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An examination of trans-Arctic vessel routing in the Central Arctic Ocean

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ABSTRACT

As the Arctic continues to warm, summer sea ice will continue to recede and a greater expanse of Arctic waters will become navigable. These changes may result in an increase in vessel traffic to the region, including via the Transpolar Sea Route (TSR), through the high seas area of the central Arctic Ocean (CAO). This paper begins with a review of the literature on Arctic vessel traffic to assess the potential effects of various stressors related to vessel traffic in the Arctic Ocean. Available data concerning environmental and safety risks for the Arctic Ocean are used to propose vessel TSR vessel traffic routes that can reduce those risks. The paper concludes with a brief discussion of several examples of vulnerability assessments focused on impacts from vessel traffic in the Arctic as potential models for future work specific to the CAO. The results from this review indicate vessel oiling, air pollution, and noise from icebreakers are immediate concerns to the Arctic Ocean that will likely worsen as the region becomes more navigable and vessel traffic increases. The proposed vessel routes for the Arctic Ocean are meant to serve as a starting point for further discussions before the region becomes fully navigable. As additional data become available, these efforts can be refined further, and a rigorous vulnerability assessment may become possible. Designation as a Particularly Sensitive Sea Area under international law could provide a useful mechanism for creating and updating precautionary shipping measures as more information becomes available.

1. Introduction

The Arctic is projected to experience ice-free summers sometime between mid- to late-century [1–3]. These projected changes are particularly important for the Arctic Ocean (Fig. 1), an ecosystem that is covered during the majority of the year by sea ice, serves as important habitat for several regionally endemic species, and may help stabilize global climate systems [4]. There are many seamounts, ridges, and other important geomorphic features in the Arctic Ocean that may also serve as important habitat for sustaining existing, and presumably future, biodiversity in the region. Legally, the central Arctic Ocean (CAO) is defined as the region of the Arctic Ocean beyond the 200-mile Exclusive Economic Zones (EEZs) of the five Arctic coastal states, and thus any management or governance actions concerning human activity in the CAO require international agreement.

Arctic sea ice retreat is expected to make new shipping routes available for seafaring vessels transiting the Arctic Ocean [5–7]. Globally, maritime vessel densities are disproportionately concentrated in mid-latitude regions, but some routes in the Arctic are attracting interest [8], particularly for destinational shipping, that is, voyages to and from Arctic ports. Arctic vessel traffic projections suggest this pattern will continue. For example, in the U.S. Arctic, vessel traffic is projected to grow somewhere between 100% and 500% by 2025 [9]. Over the last decade, shipping through or along the Northern Sea Route (NSR) has experienced substantial increases in traffic [10,11]. What is more, vessels are transiting Arctic waters faster and earlier than in previous years. For example, in 2017, a Russian tanker sailed the NSR in record time without icebreaker assistance [12]. Vessel traffic is expected to grow in the NSR and the Northwest Passage (NWP), with different climate-forcing scenarios influencing growth in the former route and the latter route increasing independent of climate forcers by mid-century [13]. While vessel traffic is predicted to increase across the Arctic, particularly along the NWP and NRS, little attention has been given to the potential for transit shipping via the Transpolar Sea Route (TSR) and how vessel traffic in the CAO could affect the environment of this region. While the prospects for trans-polar shipping are uncertain, a precautionary approach suggests considering potential risks and available options for reducing those risks. We therefore explore those risks and options to assess how trans-polar shipping might affect the CAO environment and what actions could be taken to reduce those risks.

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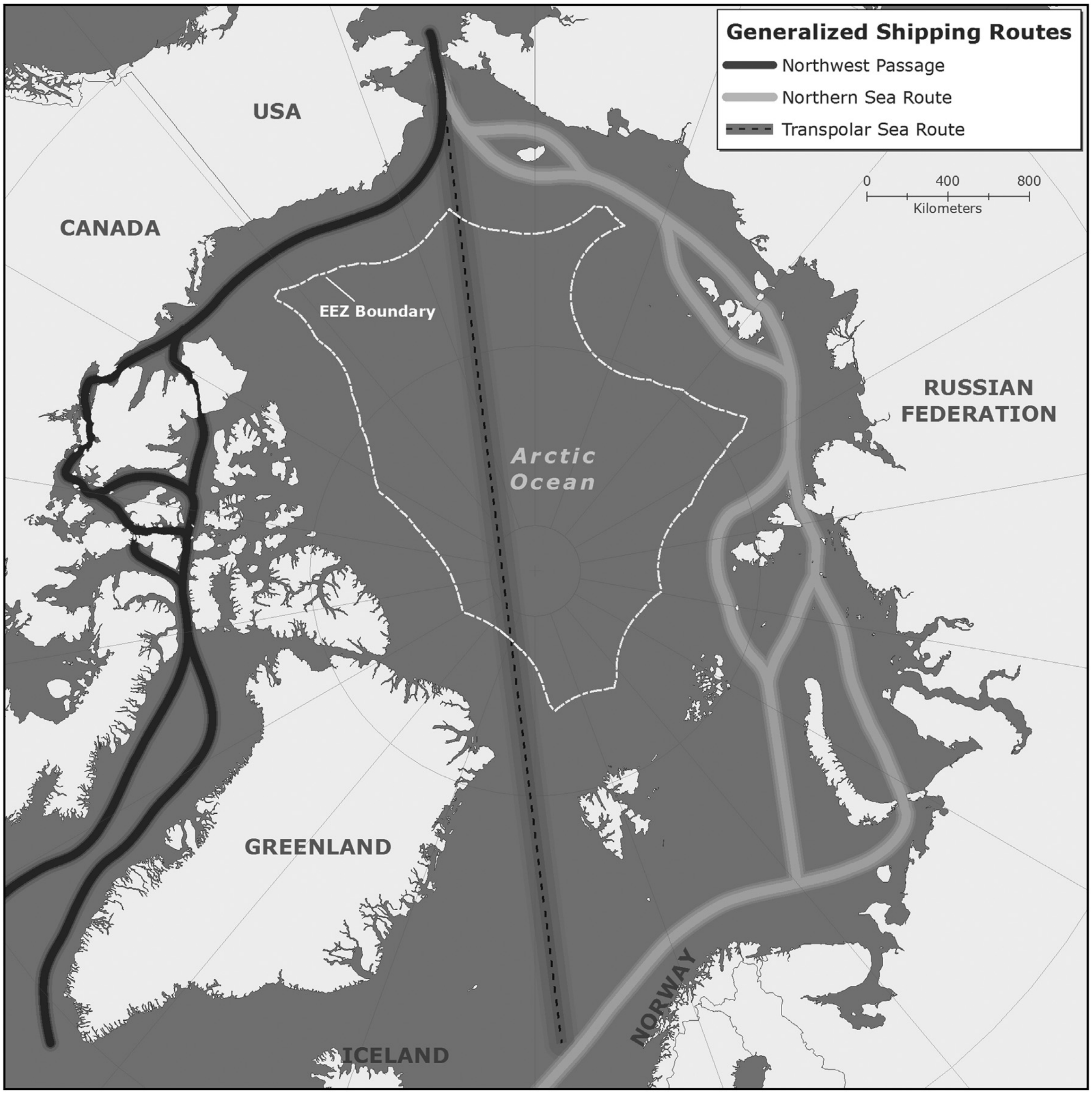

Fig. 1. The Arctic Ocean, including the boundary of the high seas region of the central Arctic Ocean (CAO), and the three major Arctic trans-shipping routes.

The paper begins with a review of the literature on environmental concerns around increases in vessel traffic in the CAO, drawing on past efforts to assess ecosystem vulnerability to the effects of vessel traffic in the Arctic, and presents criteria for establishing a trans-Arctic shipping route that reduces vessel risk and takes into account environmental sensitivities. The goal is to inform future CAO management efforts and vulnerability assessments related to vessel traffic in the region. We acknowledge that in addition to environmental concerns, maritime safety is a major concern for Arctic shipping [14], but that topic is largely outside the scope of this paper.

2. The Central Arctic Ocean

Sea ice is the most important physical characteristic of the Arctic Ocean and is changing rapidly. The extent and thickness of multi-year sea ice (i.e., sea ice that has persisted through at least one summer) in the Arctic has significantly declined over the last several decades [15,16]. Higher winter temperatures have hindered sea ice growth and likely contributed to the lower likelihood that first-year ice will last through summer [17,18]. These new multi-year sea ice trends are influenced by natural variability and warming atmospheric and ocean temperatures resulting from global greenhouse gas loading in the atmosphere [19,20]. While earlier models predicted an ice-free Arctic during the summer months occurring by year 2040 or sooner [21,22], more recent models suggest ice-free conditions will become more reliable toward the latter part of the century [2].

Ecologically, the deep-water region of the Arctic Ocean has been described as an important Large Marine Ecosystem [23], despite a relative scarcity of information about it. It supports iconic and ecologically important ice-obligate marine mammals, such as polar bear and ringed seals, and ice-associated sea birds, such as the Ivory Gull (*Pagophila eburnean*) and Ross's Gull (*Rhodostethia rosea*) [24,25]. The under-sea ice ecosystem in the CAO supports a diverse macroinvertebrate community that feed potentially large numbers of polar cod (*Boreogadus saida*) and Arctic cod (*Arctogadus glacialis*), with a recent study finding between 10,000 and 16,000 juvenile polar cod per square kilometer underneath the sea ice at sites in the CAO [26,27]. Polar cod are expected to become more restricted to their pelagic distribution as sea ice retreats during the summer months and it is possible these restrictions will influence the broader CAO ecosystem [28]. Recent efforts have resulted in a 16-year fisheries agreement for the CAO among ten Arctic and non-Arctic states, with the justification of encouraging fisheries and ecosystem research to inform future management for the region before exploitation begins [29–31].

Unlike the CAO fisheries agreement, which was undertaken as a comprehensive approach to managing potential impacts to the CAO, development of vessel traffic management measures has proceeded in more piecemeal fashion, with the IMO recently making some provisions of the Polar Code mandatory, while the development of other potential management measures is taking place across a range of other venues, such as the Arctic Council. For example, as part of the Arctic Council follow-up to the Arctic Marine Shipping Assessment recommendations, Det Norske Veritas [32] produced a report evaluating the potential for specially designated marine areas in the Arctic High Seas. The report recommends several options for a more comprehensive approach, centering around the concept that some or all of the CAO should be designated a Particularly Sensitive Sea Area by the IMO, and that sea ice and other important habitats should be protected via Associated Protective Measures such as Areas to Be Avoided, vessel traffic systems, and ship reporting systems. Designation as a Particularly Sensitive Sea Area provides both a higher level of recognition of the unique ecological, socio-economic, or cultural values of an area and a pathway to developing Associated Protective Measures as a single package of management measures to prevent or mitigate impacts from shipping to these attribute [33].

3. Changes in sea routes

The Arctic Council's Arctic Marine Shipping Assessment [5] provides a comprehensive summary of commercial and other vessel traffic in the Arctic Ocean. Arctic marine activity has been occurring for thousands of years, with Indigenous marine activity primarily focused on the search for food, supplies, and settlement. This has continued into current times, with Indigenous communities continuing to rely on Arctic marine transport for remote community re-supply, resource development and extraction, and hunting and fishing opportunities. Commercial and naval marine activities began in the fifteenth century, with the search for the Northwest Passage and Northeast Passage. Both were largely driven by exploration and the search for trade routes to Asia. While the Northwest Passage has not yet become a regular trade route as originally hoped by explorers, Arctic-wide marine transportation continues to increase. For the time being, however, transpolar activity remains limited to a handful of scientific expeditions.

In recent times, the majority of Arctic marine activity has continued to be destinational traffic (community re-supply and resource extraction), with a more recent emphasis on improving global trade possibilities via trans-shipping through these routes. In addition the Arctic Ocean has become of national security interest to Arctic nations. Another component of modern Arctic marine transport is the development of the Northern Sea Route along Russia's north coast. Starting in the early 1900s with exploration and settlement, the route has evolved via increased development of ports and fleets. By the early 1950s there was regular operation in the Northern Sea Route, and by the late 1970s there was year-round operation in the region. This activity decreased drastically following the break-up of the Soviet Union, but has been rising again in recent years.

Looking forward, Smith and Stephenson [34] modeled shipping routes under several climate change scenarios and concluded that September sea ice will have retreated in the Northwest Passage by midcentury to allow approximately 30% geographic distance savings in shipping between western North America and Europe. However, there is higher confidence in predicting ice-free seas for the NSR this century than for the NWP and TSR, the latter of which may retain considerable sea ice cover past midcentury [2].

With potential voyage distance savings plus the avoidance of coastal waters and potential regulatory efforts by coastal states, the TSR is also projected to become more attractive as summer sea ice retreats. Stephenson and Smith [13] explored 21st century trans-Arctic sea ice scenarios using 10 global climate models and found that the TSR will have limited and sporadic vessel route accessibility before 2035, but will gradually replace the NSR by mid-century. The TSR allows vessels to avoid the Russian EEZ, avoiding high cost tariffs associated with the NSR. Although the latter point is an economic argument for following TSR routes, hidden costs include risks inherent to the region's remoteness, sea ice-laden environment and poor emergency response infrastructure [35]. Lasserre et al. [36] evaluated perceptions held by 189 shipping companies from Asia, Europe and North America about prospects of future shipping operations in the Arctic, and found that the majority perceived environmental risks (i.e., ice, weather, remoteness, etc.) and seasonality/unpredictability as primary challenges. These factors, among others, are not accounted for in existing Arctic vessel traffic models [37].

4. Environmental effects of vessel traffic growth in the CAO

Potential vessel traffic growth in the Arctic could result in higher rates of noise and air pollution, vessel discharges (sewage, graywater, etc.), non-native species introductions, small vessel interference, oiling, and other concerns related to the wellbeing of humans and environment [11]. Although these stressors are a concern as vessel traffic increases in the Arctic Ocean, regional experts often express most concern about vessel oiling and noise pollution [38]. Nearly all stressors associated with vessel traffic have been poorly described and studied for the Arctic Ocean, particularly in comparison with the sub-Arctic. This section provides an overview of the primary stressors linked to vessel traffic in the Arctic and their relevance to shipping in the CAO.

4.1. Noise disturbance

Vessels are known to generate high levels of low frequency noise from their propulsion systems that can transmit over vast areas far from ship traffic lanes, which may mask echolocation and communication abilities and disrupt behaviors of marine mammals [39–43]. At present the primary source of anthropogenic noise in the CAO is from icebreaking vessels that seasonally visit the region. Noise from icebreakers can negatively impact Arctic marine mammals [44]. The effects of anthropogenic noise on fish are poorly studied, yet some evidence suggests it can negatively impact mate selection, egg viability, larval growth rates, and foraging performance [45,46]. The environmental effects that vessel traffic noise may have in the CAO are widely unknown. Better understanding of changes in the distribution of marine mammals and fishes in the region as sea ice melts is critical for future vessel traffic management decisions.

4.2. Vessel strikes

At present the probability of vessels colliding with marine mammals in the CAO is low. While the numbers of vessels in the CAO is supposed to increase as sea ice retreats, it is unclear how marine mammals will respond to these changes. There is some evidence indicating ice-associated cetaceans may not be as reliant on sea ice as previously thought [47], but it is difficult to say with certainty if species like bowhead, narwhal and beluga will shift toward the CAO as sea ice retreats and water temperatures warm. If these shifts occur, concerns about vessel collisions with marine mammals will presumably increase.

4.3. Air pollution

Seafaring vessels are contributors of locally emitted sources carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon monoxide (CO), and varieties of particulate matter such as organic carbon (OC) and black carbon (BC) [48]. A recent modeling study showed that emission controls, fuel type restrictions (e.g., heavy fuel oil ban), and mechanical controls (e.g., exhaust cleaning systems) on seafaring vessels can significantly reduce BC and SO_x [49]. Developing smart regulatory policies to improve vessel related air pollutants is achievable.

4.4. Oil spills

Vessel oiling is a major concern with projected vessel traffic growth in the CAO, as fuel and other oil products can cause harm to marine life [50–54]. In the absence of potential port-related accidents in the CAO, at-sea vessel collisions with sea ice or other vessels are likely the greatest concern for oil exposure from maritime vessels. Oil exposure in the Arctic marine environment is problematic because decomposition and volatilization is slow in cold temperatures and sea ice-oil interactions are complex and unpredictable [55]. While oiling/spills is/are an environmental concern, the causes are likely also to threaten maritime safety, as a collision between vessels or between vessels and sea ice may reduce the seaworthiness of the vessel or vessels involved, potentially requiring rescue. Existing regulatory mechanisms, such as those under the International Maritime Organization Polar Code, focus on maintaining technical aspects of vessel structure, stability and integrity that help prevent unintended oil spills from occurring in the CAO [38]. While these regulations offer *de facto* protections, improvements, such as making protection of the marine environment a priority within the Polar Code, have been advocated [38].

4.5. Vessel discharges

Vessels are currently allowed to discharge raw sewage at distances more than 12 nm from the nearest land; however, vessels greater than 400 gross tonnage and carrying more than 15 passengers are required to have onboard sewage treatment capabilities [56]. Most vessels transiting the CAO would presumably have onboard sewage treatment capabilities. As vessel traffic increases overtime, concerns around raw sewage and greywater discharge may become more pertinent and issues around decomposition rates of raw sewage and impacts on nutrient cycling should be considered. At present vessel discharge in the CAO is not a major concern.

4.6. Non-native species introductions

Presently the number of non-indigenous species (NIS) introduced in the Arctic is low [57], but concerns around NIS introduction is growing as Arctic waters warm and projected shipping and oil and gas activities increase [11,58]. Seafaring vessels are a common vector for NIS introductions. Many marine organisms are inadvertently acquired and transported from port to port via ballast water, which may result in NIS introductions [59]. NIS microorganisms, barnacles, and seaweeds that grow on submerged surfaces of marine vessels can also serve as a source of introductions, resulting in marine biofouling [59]. At present there are no provisions in the Polar Code addressing the potential concerns around NIS attached to vessel hulls operating in Arctic [60]. The risks from NIS introductions in the CAO remain unclear but probably low, particularly since the main invasion pathways are from ballast water or biofouling when vessels are in port.

5. Trans-Arctic shipping routes

While modeling efforts have suggested the potential for future vessel traffic growth via the TSR, none have explored vessel routes as one possible means to reduce some of the environmental risks outlined in the previous section. Other management and governance actions are likely to be necessary to address the full range of risks [11], and when sufficient data are available these could be considered as part of a vulnerability assessment as described in the next section. The CAO supports ecologically important marine mammals, birds, and fish but data illustrating their abundance and distribution in the region are lacking. In general, however, it is known where ecologically important areas are located in the Arctic, that sea ice and remoteness present risks to seafaring vessels, and that benthic structure (i.e., plateaus, terraces and ridges, and seamounts) typically serves as important habitat for fish and invertebrates [61]. As the TSR becomes more navigable and if vessels begin transiting the region, it would befit vessel operators to consider the establishment of traffic corridors to reduce safety and environmental risks. Additionally, the adage “safety in numbers” would apply if vessel operators used traffic corridors, as other transiting vessels could aid distressed vessels requiring assistance in waters far from other rescue capacity.

There are a variety of formal analytical approaches that, with sufficient data, can be used to plot shipping routes in relation to various factors including environmental conditions and risks [34,62]. In the absence of detailed data for the Central Arctic Ocean at present, an approximation of these analytical principles was used to draw two hypothetical routes as a scoping exercise. A geographic information system (GIS) was used to map a suite of data layers relevant to shipping safety, efficiency, and biological oceanography. The resulting cartographic output allows a visual optimization of routing with the following conditions in mind:

- Minimize safety risk by avoiding areas with persistent thick summer pack ice [63,64].
- Consider surface ocean surface currents [65] and place corridors a minimum of > 100 km from persistent summer pack ice an areas where prevailing surface currents could transport distressed vessels into hazardous sea ice conditions.
- Minimize ecological risks by minimizing passage through or over areas of heightened ecological and cultural sensitivity [25], as well as potential biological hotspots, such as seamounts [66,67] and shallower ridges, terraces, and plateaus [68].
- Stay in international waters [69] to the full extent possible to avoid tariffs and other geopolitical issues.
- Consider proximity of other arctic sea routes and traffic [5], so that nearby ships can provide assistance to ships in distress if needed.
- Avoid excessive route changes and detours to minimize the potential for navigation errors and extra costs associated with a longer route.

All of the geospatial data in the list above are readily available and can be used to draw hypothetical trans-Arctic shipping corridors (Fig. 2). Two potential routes are shown, both with one end at the Bering Strait and the other end going either east or west of Svalbard, depending on the destination. Option 1 gives more weight to proximity to the NSR and avoidance of ecologically sensitive areas, whereas Option 2 is straighter and thus shorter while also reducing the risks associated with the most direct pathway. Refinements to these corridors can be made with the incorporation of emerging data on changing sea ice conditions, biological productivity and hotspots, and sea surface drift. Discussing and designing trans-Arctic vessel traffic corridors before the CAO is navigable will provide time to reduce environmental risks and improve vessel safety rather than attempting to do so after TSR shipping has already begun. The identified TSR vessel traffic routes are simply a first contribution to that conversation. A more rigorous analysis would be appropriate when more data are available and route planning moves from the hypothetical to the actual.

6. The prospects for a vessel traffic vulnerability assessment for the CAO

While designating shipping routes for the TSR is a good starting point for minimizing environmental and safety risks, a more sophisticated approach would involve undertaking a vessel traffic vulnerability assessment for the CAO. Some examples of such assessments in Arctic and subarctic waters illustrate the potential contribution a CAO assessment could provide.

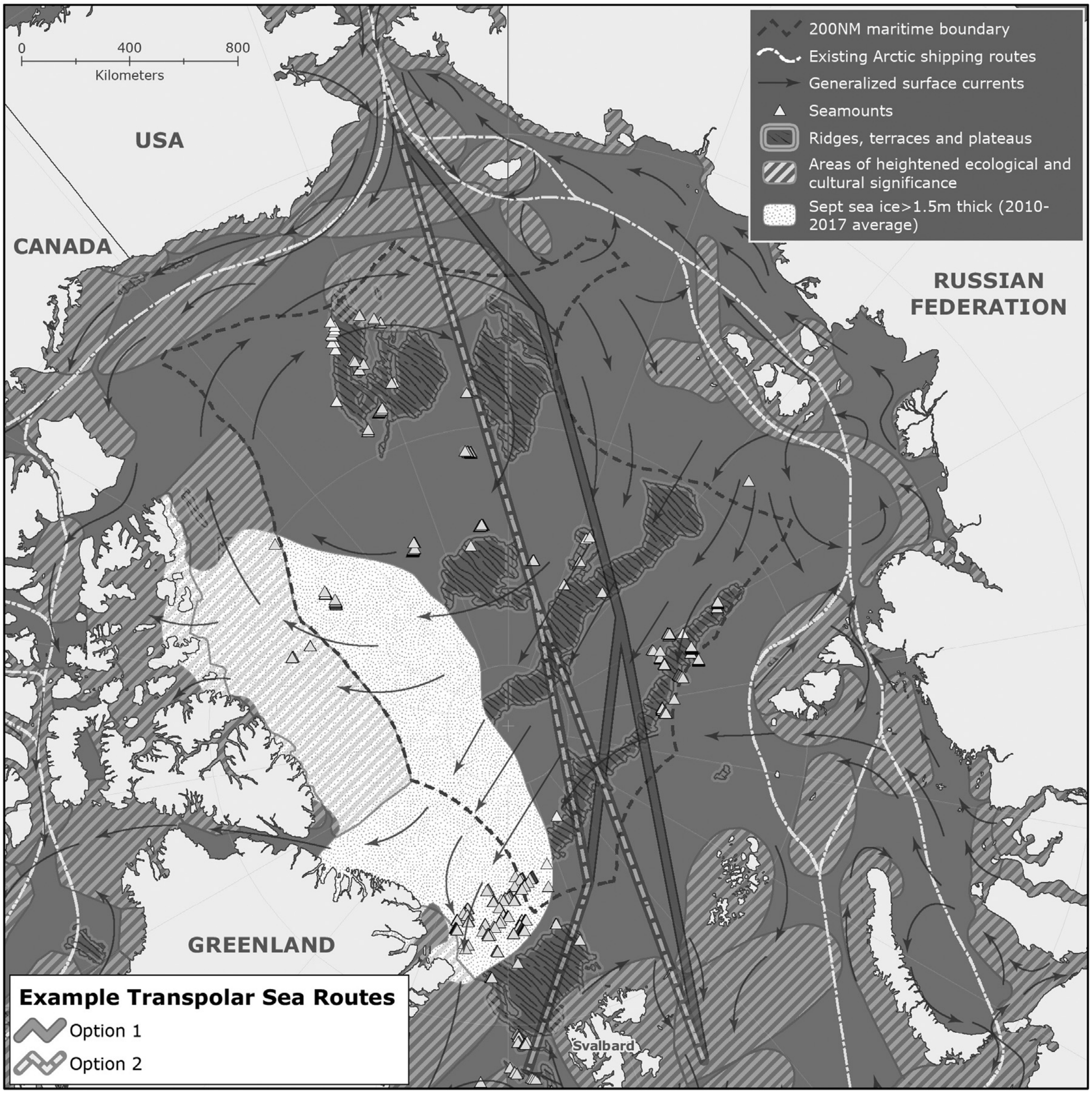

Fig. 2. Major environmental features of concern and hypothetical shipping lanes in the TSR, identified using the criteria described in the text.

First, in 2014, Det Norske Veritas launched an online interactive mapping platform that allows users to explore the vulnerability of marine mammals, birds, and fish to oil exposure [70]. They used a location- and season-specific index for environmental vulnerability with regard to oil spills. The index was applied to areas of heightened ecological significance for 17 Arctic Large Marine Ecosystems. Some of the CAO is represented in this vulnerability assessment, which may be the best vulnerability assessment for the CAO currently available.

Second, Renner and Kuletz [71] performed a spatial–seasonal analysis of the oiling risk from shipping traffic to seabirds in the Aleutian Archipelago. In Renner and Kuletz [71], a seabird vulnerability index was generated using an Oil Vulnerability Index (OVI) approach, as originally described in King and Sanger [72], and integrated it into a risk assessment framework. While Renner and Kuletz [71] may be an appropriate approach for the CAO, using OVI to calculate vulnerability is often considered suitable for species population scales, not ecosystem scales [73]. The CAO is not a monolithic ecosystem and therefore other methods for calculating vulnerability at the ecosystem scale might be more suitable. Examples of such approaches include Halpern et al. [74] who examined vulnerability of global ecosystems to different stressors occurring within different habitats, and Hare et al. [75] who evaluated vulnerability of fish and invertebrates to climate change on the Northeast U.S. Continental Shelf Large Marine Ecosystem using a trait-based vulnerability assessment approach.

Finally, scientists from the Polar Science Center at the University of Washington explored the vulnerability of marine mammals to vessel traffic through the NSR and NWP [76]. The goal of that effort was to identify and map key areas of population ranges for marine mammals that intersect the NWP and NSR during September and construct estimates of population-specific vulnerability. They used a trait-based assessment approach and the ecological subsystem framework to evaluate vulnerability, where risk exposure is defined as areas with spatial overlap between vessels and mammal populations occurring along the NSR and NWP. They also used seven variables to quantify sensitivity in terms of 1) disturbance and collision impacts, 2) frequency of exposure, and 3) ecological factors that affect population responses to vessels. Although this research focused on marine mammals and vessel traffic within the NSR and NWP, it is a good example of a trait-based vulnerability assessment in the Arctic and may serve as a model for future CAO efforts.

7. Conclusion

In the absence of port related activities in the CAO, environmental impacts from seafaring vessels remain relatively low. Impacts from vessel oiling, air pollution, and noise from icebreakers are a more immediate concern that will likely increase as vessel traffic increases. In addition to designated shipping corridors for the TSR, other policy instruments could be considered to preemptively protect the CAO from vessel traffic. For example, developing Emission Control Areas to regulate air pollutants from vessel traffic, or designating the CAO or a subset of the CAO as a Particularly Sensitive Sea Area and designing dynamic vessel routing areas that consider ecological impacts and include ship reporting systems and other vessel traffic system components are two that could be considered. The CAO could be viewed as a regional human use experiment guided by the precautionary principle, similar to the recently negotiated CAO fisheries agreement.

Existing vulnerability assessments in the Arctic region have often addressed concerns in a univariate rather than a holistic, integrated manner. A rigorous quantitative vessel traffic vulnerability assessment for the CAO that employs a nested approach and integrates the above-mentioned factors is warranted and timely. The paucity of data for the CAO makes it likely that more research will be needed to help inform a more comprehensive and integrated ecosystem assessment that evaluates vulnerability attributes. Integrating multiple stressors in a vulnerability assessment is a larger investment and more complicated, but the output would presumably be more useful for countries concerned with ocean management and conservation for the region. The proposed vessel routes for the TSR are a good starting point for future discussions on how to preemptively minimize environmental and safety risks from vessel traffic, making use of existing data. Determining the exact route or routes and the possibility of annual or seasonal adjustments requires further discussion within and between Arctic and other shipping states (presumably at the IMO and Arctic Council) that ideally connect to existing or proposed routing measures within EEZs at either end of the TSR. Continued monitoring and research as vessel traffic increases can help support additional measures that will enhance maritime safety and reduce environmental risks.

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Declaration of interests

None.

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