use of aids to navigation; • Emergency, operational and/or environmental response training; • Subsistence activities that support local economies; • Protected and/or significant areas and resources; and • Use of AIS, GPS, GIS and/or VTS to improve navigational safety and/or support research.	• Outdated infrastructure, lack of research and Indigenous community involvement; • Lack of aids to navigation and inadequate boundaries for SAR; • Outdated response training; • Poor marketing scheme; and • Insufficient oil spill response
source: Reid and Dawson 2019	

(4) conducted a comprehensive review of vessel management tools within MPAs. These tools, although specifically applicable to the management of MPAs, provide good examples of management strategies that could be applied more widely within the Arctic marine area. Some of these tools will be more practical than others. Ease of implementation, management/administrative/monitoring effort, cost, and industry/stakeholder buy-in will significantly impact the success of any shipping management strategy.

- Spatial Management Tools
    - Mandatory exclusion zones
    - Restricted Access/Permitting System
    - Voluntary Exclusion Zone
    - Vessel Re-routing/Transit Separation Scheme
- Vessel Based Tools
    - Pilotage
    - Code of Conduct
    - Reporting

    - Speed Reduction
- Monitoring Tools
    - Passive Acoustic Monitoring
    - Marine Mammals Observers (MMO)
    - Automatic identification system (AIS)
- Outreach Tools
    - Ship: training
    - Industry/Stakeholders: communication and information sharing
    - General Public: information sharing and engagement

Examples of use of these management measures are presented in case studies 2 and 3 below.

Low frequency noise from commercial vessel traffic is increasingly becoming the dominant source of sound in many arctic regions. Icebreakers by contrast produce slightly higher and more variable noise due to the episodic nature of ice breaking (this often involves maneuvering back and subsequent ramming into ice). Additionally, some icebreakers are equipped with bubbler systems that blow high pressure air into the sea water to push floating ice away from the vessel, this increases the noise levels associated with this type of vessel over short distances.

There is already evidence that several Arctic species will be negatively impacted by increasing noise levels within their habitats. For example, Beluga have been shown to quickly leave an area in response to approaching icebreakers and then not return to the area for several days. Bowheads have also been documented exhibiting similar avoidance responses, therefore the potential displacement of these species from their preferred areas will likely result in negative consequences such as reduced fitness, increased competition, and reduction in potential foraging opportunities. As covered in the previous report (D1.3 Artic & new trade routes challenges (1)), exposure to anthropogenic noise can also result in a variety of behavioral reactions, increase stress levels, impact reproductive success, cause permanent and temporary threshold shift in hearing, and result in changes to ecosystem dynamics due to reduce prey availability; all of which can negatively impact species at a population level. Case study 2 (Table 3-6) outlines an example of best practices that have been developed for the west coast of Canada, but additional vessel maintenance measures have also been identified that can help reduce noise source levels of individual vessels, these include (16):

- Regular propeller maintenance and repair
- Regular cleaning of vessel hull
- Hull coatings that reduce fouling
- Propeller design/modification (to reduce cavitation and improve wake flow)
- Alternate propulsion mechanisms such as water pump)
- Use of quieter engines (e.g. electric)
- Reduction of onboard engine and machinery noise (auxiliary noise)

Table 3-6. Case Study 2: Vessel Slow Down

Case Study 2: Vessel Slow Down
In 2014 the Vancouver Fraser Port Authority launched the Enhancing Cetacean Habitat and Observation (ECHO) Program with the aim of trying to better understand and reduce the cumulative effects of shipping on whales within the southern coastal waters of British Columbia. ECHO leads, collaborates on and supports a range of projects, educational initiatives and voluntary research trials that are designed to help inform the development of potential threat-reduction solutions. Projects focus on three main threats: acoustic disturbance (underwater noise), physical disturbance (vessel collision) and environmental contaminants. The ECHO program has installed an unwater listening station in the nearby Strait of Georgia, is working to monitor regional ambient noise levels, has supported a large whale strike risk assessment and developed a Mariner's Guide to Whales for the North West Pacific. In 2017 they initiated their first annual slowdown initiative, since then this measure, designed to reduce the amount of vessel noise within the core habitat of an endangered population of killer whales, has involved over 80 shipping organizations and six thousand ships. They have also since introduced additional measures to distance ships from the whales core foraging areas (lateral displacement of shipping lanes). Due to high levels of industry participation in these voluntary measures (incentivized by through ECHO by measures such as reduced berthing fees and prioritization for getting into Port), these initiatives have reduced underwater noise by almost 50% (slowdowns) and 70% (distancing measures) with the aim of reducing acoustic disturbance to Southern Resident Killer Whales.

Ensuring that we establish best practices for mitigating risks to wildlife (e.g. marine mammal avoidance) in the Arctic will require a balance to be struck between providing mariners with the suitable tools and ensuring that enforeable regulations are put in place. In the instance of marine mammals there are considerable oppertuinties to improve the information required to anact marine mammal avoidance measures these include but are not limited to:

- Centralised collation of best available marine mammal data this can ensure the identification of knowledge gaps and enable resources to support dedicated surveys to be undertaken in areas that are data deficient/poor/requires updating (the later may be important considering the rapid effects of climate change on ice associated species
- Standardisation of future data collection across agencies and national governments and suitable archiving of existing data

Additionally there are several established means of communicating marine mammal information to mariners (as identified in WWF/CCU -Arctic Shipping Best Practices report; (17)) and these should be explored in terms of their suitability for Arctic routes, they include:

- Electronic navigatioin charts
- Voyage planning documents
- Notices to mariners and notices to shipping
- Mariner guides, graphics and apps
- Risk assessment/decision support tools
- Real-time, satellite-based electronic notification systems

Table 3-7. Case Study 3: Real-time Passive Acoustic Detectors

Case Study 3: Real-time Passive Acoustic Detectors
Cornell University and the Woods Hole Oceanographic Institute have developed a whale-detection system along the primary shipping lanes for the Port of Boston. This system is made of 10 buoys instrumented with an underwater hydrophone 60-120ft. beneath the surface. Recorded sounds are carried to the surface where data is relayed to computers on the surface buoy. These computers continuously analyze the acoustic recordings to detect possible right whale calls. This critically endangered population of whales is particularly susceptible to vessel collisions and the leading cause of death along with entanglements for this species. When right whale calls are detected on the hydrophone recording, they are sent by satellite of cellular phone to a server at a command and control center where trained analysts validate the recordings. If an alert is confirmed an alert is sent out to all unbound LNG tankers where a whale has been detected. Updates on whale detections are sent to ships every 20mins as they proceed into Port. With the advanced warning, ships can be slowed or re-routed to reduce the risk of a lethal strike occurring. Currently only tankers are mandated to slow down but all ships are encouraged to check the whale-buoy alerts and slow down if they find themselves in the area where whales have been detected by a buoy. Slowing down increases the chance that a ship's crew can spot a whale while there's still time to avoid it or give the animals the chance to move out of the path of the vessel.

The maritime sector now widely utilises AIS technology and other e-navigation systems to track and aid the navigational efficiency and safety of vessel traffic. The advancement of AIS data allows for both on-shore and ship-ship tracking of vessels that helps to avoid collisions, ensure ships maintain a safe distance from hazardous areas, locate vessels involved in incidents/distressed and ultimately play a key role in search and rescue opeerations. Importantly, it has also paved the way for vessel monitoring systems that support safer maritime practices and compliance with both mandatory and voluntary regulations. Establishing vessel monitoring systems that have sufficient coverage and reliability has been a key objective of Arctic vessel opperations in recent years. Case study 3 explores some of the emerging technologies that can be used to monitor vessel traffic and marine mammals and presents an example of they can be integrated to support efforts to reduce risk to wildlife in a heavily traffic area.

4 Part 2: Geo-economic & societal Opportunities of Arctic shipping

4.1 Traffic is expanding in the Arctic

Figures below (Table 4-1, Table 4-2, Table 4-3) indicate that vessel voyages[1] are definitely increasing substantially in the Arctic. From 2009 to 2021, traffic was multiplied by 1.97 in the Canadian Arctic, by 1.97 between 2009 and 2019 in Greenlandic waters, and by 1.7 between 2016 and 2020 in waters of the Northern Sea Route.[2]

Table 4-1. Vessel movements in the Canadian Arctic, number of voyages, NORDREG zone

	2009	2011	2013	2014	2015	2016	2017	2018	2019	2020	2021
SHIP TONNAGE, MILLION TONS (DWT)		1.28	1.39	1.43	1.8	2.79	3.54	4.38	5.16	7.6	14.6
VOYAGES	225	319	348	302	315	347	416	408	431	345	444
OF WHICH:											
FISHING BOATS	65	136	137	119	129	131	138	139	137	132	134
CARGO OR BARGES	109	126	127	108	120	147	188	197	223	183	289
OF WHICH:											
GENERAL CARGO	23	38	35	32	34	36	50	48	59	41	55
TANKER	23	30	28	25	27	23	24	29	28	31	36
DRY BULK	27	23	27	33	36	53	72	89	106	91	167
TUGS AND BARGES	36	33	36	18	23	35	42	31	30	20	31
PLEASURE CRAFTS	12	15	32	30	23	22	32	17	19	2	1
CRUISE/PASSENGER	11	11	17	11	18	20	19	21	24	0	0
GOVERNMENT VESSELS (ICEBREAKERS, NAVY)	21	20	17	23	16	20	22	18	20	21	11
RESEARCH VESSELS	7	11	20	10	9	6	13	13	8	4	3
OTHERS					3	3	6	3		3	6

Source: figures compiled by the author from data submitted by NORDREG, Iqaluit and by XST Xpert Solutions Technologiques inc.[3]

[1] A voyage is the movement of a vessel here in the NORDREG zone, between its entry point and its exit point.
[2] The Northern Sea Route comprises Russian Arctic waters between the Kara Gate and the Bering Strait. Thus, traffic in the Barents Sea is not included in NSR figures, nor traffic in Russia's Arctic Pacific waters.
[3] The author would like to express gratitude to NORDREG and XST Xpert Solutions Technologiques inc for their cooperation in the frame of this research.

Table 4-2. Voyages to and from Greenlandic waters

	2009	2011	2013	2014	2015	2016	2017	2018	2019	2020
Container, general cargo	159	184	141	155	135	150	151	113	146	151
Passenger, cruise	96	113	130	122	105	222	249	372	241	3
Bulk	12	0	2	1	20	88	132	155	188	164
Tankers	57	60	24	29	22	20	31	36	40	28
Fishing vessels	54	145	124	120	123	144	142	168	149	156
Research vessels	62	44	20	31	24	32	33	20	10	13
Other ships	59	73	48	88	122	131	143	209	228	69
Offshore	0	61	6	0	0	0	0	0	4	2
Government vessels	12	17	12	13	13	13	19	5	3	10
Total	511	697	507	559	564	800	900	1078	1009	596
Source: Joint Arctic Command, Nuuk, 2021										

Table 4-3. Vessel movements in NSR waters, number of voyages

	2016	2017	2018	2019	2020	2021*
Volume transported, million metric tons	7.265	10.713	20.18	31.53	32.97	34.85
Voyages in NSR waters	1 705	1 908	2 022	2 694	2 905	2 739*
Of which:						
Tanker	477	653	686	799	750	
LNG tanker		13	225	507	510	
General Cargo	nd	nd	nd	nd	49	
Bulk	519	515	422	546	710	
Container	169	156	150	171	171	
Icebreaker	58	101	232	231	220	
Supply		57	104	169	264	
Research	91	87	85	93	114	
Source: adapted from CHNL (18) *Data as of October 31st.						

The years 2020 and 2021 were particular because of the impacts of the pandemic, that either affected mining (19) or triggered a ban on cruise shipping in Canada, for instance. In the Canadian Arctic, 2020 is marked by a decrease in traffic (-20%), largely attributable to the drop in traffic of pleasure craft and cruise ships, banned from entry due to the covid-19 pandemic. The number of merchant ships has decreased, but the total tonnage has increased, an indication of the arrival of larger ships to serve operating mining sites like Mary River on Baffin Island or Raglan and Jilin Jien in Northern Quebec. For 2021, the ban on tourism-related traffic (cruising and yachting) was still enforced[4], but fishing traffic recovered while commercial traffic exploded, +43.5% from 2020 and +19.7% above 2019 figures.

Despite the general and substantial increase in vessel traffic observed in the two areas, contrasting trends can be observed from these figures.

In the Canadian Arctic, in terms of voyages, fishing vessels experienced a steady expansion between 2009 and 2011, going from 65 to 136 voyages, but fishing traffic has since then stalled. Traffic was pulled by cargo ships activity (+145 % from 2009 to 2021), of which dry bulk experienced the fastest expansion (+518.5 %), driven by

[4] The only pleasure craft voyaging the Canadian Arctic in 2021 was a Chinese craft, Zhai Mo 1, that was not authorized to enter Canadian waters. Similarly, in 2020 the New Zealand Kiwi Roa pleasure craft entered Nordreg zone without clearance and transited the NWP (Nordreg database).

mining activities, and general cargo (+139.1 %), driven by community resupply. Part of community resupply is also performed by barges pushed by tugs, from Hay River on the Great Slave Lake and then down the Mackenzie River, or from the port of Moosonee to Northern Ontario communities. Tonnage is experiencing a significant growth largely due to the expansion of bulk cargo traffic, growing from 1.28 million dwt in 2011 to 14.6 million dwt in 2021 (+1 040.6%).

Bulk traffic has benefited from the exploitation of Arctic and subarctic mines, such as Voisey's Bay (Labrador), Raglan and Canadian Royalties/Jilin Jien (Quebec), and Mary River (Baffin Island, Nunavut). This expanding traffic has largely compensated dwindling traffic to and from Churchill since the port closed down in 2016 before reopening in 2019 (only 4 voyages of grain-carrying bulk vessels in 2019 and 3 in 2020). For instance, Baffinland Iron Mines shipped 920,000 tons of ore from its mine in Mary River through its port of Milne Inlet in the first year of activity in 2015, then 4.1 million tons in 2017 (20), 5.1 million tons in 2018 (21) and 5.5 million tons in 2020 (22). The company intends to eventually reach an annual volume of 12 million tons in the next few years, and eventually 30 million tons((22); (23)). Other active gold mines north of Rankin Inlet also generate traffic related to the logistics of mining operations. In the Canadian Archipelago, Fednav operates strong PC4 vessels (*Arctic*, *Umiak, Nunavik, Arvik*) capable of navigating in winter, servicing the two Deception Bay mines in northern Quebec. The company may develop a business model in partnership with mining companies for year-round shipping to Deception Bay and Milne Inlet (operational) as well as Steensby Inlet (projected). The logistics of mining activities are dominant in terms of tonnage in the Canadian Arctic: in 2020, the capacity of bulk carriers servicing mines (measured in cumulated vessel dwt), at 6.1 Mt, accounted for 77.3% of the tonnage capacity of traffic (measured in dwt) in the Canadian Arctic; in 2021, at 12,32 Mt, it accounted for 84.4%. Large, powerful dry bulk carriers transport ore from the maritime terminal built to service the mines: the construction of deep-water docks is required for base-metal mines that ship large quantities of ore, as is the case at Milne Inlet (Mary River) and Deception Bay (Raglan and Jilin Jien) (24).

In Russia, tanker traffic increased 164,2 % between 2016 and 2020. LNG tanker went from nil to 510 voyages, and icebreaker voyages increased 238 %. Tanker traffic experienced a sustained growth with the oil and gas developments in the Kara Sea (Prirazlomoye and Varandey oil terminals) (25) and on the Yamal peninsula and Ob Bay, with Sabetta and Novy Port main terminals and the impending opening up of Arctic LNG 2 terminal (26); (27). The scheduled opening of new oil fields (Vankor in particular) in the Taymyr peninsula, east of the Yenisei delta, should contribute to the expansion of traffic: the Vankor field should produce 30 million tons from 2024. With the programmed opening of coal and lead and zinc mines, and more ore shipments from the port of Murmansk, bulk traffic should experience a fast growth in the Russian Arctic as well,[5] whereas fishing, concentrated in the Barents and Bering Seas, does not appear in these statistics.

It is apparent that the main driver for the expansion of shipping in both the NWP and the NSR is natural resources exploitation, including mining, oil and gas, and fishing. Community resupply in Canadian waters and cruise ship traffic in Greenland also experienced sustained growth.

Resource extraction, in particular, accounts for the massification of traffic: more and bigger ships that account for a rapid increase in transported tonnage, especially along the NSR where resource extraction is more active than in Arctic Canada (28) and presently displaying more activity in the oil and gas sector whereas mining is the leading extractive sector in the Canadian Arctic. Community resupply in Canadian waters also experienced a sustained growth, with a temporary dip in 2020 due to the covid-19 pandemic.

However, contrary to popular belief and widespread expectations, transit traffic remains very limited along Arctic passages in Canada and Russia.

[5] Nickel ore is shipped in containers from the port of Dudinka, thus the apparently high container traffic that in fact largely reflects shipments of mineral and metallurgical semi-transformed products, besides limited reefer shipments of fish from Kamchatka to Arkhangelsk and St-Petersburg.

4.2 Limited perspectives for transit

Despite the ongoing melting of sea ice, transit traffic remains rather limited along the Northwest Passage and the Northern Sea Route, with differentiated pictures however.[6] Table 4-4 and Table 4-5 collect the transit traffic along NWP and NSR.

Table 4-4. Transit traffic along the Northwest Passage, 2006-2021

Vessel type	*2006*	*2010*	*2011*	*2012*	*2013*	*2014*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*
ICEBREAKER	2	2	4	2	2	4	3	2	2	1	1	1
CRUISE	2	4	1	2	4	2	3	3	0	5	0	
PLEASURE BOAT		12	15	22	14	10	15	22	2	13	1	
TUG	1	1		2				3	1	1		
CARGO SHIP OF WHICH:	0	0	1	1	1	1	1	2	0	3	5	4
BULK					1	1					1	
TANKER			1	1				1				
GENERAL CARGO							1	1		3	4	4
RESEARCH	1			1	1			1				
OTHER			4				1	4				
TOTAL	6	19	21	30	22	17	23	33	5	23	7	5

Source: figures compiled by the author from data submitted by NORDREG, Iqaluit and by XST Xpert Solutions Technologiques inc.

[6] A methodologic note is necessary here. The term transit is interpreted differently by the various administrations that collect and publish figures describing transit along Arctic passages. In Canada, figures are collected by the Canadian Coast Guard section responsible for the enforcement of the Northern Canada Vessel Traffic Services Zone Regulations (NORDREG). The definition used by NORDREG for transit is a movement between Baffin Bay to the Beaufort Sea. Robert Headland and his team at the Scott Polar Research Institute (SPRI) use a definition whereby transits are counted between the Labrador Sea and Bering Strait. This difference does impact figures since a vessel servicing the community of Inuvik from Montreal will be counted as a transit by NORDREG but not by the SPRI. This is why the SPRI counts 32 transits in 2017 (33 for NORDREG), and 3 in 2018 (5 for NORDREG) for instance. In Russia, figures are collected by the Northern Sea Route Administration, then formatted and published by the Center for High North Logistics (CHNL), a private association and therefore not an official Russian administration. CHNL bases its figures on the NSRA definition of transit, which is a voyage between the Bering Strait and the Kara Gate. Thus, a ship from Kamchatka to Murmansk will be counted a transit by CHNL despite the fact the ship is still in Russian Arctic waters. Other voyages, like those carried in 2009 by heavy lift vessels *Beluga Foresight* and *Beluga Fraternity* in 2009, are counted as transits by CHNL from South Korea despite the fact they unloaded their cargo at Yamburg before proceeding to Germany, thus making their voyages a destinational voyage. On these methodological issues, see (85), (86) . For this chapter, the author decided to work with official NORDREG figures and semi-official CHNL figures.

Table 4-5. Transit traffic along the NSR, 2006-2021

Vessel type	*2008*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021**
ICEBREAKER			2	3	2	2	1	2		1		2	
GOVERNMENT SHIP			1	0	1	1	2	1					
CRUISE		1	1	0	1	3	1	1				1	1
TUG, SUPPLY VESSEL	1	3	4	5	1	1	3	4	1	2		5	
CARGO SHIP OF WHICH :	2	5	31	38	64	24	11	11	24	23	32	51	84 na
BULK	2		5	10	16	1				2	3	16	
TANKER		3	17	27	33	14	2		5	3	9	7	
GENERAL CARGO			2		14	8	4	9	11	12	14	26	
CONTAINER			1							1	1	2	
REEFER			6	1	1		4	2	3	2	5		
HEAVY LIFT		2				1	1		5	3			
RESEARCH		1	2	0	2	0	0				2		
FISHING						1			2	1	3	5	
TOTAL OFFICIAL TRANSIT	**3**	**10**	**41**	**46**	**71**	**31**	**18**	**19**	**27**	**27**	**37**	**64**	**85**
VOLUME TRANSPORTED, MILLION METRIC TONS		0.11	0.82	1.26	1.18	0.27	0.04	0.21	0.19	0.490	0.697	1.281	2.027
TOTAL VOLUME HANDLED IN THE NSR, MILLION METRIC TONS	2.219	2.085	3.225	3.75	3.914	3.982	5.432	7.265	10.73	20.18	31.53	32.97	34.85
Source: (29), compiled and adapted by author. *Data as of October 31st.													

In both cases, there is a definite trend towards an expansion but with differentiated histories and composition. Transit numbers across the Northwest Passage were higher at the beginning of the period, experienced growth until 2012, witnessed a moderate decline, expanded again until 2017, then collapsed in 2018, only to recover in 2019 and then collapsing because of the ban on cruise and pleasure craft transits. Transit in the NWP was largely composed of pleasure boats as opposed to between zero and two commercial vessels. This may be about to change: 3 transits were performed by cargo vessels in 2019, 5 in 2020 and 4 in 2021. Vessels from the Dutch shipping company Royal Wagenborg accounted for 2 of the transits in 2019, all 5 in 2020 and all 4 in 2021. The company openly advertises the voyages (30), (31), hinting it may attempt to develop this market in the future. As far as cargo vessels are concerned, tankers and bulkers were prevalent among the few transits before 2017; now general cargo vessels dominate. It is interesting to note that the expansion of mining in the Canadian Arctic does not support transit expansion, despite the fact ore is at times delivered to China. In 2014, a Fednav vessel transited the NWP to deliver nickel ore to China from the Raglan mine; however, in 2018 (two transits), in 2019 (one transit) and again in 2021 (one transit), shipments of iron ore from the Mary River mine to China transited across the NSR (32); (33); (34)). In 2013, Baffinland CEO had made clear the company would not use the NWP for transit to Asia (35); the company somewhat softened its stance in 2019 but apparently has yet to use what it considers an “alternative shipping route” (36).

Figures show that both in terms of voyages and tonnage, transit represents a small share of total traffic along the NSR, despite the recent increase in transit voyages and tonnage since 2018 as transit tonnage increased to 1.2 Mt in 2020 and 2 Mt in 2021 In transit traffic along the NSR, cargo vessels are more diversified than in the NWP; between 2010 and 2014, tankers dominated transits, then general cargo vessels since 2015. Bulkers were a significant share of vessels in 2012, 2013 and again in 2020. As far as tonnage is concerned, bulkers represented the largest component of transit in 2020 with 1.004 Mt or iron ore from Murmansk (78,4%) are largely responsible for the fast expansion of transit that year, whereas in 2019, crude oil represented 43.3% of transiting cargo and iron ore 21.5%. It is noteworthy to underline, by the way, that these shipments of iron ore from Murmansk represent transit from an Arctic port and thus can be considered as Arctic destinational traffic, a methodological point evoked above.

Transit traffic along the NSR was initially very modest, then expanded up to a high of 71 voyages in 2012, then collapsed to 18 in 2014 to recovery gradually to 37 in 2019 and 85 in 2021. It may be that the increase is an ongoing process from now on, but that does not hide the fact that transit traffic remains modest especially when compared to destinational traffic along the NSR, and when compared to transit traffic along major straits or canals like Malacca, Suez or Panama (37). This transit level is clearly out of step with media forecasts announcing the advent of heavy traffic along Arctic routes ((38); (39)).

The composition of this traffic also differs by region. Commercial cargo ships represent the largest share of transit traffic along the NSR, whereas transit along the NWP is largely composed of pleasure boats, with commercial vessels comprising between zero and two units (except for five in 2019). Among the elements that explain this very weak interest for transit traffic along the NWP, let us mention a higher ice concentration in summer (40) (41), the absence of promotion of the NWP as opposed to a very proactive stance in Russia, and a higher level of equipment and infrastructure along the NSR, including ports that can harbor ships in cause of damage (38) (39). Icebreaker support also varies greatly, with Canada having only nine Arctic-capable icebreakers as opposed to Russia's five nuclear and 37 diesel icebreakers.

This comparison between total and transit traffic underlines the fact that destinational traffic (ships going to the Arctic, stopping there to perform an economic task and then sailing back) remains the driving force in Arctic shipping, along the NSR but all the more so in the NWP where commercial transit was until recently very small and still is limited. This destinational traffic is fuelled by the servicing of local communities, but traffic is growing significantly through the expanding exploration for natural resources and their exploitation, including mining, oil and gas, and fishing. Natural resources extraction is by far the strongest driver in Arctic shipping, whether in the Russian Arctic, or the Canadian Arctic, less so in Greenlandic waters since natural resources lost their attractiveness for oil & gas companies (28)). While some discoveries are rather promising, in Alaska, in Canada or in Russia, the large-scale development and operation of these projects remains uncertain in North America, whereas Siberian projects are benefiting from the Russian government's willingness to push for the rapid expansion of extraction. These ventures remain risky, since operating costs are high, but also because the industry remains very sensitive to world prices (42)). The high volatility that has marked 2020, between pandemic and price war has therefore had a definite impact on current projects, and it remains to be seen what the impact will be in the long term. Nevertheless, the moderate but ongoing expansion of cargo transit traffic and the strong expansion of destinational traffic fuelled by resource extraction attest to the influence of the ongoing globalization of the Arctic, meaning the Arctic economic expansion is presently largely fuelled by markets from outside the region.

4.3 Developing transportation for local communities: the example of Canada

4.3.1 Resupply: a market with specific logistical constraints

Community resupply is the second most important segment of commercial shipping in the Canadian Arctic. It involves the shipment of fuel as well as consumer goods to communities, fresh food products and high value-added consumer goods being also shipped by air, a situation that accounts for high retail prices experienced in Arctic communities. The reduction of sea ice due to climate change could theoretically present an opportunity for expanded service to communities through increased transportation capacity, either through more voyages (increased frequency of calls) and/or increased capacity of vessels (43) (44). Shipping service to Arctic communities is all the more important as food insecurity is a significant problem, affecting 36% of households in Nunavut in 2012 – a figure reaching 42% in 2014 (Harvey, 2020) – as opposed to a national average of 8,3% (45). Food insecurity in Nunavut is largely linked to high food prices that directly stem from transportation of food items (46) (47). The strategies developed by shipping companies are exposed below.

Community resupply is a complex logistical operation in the Canadian Arctic due to the lack of ports. There are no wharves in Arctic villages, despite a federal program for the construction of small craft harbours. Commercial vessels must therefore anchor offshore and self-unload cargo onto barges that will then be pushed by a tugboat up to the beach where engines will unload goods onto trucks. Unloading beaches being public, including to children, safety issues are a recurrent problem (48), (49), (50), (51); (52), (53)).

Loading and unloading is much more time consuming in these conditions than at a dock. For general cargo, Canadian companies NEAS and Desgagnés Transarctik operate large vessels; Marine Transportation Services MTS (formerly NTCL before it went bankrupt in 2016 and was purchased by the Government NWT) operated barge convoys pushed by tugs. For fuel products, Desgagnés operates its PetroNav subsidiary, while Woodward Group operates Coastal Shipping Limited. Given the logistical constraints, they all developed a specific expertise that has the indirect benefit of limiting competitors entering the market, as several experts requesting anonymity explained. However, despite extensive experience garnered by shipping companies, efficiency is definitely hampered. The specific unloading procedure has also long forced cargo to be handled in the form of pallets rather than containers, in stark contrast with containerization effective in Greenland where small container carriers can dock on wharves in villages (54); (55). In that perspective, the recent development of small containers by NEAS (10 feet) is both welcomed by customers and a way to streamline unloading (56)).

Churchill is currently the only community with a deep-water port and a wharf. Built in 1931 as a maritime outlet for the grain of the Prairies, it is connected to the North American railway network, a theoretical advantage that made Churchill a potential gateway to the heart of the continent. The Arctic bridge sea route, connecting Churchill to the Russian port of Murmansk, never materialized into significant traffic. The port was privatized in 1997 and sold to OmniTrax that decided to close it down in 2016. Sold to the Arctic Gateway Group, it reopened in 2019, but experiences very little export traffic. It is currently also used as supply hub by Desgagnés and NEAS, besides their Montreal base.

Attesting to the desire to increase service to communities, the project of building a deepwater port in Iqaluit, discussed for decades and relaunched in 2005, has finally come to fruition: work started in 2018 and should be completed in 2021, with service beginning in 2022 05((57); (44); (58)). Faster and more reliable service could prove particularly useful, not only to meet expanding community needs in resupply, but also to foster the development of local businesses (43). Ways to diversify links with a view to improving supply and shipment possibilities were explored by the Chamber of Commerce of Baffin Island in 2006. Considered were links between Goose Bay and Iqaluit as well as between Iqaluit, Nuuk and Reykjavik with service provided by the Danish company Royal Arctic Lines and the Icelandic company Eimskip (55). These projects never came to fruition.

4.3.2 Development strategies of shipping companies

Shipping companies that shape the community resupply market experienced major changes in recent years. These changes are depicted in the tables below.

Table 4-6. The evolution of NEAS's fleet

	Year built	Place	Ice class[7]	dwt[8]	TEU[9]	Gt[10]
2020						
Qamutik	1994	Netherlands	1A	12 754	730	8 448
Mitiq	1995	Netherlands	1A	12 754	730	8 448
Nunalik	2009	China	1A	12 744	665	9 611
Aujaq	1994	Netherlands	1A	12 754	720	8 448
Sinaa	1994	Netherlands	1A	12 754	720	8 448
2008						
Aivik	1980	France	1A	4 860	280	7 362
Avataq	1989	Japan	1A	9 686	567	6 037
Umiavut	1988	Japan	1A	9 682	567	6 037
Qamutik	1994	Netherlands	1A	12 754	730	8 448
Source: Data compiled by author from NEAS pages and professional websites.						

Table 4-7. The evolution of Desgagnés Transarctik's fleet

	Year built	Place	Ice class	dwt	TEU	Gt
2020						
Rosaire	2007	Netherlands/China	1A	12 777	665	9 611
Taïga	2007	China	1A	17 500	958	12 936
Sedna	2009	China	1A	12 612	665	9 611
Zelada	2009	China	1A	12 692	665	9 611
Nordika	2010	China	1A	19 777	958	12 974
Claude	2011	China	1A	12 580	665	9 611
Acadia	2013	China	1D	11 353	164	7 875
Miena	2017	China	1A	12 396	842	11 492
2008						
Camilla	1982	Germany	1AS	6 889	730	10 085
Anna	1986	Germany	1AS	17 850	553	15 893
Rosaire	2007	Netherlands/China	1A	12 777	665	9 611
Beluga Federation	2006	China	1A	12 744	665	9 611
Beluga Enterprise	2005	China	1A	12 744	665	9 611
Dutch Runner	1988	Germany	1D	3056	219	2279
Source: Data compiled by author from Desgagnés's pages and professional websites.						

[7] The ice class refers to a notation assigned by a classification society or a national authority to denote the level of strengthening as well as other arrangements that enable a ship to navigate through sea ice. Several scales exist, like the International Association of Classification Societies (IACS) that produced a unified scale for the Polar Code, called Polar Classes (PC), PC7 referring to a vessel able to navigate in autumn in thin first-year ice, to PC1 referring to year-round operations in all Arctic waters. For commercial vessels, a widely used classification is the Baltic or Finnish-Swedish system, with classes stemming from 1D (poorly adapted for navigation in ice-covered seas) to 1C, 1B, 1A and 1AS. 1A is approximately equivalent to PC7 and 1AS to PC6.

[8] Deadweight tons: the measure of the loaded weight of a ship, in metric tons here.

[9] TEU: twenty-foot equivalent unit: standard measure for containers, which usually come in the form of metal boxes 10, 20 or 40 feet long (0.5, 1 or 2 TEUs). Here the value indicates the number of TEUs the vessel can carry.

[10] Gross tonnage is a measure of volume, contrary to what the name could imply. It measures the transport capacity of a vessel and is measured in gross tons (100 cubic feet).

Table 4-8. Fleet, evolution of Coastal Shipping Limited (Woodward)

	Year built	Place	Ice class	dwt	Gt
2020					
Kitimeot	2010	Turkey	1A	19 983	13 097
Kivalliq	2004	China	Ice E3 = 1A	13 671	8 882
Qikiqtaaluk	2011	Turkey	1A	19 998	13 097
Tuvaq	2012	China	1A	7 595	5 422
2007					
Nanny	1993			9 176	6 544
Mokami	1989			2 853	3 015
Dorsch	1980			10 556	6 720
Tuvaq	1977		1AS	15 955	11 290
Source: Data compiled by author from CSL's webpages and professional websites.					

In the western Canadian Arctic, resupply is performed by the NWT Government-owned Marine Transportation Services (MTS), formerly Northern Transportation Company Ltd (NTCL) until its bankruptcy in 2016. Its base port is in Hay River on the Great Slave Lake shore, which is serviced by rail. Churchill was also used to resupply communities in the Western Hudson's Bay area, with a traffic volume that reached about 35 000 tons in 2002 ((59); (60)). From the Hay River terminal, convoys navigate along the Mackenzie River and then visit western Arctic communities, for a while also in Alaska. This logistical mode prevented NTCL from operating large vessels, the depth of the Mackenzie River being too shallow. Instead, the company operated tugboats and barges joined in convoys. 1972 was a record year for cargo movement on the Mackenzie River and the Arctic region, with approximately 362 000 metric tons transiting through NTCL docks in Hay River. From then on, tonnage from Hay River gradually declined. Reasons include the decline of oil exploration in and around Inuvik and the Arctic offshore; the building of the Dempster Highway across the Yukon to Inuvik (opened in 1979), and then to Tuktoyaktuk (opened in 2017); the conversion of NWT Power's power plant in Inuvik from diesel fuel to natural gas, reducing demand for fuel; and competition from Eastern shipping companies Woodward for fuel delivery and NEAS and Desgagnés for general cargo ((61); (60)).

Hit by competition and adverse economic conditions, NTCL/MTS gradually reduced the scope of their services, both reducing the network and limiting the number of voyages ((62), (61)). The number of voyages and transported volume declined from 22 voyages in 2008 to 11 in 2020, and from 154 000 tons in 1994 (61) to 10 000 tons of dry cargo and 37 000 m^3 of fuel in 2017 (63), and then to 6 350 t of dry cargo and 27 900 m^3 of fuel in 2020 (56).

Examination of the evolution of the fleets allows for several observations. First, vessels are much younger. In 2007, the age of CSL's fleet averaged 22.3 years, but only 10.8 years in 2020. In 2008, NEAS's fleet had average age of 20.3 years, but of only 11 years in 2020. In 2008, Desgagnés's fleet age averaged 12.2 years but only 9.6 in 2020 (and 3.2 years for Petro-Nav tankers). This renewal was made possible through the repeal of the import tax for foreign vessels in 2010[11] and was intended to replace an ageing fleet, but also to benefit from economies of scale provided by larger vessels.

Second, shipping companies decided to bank on economies of scale for each vessel rather than expanding the fleet with several small units. Fleet expansion was thus real but not major, remaining at four vessels for CSL, going from 4 to 5 vessels for NEAS and from 6 to 8 vessels for Desgagnés. However, capacity increased significantly, from 9 635 dwt in 2007 to 15 312 in 2020 for CSL; from 9 246 dwt in 2008 to 12 752 in 2020 for

[11] The Ferry-Boats, Tankers and Cargo Vessels Remission Order, 2010, published in the *Canada Gazette*, Part II, on October 13, 2010, allows for the remission of the 25% import duty. This tax removal facilitated the fleet renewal of Canadian shipping companies but did not cause it. Personal communication with Emmanuel Guy, professor, Université du Québec à Rimouski, January 25, 2021.

NEAS; from 11 010 dwt in 2008 to 13 961 in 2020 for Desgagnés. CSL and NEAS clearly bet on increased vessel size, while Desgagnés opted for a mixed strategy of expanded fleet with modest size increase.

NEAS somewhat expanded the number of voyages (Table 4-9), while Desgagnés remained at 21. Given that NEAS operates 5 vessels (4 in 2008) and Desgagnés 8 (from 6), the average number of voyages per vessel actually decreased. Clearly, the strategy of these companies is not an expanded frequency from their Montreal/Valleyfield base. CSL performed 14 voyages in 2010, and 19 in 2020 and appears to rely on both increased frequency and larger vessel capacity.

Table 4-9. Resupply voyages to scheduled destinations, 2008 and 2020

	NTCL/MTS	NEAS	Desgagnés	CSL
2008	22	11	21	14 (2010)
2020	11	13	21	19
Source: data compiled by author according to published company schedules and Mariport (2012) (64).				

The increased vessel carrying capacity was a strategic choice made by shipping companies to reduce their costs per transported ton. This improved capacity and, since 2019, the possibility to resupply in Churchill with the reopening of the port and the railway, made the option of an increased frequency much less attractive. Apparently, the strategy developed by shipping companies is to operate a similar frequency per vessel, given that increased carrying capacity enables vessels to service more communities. This is apparent when examining the network operated by shipping companies in 2008 and in 2020.

In 2020, CSL's network covered a large area of the Canadian Arctic. MTS remained concentrated in the Mackenzie River valley and the western Arctic, with fewer destinations serviced than NTCL twenty years ago. From 2008 to 2020, Desgagnés's transported volumes shifted somewhat to communities along the NWP and in western Hudson's Bay, to the expense of communities in northern Quebec. Over the same period, NEAS significantly expanded its network westwards, with more destinations and transported volume along the Northwest Passage and in western Hudson's Bay.

Shipping development can be illustrated through this traffic density map. Areas of concentration of ship movements are apparent: the entrance of Hudson Strait; Frobisher Bay leading to Iqaluit; the entrance of Navy Board Inlet between Bylot Island, and Baffin Island. Secondary commercial routes are the approaches to Rankin Inlet; Lancaster Sound, the coast of the NWT and Amundsen Gulf. The map clearly underlines strong spatial disparities in the Canadian Arctic Archipelago, with zones of higher shipping traffic and vast areas with scant traffic, and even no traffic at all, as already illustrated in past research (65).

4.4 Strong growth perspectives for destinational traffic from the extractive sector

The presence of valuable deposits in the Canadian Arctic has long been documented. Increase in world prices has triggered their exploitation, much more than climate change and melting sea ice, which still had a facilitating effect on the development of mining ventures (42). A few mines and oil fields, developed when the ice-cover was still thick and extensive, were closed down because of depressed global prices, including the Polaris and Nanisivik mines (closed in 2002) and the Bent Horn oil field (closed in 1996).

Bulk traffic has benefited from the exploitation of Arctic and subarctic mines, such as Voisey's Bay (Labrador), Raglan and Canadian Royalties/Jilin Jien (Quebec), and Mary River (Baffin Island, Nunavut). This expanding traffic has largely compensated dwindling traffic to and from Churchill since the port closed down in 2016 before reopening in 2019 (only 4 voyages of grain-carrying bulk vessels in 2019 and 3 in 2020). For instance, Baffinland Iron Mines shipped 920,000 tons of ore from its mine in Mary River through its port of Milne Inlet in the first year of activity in 2015, then 4.1 million tons in 2017 (Maritime Magazine, 2018) and 5.1 million tons in 2018 (21). The company intends to eventually reach an annual volume of 12 million tons. Other active gold mines north of Rankin Inlet also generate traffic related to the logistics of mining operations. In the Canadian Archipelago, Fednav operates PC4 vessels (*Arctic*, *Umiak, Nunavik*) capable of navigating in winter, servicing the Deception Bay mines in northern Quebec. The company may develop a business model in partnership with mining companies for year-round shipping to Deception Bay and Milne Inlet (operational) as well as Steensby Inlet (projected).

The logistics of mining activities are dominant in terms of tonnage in the Canadian Arctic: the capacity of bulk carriers servicing mines (measured in cumulated vessel dwt), at 6.1 Mt, accounted for 77.3% of the tonnage capacity of traffic in the Canadian Arctic in 2020. Large, powerful dry bulk carriers transport ore from the maritime terminal built to service the mine: the construction of deep-water docks is required for base-metal mines that ship large quantities of ore. By contrast, sealift for gold or diamond exploitation is overwhelmingly related to supply of fuel, food and equipment. As a consequence, general cargo and tanker companies, such as NTCL/MTS, NEAS, Desgagnés and Coastal Shipping/Woodward, are also tapping into the market created by expanding mining activities for delivery of fuel (Coastal Shipping) and supply (NEAS, Desgagnés, MTS).

For instance, Baker Lake haven (a small terminal built to accommodate large barges and small vessels) saw traffic expand significantly in the past due to the development of gold mining ventures north of the community.

In the Kitikmeot district of Nunavut, several mining projects are ongoing, mostly gold development ventures, including the mining company TMAC property considered for purchase by the Chinese company Shandong Gold, a transaction blocked by the federal government in December 2020 (66). TMAC eventually sold to Agnico Eagle that also develops the mining projects north of Baker Lake. Sabina Gold and Silver Corp. is proceeding with its Black River project, which included the construction of the Bathurst Inlet haven, now operational and serviced by Desgagnés and MTS on an occasional basis. Transportation for the mining project will in part depend on shipping, in part on winter roads to the actual mining site (67).

Further west, other gold mining projects held by Blue Star Gold Corp. rely on the construction of a road and a port located on Grays Bay. The Grays Bay road would overlap with a road proposed as part of the mothballed Izok corridor zinc-lead mining project that was promoted by Chinese-owned MMG Ltd., but has been shelved since April 2013 ((68)). The Grays Bay project is experiencing significant logistical challenges (69). This situation sums up the dilemma faced by several inland mining project: is it preferable to construct a year-round land road reaching south and connecting to the road and rail network despite high costs or is it more profitable to build a shorter road northward connecting with a haven, with a navigable season bound to expand in the future but still limited to a few months per year? ((70); (37)). It seems noteworthy that most inland projects, either active or under development, are gold or diamond mining projects that require a lighter logistical infrastructure than mining of industrial metals. The Mary River iron mine is a significant exception that can be accounted for by the very high grade of its ore and the sheer size of the deposit ((71); (72)).

In conclusion, mining is the most significant driver of shipping in the Canadian Arctic, both with respect to the logistics of mining operations and to the shipment of produced ore (iron ore in Mary River; nickel ore in Deception Bay from Raglan and Jilin Jien mines). The ongoing development of gold and diamond ventures in Nunavut and possibly north-eastern NWT is also fuelling navigation because of logistical needs for these projects. Most of the traffic generated by mining is concentrated in the eastern part of the Canadian Archipelago.

4.5 A new business model: the development of transhipment hubs?

Russian officials are aware of the reluctant of many shipping companies to develop transit traffic along the NSR, let alone the NWP. Shorter routes proving a poor incentive when considering the difficulties of Arctic shipping, a new business model is gradually emerging articulating regular shipping routes and classical vessels with Arctic transhipment hubs and shuttle high-ice class vessels that could offer year-round service. The advantage of this business model rests in the possibility for shipping companies to benefit from a yearlong and thus regular service permitting (in theory) just-in-time delivery without having to invest in costly, high-ice class ships. It implies the construction of sets of port hubs, one at each entrance of Arctic routes, and bets the advantage of shorter routes will outweigh the need for two transhipments.

Arctic transhipment hub projects have blossomed in recent year across the Arctic, with proposed sites in Iceland (Finnafjord), Norway (Kirkenes), Russia (Murmansk, Arkhangelsk, Indiga on the European maritime window, and Vladivostok, Zarubino and Petropavlovsk on the Pacific shore), Japan (Tomakomai), South Korea (Busan), Alaska (Nome), Maine (Portland), Greenland (Nuuk), France (St-Pierre, south of Newfoundland), and Canada (Halifax, St Anthony, Churchill, Iqaluit, Nanisivik and Qikiqtarjuaq) (Cyr, 2021). It is unlikely, given the requested investments in port infrastructure and in shuttle vessels, that all these projected Arctic hubs will ever be built. Some projects appear to be definitely one step ahead in the developing competition between all these projects, with the support of local and national authorities, while others like Kirkenes suffered a major blow when the projected railway between Kirkenes and Rovaniemi that would have connected the port with the European railway network was blocked by the Lapland Regional Council (73), and with several not even having gone past the formal approval of regional authorities.

In this struggle for the advent of Arctic transhipment hubs, Russia definitely appears to take the lead. It has already experimented transhipment for the shipping of oil and gas in Murmansk (37). The Russian government seems willing to set up and subsidize a dedicated container shuttle company between Murmansk and Kamchatka, very likely Petropavlovsk or Vladivostok. It may even subsidize directly foreign shipping companies for them to opt for this new shuttle service ((74); (75)) along a planned Northern Sea Transport Corridor (76), while construction for the expansion of the port of Murmansk in under way with the Lavna terminal being dedicated for the planned expansion of coal exports but also for containers (77). With Arctic ports already running facing the Atlantic and the Pacific, and with Moscow's will to set up the shuttle company, there may be little room for hub projects along the NWP, already suffering from a higher ice concentration. The port of Iqaluit, about to be finished, is merely a wharf with little equipment (24). The idea of building a port in Qikiqtarjuaq (Qikiqtaaluk Corporation, n.d (78)) stemmed from the desire to support the fishing industry, but also from the vision of developing a "little Singapore of the Arctic" with the help of "Chinese investors" (79) whose identity remains elusive (80). This project is reportedly stalled, especially as Chinese investors may not be welcome now for Ottawa in the context of tense Sino-Canadian relations. Senator Patterson recently included the Qikiqtarjuaq port in his budget recommendations for Nunavut's development (81), but the government does not seem to have followed suit (24). Halifax may be better positioned as it boasts functioning infrastructure and a solid reputation, but the Arctic hub project seems preliminary, as is for St Anthony in Newfoundland (82).

4.6 Conclusion

Climate change is definitely impacting sea ice and the environment in the Arctic. Sea ice is receding fast in summer, giving credit to the possibility of ice-free summers in the future. The decline in sea ice may not be a trigger of shipping development in the Arctic, but it certainly acts as an enabler (83). However, this decline is not linear nor does it provide for smooth navigation: as sea ice melts, it is more mobile, giving way to increased unpredictability and the recurrent occurrence of pressure ridges, while the melting of continental ice produces more growlers and thus serious hazards for vessels.

With the advent of climate change and the interest for natural resources extraction, actively supported by the federal State in Russia or pulled by contrasted market forces in Norway, Greenland and in the North American Arctic, the picture of shipping is transforming in the Arctic. Similarities but also major differences have emerged between the Canadian and the Russian situations.

In Canada, pleasure crafts and cruise ships for long dominated a gradually expanding transit traffic before this trend was halted by sanitary regulations in the frame of the covid-19 pandemic. An emerging commercial transit traffic could be in the making with the initiatives of the Dutch shipping company Wagenborg. In Russia, transit, here again pushed by the Russian government, represent a modest but expanding commercial activity where foreign shipping companies are active, contrary to past traffic where transit was largely composed of Russian vessels to or from Murmansk.

General traffic is expanding in both the Canadian and the Russian Arctic, albeit traffic being largely superior in the Russian Arctic. Both regions witness the development of traffic generated by natural resources extraction and the increasing participation of foreign shipping companies in this traffic, attesting to the accelerating globalization of this economic activity in the Arctic.

There are major differences between the Canadian and the Russian shipping portrait: if both regions welcomed and adapted the enactment of the Polar Code in 2017, and if both feel the pressure for tighter environmental regulations from NGOs and negotiations at the IMO, notably through the gradual ban of HFO, there seems to be temptations in Russian to ease regulations with a view to facilitating the development of commercial traffic, whereas Canada rather tries to better frame shipping activities through the definition of low impact shipping corridors. This is consistent with the efforts deployed in Russia to promote and advertise shipping in the Russian Arctic, notably the development of an alternate business model of transhipment hubs, a model discussed in Canada too but that remains at very preliminary stages when compared to Russia, Iceland or Norway.

Arctic shipping is developing, and it is mainly fuelled by destinational shipping. Because of its sensitivity to just-in-time in the context of Arctic shipping where uncertainty is bound to remain the norm for years to come, transit traffic remains insignificant in the Northwest Passage and weak in the Northern Sea Route, all the more so as a large share of the official traffic figure reflects in fact Arctic destinational voyages to and from Murmansk, increasingly a major Arctic hub. This destinational traffic stems from community resupply, and natural resources extraction - mining in Canada and oil & gas in Russia, although mining is set to experience a significant development in Siberia in the next few years. Arctic shipping is thus vital for communities in Canada, Greenland and Siberia, while an economic leverage for the development of natural resources extraction (mining, oil & gas, fishing) in the frame of a growing economic integration of these Arctic spaces in the global economy (84). Container shipping for the foreseeable future remains marginal, but the possible development of transhipment Arctic hubs coupled with dedicated Arctic shuttle lines could enable the emergence of an alternate business model that would facilitate its expansion.

5 Part 3: Technical and Economic Opportunities of Arctic Shipping

5.1 General

Key challenges of shipping in arctic waters are summarized below. These are further considered in the report D1.3 (1). It should be noted that the items listed below are heavily case-specific, interrelated and controlled by multiple regulations and standards. Therefore, they should be considered exemplary and do not represent all possible arctic shipping scenarios.

Ice resistance
Ice generates extra resistance to a ship's movement. This can affect ship speed, power requirement, power usage and the number of vessels in the fleet. This ice resistance increases fuel consumption as well as other operational expenses. The increased power requirement may also require machinery upgrades which increases ship price. Ice resistance can be minimized with appropriate ship design.

Ice loads
Ice generates additional loads on a ship's hull and propulsion, therefore a vessel operating in the icy waters needs to be reinforced. This will impact weight, size, payload and price of the vessel.

Accidental and uncontrolled ice events
Some Arctic (and Antarctic) areas include multi-year ice obstacles such as icebergs, growlers, bergy bits, … These can be difficult to detect in advance and are much stronger than first-year ice. In these areas, the risk of ship damage due to collision with this multi-year ice increases.

The vessel may also get jammed in the ice, especially if ice conditions in the area around the vessel are compressive, which may cause damage to the ship's hull (because of ice compression). An especially dangerous situation occurs if the vessel gets jammed in drifting ice. If this ice drifts towards the shallows and the vessel cannot cut loose, the grounding of the vessels is evident.

The abovementioned events may affect, for example, insurance costs.
Risks of accidental/uncontrolled ice events can be decreased by specific ice detection devices; safe speed limits; and well-trained, experienced ship crews.

Icebreaker assistance
Arctic shipping is often assisted by icebreakers. The icebreaker navigates in front of the assisted vessel (or vessels in a convoy) and breaks ice in advance so that it is easier for the assisted vessel to follow the icebreaker and proceed in ice. Icebreaker assistance can be arranged, on a regular or seasonal basis, as a part of the shipping scenario if the vessels are not designed for independent navigation in all anticipated ice conditions along the route. Even if a vessel is designed for independent ice navigation assistance may still be needed occasionally, for instance if the vessel gets jammed due to unexpectedly difficult ice conditions or if the vessel's speed becomes unreasonably low.

Icebreaker assistance may take time (waiting for the icebreaker, waiting for other vessels to join the convoy, etc.) and it is charged by the operator of the icebreaker, increasing the cost of the voyage. On the other hand, sometimes assisted navigation may save fuel for the assisted vessel, because the power needed may be much lower than without assistance. The net cost-impact of assistance is very case specific.

Ice-initiated accidents with other ships and structures
Sometimes ice resistance may drop suddenly which may lead to an uncontrolled increase in the speed of the ship. This increases the risks of a collision with other vessels nearby or with terminal structures and berths. Especially during icebreaker assistance, the risk of collision between a vessel and an assisting icebreaker can be significant.

The events described above, like accidental ice events (see the previous paragraph), may also have effects on other costs such as insurance.
Risks related to events described above can be minimised by well-trained and experienced ship crews, suitable design of the ships as well as appropriately planned operations and operational regulations.

Undetected and unpredictable ice conditions
Ice conditions are varying and reforming continuously and identification of ice conditions along a planned ship route in advance is difficult. In most cases, the direct route is not the optimal one. Hard ice conditions (e.g. compressive ice areas, compacted/ridged ice, etc) should be avoided. The planning of shipping activities is based on several assumptions regarding ice conditions. Finding an updated optimal route through ice is significantly difficult, thus unpredictable delays in shipping often occur. This makes planning and managing interrelated overall logistics difficult.

Recent developments in the availability and quality of satellite images provide new possibilities to significantly improve real-time recognition and prediction of ice conditions. These possibilities could be utilized in the planning of arctic shipping activities and real-time routing in icy waters.

In ePIcenter Aker Arctic is concentrating to this topic: the idea is to develop transportation analyses and route optimization algorithms and methodologies based on state-of-the-art satellite technologies and their applications (i.e., ice detection and mapping).

Cold weather
Cold weather in general sets multiple specific requirements for ship systems. The equipment and machinery must tolerate and work in low, freezing ambient air temperatures. The systems, equipment and vessel outfit need to be “winterized”. This means utilization of specific materials, different heating and ice removal arrangements. All these increases the operational and capital costs of shipping in cold temperature regions.

Environmentally sensitive areas
Some areas in icy waters are environmentally sensitive due to vulnerable animal or vegetation populations; traditional hunting- and fishing seasons of indigenous people; etc. This causes navigation in these areas to be continuously or temporarily restricted or requires specific permissions to access. Avoiding these areas on routes where favourable navigation options are rare in any case, causes additional challenges for shipping.

An example is the impact of Arctic shipping on cetaceans. They can be impacted in a variety of ways including: disturbance by noise generated by the propulsion of passing ships, suffering lethal and sub-lethal ship strikes, or being exposed to discharges and pollution emitted from vessels. Mitigation options include altering a vessel’s course, as mentioned above; or slowing down which reduces vessel noise emissions and the severity of impact and likelihood of a collision event occurring.

The sensitive areas described above can be taken into account in the services intended to be developed by Aker Arctic (see earlier topic “Undetected and unpredictable ice conditions”). This sensitive area information will also be integrated with the AI minimum fuel consumption algorithm developed by Stena Line. For simulating the effect of voyage strategies on Fuel Consumption and wildlife.

Fuel Consumption
95% of the world’s goods are moved by sea, making shipping an essential and efficient means of goods transport. However, serious environmental concerns about shipping have put pressure on the shipping industry to become greener. Stringent regulations (MARPOL Annex VI, the International Maritime Organisation (IMO)), to reduce greenhouse gas emissions by 50% by 2020 and 2050 respectively, have been put in place to address this environmental objective. The result of these regulations is a significant rise in fuel prices. Considering that current fuel costs represent up to 60% of total operating costs, shipping lines need to reduce the fuel consumption of their vessels to cut costs and reduce greenhouse emissions. This general challenge is even more relevant within the Arctic region where parameters such as ice formation, harsh weather conditions and environmentally sensitivity ask for a specific approach.

Compared to conventional open water shipping, the arctic shipping includes multiple challenges. Sea ice, even if it is thinning, still creates major challenges for economically feasible shipping. Ice generates additional resistance to the ship navigation increasing thus need of power and fuel consumption. Different ice types, especially ice features like multi-year (icebergs, etc.), may cause high loads the hull and propulsion of the ship thus to match these loads extra strengthening is required. All these, together with other associated challenges, increase the costs of arctic shipping.

The negative impacts of the ice associated challenges to the safety and economics of arctic shipping, can however be significantly decreased by applying state-of-the art -opportunities enabled by latest technology developments. Technical opportunities, as well as measures that should be considered to utilize these opportunities, are introduced in the following sections.

5.2 Opportunities to improve safety, environmental friendliness, and economics of future Arctic shipping

5.2.1 Identification of ice conditions

Sea ice is the greatest obstacle affecting Arctic. In offshore, the ice conditions are dynamic, varying and reforming continuously. In one local area the ice condition may be very difficult (Figure 5-1), while only short distance from this area it may be easy for ships to navigate. Identification of ice conditions in advance at the areas along the route (and also ice conditions surrounding the ship) enables selection of the easiest ice conditions for the route. This correspondingly, even it requires deviation from straightforward route, enables decreased fuel consumption improving thus economics of shipping. This is illustrated in Figure 5-2.

Representative examples of the state-of-the-art opportunities to identify ice conditions around the ship and from the planned route listed below.

1. Satellite based remote sensing.

   The number of satellites and amount and accuracy of information generated by these satellites increase year by year. This provides possibilities to produce tailor made ice maps in route guidance services (Figure 5-2).

2. Drones

   The drone technology develops rapidly. Drones having wide autonomic operational range becomes cheaper and cheaper all the time. These devises could be equipped with multiple different instruments which are employed to collect ice data from, for example within 2-5 km range, around the ship.

3. Radars

   Radars can be tailored to detect ice features in front and around the ship. Especially, to increase safety, radars could be used to detect multiyear ice obstacles (icebergs, growlers, bergy bits) in low visibility environment. It can be assumed that also radar technology develops continuously thus this technology may provide new additional opportunities for the arctic shipping in the future.

4. Image recognition technologies

   Infrared cameras, laser scanning and associated technologies could be applied to detect dangerous ice features like and gathering information from surrounding ice conditions. Infrared cameras could for example be used to detect icebergs, growlers and bergy bits in the dark or foggy conditions in open water. Especially growlers and bergy bits are dangerous in rough open water seas for the ships because they are difficult to be detected in advance among the waves and swells. 3D-scanning with the laser installed to the ship could correspondingly be applied to collect and analyse quantitatively ice conditions along the route of the ship.

Continuous gathering and storing the gathered ice data for future needs provides an important opportunity that could be undertaken on a regular basis today. Advanced IT based analysis and possible utilization of historical ice data may provide additional opportunities to generate more accurate plans for artic shipping. Further, utilization of up-to-date satellite-based ice information enables the opportunity to develop route optimization services that provide online guidance to find the easiest route to the destination (Figure 5-2) and thus improve the economics, safety and environment-friendly arctic shipping in the future.

Figure 5-1. Ridged ice among larger ice field.

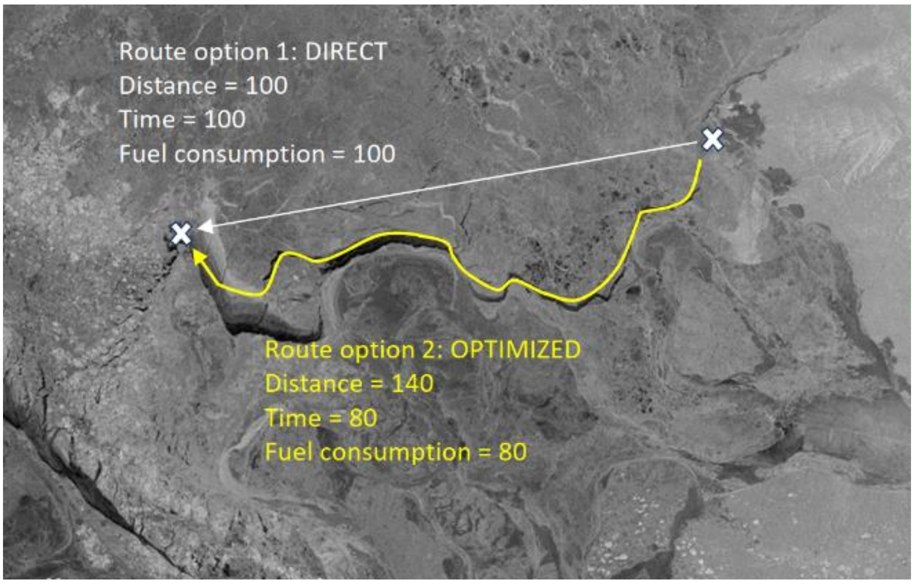

Figure 5-2. Illustration of route optimization. The direct route is not always the most economical.

5.2.2 Appropriate design

The key element in the design of ice-going ships is understanding the nature of ice resistance and ice loads. Ice generates extra resistance and loads on the ship's hull as it moves through ice. These depend mainly on the ice thickness, ice strength, ship hull geometry and ship speed. Ice thickness and strength cannot be affected directly. However, as described in the previous section, hard and dangerous ice areas can be avoided by appropriate route planning and this way decrease the resistance and the risk of collision with hazardous ice features.

Structural design of the ship hull is probably the most important segment in ship design. Therefore, it is regulated by several requirements, standards, and guidelines. Inappropriate hull structural design may lead to dramatic ice-caused consequences causing significant economic losses or even loss of human lives.

While ice loads are mainly connected to the hull and propulsions structural strength, the ice resistance is mainly connected to the hull geometry (and propulsion type). The bow shape, which is specifically designed for ice conditions, may decrease ice resistance significantly. On the other, such a bow shape is not typically efficient in open water conditions. This leads to challenges in the design because most of the ships navigate also in the open water and full optimization of the bow shape to both of these conditions at the same time cannot be done.

An example of ship concept, which is developed for both ice and open water conditions is so called Double Acting Ship ("DAS") (Figure 5-3). The idea of this concept is that the bow shape of the vessel is purely designed for open water navigation (often bulbous-shaped) but the stern of the vessel is designed for ice navigation. Hence, in open water the vessel operates "normally" as a bow-first-mode, but when it meets ice, it turns and starts to operate stern-first. This is enabled by azimuthing propulsion unit(s) installed to the vessel. This unit can be turned horizontally full 360 degrees (i.e. the thrust of the unit can be directed to any direction and no rudders for steering are needed). The DAS-concept may reduce ice resistance even up to tens of percentages due to the flushing effect azimuth has on "lubricating" the hull and reducing the friction (resistance) between the hull and the ice. Thus, compared to the "conventional ships" the benefits regarding fuel consumption and conducted operational costs are clear. Photo of DAS-concept is in the Figure 5-3.

Figure 5-3. The DAS-concept. MT Tempera proceeding by stern-first mode in thick ice.

Another example of state-of-the-art ship is presented in the Figure 5-4. The photo presents the icebreaker, which is designed to operate ahead, backwards and sideways in ice. Operating sideways enables creation of a wider channel than “normal” icebreaker thus making it easier for the cargo vessel to follow. This icebreaker can adjust it’s proceeding angle according to the width of the assisted cargo vessel. Two icebreakers are sometimes needed to assist large cargo vessels (to make a broken ice channel through ice, which is as wide as the width of the cargo vessel). The presented icebreaker concept thus removes the need of another icebreaker in assistance. Both novel ship examples, i.e. “sideways proceeding icebreaker” and “DAS -concept”, represent potential opportunities that could be utilized to improve the economics and safety of arctic shipping.

Studies associated to ice resistance and the definition of ships performance are important part of the ship design. This is the case especially when new types of ships and/or new navigational areas are considered. Utilization of ice model tests is the most reliable means to define ship performance in advance (Figure 5-5). Ice resistance, power utilization, manoeuvring capability etc. can be determined by appropriate model tests. Model tests also provides information to the ship designers providing them an opportunity to fine-tune / optimize the design before the start of the ship building.

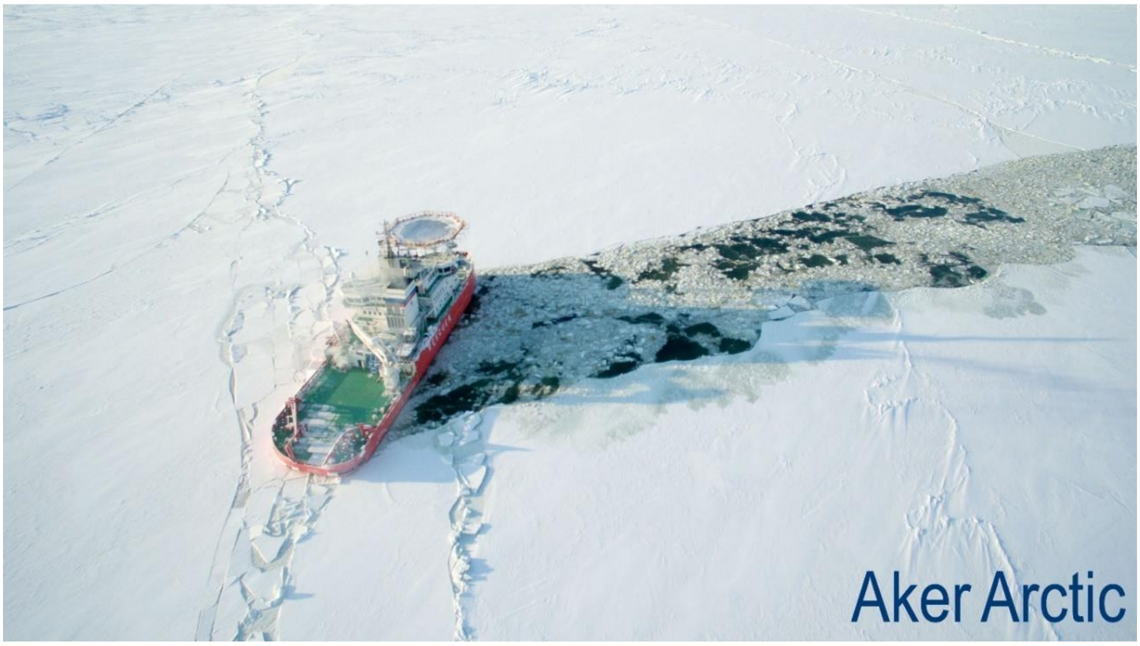

Figure 5-4. Icebreaker Baltika opening wider channel of broken ice by proceeding obliquely.

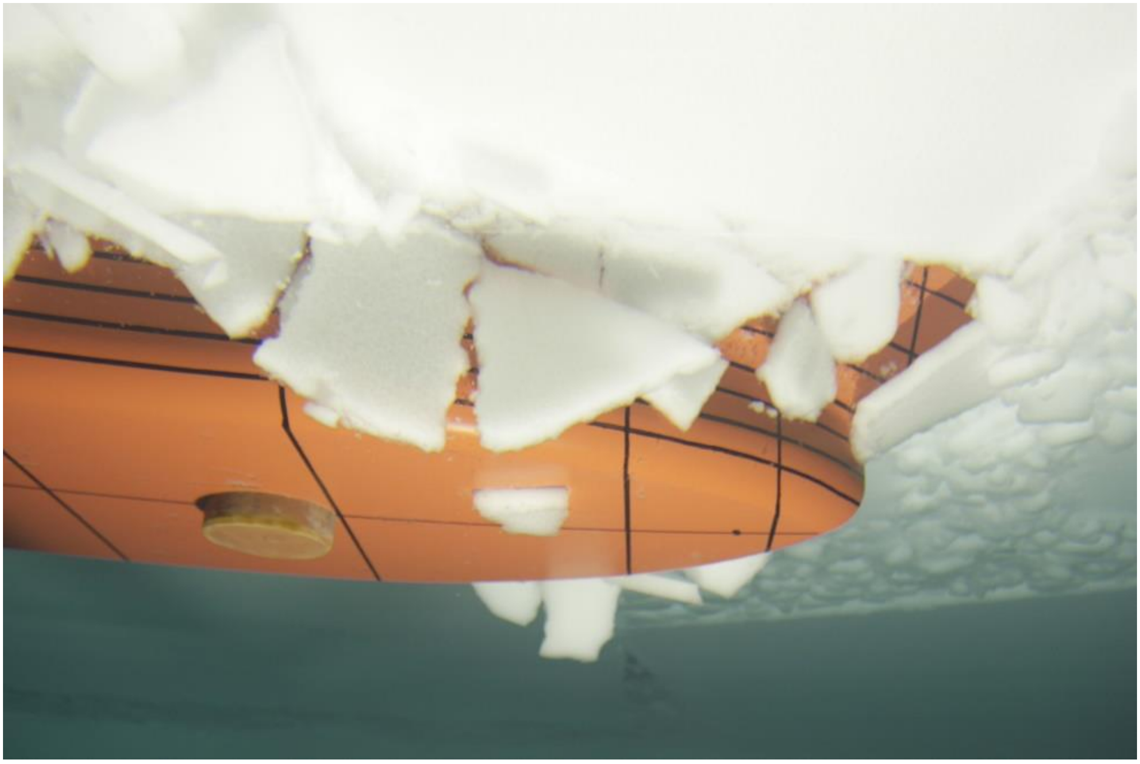

Figure 5-5. Example proto of model testing (underwater view).

Naturally, also understanding of ice conditions and their annual and seasonal variation is important when planning shipping activities on specific routes. Such studies can be based on existing information or/and dedicated field studies. Especially, if the amount of existing information is inadequate, the field experiments could be needed (Figure 5-6). Dedicated field experiments are often done in connection with ice trials of the ships. To the ship owners, the ice trials provide valuable information regarding ship performance and its limitations. They also produce site specific ice information that could be later applied in other studies.

Figure 5-6. Taking ice sample during field experiment.

Understanding the ship-specific ice loads can be significantly increased by Ice Load Monitoring System (ILMS). This system measures and records ice loads from different hull areas and propulsion in real time, thus giving the ship officers a possibility to follow actual stress at the ship is experiencing. The effects of ship speed, manoeuvres, different ice conditions etc. to the ice loads can be monitored online. If the stress level increases too much, the officers can react accordingly. ILMS thus provides a significant opportunity to increase the safety of navigation in arctic waters. It also generates valuable information of ice load behaviour in different situations and conditions to the ship owner and their possible partners. This data can later be used for example in different studies, training purposes and design projects. Example of ILMS display located at the ship's bridge is presented in Figure 5-7.

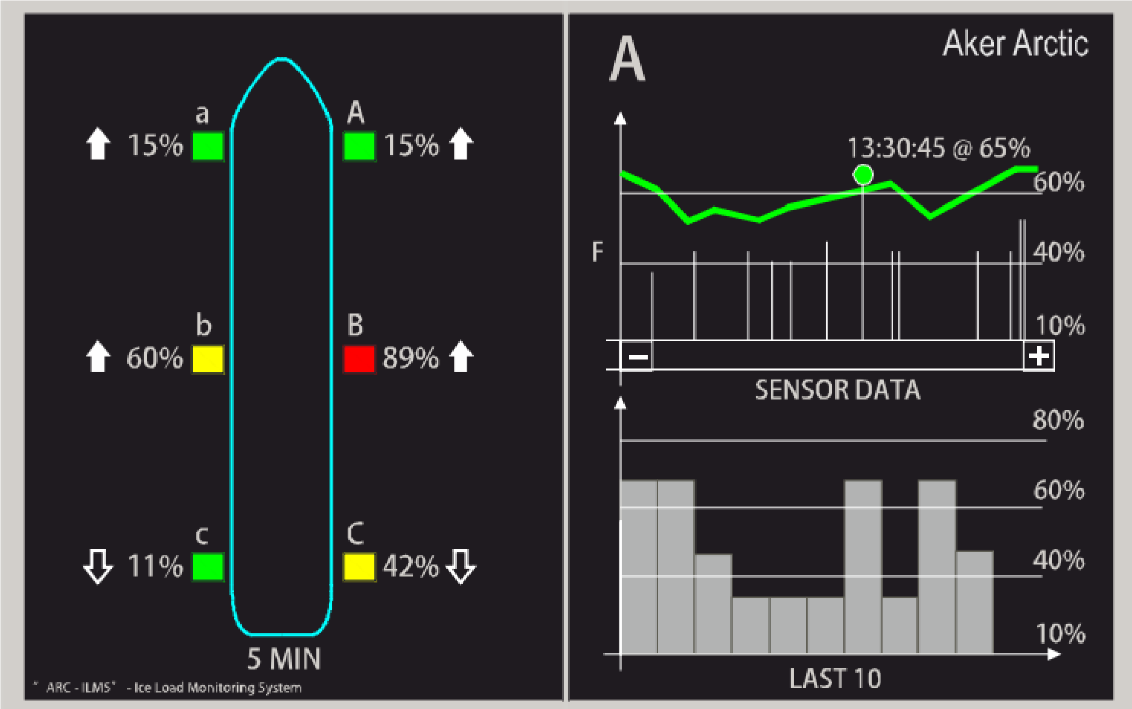

Figure 5-7. Example of the view of ILMS display.

In general, efforts addressed to continuous research and development activities increase understanding of arctic shipping challenges forming the basis for creation of new innovations which may open new opportunities for future arctic shipping.

5.2.3 Training and co-operation

Shipping in icy waters differs in multiple ways from shipping in open water. Features like remoteness, limited communication possibilities, continuous darkness, freezing ambient air temperatures, assisting procedures and of course ice itself are often typical for Arctic shipping. These elements are often unfamiliar to the ship crews especially if it is their first time in such areas. Training in advance provides an opportunity to prepare ship crews and officers to learn arctic shipping and procedures associated. This is the case especially if the ship officers do not have earlier experiences of arctic environment or if the ship in question is novel or unfamiliar for the crew.

Training programs can be tailored for the specific needs and a practical extension to training can be arranged by using an "Ice simulator" (Figure 5-8 left) where different complicated and risky practices can be trained in a safe simulated icy environment. In addition, model testing could also be used for the training purposes. Such tests may be primarily focused on testing of different tasks in ice (like berthing, departure from the berth, etc.) but secondarily it gives ship officers a possibility to follow and learn at the same time about the ship performance and about the risks in a safe environment. Today the possibility to conduct model tests with multiple ships (Figure 5-8 right) at the same time provides opportunity to test and exercise practices like escorting, towing etc. including two ships in model scale. It is even possible to arrange steering consoles for the officers so that they can steer the ships themselves in ice tank and thus achieve more understanding on the ship behaviour. Such exercises, even it is in model scale, provides surprisingly a lot of understanding about the ship behaviour. This is the case especially if the ship is equipped with azimuth thrusters, whose working principle differ significantly from the ships equipped with conventional shaft line(s).

It is anticipated that the number of ship operators in Arctic increases in the future. It means that the knowledge and experience of arctic shipping among these players increases. Forming co-operation and sharing knowledge and experience between co-operative partners provides an opportunity to improve the understanding of arctic conditions and challenges. Further, such cooperation can also consider practical actions, such as the up-to-date transfer of information (for example regarding easy, difficult or dangerous ice areas or observations of endangered animal species, etc. between ships operating in the same route, conducting transits in convoys, etc. This kind of co-operation may provide a good opportunity for the arctic shipping operators, even they may be competitors in wider perspective, to increase their economics and minimize risks of their shipping arctic.

It should be noted in this connection that shipping in many arctic regions is controlled by local administrators and governmental bodies. Icebreaker services and for example formation of convoys (so that multiple cargo ships can be assisted at the same time) are often requested by these authorities thus it is also important to include these interest groups in co-operative framework.

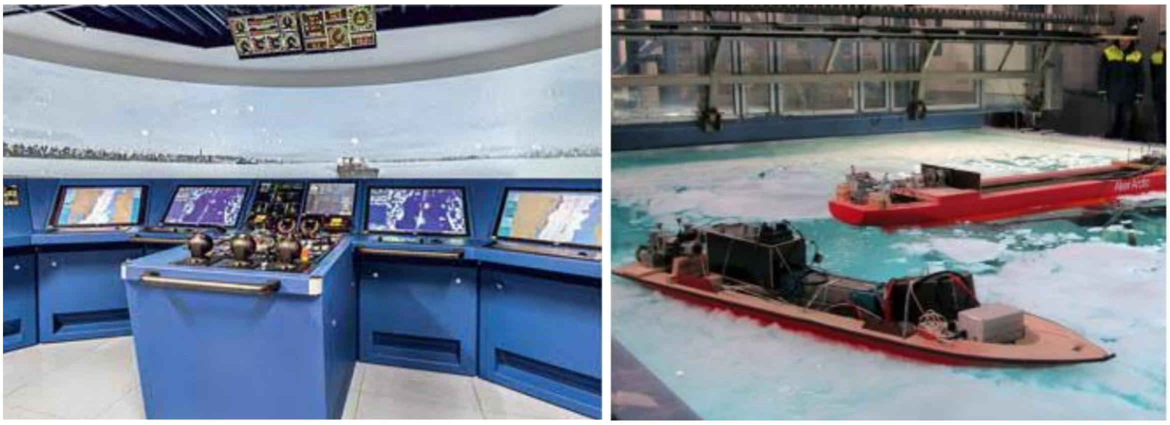

Figure 5-8. Photos of bridge of Ice Simulator (left) and model tests with multiple ships r (right).

5.2.4 Understanding environmental effects

Arctic environment is vulnerable. Some local areas in the Arctic Archipelago may have seasonal wildlife populations, which are disturbed by shipping. Therefore, it is important to gather information about such areas and provide this information to shipping companies which are potentially operating and/or plans to operate in these areas. As illustrated in Figure 5-9, one practical opportunity is to include this information directly in the route planning service (described earlier in Section 5.2.1).

Close co-operation with environmental authorities may provide opportunity to shipping companies to minimize their environmental impacts and improve their reputation regarding environmental friendliness. This kind of co-operation may even provide an opportunity to share information from ships to environmental bodies. Such information could for example be associated with animal species, which are observed from the cargo ship during its voyage in the arctic. This would provide valuable information for environmental studies thus increasing the understanding of arctic environment and further improve the environmental friendliness of shipping in the arctic.

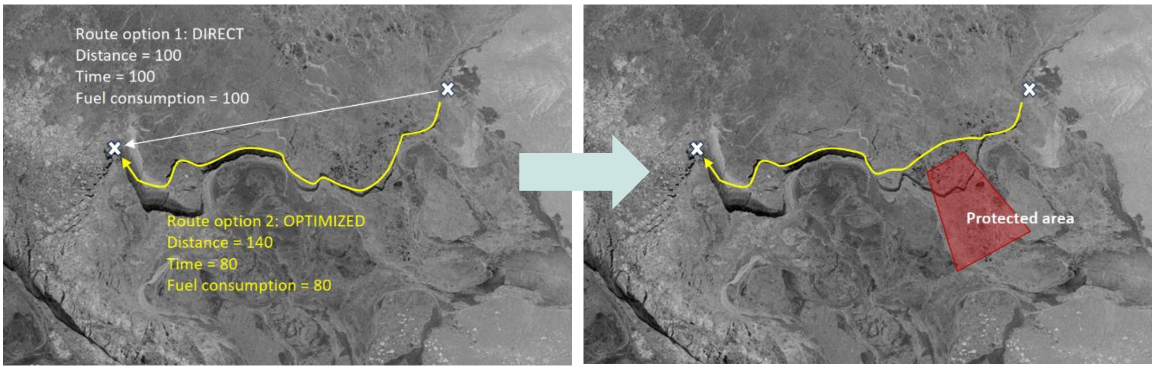

Figure 5-9. Illustration of route optimization so that the suggested route does not cross the environmentally sensitive area ("Protected area").

6 Conclusions

Climate change is impacting the Arctic environment and nature. During future the sea ice extend and thickness are predicted to decrease in the future, which provides more attractive conditions for Arctic shipping than earlier. However, due to this decline is not linear, difficult conditions for the Arctic shipping may also occur in the future. This, together with possible political uncertainties and tensions affecting to the global and regional shipping, makes confident long-term planning of Arctic shipping difficult.

Arctic environment is vulnerable and therefore specific attention to environment-friendly shipping practices in Arctic should be paid. Continuous research and development activities together with active co-operation between shipping companies and environmental scientists provide significant opportunity to minimize the impacts of shipping to the Arctic nature.

The key technical, economic and environmental opportunities of Arctic shipping could be concluded as follows:

- Utilization of modern satellites and state-of-the-art remote sensing techniques to identify ice conditions and accordingly plan and optimize routes in advance to minimize costs and maximize safety.
- High-quality design of the ships for the intended ice conditions (sea regions, navigational seasons) to minimize operational costs, risks and environmental impacts associated to Arctic shipping.
- Utilization of high-tech products and services associated to the data recording, monitoring, analysing and storing for later use to increase understanding of the challenges of Artic shipping and its impacts to nature.
- Co-operation between ship owners, governmental bodies, researchers, etc. in sharing knowledge and experiences to increase understanding of challenges of Arctic shipping and impacts to nature.
- Utilization of appropriate training to prepare ship crews to work and navigate in remote Arctic environment safely, efficiently and environment-kindly.

Conclusions regarding geo-economic & societal opportunities of Arctic shipping are considered more detail in Section 4.6.

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Appendix A. Protected Area Designation by Arctic Country

Country	*Protected Area Designation Type*	*Level*
Canada	Canadian Landmark	National
	Ecological Reserve	National
	Marine Protected Area By Ministerial Order	National
	Migratory Bird Sanctuary	National
	National Marine Conservation Area	National
	National Park	National
	National Wildlife Area	National
	Other Effective Area-Based Conservation Measure	National
	Proposed Biodiversity Reserve	National
	Quebec's National Park Reserve	National
	Territorial Park	National
	Territorial Park - Historic Park	National
Denmark/Greenland	Nature Reserve	National
	Ramsar Site, Wetland of International Importance	International
	UNESCO-MAB Biosphere Reserve	International
UK	Nature Conservation Marine Protected Area	National
	Site of Community Importance (Habitats Directive)	Regional
Iceland	Conservation Area	National
	Habitat Protection	National
	Natural Monument	National
	Public Recreation Area Or Country Park	National
	World Heritage Site (natural or mixed)	International
Norway	Botanical Conservation Area	National
	Botanical Protection Of Species	National
	Botanical/Zoological Protection Of Species	National
	Emerald Network	Regional
	Marine Protected Area (OSPAR)	Regional
	National Park	National
	National Park (Svalbard)	National
	Nature Reserve	National
	Nature Reserve (Jan Mayen)	National
	Nature Reserve (Svalbard)	National
	Protected Geotope (Svalbard)	National
	Protected Landscape	National
	Ramsar Site, Wetland of International Importance	International
	Wildlife Conservation Area	National
	Zoological Protection Of Species	National
Russia	National Park	National
	Natural Monument	National
	Resource Reserve	National

	State Natural Zakaznik	National
	State Natural Zapovednik	National
	UNESCO-MAB Biosphere Reserve	International
	World Heritage Site (natural or mixed)	International
USA	Access	National
	Conservation Easement	National
	Critical Habitat Area	National
	Game Refuge	National
	Marine Protected Area	National
	National Wildlife Refuge	National
	Refuge	National
	Research Natural Area	National
	State Game Sanctuary	National
	State Marine Park	National
	State Park	National
	Wilderness Area	National
	Wildlife Refuge	National

Appendix B. Marine Management Case Studies

(Reid and Dawson, 2019) (15)

Existing Systems	*Key Findings Strengths*	*Areas for Improvement*
Beaufort Sea Large Ocean Management Area	Public right of navigation during ice-free season • Resource provision/resupply, hydrocarbon support, transport • Seafloor bathymetry dictates location of corridors • National defense and public safety operations conducted along the Mackenzie Delta and Arctic Coasts • Resource industries including oil/gas exploration, gravel/sand extraction • Locals work as tour operators and guides • Protected and/or significant areas and resources include 2 MPA's, 3 EBSA's, and protection against large-scale fishing industries	• Insufficient/outdated oil spill and incident response planning and training • Insufficient oil spill response systems considering quantities of oil tankers transport through the Strait
Bering Strait U.S. and Russian TwoWay Shipping Routes	Traffic lanes, voluntary routing measures and corridors ensure no obstructions and allow for bi-directional traffic • Resource provision/resupply to Alaskan villages • Recommendations for safer navigation, improved monitoring, and more time for intervention in the event a vessel breaks down • Subsistence activity areas will not be limited by shipping routes • Resource industries (ie. commercial fisheries) will also not be limited by routes • Protected and/or significant areas and resources include precautionary areas and ATBA's • Routing measures exist within AIS and GPS coverage • Hydrographic survey data dictates boundaries and traffic patterns	No existing aids to navigation associated with routes • Oil spill response and discharge regulation concerns were not addressed
Imappivut Marine Management Plan	Right to resource extraction exists under federal jurisdiction, with permission from Nunatsiavut Gov't and engagement with Labrador Inuit • Search and rescue operations (RAMSARD) and equipment from CCG • Safety system suited to local needs, understand risks and SAR capacity of Labrador coast • Marine tourism areas based on input from	

	Elders • Protected and/or significant areas and resources include potential marine conservation area(s) and development of MPA's • Contribute to International conservation targets while prioritizing Inuit interests Resource provision/resupply of SAR equipment to ensure communities can respond to emergencies and hold a formal role in SAR system • Search and rescue operations including rescue boat station • Safety system suited to local needs of communities • Emergency and/or environmental response training provided • Operational training with joint rescue center, aircraft and CCG operations • Programs to increase Indigenous participation in the marine sector through training and CCGA Arctic membership • Government funding via applying for SAR equipment • Careers in the marine sector for Indigenous students	
Pacific North Coast Integrated Management Area	Voluntary routing measures for tankers transiting near the Gwaii Haanas • Port systems and services handle large portion of marine exports from western provinces • Vessel types that pass through IPR and GCR Routes • Vessel design involves two systems to reduce likelihood of breakdowns • National defense and public safety operations are conducted along the coast • Area supports subsistence activities and harvesting of marine resources • Resource industries such as commercial fishing marine mining contribute to economic development • Marine tourism, specifically cruise ship tourism contributes to economic development • Emergency and/or environmental response training with CCG to support SAR missions is offered • Protected and/or significant areas and resources include 3 MPA's, Gwaii Haanas	Inadequate boundaries for effective SAR in severe weather conditions • Insufficient oil spill response systems due to lack of dedicated tug barge in BC

	Islands • SAR equipment and technology meet CCGA and TC standards	
The Great Lakes - St. Lawrence Seaway System	• Port systems and services are bi-nationally co-managed (U.S. and Canada) • Speed limits have been set in order to protect right whales • Vessel design mandated by IMO standards and enforced by TC and USCG • Standards require regular ship inspections and certification oversight • National defense, public safety operations and law enforcement are conducted by RCMP or DND • Operational training; specialized training for mariners, as well as many programs available to graduate students • Offer vast numbers of careers in the marine sector • Ships are subject to fines who do not obey speed limits • Protected and/or significant areas and resources include the AOC • Pollution response systems include local level planning • Regulations on ballast water discharge for vessels traveling from Atlantic to Canadian ports (and vice-versa) • Use of AIS to improve navigation	Governance issues related to harmonizing regulatory and operational functions • Outdated infrastructure and various physical features limit vessel size • Poor marketing scheme results lack of competitiveness
Newfoundland and Labrador Port Readiness Program	Port systems and services support in management cruise industry development • Cruise tourism management training, workshops, and an information manual provided to parts of call • Marine tourism with respect to informing locals of revenue opportunities, adventure cruises, local attractions contributes to economic development • Use of Internet communication technologies for sustainable tourism practices	Outdated infrastructure, limited size/capacity of docking facilities • Poor marketing scheme • Lack of guaranteed local economic benefits • Lack of strategies to protect natural/cultural resources in ports of call
The Panama Canal	• Traffic lanes locks expansion doubled cargo capacity, slot capacity, and increased maximum beam and draft of ships allowed • Operational training programs in maritime specialties are offered • Toll system meets IMO guidelines and still allows ACP to control policies • Vessels are subject to fines who do not submit a	Inadequate services and infrastructure for safe navigation due to too much responsibility placed on tug boat captains to guide ships through the Canal

	compliant PCSOPEP • Many careers in the marine sector available to national Panamanians • Government funding provided for training programs • Protected and/or significant areas and resources programs in collaboration with local communities on projects to protect the Panama Canal Watershed • Oil spill and pollution response systems are implemented by the PCSOPEP • Use of GIS and VTS to monitor land-use changes and maritime operations	
Torres Strait and the Great Barrier Reef Region	Routing measures imposed by PSSA status related to pilotage • Regulations on various vessel types transiting protected or biosecurity zones • Port systems and services, pilotage areas and requirements • Aids to navigation provided by AMSA • Ship inspections/investigations aimed at establishing causes of accidents • Emergency and/or environmental response training related to SAR and pollution response • Programs to increase Indigenous participation in the marine sector involve enhancing skills of Islander and Aboriginal people to operate commercial vessels • Subsistence activities such as local fisheries and trade are supported and contribute to economic development • Resource industries (i.e. oil operations and fisheries) • Government funding provides careers in the marine sector through the Torres Strait Land and Sea Ranger Project • Protected and/or significant areas and resources include 3 IPA's, and the GBR (declared a PSSA by the IMO) • Regulations on ballast water discharge and dumping of waste at sea • Invasive species prevention and mitigation; prevents arrival, guides responses, minimizes impacts of invasive species • Use of AIS and VTS to assist on-board decision-making •	• Lack of research regarding consequences of shipping and mechanisms to deal with them with more Indigenous community engagement needed • There are uncharted hazards such as shoals in shallow waters • Outdated oil spill response training • Insufficient oil spill response systems

	Meteorological ocean sensors measure tidal wave heights and tide streams	
The Malacca and Singapore Straits	• Traffic lanes segregate west and eastbound traffic • Port systems, services and smaller ferry terminals support international and local transport • Aids to navigation installed by Japan • Responses to marine threats (piracy, oil spills) addressed by CM • Offers training program to combat maritime threats for maritime enforcement officers • Subsistence activities such as harvesting local goods to trade with PNG villages supports economic development • Revenue from local shipping operations; network of formal/informal trade relations supports local economy • Oil spill and pollution response systems are established in Malaysia, Singapore and the South China sea • Use of VTS to monitor ship movements and enhance communication; as well as the mandatory reporting system STRAITREP	Governance issues related to unequal responsibility sharing and distribution of economic benefits • Insufficient awareness to threats and inadequacy of early warning signs; CM needs strengthening • Insufficient pollution response training to deal with increasing amounts of hazardous materials being transported through the Straits

Appendix C. Stena's view on Arctic & New Trade Routes Opportunities

This section has been prepared by Stena as a type of questionare by interviwing seafarers & operating managers within Stena.

Questions **(Q#)** and answers are presented below.

Q1. General description of Stena fleet of ice classed vessels and experience about shipping in ice covered water?

Stena fleet has the following Ice classified ships:

Ice Class	*Number of ships*
1AS	1
1A	2
1B	8
1C	3
TOTAL	14

Stena had two Arctic Voyage experience:

- One trip was transporting oil along Northern Sea Route following an Icebreaker https://shippingwatch.com/cfarriers/article5948462.ece
- Another trip was transporting general cargo from North Alaska.

Q2. Perspective on future business plan in Arctic shipping, especially the Northern Sea Route (NSR). Despite the Oil Tankers, is there other cargo is potential to be transported over NSR by Stena.

From the perspective of Stena, there is not much demand of oil/general cargo transporting requests along NSR for now. However, Stena can see a big potential for requesting LNG transporting from Yamal, Russia to South Korea and Japan.

Q3. Besides NSR, is there any other routes has the potential to be investigated? How shall we evaluate the benefits vs challenges while picking the route in ice covered water OR Arctic Voyage?

Stena agree with the potentials by following NSR, but there are many challenges and uncertainties as well, thus our Stena ships currently would prefer to follow Icebreaker in the Arctic Region.

It would be even harder to go west path, along Canada.

The evaluation standard would be the lease request and operating cost. As a shipping company, Stena will only provide regular Arctic Voyage Service based on long term lease request, and normally during summer.

Q4. What are the differences between Arctic Voyage and normal voyage?

Q4a. New shipping build cost (generally, how much extra XX%-XX% to build a ice classed oil tanker than normal oil tanker)?

For example, it would cost around 50 million to build a 65000t regular oil tanker. For building a similar size 1AS oil tanker would cost 10%-15% more, around 57 million.

Q4b. Additional costs to voyage in icy water, such as operational cost and insurance cost, etc.?

For Arctic Voyage, Stena needs to follow the Polar Code,
https://www.unols.org/sites/default/files/DNV_GL_IMO_Polar_Code_2017-05_web.pdf

a. Baltic extra IWL insurance
b. Crew training
c. Navigation
d. Extra equipment
e. 30% more bunker than normal voyage

Q5. Documents/permits required for Arctic Voyage, how EU could help to improve the possibilities of using Arctic routes (e.g. new services, easiness to apply permits, etc.)

Polar Code. Otherwise, there is no special documents requested by following an Icebreaker.

Q6. Communicating channels and on-live data sharing. (e.g. one ship noticed a group of whales are locating in XXX, XXX, heading south west, how could this information be shared with the other ships around? Many interest groups are willing to protect the marine mammals and would like to understand how to reduce the effect from Arctic Voyage. If we don't have this on-live data sharing today, what's your opinion to pick the technology/tools for achieving that function?)

There is no such equipment installed or planned to be installed.

Based on our existing experience of Arctic Voyage, the Icebreaker will decide the route and speed. It would be more practical to install the advanced communicating channels and on-live data sharing equipment on those Icebreakers.

Appendix D. Research Progress by Zhihua Zhang

Part 1. Background

The dramatic shrinking and thinning of the summertime area of Arctic sea ice over the preceding 4 decades, especially in autumn and summer, accelerates deployments of large-scale trans-Arctic maritime transportation in the near future. The shipping industry has become increasingly interested in Arctic shipping due to lower shipping costs, reduced carbon emissions, and shorter voyage times when Arctic routes are compared with the traditional Asia-Europe Suez Canal Route (Fu et al. 2021). Main Arctic shipping routes include the Arctic northeast passage along the Russian Siberian coast, the Arctic northwest passage through the Canadian Arctic Archipelago, and the Arctic pole route (Giguère et al. 2017). Among these three routes, the most feasible is the Arctic northeast passage, since more sea ice has retreated and will continue to retreat near the Russian Siberian coast than in other parts of Arctic Ocean (Zhang et al. 2016). In practice, since 2000, the number and size of vessels navigating through the Arctic northeast passage has been much high than through the other two routes. Seventy-one vessels passed through the Arctic northeast passage in 2013, while the first vessel passed through the Arctic northwest passage in 2014. The Arctic pole route is not accessible in the near future. Compared with the routes via the Suez Canal or the Cape of Good Hope, the relatively mature Arctic northeast routes along the Siberian coast can reduce the navigational distances between East Asia and Europe ports by 25–43% (Aksenov et al. 2017). At the same time, increasing Arctic shipping activities will harm the Arctic ecosystem, especially given that the negative effects. of carbon and pollutant emissions in the Arctic routes would outweigh the advantage of shorter distance (Østreng 2015). Under the business-as-usual scenario, the overall shipping carbon emission on the Arctic northeast passage by 2050 will be 1.76 times the emission level in 2020. Jing et al. (2021) suggested that switching to cleaner fuels (such as LNG) and slow steaming are effective ways of emission reduction.

Part 2. Trend of Sea Ice Extent (SIC)

We investigated the sea ice changes in 2000-2021 in five regions: The Arctic, North Pacific, North Atlantic, Okhotsk, and Bering Sea.

Table 1. Geographical scope of five regions

	The Arctic	*North Pacific*	*North Atlantic*	*Okhotsk*	*Bering Sea*
Longitude	180°W-180°E	42°-70°N	55°-80°N	42°-63°N	53°-66°N
Latitude	40°-90°N	131°E-158°W	45°W-60°E	131°-161°E	161°E-158°W

The average monthly sea ice extents from 2000 to 2021 are showed in Table 2. Sea ice begins to melt in April and freeze in October, and it reaches its minimum between August and September in all regions. Sea ice is maximum between February and April of the following year, indicating that the variation in sea ice extent has a lag behind the variation in temperature, as much heat is needed to melt sea ice in an energy-accumulating process. Changes of sea ice in the North Pacific are more dramatic than those in the North Atlantic. There is more sea ice in the North Pacific in winter, but less in summer. Since sea ice absorbs or releases a large amount of heat during the melting and freezing process, it will inevitably have a huge effect on the heat exchange between the atmosphere and the ocean, thereby affecting the temperature of the surrounding area and having an important impact on the Arctic. In particular, the Bering Sea and the Sea of Okhotsk are basically ice-free between July and September.

Table 2. The average monthly sea ice extents from 2000 to 2021 (10^6 km^2)

Month	The Arctic	North Atlantic	Bering Sea	North Pacific	Okhotsk
Jan.	13.759	1.138	0.581	1.518	0.686
Feb.	14.671	1.299	0.690	1.948	1.006
Mar.	14.886	1.402	0.715	2.003	1.036
Apr.	14.145	1.343	0.627	1.544	0.665
May.	12.770	1.072	0.296	0.784	0.260
Jun.	11.005	0.763	0.060	0.292	0.097
Jul.	8.291	0.407	0.003	0.046	0.002
Aug.	5.925	0.181	0.000	0.012	0.002
Sept.	5.101	0.157	0.003	0.017	0.002
Oct.	6.982	0.340	0.025	0.090	0.037
Nov.	9.862	0.593	0.081	0.253	0.066
Dec.	12.155	0.881	0.290	0.793	0.276

Sea ice in the Arctic can be divided into one-year ice and perennial ice, in which one-year ice refers to the newly formed sea ice in that year, and perennial sea ice is ice that remains frozen through at least one summer, i.e., it persists after the minimum sea-ice cover is reached. Table 3 shows that the perennial ice in the Arctic region accounts for more than half of the total ice. But there is almost no multi-year ice in the other areas. The significant decrease of Arctic sea-ice cover during summer, compared with winter, produces a larger open water surface, lowering the albedo of the Arctic sea surface and, consequently increasing the absorption of solar radiation. This in turn results in a greater impact on climate and oceans.

Table 3. The average seasonal sea ice extents from 2000 to 2021 (10^6 km2)

Season	The Arctic	North Atlantic	Bering Sea	North Pacific	Okhotsk
Winter (DJF)	13.528	1.106	0.520	1.420	0.656
Summer (JJA)	8.407	0.450	0.021	0.117	0.034

The winter sea ice charts (Figure 1 a-e) reveal approximate trends of sea-ice extent variation each winter (December, January, February) over 21 years (2000-2021) and the trend in each region has significant under the statistical framework. The summer sea ice charts (Figure 2 a-e) shows the situation in summer (June, July, August), however the Bering Sea and Okhotsk did not pass the significance test. Both charts exhibit strong sea-ice interannual variations.

The winter sea ice charts all show downward trends and strong sea ice volatilities, indicating that sea ice is greatly affected by fluctuations in the outside world. However the trends are not consistent in all regions over the 21 years, which shows that the sea ice in the Arctic has obvious regional characteristics. In particular, the sea ice in the Pacific may have a change cycle of about 10 years with peaks in 2001 and 2012, and troughs in 2005 and 2015. This conclusion has yet to be proved by further observational data.

The Arctic summer sea ice chart (Figure 2a) shows a decreasing trend over the past 21 years of sea ice at an annual rate of 0.67×10^5 km^2/yr, which means the reduction of perennial ice in the Arctic. The Atlantic summer sea ice (Figure 2b) reveals that the minimum sea-ice area is 0.24 × 106 km2 in 2016 and that the maximum is 1.01 × 107 km2 in 2003, 2.5 times the former. That indicates that large interannual variations of sea ice has happened in the North Atlantic.

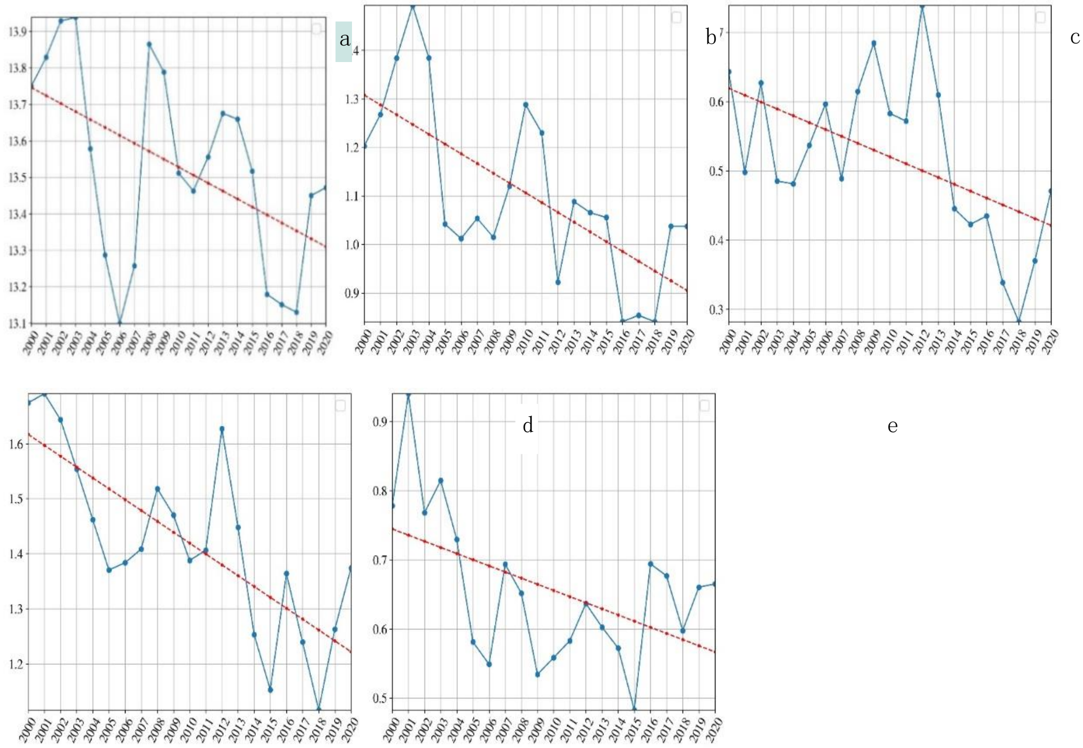

Figure1. Annual variations of sea ice extents in winter from 2000 to 2021 (a: The Arctic, b: North Atlantic, c: Bering Sea, d: North Pacific, e: Okhotsk)

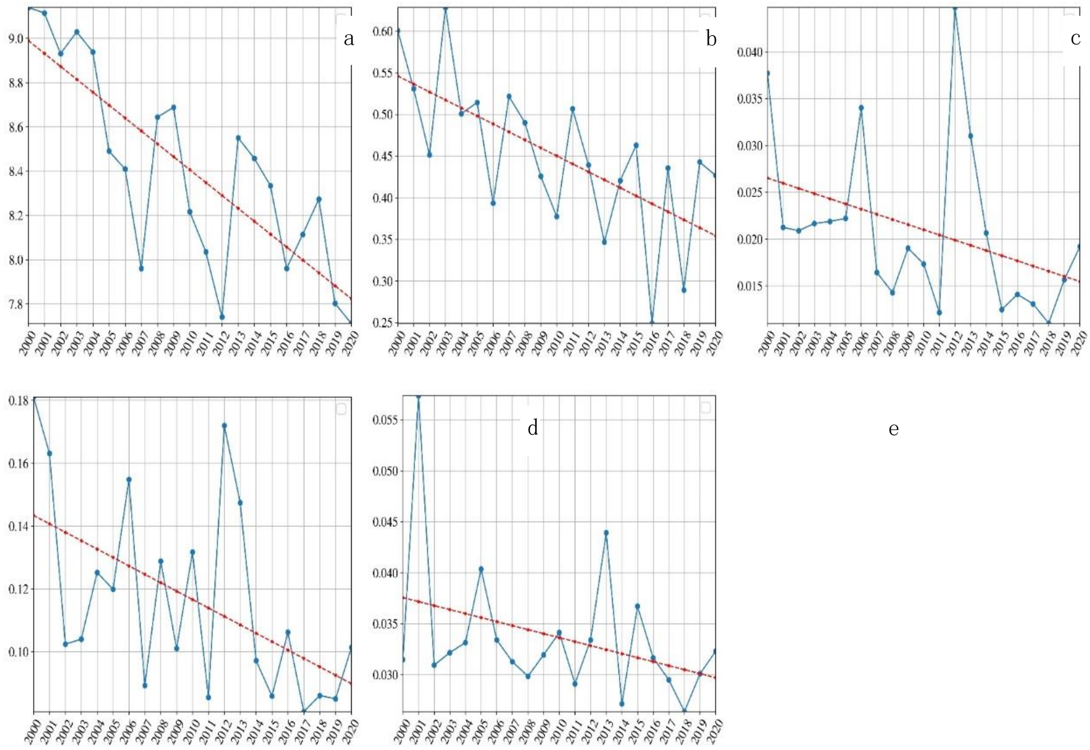

Figure 2. Annual variations of sea ice extents in summer from 2000 to 2021 (a: The Arctic, b: North Atlantic, c: Bering Sea, d: North Pacific, e: Okhotsk)

Part 3. Dominant Pattern of Sea Ice Evolution

The EOF analysis has been widely used to separate the dominant patterns of large-scale variability of sea ice over the Arctic. Most of the total variance in the Sea ice extent (SIC) can be explained by the first EOF mode (Figure 3), and the associated principal component (PC) time series can describe the amplitude variations of the spatial patterns.

The first EOF mode of winter SIC data (Figure 3a) represents variations from 2000 to 2020, which reflects the low frequency of sea ice spatial changes. The positive value in the spatial pattern of SIC data corresponds to Baffin Bay, Labrador Sea, and the Davis Strait where sea ice has increased. Sea ice in the Greenland Sea and Kara Sea has decreased, presenting a seesaw structure on the Atlantic side. Both the Okhotsk and the Bering Strait have reduced on the Pacific side. The PCs of the first mode (Figure 3b) show that the change trend of this spatial distribution pattern is upwards overall, from negative to positive, and mainly positive after 2011.

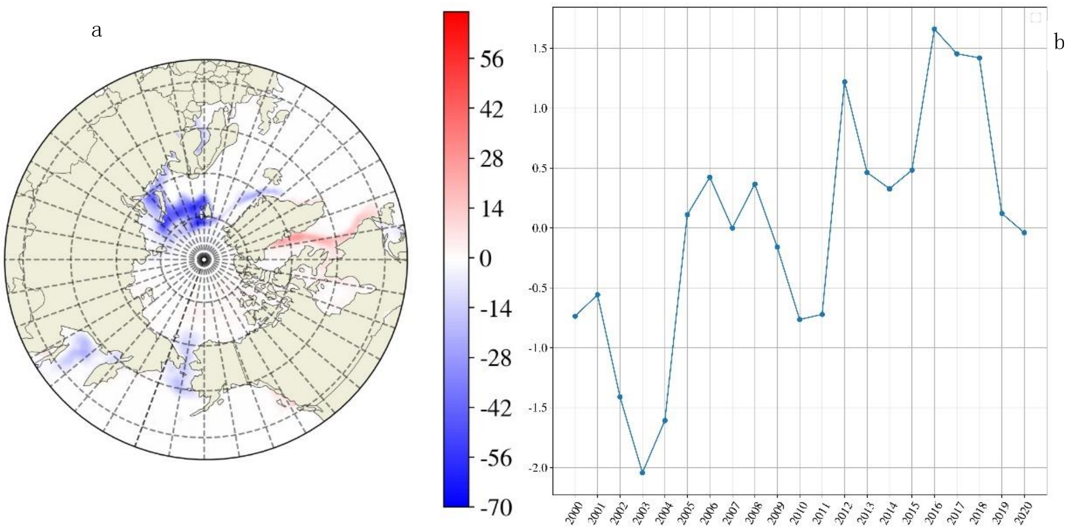

Figure 3. The first mode of EOFs (a) and first PCs time series (b)

Figure 4a is the first mode of the EOF analysis of the Arctic SIC in summer. With no sea ice in the Okhotsk Sea and the Bering Sea in summer, it is mainly manifested in the sharp reduction of sea ice in the Arctic Ocean including the Eastern Siberian Sea, the Laptev Sea, and the Kara Sea. The sea-ice increase has exceeded 20% in some areas around Greenland. The linear trend of the principal component (Figure 4b) is upward overall.

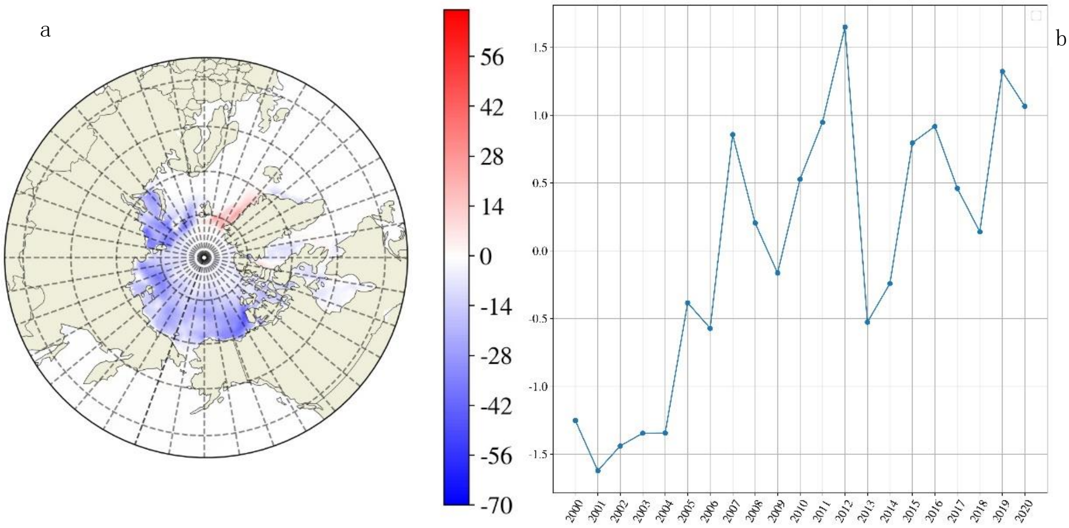

Figure 4. The first mode of EOFs (a) and first PCs time series (b) during 2000-2020 over Arctic in summer

Part 4. When did the Northeast Passage access during 2000-2021

The Arctic Northeast Passage (or Northern Sea Route) is a sea route connecting the Far East and Europe, by travelling along Russia's and Norway's Arctic coasts from the Chukchi, East Siberia, Laptev, and Kara, to the Barents Seas. Its navigational distance is 5000-7000 miles shorter than the route via the Cape of Good Hope and 2000-4000 miles shorter than the route via the Suez Canal. The Arctic Northeast Sea Passage presently open for four-five months per year for ice-strengthened vessels to navigate. The following five tables demonstrate when ships can pass though the sea of five regions on the Northeast Passage of the Arctic.

Table 4. Days when ships can pass through the Bering Strait

Year	the Start Date	the End Date
2000	June-16	November-27
2001	May-28	November-6
2002	May-30	December-15
2003	May-18	November-20
2004	May-18	December-5
2005	May-24	November-24
2006	May-27	December-10
2007	May-22	December-16
2008	May-28	November-18
2009	May-27	November-17
2010	June-4	December-10
2011	May-20	November-22
2012	June-2	November-17
2013	June-7	December-14
2014	May-27	December-11
2015	May-23	December-2
2016	May-12	December-9
2017	May-12	December-17
2018	May-15	December-5
2019	May-9	December-6
2020	May-28	December-9

Table 5. Days when ships can pass through the Chukchi

Year	the Start Date	the End Date
2000	August-19	October-5
2001	August-7	October-7
2002	July-30	October-26
2003	July-20	October-24
2004	August-3	October-31
2005	July-16	November-10
2006	August-2	November-8
2007	June-23	December-13
2008	July-18	October-24
2009	July-4	November-8
2010	July-30	November-9
2011	July-10	November-9
2012	July-30	October-15
2013	July-17	October-25
2014	July-10	December-7
2015	July-7	November-14
2016	July-13	November-25
2017	July-13	December-10
2018	July-21	November-14
2019	July-9	November-23
2020	July-10	December-6

Table 6. Days when ships can pass through the East Siberia

Year	the Start Date	the End Date
2000	September-1	October-4
2001	None	None
2002	August-3	October-16
2003	August-9	October-17
2004	August-12	October-5
2005	July-24	October-21
2006	August-9	October-13
2007	July-23	October-26
2008	August-12	October-13
2009	July-31	October-9
2010	July-30	October-14
2011	July-25	October-14
2012	August-8	October-15
2013	August-16	October-3
2014	August-2	October-18
2015	July-20	October-14
2016	July-24	October-22
2017	July-17	October-16
2018	August-9	October-20
2019	July-27	October-25
2020	July-6	November-2

Table 7. Days when ships can pass through the Lapkev Sea

Year	the Start Date	the End Date
2000	August-11	October-1
2001	None	None
2002	August-9	September-22
2003	None	None
2004	None	None
2005	August-17	October-11
2006	July-30	September-13
2007	October-6	October-6
2008	August-31	October-4
2009	July-30	October-12
2010	August-28	October-3
2011	July-6	October-23
2012	July-11	October-21
2013	July-5	October-6
2014	July-5	October-12
2015	July-25	October-14
2016	August-23	October-19
2017	August-17	October-5
2018	July-11	October-25
2019	July-13	October-16
2020	June-27	November-2

Table 8. Days when ships can pass through the Kara

Year	the Start Date	the End Date
2000	August-22	September-28
2001	August-7	October-13
2002	August-8	September-22
2003	None	None
2004	August-12	September-20
2005	August-13	October-20
2006	July-29	August-21
2007	August-3	October-19
2008	August-12	October-7
2009	August-28	October-27
2010	July-8	October-8
2011	July-3	October-24
2012	July-28	October-28
2013	August-22	October-5
2014	August-7	October-5
2015	July-17	October-17
2016	August-2	October-30
2017	August-12	October-12
2018	August-5	October-24
2019	July-21	October-24
2020	July-12	October-29

Table 9. Days when ships can cross the Barents Sea

Year	the Start Date	the End Date
2000	May-8	December-27
2001	May-3	December-24
2002	May-7	December-25
2003	May-9	December-31
2004	May-5	December-29
2005	May-21	December-31
2006	April-25	December-27
2007	April-11	December-31
2008	April-26	December-31
2009	May-14	December-16
2010	May-17	December-29
2011	May-15	December-31
2012	April-25	December-25
2013	May-17	December-31
2014	April-21	December-30
2015	April-3	December-31
2016	April-11	December-31
2017	May-7	December-31
2018	May-20	December-31
2019	April-7	December-31
2020	March-27	December-28

Part 5. Steaming-data–based management systems for trans-Arctic routes

Yearly variations in Arctic sea ice distribution and thickness will still threaten the safety of vessel navigation along Arctic routes. Potential risks depend on intra-annual spatial variability and sudden changes in sea ice conditions in the Arctic. The Arctic severe weather (e.g., the strong winds, snow storms, reduced visibility in fog) and the remoteness from navigation support services (e.g., navigational, hydrographic, meteorological, communication, emergency rescue, vessel waste disposal) also increase navigational threats (Gavrilov et al. 2019).

Dynamic accurate predictions of Arctic sea ice, ocean, atmosphere, and ecosystem are necessary for safe and efficient Arctic maritime transportation, however a related technical roadmap has not yet been established. Zhang and Crabbe (2021) proposed a management system for trans-Arctic maritime transportation supported by near real-time streaming data from air-space-ground-sea-integrated monitoring networks and high spatio-temporal sea ice modeling. As the core algorithm of integrated monitoring networks, a long short-term memory (LSTM) neural network is embedded to improve Arctic sea ice mapping algorithms. Since the LSTM is localized in time and space, it can make full use of streaming data characteristics. The sea ice–related parameters from satellite remote sensing raw data are used as the input of the LSTM, while streaming data from shipborne radar networks and/or buoy measurements are used as training datasets to enhance the accuracy and resolution of environmental streaming data from outputs of LSTM. Due to large size of streaming data, the proposed management system of trans-Arctic shipping should be built on a cloud distribution platform using existing wireless communications networks among vessels and ports.

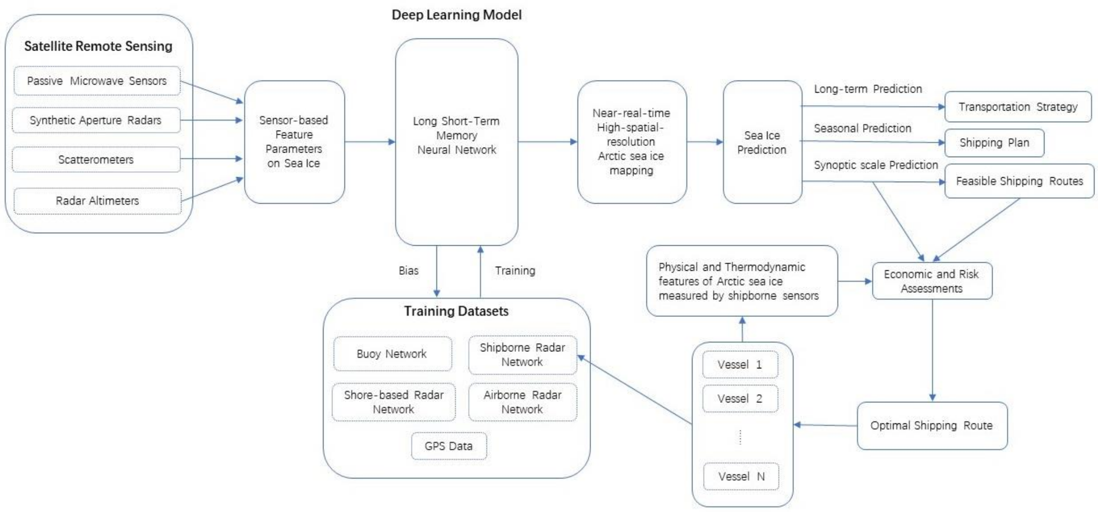

Figure 5. Management of environmental steaming data to optimize Arctic routes (Zhang and Crabbe, 2021)