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Effects of Arctic commercial shipping on environments and communities: context, governance, priorities

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ABSTRACT

Increasing shipping traffic in the Arctic Ocean creates an emerging need to understand the consequences of maritime operations on the Arctic environment and coastal Indigenous and non-Indigenous communities, as well as potential governance responses. To address this need, we examine recent shipping trends and assess their impact on Arctic environments and communities. Our arguments are novel, and are built around contemporary empirical investigations and published scientific studies, reports, and government documents. The paper concludes that the environmental and community impacts vary across the Arctic and that greater international coordination is needed to learn from experience, to share assets and capacities, and to guide responsible and sustainable development of Arctic shipping. Given the possibility for opening of the Transpolar Sea Route within the coming decades, further proactive steps, such as developing a governance framework, could help Arctic shipping avoid rather than attempt to correct problems.

1. Introduction

The prospects for Arctic shipping have received a great deal of governmental, economic, scholarly, and public attention, especially

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since publication of the *Arctic Marine Shipping Assessment* (AMSA 2009). Recent growth in Arctic shipping activities has led to a variety of environmental impacts that affect local viability and cultural concerns of residents of the Arctic coastal states (Norway, Russia, USA/Alaska, Canada and Greenland/Denmark). Most vessels today typically operate close to coastal areas and pass through the areas of ecological significance (AMAP/CAFF/SDWG 2013). Any accidents in vulnerable Arctic environments may pose cascading impacts for local communities, affecting their livelihoods, well-being, and food security. Moreover, the prospect of further increases in Arctic shipping raises concerns about additional socio-cultural effects on Arctic peoples and environmental effects on Arctic ecosystems even from normal operations (ITK 2017, Dawson et al. 2020, Olsen 2020, Panahi et al. 2022, Osmundsen 2023, Richard et al. 2023). These topics have not been reviewed for Arctic shipping as a whole since publication of the 2009 *Arctic Marine Shipping Assessment*. Hence, the holistic review and synthesis of existing knowledge on Arctic shipping impacts present the rational for this study.

To consider what has happened in the decade and a half since the *Arctic Marine Shipping Assessment*, this paper examines Arctic shipping development and its impact on local communities and environments to assess where action is most needed to reduce risks while also considering the opportunities that such shipping presents. It begins with a review of the context of local and commercial shipping in the Arctic. Furthermore, this review comprises the description of shipping types and routes, and cultural and environmental concerns and governance responses and limitations. In doing so, trends in shipping of different kinds and along different routes are examined, and potential governance measures at international and national levels, including efforts to promote Arctic shipping. Finally, based on this review, needs for action specific to each of the three major Arctic shipping routes are identified.

The term "Arctic shipping" encompasses a variety of routes, vessel types, activities, destinations, effects, and governance strategies (Østreng et al. 2013). Vessel traffic is unevenly distributed across the Arctic. The Barents sector of the Arctic is the most navigable and least limited by sea ice, so it is not surprising that about 80 % of all Arctic shipping crosses the Norwegian sector of the Barents Sea. By any measure, the quantity of vessel traffic along the two main Arctic Sea routes, the Northeast and the Northwest Passages (NEP and NWP), has increased in recent years, a trend that is expected to continue (PAME 2020, Min et al. 2022, 2023). Navigation along the third route, the Transpolar Sea Route (TSR), may become feasible by the middle of the 21st century or even sooner, by 2040, as sea ice continues to retreat in the Arctic Ocean (Bennett et al. 2020, Stephenson et al. 2013, Cao et al. 2022, Li and Lynch 2023).

Arctic routes are increasingly integrated in the global marine transportation system and provide considerable potential economic benefits (Goldstein et al. 2022, Li et al. 2023), even as loss of Arctic sea ice incurs considerable costs globally (Yumashev et al. 2019). Despite this attention, a broad overview of the context of Arctic shipping, its prospects, and impacts has not recently been undertaken. Though multiple studies (also in this Journal) have examined the environmental impacts of the Arctic shipping (e.g., Afenyo et al. 2019, 2020, Cheaitou et al. 2020, Ding et al. 2020, Xu and Yang 2020, Chen et al. 2022), its influences on coastal Arctic communities are still understudied. The existing literature on potential shipping impacts on environmental aspects of communities' viability (e.g., Ng et al. 2018, Raymond-Yakoubian 2018, Bennett et al. 2020, Olsen et al. 2019, Panahi et al. 2021, Afenyo et al. 2022a, b, van Luijk et al. 2022) also calls for a broader understanding of potential environmental impacts of shipping growth and governance responses, at

Table 1
Classification of Arctic shipping (adopted from Dawson et al. 2017).

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

local, regional, and international levels (e.g., Todorov 2022).

Depending on the calculation methods, there are 4–7 million people living in the Arctic, the greater part of in coastal areas (Jungsberg et al. 2019). Arctic coastal communities have historically relied on shipping as a means of mobility, community supply services, resource extraction, fishing, and additional income, for example from tourism. These communities engage in a wide variety of marine activities at sea and on sea ice, depending on location, time of year, and cultural patterns (AMAP 2011). Arctic marine ecosystems display extreme seasonal patterns and a wide range of biological productivity and abundance (AMAP/CAFF/SDWG 2013), factors that need to be taken into account when assessing the environmental effects of vessel traffic.

2. Context and status

2.1. Arctic shipping types

Arctic maritime activities started with local uses of marine environments, and later extended to commercial fishing and whaling, to

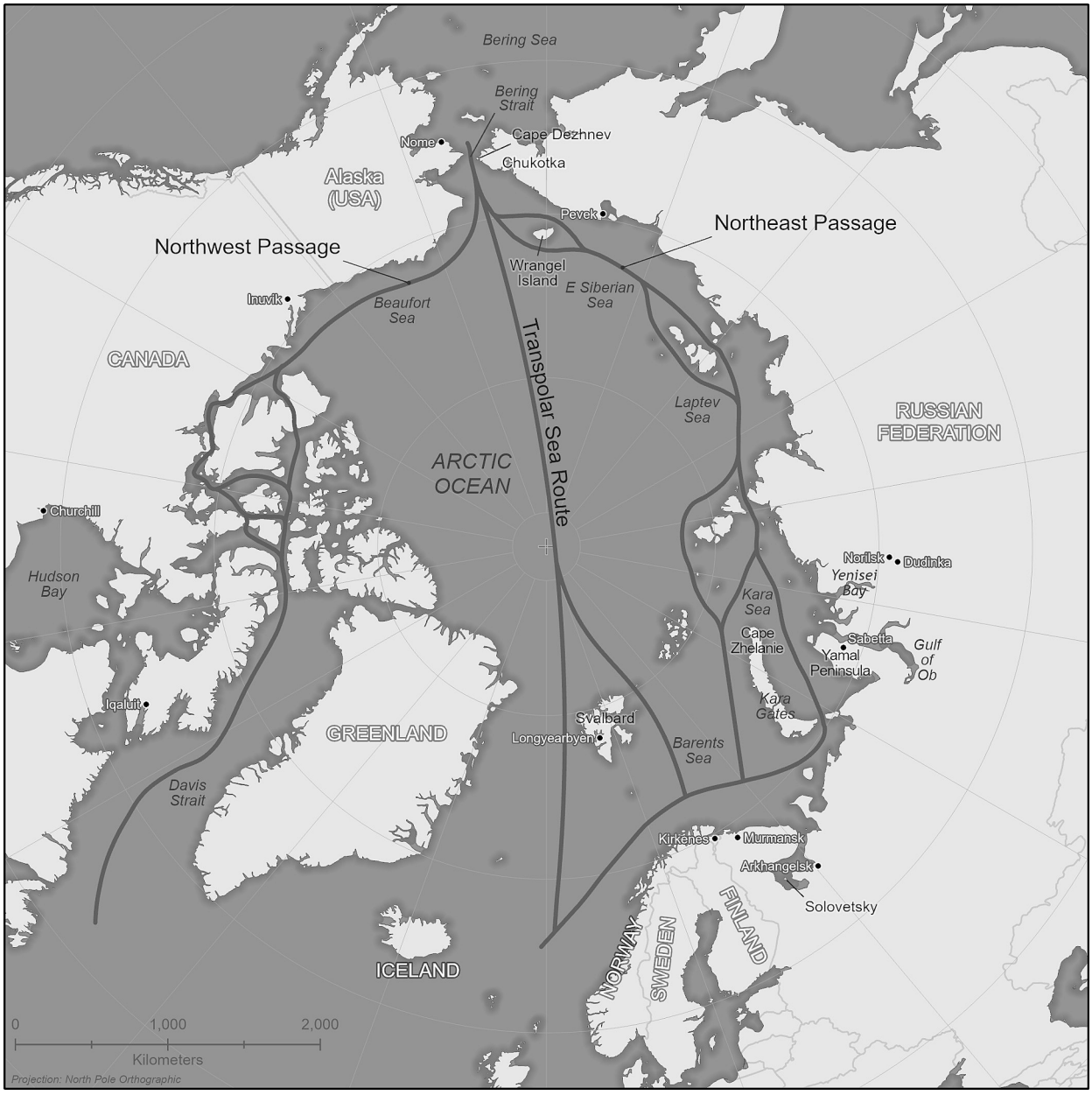

Fig. 1. Map of the major shipping routes through the Arctic and significant places mentioned in the text.

the quest for Arctic transit routes along the Canadian and the Russian coastline, and to resource development and the establishment of the NEP and the NWP (AMSA 2009). At present, less than 10 % of the world's shipping occurs in the Arctic (Eguíluz et al. 2016), but the number of vessels operating in the region has been increasing substantially during the past few decades. In the Polar Code area (the International Maritime Organization's definition of the Arctic waters), the number of vessels increased by 25 % from 2013 to 2019 (PAME, 2020). Shipping in the Arctic, as elsewhere in the world, includes a variety of vessel types and purposes (see Table 1). Shipping operations can be divided between internal (between Arctic ports), destination (between two ports, one of those outside the Arctic), and transit operations (both ports outside the Arctic, but the route crosses the Arctic).

Cargo is carried to the Arctic to supply communities and other installations, from the Arctic in the form of raw materials such as mineral ore and liquefied natural gas (LNG), and through the Arctic to connect manufacturing centers and markets. Cargo vessels of all kinds are typically traveling from one point to another in the most efficient manner possible. Fishing vessels are another form of resource extraction but spend time seeking and catching fish rather than simply in transit. Research vessels, similarly, may follow specific patterns in an area or stay in one location to take measurements.

Passenger transportation, including cruise vessels and pleasure craft, has been one of the fastest- growing shipping industries in Arctic waters (e.g., Johnston et al. 2017, Têtu et al. 2018, Olsen et al. 2020a). Luxury and expedition cruise ships both large (greater than200 passengers) and small (less than200 passengers) are likely to seek out places of high natural beauty or biological abundance. Similarly, passenger vessels (i.e., private, or chartered yachts) tend to travel off the main shipping corridors into specific and often remote areas that have high aesthetic or adventure value (Johnston et al. 2017, Lau et al. 2023). Tourist voyages in the European part of the Arctic have been conducted since the middle of the 19th century. However, the number of vessels and the number of passengers on those vessels across the Arctic has rapidly increased over the past 30 years (e.g., Dawson et al. 2018). The phenomenon of "last chance tourism" premised on disappearing Arctic nature has become a popular trend in several Arctic destinations (Lemelin et al. 2010).

In addition to commercial and passenger shipping, military activity in the Arctic has a long history, especially involving submarines (Palma et al. 2019). There is growing attention to national security issues related to the loss of sea ice and the increase in commercial shipping and other industrial activities in the region (e.g., Office for the Undersecretary of Defense Policy 2019). Attention to shipping routes, port facilities, and other aspects of commercial shipping also raises questions about militarization (Zagorskiy 2019). Information about military activities and plans, however, is not readily available, and so this topic lies beyond the scope of this paper. The fact that national security matters often outweigh commitments to cultural and environmental protection, however, makes this an important topic for future research. (*The authors note in this context that the armed conflict in Ukraine and the ensuing sanctions by many countries have at least temporarily reduced those countries' interest in the NEP as well as the prospects for international cooperation involving Russia. How long this situation will persist is unknown at the time of writing and may have a lasting effect on at least some of the topics examined here.*).

2.2. Arctic shipping routes

There are three major shipping routes through the Arctic (Fig. 1). The NEP extends from northern Norway across Russia to the Bering Strait, encompassing the Northern Sea Route (NSR). The NSR is currently defined by Russia as the waters within its exclusive economic zone (EEZ) between Cape Zhelanie (68°35′E) and the Kara Gates in the west and Cape Dezhnev (168°58′37″ W) in the east. The NWP extends from Davis Strait by various passages through the Canadian Arctic Archipelago and around Alaska to the Bering Strait. The TSR, a still-hypothetical route, goes from the Bering Strait to the North Atlantic, through the high seas of the middle of the Arctic Ocean. All three routes include variations around islands and other geographic features. Additional routes such as the Arctic Bridge from Churchill, Manitoba, through Hudson Bay to Europe overlap with portions of the major Arctic routes, but will not be considered separately here insofar as the environmental and cultural concerns are similar.

2.2.1. Northeast Passage/Northern sea route

Parts of the NEP have been navigable for centuries, but the full route was first transited in a single season in 1932, under the command of Otto Schmitt. This event was followed by the establishment of an administrative body for the NSR, Glavsevmorput, and later the establishment of several settlements and polar stations to support this east–west transportation link (Komarova 2016). The amount of total cargo transported along the NSR peaked in 1986–1987, before a significant decrease during the collapse of the Soviet Union (Marchenko et al. 2016). In the 1990s, Arctic shipping reached a new milestone with the opening of Russian Arctic waters to international vessels.

Most Arctic shipping at present occurs in the European part of the Arctic and along the NEP. Depending on the ports at either end of a transit voyage, the NEP is 24–37 % shorter than the route via the Suez Canal (Farré et al. 2014, Middleton 2021, Hermann et al. 2022). However, the attractiveness of this route is limited by harsh climate conditions and the short navigation season, the world's geopolitical situation, technological requirements, and high insurance costs, among other considerations. These features determine the structure of vessel traffic on the NSR. Destination shipping remains dominant and has been increasing. The cargo volume on the Northern Sea Route (NSR) increased from 7.5 million tons in 2016 to 31.5 million tons in 2019 (Gunnarsson 2021), and much of this can be attributed to LNG shipments from the Yamal Peninsula beginning in 2017.

In 2020, LNG shipping accounted for 510 voyages (including return voyages in ballast), amounting to 59 % of cargo volume on the NSR. Crude oil accounted for 435 voyages (including in ballast), or 24 % of cargo volume. Diverse operations between the port of Dudinka serving the Norilsk mining complex and the Russian ports of Murmansk and Arkhangelsk located outside the NSR accounted for a further 201 voyages. These operations are performed by ice class Arc 7 and Arc 4 vessels (NSR Information Office 2021, Rosatom

2021). Transit shipping is concentrated in the navigation season, involves lower ice class Arc 4 and 5 vessels (NSR Information Office 2021), and is dominated primarily by the transportation of iron ore (78 % of cargo in 2020), oil products (7 %), cellulose, and fertilizers (5 % each) (Rosatom 2021).

The interest in transit operations along the NEP is still low (Zagorski 2017, Brigham 2020, Gunnarsson and Mo 2021), but slightly increasing, including the transit of the first container ship in 2018 (Humpert 2018). Interest may increase with Russia's plan to facilitate year-round shipping along the NSR in the near future (Reuters 2021), supported by the new 120 MW leader-class nuclear icebreakers expected in operation by the late 2020s (Rosatom 2020).

2.2.2. Northwest Passage

The existence of the NWP was proposed by Europeans as early as 1490, however not until 1944 was it transited during a single navigation season (AMSA 2009). The NWP passes through the Canadian Arctic Archipelago and consists of several potential routes between the Bering Strait in the west and Davis Strait in the east, with the southernmost route being by far the most common due to milder ice conditions. From the 1940s to the 1990s, transit voyages occurred at very low levels, with a handful of notable transits marking the firsts of their kind. Not until 2013 did the first commercial transit of the NWP take place (Neuman 2013). Most transit voyages continue to be undertaken by passenger ships and small vessels on expedition-type trips, rather than to transport goods (Dawson et al. 2018, Copland et al. 2021).

Destination shipping remains and is expected to continue to be the primary type of traffic in the NWP, with community-resupply, government operations, traffic related to mining projects, research, and tourism all steadily increasing (Dawson et al. 2018, 2021). Canada maintains that the NWP is internal waters and that vessels must adhere to domestic regulations, a position disputed by the United States and others (AMSA 2009). Though there has been speculation of increasing commercial transits as a result of decreasing ice cover and shorter distances between some ports, in practice the challenging nature of the route, including highly variable ice conditions and limited supporting infrastructure and services, means there continues to be limited commercial interest (Lasserre 2011).

Persistent and increasingly mobile sea ice has thus far prevented any sustained transit traffic from utilizing the NWP to any great effect. Despite imagined economic prosperity related to maritime trade via the NWP, this has not become a reality, albeit with climate change it will become increasingly possible in the future (Constable et al. 2022). Although some debate persists regarding what constitutes a "transit" of the NWP considering route variability, data collection methods, and definitional disputes, there is indeed a clear increase in ship traffic operating within its various passages. Most current traffic includes re-supply cargo ships that are servicing local communities and mines, fishing vessels (local and commercial), tankers, and tourist vessels (passenger vessels and pleasure craft). Although cargo ships, tankers, fishing, and military/research vessels make up the majority of total traffic volume currently operating within the NWP, the fastest growing maritime sector within the NWP in recent years (by far) is pleasure craft. Over the past thirty years the number of vessels operating within the region of the NWP with limited to no ice-strengthening has increased while the number of icebreaking and highly ice-strengthened vessels has decreased. This is in part due to societal and economic trends but it is also largely due to climate change which is creating increased accessibility to some areas of the NWP. Accessibility among vessels with medium or little ice strengthening within the NWP has increased substantially over time especially in the shoulder seasons (i.e., early season just after break-up and late season just before freeze-up) (Dawson et al. 2022). It is expected that future climate change will increase accessibility of the NWP even further. Mudryk et al. (2021) projected the future season length of the NWP, finding an increase of up to two-and-a-half months for the entire route and perhaps even longer in the Beaufort Sea region.

2.2.3. Transpolar sea route

The TSR presents the shortest pathway from the North Pacific to the North Atlantic. Still, there is no defined route for the TSR at present (Stevenson et al. 2019), as vessels would likely be constrained by where sea ice is present as well as the desire for the shortest pathway. No commercial shipping has taken place along the whole TSR, though parts of it have been navigated by research and cruise vessels and some full transits have been made by icebreakers. The Arctic region is warming four times faster than the world average, resulting in dramatic sea ice reduction (Rantanen et al. 2022). Several studies project the route to become seasonally ice free by mid-century, or even by 2040 (e.g., Bennett et al. 2020, Smith and Stephenson 2013). The question of how the opening of the TSR will affect activity level along the NEP remains open. The route may be attractive because it is the most direct, avoiding navigation challenges as well as fees or other restrictions and administrative barriers associated with the NEP and NWP. Whether and when these advantages will attract significant commercial traffic remains to be seen. Unlike the NEP and NWP, Svalbard is the only intermediate destination along the TSR between the Bering Strait and the North Atlantic.

3. Impacts and concerns

3.1. Environmental concerns

The Arctic marine environment is changing rapidly due to global warming (Huntington et al 2020). Much of the region remains relatively undisturbed by local human activity, potentially leaving it susceptible to substantial environmental effects from even a relatively modest volume of shipping (AMSA 2009). Some of the effects of Arctic shipping have been documented and can be predicted with some confidence (Bennett et al. 2020, Huntington et al. 2015, Olsen et al. 2019). These include disturbance of marine mammals and seabirds, pollution of water and air from emissions and discharges from ships (Chen et al. 2021), potential transport and release of invasive species, and the risk of accidents and especially fuel spills (Afenyo et al. 2019). In general, environmental concerns can be

divided into three categories: the chronic effects of routine shipping, the acute effects of accidents and spills, and the effects of targeted activities such as fishing or tourism to ecological hotspots. Emergency response is particularly challenging. Environmental concerns in the Bering Strait region mirror those described for cultural and social concerns above, so this section focuses on other areas of the NEP and NWP.

With expected and already planned new economic development along the Arctic coast and in the Arctic Seas of Russia, shipping activity along the NEP/NSR is likely to grow in the near future (Government of the Russian Federation 2019). To minimize or mitigate possible adverse impacts of shipping along the NEP/NSR, it is important to consider vessel traffic patterns in the different parts of the route in light of the specific environmental characteristics of each part of the route. Shipping activities are unevenly distributed throughout the Russian maritime Arctic and therefore their impact on the environment varies sea by sea. Each economic activity results in a specific impact on biologically significant areas and is associated with specific risks. The impacts of vessel traffic on marine ecosystems along the NEP are limited mostly to physical disturbance, noise, both air and water pollution, icebreaking activities, the spread of invasive aquatic species, and the risk of a fuel or cargo spill. However, one of the noticeable environmental problems, marine litter from fisheries, has started to receive more attention, as both fishing activities and litter moves northward (Höjman et al. 2022; Olsen et al. 2020b) negatively affecting marine life and coastal populations.

A comparison of a recent assessment of priority conservation areas in the Russian Arctic seas (Spiridonov et al. 2020) with the distribution of shipping density along the NEP/NSR (Grigor'yev, 2016) shows three large areas where shipping co-occurs with conservation needs and demands more careful regulation and spatial planning including designation of recommended shipping corridors. One of these areas is the coast of the Barents Sea and particularly to its southeastern part (Kolguyev Pelagic Region) and waters adjacent to the western shores of Novaya Zemlya and Vaygach Island. All transit vessel traffic passes through those areas heading to the Kara Gates and Cape Zhelaniye to enter the NSR. The next area of substantial overlap is between the Kara Gates or Cape Zhelaniye and the Gulf of Ob (to the LNG and oil port of Sabetta) and Yenisei Bay (Dudinka and Norilsk) in the Kara Sea. The third area of high biodiversity value and with relatively high vessel traffic stretches between Pevek and the Bering Strait. Suggested priority biodiversity conservation areas along this stretch of the NEP include Chaun Bay (in the East Siberian Sea), Long Strait between Wrangel Island and Chukotka, the Wrangel Island marine zone, the Kolyuchinskiy marine region at the entrance in Kolyuchin Bay, and the Chukotskiy marine region located east of Wrangel and Herald Islands.

Due to the absence of sea ice in most parts of the Barents Sea, the region is one of the most navigable in the Arctic. The shipping lines and corridors in the Barents Sea usually pass areas of ecological significance for several marine species and birds, presenting a high risk for vulnerable species in case of any accidents. The use of marine environments by the local community of Longyearbyen differs from the Indigenous populations in Canada and Bering strait. Locals do not use the marine environment for subsistence purposes, but fish and hunt occasionally for recreational purposes only. However, local residents and stakeholders have emphasized that the increased traffic in the Svalbard fjords have resulted in wildlife disturbance, emission to the air, and also marine litter from increased commercial fishing activities (Olsen et al. 2019). Another problem associated with increased human presence is seen on Solovetsky Archipelago, Barents Region. Members of that community have pointed out that wildlife disturbance has been limited on the archipelago due to stricter regulations (Olsen et al. 2019). However, waste generation on the island presents an emerging concern. The waste generated by residents and an increasing number of visitors bothers the local population as only a small portion of the garbage is transported to the mainland (Olsen et al. 2020a).

In the NWP, the marine environment is characterized primarily by dramatic seasonal fluctuations in ice cover and ecological productivity. The environment is highly dynamic with key habitat areas exhibiting increased sensitivity to disturbance and pollution at different times of year. Routes through the NWP overlap to a great extent with identified Ecologically and Biologically Significant Areas (EBSAs) (Pew Charitable Trusts 2016) and newly identified CSMAs (Dawson et al. 2020, 2021). Given the characteristics of Arctic food webs and the stresses already created by climate change, major or cumulative pollution events or the introduction of invasive species could have devastating and long-lasting consequences (AMSA 2019, Huntington et al. 2015). This is a major concern, given the high degree of local reliance on healthy food from the ocean and the extremely limited capacity to respond, clean up, or undertake salvage operations (ICC-Canada 2008, AMSA 2009).

Noise disturbance in key habitat areas has been repeatedly observed by Inuit and increasingly by science to negatively impact habitat use (Kochanowicz et al. 2021, Halliday et al. 2020). Key Arctic species, such as walrus and narwhal, have been observed to be especially sensitive to ship noise. In areas of intensive ship traffic, Inuit observers have seen major shifts in habitat use associated with aversion to underwater noise from large vessels. In other cases, Inuit have observed whales such as beluga following tracks created by icebreakers, leading to a high risk of ice-entrapment mortality events if the open water freezes behind them.

Some recent efforts to protect sensitive ecological areas from shipping impacts have taken place, such as three recent Notices to Mariners issued by Transport Canada that aim to alert mariners to area-specific risks. Given the vast area covered by the NWP and the major shifts underway in the biophysical environment due to climate change, greater work is needed to identify and protect seasonally sensitive areas to prevent cumulative impacts and manage human activity accordingly. A key tool for shipping management in the Canadian Arctic is the establishment of marine protected areas with associated regulations, although these have not yet adequately addressed impacts from shipping and recent evidence suggests that ships are not abiding voluntary exclusion zones (Halliday et al. 2022).

Aside from the Bering Strait, the TSR does not pass near any coastlines or navigational hazards other than sea ice (Stevenson et al. 2019). The middle section of the route does not pass through any known ecological hotspots, though spills and pollution would nonetheless damage the ecosystem. The risk of environmental damage has exacerbated the difficulty of responding to any ship that had an accident, since much of the route is far from any rescue capacity. If few ships are traversing the route, even response by another vessel could not be counted on. Thus, even a small problem may not be fixable for some time, magnifying the extent of the damage to

ship and sea. Nonetheless, the TSR can also be seen as the Arctic route that creates the least transit traffic through known ecological hotspots.

3.2. Cultural and social concerns

Impacts on the natural environment are closely interrelated with socio-cultural aspects of Arctic communities' well-being. Traffic on the NEP and adjacent routes passes the coastal communities and port towns of Arctic Russia as well as northern Norway. NWP traffic passes western and northern Alaska as well as the Inuit communities of Arctic Canada and Greenland. The TSR, by contrast, remains far away from coastal communities apart from the Bering Strait and Svalbard area. Even though those areas are sparsely populated, existing studies document multiple social and cultural impacts on Indigenous and non-Indigenous peoples in this area (e.g., AMSA 2009, Raymond-Yakoubian 2018). Cultural concerns include disturbance to the marine environment and to traditional hunting and fishing activities, and disruption to communities and archeological sites if vessel crew and passengers come ashore (Huntington et al. 2015, 2019, Davydov and Mikhailova, 2011). These effects differ across Arctic communities and depend on location, type of ship traffic, seasonality, and how communities engage with their local environment (Olsen et al. 2019).

Along the NEP, the Indigenous peoples of the Russian Arctic coast include three major cultural and economic ways of life (Krupnik 1989, Klokov et al. 2001): Arctic marine mammal hunters (Yupik and Coastal Chukchi), tundra reindeer herders (Nenets, Evens, and Chukchi), and settled and semi-settled fishers and hunters living along the sea coasts and estuaries (Dolgans and Yakuts, as well as ethnic Russians who settled in the Arctic in the late 1700s). Shipping and vessel traffic often conflict with the traditional way of life of marine mammal hunters of Eastern Chukotka, particularly in the Bering Strait region as described above. Examples of a region along the NSR where traditional subsistence users may experience negative effects from shipping are the large deltas of the Ob, Taz, Pur, Yenisei, Lena, Indigirka, and Kolyma rivers. In these areas, shipping and associated infrastructure can have negative impacts on artisanal fishing, which has an important role in traditional subsistence practices of the Indigenous inhabitants. Shipping may also impact commercial fishing that often benefits local communities as well, especially around busy ports such as Sabetta and Dudinka.

Studies from the Solovetsky archipelago in the White Sea describe multiple effects on a local community from increased ship traffic, especially from passenger vessels. Each summer, with the opening of the navigation season, the residents of the Solovetsky community are visited by tourists who arrive on domestic and international passenger and cruise vessels (Olsen and Nenasheva 2018, Olsen et al. 2020a). One local concern is that cruise development comes with a need for infrastructure improvement, that in some occasions may conflict with the local desire to leave the natural environment and existing infrastructure in its original state to preserve the island's history, nature, and spiritual solitude (Olsen and Nenasheva 2018).

Despite these concerns, shipping remains the most affordable way to deliver supplies including fuel to Arctic communities. One of the critical functions of shipping along the NSR is the Northern Supply Haul (*Severniy Zavoz*) made possible by icebreaker support for vessels navigating through coastal Arctic seas into the ports frozen for most of the year. Over many decades, this method has proved to be the most reliable way to deliver all necessary supplies to local communities and to provide local transportation. Cruise vessels provide other economic opportunities in the form of new employment opportunities, value creation for local enterprises, and improvements in infrastructure and services (Olsen 2020, Østreng et al. 2013). Cruise tourism also contributes to increased awareness among passengers on climate and environmental changes (Olsen et al. 2020a). Transit shipping has limited impact on local and Indigenous communities' social and cultural well-being, since those shipping routes lie at a substantial distance from the shore.

A study of the Svalbard community of Longyearbyen indicates that increased shipping activities have led to the development of the local harbor, town infrastructure, and search and rescue services (Olsen et al. 2020a). The same development comes with an increase in the number of tourists that results in a greater social disturbance and additional pressure on the natural environment and cultural heritage. The local population reports cases of inappropriate behavior of some cruise passengers. Disturbance of cultural heritage is another area of concern, as cultural monuments from before 1946 are automatically protected (Governor of Svalbard 2022a). Svalbard's cultural heritage has international significance as the archipelago has been used by different countries since the 16th century. Remains of earlier human activities, such as small houses from the whaling industry, trapper huts, and artifacts from the mining industry in the 19th and 20th centuries, are an attraction for the visitors (Hagen et al. 2012). The overarching protection principles state "that Svalbard's cultural monuments shall be protected and looked after as a part of Svalbard's cultural heritage and identity, and as a part of a comprehensive policy towards environmental management" (The Ministry of Climate and Environment 2001).

On the other side of the Arctic, the Indigenous communities of the Bering Strait region are directly dependent on the sea (Ahmasuk et al. 2008) and provide a pertinent example of the cultural concerns of Arctic shipping, especially as all transit routes through the Arctic pass through the Bering Strait. The main features of the local way of life are traditional subsistence and a strong dependence on marine mammals, fish, and birds, which have been and remain the cornerstone of local communities, sustaining their vitality, identity and well-being. In the Bering Strait region, local communities are concerned that increased vessel traffic, especially those with icebreaker escorts, will affect the migration routes of marine mammals and the feeding and breeding areas of ice-related animals (Raymond-Yakoubian 2018; see Text Box). This scenario threatens the viability of Indigenous settlements. However, these same communities have an inherent right to exist (UN 2007) and are an integral part of today's global society, dependent on shipping as a supplier of essential food, fuel, goods, and equipment. Thus, shipping is both a threat to Indigenous peoples and a support of their existence today.

> *It was early summer a couple of years ago. You know, at this time of year, after a long winter, our village can finally eat fresh meat. We went hunting and found an ice floe where walruses were resting. The ice floe was strong and convenient for butchering walruses. At some point, one of us accidentally saw a ship approaching us and shouted about danger. It was scary. The ship was huge and was going straight*

for us quickly. We rowed off the ice and started the engines to get away. We were lucky; the ship managed to turn to the other side and did not crush the ice floe where the half-cut walruses lay.

–Konstantin Veketcheivun, Chukchi marine hunter, 53 years old, Chukotka, Russia, July 2016

In Canada as in the Bering Strait region, Inuit communities lie along the coast of the NWP where their travel and harvesting activities inevitably intersect with shipping routes. As traffic has intensified more dramatically since approximately 2007 (Pizzolato et al. 2014, Dawson et al. 2018), so too has local concern over impacts and risks to sensitive ecological areas and to cultural sites and practices. The Arctic Corridors and Northern Voices project has worked with more than 14 Inuit communities across Arctic Canada to map local and Indigenous knowledge of relevant 'culturally significant marine areas' (CSMAs) that can now be used to co-manage ocean environments where shipping activity is increasing (Arctic Corridors Research 2023). Mobility and harvesting in the marine environment are at the core of Inuit cultural identity (Aporta 2009, ICC-Canada 2008, ITK 2017). Moreover, the harvesting rights of Inuit communities are protected by the Canadian Constitution as well as modern land claims agreements. Thus, interference with local access to or degradation of key harvesting sites from maritime activity would infringe upon Indigenous rights (Van Luijk et al. 2022). Ensuring that Arctic shipping does not undermine cultural integrity and continuity in a changing Arctic is all the more important given that almost the entire Canadian Arctic is not accessible by road. For both communities and resource development projects, destination shipping in particular provides the economic backbone of Arctic development.

4. Governance

This section examines the governance and promotion of Arctic shipping, to help identify where cultural and environmental threats are likely to be highest. Some degree of governance for Arctic shipping already exists, and more measures are emerging as Arctic shipping especially via the NEP is being promoted in various ways by different countries and organizations (e.g., OCIMF 2017). At the same time, some major corporations have pledged not to ship via the Arctic (Ocean Conservancy 2022), which may dissuade some commercial interest in Arctic shipping (Akbayirli and Tuna 2022). Furthermore, a recent economic analysis of Arctic shipping suggests that many of the supposed benefits may be overestimated (Wang et al. 2021). An important consideration with increased shipping is environmental justice, whether Arctic communities are bearing the risks of Arctic shipping without a proportionate share of the benefits or a proper voice in governance (Raymond-Yakoubian and Daniel 2018).

Governance of shipping includes international and national measures, no less in the Arctic than elsewhere. The IMO has responsibility for international shipping governance. In the Arctic and the Antarctic, the IMO has created the Polar Code, governing various aspects of ship operation, crew training, and environmental protection. The Arctic marine environment is reasonably well studied, but much remains to be learned, especially in a time of rapid biophysical change. Hence, the Polar Code includes recognition of this lack of knowledge and takes a precautionary approach to at least some aspects of Arctic shipping governance (Huntington et al. 2019). Furthermore, in June 2021 the IMO banned some uses of heavy fuel oil in the Arctic as of 2024. The provisions of the IMO ballast water convention could also be applied in the Arctic. Ongoing negotiations concerning "biodiversity beyond national jurisdictions" or BBNJ may have implications for the TSR. In addition, the IMO has created shipping lanes and areas to be avoided in the Bering Strait region (Maritime Executive 2018). The shipping lanes were a joint proposal from Russia and the United States, suggesting at least some potential for cooperation on Arctic matters even in the midst of disagreements on other topics (Todorov 2022). At the regional level, the Arctic Council and Arctic Coast Guard Forum provide other regional mechanisms for cooperation on the governance of shipping (e.g., the *Agreement on Cooperation in Aeronautical and Maritime Search and Rescue in the Arctic*).

At the national level, the vast majority of Arctic shipping passes along the coasts of Canada, Norway, Russia, and the United States. Each country has taken measures to address some aspects of shipping in their waters, which are summarized below. Greenland also borders the Arctic Ocean, but major international shipping activities have not yet taken place in Greenlandic waters. Domestic measures may be included in insurance policies, promoting compliance without a legal mechanism for enforcement. Under Article 234 of the United Nations Convention on the Law of the Sea (UNCLOS), Canada and Russia have introduced special rules within their EEZs for waters that are ice-covered most of the year (Beckmann et al. 2017, Brigham 2020). Some aspects of these rules remain controversial, especially concerning internal waters and international straits. If international shipping continues to increase in the NEP and NWP, the balance of interests between coastal states and users of those routes should be defined more clearly (Beckmann et al. 2017). In addition, diminishing sea ice may change the areas where Article 234 applies and allow ships to avoid areas of contention especially along the NEP (Lynch et al. 2022).

4.1. Russia

Along the NEP/NSR, the Northern Sea Route Administration (NSRA) was established for managing the safety of navigation and the protection of the marine environment from pollution in the NSR. The NSRA issues permissions for navigation in the area based on the information provided by shipowners or masters. Whether permission is granted depends on whether the specifications of the ship match anticipated ice conditions in the relevant areas of the NSR during the proposed period of the voyage. The NSRA also decides whether and where a ship needs icebreaker support. The requirements formulated in the Polar Code are incorporated in the criteria used while processing applications. The NSRA also performs other related functions, such as providing the users of the NSR with information on ice and hydrometeorological conditions, assisting in the organization of search and rescue operations, and maintaining daily communications with ships. In 2021, the NSRA issued 1229 permissions to enter or transit the NSR and denied permissions to 35 applicants (32 of them flying the Russian flag). At the beginning of NSRA operation, permissions were mainly denied due to the lack of

a valid classification certificate or the lack of valid civil liability insurance or a pollution-damage convention certificate. Now, typical grounds for denial include insufficient information provided by applicants, failure to conclude a contract for icebreaker support (if required), or unsuitability of the ship to navigate in anticipated ice conditions in requested areas in the relevant period of time. At the same time, the NSRA has limited powers to enforce the denial of permissions. In cases of violation of its decisions (to date, almost exclusively by ships flying the Russian flag), it simply informs the relevant national maritime authority (NSRA 2022, Moe and Brigham 2017, Zagorski 2015).

4.2. Norway

An evaluation of future shipping trends shows that in the opening areas in the Barents Sea, the activity level will continue to increase, mostly by fishing and passenger vessels (Borch et al. 2016, DNV-GL 2014). Svalbard may in the future provide infrastructural, communication, and search-and-rescue services for traffic along the TSR (Olsen et al. 2020a, Olsen et al. 2022).To address this growth, a white paper on the High North (The Ministry of Foreign Affairs 2020) sets out the government's policy on the commercial potential of Arctic transport routes, while simultaneously recognizing the need to address safety of navigation and environmental concerns (see also The Ministry of Foreign Affairs 2014). One of the examples for achieving those goals is the government's implementation of a heavy fuel oil ban for vessels operating in Svalbard waters.

The growth in tourism activities in Svalbard waters, including cruise ship voyages, has led to a number of changes in environmental regulations on Svalbard (e.g., Hovelsrud et al. 2021). The Svalbard Environmental Protection Act (Ministry of Climate and Environment 2001) is comprehensive and stricter than mainland Norway conservation legislation. Environmental policy in Svalbard states that in cases of conflict, environmental protection shall be prioritized over commercial interests. This policy principle is evident in the current revision of several environmental regulations pertaining to marine and terrestrial traffic, cultural heritage, research activities, commercial tourism operations and safety. The gradual tightening of environmental control causes tensions among residents in Svalbard, most of the commercial sector, as well as among some of the nations that are signatories to the Svalbard Treaty. Moreover, due to disappearing sea ice, ice-breaking activities are prohibited in the fjords for commercial traffic (Olsen et al. 2019).

To address the impacts from increasing shipping traffic in Svalbard waters, several measures have been implemented, such as the establishment of a cruise network, visitor management services and community and site guidelines (AECO 2018). However, as more restrictions on heavy fuel oil are imposed in the Svalbard area, there may be significant reductions in overseas cruise ships visiting the archipelago, while small, expedition cruises could increase. This will also change the type and number of visitors to Longyearbyen.

4.3. Canada

Along the NWP, Canada neither actively promotes nor deters Arctic shipping activity. The government continues to focus its efforts primarily on enabling community resupply and resource extractive industries, while making efforts to mitigate risk and improve management of other types of traffic. The Arctic Water Pollution Prevention Act has served as the primary vehicle for Arctic-specific regulation of shipping. Under this Act, key aspects of the IMO Polar Code and the Canadian domestic regime are implemented including mechanisms for assessing vessel ice strengthening and the requirement for an Arctic Pollution Prevention Certificate. Canada's mandatory reporting system is also implemented under this Act and operates through the Marine Communication and Traffic Services offices in Iqaluit, Nunavut, and Inuvik, Northwest Territories. These offices also provide regular information to vessels in the Arctic on weather and ice forecasts (provided by Environment and Climate Change Canada) and safety and navigational warnings.

Passenger vessels planning to operate in the Canadian Arctic are subjected to the highest level of oversight and scrutiny, including voyage-specific permitting and certification requirements outlined in the Guidelines for the Operation of Passenger Vessels in Canadian Arctic Waters. Two high profile grounding events in 2010 and 2018 have highlighted the elevated risk posed by these vessels and reviews by the Transportation Safety Board identified insufficient voyage planning and risk mitigation as key factors in these grounding events.

A key element of risk in the Canadian Arctic is the lack of modern bathymetric information, with only 15.2 % of Canadian Arctic waters surveyed to modern or adequate standards (Government of Canada 2023). To improve chart accuracy and other services along key routes, the Government of Canada has undertaken to implement the Low Impact Shipping Corridors Initiative (see https://www.arcticcorridors.ca). This initiative seeks to designate primary and secondary routes throughout the Canadian Arctic where a higher level of information and services will be available, including modern charting, navigational aids and emergency response capacity.

Recent investments through the Ocean Protection Plan and other initiatives, including marine protected areas, have increased much-needed local infrastructure, Coast Guard presence, and aerial oversight, as well as accelerating bathymetric surveying and charting efforts. Canada has also announced plans to build additional ice capable vessels for the Canadian Coast Guard and Canadian Navy to increase capabilities in the future. Notably, Transport Canada has made recent efforts to improve Arctic shipping management by working with Inuit rights holders to address local concerns, primarily through the implementation of new governance tables and development of Notice to Marines (NOTMARs). Greater effort, however, is needed to monitor and ensure compliance with these new rules.

4.4. United States

The U.S. has carried out one port access route study for its waters in the Bering Strait area and is conducting a second for its Arctic waters in the Chukchi and Beaufort Seas. The one for the Bering Strait, completed in 2016 (USCG 2016), led to proposals to the IMO for

shipping lanes and areas to be avoided in the Bering Strait area (Huntington et al. 2019). The study for the Chukchi and Beaufort Seas is underway, delayed in part by COVID-19. That study may also propose shipping lanes, which ideally would connect with shipping lanes established by Canada in the eastern Beaufort Sea as well as with the IMO-designated lanes in the Chukchi Sea. Neither study was intended to promote or deter shipping through U.S. waters. More recently, the U.S. has committed $250 million to expansion of port facilities in Nome, Alaska, on the southern side of the Seward Peninsula in the Bering Sea (Schreiber 2022). The expansion may be seen as an effort to promote shipping, or to be ready for shipping that will happen regardless, or simply as part of a nationwide effort to improve infrastructure. Planning efforts for Arctic shipping in Alaska have not to date been accompanied by substantial investment in Coast Guard capacity in the region, though there have been seasonal deployments of personnel and aircraft in northern Alaska.

4.5. Indigenous and local engagement

An important challenge in Arctic shipping governance has been inherent difficulties in bringing local concerns over shipping impacts borne out in small Arctic communities to the national and international fora where shipping regulations are made (e.g., Shadian 2014). Local communities in the Arctic, including those from the Bering Strait region, are having to deal with the effects of rapid climate change (Huntington et al. 2020). Among the natural factors, there have been temporal and spatial shifts in the migrations of marine mammals (Moore and Huntington 2008) and diseases and die-off of seals and seabirds (NOAA Fisheries 2022, Will et al. 2020). This chain of events in turn changed the patterns of subsistence activities and the traditional diet. The melting of sea ice has also led to an increase in anthropogenic pressure on the region. There has been a noticeable increase in the Arctic offshore exploration and shipping along the NSR and NWP. In recent years, year-round ship expeditions accompanied by icebreakers along the NSR began. This has given rise to yet another concern about possible ship collisions with marine mammals in breeding areas. Therefore, Indigenous and non-Indigenous peoples were looking for leverage to deal at least to some degree with the manageable problems faced by the communities, for example to be represented in international regulatory mechanisms.

In cooperation with conservation organizations, a number of meetings and presentations by Indigenous representatives from Canada, the U.S., and Russia have been organized over the years at Marine Environment Protection Committee meetings of the International Maritime Organization (IMO), which is responsible for international shipping regulations. The main goals of this activity were to articulate and visualize Indigenous peoples' concerns about the impacts of Arctic shipping on their culture and environment and their need to be represented in decision-making processes. The efforts have met with success at the international level, as the Inuit Circumpolar Council (ICC) has become the first Indigenous organization to achieve provisional status at the IMO. The participation of ICC in the forum may facilitate greater consideration and action by the international shipping community to understand, address, and prevent impacts of Arctic shipping to Inuit communities. The full implications of the United Nations Declaration on the Rights of Indigenous Peoples in the work of the IMO, however, has yet to be determined.

Inuit in Canada have also made repeated calls for greater involvement in the governance and management of Arctic shipping activities. In particular, interest in increasing local capacity and control over shipping activities, such as through local hunters and trappers organizations and committees, as well as a desire for stronger regulation and government presence have been a consistent finding in recent research (ITK 2017, Falardeau et al. 2019, Dawson et al 2020, Carter et al. 2022). Inuit organizations, communities, academia and civil society have engaged with the Government of Canada to improve the Low Impact Shipping Corridors by including co-governance with Indigenous groups and environmental protection. Work in this regard is on-going. Through the development of Low Impact Shipping Corridors in Arctic Canada (Chenier et al. 2017, Dawson et al. 2020), extensive efforts have been taken to identify community concerns related to Arctic shipping activity and growth and to identify culturally significant marine areas (CSMAs) that may require some level of protection or consideration among ship operators. Identification of CSMAs was a recommendation of the 2009 AMSA report in recognition of the cultural importance of marine areas and of the value of marine resources for northern and Indigenous peoples who continue to engage in subsistence hunting and fishing activities for health, wellbeing, and to support local livelihoods.

Non-Indigenous populations in the Arctic have also engaged in adaptive responses to increasing ship traffic, especially cruise vessels. The local community of Longyearbyen has been involved in visitor management, development of community guidelines and search and rescue activities (AECO 2018, Olsen et al. 2020a). Participation in visitor management is also common for local communities in North Norway, e.g., the Lofoten islands (Fabritius and Sandberg 2012), and Northern Russia, e.g., Solovetsky (Olsen and Nenasheva 2018).

5. Priorities for the future

Given the existing environmental and socio-cultural concerns related to Arctic shipping, the expectation of further increases in all seasons, and the resources available for effective management, the areas and topics in greatest need of further attention are assessed next. A lack of knowledge on and management responses to impacts from shipping will lead to accumulating effects on Arctic cultures and ecosystems. Moreover, unmanaged impacts may add further exposure to communities who already experience multiple changes in environmental, demographic and economic. The steady erosion of cultural integrity and ecosystem health has been seen elsewhere in the world. An alternative is a vigorous program of coordinated action, not just to study Arctic shipping, but to continue developing effective governance practices that are appropriate for local conditions in relation to the type and magnitude of contemporary and projected shipping. In this section, several areas for attention are proposed (see Table 2).

For the NEP and NWP, resource development is likely to be the main driver of increased shipping in the near future. Transshipping will remain of interest, and of course be the only shipping of interest via the TSR, but large increases in transshipping appear unlikely at

this point. Further attention is needed to the prospects for shipping of all types and on all routes, in part to identify emerging challenges to culture, environment, and governance as well as likely patterns of vessel traffic and economic factors (Cheaitou et al. 2020, Ding et al. 2020, Xu and Yang 2020, Jones et al. 2023).

Regarding cultural and social concerns, the Bering Strait region is a clear focus of concern for the present, since all three routes converge here. The rest of the NWP and the NEP especially in northern Europe also deserves attention due to intensity of shipping activities. Pressure for increased shipping comes almost entirely from outside the region, and the benefits from that shipping accrue largely outside the region as well. With the prospect of environmental injustice—benefits to one group, costs or risks to another—there is an urgent need for further work to develop appropriate management and governance approaches to reduce negative impacts to coastal communities and, where possible, to identify local benefits that can be achieved. A comprehensive, interdisciplinary assessment of the impact on the Bering Strait region would be a starting point and could be copied or extended to other regions as well. A crucial question is the role of Indigenous peoples and local communities in helping shape their own futures. Monetary compensation and infrastructure development are usually described as benefits from shipping, but money and infrastructure alone cannot preserve cultures and ecosystems. Greater attention is needed to alternative ways of rectifying environmental injustice and protecting Indigenous cultures and local communities' well-being. Also, the agency of Arctic populations in developing adapting responses is yet understudied, while the existing examples from the European and the Canadian Arctic emphasize their importance.

Environmentally, chronic pollution and noise disturbance are concerns, and accidents including oil spills are an even larger threat. Improved traffic management, communication services, vessel and crew standards, and charting of Arctic waters can all help reduce the threat but cannot eliminate it. In addition to making all efforts to reduce the risk of accidents and spills, response capacity needs to be increased as well. The 2011 Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic and the 2013 Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic initiated by the Arctic Council are a start but need further to be backed up by investment in equipment and trained personnel to respond quickly. Furthermore, the oil spill agreement does not cover the high seas area of the Central Arctic Ocean, leaving a gap along the TSR. In addition, more attention is needed to environmentally sensitive areas including measures to adjust vessel traffic to avoid aggregations of wildlife.

Finally, the green energy transition aims to reduce greenhouse gas emissions from ships in the Arctic. The IMO and its members states are moving toward a ban on heavy fuel oil after July 1, 2024 with a series of exemptions (IMO 2021), while the Norwegian Government has already adopted heavy fuel oil ban in Svalbard waters that came into effect on January 1, 2022 (Governor of Svalbard 2022b). In addition to national and international regulation, some Arctic tourism industry operators, e.g., Hurtigruten, are already limiting their emissions by using hybrid engines for their vessels (Hurtigruten 2019). Larger questions of an industry-wide transition in fuels and operations are beyond the scope of this paper, though in future they may have implications for greenhouse gas emissions and pollution risk.

Future shipping trends of concern include the rise in winter traffic, requiring ice-breaking capacity and causing additional disturbance in time and space for Arctic cultures and ecosystems. Open-water traffic carries risk, but not as great as the risk created

Table 2
Comparison of the Northeast Passage, Northwest Passage, and Transpolar Route, with key concerns and unknowns in **bold**.

Parameter	*NEP/NSR*	*NWP*	*TSR*
Main types of shipping	Resource development, community re-supply, fishing, cruises, research transit shipping, government vessels	Community re-supply, **resource development, cruise**, government vessels	(Anticipated) Transshipping, including cruises, research and government vessels
Socio-cultural concerns	**Disturbance and social wear and tear in the Bering Strait region, Barents Sea** and North Norway, less of a concern along most of the Siberian Russian coast because there are few maritime communities or cultures except for Chukotka	**Disturbance throughout the NWP**, from Bering Strait to Davis Strait, due to prevalence of maritime cultures and communities along most of the route	**Disturbance in the Bering Strait Region and Svalbard**
Environmental concerns	**Shipwreck or oil spill**, noise disturbance, icebreaking, discharges, emission, disturbance of species by passengers, waste concerns (including marine litter from fishers) in important marine areas throughout the NEP/NSR	**Shipwreck or oil spill, lack of charting and navigational aids**, noise disturbance icebreaking, important marine areas throughout the NWP	**Shipwreck or oil spill**, noise disturbance; Bering Strait and Svalbard are areas of greatest concern
Shipping volume and trend	Moderate but rising quickly **Year-round traffic in some areas, increasing volume of traffic, especially in winter**	Modest **Year-round traffic in some areas**	Only research and cruise vessels to date **When the route may become commercially viable, with or without ice-strengthened vessels**
Promotion of route	Strong support and investment from Russian government, **"Polar Silk Road" in China's Belt and Road Initiative**, interest from other countries & shipping companies	Limited support or investment from Canadian and US governments, limited interest by other countries	Almost none to date
Governance	Strong control by Russian and Norwegian government, IMO-approved Bering Strait shipping routes and ATBAs, extensive capacity for response and enforcement Regional agreements on SAR and oil spill preparedness.	Development of "Arctic Corridors" system, Arctic PARS, IMO-approved Bering Strait shipping routes and ATBAs, **minimal capacity for response and enforcement**	IMO Polar Code, IMO-approved Bering Strait shipping routes and ATBAs, **minimal capacity for response and enforcement, no specific TSR measures**

during the ice season. Ice conditions may also cause vessels to deviate from established shipping routes to reduce hazards to ship and crew, which can reduce the predictability of ship traffic patterns and cause disturbance in additional areas.

In recent years, non-Arctic states have taken an interest in Arctic shipping. These include China (Gao and Erokhin 2019), as well as the Republic of Korea, which has constructed several LNG carriers for Arctic conditions (Reuters 2018). China has also identified the NEP as the "Polar Silk Road" component of its global Belt and Road initiative, raising the prospect of extensive investment not only in port and maritime facilities but also in transportation links by river and rail. At present, however, these ideas remain largely confined to paper, though they have attracted considerable attention in Finland, Norway, and Iceland as well (Bennett 2014, Staalesen 2016, Humpert 2019). The Norwegian port city of Kirkenes, for example, is positioning itself as an Arctic hub for the Polar Silk Road (Daily Scandinavian 2020).

The extent to which Arctic and non-Arctic states and companies will continue to invest in and promote Arctic shipping is also unknown. Resource development projects are clearly dependent on ship access, whether seasonal or year-round. Transshipping prospects may be enhanced by investments in ports and maritime facilities and navigation support, such as accurate charting. A major question is the extent to which China will invest in the Polar Silk Road, which has the potential to reshape Arctic vessel traffic for decades to come. Another question is the degree to which Canada and the U.S. will continue to be largely reactive to Arctic shipping, rather than attempting to promote or deter the use of the NWP and perhaps TSR.

Finally, the question of governance brings many of these concerns together (Cao et al. 2022). Russia has invested extensively in the development and management of the NSR, building considerable capacity and experience. Should this level of control be combined with genuine attention to cultural and environmental concerns, Russia could provide a model for effective governance of sustainable Arctic shipping - but this is yet to be seen. Canada and the U.S., on the other hand, have limited capacity for response and enforcement in their waters, though vessel traffic measures in both countries are likely to enjoy a high rate of compliance. The focus on reconciliation with Indigenous Peoples in Canada from the current federal government, including major commitments via the Inuit Nunangat Policy and a renewed commitment to the UN Declaration on the Rights of Indigenous People (UN 2007), suggest that the role of northern and in particular northern Indigenous peoples in Canada in co-managing or governing the future Arctic shipping will be very important. The involvement of Indigenous peoples and local communities in shipping governance remains a work in progress. Internationally, the IMO's Polar Code has been a powerful device as well as a contribution to effective governance of Arctic shipping, and more recent measures such as shipping lanes and areas to be avoided in the Bering Strait are a welcome addition. Further steps, such as a governance framework for the TSR (Bennett et al. 2020, Cao et al. 2022) or even an agreement not to use it commercially for the time being, could help avoid problems rather than trying to rectify them after they occur.

In summary, Arctic shipping continues to supply remote communities, support resource development, and offer potential for transshipping. Most activity is and is likely to remain along the NEP, particularly in the Kara and Barents Seas. Cultural and environmental concerns remain high, given high reliance by Indigenous communities on the Arctic marine environment and the risks from disturbance and accidents in waters that remain relatively undisturbed. Effective governance can contribute a great deal to reducing risks and promoting equitable benefits. Such governance, however, depends on attention and investment, which to date has been forthcoming mostly from Russia. Given the rate of sea ice decrease in the Arctic, greater international coordination is urgently needed to learn from experience, to share assets and capacities, and to guide responsible and sustainable development of the Arctic and shipping operations. As noted above, further research on specific aspects of Arctic shipping can improve understanding of shipping trends, cultural impacts, environmental concerns, and the prospects for effective governance, topics that are relevant globally as well as in the Arctic.

CRediT authorship contribution statement

Henry P. Huntington: Conceptualization. **Julia Olsen:** Conceptualization. **Eduard Zdor:** Conceptualization. **Andrey Zagorskiy:** Conceptualization. **Hyoung Chul Shin:** Conceptualization. **Olga Romanenko:** Conceptualization. **Bjørn Kaltenborn:** Conceptualization. **Jackie Dawson:** Conceptualization. **Jeremy Davies:** Conceptualization, Visualization. **Erin Abou-Abbsi:** Conceptualization.

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References

AECO, 2018. Community guidelines. Association of Arctic Expedition Cruise Operators. https://www.aeco.no/guidelines/community-guidelines/; accessed 17 January 2023.

Afenyo, M., Jiang, C., Ng, A.K.Y., 2019. Climate change and Arctic shipping: a method for assessing the impacts of oil spills in the Arctic. Transp. Res. D 77, 476–490. https://doi.org/10.1016/j.trd.2019.05.009.

Afenyo, M., Khan, F., Veitch, B., Ng, A.K.Y., Sajid, Z., Fahd, F., 2020. An explorative object-oriented Bayesian network model for oil spill response in the Arctic Ocean. Safety in Extreme Environ. 2 (1), 3–14. https://doi.org/10.1007/s42797-019-00012-7.

Afenyo, M., Jiang, C., Ng, A.K.Y., Lee, P.T.W., 2022a. A Bayesian-loss function-based method in assessing loss caused by ship-source oil spills in the Arctic area. Risk Analysis: An. Int. J. https://doi.org/10.1111/risa.14025.

Afenyo, M., Ng, A.K.Y., Jiang, C., 2022b. A multi-period model for assessing the socioeconomic impacts of oil spills during Arctic shipping. Risk Analysis: An Int. J. 42 (3), 614–633. https://doi.org/10.1111/risa.13773.

Ahmasuk, A., Trigg, E., Magdanz, J., Robbins, B., 2008. Bering Strait Region local and traditional knowledge pilot project: a comprehensive subsistence use study of the Bering Strait Region. Kawerak Inc, Nome, Alaska. North Pacific Research Board Project Final Report, Project #643.

Akbayirli, K., Tuna, O., 2022. How do practitioners view Arctic shipping Routes? a cognitive appraisal approach. Transp. Res. D 110, 103432. https://doi.org/10.1016/j.trd.2022.103432.

AMAP, 2011. Snow, water, ice, and permafrost in the Arctic (SWIPA). Climate change and the cryosphere, Arctic Monitoring and Assessment Programme, Oslo.

AMAP/CAFF/SDWG, 2013. Identification of Arctic marine areas of heightened ecological and cultural significance. Arctic Monitoring and Assessment Programme, Oslo, Arctic Marine Shipping Assessment (AMSA).

AMSA, 2009. Arctic marine shipping assessment. Arctic Council, Copenhagen.

Aporta, C., 2009. The trail as home: Inuit and their pan-Arctic network of routes. Hum. Ecol. 37, 131–146. https://doi.org/10.1007/s10745-009-9213-x.

Arctic Corridors Research, 2023. Arctic corridors: research for policy on shipping governance in Arctic Canada. accessed 17 January 2023. https://www.arcticcorridors.ca/;.

Beckmann, R.C., Henriksen, T., Dalaker Kraabel, K., Molenaar, E.J., Roach, J.A., 2017. Governance of Arctic shipping: balancing rights and interests of Arctic states and user states. Brill Nijhoff, Leiden. https://doi.org/10.1163/9789004339385.

Bennett, M., Stephenson, S.R., Yang, K., Bravo, M.T., De Yonghe, B., 2020. The opening of the Transpolar Sea Route: logistical, geopolitical, environmental, and socioeconomic impacts. Mar. Policy 121, 104178. https://doi.org/10.1016/j.marpol.2020.104178.

Bennett, M., 2014. Interview with Arctic Corridor spokesman Timo Lohi. Cryopolitics, March 27, 2014. https://www.cryopolitics.com/2014/03/27/interview-with-arctic-corridor-spokesman-timo-lohi/; accessed 17 January 2023.

Borch, O.J., Andreassen, N., Marchenko, N., Ingimundarson, V., Gunnarsdóttir, H., Iudin, I., Petrov, S., Jacobsen, U., Dali, B.Í., 2016. Maritime activity in the High North: current and estimated level up to 2025: MARPART Project Report 1. https://www.nord.no/no/om-oss/fakulteter-og-avdelinger/handelshogskolen/Documents/MARPART%20WP1%20report%201.pdf; accessed 17 January 2023.

Brigham, L., 2020. Governance and economic challenges for the global shipping enterprise in a seasonally ice-covered arctic ocean. In: Spohr, K., Hamilton, D.S. (Eds.), The Arctic and World Order. Kissinger Center for Global Affairs, Johns Hopkins University, Washington DC, Foreign Policy Institute/Henry A, pp. 143–159.

Cao, Y., Liang, S., Sun, L., Liu, J., Cheng, X., Wang, D., Chen, Y., Yu, M., Feng, K., 2022. Trans-Arctic shipping routes expanding faster than the model projections. Glob. Environ. Chang. 73, 102488 https://doi.org/10.1016/j.gloenvcha.2022.102488.

Carter, N.A., Dawson, J., Stensland, A., 2022. Opportunities and strategies for effective management of low impact Arctic shipping corridors. University of Ottawa, Ottawa. https://doi.org/10.20381/epj4-fz32.

Cheaitou, A., Faury, O., Cariou, P., Hamdan, S., Fabbri, G., 2020. Economic and environmental impacts of Arctic shipping: a probabilistic approach. Transp. Res. D 89, 102606. https://doi.org/10.1016/j.trd.2020.102606.

Chen, Q., Lau, Y., Ge, Y.E., Dulebenets, M.A., Kawasaki, T., Ng, A.K.Y., 2021. Interactions between Arctic passenger ship activities and emissions. Transp. Res. D 97, 102925. https://doi.org/10.1016/j.trd.2021.102925.

Chen, Q., Ge, Y., Ng, A.K.Y., Lau, Y.Y., Tao, X., 2022. Implications of Arctic shipping emissions for marine environment. Marit. Policy Manag. 49 (2), 155–180. https://doi.org/10.1080/03088839.2021.1990427.

Chénier, R., Abado, L., Sabourin, O., Tardif, L., 2017. Northern marine transportation corridors: creation and analysis of northern marine traffic routes in Canadian waters. Trans. GIS 21, 1085–1097. https://doi.org/10.1111/tgis.12295.

Constable, A.J., Harper, S., Dawson, J., Holsman, K., Mustonen, T., Piepenburg, D., Rost, B., 2022. Cross-Chapter Paper 6: Polar regions. In: Climate Change 2022: impacts, adaptation and vulnerability. In: Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., Rama, B. (Eds.), Contribution of Working Group II to the sixth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 2319-2368. Doi:10.1017/9781009325844.023.

Copland, L., Dawson, J., Tivy, A., Delaney, F., Cook, A., 2021. Changes in shipping navigability in the Canadian Arctic between 1972 and 2016. FACETS 6, 1069–1087. https://doi.org/10.1139/facets-2020-0096.

Daily Scandinavian, 2020. Norwegian mayor courting chinese investors to build a Polar Silk Road. accessed 16 January 2023. https://www.dailyscandinavian.com/norwegian-mayor-courting-chinese-investors-to-build-a-polar-silk-road/;.

Davydov, A.N., Mikhailova, G.V., 2011. Climate change and consequences in the Arctic: perception of climate change by the Nenets People of Vaigach Island. Global Health Action 4, 11/14. https://doi.org/10.3402/gha.v4i0.8436.

Dawson, J., Cook, A., Holloway, J., Copland, L., 2022. Analysis of changing levels of ice strengthening (ice class) among vessels operating in the Canadian Arctic over the past 30 years. Arctic 75 (4). https://doi.org/10.14430/arctic75553.

Dawson, J., Copland, L., Johnston, M.E., Pizzolato, L., Howell, S.E., Pelot, R., Etienne, L., Matthews, L., Parsons, J., 2017. Climate change adaptation strategies and policy options for Arctic shipping. A report prepared for Transport Canada. https://www.arcticcorridors.ca/wp-content/uploads/2020/07/Climate-Change-Adaptation-Strategies-sm.pdf; accessed 17 January 2023.

Dawson, J., Pizzolatto, L., Howell, S.E.L., Copland, L., Johnston, M.E., 2018. Temporal and spatial patterns of ship traffic in the Canadian arctic from 1990 to 2015. Arctic 71 (1), 15–26. https://doi.org/10.14430/arctic4698.

Dawson, J., Carter, N., van Luijk, N., Parker, C., Weber, M., Greydanus, K., Provencher, J., 2020. Infusing local knowledge and community perspectives into the Low Impact Shipping Corridors: an adaptation to increased shipping activity and climate change in Arctic Canada. Environ Sci Policy 105, 19–36. https://doi.org/10.1016/j.envsci.2019.11.013.

Dawson, J., Carter, N.A., van Luijk, N., Cook, A., Weber, M., Orawiec, A., Stewart, E.J., Holloway, J.E., 2021. Tourism vessels and low impact shipping corridors in Arctic Canada: trends, risks, community perspectives, and management strategies. University of Ottawa, Ottawa. https://doi.org/10.20381/d3dd-yk49.
Ding, W., Wang, Y., Dai, L., Hu, H., 2020. Does a carbon tax affect the feasibility of Arctic shipping? Transp. Res. D 80, 102257. https://doi.org/10.1016/j.trd.2020.102257.
DNV-GL, 2014. Prognoser for skipstrafikken mot 2040. (Prognosis for ship traffic till 2040). DNV Gl Maritime, Høvik, Norway [In Norwegian]. Report number 2014–1271.accessed 17 January 2023.
Eguíluz, V.M., Fernández-Gracia, I., Irigoien, X., Duarte, C.M., 2016. A quantitative assessment of Arctic shipping in 2010–2014. Sci. Rep. 6, 30682. https://doi.org/10.1038/srep30682.
Fabritius, M., Sandberg, A., 2012. Lofoten tourism futures; actors and strategies - MISTRA Arctic Futures Programme. accessed 17 January 2023 UiN-rapport nr. 3/2012. https://nordopen.nord.no/nord-xmlui/bitstream/handle/11250/141849/Sandberg_A.pdf?sequence=1;.
Falardeau, M., Raudsepp-Hearne, C., Bennet, E.M., 2019. Our future - Hivunikhavut. McGill University, Montreal accessed 17 January 2023.
Farré, B. A., Stephenson, S.R., Chen, L., Czub, M., Dai, Y., Demchev, D., Efimov, Y., Graczyk, P., Grythe, H., Keil, K., Kivekäs, N., Kumar, N., Liu, N., Matelenok, I., Myksvoll, M., O'Leary, D., Olsen, J., Pavithran.A.P., S., Petersen, E., Raspotnik, A., Ryzhov, I., Solski, J., Suo, L., Troein, C., Valeeva, V., van Rijckevorsel, J., Wighting, J., 2014. Commercial Arctic shipping through the Northeast Passage: routes, resources, governance, technology, and infrastructure. Polar Geography 37(4), 298-324. Doi:10.1080/1088937X.2014.965769.
Gao, T., Erokhin, V., 2019. China-Russia collaboration in shipping and marine engineering as one of the key factors of secure navigation along the NSR. Arctic Yearbook 2019. https://arcticyearbook.com/images/yearbook/2019/Scholarly-Papers/20_AY2019_Gao_Erokhin.pdf; accessed 17 January 2023.
Goldstein, M.A., Lynch, A.H., Norchi, C.H., 2022. Conflict's impact raises costs for Arctic shipping and the climate. Nature 606, 250. https://doi.org/10.1038/d41586-022-01538-w.
Government of Canada, 2023. Arctic charting. Fisheries and Oceans Canada. https://www.charts.gc.ca/arctic-arctique/index-eng.html; accessed 17 January 2023.
Government of the Russian Federation, 2019. Plan razbitiya infrastructury severnogo morskogo puti na period do 2035 goda. (NSR Infrastructure Development Plan until 2035.) [In Russian]. Order of the Government of the Russian Federation, 21.12.2019, No. 3120-r.
Governor of Svalbard, 2022a. Cultural heritage management. accessed 17 January 2023. https://www.sysselmesteren.no/en/the-governor-of-svalbard/environmental-protection/cultural-heritage-management/.
Governor of Svalbard. 2022b. Tungoljeforbud på Svalbard. 07.06.2022. [In Norwegian.] ; accessed 17 January 2023.
Grigor'yev, M.N., 2016. Neftegsazovyye drozhzhi Sevmorputi. (Oil and gas booster for the NSR.) [In Russian.] Neftegazovaya Vertikal' 9, 46-52.
Gunnarsson, B., 2021. Recent ship traffic and developing shipping trends on the Northern Sea Route—Policy implications for future arctic shipping. Mar. Policy 124, 104369. https://doi.org/10.1016/j.marpol.2020.104369.
Gunnarsson, B., Mo., A,. 2021. Ten years of international shipping on the Northern Sea Route: trends and challenges. Arctic Review 12(0). Doi:10.23865/arctic.v12.2614.
Hagen, D., Vistad, O.I., Eide, N.E., Flyen, A.C., Fangel, K., 2012. Managing visitor sites in Svalbard: from a precautionary approach towards knowledge-based management. Polar Res. 31 (1), 8432. https://doi.org/10.3402/polar.v31i0.18432.
Halliday, W.D., Dawson, J., Yurkowski, D.J., Doniol-Valcroze, T., Ferguson, S.H., Gjerdrum, C., Hussey, N.E., Kochanowicz, Z., Mallory, M.L., Marcoux, M., Watt, C.A., Wong, S.N.P., 2022. Vessel risks to marine wildlife in the Tallurutiup Imanga National Marine Conservation Area and the eastern entrance to the Northwest Passage. Environ. Sci. Policy 127181–195. https://doi.org/10.1016/j.envsci.2021.10.026.
Halliday, W.D., Barclay, D.R., Cook, E., Dawson, J., Hildebrand, J., Hilliard, C., Hussey, N., Jones, J., Juanes, F., Marcoux, M., Niemi, A., Nudds, S., Pine, M., Richards, C., Scharffenberg, K., Westdal, K., Insley, S., 2020. A quantitative soundscape analysis of the Canadian Arctic, 2014–2019. The Journal of the Acoustical Society of America 148, 2688-2688. 10.1121/1.5147444.
Hermann, R.R., Lin, N., Lebel, J., Kovalenko, A., 2022. Arctic transshipment hub planning along the Northern Sea Route: a systematic literature review and policy implications of Arctic port infrastructure. Mar. Policy 145, 105275. https://doi.org/10.1016/j.marpol.2022.105275.
Höjman, C., Fabres, J., Rødås Johnsen, H., Sklet, S., Olsen, J., Nogueira, A., Bragtvedt, S., 2022. Macro plastic from fisheries and aquaculture: knowledge status, preventive measures and knowledge needs. accessed 17 January 2023 Norwegian Centre against Marine Litter. https://cdn.sanity.io/files/gcyuq3ns/production/86fbb05caef9d3050f3b5d681d682aa38d608692.pdf,.
Hovelsrud, G.K., Veland, S., Kaltenborn, B., Olsen, J., Dannevig, H., 2021. Sustainable tourism in Svalbard: balancing economic growth, sustainability, and environmental governance. Polar Rec. 57, e47. https://doi.org/10.1017/S0032247421000668.
Humpert, M., 2018. Maersk container ship embarks on historic Arctic transit. High North News. 20 August 2018. https://www.highnorthnews.com/en/maersk-container-ship-embarks-historic-arctic-transit; accessed 17 January 2023.
Humpert, M., 2019. Iceland invests in Arctic shipping with development of Finnafjord deepwater port. Arctic Today. April 17, 2019. https://www.arctictoday.com/iceland-invests-in-arctic-shipping-with-development-of-finnafjord-deepwater-port/; accessed 17 January 2023.
Huntington, H.P., Daniel, R., Hartsig, A., Harun, K., Heiman, M., Meehan, R., Noongwook, G., Pearson, L., Prior-Parks, M., Robards, M., Stetson, G., 2015. Vessels, risks, and rules: planning for safe shipping in Bering Strait. Mar. Policy 51, 119–127. https://doi.org/10.1016/j.marpol.2014.07.027.
Huntington, H.P., Bobbe, S., Hartsig, A., Knight, E.J., Knizhnikov, A., Moiseev, A., Romanenko, O., Smith, M.A., Sullender, B.K., 2019. The role of Areas to Be Avoided in the governance of shipping in the greater Bering Strait region. Mar. Policy 110, 103564. https://doi.org/10.1016/j.marpol.2019.103564.
Huntington, H.P., Danielson, S.L., Wiese, F.K., Baker, M., Boveng, P., Citta, J.J., De Robertis, A., Dickson, D.M.S., Farley, E., George, J.C., Iken, K., Kimmel, D.G., Kuletz, K., Ladd, C., Levine, R., Quakenbush, L., Stabeno, P., Stafford, K.M., Stockwell, D., Wilson, C., 2020. Evidence suggests potential transformation of the Pacific Arctic Ecosystem is underway. Nat. Clim. Chang. 10, 342–348. https://doi.org/10.1038/s41558-020-0695-2.
Hurtigruten. 2019. Hurtigruten Introduces Three New Hybrid Powered Cruise Ships. https://www.hurtigruten.com/us/press-releases/2019/three-new-hybrid-powered-cruise-ships/; accessed 17 January 2023.
ICC-Canada, 2008. The sea ice is our highway: an Inuit perspective on transportation in the Arctic. Inuit Circumpolar Council-Canada, Ottawa.
IMO, 2021. International Maritime Organization (IMO) adopts key mandatory measures to reduce ships' carbon intensity; establishes ship rating system. accessed 17 January 2023. https://www.imo.org/en/MediaCentre/PressBriefings/pages/MEPC76.aspx;.
NSR Information Office, 2021. Analysis of shipping traffic in the NSR waters in 2020. Northern Sea Route Information Office, 28 August 2021. https://arctic-lio.com/analysys-of-shipping-traffic-in-the-nsr-waters-in-2020/; accessed 17 January 2023.
ITK, 2017. Nilliajut 2: Inuit perspectives on the Northwest Passage, shipping and marine issues. Inuit Tapiriit Kanatami, Ottawa.
Johnston, M., Dawson, J., De Souza, E., Stewart, E.J., 2017. Management challenges for the fastest growing marine shipping sector in Arctic Canada: pleasure crafts. Polar Rec. 53 (1), 67–78. https://doi.org/10.1017/S0032247416000565.
Jones, D., Labib, A., Willis, K., Costello, J.T., Ouelhadj, D., Ikonen, E.S., Dominguez Cainzos, M., 2023. Multi-criteria mapping and prioritization of Arctic and North Atlantic maritime safety and security needs. Eur. J. Oper. Res. 307 (2), 827–841. https://doi.org/10.1016/j.ejor.2022.09.002.
Jungsberg, L., Turunen, E., Heleniak, T., Wang, S., Ramage, J., Roto, J., 2019. Atlas of population, society and economy in the Arctic. Nordregio Working Paper 2019: 3. Nordregio, Stockholm. http://norden.diva-portal.org/smash/get/diva2:1352410/FULLTEXT03.pdf; accessed 17 January 2023.
Klokov, K.B., Krasovskaya, T.M., Yamskov, A.N., 2001. Problemy perekhoda k ustoychivomu razbitiyu rayonov rasseleniya korennykh narodov Rossiyskoy Arktiki. (Issues of transition to sustainable development of the regions populated by Indigenous Peoples of the Russian Arctic.) [In Russian]. Research in Applied and Urgent Ethnology, No. 141.24.s. IEiA RAN, Moscow.
Kochanowicz, Z., Dawson, J., Halliday, W.D., Sawada, M., Copland, L., Carter, N.A., Nicoll, A., Ferguson, S.H., Heide-Jørgensen, M.P., Marcoux, M., Watt, C., Yurkowski, D.J., 2021. Using western science and Inuit knowledge to model ship-source noise exposure for cetaceans (marine mammals) in Tallurutiup Imanga (Lancaster Sound), Nunavut. Canada. Marine Policy 130, 104557. https://doi.org/10.1016/j.marpol.2021.104557.
Komarova, N.G., 2016. The history of northern navigation as a resource for territory development. The Life of The Earth 38 (1), 103–117.
Krupnik, I.I., 1989. Arctic adaptations. University of New England Press, Hanover, NH.
Lasserre, F., 2011. Arctic shipping routes: from the Panama myth to reality. Int. J. 66 (4), 793–808. https://doi.org/10.1177/002070201106600409.

Lau, Y., Kanrak, M., Ng, A.K.Y., Ling, X., 2023. Arctic region: analysis of cruise products, network structure, and popular routes. Polar Geogr. https://doi.org/10.1080/1088937X.2023.2182381.
Lemelin, H., Dawson, J., Stewart, E.J., Maher, P., Lueck, M., 2010. Last-chance tourism: the boom, doom, and gloom of visiting vanishing destinations. Curr. Issue Tour. 13 (5), 477–493. https://doi.org/10.1080/13683500903406367.
Li, Z., Ding, L., Huang, L., Ringsberg, J.W., Gong, H., Fournier, N., Chuang, Z., 2023. Cost–benefit analysis of a trans-Arctic alternative route to the Suez Canal: a method based on high-fidelity ship performance, weather, and ice forecast models. J. Marine Sci. Eng. 11 (4), 711. https://doi.org/10.3390/jmse11040711.
Li, X., Lynch, A.H., 2023. New insights into projected Arctic sea road: operational risks, economic values, and policy implications. Clim. Change 176, 30. https://doi.org/10.1007/s10584-023-03505-4.
Lynch, A.H., Norchi, C.H., Li, X., 2022. The interaction of ice and law in Arctic marine accessibility. Proceedings of the National Academy of Sciences 119 26 e2202720119. Doi:10.1073/pnas.2202720119.
Marchenko, N.A., Borch, O.J., Markov, S.V., Andreassen, N., 2016. Maritime safety in the High North - risk and preparedness. 26th International Ocean and Polar Engineering Conference, International Society of Offshore and Polar Engineers, Rhodes, Greece. https://onepetro.org/ISOPEIOPEC/proceedings-abstract/ISOPE16/All-ISOPE16/ISOPE-I-16-363/17796; accessed 17 January 2023.
Maritime Executive, 2018. IMO authorizes new Bering Sea routing. 26 May 2018, https://www.maritime-executive.com/article/imo-authorizes-new-bering-sea-routing; accessed 17 January 2023.
Middleton, A., 2021. Maritime transportation along the Northern Sea Route. In: Fiorini, M., Gupta, N. (Eds.), ICT Solutions and Digitalisation in Ports and Shipping. The Institution of Engineering and Technology, London, pp. 107–135. https://doi.org/10.1049/PBTR030E_ch4.
Min, C., Yang, Q., Chen, D., Yang, Y., Zhou, X., Shu, Q., Liu, J., 2022. The emerging Arctic shipping corridors. Geophysical Research Letters 49, e2022GL099157. Doi: 10.1029/2022GL099157.
Min, C., Zhou, X., Luo, H., Yang, Y., Wang, Y., Zhang, J., Yang, Q., 2023. Toward quantifying the increasing accessibility of the Arctic Northeast Passage in the past four decades. Adv. Atmos. Sci. https://doi.org/10.1007/s00376-022-2040-3.
Ministry of Climate and Environment, 2001. Lov om miljøvern på Svalbard (Svalbardmiljøloven). (Svalbard Environmental Protection Act.) [In Norwegian.] https://lovdata.no/dokument/NL/lov/2001-06-15-79; accessed 17 January 2023.
Moe, A., Brigham, L., 2017. Organization and management challenges of Russia's icebreaker fleet. Geogr. Rev. 107 (1), 48–68. https://doi.org/10.1111/j.1931-0846.2016.12209.x.
Moore, S.E., Huntington, H.P., 2008. Arctic marine mammals and climate change: impacts and resilience. Ecol. Appl. 18 (sp2), S157–S165. https://doi.org/10.1890/06-0571.1.
Mudryk, L.R., Dawson, J., Howell, S.E.L., Derksen, C., Zagon, T.A., Brady, M., 2021. Impact of 1, 2 and 4 °C of global warming on ship navigation in the Canadian Arctic. Nat. Clim. Chang. 11, 673–679. https://doi.org/10.1038/s41558-021-01087-6.
Neuman, S., 2013. Freighter makes first-of-its-kind transit of Northwest Passage. Alaska Public Media, NPR accessed 17 January 2023.
Ng, A.K.Y., Andrews, J., Babb, D., Lin, Y., Becker, A., 2018. Implications of climate change for shipping: opening the Arctic seas. WIREs Clim Change 9, e507.
NOAA Fisheries, 2022. 2018–2022 Ice seal unusual mortality event in Alaska. accessed 17 January 2023 National Oceanic and Atmospheric Administration. https://www.fisheries.noaa.gov/alaska/marine-life-distress/2018-2022-ice-seal-unusual-mortality-event-alaska;.
NSRA, 2022. The Northern Sea Route Administration. Federal Agency for Maritime and River Transport and Ministry of Transport of Russian Federation. www.nsra.ru/en/glavnaya/celi_funktsii.html; accessed 17 January 2023.
Ocean Conservancy, 2022. Take the Arctic corporate shipping pledge. accessed 17 January 2023. https://oceanconservancy.org/climate/shipping/arctic-shipping-pledge/;.
OCIMF, 2017. Northern Sea Route navigation: best practices and challenges. Oil Companies International Marine Forum, London. https://www.ocimf.org/document-library/94-northern-sea-route-navigation-best-practices-and-challenges-1/file; accessed 17 January 2023.
Office of the Undersecretary for Defense Policy, 2019. Report to Congress: Department of Defense Arctic strategy. U.S. Department of Defense. https://media.defense.gov/2019/Jun/06/2002141657/-1/-1/1/2019-DOD-ARCTIC-STRATEGY.PDF; accessed 17 January 2023.
Olsen, J., Nenasheva, M., 2018. Adaptive capacity in the context of increasing shipping activities: a case from Solovetsky. Northern Russia. Polar Geogr. 41 (4), 241–261. https://doi.org/10.1080/1088937X.2018.1513960.
Olsen, J., Carter, N.A., Dawson, J., 2019. Community perspectives on the environmental impacts of Arctic shipping: case studies from Russia. Norway and Canada. Cogent Social Sciences 5 (1), 1609189. https://doi.org/10.1080/23311886.2019.1609189.
Olsen, J., Antunes Nogueira, L., Normann, A.K., Vangelsten, B.V., Bay-Larsen, I., 2020b. Marine litter: institutionalization of attitudes and practices among fishers in Northern Norway. Marine Policy 121, 104211. 10.1016/j.marpol.2020.104211.
Olsen, J., Nenasheva, M., Wigger, K., Pashkevich, A., 2020a. Cruise tourism development in the Arkhangelsk region, Russian Arctic: stakeholder perspectives. In: Pongrácz, E., Pavlov, V., Hänninen, N. (Eds.), Arctic Marine Sustainability: Arctic Maritime Businesses and Resilience of the Marine Environment. Springer, Cham, Switzerland, pp. 365–389. https://doi.org/10.1007/978-3-030-28404-6_17.
Olsen, J., Vlakhov, A., Wigger, K.A., 2022. Barentsburg and Longyearbyen in times of socioeconomic transition: residents' perceptions of community viability. Polar Rec. 58, e7.
Olsen, J., 2020. Shipping and Arctic communities: an empirical study of local adaptive capacity. Unpublished Ph.D. thesis. Nord University #43, 2020.
Osmundsen, L., 2023. Port reception facilities and a regional approach: a bridge for abating plastic pollution in the arctic? Mar. Policy 148, 105436. https://doi.org/10.1016/j.marpol.2022.105436.
Østreng, W., Eger, K.M., Fløistad, B., Jørgensen-Dahl, A., Lothe, L., Mejlænder- Larsen, M., Wergeland, T., 2013. Shipping in Arctic Waters: a Comparison of the Northeast, Northwest and Trans Polar Passages. Springer, Heidelberg. 10.1007/978-3-642-16790-4.
Palma, D., Varnajot, A., Dalen, K., Basaran, I.K., Brunette, C., Bystrowska, M., Korablina, A.D., Nowicki, R.C., Ronge, T.A., 2019. Cruising the marginal ice zone: climate change and Arctic tourism. Polar Geogr. 42, 215–235. https://doi.org/10.1080/1088937X.2019.1648585.
PAME, 2020. The increase in Arctic shipping: 2013–2019. Arctic shipping status report (ASSR) #1. accessed 17 January 2023 Arctic Council. https://oaarchive.arctic-council.org/handle/11374/2733;.
Panahi, R., Ng, A.K.Y., Afenyo, M., Lau, Y.Y., 2021. Reflecting on forty years contextual evolution of Arctic port research: the past and now. Transp. Res. A Policy Pract. 144, 189–203. https://doi.org/10.1016/j.tra.2020.12.001.
Panahi, R., Afenyo, M., Ng, A.K.Y., 2022. Developing a resilience index for safer and more resilient Arctic shipping. Marit. Policy Manag. https://doi.org/10.1080/03088839.2022.2061059.
Pew Charitable Trusts, 2016. Integrated Arctic Corridors framework: planning for responsible shipping in Canada's Arctic waters. accessed 17 January 2023. https://www.oceansnorth.org/wp-content/uploads/2018/11/The-Integrated-Arctic-Corridors-Framework.pdf;.
Pizzolato, L., Howell, S.E.L., Derksen, C., Dawson, J., Copland, L., 2014. Changing sea ice conditions and marine transportation activity in Canadian Arctic waters between 1990 and 2012. Clim. Change 123, 161–173. https://doi.org/10.1007/s10584-013-1038-3.
Rantanen, M., Karpechko, A.Y., Lipponen, A., Nordling, K., Hyvärinen, O., Ruosteenoja, K., Vihma, T., Laaksonen, A., 2022. The Arctic has warmed nearly four times faster than the globe since 1979. Commun. Earth & Environ. 3 (1), 168. https://doi.org/10.1038/s43247-022-00498-3.
Raymond-Yakoubian, J., 2018. Arctic vessel traffic and Indigenous communities in the Bering Strait Region of Alaska. In: Hildebrand, L., Brigham, L., Johansson, T. (Eds.), Sustainable shipping in a changing Arctic. WMU Studies in Maritime Affairs, Vol. 7. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-319-78425-0_16.
Raymond-Yakoubian, J., Daniel, R., 2018. An Indigenous approach to ocean planning and policy in the Bering Strait region of Alaska. Mar. Policy 97, 101–108. https://doi.org/10.1016/j.marpol.2018.08.028.
Reuters, 2018. TABLE-Arc7 class Arctic vessels for Yamal LNG facility. November 21, 2018. https://www.reuters.com/article/lng-yamal-shipping-idUKL8N1XW3DC; accessed 17 January 2023.

Reuters, 2021. Russia aims for year-round shipping via northern sea route in 2022 or 2023. October 11, 2021. https://www.reuters.com/world/europe/russia-aims-year-round-shipping-via-northern-sea-route-2022-or-2023-2021-10-11/; accessed 17 January 2023.
Richard, G., Mathias, D., Collin, J., Chauvaud, L., Bonnel, J., 2023. Three-dimensional anthropogenic underwater noise modeling in an Arctic fjord for acoustic risk assessment. Mar. Pollut. Bull. 187, 114487 https://doi.org/10.1016/j.marpolbul.2022.114487.
Rosatom, 2020. Leader project: Atomflot and shipbuilder Zvezda sign nuclear icebreaker construction contract, April 23, 2020. https://www.rosatom.ru/en/press-centre/news/leader-project-atomflot-and-shipbuilder-zvezda-sign-nuclear-icebreaker-construction-contract/; accessed 17 January 2023.
Rosatom, 2021. Severniy morskoy put': itogi 2020 goda. (Northern Sea Route: Results of 2020.) [In Russian]. https://arctic.gov.ru/wp-content/uploads/2021/02/2020.pdf; accessed 17 January 2023.
Schreiber, M., 2022. A key Arctic Alaska port expansion gets $250 million in federal funding. Arctic Today. 20 January 2022. https://www.arctictoday.com/a-key-arctic-alaska-port-expansion-get-250-million-in-federal-funding/; accessed 17 January 2023.
Shadian, J., 2014. The politics of arctic sovereignty: oil, ice, and inuit governance. Routledge, London. https://doi.org/10.4324/9781315851419.
Smith, L.C., Stephenson, S.R., 2013. New trans-Arctic shipping routes navigable by midcentury. Proc. Natl. Acad. Sci. 110, E1191–E1195. https://doi.org/10.1073/pnas.1214212110.
Spiridonov, V.A., Solovyov, B.A., Onufrenya, I.A., 2020. Prostranstvennoye planirovaniye sokhraneniya bioraznoobraziya morey Rossiyskoy Arktiki. (Spatial planning for biodiversity conservation in the seas of the Russian Arctic.) [In Russian]. WWF Russia, Moscow.
Staalesen, A., 2016. Kirkenes, Norway becoming a hub for marine traffic heading to Arctic Russia. Radio Canada International. June 30, 2016. https://www.rcinet.ca/eye-on-the-arctic/2016/06/30/kirkenes-norway-hub-marine-traffic-russia-arctic-shipping-ports/; accessed 17 January 2023.
Stephenson, S.R., Smith, L.C., Brigham, L.W., Agnew, J.A., 2013. Projected 21st-century changes to Arctic marine access. Climat. Change 118, 885–899. https://doi.org/10.1007/s10584-012-0685-0.
Stevenson, T.C., Davies, J., Huntington, H.P., Sheard, W., 2019. An examination of trans-Arctic vessel routing in the Central Arctic Ocean. Mar. Policy 100, 83–89. https://doi.org/10.1016/j.marpol.2018.11.031.
Têtu, P.-L., Dawson, J., Olsen, J., 2018. Navigating governance systems & management practices for pleasure craft tourism in the Arctic. In: Heininen, L., Exner-Pirot, H. (Eds.), Arctic Yearbook 2018. Northern Research Forum, Akureyri, pp. 141–161.
The Ministry of Climate and Environment, 2001. Svalbard Environmental Protection Act. Act of 15 June 2001 No.79 Relating to the Protection of the Environment in Svalbard. https://www.regjeringen.no/en/dokumenter/svalbard-environmental-protection-act/id173945/; accessed 17 January 2023.
The Ministry of Foreign Affairs, 2014. Nordområdene. (The High North.) [In Norwegian]. https://www.regjeringen.no/globalassets/upload/ud/vedlegg/nordomrc3a5dene/nordkloden_rapport.pdf; accessed 17 January 2023.
The Ministry of Foreign Affairs, 2020. Meld. St. 9 (2020–2021). Mennesker, muligheter og norske interesser i nord. (People, opportunities and Norwegian interests in the North.) [In Norwegian]. https://www.regjeringen.no/no/dokumenter/meld.-st.-9-20202021/id2787429/; accessed 17 January 2023.
Todorov, A., 2022. Shipping governance in the Bering Strait Region: protecting the Diomede Islands and adjacent waters. Mar. Policy 146, 105289. https://doi.org/10.1016/j.marpol.2022.105289.
UN, 2007. Declaration on the Rights of Indigenous Peoples. United Nations, New York. https://www.un.org/development/desa/indigenouspeoples/declaration-on-the-rights-of-indigenous-peoples.html; accessed 17 January 2023.
USCG, 2016. Port access route study: in the Chukchi Sea, Bering Strait, and Bering Sea. United States Coast Guard. https://downloads.regulations.gov/USCG-2014-0941-0040/attachment_1.pdf; accessed 17 January 2023.
Van Luijk, N., Carter, N., Dawson, J., Parker, C., Grey, K., Provencher, J., Cook, A., 2022. Community-identified risks to hunting, fishing, and gathering (harvesting) activities from increased shipping activity in Inuit Nunangat. Canada. Regional Environ. Change 22, 24. https://doi.org/10.1007/s10113-022-01894-3.
Wang, Z., Silberman, J.A., Corbett, J.J., 2021. Container vessels diversion pattern to trans-Arctic shipping routes and GHG emission abatement potential. Marit. Policy Manag. 48 (4), 543–562. https://doi.org/10.1080/03088839.2020.1795288.
Will, A., Thiebot, J.B., Ip, H.S., Shoogukwruk, P., Annogiyuk, M., Takahashi, A., Shearn-Bochsler, V., Killian, M.L., Torchetti, M., Kitaysky, A., 2020. Investigation of the 2018 thick-billed murre (*Uria lomvia*) die-off on St. Lawrence Island rules out food shortage as the cause. Deep Sea Res. Part II 181, 104879. https://doi.org/10.1016/j.dsr2.2020.104879.
Xu, H., Yang, D., 2020. LNG-fuelled container ship sailing on the Arctic Sea: economic and emission assessment. Transp. Res. D 87, 102556. https://doi.org/10.1016/j.trd.2020.102556.
Yumashev, D., Hope, C., Schaefer, K., Riemann-Kampe, K., Iglesias-Suarez, F., Jafarov, E., Burke, E.J., Young, P.J., Elshorbany, Y., Whiteman, C., 2019. Climate policy implications of nonlinear decline of Arctic land permafrost and other cryosphere elements. Nat. Commun. 10, 1900. https://doi.org/10.1038/s41467-019-09863-x.
Zagorski, A., 2015. Perspective: implementation of Polar Code. In: Young, O., Kim, J.D., Kim, Y.H. (Eds.), the Arctic in World affairs: a North Pacific Dialogue on the Arctic in the Wider World. Korea Maritime Institute and East-West Center, Busan and Honolulu, pp. 215–233.
Zagorski, A., 2017. Economic and political perspectives on the development of the Northern Sea Route. In: Corell, R.W., Kim, J.D., Kim, Y.H., Young, O. (Eds.), The arctic in World affairs: a North Pacific Dialogue on Building Capacity for a Sustainable arctic in a Changing Global Order. Korea Maritime Institute and East-West Center, Busan and Honolulu, pp. 214–237.
Zagorskiy, A., 2019. Bezopastnost' v Arktikye. (Security in the Arctic.) [In Russian]. IMEMO, Moscow. Doi:10.20542/978-5-9535-0570-3.