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The opening of the Transpolar Sea Route: Logistical, geopolitical, environmental, and socioeconomic impacts

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A B S T R A C T

With current scientific models forecasting an ice-free Central Arctic Ocean (CAO) in summer by mid-century and potentially earlier, a direct shipping route via the North Pole connecting markets in Asia, North America, and Europe may soon open. The Transpolar Sea Route (TSR) would represent a third Arctic shipping route in addition to the Northern Sea Route and Northwest Passage. In response to the continued decline of sea ice thickness and extent and growing recognition within the Arctic and global governance communities of the need to anticipate and regulate commercial activities in the CAO, this paper examines: (i) the latest estimates of the TSR's opening; (ii) scenarios for its commercial and logistical development, addressing the various transportation systems that could evolve; (iii) the geopolitics of the TSR, focusing on international and national regulations and the roles of Russia, a historic power in the Arctic, and China, an emerging one; and (iv) the environmental and socioeconomic consequences of transpolar shipping for local and Indigenous residents of communities along the TSR's entrances. Our analysis seeks to inform national and international policymaking with regard to the TSR because although climate change is proceeding rapidly, within typical policymaking timescales, there is still time to prepare for the emergence of the new Arctic shipping corridor.

1. Introduction

For millennia, thick multi-year sea ice prevented voyages across the Arctic Ocean from reaching the planet's apex. The geographic North Pole and its surrounding waters held little navigational or metaphysical importance for Indigenous Peoples in the region. While well-traveled across the Arctic, they tended to reside in winter and spring on the seasonal sea ice that formed atop the Arctic Ocean's habitable coastal waters, setting up hunting and fishing camps and making the ice their home [1,2]. In contrast, beginning in the sixteenth century, British and Dutch explorers, excluded from Spanish and Portuguese imperial trade routes, sought Arctic passages for trade with Asia, including a direct shortcut via the North Pole. Yet insurmountable ice forced them to cling to the coastlines of present-day Canada and Russia. Still, gentlemen of science like Robert Boyle (1627-1691) argued that sea ice could form only by extending out from land. This hypothesis allowed for an "open polar sea" further offshore, warmed by six months of daylight and temperate ocean currents [3]. Such dreams persisted despite continuously treacherous conditions forcing scientific navigators like Fridtjof Nansen, who tried to drift in his ship with the pack ice towards the North Pole between 1893 and 1896, to abandon their attempts. He and others, like American naval officer Robert Peary, relied on the knowledge, experience, and material culture of the Inuit, with whom Peary traveled to approach the North Pole between 1908 and 1909. Yet maritime expeditions would still not successfully sail all the way to the North Pole until the invention of nuclear power. On August 3, 1958, the nuclear submarine USS *Nautilus* reached 90°N – but even then, it did so only by sailing under the frozen Arctic Ocean. A surface vessel would not achieve the North Pole until 1977, when the Soviet Union's nuclear icebreaker, *Arktika,* accomplished the feat.

Today, as climate change thins and melts the sea ice, imperial dreams of an open polar sea may soon be realized even if only seasonally, making sailing via the North Pole much more feasible. In recounting their respective nineteenth and twentieth-century expeditions, both

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Nansen and USS *Skate's* commander described towering ridges and daunting walls of ice. But by 2014, while skiing from the North Pole to Canada, Dutch explorer Bernice Notenboom wondered if she might be one of the last individuals to undertake the journey given the rapid disappearance of the Arctic Ocean's frozen cover [1]. Between 1958–1976 and 2011–2018, average sea ice thickness (SIT) near the annual end of the melt season decreased by 2 m (66%) [4]. In September 2012, sea ice extent[1] declined to its lowest level since satellite records began in 1979, comprising only 56% of the average annual minimum between 1981–2010 [5]. It now appears that due to warming trends set in motion, regardless of whether greenhouse gas emissions are controlled, the Arctic will become ice-free (defined as <1 million km^2) in September before 2050 [6]. This event would mark the first time in 2.6 million years that the Arctic Ocean lacks sea ice [7].

The loss of summer sea ice promises to open a new Arctic shipping lane known as the Transpolar Sea Route (TSR). Linking the Atlantic and Pacific Oceans via the North Pole, the TSR represents an addition to the two better known Arctic shipping lanes: the Northeast Passage (NEP), which hugs the north coast of Russia where it is called the Northern Sea Route (NSR), and the Northwest Passage (NWP), which cuts through the Canadian Arctic Archipelago (Fig. 1a). The NEP and NWP have long been plied either in part or whole by Indigenous Peoples, mariners, naval explorers, and more recently militaries and shipping and cruise lines [2,8]. In contrast, though mythologized since at least the Age of Exploration, the TSR only began to be used in the second half of the twentieth century after the development of nuclear icebreakers and submarines for occasional military, scientific, and more recently, tourist purposes. By the middle of this century, however, the TSR could be 56% more accessible relative to its early 21st-century baseline, representing a more dramatic change than the NWP (30% more accessible) and NSR (16% more accessible) [9]. Moreover, while the NSR already reduces sailings between Europe and East Asia from ~30 days via the Suez Canal to ~18 days, the TSR offers even greater time savings by cutting an additional 1–5 days off the journey [9,10]. Ultimately, the TSR could challenge the utility of the NSR and NWP. As a representative of a shipping company surmised, there exists "the possibility of the transpolar route becoming navigable over the long term, which would make the routes passing through Arctic straits obsolete" [11].

Despite these portending changes, until recently, the TSR has been understudied compared to the NEP and NWP. One of the most widely cited reports on Arctic shipping, the Arctic Council's *Arctic Marine Shipping Assessment (AMSA)* (2009), omits the TSR from a map of Arctic shipping routes even though it contends that "increased marine traffic in the central Arctic Ocean is a reality – for scientific exploration and tourism" [12]. Yet in the decade since *AMSA's* publication – and concurrent with a ~20% decline in sea ice extent between September 2009 and 2019 – the TSR and other trans-Arctic shipping routes have attracted more attention from academics, policymakers, and industry [13–16]. So, too, have the North Pole [1] and Central Arctic Ocean (CAO). Whereas *AMSA* uses a miniscule "c" in the term "central Arctic Ocean," the title case ("Central Arctic Ocean") began appearing in 2011 as regional and international policymaking efforts to formalize and regulate the maritime space strengthened [17].

Climate change is occurring rapidly, but changes to Arctic shipping, including any move from the NSR to the TSR, will likely be gradual [15]. There is thus still time to inform and craft policies to manage future activities in the CAO. Doing so would build on the enactment of other precautionary measures in the region such as the 2018 Agreement to Prevent Unregulated High Seas Fisheries in the CAO, which placed a 16-year moratorium on fishing in its high seas. The international policymaking community recognizes the need to prepare for increased commercial use of the CAO, within which the TSR could form a central feature. Scientists do, too: a 2020 special issue of *Marine Policy* [18,19] addresses the future of ecosystem governance of marine biodiversity of areas beyond national jurisdiction in the Arctic Ocean, underscoring the importance of both researching and regulating its increasingly accessible high seas.

In light of these environmental, regulatory, and scientific shifts, this paper synthesizes the literature on transpolar shipping, the CAO, and the TSR to consider: (i) the timeline for the TSR's opening; (ii) scenarios for its commercial and logistical development, considering what would push traffic north from the NSR towards the TSR and what would stimulate the operationalization of icebreakers, polar class vessels, and/or the construction of transshipment hubs; (iii) the geopolitics of the TSR, focusing on international and national regulations and the roles of Russia, a historic power in the Arctic, and China, an emerging one; and (iv) the environmental and socioeconomic impacts of the TSR's development for people living along its entrances in the Bering and Fram Straits. Although transpolar shipping is imagined primarily as connecting global markets, local communities will bear the more immediate consequences of developing a route across the North Pole.

2. Timeline for the opening of the TSR

We consider the "opening" of the TSR to concur with the onset of short annual periods of ice-free conditions in the Arctic Ocean, which scientists predict will occur for at least some portion of the year before mid-century. Reaching this threshold requires adding between +0.6 and +0.9°C to the current global mean temperature [20]. Predicting the date of the TPP's initial opening typically involves analysis of sea ice outputs from multiple global climate models representing a range of environmental and anthropogenic uncertainties, which are constrained by observations of natural cycles [21].

Current models predict an ice-free Arctic Ocean considerably sooner and across a wider range of warming scenarios than estimates made just a few years prior. A study published in 2020 relying on the latest climate model ensemble from the Coupled Model Intercomparison Project (CMIP6), which will feature in the 2021 Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, projects sea-ice-free conditions in the Arctic in September before 2050 regardless of whether emissions are controlled [6]. In contrast, research based on CMIP5 and models contained within the ensemble, which were presented in the 2013 IPCC Fifth Assessment Report, determined that such conditions were considerably less likely if warming were limited to 1.5°C [22–24]. CMIP5 studies projected sea-ice-free conditions by 2040 or later, even while admitting that these estimates remained conservative in light of rapid observed decline in ice area and thickness [25,26]. CMIP3 studies had put the date closer to 2070 [27,28].

Declines in SIT are particularly relevant for transpolar shipping, as the measure is a chief determinant of the type of polar class (PC) vessel required in ice-covered waters. Like sea ice extent, SIT has been declining: at the North Pole, while average SIT was ~4 m between 1958–1976, by 2011–2017, it dropped to <1 m [4]. As recently as 1994, technologies like an "iceraker" – a modified icebreaker that would have been capable of navigating through 8 m thick multi-year ice – were being proposed and deemed to represent "an innovation that may not become a reality for a long time" [29]. Now, rather than representing technologies ahead of their time, their time may never come. Overall in the Arctic Ocean, between 2011–2017, model-derived average SIT in September was <2 m [30], which aligns with CryoSat-2 observations in November 2013 of SIT of <2 m along the TSR [31]. Declining SIT means that PC vessels of lower classes may eventually able to transit the TSR, attracting ships north and away from lengthier coastal Arctic shipping routes [32]. Sailing in thinner ice is also faster and requires less fuel, which could reduce costs and lower exhaust emissions [33].

In terms of the geography and seasonality of ice loss, the Arctic Ocean is predicted to first become ice-free in September, when sea ice reaches its annual minimum extent. Sea ice will persist in the Canadian

[1] In satellite observations, sea ice extent is typically measured as the sum of all areas of grid cells with >15% ice concentration.

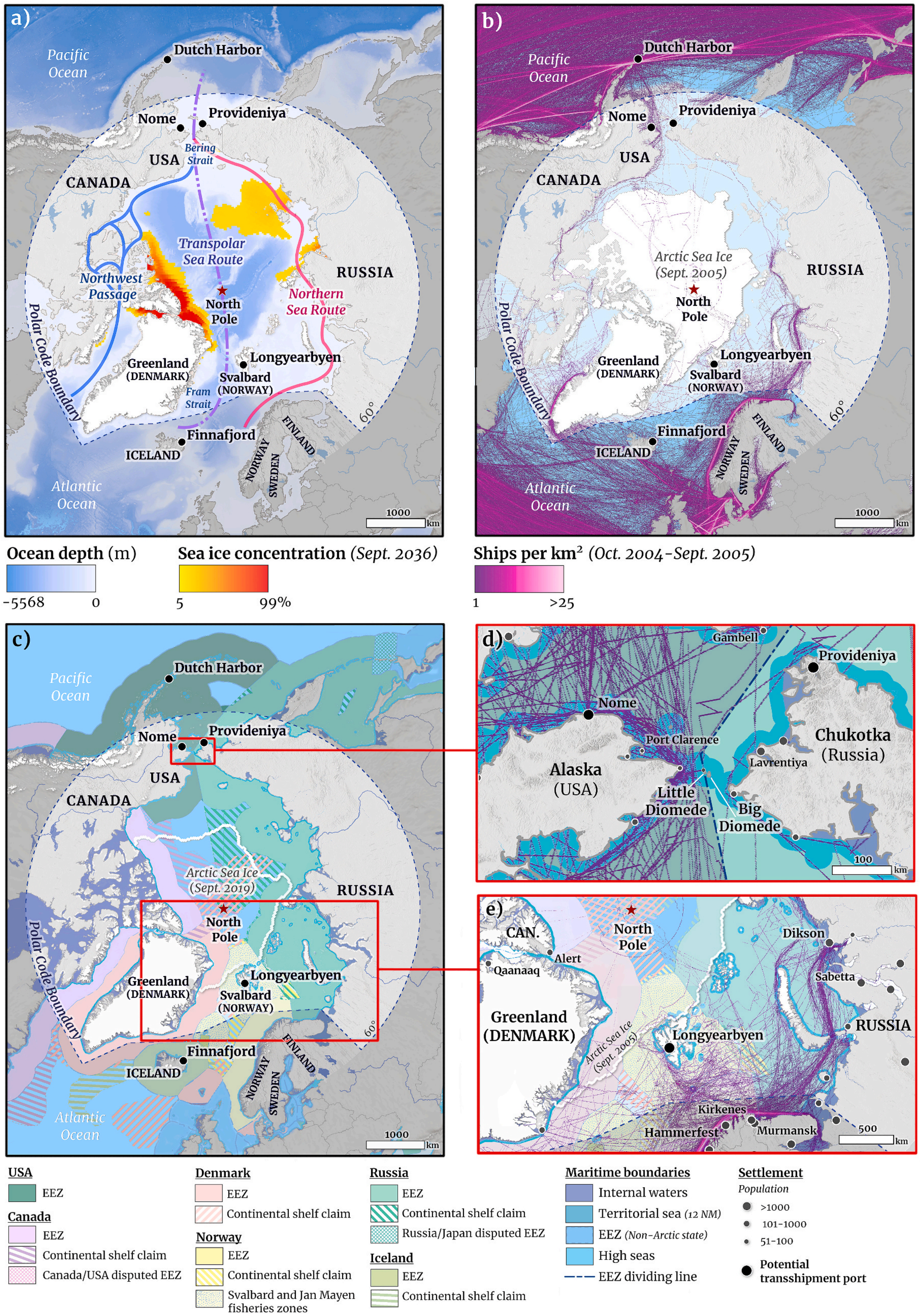

Fig. 1. (a) Arctic shipping routes, ocean bathymetry, and sea ice concentration in September 2036, one of the first years in which the TSR is widely navigable in summer (under RCP 8.5 in CMIP5). Data: IBCAO Version 3.0, GEBCO, and the Community Earth System Model (CESM) in CMIP5. (b) Sea ice extent and Arctic vessel traffic from October 2004 – September 2005. Tracks comprise commercial and research vessels >1000 dwt. Data: NSIDC and Halpern et al. (2015) [149]. (c) Exclusive economic zones and continental shelf claims in the CAO. Data: Flanders Marine Institute and GRID-Arendal UNEP Continental Shelf Programme. (d) Close-up of the Bering Strait with coastal communities, vessel traffic from 1(b), and maritime boundaries and claims from 1(c). (e) Close-up of the Fram Strait with the same features as 1(d).

Arctic Archipelago, where it tends to be thickest. As the ice disappears, new risks to shipping could arise such as increased wind speeds, wave heights, and changes to surface and subsurface currents, which could cause icebergs coming off of Greenland's ice sheet to cross Arctic shipping routes [34]. In October, the CAO will lose its ice-free status and re-cross the 1 million km^2 threshold as it refreezes. Therefore, the first ice-free date does not necessarily signal the beginning of reliable shipping accessibility along the TSR. Commercial shipping will require robust forecasts meeting more stringent criteria, such as the IPCC's definition of "nearly ice-free conditions" when sea ice extent dips below 1 million km^2 for at least five consecutive years [35], or seasonal benchmarks of 90 days or more of operational accessibility in the CAO [36]. In the near term, making such forecasts may prove challenging since sea ice variability is projected to grow substantially even as its total amount declines [37]. Nevertheless, in the long term – i.e. by mid-century and more certainly by 2100 – ice-free summers are expected to occur regularly, promising greater predictability for shipping lines.

3. Scenarios for the TSR's commercial and logistical development

Representing the shortest route between Europe and Asia, the TSR crosses 2100 NM between the Bering and Fram Straits via the North Pole and connects to shipping routes in the North Pacific and Atlantic Oceans [38]. Besides offering a more direct trans-Arctic route than the NSR or NWP, the TSR's deeper bathymetry eliminates the need for draft restrictions (Fig. 1a), which may eventually serve to boost traffic along the route [39]. The TSR could consequently enable greater economies of scale for container shipping than the NSR, whose shallow straits prohibit transits by vessels of Panamax size (drafts of 13–15 m) or larger unless they sail north of the New Siberian Islands [40]. The maximum carrying capacity of ships along the NSR (and NWP, due to similar bathymetric constraints) is ~3000–4000 twenty-foot equivalent units (TEU), resulting in higher costs per TEU compared to the Suez Canal, which can handle the world's newest and largest (>20,000 TEU) ships.

With its direct routing, deeper bathymetry, and, as we discuss in Section 4.2, lack of Russian tariffs and jurisdiction, the TSR may eventually attract Europe-Asia transit shipping away from the NSR. Still, the TSR's ability to compete with the NSR, let alone the Suez or Panama Canals, faces several obstacles. First, the TSR's potential for container shipping remains limited by a lack of intermediate markets, an issue which the NSR (first transited by a container ship, the 3600-TEU *Venta Maersk*, in 2018) also faces. Second, the continued prevalence of ice throughout most of the year along the TSR is problematic for just-in-time container shipping [41]. The TSR's near-term potential relative to other Arctic routes therefore may lie more in bulk cargoes, which are less tied to tight schedules, and Atlantic – Pacific transit shipping prioritizing the speedy delivery of goods which cannot be transported by plane, such as automobiles. Third, due to a lack of hydrographical knowledge about the TSR and its unpredictability, insurance costs in the near term will likely be higher than for the NSR and NWP [42].

Fourth and finally, much of the recent growth in Arctic shipping has been destinational, involving the transportation of cargo to Arctic locations and of resources out of the region, rather than transit, or using Arctic waterways to move cargo between two non-Arctic ports [43]. Unlike the NSR and to a lesser extent the NWP, there is presently little demand for destinational shipping along the TSR. The route directly crosses the remote CAO without passing any natural resource extraction sites or, except along the Bering and Fram Strait entrances, communities requiring resupply. In the long term, however, should fishing or extraction of resources like hydrocarbons [44,45] or methane hydrates [46] take place in the CAO, destinational shipping could take off.

Bearing in mind the opportunities, challenges, and limitations for developing transpolar commercial shipping, there exist three main logistical options for a TSR transportation system: 1) employing icebreakers to escort open water or ice-capable vessels; 2) using PC vessels, especially double acting ones which can operate in both ice-covered and open water; and 3) establishing a hub-and-spoke port system for transshipment between ice-class and non-ice-class vessels [47]. We next explore the conditions in which each of these scenarios could arise and their implications, which Table 1 summarizes.

3.1. Icebreaker escorts

Outside of summer when ice-free conditions are reached, non-ice-strengthened ships will not be able to transit the NSR unless escorted by icebreaker. Developing a TSR transportation system based on icebreaker escorts would draw on technologies and practices developed by the Soviet Union still employed along the NSR today. Russian regulations continue to mandate icebreaker escorts along the NSR regardless of ice conditions and vessel class. In 2019, state-owned Atomflot's fleet of >40 icebreakers (mostly diesel and some nuclear-powered [48]) escorted 510 vessels along the route [49]. For large vessels to efficiently transit the NSR, two icebreaker escorts are required [50]. This system is costly for shipping lines, which must pay escort fees, and the Russian government. Atomflot's fees are reportedly only enough to cover the company's direct operations, implying that the NSR may not have generated profits in recent years [51].

Given the economic challenges facing the NSR and other icebreaking systems such as in Sweden, where the public sector bears most of the costs [52], a TSR transportation system dependent on icebreaker escorts leading open water vessels would likely not be cost effective given the route's icier conditions. Another option would be to develop a TSR transportation system reliant on icebreakers escorting ice-capable (i.e. IA[2]) vessels. In the Baltic Sea, such a system has been shown to be more energy efficient, requiring less fuel and producing fewer CO_2 emissions than escorts for open water vessels [53]. Either way, developing a TSR icebreaker escort system would probably require the construction of new icebreakers, which is a lengthy and expensive process that tends to be state-sponsored [54]. Since the TSR lies largely in the high seas, the potential for any one government to manage and subsidize an icebreaker fleet is uncertain. As ships with icebreaking capabilities are likely to remain critical elements of any TSR transportation system for most of the year, one alternative to escorts would be to rely upon vessels that can break ice themselves.

3.2. PC and double acting vessels

High PC vessels, especially those with double acting technology (DAT), represent a second option for developing commercial shipping along the TSR. PC vessels are ranked in decreasing strength from "1" (able to operate in up to 4 m of ice) to "7" (up to 1.5 m of ice), followed by weaker ice-class and non-ice-strengthened open water vessels. PC vessels typically have enhancements intended to support operations in ice including strengthened hulls, higher propulsion and maneuverability, and other winterizing features [55,56]. These enhancements enable them to operate for longer periods in the Arctic ranging from "year-round operation in all Arctic ice-covered waters" (PC 1) to "summer/autumn operation in thin first-year ice which may include old ice inclusions" (PC 7) [57]. Vessels sailing in polar waters are also equipped to encounter risks such as sea ice, cold air and water temperatures, severe weather, magnetic variation, solar flares, and lengthy daylight and/or night-time conditions [12].

Currently, all PC vessels can operate independently in summer in areas of the CAO where thin first-year ice predominates. Depending on the degree of ice strengthening, summer navigation seasons for independently-operating PC vessels typically last just 1–2 months along

[2] Ice Class IA is a Baltic ice class similar to PC7, but which is not built to handle multi-year ice.

Table 1
Conditions and implications of three scenarios for the TSR's commercial and logistical development.

	Icebreaker escorts	PC vessels	Hub-and-spoke system
Timeline and feasibility	• Sufficient icebreaking technology exists, but process of building new icebreakers is lengthy • Useful for near-term TSR operations, especially outside of summer for open water vessels	• Sufficient technology (i.e. DAT) exists • Could be useful for niche cargo shipments • Likely would require expansion of global fleet of PC tankers, especially those with DAT	• Requires construction of transshipment ports, which may occur in the 2020s in Nome, Longyearbyen, and/or Finnafjord • Perhaps more economically feasible by mid-century if larger vessels transit the TSR
Economic implications	• Expensive to build new icebreakers • System may not be economically feasible, as NSR already appears unprofitable • Could result in escort fees for shipping lines	• Costly for shipping lines needing to purchase new PC vessels, but would allow avoidance of some icebreaker escort fees • Would create commercial opportunities for ice-class ship-building industry (i.e. in Finland, China, S. Korea)	• Expensive for port states • Funding arrangements could include public-private partnerships, foreign investment, or cooperation with Indigenous corporations
Political implications	• May be difficult or untenable for states to manage or subsidize in the CAO's high seas	• Direct transit voyages that do not stop could frustrate bypassed communities missing out on benefits of transpolar shipping	• Requires substantial buy-in from national governments and support from local communities in port states
	Russia may interpret their zone of jurisdiction to extend north of their EEZ to include (parts) of the TSR		
Environmental and socioeconomic implications	• Could negatively impact subsistence activities dependent on solid ice • Could disturb marine species reliant on sea ice, such as seals and other marine mammals • Nuclear icebreakers require maintenance and storage of radioactive uranium fuel • In ice-covered waters, a system involving icebreakers escorting ice-capable ships (i.e. IA) rather than open water ships would be more energy efficient (lower fuel use and CO_2 emissions)	• Ships that directly transit the TSR without stopping would not need to report their cargo, posing environmental risks • Vessels operating in ice regimes above their ice class are at increased risk for accidents and oil spills • Fuel use and emissions depend on vessel type, icebreaking capacity, and ice conditions • In thick ice, high PC (1–3) vessels may be preferable over low PC (5–7) vessels as they have shorter travel times, use less fuel and produce fewer emissions	• Port construction and dredging could harm marine ecosystems and disturb cultural and archaeological heritage • Ports could increase cost of living • Potential for new temporary and permanent jobs • Vessel activity around ports could interfere with subsistence activities • New ports could be designed to increase subsistence access • Emissions from nearby and anchoring ships could increase local air pollution (e.g. SO2, NO_x, and black carbon)

the TSR compared to 2–6 months along the NSR [9,58]. If longer seasons and/or winter operations are required, vessels classed below PC1 could conceivably operate along the TSR (or technically anywhere there is ice, though risks may be high) with icebreaker escorts. Otherwise, open water vessels are presently restricted to ice-free areas in the Barents and Bering Seas and along the NSR unless escorted by an icebreaker. They may, however, gain limited access beginning in the 2030s [59]. By 2040, high PC (1–3) ships may be able to navigate the TSR year-round [33]. Thanks to their greater ice-breaking capacity, they would also be preferable over low PC (5–7) vessels in thick ice due to their shorter travel times and consequent reduced fuel use and emissions [33].

The ongoing expansion of commercial activities in the Arctic is driving an increase in ice-class shipbuilding, which could help advance development of the TSR. Already along the NSR, oil and gas development on the Yamal Peninsula has stimulated shipbuilding, shipping, and maritime infrastructure construction [60,61]. Likewise, expanding operations at the Mary River iron ore mine on Baffin Island in the Canadian Arctic (71°N) led American company Pangaea Logistics Solutions to order four ice class IA post-Panamax dry bulk vessels from China's Guangzhou Shipyard International in 2019. Notably in November of that year, Pangaea shipped 42,000 t of ilmenite from Moriusaq, Greenland (76°N) by employing MV *Nordic Barents* [61], the very vessel which carried out the first international transit of the NSR in 2010 while delivering iron ore from Kirkenes, Norway to Qingdao, China. Further expansion of the world's fleet of ice-class vessels, including bulk carriers and tankers, could support proposed mining operations in places like northern Greenland and Canada, boosting destinational shipping via the TSR. Although Berkman et al. (2018) hypothesize that a reduction in sea ice has spurred the recent increase in Arctic shipping [62], Stephenson and Smith (2015) [59] find that access to PC6 vessels is significantly more important than accelerated climate warming in increasing the potential for trans-Arctic shipping.

The continued development of technologies like DAT, which allows ships to sail ahead in open water and astern in heavy ice, could also present new logistical possibilities for Arctic shipping even if the economics are not always immediately favorable. DAT is employed in the fleet of 15 ice-class liquefied natural gas (LNG) tankers built for the Yamal LNG project such as *Christophe de Margerie*. In August 2017, the Yamalmax tanker – graded Arc7 according to Russian standards (~PC3) – became the first unescorted tanker to transit the NSR. Aker Arctic, the Finnish engineering company which designed the tankers, has also proposed developing a "transpolar very large crude carrier" (VLCC) to deliver crude oil from Alaska's Beaufort Sea across the CAO to the nearest refinery, which happens to be in Mongstad, Norway [63]. Double acting vessels have significantly less need for icebreaker escorts. Yet as their operational costs remain high, their sailing distances should be kept to a minimum and cargo switched to conventional oceangoing vessels when possible [64]. This is one reason why transshipment facilities may be a preferred development option, especially for shipping lines, which would bear the costs of new vessels. Direct transit voyages that do not stop could also frustrate bypassed communities, which would miss out on any benefits of transpolar shipping while being exposed to greater risks.

3.3. *A Central Arctic Ocean hub-and-spoke system*

An alternative to icebreaker escorts or double acting vessels would be a hub-and-spoke system centered on the TSR. Since the 1990s, the global shipping network has shifted from direct service involving multiport calling to hub-and-spoke systems relying on transshipment, which are concentrated in East Asia, Northwest Europe, and Southeast Asia [65,66]. This reconfiguration has partly been driven by the race to achieve lower unit costs by building >20,000 TEU vessels, which not all ports can handle. While such ships are unlikely to ply the TSR anytime soon, the specialized PC vessels that will still be required in much of the CAO outside of summer could play a similar role in compelling the creation of a hub-and-spoke system. At transshipment hubs, cargo could be switched between PC vessels using the TSR and non-ice strengthened southbound open water vessels, reducing the required travel distance for the slower, costlier PC vessels.

For shipping lines, deciding between transshipment and direct routing involves weighing shipping costs (capital and operating costs, fuel, and port charges) against inventory costs [67]. When shipping costs are higher, transshipment becomes more attractive. Shipping costs for ice-class vessels are found to be 9% higher than conventional ships when operating in open water [68], which could push calculations in favour of constructing transshipment ports. While port states may be reluctant to invest in new maritime infrastructure, a turn to public-private partnerships [69] and increasing investment in the world's container ports by private companies [70] and state-supported port enterprises from countries such as China [71], Singapore, and the Gulf states may offer new mechanisms for financing a transpolar port network. Such trends are already emerging along the NSR: in 2019, Rosatom, the state nuclear energy corporation operating the route, Norilsk Nickel, a major Russia mining company and NSR customer, Russia's sovereign wealth fund, and DP World, the Dubai-based global ports operator, signed a memorandum of understanding to jointly develop the NSR [72].

As of 2020, national, state, and municipal governments in Norway, Iceland, and the U.S. have expressed interest in expanding existing ports or building new ones that could support transpolar shipping. Such developments could enable a TSR hub-and-spoke system featuring transshipment facilities at the route's two main entrances: the Fram and Bering Straits, which adjoin two of the world's primary regional hub-and-spoke systems in the Atlantic and Pacific, respectively (Fig. 1b).[3]

3.3.1. Fram Strait: Svalbard (Norway) and Iceland

The Fram Strait links the CAO to North Atlantic shipping routes and the NSR. Most potential TSR routings pass the Norwegian-administered archipelago of Svalbard, whose main port of Longyearbyen (pop. 2368) could serve as a transshipment hub. The 1920 Svalbard Treaty protects its signatories' rights to international maritime trade within the archipelago, grants all parties the right to take on and discharge passengers and cargo, and prohibits signatories from being subject to any restrictions not borne by Norway's most favored trading partners [73]. While Svalbard's location (between 74°N and 81°N) is not ideal for serving the NSR, situated halfway between Norway's north coast and the North Pole, it is well-placed with regard to the TSR and wider Arctic shipping networks [74] (Fig. 1e).

Growth in tourism and climate change research has led port calls in Longyearbyen to rise from under 200 in 2000 to more than 1500 in 2016 [74] and motivated renovations to the port, which now bears one floating and three permanent quays with drafts of 5–9 m that can accommodate ships up to 335 m long. These drafts are still shallower than the facilities required by Handymax and Panamax ships and even some of the vessels sailing along Arctic routes: the aforementioned MV *Nordic Barents* used along the NSR and recently off northwest Greenland, for instance, is a 190 m bulk carrier with an 11.5 m draft. To further expand Longyearbyen's port, the Norwegian government has allocated NOK 400 million (US$43.8 million) for a new floating dock and terminal [73], although such renovations are mostly aimed at supporting the Arctic cruise sector, once booming pre-pandemic. There is also a possibility that Norway and Russia, the latter of which dominates the nearby coal mining and port town of Barentsburg (pop. 471), could partner to develop port infrastructure, building upon their cooperation on oil spill response in the Barents Sea [75]. Finally, since all Svalbard Treaty signatories enjoy the same rights to maritime, industrial, mining, and commercial activities on land and in the archipelago's territorial waters, consortiums of states or individual ones other than Norway and Russia, such as China, could conceivably build a port on Svalbard, too – much as they have done in building scientific research stations [76].

Though nearly 1000 NM farther south of the Fram Strait than Svalbard, Iceland seeks to develop a TSR transshipment hub on the country's remote northeast coast in Finnafjord (66°N) near three fishing villages (pop. ~1300). In 2015, the Icelandic government, Icelandic engineering consultancy Efla, and German company Bremenports agreed to invest ISK 450 million (~US$3.3 million) in the planned facility, which would host an ice-free hub port entailing 6 km of quays with depths of >50 m and 1200 ha of hinterland development to support trans-Arctic shipping, a base port for Arctic oil and gas extraction, and a service port for potential offshore oil and gas and Arctic shipping industries [77]. Progress on the Finnafjord Harbour Project continued in 2019 with the establishment of Finnafjord Port Development Company, a joint venture. That year, an agreement was also signed between Efla, Bremenports, and the two local municipalities on port construction (planned from 2021 to 2023) and operations (to be maintained through at least 2040) [78]. As the TSR may not open until then, feasibility studies modeling port demand beyond that year may be worthwhile. That being said, a government-commissioned study in 2019 concluded that transshipment via Iceland was less economical than transshipment via Norway or direct shipping to Rotterdam on ice-strengthened vessels [79]. The likelihood that Finnafjord can only be competitive once very large container ships begin transiting the TSR suggests that at least until mid-century, Longyearbyen may offer a more economically viable option for a transshipment hub in the Fram Strait.

3.3.2. Bering Strait: Alaska (U.S.) and Russia

The Bering Strait links the CAO to Pacific shipping routes such as the Great Circle Route, which links East Asia and western North America (Fig. 1d). In 2004, ~2800 of the ~6000 vessels that operated in the Arctic sailed along this route [12]. A transshipment hub could be built on the American or Russian side of the 44-NM-wide Bering Strait. The Alaskan side of the Bering Strait has viable ports in the city of Nome (pop. 3866) and in Red Dog, the world's largest zinc mine.[4] Port Clarence, a former U.S. Coast Guard Long Range Navigation (LORAN)-C Station 100 km to Nome's northwest, has also been evaluated as a potential site for port construction [80], but an economic feasibility study determined it to have low revenue potential from local and Bering Strait vessel traffic [81]. Farther south, a handful of ice-free deepwater ports in the Aleutian Islands could also serve as TSR transshipment hubs. Though 700 NM from the Bering Strait, the Port of Dutch Harbor in Unalaska (pop. 4376) has docks with depths of 9–15 m and is situated on the Great Circle Route. So, too, is the Port of Adak (pop. 326), for which the State of Alaska funded a US$50000 transshipment feasibility study in 2005 [82]. The port is managed by the Aleut Enterprise Corporation, a subsidiary of the Alaska Native Aleut Corporation [83]. Aleut corporate officials have sought partners seeking to invest in Arctic maritime development and cooperate with Indigenous Peoples, such as, perhaps surprisingly, Singapore [84].

Recent developments suggest that Nome, whose municipal government has examined the possibility of turning the city into a CAO shipping hub [85], may be Alaska's likeliest contender for a TSR transshipment hub. The city's port already serves as the staging ground for seasonal ice-free operations north of the Bering Strait and as a transshipment hub for 54 communities in western Alaska. In June 2020, the U.S. Army Corps of Engineers approved a US$618 million plan to increase the port's outer basin from 6.7 m to 8.5 m and dredge a new deepwater basin of 9–12 m: depths similar to Longyearbyen, but shallower than Finnafjord. As of August 2020, the plan awaits approval from the U.S. Congress.

[3] Two less relevant entrances for shipping from North America's east coast along a shorter routing of the TSR would be through the NWP and the Nares and Davis Straits, which have historically been ice-clogged.

[4] Kotzebue, while often mentioned as a potential port, is too shallow to accommodate large vessels. Even resupply can prove challenging.

On the Russian side of the Bering Strait, there are ports in Provideniya, Anadyr, Evgenikot, and Beringovsky [86]. The port of Provideniya (pop. ~2000) is deeper than Nome's, with depths of 9 m near the berths and 30–35 m in the bay [87], and already has oil spill response equipment [48]. While Provideniya serves as the NSR's eastern gateway, more improvements are required to enhance its capacity for operations along that route, not to mention the TSR. It is unclear if the Russian government intends to invest further in Provideniya's facilities or those of its other three Bering Strait ports. The Kremlin's plan from 2017 to 2024 to develop Arctic sea ports concentrates on the NSR's western section [88], where hydrocarbon and mineral extraction is accelerating. For the time being, momentum within the Bering Strait for building infrastructure to support the TSR appears stronger on the Alaskan side.

In the very long term, as sea ice conditions change, the ideal sites for transshipment ports could, too. As one example, a model calculating the optimal locations for transshipment hubs in a world in which the NSR and NWP were open year-round determined that the Bering Strait, Dikson (Russia), and Arctic Bay (Canada) were among the top 12 sites worldwide [89]. The model did not include the TSR, however, nor did it account for (geo)political interests in port construction – both of which are critical considerations when envisaging the future of Arctic shipping.

4. Geopolitics and governance of the TSR

One of the TSR's main purported advantages is that in the absence of ice, it offers a navigationally and politically simpler alternative to the NWP and NSR [14]. Yet the governance and geopolitics of the TSR remain complex. The opening of a route previously plied only by submarines and icebreakers may affect relations between governments both within and outside the region, especially maritime states. In what follows, we address three geopolitical concerns regarding the TSR: international governance, Russia, and China.

4.1. International governance: UNCLOS, the IMO, and the Polar Code

Trans-Arctic shipping is regulated by a mix of international and national regulations [90]. Unlike the NWP, which Canada claims as internal waters [91], and the NSR, along which Russia de facto controls navigation of foreign vessels [92], the TSR crosses the high seas, where international regulations apply. Chief among them are the United Nations Convention on the Law of the Sea (UNCLOS 1982) and the International Maritime Organisation's (IMO) Polar Code (2017). UNCLOS governs use of the oceans, including the high seas, which constitute 4.7 million km^2 of the Central Arctic Basin [38]. UNCLOS Article 87 allows all states the use of the high seas for freedom of navigation, overflight, laying submarine cables and pipelines, constructing artificial islands and other installations permitted under international law, fishing (subject to conditions), and scientific research. The TSR's opening in the 2030s or 2040s could facilitate the development of several of these maritime activities, especially fishing. The 2018 Fisheries Agreement initially prohibits commercial fishing in the CAO until 2034[5], meaning an extension would be considered just a few years before the earliest predictions of a seasonally ice-free Arctic Ocean.

Surrounded by continents, the Arctic is unique among the world's oceans in having just one high seas point of access: the Fram Strait between the Greenland and Norwegian Seas (Fig. 1e).[6] Shipping regulations are relatively more complex within the Bering Strait separating Russia and the U.S. Generally, it is considered a strait used for international navigation, defined as connecting one part of the high seas or a state's exclusive economic zone (EEZ), which extends up to 200 NM out from a country's baseline, with another part of the high seas or EEZ [90]. Vessels consequently enjoy the right of transit passage under UNCLOS Article 37. The Bering Strait's two main navigational channels pass through the territorial seas of Russia (to the west of its Big Diomede Island) and the U.S. (to the east of its Little Diomede Island). Since Article 42 allows states bordering international straits to adopt regulations pertaining to maritime traffic and pollution prevention so long as they do not impede the right to transit, vessels crossing U.S. and Russian waters may be subject to differing laws at various points during their journeys. Vessels not in transit generally hew to one side or the other of the maritime boundary (Fig. 2). The U.S. and Russia, motivated by their observations of decreasing sea ice and increasing economic activity in the region, have established a two-way shipping system through the narrow Bering Strait to improve navigation safety and protect the environment [93]. In 2018, the IMO approved the two countries' joint proposal to implement six two-way routes, six precautionary areas, and three areas to be avoided in the Bering Sea and Bering Strait, which took effect later that year.

Depending on its routing, the TSR may also cross the EEZs of Canada, Greenland (Denmark), Norway, and Iceland. Article 58 grants all UNCLOS signatories the aforementioned rights of Article 87 in other countries' EEZs, including navigation. The boundaries between all but four of the five EEZs of Arctic Ocean coastal states have been delimited [94]. The only outstanding dispute, between the U.S. and Canada over a 6700-NM^2 "wedge" in the Beaufort Sea [95], does not overlap with the TSR. Navigation along the TSR should also remain unaffected by the competing claims submitted by Canada, Russia, and Denmark to the UN Commission on the Limits of the Continental Shelf to extended continental shelves in the CAO, each of which includes the North Pole (Fig. 1c).[7] As the waters over extended continental shelves constitute the high seas, they will remain free to navigate regardless of how the claims are resolved. Nevertheless, in the case of an emergency or shifting ice conditions, a vessel may have to enter the waters of an Arctic coastal state, potentially falling under national regulations [96].

Less certain are the impacts of climate change on UNCLOS Article 234, which allows coastal states to "adopt and enforce non-discriminatory laws and regulations for the prevention, reduction and control of marine pollution from vessels" in areas that are covered in ice "for most of the year" [97] within their EEZs. Whether and how the reduction of sea ice will affect the applicability of Article 234 remains debated [98,99]. Assuming it stands despite ice melt, ships sailing along the TSR may have to adhere to varying environmental regulations, some potentially stricter than others, depending on the EEZ in which they are sailing.[8] One additional regulatory scenario is that if Norway were to transform the already-disputed Svalbard Fisheries Protection Zone into an EEZ [100], the country could move to implement Article 234 around the archipelago [101]. Demonstrating the government's increasing regulation of the waters around Svalbard, in 2019, it announced that it is considering expanding an existing limited ban on heavy fuel oil (HFO) and more tightly regulating ship size and disembarkment procedures in protected areas [102].

The IMO's International Code for Ships Operating in Polar Waters (Polar Code 2017), which mandates precautions like a Polar Ship Certificate and careful voyage planning to ensure safety at sea and pollution prevention, covers the TSR.[9] The organization's binding framework regulating Arctic and Antarctic shipping evolved from the initially voluntary Guidelines for Ships Operating in Polar Waters first adopted in 2009. The Polar Code comprises a series of amendments to existing IMO conventions including the International Convention on the Safety of Life

[5] If parties agree, automatic five-year extensions will take place.

[6] The Arctic Ocean's other three entrances cross the EEZs and territorial seas of the U.S. and Russia in the Bering Strait; of Canada and Greenland (Denmark) in the Nares Strait leading to the Davis Strait; and of Canada in the NWP.

[7] While Norway and Iceland have also submitted claims to extended continental shelves, these do not extend into the CAO.

[8] See Henri Féron's 2018 article on legal issues in the Arctic Ocean [147] for further discussion.

[9] Elements of the Polar Code may conflict with Article 234 [148].

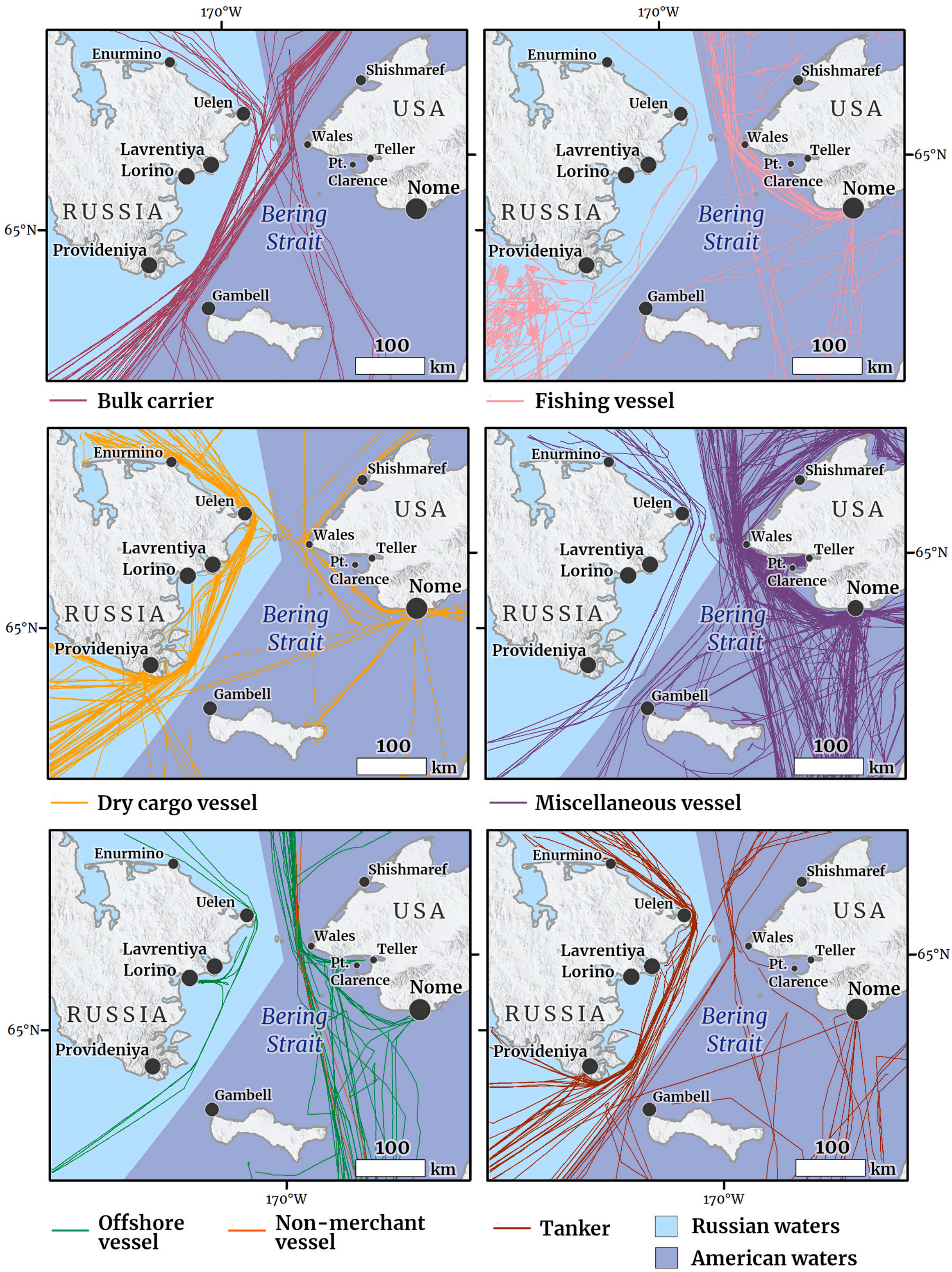

Fig. 2. AIS shipping voyages in the Bering Strait (January–December 2012). Data: exactEarth, SNAP, WCS, and ABSI.

at Sea (SOLAS 1974/1988) and the International Convention for the Prevention of Pollution from Ships (MARPOL 1973/1978). This regulatory evolution underscores the standardization and formalization of polar shipping and the expansion of the sector's "pluralistic governance" involving both Arctic coastal/port states and flag states [103].

Currently, no additional requirements apply to shipping within the CAO vis-à-vis the rest of the Arctic. To better protect the CAO, however, various measures could be enacted including the establishment of MARPOL Special Areas, Particularly Sensitive Sea Areas, Marine Protected Areas, or an emissions control zone similar to those in the Baltic

Sea and off the coasts of the U.S [104]. Stricter regulations regarding ballast water, anti-fouling paint, ship routing, and reporting systems could also be mandated [105]. Ultimately, enforcement of the Polar Code and other regional soft-law instruments like the Arctic Council's 2011 Search and Rescue Agreement and the 2013 Agreement on Cooperation on Marine Oil Pollution Preparedness and Response depends on Arctic port state control, or governments' willingness and capacity to inspect foreign-registered vessels [106]. While a key attraction of the TSR for the shipping industry is that it largely transits international rather than internal waters, this very reason hinders enforcement of environmental regulations. Indeed, since ships transiting Arctic waters do not need to report their cargo to countries where they do not call, as a 2010 Arctic Council report asserted, "The greatest risk to the Arctic comes not from traffic originating or ending in the Arctic region, but from shipments that are simply passing through Arctic waters" [107].

4.2. National governance: Russia

With its established legal framework for the NSR and large fleet of icebreakers – among which *50 Let Pobedy* provides the world's only tourist cruises to the North Pole each summer – Russia is strongly positioned to offer its expertise and services along the TSR. Yet unlike along the NSR, shipping lines are not legally obligated to avail of them. The TSR is situated farther north than the northernmost extent of the NSR, which Russian federal law asserts falls entirely within the country's EEZ, territorial sea, and internal waters [92,108]. Nevertheless, with some Russian scholars emphasizing the "leading role of Arctic coastal States in specifying [the] legal regime of Arctic marine regions" [99], the Kremlin could still attempt to influence regulation of the TSR. In what would represent a highly controversial move, Russia could also consider enforcing national transit regulations in the high seas adjacent to their EEZ through which parts of the TSR run, for example in the waters within its claimed extended continental shelf. Yet equally, a slightly longer routing of the TSR could be devised to circumvent Russia's EEZ and its extended claim (Fig. 3).

The Russian government has already dissented from the seven other Arctic states in discussions over regional shipping regulations. During February 2020 IMO meetings on amendments to the Polar Code, unlike its Arctic counterparts, Russia (along with China and Saudi Arabia) preferred a delayed rather than immediate ban on HFO in the Arctic [109]. This Sino-Russian alliance in Arctic policymaking, which could spill over to governance of the TSR, reflects the two countries' strengthening relationship, with Russia relying on China to invest in and import its natural resources [110,111].

Russia's opposition to an immediate HFO ban also highlights the sector's economic importance to the country, which the TSR's opening could undercut. A 2010 report by Det Norske Veritas, a Norwegian classification society, described "the currently untenable and future uncertain fee level" associated with shipping through the NSR and consequently examined the potential of a route "designed to lead vessels mostly outside the Russian EEZ" but south of the North Pole to avoid thick sea ice [16]. As ice avoidance becomes less of a concern with climate change, shipping lines may select routes that minimize distance rather than ice avoidance, possibly making routes north of the NSR and

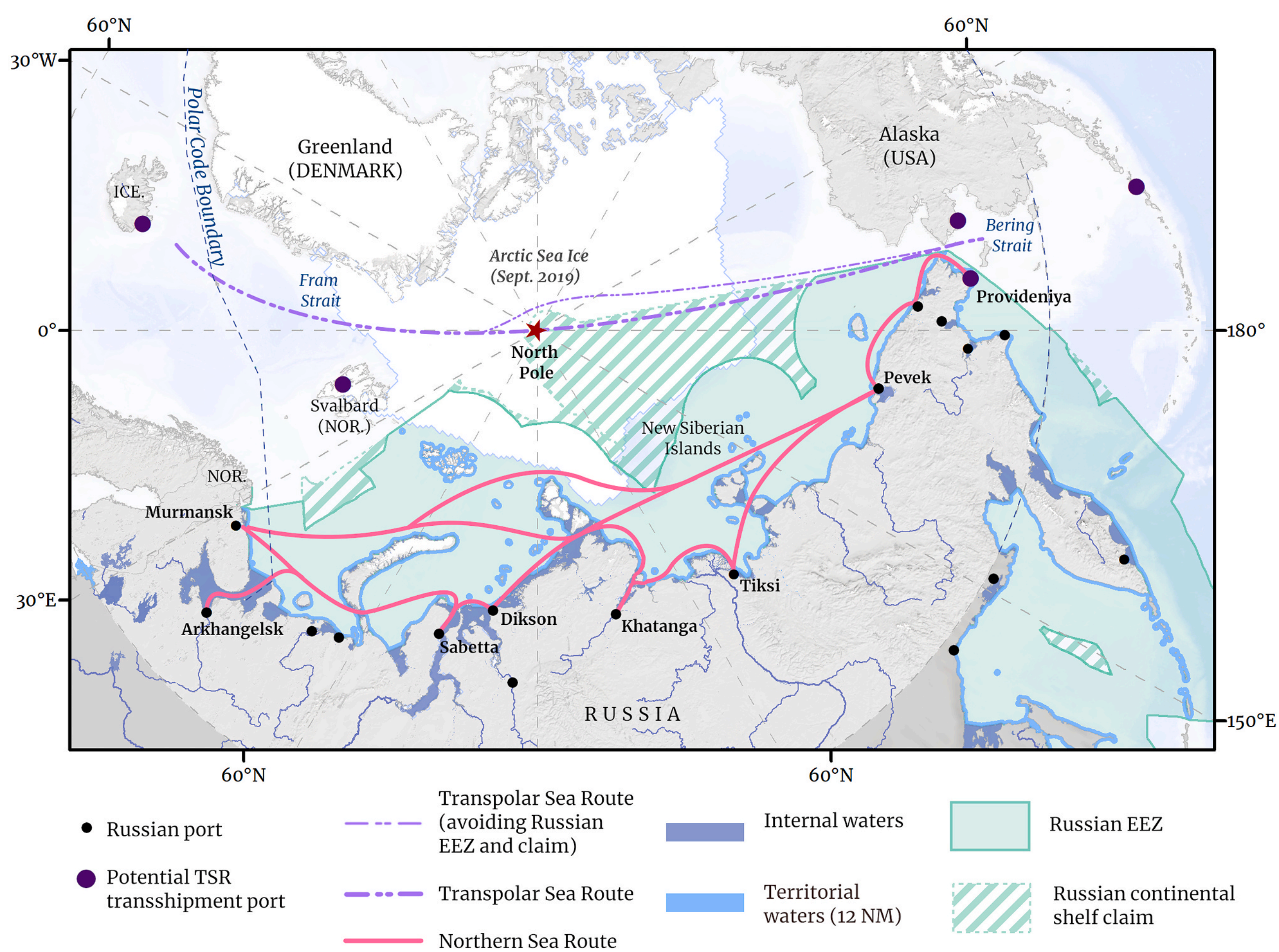

Fig. 3. The Northern Sea Route and Transpolar Sea Route in relation to Russia's EEZ and extended continental shelf claim.

eventually the TSR itself more attractive [9]. The Russian government could then encounter difficulties in attracting transit shipping to the NSR. Incidentally, if ships do shift northward towards the TSR, this could reduce risks to Russia's coastal environment and the Indigenous Peoples who rely upon it.

4.3. National governance: China

Since the early 2000s, China's commercial and scientific activities in the Arctic Ocean have expanded [112,113]. The country's Arctic Policy released in 2018 emphasizes, "China attaches great importance to navigation security in the Arctic shipping routes. It has actively conducted studies on these routes and continuously strengthened hydrographic surveys with the aim to improving the navigation, security and logistical capacities in the Arctic" [114]. A proliferation of studies on Arctic shipping by Chinese scholars demonstrates the country's rapid build-up of expertise [115–118]. Since 2013, Chinese state-run shipping line COSCO has sent cargo vessels, heavy lift ships, and container ships to pioneer test voyages of the NSR, which 13.4% of Chinese trade could use by 2030 [119]. The motivations for these surveys, expeditions, and commercial activities may partly stem from China's apparent need to explore the maritime Arctic as broadly as possible in order to credibly participate in regional affairs, since a more limited geographic scope might make the state look less capable as an Arctic actor. In contrast, as Arctic territorial states, Russia and Canada can more solely focus on the NSR and NWP, respectively, without undermining their legitimacy as regional stakeholders.

Recently, Chinese officials and academics have begun to pay attention to the TSR, arguably more than other maritime states. China's interest in the forthcoming route may be reinforced by the government's lengthy time horizons [120], which significantly outlast the average maximum policymaking time horizon of 30 years [121] that likely applies to most Arctic states. Two Chinese scholars suggest, "Although the Central Passage does not open for commercial navigation due to sea ice in the central region of the Arctic Ocean, with the complete melting of the Arctic Ocean ice in decades, the strategic value of the Central Passage will be fully revealed, and China must take precautions" [122]. The Chinese government already appears to be doing so: to the best of our knowledge, China is the only country to have led official expeditions of all three Arctic shipping passages, including the TSR. In 2017, during an 83-day, 20000-NM voyage, China's Ukrainian-built icebreaker, MV *Xue Long* (built in 1990 for Soviet logistics and resupply along the NSR, purchased by China in 1994, and rebuilt there in 2007 to support polar research and logistics) sailed via the TSR en route to the NWP.[10] Chinese state media heralded this journey as the country's first crossing of the CAO [123]. Two Chinese scholars similarly extolled, "China's eighth Arctic expedition team crossed the Central Passage for the first time by icebreaker *Xuelong*, successfully opening a new sea route linking Eurasia" [122]. The following year in 2018, China launched its first domestically built icebreaker, MV *Xue Long 2*. The PC3 vessel can navigate throughout the CAO in summer and embarked on its first expedition to the area in July 2020.

Both China's Arctic Policy and publications by Chinese scholars posit that the TSR forms an integral part of a future Arctic shipping network, one that China seeks to help develop. China's Arctic Policy explains, "The Arctic shipping routes comprise the Northeast Passage, Northwest Passage, and the Central Passage," and affirms that the country "hopes to work with all parties to build a 'Polar Silk Road' through developing the Arctic shipping routes" [114]. This description represents a more expansive vision of the Polar Silk Road (PSR) compared to its initial conception as a more eastward-focused version of the NSR that Russia and China would develop together [124,125]. The PSR is intended to form one of several corridors within China's Belt and Road Initiative, a multitrillion-dollar plan to enhance trade and transportation routes between China and markets and resources in Eurasia, Africa, and beyond. Certain Chinese officials may hold even greater ambitions for the PSR: Yao Zhang, director of the Center for Maritime and Polar Studies at the Shanghai Institutes for International Studies, an influential state-run Chinese think tank, suggested that the "Ice Silk Road" (another name for the PSR) could represent "a new direction for future governance and cooperation" that helps avoid "bottlenecks in regional governance and cooperation" [126]. Such statements indicate that while the Chinese state and associated entities officially support the existing international laws undergirding Arctic shipping governance, as the country's Arctic activities grow, some representatives may be willing to point out perceived shortcomings. At the same time, the admission of China and four other Asian states as Arctic Council observers in 2013 and the participation of China, Japan, and South Korea in negotiations regarding the 2018 Fisheries Agreement illustrates their integration into existing regional governance structures, even as these still give primacy to Arctic territorial states [127].

5. Environmental and socioeconomic impacts of transpolar shipping

Should regular commercial use of the TSR and the wider CAO commence, shipping will likely generate environmental and socioeconomic impacts at a range of scales that will be most acute near coastlines. Localized externalities from shipping that could disturb Arctic marine environments include vessel oiling, air pollution, noise, collisions, icebreaker-induced habitat disruption [128], and the introduction of invasive species [13]. Ecologically sensitive places along the TSR like Svalbard already face heightened risks of oil spills and air pollutants like SO_2, NO_x, and black carbon due to an increase in vessel traffic [129,130]. Svalbard's Heavy Oil and Traffic ban restricts the use of HFO for ships sailing through the archipelago's three largest national parks, all near Longyearbyen, but the tar-like fuel is still allowed in an open-water channel through the fjord connecting the port to the Greenland Sea. Following the aforementioned IMO discussions, it looks likely that HFO will be banned across the Arctic from 2029, as it already is in Antarctic waters under the Polar Code. This may reduce risks from HFO-related spills and atmospheric pollution before the TSR opens. As vessels approach the mid-point of the TSR near the North Pole, they will pose fewer risks to coastal ecosystems and communities. Yet search and rescue and spill response capacities will be severely limited, meaning the impacts of a disaster could be harder to immediately contain than if it were to occur nearshore. The settlement closest to the North Pole – Alert, Canada (pop. 62) – is still 441 NM away, with only an airfield manned by the Royal Canadian Air Force and no port due to persistent sea ice.

Shipping via the TSR could deliver certain benefits to people living in communities along the route's entrances in the Fram and Bering Straits, such as temporary or permanent job creation relating to port construction and operations and greater availability of goods. Yet the industry also poses risks to socioeconomic and cultural well-being. In Svalbard, residents express frustration with existing levels of tourists and cruise ships [74]. Shipping-induced strains on the environment and society are perhaps more severe for Indigenous Peoples in the Bering Strait, where the Chukchi, Iñupiat, and Yupik peoples still rely on the marine environment for subsistence [131]. During a workshop in Nome held in 2014 by Kawerak, Inc., the non-profit division of the Bering Straits Native Corporation, one participant explained, "Our ocean is like our savings account" [132]. Shipping could disturb or lead to the loss of sea mammals, threatening food security. As Norman Menadelook, a Bering Sea Elder from the village of Teller on Port Clarence Bay, remarked, "This spring there were container ships passing through the migrating route for walrus and interfering with our 'Eskimo sonar' – the way we stick an oar in the water and listen for the walrus. All you could hear is the engine. Ships were too close this spring" [133]. Activities relating to

[10] This was not the first time *Xue Long* sailed near Canada. In 1999, the vessel unexpectedly visited Tuktoyaktuk, a coastal village of 900 people.

Iceland's proposed Finnafjord port could similarly disturb fishing activities based out of nearby villages, while its planned 1200-ha hinterland could affect land-based activities like farming. Finally, across the Arctic, port construction could threaten cultural and archaeological resources and result in increased costs of living.

Places with a history of shipping activity, such as Longyearbyen, have been shown to be able to develop local institutional and regulatory responses to mitigate the industry's impacts [134]. Yet local capacity can and should be built *before* ships begin to dock through a variety of means including integrating traditional and Western knowledge, training villagers in Arctic search and rescue, establishing community harbor safety committees, and providing for subsistence use within expanded ports, such as by ensuring access for small skiffs [132,135,136]. Capacity building could empower local communities and give them not only a stake in the TSR, but a degree of control over it, too. An effort in this vein to establish Tribal co-management in the Bering Sea through the enactment of the Northern Bering Sea Climate Resilience Area by former U.S. President Barack Obama in 2016 [137], however, was reversed by the Trump administration, demonstrating that including Indigenous People within American federal policymaking remains contentious. Even when Indigenous concerns are considered, they are often trivialized: the U.S. Army Corps of Engineers found that expanding the Port of Nome would have "no significant impact," which Kawerak, Inc. strongly disputes [136].

A lack of support from national governments for empowering local and Indigenous communities might seem to subvert their ability to influence the global shipping industry and foreign governments interested in developing Arctic ports and waterways. But the wider Arctic governance community increasingly recognizes the importance of working with Indigenous Peoples. Six Indigenous Peoples' organizations are included within the Arctic Council as Permanent Participants. One of the most active, the Inuit Circumpolar Council, lobbied for the ban on HFO at the IMO and has applied for observer status in the organization. Two Asian maritime states, Singapore and South Korea, have partnered with the Permanent Participants [138]. For instance, the Korea Maritime Institute funded and collaborated with the Aleut International Association on the Arctic Marine Indigenous-Use Mapping (AMIUM) project under the auspices of the Arctic Council's Protection of the Arctic Marine Environment (PAME) Working Group. AMIUM's goal is to produce a tool allowing Indigenous communities to create "scientifically justifiable maps of marine use" [139], and the project's coordinators seek to expand beyond the Aleutian Islands across Alaska, Russia, Canada, and Northern Europe. Such efforts would establish a standardized record of Indigenous activities in Arctic marine areas before commercial shipping along the TSR develops further.

While the localized impacts from TSR shipping and port development may be salient, the regional and global impacts of commercial Arctic shipping appear relatively less so. By 2050, the entire Arctic shipping industry is predicted to contribute less than 1% of black carbon deposited north of 60°N [140]. Shipping via the TSR may even reduce Arctic warming by 1°C as sulphur oxide emissions from ships lead to an increase in clouds [141]. Yet given the paucity of research and coordination at regional and cross-boundary scales in the CAO [142], more work is required to understand and plan for the impacts of shipping via the TSR and other related environmental, economic, and geopolitical processes, too. The opening ocean is leading sea ice to move at increased speeds across Arctic states' EEZs, potentially exacerbating cross-boundary pollution [143]. As not just a new shipping route but an entirely "new biome" arises [143], complex issues will require creative regulatory solutions and robust regional cooperation. Representing a start, PAME is tackling issues relating to the CAO and TSR at a regional scale through initiatives such as the Integrated Ecosystem Assessment for the CAO, the Arctic Ship Traffic Data project, and the Arctic Shipping Best Practice Information Forum. Lessons from how the Arctic Council partners with Indigenous Peoples could also inform the development of an inclusive approach to governance in the high seas and areas beyond national jurisdiction that leverages their knowledge of transboundary phenomena like species migration to craft policies and management practices that will arguably impact them, as traditional residents and users of these waters, more than anyone else [144].

As recognition of the negative impacts of Arctic shipping across a range of scales grows, shipping lines and consumer goods companies are increasingly opting out of the industry. Corporations like CMA CGM, Evergreen, Hapag-Lloyd, Mediterranean, H&M, and Columbia have committed to refrain from using Arctic routes for global transshipment by signing the "Arctic Shipping Corporate Pledge" spearheaded by the Ocean Conservancy, an environmental non-governmental organization, and Nike in 2019. The pledge's popularity parallels recent decisions by several investment banks to not invest in Arctic oil and gas projects, much to the consternation of Alaska Native politicians and businesses with industry stakes [145]. As more corporations with international influence decline to participate in the Arctic's maritime and extractive industries, this may diminish Arctic shipping's commercial viability. The private sector's withdrawal could also lead to a preponderance of the public sector, especially state-backed shipping lines and terminal operators, in promoting and developing the TSR. Either way, refusal to partake in trans-Arctic shipping may undermine efforts to make certain that, if the industry develops, it does so sustainably and equitably. Indigenous communities and organizations often recognize that subsistence and economic development can be balanced. Should the TSR take off, ensuring that subsistence activities can continue safely alongside global shipping will require not the abstention of global corporations, but rather the inclusion of local and Indigenous people, knowledge, and needs in policymaking.

6. Conclusion

The CAO may be ice-free in summer as soon as the 2040s, setting in motion the seasonal opening of the TSR. Even if this sea change does not immediately reconfigure global shipping networks, already perceptible increases in the region's economic activity suggest that preparations are in order. As open water replaces the ice that has shaped northern livelihoods and environments for millennia, local communities, national governments, and international policymakers will need to reckon with the consequences of a seasonally navigable polar sea. For several decades, international organizations like the UN, IMO, and Arctic Council and national governments like those of Russia and Canada have established norms and practices enabling Arctic peoples and coastal states to accommodate different uses of northern waters. The opening of the CAO and TSR will test the flexibility and responsiveness of these regimes, particularly as extraregional maritime states seek to exert influence, too.

Within a policymaking timeframe, there is still ample room to consider emerging commercial, logistical, geopolitical, environmental, and socioeconomic issues. First, the lack of intermediate markets and the continued existence of sea ice outside of summer will challenge the regularization of shipping across the North Pole, particularly container shipping. But over time, the opening of seasonal navigation along the TSR may encourage the development of an icebreaker transportation system, the use of PC vessels (especially double acting ones), or a hub-and-spoke system with transshipment ports along the two main entrances in the Fram and Bering Straits. Longyearbyen and Nome appear the most likely candidates for building deepwater ports that could accommodate ships seeking to leverage the TSR's more direct routing and deeper drafts compared to the NSR and NWP. Apart from climate change, an expansion in the world's ice-class fleet could also boost opportunities for shipping and resource development across the CAO.

Second, the TSR may seem to offer a geopolitically straightforward alternative via the high seas compared to the internal waters of Russia's NSR and Canada's NWP. Yet the TSR also crosses six countries' EEZs and territorial waters, which complicates its regulatory environment. The IMO Polar Code applies, and UNCLOS Article 234 still does as well. Russia, given its experience in managing the NSR, may seek to influence governance of the TSR. China, capitalizing on its efforts to develop the PSR and experience navigating all three polar routes, may play a pivotal role in the TSR's commercialization and perhaps its governance, too. Despite these complexities, the international regulatory framework for shipping across the CAO appears robust, with the region's coastal states still dominating policymaking while increasingly including other maritime states, especially Asian ones, in negotiations.

Third, the environmental and socioeconomic impacts of the TSR will be more acute at local rather than regional or global scales. While the shipping route promises new avenues for economic development, it may jeopardize the health of coastal ecosystems and vitality of subsistence activities. Although the CAO is uninhabited, thousands of people live in communities along the Bering Strait, in Svalbard, and in northeast Iceland where transshipment ports may be constructed and where large vessels could one day dock. Particularly along the Bering Strait, commercial shipping threatens subsistence whaling, sealing, and fishing. Empowering Indigenous and local communities to exercise stakeholder rights and participate in maritime policy forums for Arctic shipping while minimizing the industry's negative impacts – and, if possible, finding a way that development of the TSR could provide tangible benefits – is crucial.

Climate change and an expansion of the world's ice-class fleet may fail to be game-changers for the TSR. Yet regardless of the ultimate extent of the TSR's commercialization, the moment at which the Arctic becomes ice-free will mark a profound turning point in human and environmental history. As warming and melting accelerate, regions like the Arctic that "had for centuries dramatized the fragility of human life have, in a few short decades, been refigured as representing the earth's profound vulnerability to collective human agency" [146]. The increasing accessibility of the TSR epitomizes the ambivalence of changes to the Arctic in the Anthropocene. While the opening of a truly trans-Arctic shipping route is a symbol of mankind's greater freedom of navigation, it also presents a stark reminder of the social and environmental costs of this freedom, the conditions that have given rise to it, and the sudden transience of a long-frozen region.

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CRediT authorship contribution statement

Mia M. Bennett: Conceptualization, Writing - original draft, Writing - review & editing, Visualization. **Scott R. Stephenson:** Writing - original draft, Writing - review & editing, Formal analysis. **Kang Yang:** Writing - review & editing. **Michael T. Bravo:** Writing - review & editing. **Bert De Jonghe:** Writing - review & editing.

Declaration of competing interest

None.

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