Research Report

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The Future of Maritime Presence in the Central Arctic Ocean

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About This Report

In this report, we explore how global actors may leverage new maritime access in the Central Arctic Ocean for economic, political, and military purposes. We examine current and potential future maritime use of the ocean by Arctic states and global actors. We then present a scenario in four phases of how the ocean and these maritime activities could develop over time.

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Summary

The Arctic is warming nearly four times faster than the rest of the world. Climate models project that the Arctic Ocean will become ice-free in summer for a limited window of time over the next ten to 30 years, opening a seasonally navigable route connecting Asia to Europe by crossing over the North Pole.[1] A seasonally ice-free Central Arctic Ocean (CAO) will enable maritime commercial activities to take place farther north than ever before. Trans-Arctic shipping traffic may gradually move into ice-free international waters, tourist visits to the North Pole may become increasingly common, and fishing activity may also migrate north. Uncertainty over how Arctic states may respond to these and other consequences of increasing marine access suggests the possibility of an expanded surface military and law enforcement presence in the CAO in the future. Global actors may increasingly seek to expand presence and exert influence in this rapidly evolving strategic, commercial, and legal environment, potentially affecting the security of the United States and other Arctic states.

In this report, we examine current and potential future maritime use of the CAO for commercial and security or military activity and present a scenario in four phases of how these activities could plausibly develop in the CAO over time. Drawing on insights from climate models, literature, and expert interviews, we address the following three research questions: What factors could drive or inhibit increased use of the CAO? What would these activities look like, and during which time horizons might they be possible? Which state and nonstate actors might be the first movers or main beneficiaries of this new or increased activity in the CAO?

Findings

A key finding from this report is that activities in the CAO will not be everything all at once. For instance, fishing will not occur before at least the end of the Central Arctic Ocean Fisheries Agreement fishing moratorium in 2037. Cargo shipping will not occur in significant volumes before there is reliable access for at least two months at a time. Mining will develop incrementally. Future activity in the CAO will thus happen in a staggered way, with new activities gradually piling up on top of one another and some taking place together (for instance, increased shipping and increased search-and-rescue presence and capacity).

Accordingly, the scenario developed from our analysis describes the following four successive phases of activities that we expect to be possible for a given period of reliable access to the CAO: limited activity in the CAO (2025–2034), a theoretical opening of the CAO to fishing (2035–2049), the emergence of the Transpolar Sea Route as a seasonal alternative to traditional shipping routes

[1] Alexandra Jahn, Marika M. Holland, and Jennifer E. Kay, "Projections of an Ice-Free Arctic Ocean," *Nature Reviews Earth & Environment*, Vol. 5, No. 3, March 2024.

(2050–2059), and a sustained summer presence in the CAO by a variety of actors (2060s and beyond).

Additional findings are as follows:

- The most plausible scenario for maritime use of the CAO in the next 25 years is one of limited activity, consisting mainly of some seasonal shipping and tourism.
- There are still major uncertainties about the future environment of the CAO, such as the likely species mix and volume of future fish stocks and the pace of technological advances needed for oil, gas, and mineral exploitation.
- Reliable access to the CAO does not mean safe navigation in the CAO because of hazards, such as moving ice floes and storms, that will continue to be present even as overall sea ice declines.
- Increased activity in the CAO from beyond the Arctic will mean that new actors will also be entering Arctic state exclusive economic zones and even territorial waters, increasing the risk of security and safety hazards close to shore.
- When activities develop in the CAO, the actors best positioned to be first movers will be those that have already planned and developed the capacity to operate in this region because ice-capable assets will be necessary to sustain a meaningful presence in the CAO, whether for commercial, safety, or security purposes.
- In addition to Arctic states, non-Arctic actors, such as China, the European Union, Japan, and South Korea, are signaling that they have strategic or economic stakes in the CAO, which could justify significant allocation of resources for building capacities in Arctic-capable infrastructure.
- Not every state stands to gain equally from the opening of a commercially viable CAO. Russia would be seriously affected by the creation of a direct competitor to the Northern Sea Route, which it has sought to develop and promote as a seasonal trade route between Asia and Europe.
- The risk of resource-driven geopolitical conflict in the CAO is limited, although accidental escalation is always possible.
- The scenario examined here supposes the absence of a major disaster, such as a cruise ship accident or oil spill, that could significantly alter the likelihood of any of these activities durably expanding in the CAO.
- Therefore, sustained activity in the CAO will depend on a robust presence of search and rescue and disaster response provisions, neither of which is currently in place.

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Chapter 1

Introduction

The Arctic is warming nearly four times faster than the rest of the world.[2] Climate models project that the Arctic Ocean will become ice-free in summer for a limited window of time over the next ten to 30 years and possibly sooner, opening a seasonally navigable route connecting Asia to Europe by crossing over the North Pole.[3] Unlike other Arctic routes—such as the Northern Sea Route (NSR) along Russia's coast, or the Northwest Passage (NWP) along Canada's coast—this route, which can be referred to as the *Transpolar Sea Route* (TSR), will mainly cross through international waters that have only seen extremely limited military, scientific, and touristic uses to date.[4]

Although symbolically significant in its own right, the TSR represents a broader geophysical phenomenon: the opening of the Central Arctic Ocean (CAO) to seasonal commercial and surface military activity. The *CAO* is defined as the part of the Arctic Ocean that consists only of international waters (also called *high seas*) and is surrounded by the exclusive economic zones (EEZs) of Canada, Denmark (through Greenland and the Faroe Islands), Norway, Russia, and the United States (Figure 1.1). These EEZs are located either in the peripheral parts of the CAO or in its marginal seas (such as the Greenland Sea or the Kara Sea). The CAO comprises 2.8 million square km—about the size of Argentina.[5] The CAO has historically been entirely or nearly covered in ice year-round. Yet in 2024, Arctic sea ice extent shrank to 4.28 million square km in September, the month when Arctic sea ice reaches its annual minimum. Although the CAO remained ice-covered, 2024 ranked as the seventh-lowest September sea ice extent on record, and the lowest 18 Arctic sea ice extents were recorded in the past 18 years.[6]

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[2] Mika Rantanen, Alexey Y. Karpechko, Antti Lipponen, Kalle Nordling, Otto Hyvärinen, Kimmo Ruosteenoja, Timo Vihma, and Ari Laaksonen, "The Arctic Has Warmed Nearly Four Times Faster Than the Globe Since 1979," *Communications Earth and Environment*, Vol. 3, 2022.

[3] The scientific definition of *ice free* is generally accepted to be the state when sea ice extent (the area with at least 15 percent ice concentration) drops below 1 million square km (Alexandra Jahn, Marika M. Holland, and Jennifer E. Kay, "Projections of an Ice-Free Arctic Ocean," *Nature Reviews Earth & Environment*, Vol. 5, No. 3, 2024; Céline Heuzé and Alexandra Jahn, "The First Ice-Free Day in the Arctic Ocean Could Occur Before 2030," *Nature Communications*, Vol. 15, March 2024).

[4] Mia M. Bennett, Scott R. Stephenson, Kang Yang, Michael T. Bravo, and Bert De Jonghe, "The Opening of the Transpolar Sea Route: Logistical, Geopolitical, Environmental, and Socioeconomic Impacts," *Marine Policy*, Vol. 121, November 2020.

[5] Arctic Council, "Exploring the Arctic Ocean: The Agreement That Protects an Unknown Ecosystem," October 28, 2020.

[6] National Snow and Ice Data Center, "Arctic Sea Ice Has Reached Minimum Extent for 2024," news release, September 24, 2024.

Figure 1.1. The Arctic Region

SOURCE: Adapted from National Snow and Ice Data Center, Sea Ice Index Daily and Monthly Image Viewer, database, undated.

A seasonally ice-free CAO will enable maritime commercial activities to take place farther north than ever before. Trans-Arctic shipping traffic may gradually migrate into ice-free international waters to avoid Arctic state EEZs, and ships carrying Arctic minerals and hydrocarbons may take advantage of more-direct routes to reach global markets. Tourist visits to the North Pole may become increasingly common. Fishing activity may migrate northward as well; the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean (also known as the *Central Arctic Ocean Fisheries Agreement* [CAOFA]) will expire in 2037,[7] setting the stage for potentially contentious

[7] Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean, October 3, 2018.

exploitation of a new and environmentally sensitive fishery.[8] Uncertainty over how Arctic states may respond to these and other consequences of increasing marine access at the outer margins of their EEZs suggests the possibility of expanded surface military and law enforcement presence in the CAO in the future. Global actors may increasingly seek to expand presence and exert influence in this rapidly evolving strategic, commercial, and legal environment, potentially affecting the security of the United States and other Arctic states.

In this report, we explore how sea ice melting will enable new maritime access in the CAO and how global actors may leverage this access for economic, political, and military gain. We focus on the opening of the CAO but also mention activities in the surrounding EEZs when they are likely to trigger new or different uses of the CAO. Drawing on insights from climate models, literature, and expert interviews, we address the following three research questions:[9] What factors could drive or inhibit increased use of the CAO? What would these activities look like, and during which time horizons might they be possible? Which state and nonstate actors may be the first movers or main beneficiaries of this new or increased activity in the CAO?

Given limited current understanding of many aspects of the CAO, such as the economic viability of Arctic fishing stocks and mineral resources over decadal time scales, we adopt a scenario approach that describes a plausible future unfolding over different points in time. We focus on factors that are already at play in the Arctic or will likely come into play that may affect the level and type of activity that will occur in the coming decades. Depending on the directions that these factors take, we anticipate different outcomes from these factors and combine these outcomes into a plausible scenario.

In this report, we examine current and potential future maritime use of the CAO—and the TSR within it—for commercial activity (Chapter 2) and security or military activity, including law enforcement activities (Chapter 3). We then present a scenario in four phases of how these activities could plausibly develop in the CAO over time, using a model of future Arctic marine access based on sea ice projections from a global climate model (Chapter 4). A conclusion (Chapter 5) highlights our key findings on the broader dynamics of the future opening of the CAO. The appendix details our methodology for projecting future Arctic maritime access.

[8] Arctic Council, "An Introduction to: The International Agreement to Prevent Unregulated Fishing in the High Seas of the Central Arctic Ocean," June 25, 2021.

[9] We conducted six interviews with Arctic experts.

Chapter 2

Commercial Use of the Central Arctic Ocean

Sustained commercial activities are already present in the Arctic at latitudes lower than the CAO (for instance, oil and gas shipping along the NSR or mining in northern Canada, Greenland, or Sweden). Some of these activities may extend north as access increases. Other activities that are rarer in the Arctic (such as cargo shipping) could be redirected from non-Arctic regions. The different levels at which these activities could develop is key to understanding whether the CAO could become a hub of activity or if its overall value to global trade will remain marginal. In this chapter, we examine projected use of the CAO for cargo shipping, fishing, extractive industries (oil, gas, mining), and other such activities as scientific research, tourism, wind energy, and subsea cables. In each case, we highlight the factors that could drive activity up or hinder it.

Cargo Shipping

Arctic shipping increased by 37 percent from 2013 to 2023 as a result of longer navigation seasons because of the loss of sea ice and the extraction of resources located in the Arctic, such as natural gas in Russia's Yamal Peninsula or iron ore in Canada's Nunavut.[10] Commercial shipping in the Arctic currently takes place seasonally through the NSR and, to a lesser extent, the NWP. Understanding how much of this traffic may be redirected toward the North Pole requires understanding what ways the TSR would offer a better economic proposition than these two existing routes. Route selection for commercial shipping is, broadly speaking, a factor of all costs for a given voyage, driven primarily by distance traveled (which reduces labor and other operational costs) and per-unit fuel costs. From this perspective, Arctic routes offer significant potential advantages over traditional shipping routes. The NSR is approximately 40 percent shorter than the Suez Canal route from northern East Asia to Europe, and we calculate that the TSR is approximately 15 percent shorter than the NSR (and is 25 percent shorter than the NWP).[11] A shorter voyage generally means less fuel needed and lower

[10] Data are for number of unique ships entering the Polar Code area (Protection of the Arctic Marine Environment Working Group, "Arctic Shipping Update: 37% Increase in Ships in the Arctic Over 10 Years," Arctic Council, August 20, 2024).

[11] Distance savings from Asia to Europe via Arctic routes compared with the Suez Canal diminish as the port of origin moves south (Albert Buixadé Farré, Albert, Scott R. Stephenson, Linling Chen, Michael Czub, Ying Dai, Denis Demchev, Yaroslav Efimov, Piotr Graczyk, Henrik Grythe, Kathrin Keil, et al., "Commercial Arctic Shipping Through the Northeast Passage: Routes, Resources, Governance, Technology, and Infrastructure," *Polar Geography*, Vol. 37, No. 4, 2014). Our analysis here is based on a hypothetical shortest-path transit from Rotterdam in the Netherlands to the Bering Strait.

operational costs overall.[12] These savings generally increase as the origin or destination port increases in latitude; for example, a voyage to Rotterdam via the NSR is approximately 20 percent shorter from Yokohama than from Hong Kong.[13] Furthermore, the deep bathymetry of the TSR circumvents the draft restrictions of the NSR and NWP,[14] opening the TSR to ships with larger cargo capacities than those that can currently transit through the shallow straits found along the NSR (which has a draft of only 12.5 meters near the New Siberian Islands) and NWP (where a draft of less than 10 meters can be found at certain locations along the principal route).[15] In theory, this lack of draft restrictions represents an advantage of economies of scale for the TSR over the NSR and NWP, raising the appeal of the route for large bulk cargo shipments, such as oil, minerals, and grain. Such commodities are also less dependent on just-in-time shipping schedules and generally do not require access to intermediate markets, which are lacking along Arctic routes.

The CAO will become more accessible as the region warms and ice conditions trend toward longer ice-free seasons in the future.[16] Although the NSR and NWP are also becoming more accessible, the increase in access along the NSR and NWP is projected to be less significant than in the CAO because the NSR and NWP are already seasonally accessible today.[17] As thick multiyear ice recedes and is replaced by thinner first-year ice, more types of vessels, including vessels without ice strengthening, will be able to access the CAO. This will reduce the need for investments in the highest class of ice-strengthened vessels and lower overall fuel use per nautical mile.[18] Climate models project that by midcentury, the TSR will be the fastest technically accessible trans-Arctic route on more days in summer than any other route (Figure 2.1).[19]

[12] In some cases, there may be economic incentives for longer trips; for instance, when carrying oil while biding time in the hope of a rise in market prices (Chris Baraniuk, "Cheap Oil Is Taking Shipping Routes Back to the 1800s," BBC News, March 4, 2016).

[13] Buixadé Farré et al., 2014.

[14] A ship's *draft* is defined as its depth below the waterline.

[15] Jeroen F. J. Pruyn, "Will the Northern Sea Route Ever Be a Viable Alternative?" *Maritime Policy and Management*, Vol. 43, No. 6, 2016, p. 662; Dongin Lu, Gyei-Kark Park, Kyounghoon Choi, and Sangjin Oh, "An Economic Analysis of Container Shipping Through Canadian Northwest Passage," *International Journal of e-Navigation and Maritime Economy*, Vol. 1, 2014.

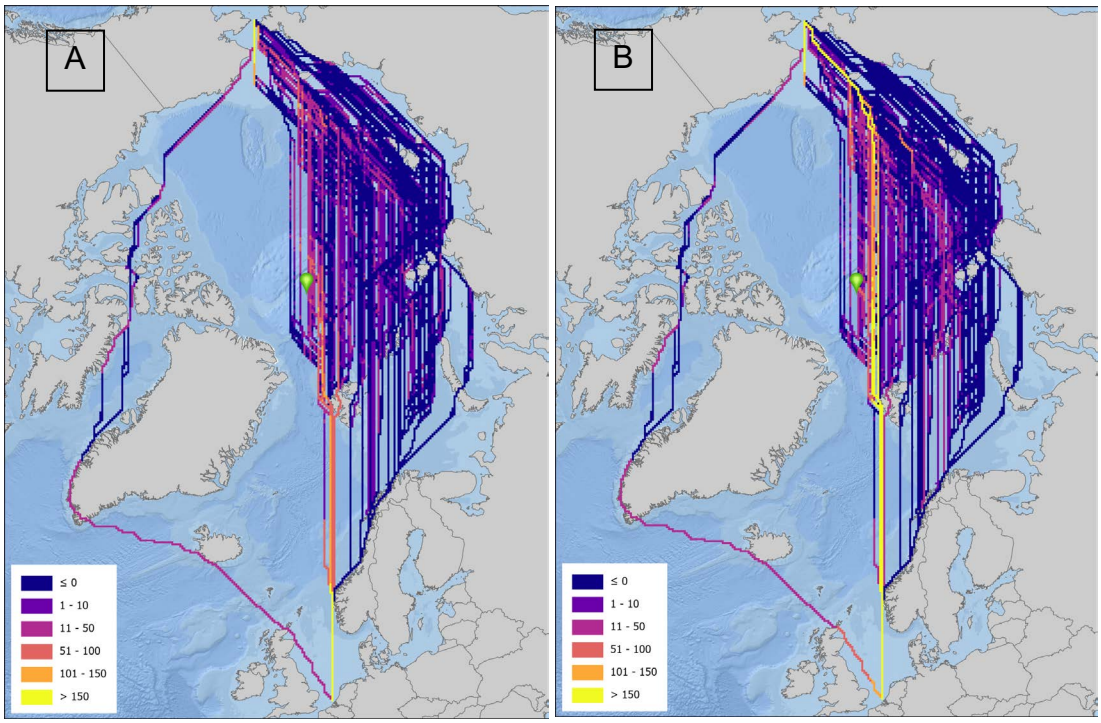
[16] Xueke Li and Amanda H. Lynch, "New Insights into Projected Arctic Sea Road: Operational Risks, Economic Values, and Policy Implications," *Climatic Change*, Vol. 176, 2023; Xueke Li, Scott R. Stephenson, Amanda H. Lynch, Michael A. Goldstein, David A. Bailey, and Siri Veland, "Arctic Shipping Guidance from the CMIP6 Ensemble on Operational and Infrastructural Timescales," *Climatic Change*, Vol. 167, 2021; Laurence C. Smith and Scott R. Stephenson, "New Trans-Arctic Shipping Routes Navigable by Midcentury," *Proceedings of the National Academy of Sciences*, Vol. 110, No. 13, 2013.

[17] Smith and Stephenson, 2013.

[18] Bennett et al., 2020, p. 2.

[19] Amanda H. Lynch, Charles H. Norchi, and Xueke Li, "Data from: The Interaction of Ice and Law in Arctic Marine Accessibility," dataset, version v1, Zenodo, May 11, 2022b; Li and Lynch, 2023.

Figure 2.1. Projected Change in Time-Optimal Trans-Arctic Shipping Routes

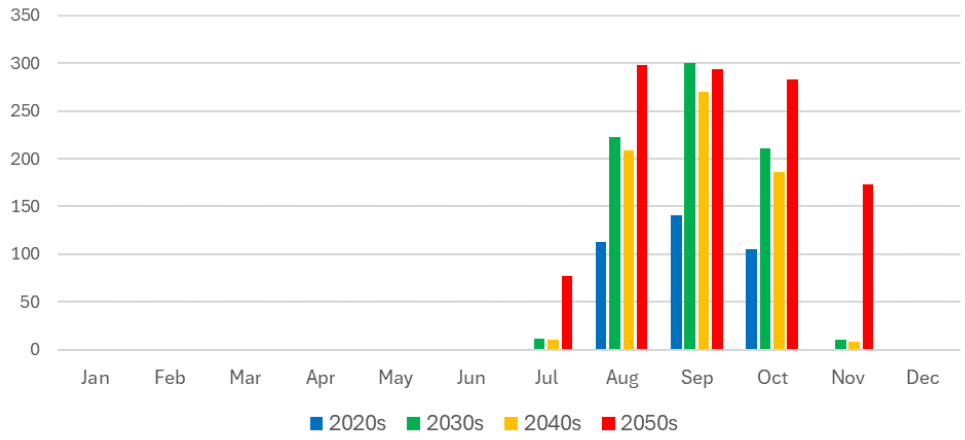


SOURCE: Authors' analysis of data published in Lynch, Norchi, and Li, 2022b; Amanda H. Lynch, Charles H. Norchi, and Xueke Li, "The Interaction of Ice and Law in Arctic Marine Accessibility," *Proceedings of the National Academy of Sciences*, Vol. 119, No. 26, 2022a.
NOTE: Colors represent the change in the number of days over a decade on which the surrounding area (within a 20-km grid cell) encompasses the shortest technically accessible sea route from Rotterdam, the Netherlands, to the Bering Strait from the 2020s to the 2030s (panel A), and from the 2020s to the 2050s (panel B). *Time-optimal* refers to routes that minimize the total time to travel from origin to destination. Projections are based on outputs from the CESM2 climate model (SSP585 climate scenario). Methodological details are provided in the appendix.

From a purely time-saving perspective, these projections portend a marginalization of the NSR in favor of the TSR in the coming decades. This shift will occur not only during the sea ice minimum in September but also increasingly earlier in summer and later in fall (Figure 2.2), indicating an expansion of the overall season during which ships may operate in the CAO. Furthermore, the shift will not necessarily occur with a uniformly gradual pace: Ice may be more severe in some years than in the preceding years because of natural variability, underscoring the uncertainty inherent in the climate system, despite high confidence in the long-term trend.[20]

[20] The CESM2 climate model shows a decline in maritime accessibility in the CAO in the 2040s compared with the 2030s and a subsequent increase in the 2050s, as depicted in Figure 2.2. Such decadal fluctuations reflect natural variability in the climate system and differ from model to model, though the overall trend in climate models is toward long-term ice decline.

Figure 2.2. Projected Days Per Decade on Which the TSR Is the Shortest Accessible Trans-Arctic Route



SOURCE: Authors' analysis of data published in Lynch, Norchi, and Li, 2022b.
NOTE: The *TSR* is defined here as a time-optimal (see Figure 2.1) route passing within 500 km of the North Pole. Projections are based on outputs from the CESM2 climate model (SSP585 climate scenario).

The TSR could also benefit from a redirection of global shipping toward the Arctic driven by geopolitical uncertainties and traffic congestion along traditional routes. Several drivers in the maritime supply chain could drive transoceanic commercial traffic into the CAO. A first one would be avoiding instability in maritime choke points that are dangerous or politically unstable. For many years, acts of piracy have been occurring along the eastern coast of Africa and in the Strait of Malacca.[21] More recently, in the Bab al Mandab Strait between the Red Sea and Indian Ocean, attacks on commercial shipping by Houthi forces based in Yemen have been making some vessels reroute around Africa.[22] By April 2024, cargo and tanker volume through the Suez Canal were 71 percent and 61 percent below that of the previous year, respectively.[23] In response to attacks in the Red Sea, large numbers of ships rerouted via the Cape of Good Hope but at significant additional costs.[24] The alternative of redirecting cargo by land can be problematic, given the sheer volume of the cargo that typically travels by sea.[25] Transiting through the CAO presents an alternative to sailing through embattled waters.

[21] See, for instance, Neslihan Küçük, Serdar Yildiz, Ozkan Ugurlu, and Jin Wang, "Hotspot Analysis of Global Piracy and Armed Robbery Incidents at Sea: A Decadal Review of Regional Vulnerabilities and Security Strategies," *Ocean & Coastal Management*, Vol. 260, January 2025.

[22] Peter Eavis and Liz Alderman, "Houthi Attacks Turn Back the Clock for Shipping as Costs Pile Up," *New York Times*, December 11, 2024.

[23] UK Office for National Statistics, "Ship Crossings Through Global Maritime Passages: January 2022 to April 2024," webpage, April 24, 2024.

[24] Eavis and Alderman, 2024; Maersk, "Maersk Asia Pacific Market Update—June 2024," June 12, 2024.

[25] Chris Baraniuk, "Red Sea Crisis: What It Takes to Reroute the World's Biggest Cargo Ships," BBC News, January 21, 2024. On alternative routes to the Suez Canal, see also Lawson W. Brigham, "The Suez Canal and Global Trade Routes," *Proceedings*, U.S. Naval Institute, Vol. 147, No. 5, May 2021b.

Another consideration is the capacity of the canals used to connect the world's oceans. The Suez Canal can only handle vessels of 66 feet draft and sees only around 50 transits per day.[26] The Panama Canal is limited to vessels of less than 49 feet draft, and the number of transits is limited by the amount of water in Lake Gatún.[27] Although the operators of these canals continue to try to expand the canal's infrastructure, the shipping industry has been building larger and larger ships.[28] There are no significant draft limitations in the CAO.

The TSR could also offer cost savings over the Suez Canal in terms of transit fees. The Suez Canal requires payment of an expensive toll: an estimated $350,000 per ship in 2016, which has experienced multiple increases since.[29] The Russian government also requires a toll in addition to an already costly icebreaker escort fee to use the NSR, with no clear or consistent regard to ice conditions or vessel class.[30] In addition, a 2021 article notes that

> currently active NSR icebreaking tariffs issued in 2014 are ceiling tariffs, which mean the maximum level. In practice, ship operators often negotiate with Rosatomflot to reach a lower icebreaking fee, therefore it lacks transparency and incurs uncertainty in the economic assessment of NSR shipping.[31]

In comparison, the TSR would likely not require any toll.[32] Furthermore, ships going through the TSR would not have to comply with Russia's requirements for the use of the NSR, which include notification of Russian authorities. Thus, redirection of traffic from the NSR to the TSR will depend, to some extent, on geopolitical and diplomatic factors and on shipping companies' willingness to engage with Russia, which thus far has been limited. Apart from Russian domestic traffic, only a small number of Chinese companies have negotiated transit via the NSR of late. Even if tensions between Russia and the West were to abate in the future, it is unclear that European or North American shipping companies would use the NSR in great numbers, and especially so if the TSR were available as an alternative.

However, the potential cost savings of shorter distances and foregone fees along the TSR may be offset in part by hazardous environmental conditions, such as drifting sea ice, sea ice ridges, glacier icebergs, polar storms, and limited visibility (because of fog and reduced daylight hours in fall and winter).[33] At best, these hazards can force vessels to navigate at slower speeds, and in severe conditions, they may precipitate a disaster at sea. Limited communications from poor satellite

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[26] Suez Canal Authority, "Canal Characteristics," webpage, undated-a; Suez Canal Authority, "Navigation Statistics," undated-b.

[27] Panama Canal Authority, "Panama Canal Increases Maximum Allowable Draft to 49 Feet," August 6, 2024; Peter S. Goodman, "To Save the Panama Canal from Drought, a Disruptive Fix," *New York Times*, August 14, 2024.

[28] Chris Baraniuk, "Why Container Ships Probably Won't Get Bigger," BBC News, July 4, 2022.

[29] Baraniuk, 2016; "Egypt's Suez Canal to Increase Tolls by up to 10%," Reuters, February 27, 2022; "Suez Canal to Increase Transit Fees for Ships from January 2024," Marine Insight, October 26, 2023.

[30] Bennett et al., 2020, p. 4.

[31] Hua Xu and Zhifang Yin, "The Optimal Icebreaking Tariffs and the Economic Performance of Tramp Shipping on the Northern Sea Route," *Transportation Research Part A: Policy and Practice*, Vol. 149, July 2021, p. 94.

[32] However, it is also possible to imagine some international management system for the CAO collecting tolls to offset the costs of icebreaker support or to address some environmental offsets caused by cargo shipping.

[33] Xueke Li and Amanda H. Lynch, "Projections for Arctic Marine Accessibility: Risk Under Climate Change," *Ocean and Coastal Law Journal*, Vol. 29, No. 2, January 2024, p. 356.

coverage, minimal emergency and rescue resources, and minimal port infrastructure compound the risks and are particularly salient for ships operating in the CAO at a great distance from coastal settlements. Although icebreaker escort reduces the risk, ships transiting the TSR are limited in width (beam) according to the path that can be cleared by the icebreaker, which may partially negate the TSR's draft advantage over the NSR. Thus, use of the TSR by large ships (e.g., Suez-max class with beams up to 50 meters) is unlikely to happen in ice-covered waters unless a new class of larger icebreakers were to be developed.[34] Furthermore, a regular icebreaker escort system in the CAO might be difficult to establish because coastal states have fewer incentives to exercise domain awareness and environmental protection in international waters than in their EEZs and territorial waters.

These hazards and infrastructure gaps incur additional costs on commercial shipping along the TSR. One key cost stemming from environmental hazard uncertainty is insurance. Insurance cost correlates with the level of risk that a route presents for the ship, its crew, and its cargo. Factors used by insurers to determine premiums for shipowners include crew experience, availability of rescue units (e.g., icebreakers), distance to ports, ship ice class,[35] and the prevalence of fog and ice along the route.[36] Because the TSR has no ports, no regular icebreaker service, and will continue to be mostly ice-covered except during summer (typically July to September) for the foreseeable future, it is possible that insurance premiums for voyages along the TSR will be prohibitive. Other costs include specific ship features required by polar operations, such as reinforced hulls and powerful engines to navigate in ice.[37] The IMO International Code for Ships Operating in Polar Waters (or Polar Code), in force since 2017, specifies what designs, equipment, crew training, and other specifications are required of ships operating in polar areas. Compliance with the Polar Code is mandatory under the International Convention for the Safety of Life at Sea and the International Convention for the Prevention of Pollution from Ships.[38] Yet even when ships are in compliance with the Polar Code, insurance underwriters may still require icebreaker escort, which, aside from the significant additional costs imposed, can also force ships to use coastal routes rather than the TSR depending on where specific icebreakers are allowed to navigate.[39]

All together, these hazards, constraints, and uncertainties pose significant limitations on the attractiveness of Arctic routes for container transit shipping. Arctic ice conditions can be unpredictable even during summer, creating travel-time uncertainty that can pose logistical and planning challenges for industries that depend on container-based just-in-time supply chains. Moreover—barring the establishment of transshipment systems, such as hub-and-spoke, at either terminus of the route—the lack of intermediate markets along the TSR means that the potential cost

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[34] Raunek Kantharia, "The Ultimate Guide to Ship Sizes," Marine Insight, February 1, 2021; Pruyn, 2016, p. 662.

[35] A ship's ice class determines its capability to operate in ice-covered waters. The International Maritime Organization (IMO) Polar Code defines three categories of ships (A, B, and C) related to this capability (IMO, "International Code for Ships Operating in Polar Waters [Polar Code]," webpage, undated).

[36] Frédéric Lasserre, "Case Studies of Shipping Along Arctic Routes. Analysis and Profitability Perspectives for the Container Sector," *Transportation Research Part A: Policy and Practice*, Vol. 66, 2014, p. 150.

[37] Olivier Faury, Ali Cheaitou, and Philippe Givry, "Best Maritime Transportation Option for the Arctic Crude Oil: A Profit Decision Model," *Transportation Research Part E: Logistics and Transportation Review*, Vol. 136, April 2020, pp. 1–2.

[38] IMO, undated.

[39] Faury, Cheaitou, and Givry add that "the area, the category, the size of the vessel and the season of navigation enter in combination to determine the need for icebreaker assistance" (2020, p. 2).

savings of the route can only be realized for direct port-to-port shipments, complicating use of the route for shipping companies that follow a pendulum model by which ships visit multiple routes during a long-distance journey. These constraints are reflected in the current commercial use of Arctic routes, which is primarily destination-based and oriented toward carriage of resources extracted in the Arctic toward importing markets. In 2022, while nearly 24,000 ships passed through the Suez Canal, only 1,661 unique ships entered the geographic area in which the Polar Code applies—81 percent of which belonged to Arctic states.[40] The limited traffic on the NSR, which has more support infrastructure than the TSR might ever have, suggests that transpolar shipping is still not perceived as a desirable option by most shipping companies, even at a time when other more popular routes are encountering challenges.[41] It remains to be seen whether some technological advances, however, could bring some significant changes—for instance, the use of artificial intelligence (AI) and machine learning to predict how ice will move and optimize shipping routes.[42]

Fishing

Under the United Nations Convention on the Law of the Sea (UNCLOS), Arctic littoral states own the fish found in their EEZs surrounding the CAO, while no one country has exclusive fishing rights within the high seas of the CAO (see Figure 1.1).[43] The CAO is unique in that it is the first high seas region to have a form of international fisheries management in place before the onset of commercial fishing activity—the CAOFA. The CAOFA currently prohibits the development of commercial fisheries in the Arctic and is set to expire in 2037, with a possibility of extension. Signatories on the CAOFA are Canada, China, Denmark (in respect of the Faroe Islands and Greenland), the European Union, Iceland, Japan, Norway, South Korea, Russia, and the United States. The agreement is significant in that it includes states with direct access to the Arctic Ocean and states that do not have direct access but have distant water fishing fleets that could feasibly access and fish in the Arctic—and, thus, might seek to do so in the future.[44]

Future governance of commercial fishing in the CAO spans a broad range of possibilities. On one end of the spectrum, no fishing activity would take place if the region were to be declared a marine protected area under the 2023 United Nations Biodiversity Beyond National Jurisdiction (BBNJ) treaty.[45] On the other end, the CAO ultimately could be treated as any other high seas area, in which

[40] Protection of the Arctic Marine Environment Working Group, "New Report Released on Flag States of Ships in the Arctic," Arctic Council, December 19, 2023.

[41] Arctic shipping expert, interview with the authors, February 2025.

[42] Jeremy Rehm, "New AI Promises Ships Safer Passage While Traversing Arctic Seas," Johns Hopkins Applied Physics Laboratory, June 2, 2023.

[43] The United States has not ratified UNCLOS and therefore is not an official party to the treaty. However, the United States has historically treated UNCLOS as customary international law and has abided by its provisions, including asserting exclusive fishing rights within its EEZ.

[44] CAOFA is also the only attempt at commercial fisheries management that explicitly requires use of Indigenous knowledge and participation in negotiations (David Balton, "The Arctic Fisheries Agreement Enters into Force," Polar Points No. 9, Polar Institute, Wilson Center Polar Institute, June 25, 2021).

[45] Agreement Under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction, Part III, 2023.

all states have equal fishing rights, and little management of fisheries occurs. In between these extremes are intermediate management possibilities, most of which would likely involve some form of limited-access regional fisheries agreement organization (RFMO) that could be managed with a goal to optimize economic gain, equitable access, and fish stock health. Although such agreements can be effective management tools for the long-term sustainability of some species, they require voluntary commitments among participating countries.

Within Arctic EEZs north of the Atlantic Ocean, commercially viable fisheries are already mature, with science-informed management and international agreements in place. From 2013 to 2024, 39 percent of all ships that entered the Arctic Polar Code area were fishing vessels, more than any other vessel type.[46] It is expected that these fisheries will continue to be used and managed by the littoral Arctic states and can potentially continue to produce in perpetuity if they are well managed.[47]

Several global environmental trends portend significant impacts for Arctic fisheries. Globally, fish are moving toward colder climates as ocean temperatures rise, which could eventually lead to commercial viability. However, not all species will be able to thrive in this environment. For instance, one study finds that out of 17 fish and shellfish species examined, "Only six stocks were highly likely to exhibit expansions sufficient to support commercial fishing in the Arctic Ocean."[48] It remains to be seen whether this northward shift will result in the CAO having the sufficient volume of the right species of fish to maintain ecosystem stability and economic viability. Low primary production (resulting in part from the length of the polar winter and lack of solar energy to fuel plant growth) limits the potential for large commercial harvests in the Arctic compared with fisheries at lower latitudes. Moreover, reduced sea ice increases *wind fetch* (the unobstructed distance over which wind blows across a body of water), fog, and highly variable conditions within the marginal ice zone, creating dangerous and unpredictable conditions for fishing. Although the development of an as-yet undiscovered Arctic fishery is always possible, not enough is yet known about Arctic fish species and their likely depth and distribution ranges, migration patterns, and population sizes to determine the potential for commercial viability at this time.[49] This knowledge is expected to progress greatly over the next decade, however, as the Joint Program for Scientific Research and Monitoring (adopted as part of CAOFA) will determine whether sustainable Arctic fisheries are possible and will assess the possible impacts of fisheries on the CAO ecosystems.[50]

Additionally, a significant factor determining the viability of commercial fishing in the Arctic is the state of fisheries *outside* the Arctic. If a fish can be caught closer to home in less extreme climates,

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[46] Protection of the Arctic Marine Environment Working Group, "The Increase in Arctic Shipping 2013–2024," January 2024.

[47] Alternatively, these fisheries may collapse because of mismanagement, overfishing, or environmental stressors.

[48] Anne Babcock Hollowed, Benjamin Planque, and Harald Loeng, "Potential Movement of Fish and Shellfish Stocks from the Sub-Arctic to the Arctic Ocean," *Fisheries Oceanography*, Vol. 22, No. 5, 2013, p. 365.

[49] One extensive study notes from the start that "[i]n the CAO, there have been no systematic, quantitative surveys of fishes. Hence, there is no sound information about the distribution ranges, migration patterns and population sizes of any fish species living in the CAO" (Pauline Snoeijs-Leijonmalm, Hauke Flores, Filip Volckaert, Barbara Niehoff, Fokje L. Schaafsma, Joakim Hjelm, Jonas Hentati-Sundberg, Susa Niiranen, Anne-Sophie Crépin, and Henrik Österblom, *Review of the Research Knowledge and Gaps on Fish Populations, Fisheries and Linked Ecosystems in the Central Arctic Ocean [CAO]*, European Commission, January 2020).

[50] Inuit Circumpolar Council, "Inuit Delegates with Strong Presence at Central Arctic Ocean Fisheries Agreement Scientific Coordinating Group Meeting," press release, March 23, 2023.

that fish will be cheaper to catch and a fresher (and therefore more valuable) product. Outside the Arctic, fisheries face a variety of pressures stemming from overall demand, the type of management regime, and the impact of illegal, unreported, and unregulated (IUU) fishing. In the past decade, such technology as satellite remote sensing has enabled greater visibility around these pressures, which in turn has enabled countries to better manage their fisheries.[51] These better management practices, along with reduced IUU fishing aided by further adoption of remote sensing data and tools, should increase fish supplies where they are applied and therefore reduce the appeal of remote Arctic fisheries in the global context.[52]

Another factor of note is the growing trend of aquaculture worldwide. In 2022, the volume and consumption of farmed fish exceeded that of wild caught fish for the first time.[53] In the past 20 years, the field of aquaculture has been transformed by improvements in value chains, efficiency in feed formulations, advances in genetics, and expanded use of aquaculture-grown products.[54] If countries continue to expand the scale of domestic aquaculture development, Arctic fisheries will become comparatively less attractive.

Conversely, an increase in overexploited global fisheries or a declining trend in aquaculture may make Arctic fishery development more attractive. Fishing costs per unit are higher in overexploited fisheries because the fish are harder to catch, with profits decreasing until the demand pressure is relieved and the stock recovers. If global fisheries became overexploited, competition for fish would increase, thus potentially making the higher cost and risks of fishing in the Arctic profitable.

In all cases, significant expansion of Arctic fishing activity would require expanding logistical support for long-distance ice-capable fishing vessels and a supply chain to support the processing and transport of fish products. The capability and capacity to process fish efficiently at scale already exists in the Arctic to some extent; fish processing plants scaled to current fishery production levels operate in Alaska, Iceland, Norway, and Canada. However, operating in the remote CAO may require use of distant water "factory vessels" with onboard processing capabilities, especially in light of the recent closure of several fish processing plants in Alaska.[55] These vessels require a significant amount of logistical support to maintain production and move product offboard in a timely manner, which may only be feasible if commercially viable fisheries are abundant in the CAO. Furthermore, making such vessels ice-capable is likely to be expensive, and sourcing the labor needed to maintain these operations from within the Arctic may be challenging in light of ongoing labor shortages in some Arctic countries.[56]

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[51] Victor Klemas, "Fisheries Applications of Remote Sensing: An Overview," *Fisheries Research*, Vol. 148, November 2013.

[52] Zuzanna Klawikowska, Tomasz Ujazdowski, Michal Grochowski, and Robert Piotrowski, "How High-Tech Solutions Support the Fight Against IUU and Ghost Fishing: A Review of Innovative Approaches, Methods, and Trends," *IEEE Access*, Vol. 10, 2022.

[53] Food and Agriculture Organization of the United Nations, "FAO Report: Global Fisheries and Aquaculture Production Reaches a New Record High," June 7, 2024.

[54] Rosamond L. Naylor, Ronald W. Hardy, Alejandro H. Buschmann, Simon R. Bush, Ling Cao, Dane H. Klinger, David C. Little, Jane Lubchenco, Sandra E. Shumway, and Max Troell, "A 20-Year Retrospective Review of Global Aquaculture," *Nature*, Vol. 591, March 24, 2021.

[55] Ava White, "3 Seafood Processors Announce Closures, Selloffs Following Historic Price Collapse for Alaska Fishing Industry," Alaska Public Media, February 15, 2024.

[56] Elias Thorsson, "Greenland's Economic Future Relies on Finding Workers," *Arctic Today*, October 18, 2024.

Extractive Industries

The 2008 Circum-Arctic Resource Appraisal published by the U.S. Geological Survey (USGS) remains the reference for undiscovered oil and gas resources in the Arctic, which amount to 30 percent (for oil) and 13 percent (for gas) of the world's undiscovered reserves.[57] The prospective hydrocarbon provinces believed to hold the most reserves, however, tend to be onshore or on continental shelves in less than 500 meters of water, and "[d]eep oceanic basins have relatively low petroleum potential."[58] The provinces that the USGS study examined and that most fully map onto the Arctic Ocean—the Lomonosov-Makarov Province and the Eurasia Basin Province[59]—have gas as their "predominant petroleum resource" but contain limited reserves compared with most of the other provinces studied.[60] Additionally, in each case, parts of the province "were not quantitatively assessed owing to their low probabilities of containing resources."[61] For the Eurasia Basin, this includes the part extending farthest into the CAO and encompassing the North Pole.

Although the USGS is careful to highlight the limits of the geological information that it was able to gather, the CAO is believed to have limited undiscovered hydrocarbon reserves, and these would be costly to explore and extract.[62] Even in the event of technological advances that may lower these costs and high and sustained global market prices for these commodities (which would suppose a drastic slowdown of the energy transition), hydrocarbon exploration in the Arctic would likely take place closer to shore, where hydrocarbon accumulations are larger and exploitation is easier. Of note, even these much more accessible and technically exploitable resources present challenges that reduce incentives to invest; examples include some gas resources in Alaska and disappointing exploration results in Greenland or the stalling of exploration or exploitation projects in areas that once seemed to hold promise, such as the Dreki area off the coast of Iceland or the Shtokman field in Russia.[63] In

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[57] Donald L. Gautier, Kenneth J. Bird, Ronald R. Charpentier, Arthur Grantz, David W. Houseknecht, Timothy R. Klett, Thomas E. Moore, Janet K. Pitman, Christopher J. Schenk, John H. Schuenemeyer, et al., "Assessment of Undiscovered Oil and Gas in the Arctic," *Science*, Vol. 324, No. 5931, May 2009.

[58] Gautier et al., 2009.

[59] For other provinces studied, see Gautier et al., 2009, Figures 1 and 2; Moore and Pitman, 2019, p. 28; Moore, Bird, and Pitman, 2019, p. 37.

[60] The *Lomonosov-Makarov Province* is defined as including "the northern part of the Amerasia Basin and its margins, comprising a wedge-shaped area of about 715,000 [km squared] in the central part of the Arctic Ocean [with] the continental Lomonosov Ridge, oceanic Makarov and Podvodnikov Basins, and the outer shelf and slope of the Siberian continental margin" (Thomas E. Moore, Kenneth J. Bird, and Janet K. Pitman, "Geology and Assessment of Undiscovered Oil and Gas Resources of the Lomonosov-Makarov Province, 2008," in T. E. Moore and D. L. Gautier, eds., *The 2008 Circum-Arctic Resource Appraisal*, U.S. Geological Survey Professional Paper 1824, 2019, p. 2).

The *Eurasia Basin Province* is geographically defined as follows: "The Eurasia Basin composes the eastern part of the Arctic Ocean basin between the continental margin of Europe and the submerged Lomonosov Ridge and includes the North Pole" (Thomas E. Moore and Janet K. Pitman, "Geology and Assessment of Undiscovered Oil and Gas Resources of the Eurasia Basin Province, 2008," in T. E. Moore and D. L. Gautier, eds., *The 2008 Circum-Arctic Resource Appraisal*, U.S. Geological Survey Professional Paper 1824, 2019, p. 3).

[61] Moore and Pitman, 2019, p. 28; Moore, Bird, and Pitman, 2019, p. 36.

[62] Gautier et al., 2009.

[63] Arild Moe, *Arctic Minerals and Sea Routes: An Overview of Resources, Access and Politics*, Konrad Adenauer Stiftung, January 2023, pp. 23–24; Arctic economic expert, interview with the authors, February 2025; Atle Staalesen, "Gazprom Scrapped Shtokman, but Does Not Want to Abandon Projected Terminal Site on Barents Coast," *Barents Observer*, March 19, 2021a; Tasha Anderson, "How Eight Arctic Nations Handle Their Energy Needs," *Alaska Business Magazine*, May 23, 2022.

Norway, which has significant near-shore oil reserves (discovered and undiscovered), Arctic expert Arild Moe noted in 2023 that "interest from industry has fluctuated and the response to recent licensing rounds has been modest."[64] The combination of expected low reserves, technological challenges, and economic risks suggests that, although oil and gas exploration in the territorial seas and EEZs surrounding the CAO may increase in the near future—such as in Norway's Johan Castberg field in the Barents Sea—such activities in the CAO are unlikely to happen before other resources have been thoroughly exploited.[65]

A somewhat similar analysis applies to mining. There is limited knowledge of what the CAO might hold, and there are many resources that are easier and cheaper to access, whether globally or in the Arctic. Arctic states have been active in mining, and some resources appear plentiful—Sweden, for instance, has been extracting iron ore in Kiruna, Canada is the world's largest producer of potash, and Alaska's Red Dog Mine is one of the world's largest zinc producers.[66] Critical minerals, however, might provide more of an incentive to reach into the CAO.[67] Critical minerals are indispensable to a wide array of products, including mobile phones, medical devices, electric car batteries, semiconductors, magnets in wind turbines, and advanced defense equipment.[68] The projected growing needs for these minerals, as well as the major role of China as a producer and processor in this sector, have prompted the United States and others to issue dedicated strategies and to develop measures to secure and diversify supply chains.[69]

Critical minerals can be found in the Arctic, and are in some cases already under exploitation, such as niobium in Quebec and uranium in Saskatchewan. In 2023, Sweden found some rare earths mixed

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[64] Moe, 2023, p. 25.

[65] Solveig Glomsrød, Gérard Duhaime, and Iulie Aslaksen, eds., *The Economy of the North—ECONOR 2025*, Arctic Council Secretariat, 2025.

[66] Government of Canada, "Potash Facts," webpage, last updated February 4, 2025; Jackie Northam, "It's a Journey to the Center of the Rare Earths Discovered in Sweden," NPR, July 18, 2023.

[67] As outlined by the USGS, which issued a list of 50 critical minerals in 2022,

> [t]he Energy Act of 2020 defines a "critical mineral" as a non-fuel mineral or mineral material essential to the economic or national security of the U.S. and which has a supply chain vulnerable to disruption. Critical minerals are also characterized as serving an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economy or national security (USGS, "U.S. Geological Survey Releases 2022 List of Critical Minerals," press release, February 22, 2022).

[68] Linda R. Rowan, *Critical Mineral Resources: National Policy and Critical Minerals List*, Congressional Research Service, R47982, updated February 21, 2025; David Vergun, "Securing Critical Minerals Vital to National Security, Official Says," DoD News, January 10, 2025.

[69] See, for instance, the Minerals Security Partnership initiative, which features 14 countries (including the United States) and the European Union; the development of a National Offshore Critical Mineral Inventory to identify sources of critical minerals on the U.S. outer continental shelf; and the 2019 U.S. Department of Commerce's Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals. Other states and organizations have taken similar steps; see, for instance, the European Union's 2023 European Critical Raw Materials Act. U.S. Department of State, "Minerals Security Partnership," webpage, undated; Bureau of Ocean Energy Management, "Critical Minerals," U.S. Department of the Interior, webpage, undated; U.S. Department of Commerce, *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*, June 2019; European Union, "Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials," April 11, 2024.

with iron ore in Kiruna.[70] Farther into the CAO, the Gakkel Ridge and other deep-sea ridges are believed to be mineral-rich.[71] Deep-sea mining technologies have been advancing.[72] In 2021, a remotely operated vehicle was able to collect samples from the Gakkel Ridge despite ice cover and drifting ice.[73] So, although knowledge of the quantity and location of minerals remains limited, more exploration leading to mining in the CAO appears likely once access improves, provided that there are no legal impediments to this activity.[74]

There is indeed considerable uncertainty as to the potential impact that deep-sea mining might have on the ocean ecosystem. This uncertainty has been a driver of Canada's opposition to commercial seabed mining, both in areas under Canada's jurisdiction and in the high seas.[75] Greenland, too, has prohibited deep-sea mining in its waters, and the Norwegian Parliament suspended its deep-sea mining exploration plans in December 2024.[76] Under UNCLOS, states have the right to mine the seabed of its continental shelf within their EEZ, which extends 200 nautical miles beyond a country's coast. A country could also mine on its extended continental shelf beyond this limit if it can prove scientifically in a submission to the Commission on the Limits of the Continental Shelf (CLCS) that the additional areas are a geological extension of its continental shelf. Submissions from Russia, Denmark, and Canada, some of them overlapping, are currently under review by the commission. In addition, despite not being a party to UNCLOS, the U.S. government unilaterally announced the outer limits of its extended continental shelf in December 2023, delineating an area that overlaps with submissions by Canada and Russia.[77] If these states were to have large areas added to their continental shelf, only a small part of the CAO would still remain in the high seas for mining purposes, where the International Seabed Authority (ISA) has been working since 2011 to develop a set of regulations.[78]

The lack of more-detailed information about the type and quantity of critical minerals that may exist in the CAO seabed makes it difficult to assess its economic attractiveness. As with hydrocarbons, easier-to-access (i.e., closer to shore) minerals will be exploited before more expensive resources that are farther from shore. However, assuming that there would be no significant policy barriers to deep-sea mining, we would expect that minerals in the CAO could potentially attract commercial interest as

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[70] Stanley Reed, "Sweden Says It Has Uncovered a Rare Earth Bonanza," *New York Times*, January 13, 2023; Daniel Johnson, "How Do Canada's Critical Minerals Fit into Tariff Tensions?" BNN Bloomberg, February 15, 2025. On these land resources, see Arctic Economic Council, *Arctic Mining Report 2024*, September 2024; Brett Watson, Steven Masterman, and Erin Whitney, "Critical Minerals in the Arctic: Forging the Path Forward," Wilson Center, July 10, 2023.

[71] Marine scientist with Arctic expertise, interview with the authors, February 2025.

[72] Moe, 2023, p. 30; Alex Gilbert and Morgan Bazilian, "U.S. Ratification of the Ocean Treaty Will Unlock Deep Sea Mining," Atlantic Council, April 2, 2024.

[73] Eva Ramirez-Llodra, Claudio Argentino, Maria Baker, Antje Boetius, Carolina Costa, Håkon Dahle, Emily M. Denny, Pierre-Antoine Dessandier, Mari H. Eilertsen, Benedicte Ferre, et al., "Hot Vents Beneath an Icy Ocean: The Aurora Vent Field, Gakkel Ridge, Revealed," *Oceanography*, Vol. 36, No. 1, March 2023.

[74] Eliza Gkritsi, "Norway's Deep-Sea Mining Decision Is a Warning," *Wired*, January 12, 2024.

[75] Global Affairs Canada, "Canada's Position on Seabed Mining in Areas Beyond National Jurisdiction," statement, Government of Canada, July 10, 2023.

[76] Adrienne Murray, "Inside the Race for Greenland's Mineral Wealth," BBC News, January 26, 2025; Gwladys Fouche and Nerijus Adomaitis, "Norway Stops Deep-Sea Mining, For Now," Reuters, December 2, 2024.

[77] IBRU Centre for Borders Research, "Briefing Notes for IBRU Arctic Map Series," Durham University, 2024.

[78] Catherine Blanchard, Ellycia Harrould-Kolieb, Emily Jones, and Michelle L. Taylor, "The Current Status of Deep Sea Mining Governance at the International Seabed Authority," *Marine Policy*, No. 147, January 2023, p. 1.

soon as access becomes easier, unless the green transition were to slow down or new, more-accessible resources were discovered elsewhere. In any case, sustained mining operations in the CAO may require several months of ice-free operations in summer to minimize hazard risks and icebreaker requirements.

Other Activities

Several other commercial activities are occurring or have the potential to increase in the CAO. These include scientific research, tourism, offshore wind energy, and the laying of subsea telecommunications cables.

Scientific research in the CAO may increase as the ability to obtain previously inaccessible data increases. Research cruises are routine in the maritime Arctic today, and some of these cruises may migrate northward to the outer limits of EEZs or into the CAO as ice recedes. Knowledge areas that would benefit from this increased access include fish stocks, marine mammal migration, oil and mineral deposits, and the general topography of the CAO's seafloor. *Environmental intelligence*, which refers to the collection and analysis (including through AI) of information about the environment to improve decisionmaking, requires large amounts of data gathered through sensors and other types of monitoring systems and would play an important role in supporting the communities and industry involved in new and growing activities in the Arctic.[79]

Tourism is another activity that is likely to develop in the CAO. A 2022 report from the government of Norway noted an increase in cruise traffic in its waters and a trend toward larger ships with more passenger capacity, as well as an extension of the cruising season into the winter.[80] Polar cruises were described in 2024 as "one of the fastest-growing segments of the cruise industry."[81] As of 2024, two cruise ships, both with icebreaking capabilities, have taken tourists to the geographic North Pole.[82] China is planning to launch its own brand of polar expedition cruises in 2025 to respond to a significant increase in demand from its nationals and plans to build its own fleet of cruise ships for that purpose.[83]

As access to the CAO increases, more companies might offer cruises farther north, as a French cruise company did in summer 2024 with a voyage to the North Pole of Inaccessibility.[84] Some may start offering long-distance repositioning cruises between Asia and northern Europe during ice-free periods in the high latitudes, with a stop by the North Pole. Yet it is likely that sea ice, icebergs, and rough weather will continue to pose navigational hazards for the foreseeable future, meaning that icebreaker escort availability or ice capability in cruise vessels will be important limiting factors to an

[79] National Oceanic and Atmospheric Administration, "NOAA in the Arctic," webpage, undated; K. Maher, "Environmental Intelligence: Applications of AI to Climate Change, Sustainability, and Environmental Health," Stanford Institute for Human-Centered AI, July 16, 2020.

[80] Government of Norway, *Cruise Traffic in Norwegian Waters and Adjacent Sea Areas: Maritime Safety, Emergency Preparedness and Rescue—Challenges and Recommendations*, 2022, p. 26.

[81] "China Plans First Domestic Expedition Cruise Line as Part of Polar Growth," *Maritime Executive*, September 16, 2024.

[82] Andy Marsh, "North Pole Cruise Ships," North Pole Cruises, last updated 2024.

[83] "China Plans First Domestic Expedition Cruise Line as Part of Polar Growth," 2024.

[84] "Ponant's Icebreaker Is First Ever to Reach North Pole of Inaccessibility," *Maritime Executive*, September 24, 2024.

increase in polar tourism. However, part of the current appeal of visiting the North Pole is that passengers can disembark the ship and walk on the ice—the "typical" Arctic landscape. Therefore, an ice-free North Pole might be less enticing to visit because of the long transit time and lack of activities to enjoy. Another part of the appeal of these cruises is the exclusivity of the experience. Few people can claim to have been to the actual North Pole. Whether spending a week at sea to reach a symbolic point in the middle of the ocean will still be appealing when this has become an experience that a larger part of the population can enjoy remains to be seen.

Mass tourism in the CAO thus seems unlikely, and polar tourism could even take a setback if hypothetical events were to take place. One such setback would be the occurrence of a global financial crisis limiting leisure spending. Another would be a major cruise ship accident, which may durably dampen enthusiasm for this type of voyage. A close call was the technical failure experienced by the Viking Sky cruise ship during a storm near the coast of Norway in 2019, which led the Norwegian Safety Investigation Authority to note in its report on the incident that

> [t]he vessel is estimated to have come within a ship's length of running aground with 1,374 persons on board, and the accident had the potential to develop into one of the worst disasters at sea in modern times.[85]

A report published by the Norwegian government on maritime safety in the wake of the Viking Sky near-disaster assessed that

> [i]t is the committee's conclusion that it is impossible to dimension an emergency preparedness and response system that takes into account a worst-case incident involving a cruise ship. A serious accident with a large cruise ship will result in many injuries and deaths.[86]

Given the challenges of navigating in polar waters and weather, and the limited availability of search and rescue (SAR) assets—not only in the CAO, but also in areas more commonly traveled today, such as around Svalbard—the possibility of a major accident durably cooling down enthusiasm for polar cruises cannot be excluded. Still, as demonstrated by the recent tourism boom in Antarctica, in the absence of a major disaster, the potential for a significant rise in tourism in the most remote parts of the Arctic remains.[87]

The search for alternative energy sources, such as offshore wind power, could be another driver of activity in the CAO. Wind energy, sometimes used in combination with solar energy, is already commonly used in the Arctic—it brings power, for instance, to Anchorage, Kodiak, and several other locations in Alaska. Winds are particularly strong near the coast, and turbines have brought some

[85] Norwegian Safety Investigation Authority, "Report on Loss of Propulsion and Near Grounding of Viking Sky, Hustadvika, Norway 23 March 2019," Marine Report 2024/05, March 19, 2024.

[86] Government of Norway, 2022.

[87] V. Senigaglia, D. Hatton MacDonald, N. Stoeckl, J. Tian, E. Leane, V. Adams, R. Baird, A. Boothroyd, R. Costanza, E. A. Fulton, et al., "Managing Tourism in Antarctica: Impacts, Forecasts, and Suitable Economic Instruments," *Journal of Sustainable Tourism*, 2025.

degree of energy security to isolated villages. Wind turbines also happen to be particularly productive in cold temperatures.[88]

The installation of wind turbines in the CAO might be possible with the use of floating platforms, which were operationalized for the first time in 2017 off the coast of Scotland.[89] Locating turbines farther from the shore has other advantages: Winds are stronger and more consistent, and turbines are less likely to disturb maritime traffic along the coasts.[90]

There are some challenges, however. Winds would have to be within the range that turbines can accommodate (up to 55 miles per hour, approximately) or new, more-resilient infrastructure would have to be developed to take advantage of what is currently called "non-usable" wind for energy production.[91] Some models and projections also show that wind power density will increase seasonally until the end of the century, along with its variability, with the latter resulting in "a higher irregularity of wind energy production."[92] Another challenge is that turbine blades cannot function properly when covered in ice and require some advanced de-icing techniques.[93]

More generally, it is unclear whether there would be a business case for installing wind turbines in the CAO, given the cost of connecting the turbines to the coast by cable to carry power to customers; installing such turbines closer to the coast would be cheaper both in terms of cable cost and in maintenance. In addition, there are no provisions in UNCLOS regarding the legal status of offshore wind turbines in the high seas, while the jurisdiction of coastal states over these facilities is clearly established in their territorial waters and EEZ.[94] Arctic states thus have an incentive to install such infrastructure in their EEZ, while non-Arctic states are unlikely to be attracted to this energy source because it would require lengthy land or subsea cables, part of which would require the authorization of the countries they pass through.

Finally, subsea cables may become more common across the Arctic. As of 2025, one communications cable project that would cross through the CAO was in development: Polar Connect, a joint effort of Nordic countries with financial support from the European Union that would connect Sweden to Japan and South Korea.[95] This cable would potentially connect with Far North Fiber, a project led by Finnish, U.S., and Japanese companies expected to be completed in 2027, which would

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[88] Yereth Rosen, "Alaska's Experience Shows Benefits—and Challenges—of Wind Energy in the Arctic," *Arctic Today*, September 16, 2020.

[89] Lawson W. Brigham, "Global Offshore Wind Energy: Emerging Ocean Use," *Proceedings*, U.S. Naval Institute, Vol. 147, No. 1, January 2021a. This author notes that previously, the necessity to anchor the turbine to the seabed meant that it could not be installed at depths exceeding 250 feet.

[90] Brigham, 2021a.

[91] Mirseid Akperov, Alexey V. Eliseev, Annette Rinke, Igor I. Mokhov, Vladimir A. Semenov, Mariya Dembitskaya, Heidrun Matthes, Muralidhar Adakudlu, Fredrik Boberg, Jens H. Christensen, et al., "Future Projections of Wind Energy Potential in the Arctic for the 21st Century Under the RCP8.5 Scenario from Regional Climate Models (Arctic-CORDEX)," *Anthropocene*, Vol. 44, December 2023, p. 10.

[92] Akperov et al., 2023, p. 14.

[93] Fakorede Oloufemi, Zoé Feger, Hussein Ibrahim, Adrian Ilinca, Jean Perron, and Christian Masson, "Ice Protection Systems for Wind Turbines in Cold Climate: Characteristics, Comparisons and Analysis," *Renewable and Sustainable Energy Reviews*, Vol. 65, November 2016.

[94] Brigham, 2021a.

[95] Dan Swinhoe, "Arctic Subsea Cable Through the North Pole Proposed," Data Centre Dynamics, May 31, 2024; Swedish Polar Research Secretariat, "North Pole Fiber—Laying the Foundations for Polar Connect," webpage, undated.

connect Norway to Japan via the NWP.[96] The CAO route allows for a shorter time delay (or latency) between Europe and East Asia, which is highly valuable in particular for financial transactions.[97] A technologically complex project, Polar Connect would seek to provide an alternative route to avoid congestion of existing ones and to increase resilience.[98]

Even assuming that Polar Connect moves ahead, and that other states and organizations seek to follow the same route with their own cables, this should only create limited activity overall—presence would only be needed to lay down the cables on the seafloor, and then for occasional repair or maintenance. A security presence may be required to monitor areas around the cables, or intervene if there is suspected sabotage. This potential security activity is discussed in Chapter 3.

[96] Trine Jonassen, "Far North Fiber One Step Closer to Pan-Arctic Connectivity," High North News, April 12, 2023.

[97] Subsea cable science expert, interview with the authors, December 2024.

[98] Nordic Gateway for Research & Education, "Polar Connect," webpage, undated. Another large trans-Arctic subsea cable project of note is the Russian state-run Polar Express project, originally conceived as a project funded by international investors, which aims to connect Murmansk to Vladivostok following the NSR; cable-laying operations started in 2021, with an expected completion of the overall project in 2026 (Gleb Stolyarov, "Russia Starts Operation to Lay Undersea Fiber Optic Cable Through Arctic," Reuters, August 6, 2021). Several other cables traverse parts of the Arctic: the Svalbard Undersea Cable System connecting Svalbard to the Norwegian mainland; Greenland Connect with landing points in Iceland, Greenland, and Canada (Ontario); several cables (EAFON 1, 2 and 3) connecting communities in northern Quebec; and the Quintillion Subsea Cable Network along the Alaskan coast from Nome to Prudhoe Bay (TeleGeography, "Submarine Cable Map," webpage, undated).

Chapter 3

Military and Security-Based Use of the Central Arctic Ocean

As access to the Arctic increases, threats emerge that compel investments by Arctic states to protect their interests in the region. Historically, U.S. military and security efforts have focused on the North American Arctic because of Alaska's interconnection with economic activity in the Bering Sea, as well as air and subsurface threats in the region.[99] National defense threats to European Arctic states and their investments are primarily driven by their proximity to Russia. The accession of Sweden and Finland to the North Atlantic Treaty Organization (NATO) has multiplied the obligations of NATO Arctic states in the event of conflict. Moreover, the U.S. Department of Defense sees China as a potentially destabilizing force in the region.[100]

Furthermore, any increased commercial activities in the CAO—such as those described in the previous chapter—will likely drive an increase in government activity to ensure the security and safety of people, assets, and infrastructure. Much of this activity will include enforcing governance and a rules-based order to include maritime law enforcement and environmental protection, SAR, protection of subsea infrastructure, and other security requirements. In this chapter, we identify drivers and barriers to increased future security activity in the CAO through analysis of publicly available academic and policy literature and strategic documents of Arctic states and China.

Maritime Law Enforcement

Increased access to the Arctic may be accompanied by increases in illegal maritime activity observed in other areas of the world, such as smuggling, transnational threats, and terrorism. Most of these activities will drive an increase in maritime law enforcement presence from coast guards and other similar agencies.

Arctic sea routes may be shorter than southern routes for reaching some illicit markets and offer reduced risk of at-sea interdiction and boarding because of challenging conditions and remoteness. Increased access and commercial activity may also increase vulnerability to acts of disruption, in both peaceful and violent ways by nonstate actors aiming to disrupt the economies of entities with which they have disputes. Such acts as Greenpeace's disruption of a Russian Arctic oil rig in 2013, as well as

[99] National Security Presidential Directive 66 and Homeland Security Presidential Directive 25, *Arctic Region Policy*, U.S. Department of Homeland Security, January 9, 2009; Barack Obama, "The National Strategy for the Arctic Region," White House, May 2013.

[100] U.S. Department of Defense, *2024 Arctic Strategy*, 2024.

more violent acts, could increase the demand for law enforcement assets that can respond in a timely manner.[101] If national policy shifts toward providing additional resources and funding to maritime law enforcement agencies, there will likely be an increase in purpose-built assets to operate in state EEZs and, eventually, the CAO. This investment will likely be counterbalanced by the high cost of specialized vessels and the time required to build them, as evidenced by the United States's delayed response in building additional icebreakers.[102]

In addition, enforcing regulations that are meant to reduce risk of oil spills and accidents at sea—such as those outlined in the Polar Code—will likely require enhanced presence of law enforcement assets, including crewed and uncrewed systems, such as unmanned aircraft systems.[103] However, an increase in space-based domain awareness capabilities may reduce the required asset and infrastructure footprint by enabling a more-targeted presence in specific regions of high hazard risk and where Polar Code regulations are less likely to be followed.

Another area for maritime law enforcement will be the protection of underwater cables. Several Arctic cables in or adjacent to the Arctic have experienced major damage in recent years: Cables used for scientific observation off the coast of Western Norway and cables connecting Svalbard to the Norwegian mainland were severed in November 2021 and January 2022, respectively.[104] Cables are vulnerable to rupture because of seismic activity, landslides, ocean currents, and damage caused by ships' anchors, whether accidental or deliberate. Subsea cables in the CAO would be somewhat protected by the geography and remoteness of the ocean floor. Accidental disruption of undersea cables in the CAO because of ships' anchors would be difficult because of its depth and seasonal ice cover. However, these factors also make cable repair difficult because moving ice challenges a repair ship's ability to remain stationary over the cable. Additionally, the depth of the CAO could prohibit the use of divers and remotely operated vehicles for repairs. The importance of these cables in a highly connected world, combined with the high cost of building redundant cables on this particular route, might make for an attractive target for saboteurs, who may be deterred by additional security presence.[105]

Finally, a more hypothetical driver for a military presence in the Arctic may be the unresolved and overlapping claims around extensions of Arctic states' continental shelves. Although the CLCS evaluates and makes recommendations on the validity of the scientific submissions, it leaves states to establish the limits of their continental shelves on the basis of these recommendations, and states must negotiate among themselves the delimitation of their extended shelves when submissions overlap. If the bilateral or multilateral process to establish boundaries were to become prolonged or even contentious, such as if the CLCS recommendations were favorable for some claimants and unfavorable

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[101] Shaun Walker, "Greenpeace Activists Could Be Charged with Terrorism After Ship Stormed," *The Guardian*, September 20, 2013.

[102] U.S. House of Representatives, "Examining the Polar Security Cutter: An Update on Coast Guard Acquisitions," hearing before the Committee on Homeland Security, December 18, 2024.

[103] IMO, *International Code for Ships Operating in Polar Waters (Polar Code)*, November 21, 2014.

[104] Håvard Gulldahl and Inghild Eriksen, "This Is What the Damaged Svalbard Cable Looked Like When It Came Up from the Depths," trans. by Arnstein Friling and Håvard Gulldahl, Norwegian Broadcasting Corporation, May 26, 2024; Nina Berglund, "Surveillance Cables Mysteriously Cut," *Norway's News in English*, November 7, 2021.

[105] For instance, the cost of Arctic Connect was estimated at up to approximately $1.25 billion (Atle Staalesen, "Megafon Halts Trans-Arctic Cable Project Arctic Connect," *Barents Observer*, May 28, 2021b).

for others, this could trigger tensions—and possibly subsequent increased security presence—in the CAO. Coastal states might seek to engage in scientific exploration of the Arctic seabed and attempt to block similar activity by other states in areas of overlapping claims. They may also grant authorization for commercial entities to install infrastructure to support future extraction activities. In areas of overlapping claims, this infrastructure could be targeted for sabotage or disruption by actors of competing states. Coastal states might even attempt to extract the resources of the seabed in disputed portions of the continental shelf. These scenarios, however, appear fairly unlikely given the limited attractiveness of resources located so far out into the CAO when they are relatively plentiful onshore and in coastal waters (see Chapter 2 on extractive industries). This view is supported by the precedent of the conflictual determination of the delimitation between Norway and Russia in the Barents Sea, where both countries refrained from engaging in any drilling while negotiations—that took 40 years—were still going on.[106] Finally, these scenarios would present a drastic departure from the general understanding by Arctic states—including Russia—that all states have an interest in following the established governance procedures on these matters. Doing otherwise would create uncertainty that would be detrimental to economic activity or would risk putting in question past UNCLOS-based decisions from which Arctic states—including Russia—benefited.[107]

Search and Rescue and Disaster Response

Increases in cargo shipping, fishing, extractive industries, and tourism in and at the margins of the CAO will heighten the risk of maritime accidents, including groundings, collisions, allisions, vessels taking on water, and fire, as well as any oil spills or other hazardous discharge that may result from these accidents. This will increase the requirements for SAR and disaster response assets in the region. The already limited time to reach a distressed asset in a SAR response is further shortened in the Arctic; as low water and air temperature shortens survivability for accident victims in exposed conditions. The 2011 Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic divides the Arctic Ocean, including the CAO, into areas of responsibility and is intended to enhance SAR response capability through improved communication and coordination among member states.[108]

All else being equal, a more effective SAR response stemming from adherence to the treaty accompanied by attendant investments in SAR assets and infrastructure would likely lead to greater SAR presence overall relative to current levels. Increased adoption of the voluntary Automated

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[106] Moe notes that both Norway and Russia

> largely refrained from exploration in the area, although it was reported that at some point the Soviet Union tried to entice Western oil companies to drill there, presumably to put pressure on Norway, but to no avail. This underscores a general point, namely that oil companies are loath to work in areas with unclear or contested jurisdiction. One exploration may well cost upwards from 100 million US dollars (Moe, 2023, p. 21).

[107] Arctic economic expert, interview with the authors, February 2025; Stephanie Pezard, Abbie Tingstad, Kristin Van Abel, and Scott R. Stephenson, *Maintaining Arctic Cooperation with Russia: Planning for Regional Change in the Far North*, RAND Corporation, RR-1731, 2017, p. 48.

[108] Responsibility to coordinate SAR in the CAO is shared by the United States, Canada, Denmark, Norway, and Russia (Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic, May 12, 2011).

Mutual Assistance Vessel Rescue system would enhance coordination further. In contrast to the 2011 SAR agreement, the 2013 Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic does not explicitly divide the CAO into areas of responsibility; instead, it focuses on enhancing cooperation, coordination, and mutual assistance among the Arctic states in matters related to oil pollution and response.[109] Such activities could include joint exercises and training, some of which could occur in the CAO as the marginal ice zone retreats northward. Furthermore, recent increases in cold-weather battery performance may enable some future Arctic SAR operations to be conducted using uncrewed rescue assets, particularly in hazardous and remote locations.[110]

Regardless of possible increases in commercial activity, both SAR and disaster response activities in the CAO could be limited by persistent gaps in response assets and infrastructure. Apart from Russia's investment in bases along the NSR and global improvements in space-based capabilities for awareness, there has been minimal growth in infrastructure to support Arctic SAR since the 2011 agreement was signed. Offshore helicopter rescue is limited by helicopter range (assuming fair weather) and uncertainty about the distressed individual's location. Most practical medical evacuation capabilities offered via helicopter airlift are limited to the EEZ boundary, and there remain significant gaps in coverage along the coastlines in which fuel resupply infrastructure is lacking.[111] Range issues can be addressed by maintaining ships capable of landing or supporting helicopters in the region, but the hazardous environment and additional capital cost may be prohibitive for covering the entirety of the CAO. Alternatively, states may take more-assertive measures to limit the need for response capabilities by requiring more ships to have enhanced lifesaving capabilities, similar to the requirements outlined in the Polar Code, or may implement a buddy rescue system by mandating that voyages be conducted with escorts or partner vessels, similar to Russia's regulations along the NSR.[112] Increases in space-based domain awareness capabilities may further reduce the need for SAR and disaster response through enhanced monitoring of environmental hazards and shipping traffic.

Exercises and "Meeting Presence with Presence"

Military activity in the Arctic is on an upward trend.[113] From 2015 to 2023, Russian military exercises in the Arctic have grown in frequency and moved farther north, shifting from the Norwegian

[109] Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic, May 15, 2013.

[110] Jinhoo Yoo, Floris Goerlandt, and Aldo Chircop, "Unmanned Remotely Operated Search and Rescue Ships in the Canadian Arctic: Exploring the Opportunities, Risk Dimensions and Governance Implications," in Aldo Chircop, Floris Goerlandt, Claudia Aporta, and Ronald Pelot, eds., *Governance of Arctic Shipping: Rethinking Risk, Human Impacts and Regulation*, Springer Polar Sciences, 2020; Liezel Labios, "These Energy-Packed Batteries Work Well in Extreme Cold and Heat," *ScienceDaily*, July 4, 2022.

[111] U.S. Coast Guard Arctic pilot and rescue swimmer, interview with the authors, January 2025.

[112] IMO, undated; Government of the Russian Federation, Rules of Navigation in the Water Area of the Northern Sea Route, Resolution No. 1487, September 18, 2020.

[113] Duncan Depledge, "Train Where You Expect to Fight: Why Military Exercises Have Increased in the High North," *Scandinavian Journal of Military Studies*, Vol. 3, No. 1, 2020.

Sea to the Barents Sea to bolster the Northern Fleet's bastion defense.[114] Simultaneously, Western-led multinational Arctic exercises involving non-Arctic nations have also increased in number. From 2006 to 2019, such exercises rose from one per year to four per year.[115] There have been instances of tensions between U.S. fishing vessels and Russian military conducting exercises in the U.S. EEZ.[116]

As the Arctic attracts more commercial and security activity, Arctic states will want to meet presence with presence.[117] For the United States, a major incentive to increase such presence has been the still-limited but growing military and security activities that China started conducting in the Arctic. Chinese military ships have been observed crossing through the Bering Sea on multiple occasions.[118] In October 2024, China and Russia conducted a first joint Arctic patrol of their coast guards that passed through the Bering Strait.[119] In response, the U.S. Coast Guard dispatched aircraft and cutters to observe the Chinese and Russian ships.[120] Despite these operations being limited in nature, they suggest that China is intent on demonstrating presence in the Arctic and near U.S. territory.

Although the stated purpose of China's Bering Sea presence in summer 2024 was to conduct a freedom of navigation operation, future Chinese naval operations in the region may be driven by several factors. The most important factor in the near term is China's push to continue demonstrating its interest and presence in polar affairs. China has a long-term interest in shifting Arctic governance toward a less regional approach in which non-Arctic states would play a stronger role, and presence might be a way to showcase its relevance as an Arctic stakeholder. Its presence in the region is underwritten by its capability: the People's Liberation Army Navy now has the capability to send patrols abroad, with increasing access to maintenance and resupply for Arctic operations, because the strengthening of the China-Russia partnership and China's investments in Russia's Arctic energy infrastructure have facilitated Chinese access to Russian ports.[121] In the future, an increase in China's commercial interests (primarily resources and energy) in the Arctic may create incentives for Beijing to

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[114] Kristian Åtland, Thomas Nilsen, and Torbjørn Pedersen, "Bolstering the Bastion: The Changing Pattern of Russia's Military Exercises in the High North," *Scandinavian Journal of Military Studies*, Vol. 7, No. 1, 2024.

[115] Depledge, 2020.

[116] Nathaniel Herz, "Move Out of the Way: Bering Sea Fishing Boats Report Close Encounter with Russian Military," Alaska Public Media, August 28, 2020.

[117] We define *presence* as having an enduring posture in a region, for which *access* is a necessary but not sufficient condition. See also Abbie Tingstad, Scott Savitz, Benjamin J. Sacks, Yuliya Shokh, Irina A. Chindea, Scott R. Stephenson, Michael T. Wilson, James G. Kallimani, Kristin Van Abel, Stephanie Pezard, Isabelle Winston, Inez Khan, Dan Abel, Clay McKinney, Yvonne K. Crane, Katheryn Giglio, Sherrill Lingel, and Lyle J. Morris, *Report on the Arctic Capabilities of the U.S. Armed Forces*, RAND Corporation, RR-A1638-1, 2023, p. 17.

[118] See, for instance, Mark Thiessen, "Patrol Spots Chinese, Russian Naval Ships off Alaska Island," Associated Press, September 26, 2022; Dzirhan Mahadzir, "Russian, Chinese Warships Operated Near Alaska, Say Senators," USNI News, August 6, 2023; U.S. Coast Guard, "U.S. Coast Guard Encounters People's Republic of China Military Naval Presence in Bering Sea," press release, July 10, 2024a.

[119] U.S. Coast Guard, "U.S. Coast Guard Encounters Joint Chinese Coast Guard, Russian Border Guard Patrol in Bering Sea," press release, October 1, 2024b.

[120] Andrew Tiongson, "Keynotes: U.S. Perspectives on Defense in the North," speech delivered at the Anchorage Security and Defense Conference, November 19, 2024; U.S. Coast Guard, 2024b.

[121] Seth Robson, "Russia Welcomes Chinese Shipping to Far East Port for First Time," *Stars and Stripes*, May 17, 2023.

increase its military maritime presence in the region further to complement its diplomatic, scientific, and economic efforts with Arctic countries.[122]

Arctic strategies can reflect which states might seek to increase their presence in the CAO to protect commercial or security interests. For instance, various Arctic and broader strategy documents of the United States, Canada, Finland, Norway, and Denmark mention domain or situational awareness and often emphasize a desire for a low-tension, stable Arctic.[123] In the United States, the 2024 U.S. Department of Defense Strategy advocates a "monitor-and-respond approach" in which "DoD will remain able to deploy the Joint Force globally at the time and place of our choosing."[124] In its 2023 *Arctic Strategic Outlook Implementation Plan*, the U.S. Coast Guard intends to "increase presence, awareness, and understanding within the Arctic and reinforce adherence to international laws and norms."[125] Russia sees the Arctic as a critical region to assert its maritime power.[126]

In addition to strategies, states willing to be present in the CAO will need adequate capability and capacity, especially if they wish to position themselves to be first movers as the region becomes more accessible. A number of procurement programs are already underway. In 2024, the U.S. Coast Guard received appropriation to procure a commercially available icebreaker.[127] This new light icebreaker—renamed from the motor vessel *Aiviq* to U.S. Coast Guard Cutter (USCGC) Storis—will provide the U.S. Coast Guard with additional capability to operate in the Arctic. However, as a Polar Class 3 vessel, the USCGC Storis does not have the same capabilities as the service's medium and heavy icebreakers, including the Polar Security Cutters that are currently under construction.[128]

China, Finland, Russia, and Sweden plan to acquire one or more new icebreakers by 2035.[129] Canada will be adding six ice-capable offshore patrol vessels (OPVs) to its current fleet by the mid-2020s; Denmark has one OPV frigate under development. Norway is planning on acquiring patrol vessels with ice-strengthened hulls.[130] Meanwhile, Russia has pursued the development of Arctic assets and infrastructure in spite of its invasion of Ukraine.[131] For example, in 2024, Russia launched its first

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[122] M. Taylor Fravel, Katheryn Lavelle, and Liselotte Odgaard, "China Engages the Arctic: A Great Power in a Regime Complex," *Asian Security*, Vol. 18, No. 2, 2022.

[123] U.S. Department of Defense, *2022 National Defense Strategy of the United States of America*, 2022, p. 24; Canadian Department of National Defence, *Our North, Strong and Free: A Renewed Vision for Canada's Defence*, Canadian Armed Forces, 2024, pp. 12, 25–26; Finnish Ministry for Foreign Affairs, *Government Report on Finnish Foreign and Security Policy*, 2024, p. 37; Norwegian Ministry of Defence, *The Norwegian Defence Pledge: Long-Term Defence Plan 2025–2036*, 2024, p. 2; Danish Ministry of Defence, *Danish Defence Agreement 2024–2033*, June 2023, p. 10.

[124] U.S. Department of Defense, 2024, p. 7.

[125] U.S. Coast Guard, *Arctic Strategic Outlook Implementation Plan*, October 2023, p. 5.

[126] Janis Kluge and Michael Paul, "Russia's Arctic Strategy Through 2035," *Stiftung Wissenschaft und Politik*, No. 57, November 2020, p. 3.

[127] Kathy Murray, "Coast Guard Adds First Polar Icebreaker to Its Fleet in 25 Years," U.S. Coast Guard, December 23, 2024.

[128] Murray, 2024; U.S. Congressional Budget Office, *The Cost of the Coast Guard's Polar Security Cutter*, August 2024.

[129] Tingstad et al., 2023, Table 3.1, p. 44.

[130] Tingstad et al., 2023, pp. 29–31.

[131] For instance, satellite imagery from Google Earth shows a runway expansion project under development on Novaya Zemlya (Thomas Nilsen, "Further Expansion for Novaya Zemlya Air Base Aims to Serve Long-Range Bombers," *Barents Observer*, April 17, 2023).

armed combat icebreaker for sea trials, and at least two more such vessels are under construction.[132] The cost of ice-capable assets and their relative lack of versatility—as well as the specific expertise required for their development—mean that cooperation and pooling of assets can be useful ways to increase the collective capacities of states in this domain. In November 2024, the United States, Canada, and Finland signed a trilateral memorandum of understanding to create an Icebreaker Collaboration Effort Pact and promote exchanges of information and expertise and research and development in order to "scale production and reduce the cost of Arctic and polar icebreakers."[133] The U.S. Coast Guard and U.S. Navy are aiming to add eight to ten medium and heavy icebreakers to the U.S. fleet through the Polar Security Cutter and Arctic Security Cutter programs.[134]

In the subsurface domain, Russia commissioned the *Arkhangelsk* in December 2024, marking the fourth Yasen-M class vessel, with plans to expand to 12 vessels.[135] Norway plans to acquire six 212CD submarines, likely in response to increased Russian subsurface activities.[136] The United States' Seawolf- and Virginia-class submarines, capable of under-ice operations, participate annually in Arctic exercises, and the Navy's 2025 Shipbuilding Plan includes provisions for up to 45 Virginia-class submarines by 2054.[137] Other Arctic states either have no submarines or they are not fit for Arctic operations. Canada's four Victoria-class submarines cannot operate under the ice, and Sweden's submarine capabilities are believed to be suited for operations in the Gulf of Bothnia and the Baltic Sea, not the Arctic.[138] Denmark is reportedly examining whether to reconstitute its submarine fleet after its submarine program was terminated in 2004.[139] Among non-Arctic states, France and the United Kingdom have ballistic missile submarines (SSBNs) and attack submarines (SSNs) that can operate in the Arctic, and Portugal deployed a diesel submarine to the Arctic in 2024.[140] China's submarines, too, can operate through and under the ice.[141]

[132] "Russia's First Combat Icebreaker, Ivan Papanin, Sets Sail for Sea Trials," Marine Insight, July 3, 2024.

[133] U.S. Department of Homeland Security, "United States, Canada, and Finland Sign MOU to Build Arctic and Polar Icebreakers," press release, November 13, 2024.

[134] Lee Ferran, "After Trump's Promise of 40 'Big' Icebreakers, Coast Guard Says It'll Take Eight or Nine for Polar Ops," *Breaking Defense,* April 8, 2025.

[135] Thomas Nilsen, "Northern Fleet's Newest Yasen-M Class Submarine Will Be Based 60km from NATO Norway," *Barents Observer*, December 27, 2024.

[136] Lee Willett, "Norway's New Submarines Will Be Game Changers, Says Navy Chief," Naval News, February 16, 2024a.

[137] U.S. Congressional Budget Office, *An Analysis of the Navy's 2025 Shipbuilding Plan*, January 6, 2025.

[138] Tingstad et al., 2023, pp. 29 and 33.

[139] Tim Martin, "Denmark Considering Military Submarines After Almost 20 Year Gap: Danish Lawmaker," *Breaking Defense*, June 12, 2023.

[140] Tingstad et al., 2023, pp. 35 and 38; Lee Willett, "Portugal's First Under-Ice Patrol Demonstrated Importance for NATO of Conventional Submarine Operations in Arctic," Naval News, October 31, 2024b.

[141] Tingstad et al., 2023, p. 40.

Chapter 4

A Scenario for Future Use of the Central Arctic Ocean

In this chapter, we develop a scenario in four phases that illustrates futures that maritime use of the CAO could plausibly take. This maritime use, simply put, will be determined by the types and volumes of activities that can take place in the region and that relevant stakeholders wish to undertake. The distinction between *can* and *wish* is important here; access by itself will not necessarily create the sufficient economic or security incentives for activities to develop (but access is a necessary condition for these activities to take place). This scenario brings together the different activities examined in Chapters 2 and 3 and situates them on a prospective timeline based on the level of access that they would require to develop.

Table 4.1 summarizes the factors that will promote or inhibit levels of activity in the CAO at a given level of access. These factors are collected from our analysis of academic literature, policy documents, and interviews presented in Chapters 2 and 3 and organized by the type of activities outlined in those chapters. Although some are crosscutting—for example, an oil spill would likely inhibit numerous activities—we have organized them here according to their likely first-order effects (an oil spill would affect fishing before it would affect cargo shipping).

Table 4.1. Factors Influencing Presence in the CAO

Activity	Promoting Factors	Inhibiting Factors
Commercial		
Cargo shipping	• Time and distance savings of TSR over other routes • Absence of tolls • Russian control over the NSR • Geopolitical instability along other shipping routes • Exploitation of Arctic resources	• Environmental hazards (sea ice, icebergs, storms, waves, fog) • Lack of infrastructure and SAR capability • Lack of intermediary markets • Need for ice-strengthened vessels, icebreaker escort • New alternative land routes
Fishing	• Fish stocks shifting northward • Fish species presence/abundance • RFMO agreements established • Lack of regional fisheries governance • Increasing demand on global fisheries • Development of fish processing infrastructure	• Hazardous material spills • Regional ecosystem collapse • Environmental hazards (sea ice, icebergs, storms, waves, fog) • Fishing moratoriums established or extended • Improved management of global fisheries • Global aquaculture development • Distance from markets • Labor scarcity
Extractive industries	• Development of advanced extraction technologies • Intensification of strategic competition and search for resource autonomy • Resolution of continental shelf extension claims	• Low market prices for resources available in the CAO • Energy transition slows down (for critical minerals) • Energy transition quickens (for oil and gas) • Discovery of new, more accessible extraction sites • Highly negative environmental impact assessments • International agreements restricting extractive development
Tourism	• Continued attraction of Arctic landscapes • Availability of icebreakers to facilitate consistent access to the North Pole	• Major accident involving a cruise ship • Global or regional financial crisis limiting leisure spending
Security and Military		
Maritime law enforcement	• Development of cargo shipping, fishing, and/or extractive industries • Smuggling and human trafficking • Terrorism • Increasing global connectivity demand leading to subsea cables in the CAO	• Enhanced maritime border security at lower latitudes • Improved space-based intelligence, surveillance, and reconnaissance • Enhanced law enforcement cooperation • Cable infrastructure resilience

Activity	Promoting Factors	Inhibiting Factors
SAR and disaster response	• Development of cargo shipping, fishing, and/or extractive industries • Investment in SAR infrastructure, including ice-capable uncrewed systems	• Asset and infrastructure capability/capacity costs • Adherence to Polar Code requirements • Improved space-based intelligence, surveillance, and reconnaissance • Enhanced SAR cooperation • Increased regulations (e.g., self-rescue or enhanced safety measures)
Military exercises	• Increased presence of other militaries • Increased tension between Russia and NATO • Perception of threat • Improvements in ship ice capability • Development of Arctic air/naval military infrastructure	• Cost and time to build Arctic-capable assets • Competing geopolitical priorities (non-Arctic)
Power projection (meeting presence with presence)	• Territorial disputes or aggression • Increased gray-zone activity • Protracted continental shelf extension claim negotiations • Increased cooperation between Russia and China • Intensification of strategic competition	• Lack of incentive for commercial activities (e.g., shipping, mining, fishing) • Strategic priorities in other regions of the world

A key observation from these factors is that activities in the CAO will not be everything all at once. They will operate on different timelines. For instance, fishing will not occur before at least the end of CAOFA in 2037. Cargo shipping will not occur in significant volumes before the TSR offers reliable access for at least two months, by midcentury, as some models project. Even within a single domain, activity will develop gradually; looking at undiscovered oil reserves in the Arctic, the USGS noted in 2009 that "the estimated oil resources, if found, would not come into production at once but rather be added to reserves and produced incrementally."[142] Future activity in the CAO will thus happen in a staggered way, with new activities gradually piling up on top of each other, and some possibly taking place together (for instance, increased SAR presence and capacity may follow increased shipping activity).

The following scenario combines analysis of the factors promoting and inhibiting various types of activities in the CAO (Table 4.1) with physical projections of when such activities may be possible from an access perspective. The four phases of the scenario thus describe successive, plausible futures of the CAO along a timeline that takes account of increasing levels of access and important decision points, such as the expiration of CAOFA. These futures include the kinds of activities we would expect to be possible in a given period of reliable access to the CAO, based on the analysis of

[142] Gautier, 2009, p. 1178.

documents and expert interviews detailed in Chapters 2 and 3.[143] The phases are not definitive predictions of what activities will occur during each time horizon, though the order in which they are likely to occur is reflected in the successive stages of ice decline depicted by the sea ice projections.[144]

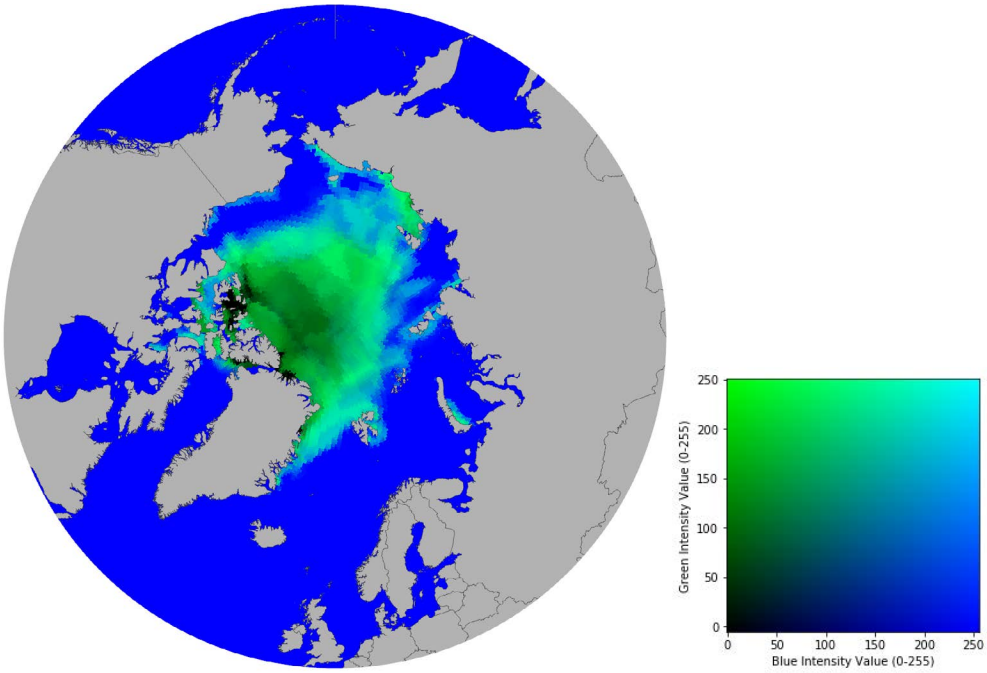
Phase 1: Activity in the CAO Remains Limited (2025–2034)

During the 2025–2034 period, the CAO may become ice-free in September at some point but will not be reliably accessible from year to year (Figure 4.1). Therefore, activities that do not depend highly on reliable access can continue to develop in the Arctic. We would expect to continue seeing tourism in the region, possibly with more and larger ships in the EEZs of Arctic states, given the current busy state of shipbuilding and the demand for Arctic tourism. However, tourism in the CAO would likely remain a rare experience, given the need for operators to have ice-capable ships devoted to this purpose and the seasonal predictability that mass tourism requires.

[143] We consider access in the CAO to be *reliable* when ice is projected to be sufficiently thin or low in concentration as to enable passage by a non–ice-strengthened vessel for a given period (e.g., one month) with low fluctuations from year to year over the period in question. It is important to note that reliable access, from a sea ice perspective, does not imply lack of other environmental hazards—such as storms, fog, and icebergs (glacier ice)—that may present significant obstacles to navigation. Further methodological details are provided in the appendix.

[144] The sea ice projections depicted in the scenarios are outputs from a global climate model (CESM2) that has been shown to well represent the observed direction and seasonality of Arctic sea ice decline (G. Danabasoglu, J.-F. Lamarque, J. Bacmeister, D. A. Bailey, A. K. DuVivier, J. Edwards, L. K. Emmons, J. Fasullo, R. Garcia, A. Gettelman, et al., "The Community Earth System Model Version 2 (CESM2)," *Journal of Advances in Modeling Earth Systems*, Vol. 12, No. 2, February 2020). Other models from the current generation of global climate models (CMIP6) exhibit different timing and magnitude of sea ice change, but all CMIP6 models project overall sea ice decline by the end of the 21st century.

Figure 4.1. Projected Reliability of Marine Access (September), 2025–2034



SOURCE: Authors' analysis of sea ice projections from the CESM2 climate model. The map is an RGB (red-green-blue) composite display of the average number of consecutive days accessible to a non–ice-strengthened vessel in September (blue band) and the standard deviation of the same (green band) from 2025 to 2034. No data are shown in the red band. Colors should be interpreted as follows: **dark blue** = high access, low variability; **dark green** = low access, high variability; **cyan** = high access, high variability; **black** = low access, low variability. The legend illustrates color intensity values of blue (x-axis) and green (y-axis) that produce these combinations. Methodological details are provided in the appendix.

Scientific activities will likely continue and maybe increase during this period, particularly to map the seabed of the CAO—including to prepare for the laying of subsea cables—and study the fisheries ecosystem in preparation for a possible lifting of CAOFA. Scientists could also conduct impact assessments of various types of activities on the Arctic marine environment, such as deep-sea mining, but we would expect these activities to take place farther south, in Arctic states' EEZs, rather than in the CAO. The installation of a transpolar subsea cable (such as Polar Connect) is very plausible, given the increased needs for cable redundancy and the appeal of reduced latency afforded by shorter routes, despite the high costs of building and maintaining such infrastructure.

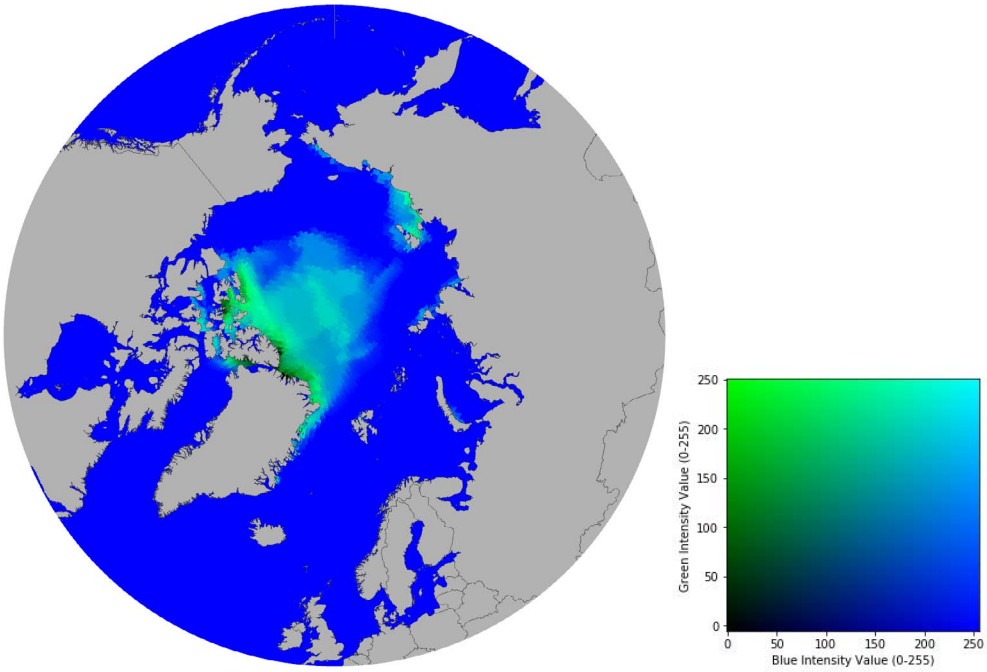
Given the very limited access that the CAO would offer during this period, any activity that can be done more easily and cheaply closer to shore is unlikely to happen in the CAO. This would include exploration for (and exploitation of) oil and gas, mining, and development of offshore wind energy. At this point, we would not expect any significant cargo shipping to take place in the CAO, given the lack of economic incentives and the risks to crew and ship given the lack of support infrastructure. Because of the limited commercial activity in the CAO, there is little need for a regular security presence there. We would expect military exercises and other deployments to take place in Arctic states' EEZs as militaries demonstrate their defense capabilities or signal presence to others.

Finally, during this period, ISA will issue regulations on deep-sea mining in the high seas. If these regulations turn out to be restrictive, we expect that this would raise the stakes for Arctic states that filed submissions before the CLCS because states would be allowed to exploit the seabed of their extended continental shelf where ISA regulations would not apply.[145] This could create tensions between states that have overlapping submissions (Canada, Denmark, Russia), particularly if these overlaps occur over ridge areas that are likely to be rich in minerals.

Phase 2: Fishing Becomes Possible, in Theory (2035–2049)

By this period, open-water access in the CAO may become reliably accessible for periods of less than one month (Figure 4.2), opening opportunities for activities that do not require long lead times or long periods of operation in one place. One such activity is fishing.

Figure 4.2. Projected Reliability of Marine Access (September), 2035–2049



SOURCE: Authors' analysis of sea ice projections from the CESM2 climate model. The map is an RGB (red-green-blue) composite display of the average number of consecutive days accessible to a non–ice-strengthened vessel in September (blue band) and the standard deviation of the same (green band) from 2035 to 2049. No data are shown in the red band. Colors should be interpreted as follows: **dark blue** = high access, low variability; **dark green** = low access, high variability; **cyan** = high access, high variability; **black** = low access, low variability. The legend illustrates color intensity values of blue (x-axis) and green (y-axis) that produce these combinations. Methodological details are provided in the appendix.

After 2037, CAOFA is automatically renewed in five-year increments unless one party to the treaty objects. Whether the latter happens will depend on the urgency for state parties to find new

[145] Marine scientist with Arctic expertise, interview with the authors, February 2025.

fisheries and on the state of the scientific evidence available at that time regarding the species, volume, and sustainability of fish stocks present in the CAO. An objection to an extension of CAOFA for another five years would likely come from Asian signatories to the treaty and the European Union, both of which advocated during the treaty negotiations for a shorter moratorium than the 16 years that were eventually decided on.[146] Parties that object to an extension would notify other parties a year or so earlier, either at the last meeting of the parties before the end of the moratorium, or at least six months before this end.[147] In practice, this means that states would start to prepare for an opening of the CAO to fishing as early as 2036, as well as possibly start engaging in discussions about the general principles of an RFMO, which would likely take several years of negotiations before any actual fishing can take place.

Several countries already have long-distance fishing fleets that could potentially exploit fishing in an ice-free CAO, such as China, Japan, South Korea, Taiwan, and the countries of the European Union.[148] China is the world's largest consumer of seafood and has mostly depleted the stocks in its coastal waters. As a result, it sends its fishing fleet, the largest deep-water fishing fleet in the world, to fish in oceans around the globe.[149] Although a percentage of China's fishing is legal, a significant portion of it is illegal and unreported.[150] China released its *14th Five Year National Fisheries Development Plan* in 2022, which detailed further expansion of China's fishing industry by 2025.[151] The plan also called for measures to make China's fishing and fisheries more sustainable, including using AI for smart fish farming and implementing systems that determine total allowable catches.[152] The enormity of China's fishing sector and its growing fish consumption is likely to drive China's interest in access to fishing resources in the Arctic, presuming that they become more obtainable and China continues to develop the maritime capability to make such efforts cost-effective enough.

In these early years, however, much will still be unknown about the fisheries of the CAO, and access would remain limited to a month or less of ice-free operations, therefore limiting fishing opportunities to those countries that have not just long-distance fishing fleets but also ice-hardened ones. We expect to likely see incursion fishing, by which vessels make opportunistic fishing voyages to the CAO when access allows and where commercially viable fish are found (if only transiently), rather than sustained activity. Even limited activity would suppose that some high-value species (or large volumes of lesser-value species) have been found to make the voyage to the CAO worthwhile. Given

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[146] Balton, 2021. David Balton (who chaired the CAOFA negotiations between 2015 and 2017) notes that, meanwhile, "those Parties whose national fishery zones surround the high seas portion of the Central Arctic Ocean—Canada, Denmark (Greenland and the Faroe Islands), Norway, Russia and the United States—would have preferred to forestall the possibility of a high seas fishery even longer" (Balton, 2021).

[147] CAOFA, Article 13, paragraph 2(a)(b).

[148] Pew Charitable Trust, "Most Long-Distance Fishing in Foreign Waters Dominated by Only a Few Governments," brief, May 2022.

[149] Steven Lee Meyers, Agnes Chang, Derek Watkins, and Claire Fu, "How China Targets the Global Fish Supply," *New York Times*, September 26, 2022.

[150] Whitley Saumweber and Ty Loft, "Distant-Water Fishing along China's Maritime Silk Road," Stephenson Ocean Security Project, July 31, 2020; Jennifer Runion, "Fishing for Trouble: Chinese IUU Fishing and the Risk of Escalation," *Proceedings*, U.S. Naval Institute, *Vol. 149, February 2023*.

[151] Hongzhou Zhang and Genevieve Donellon-May, "China's Fisheries Policy Makes a Belated Shift to Sustainability," *East Asia Forum*, April 7, 2023.

[152] Ministry of Agriculture and Rural Affairs of the People's Republic of China, *14th Five Year Fishery Development Plan*, 2022.

the paucity of current knowledge on CAO ecosystems, it is possible that there will be no commercially viable fish stocks (either because of the species found in the region—such as those that are non-edible or not appealing to humans—or because of the small stock sizes) in the CAO.

Finally, this scenario assumes that there will be scientific evidence that CAO fisheries are commercially sustainable—if that is not the case, the moratorium would likely be reconducted for at least another five years. It also assumes that the BBNJ treaty signed in 2023 is not used as the legal framework to argue that the CAO should be completely closed to all activities.[153] The BBNJ can be used to designate high seas areas as marine protected areas for ecosystem protection, which, in the case of the CAO, could mean prohibiting all human activity—including fishing, energy extraction, deep-sea mining, shipping and tourism.[154] In practice, however, the application of BBNJ to the CAO is unlikely because of several reasons: Neither Russia nor the United States is a current signatory to BBNJ; the non-Arctic signatories to CAOFA, who have agreed to the current moratorium in exchange for a seat at the table if or when the CAO opens up for commercial fishing, are unlikely to support a permanent closure of the CAO via BBNJ; and a closure of the CAO to shipping means that Arctic shipping will be pushed to the NSR, which other countries may or may not find a desirable outcome depending on the state of their relations with Russia.[155]

Some proof-of-concept cargo shipping transits along the TSR may occur in September during this phase's period (2035 through 2049). Even so, most cargo shipping will continue to use traditional routes through the Suez and Panama canals, with most Arctic cargo shipping that does occur concentrated along the NSR, carrying Russian gas and minerals to global markets, primarily in Asia. Shipping of oil, gas, and minerals will follow existing trends along the NSR and with a few destination voyages to specific mines, such as Mary River in Canada. This would suppose, however, that ships have adapted to the heavy fuel oil ban that was adopted by the IMO in 2021 and should be fully in force by 2029. Heavy fuel oil is routinely used by container ships but emits pollutants when burned, including black carbon, which accelerates sea ice melting in the Arctic. This type of fuel would also be

[153] The BBNJ agreement "does not apply to any warship, military aircraft or naval auxiliary" and therefore does not prohibit military transit or activity (Agreement Under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction, 2023, Article 4).

[154] For Arctic states, environmental concerns may not be the only reason the states support the closure of the CAO to fishing. A fisheries management phenomenon known as the *spillover effect* has been documented worldwide around marine protected areas. The *spillover effect* means that fishing efforts adjacent to an area closed to fishing generally sees higher catches, as the protected population in the protected area flourishes and "spills over" into fishing areas (Manfredi Di Lorenzo, Paolo Guidetti, Antonio Di Franco, Antonio Calò, and Joachim Claudet, "Assessing Spillover from Marine Protected Areas and Its Drivers: A Meta-Analytical Approach," *Fish and Fisheries*, Vol. 21, No. 5, September 2020).

[155] Senior U.S. expert official, personal communication with the authors, December 10, 2024. A final point is the case of Antarctica, which has seen persistent disagreement on whether marine protected areas should be established. Opposition from China and Russia has led to a stalemate, and a similar situation could take place in the Arctic—although possibly with lesser consequences because the drafters of the BBNJ were careful to select a decisionmaking process that was less constraining than the consensus rule. See Nengye Liu, "Establishing Marine Protected Areas in the Southern Ocean, Lessons for the BBNJ Agreement," *Marine Policy*, Vol. 165, July 2024.

difficult to contain and remove in the event of an oil spill.[156] The IMO also addresses greenhouse gas (GHG) emissions from ships in a 2023 strategy, which establishes the goal

> to reach net-zero GHG emissions from international shipping by or around, i.e. close to, 2050, a commitment to ensure an uptake of alternative zero and near-zero GHG fuels by 2030, as well as indicative check-points for 2030 and 2040.[157]

This ban and the 2050 ambition will affect what types of ships will be able to cross the Arctic (and navigate more broadly), as well as affect the infrastructure that may be needed at the end points of the TSR to allow ships running on biofuels, ammonia, or other alternative fuels to refill their tanks.[158]

Within this period, we would expect some exploration and survey activities in the CAO to prepare for future mining, assuming that no ISA regulations ban such activities. If international competition to safeguard the supply of critical minerals increases, one effect would likely be an intensification of these survey efforts in order to exploit Arctic minerals supply as soon as possible.

In addition, the United States, China, Finland, Russia and Sweden should have acquired one or more new icebreakers each within this period. The United States will also have three Polar Security Cutters, and Canada will have additional ice-capable OPVs. Denmark's and Norway's acquisition plans for one OPV frigate and ice-strengthened patrol vessels, respectively, might still be underway. These new assets would facilitate presence by these countries in the CAO. Any increases in fishing or cargo vessels that do occur during this time, even if marginal, would likely result in an increase in maritime law enforcement to conduct boardings and ensure compliance with agreements and regulations.

Phase 3: Shipping Begins to Develop—The TSR Is a Reality (2050–2059)

During this period, activity that only requires one to two months of reliable access can take place (Figure 4.3). This means that limited container shipping as a seasonal alternative to the Suez and Panama canals becomes possible, provided that some conditions are met, such as buildup of shore-based infrastructure and enhanced SAR and disaster response and recovery capabilities.[159] Assuming no prohibitive geopolitical instabilities or economic restrictions along the NSR, we would expect shipping to increase first in the NSR and in the deep-draft routes of the NWP, with the TSR gradually seeing more activity. The TSR may also be used for transport of minerals to global markets extracted offshore near the northern edge of state EEZs, or onshore in northern Canada or Greenland. Insurance costs, however, would remain a key factor in shipping companies' decisions because the TSR will remain hazardous even when ice-free, especially at the beginning and end of the shipping season (e.g., July and October).

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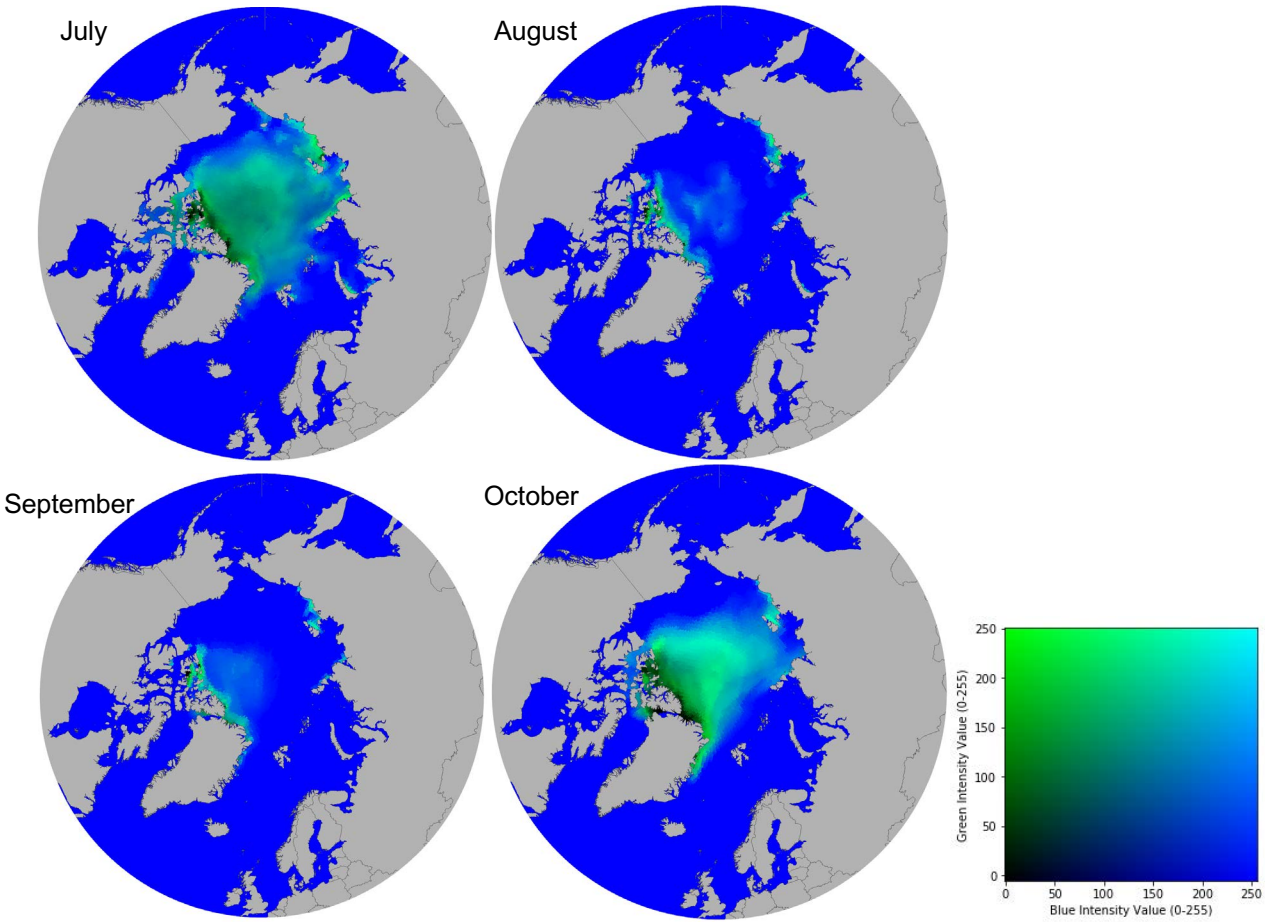
[156] "UN Adopts Ban on Heavy Fuel Oil Use by Ships in Arctic," Reuters, June 17, 2021; Matt McGrath, "Arctic 'Dirty Fuel' Ban for Ships Comes into Force," BBC News, June 30, 2024.

[157] IMO, "Revised GHG Reduction Strategy for Global Shipping Adopted," press release, July 7, 2023.

[158] Arctic shipping expert, interview with the authors, February 2025.

[159] Arctic shipping expert, interview with the authors, February 2025.

Figure 4.3. Projected Reliability of Marine Access (July–October), 2050–2059



SOURCE: Authors' analysis of sea ice projections from the CESM2 climate model. The maps are RGB (red-green-blue) composite displays of the average number of consecutive days accessible to a non–ice-strengthened vessel (blue band) and the standard deviation of the same (green band) from 2050 to 2059, in July (top left), August (top right), September (bottom left), and October (bottom right). No data are shown in the red band. Colors should be interpreted as follows: **dark blue** = high access, low variability; **dark green** = low access, high variability; **cyan** = high access, high variability; **black** = low access, low variability. The legend illustrates color intensity values of blue (x-axis) and green (y-axis) that produce these combinations. Methodological details are provided in the appendix.

At this point, transshipment hubs for cargo transported across the TSR might be built in select locations around the Arctic.[160] At such hubs, cargo could be exchanged from non–polar-class vessels to polar-class vessels for transit across the CAO to another port where the cargo is again loaded onto non–polar-class vessels. The reason for swapping cargo between vessel classes comes down to cost: Transit time across the TSR saves time when traveling between the Pacific and Atlantic oceans, but polar-class vessels are more expensive to operate.[161] This could provide economic opportunity for port

[160] For example, Finnafjord in Iceland (Malte Humpert, "Iceland Invests in Arctic Shipping with Development of Finnafjord Deep-Water Port," *High North News*, 2019).

[161] Bennett et al., 2020.

facilities at the entrances to the Arctic Ocean, such as Adak in Alaska or Tromsø in Norway, provided that the opportunity is significant enough to offset construction costs.[162]

As shipping through the CAO starts, first movers would likely be countries and companies with some degree of experience in Arctic shipping—suggesting that the flag states of ships present in Arctic waters could provide some indication of who might be most interested in using the TSR.[163] In 2022, the flag states with the most ships in the Polar Code area were, in decreasing order, Russia (with almost five times more ships than the next state on the list), Norway, Denmark, the United States, Canada, the Marshall Islands, the Netherlands, Panama, the Bahamas, Liberia, China, Portugal, Malta, the United Kingdom, Cyprus, France, Barbados, Germany, Iceland, and Singapore.[164] Aside from Russia, which will likely continue to use the NSR, these countries may have an interest in the TSR early on for long-distance voyages, assuming that the cargo in question originated outside Russia. This also assumes that these flagged vessels can find icebreaker support outside the NSR for the voyage through the TSR.

China in particular has demonstrated considerable interest in using Arctic routes—especially the NSR—for commercial shipping. Since 2013, COSCO Shipping, China's largest shipping company, has made close to a hundred voyages along the NSR, though these came to a halt in 2022 when Beijing feared sanctions from the Russia-Ukraine war.[165] A primary driver of China's pursuit of Arctic shipping routes is what Beijing perceives as a critical need to diversify China's maritime shipping options away from potentially problematic routes through the South China Sea, Malacca Strait, and Suez Canal. Another driver is the Polar Silk Road, added to China's Belt and Road Initiative in 2017 to generate political and strategic influence through infrastructure and investments in the Arctic region.[166] China's investments in energy infrastructure projects in the Russian Arctic and along the NSR have created further rationale for increased Chinese commercial presence in the region. Although China's increasingly strong partnership with Russia has supported its focus on investments and shipping along the NSR, Beijing's overall goals for its commercial Arctic strategy—to diversify shipping routes and access to energy resources—means that China will likely pursue other alternative routes as they become more viable.[167] This, in turn, could create tensions with Russia, which has been seeking to develop and promote the NSR.

Two months of open water and increased traffic would likely result in more coast guard presence to ensure governance and safety, particularly with an increased capability of different nations. We would expect that there will be a proportional increase in maritime law enforcement and SAR assets

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[162] Plans to build the first U.S. Arctic deep-draft port in Nome, Alaska were canceled in October 2024 because of cost (Ben Townsend, "Army Corp Cancels Nome Port Expansion Contracting over Costs," Alaska Public Media, October 22, 2024.)

[163] This comes with the caveat that some of these flags might be flags of convenience that indicate little about the nationality of the commercial shipping companies involved.

[164] Protection of the Arctic Marine Environment Working Group, 2023.

[165] Malte Humpert, "International Shipping on Northern Sea Route Collapses as Foreign Companies Stay Away," *High North News*, September 12, 2022.

[166] For a detailed description of the Polar Silk Road, see State Council Information Office of the People's Republic of China, *China's Arctic Policy* [中国的北极政策], 2018. See also Mia M. Bennett, "The Silk Road Goes North: Russia's Role Within China's Belt and Road Initiative," *Area Development and Policy*, Vol. 1, No. 3, 2016.

[167] Matt Puranen and Sanna Kopra, "China's Arctic Strategy—A Comprehensive Approach in Times of Great Power Rivalry," *Scandinavian Journal of Military Studies*, Vol. 6, No. 1, 2023, p. 234.

relative to the use of the CAO by commercial industries. This, however, may be limited or enhanced depending on how Arctic states' strategies evolve (for instance, if there will still be as much emphasis on survival of life at sea) and other competing global priorities.

However, ensuring timely rescue in case of an accident would remain challenging. As a result, companies may have difficulties finding sailors willing to embark on such trips.[168] An International Bargaining Forum arrangement states that seafarers should be given notice by shipping companies that they will be crossing through a high-risk area and be allowed to disembark if they wish.[169] It is thus possible that first movers on the TSR might be countries or companies that routinely disregard sailors' rights or whose crews are too economically desperate to refuse a voyage they know to be dangerous. Early interest in shipping on the TSR may also decline if a major accident were to happen. Such accidents would be more likely in this early stage because ice conditions could still be hazardous, and less-traveled routes offer fewer rescue options than in other oceans, where other ships can render assistance if needed.[170]

Another point of note is that these new shipping activities may create tensions with environmentalist groups and the broader population. Writing about the NSR, Christensen et al. describe environmental risks as "the main inhibitor for structural change and political support for largescale maritime transportation in the Arctic."[171] We would expect the same to be true for the CAO. Sustained shipping activity creates underwater noise that can be deeply disruptive to fish stocks and marine mammals.[172] Icebreaking has additional impacts on such Arctic species as caribou, seals, polar bears, narwhals, belugas, and walruses.[173] Impacts of icebreaking on deep-sea Arctic species are unknown.

During this time frame, fishing would continue to increase within the boundaries set by the RFMO as countries interested in these fishing grounds develop more ice-capable ships. However, if no RFMO had been successfully negotiated after 2037, or if a new RFMO had weak implementation mechanisms, this would be the time when the CAO's fisheries may become heavily exploited by those nations that can access the CAO—specifically, Arctic coastal nations and those nations with distant

[168] Arctic shipping expert, interview with the authors, February 2025.

[169] Jonathan Saul, "Seafarers Can Refuse to Sail Through Red Sea as Houthis Step Up Attacks—Industry," Reuters, February 16, 2024.

[170] Arctic shipping expert, interview with the authors, February 2025.

[171] Mads Christensen, Marina Georgati and Jamal Jokar Arsanjani, "A Risk-Based Approach for Determining the Future Potential of Commercial Shipping in the Arctic," *Journal of Marine Engineering and Technology*, Vol. 21, No. 2, 2022.

[172] Baraniuk, 2024.

[173] Breanna Bishop, Jade Owen, Lisette Wilson, Tagalik Eccles, Aldo Chircop, and Lucia Fanning, "How Icebreaking Governance Interacts with Inuit Rights and Livelihoods in Nunavut: A Policy Review," *Marine Policy*, Vol. 137, March 2022.

water fishing fleets—and when IUU fishing appears.[174] The most likely outcome of this would be that the fisheries collapse.[175]

Military deployments focused on a short window of access might start during this time. Any exercise would be limited to participants exploring the capabilities of new ice-capable assets with the intent to understand the challenges and limitations of operating in increasing accessible Arctic locations. Russia and Arctic states belonging to NATO may compete in conducting such exercises and demonstrating their capabilities in extreme conditions to each other in an ocean that borders all of their countries.

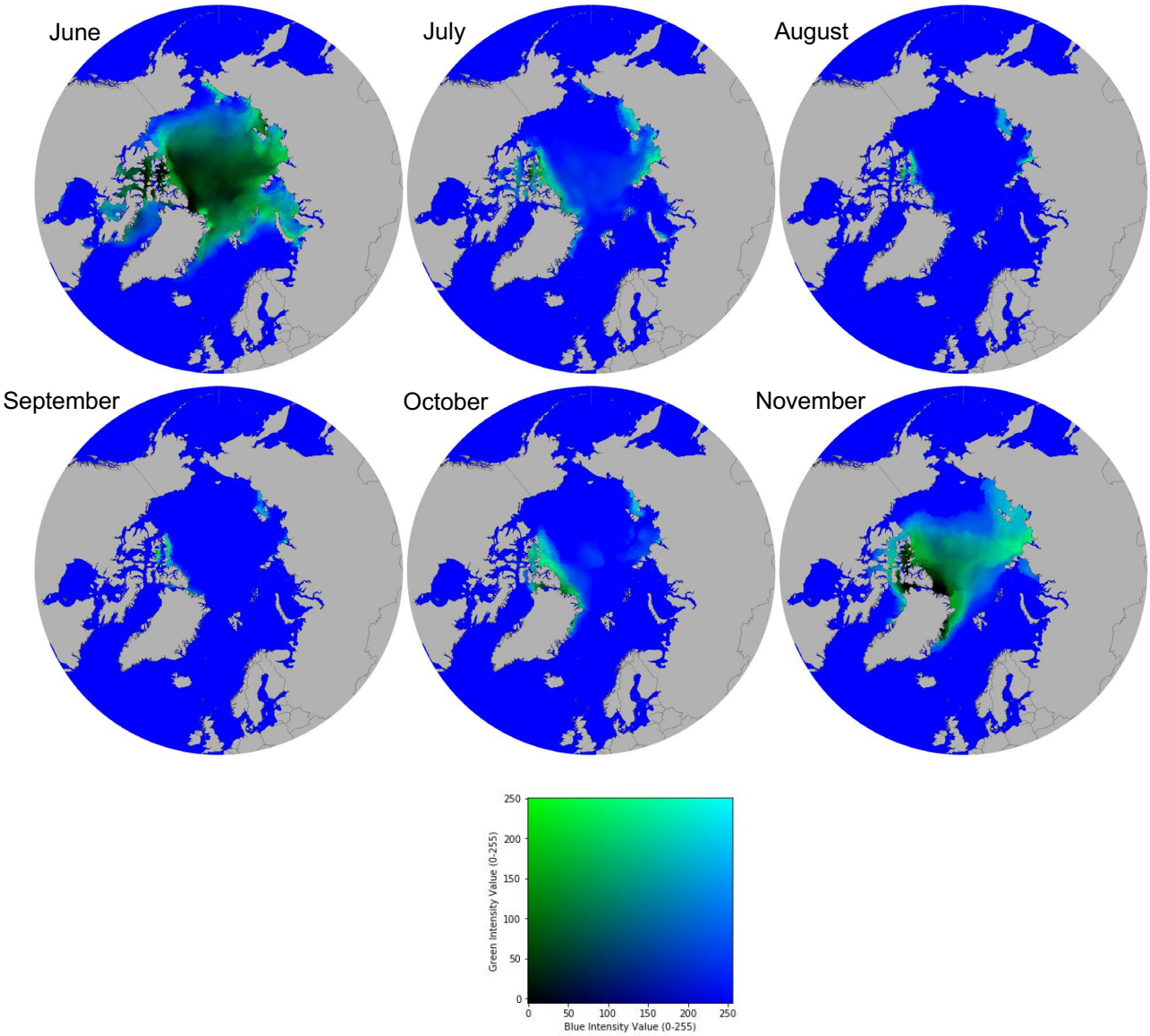
Phase 4: A Sustained Summer Presence in the CAO (2060s and Beyond)

During this period, activity that requires several months of reliable access becomes possible (Figure 4.4). Assuming that sufficiently advanced technologies have been developed by that time, exploration and exploitation of minerals in the CAO would become possible because the several months of ice-free operations in summer reduce risks of hazard both to personnel and infrastructure. Expertise in offshore drilling may put such countries as Norway or the United Kingdom at an advantage if this activity develops; they will already have some of the infrastructure and equipment needed. We would expect other countries that have prioritized having some degree of control over the supply chain for critical minerals to have developed substantial expertise in deep-sea mining. The business case for mineral extraction in the CAO would still depend on the opportunity cost of drilling in the CAO when compared with other locations, a consideration that will also be key for oil and gas exploitation.

[174] Even with an RFMO, IUU in the CAO is possible given that traditional fisheries law enforcement tools, such as the Vessel Monitoring System or Automatic Identification System, electronic monitoring, observers, or boardings, will be challenging in the Arctic. Connectivity in the Arctic is difficult, and satellite coverage is not as consistent as it is closer to the equator. Therefore, a creative and tightly controlled monitoring and law enforcement plan would be required to develop an effective monitoring and management plan. Otherwise, it is likely that there will be a major challenge with IUU fishing in the Arctic, which could endanger the long-term sustainability and viability of the fishery.

[175] Because of harsh weather conditions, it is possible that the collapse of fisheries in the CAO may be slower than what has been seen under similar pressures elsewhere in the world, such as in the Bering Sea in the 1980s (see, e.g., Vidar G. Wespestad, "The Status of Bering Sea Pollock and the Effect of the 'Donut Hole' Fishery," *Fisheries Magazine*, Vol. 18, No. 3, March 1993). However, it is unlikely that CAO fisheries will be sustainable without science-informed and effective management measures.

Figure 4.4. Projected Reliability of Marine Access (June–November), 2060–2069



SOURCE: Authors' analysis of sea ice projections from the CESM2 climate model. The maps are RGB (red-green-blue) composite displays of the average number of consecutive days accessible to a non–ice-strengthened vessel (blue band) and the standard deviation of the same (green band) from 2060 to 2069, in June (top left), July (top center), August (top right), September (bottom left), October (bottom center), and November (bottom right). No data are shown in the red band. Colors should be interpreted as follows: **dark blue** = high access, low variability; **dark green** = low access, high variability; **cyan** = high access, high variability; **black** = low access, low variability. The legend illustrates color intensity values of blue (x-axis) and green (y-axis) that produce these combinations. Methodological details are provided in the appendix.

Resource extraction in the CAO would lead to an increase in overall shipping activity because new extractive installations would require maintenance and servicing by ship.[176] More broadly, with several months of reliable access, the CAO becomes a more attractive route for cargo shipping.

[176] Arctic shipping expert, interview with the authors, February 2025.

While still minor compared with the Suez or Panama routes, the TSR can start to become a regular route during summer, with limited but consistent voyages. Reliable access along the TSR may occur for periods as long as four months. At this point, the TSR would likely already be the main Arctic route for transit shipping; it offers more-direct sailing than the NSR and does not come with Russian fees or mandatory escorts.[177] With increased shipping also comes increased risk of accident, especially because not all participants in economic activities in the CAO will respect the Polar Code.[178]

Given the additional access, trans-Arctic tourism linking locations on opposite sides of the Arctic Ocean, such as Nome, Alaska, to Svalbard could emerge, but the voyage would consist mainly of time at sea without the frequent stops that are typical of cruise voyages. For this reason, the CAO may continue to see only limited mass tourism.

On the security and military side, we expect that Arctic states will increase patrolling and surveillance near their EEZs, as well as increase the number of assets they retain for responding to vessels in distress in their area of responsibility, given the larger circulation of commercial ships. More broadly, coast guard forces of Arctic states would be performing routine and regular SAR, law enforcement, and marine protection missions in the CAO. Coast guards of non-Arctic states may be present as well. China's coast guard forces, for instance, deployed with Russian coast guard in the Bering Sea in 2024.[179] Such presence could also take place in the CAO if China and possibly other non-Arctic states intended to not only show their capabilities but also play the role of "benevolent helpers" in the CAO and demonstrate good stewardship and commitment to good governance in the region.

Mining could also drive up a security presence in the region, if companies involved were concerned about such activities as actions from activist groups that have boarded ships to protest drilling and deep-sea mining.[180] Mining companies may reach out to private companies to protect their ships from such boardings, because such activities could immobilize operations for several days, at great cost.[181] State-controlled companies may use government security or military resources for their protection, which could in turn drive up the presence of other security or military forces in the region.

We would expect military exercises to continue in the region, possibly at a larger scale as the navigation season grows longer. More broadly, the number of military assets present in the CAO would also be higher as a means of showing presence. Importantly, it would become more common for military vessels to cross over the North Pole on their way to deployments or exercises. To support this increased military presence, NATO may by this period have an Arctic command "to concentrate the particular expertise, technology and strategy necessary to operate in this singular threat environment."[182]

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[177] Arctic economic expert, interview with the authors, February 2025.

[178] Li and Lynch (2024, p. 362) noted that already Russia has been allowing "thin-hulled tankers to navigate through Arctic waters along the NSR."

[179] U.S. Coast Guard, 2024b.

[180] Shadia Nasralla, "Shell Sues Greenpeace for $2.1 Million After Activists Boarded Oil Vessel," Reuters, November 9, 2023; "Deep-Sea Mining Company Sues Greenpeace to Remove Activists from Ships," *Maritime Executive*, November 28, 2023.

[181] Marine scientist with Arctic expertise, interview with the authors, February 2025.

[182] Lee Mottola, "NATO's Arctic Command: A Case for the Expansion of NATO's Mission in the High North," Arctic Institute, January 17, 2023.

An alternative to this scenario of widespread military use is one of complete protection of the CAO. This has been mentioned in relation to the BBNJ and the opportunity it creates of turning certain areas of the high seas into marine protected areas. But even without invoking the BBNJ, scientific data may support the conclusion that the CAO is a fragile ecosystem that cannot survive sustained economic activity. These results, combined with a general lack of economic incentives to fish, drill, or mine in the CAO, could result not only in an extension of CAOFA but also in more agreements to limit other types of activities that could be destructive to the Arctic ecosystem, such as an agreement to limit ship noise pollution or to prohibit mining.[183]

[183] Arctic economic expert, interview with the authors, February 2025.

Chapter 5

Findings

The phases of the scenario outlined in Chapter 4 illustrate plausible futures of the CAO, in which new activities appear and grow over time. They also highlight several ways in which these futures could alter direction if various drivers or inhibitors of these activities were to emerge. The scenario and accompanying access projections suggest some broader findings on what we expect to see in the CAO—and who we should expect to see there—in the coming decades.

Our main finding is that **the most plausible scenario for maritime use of the CAO in the next 25 years is one of limited activity**, consisting mainly of some seasonal shipping and tourism. Fishing is prohibited until at least 2037, and although actual fish stocks are currently unknown, expectations are that it will be of limited commercial appeal. If signatories to the moratorium decide to extend the prohibition or initiate a fisheries management agreement, actual commercial fishing activities would likely start long after 2037. Regarding extractive activities, barring some radical technological advances that would make these resources easier to extract and at a competitive cost, similar resources onshore or closer to the coast will remain more attractive to exploit. There is no indication at this stage that the CAO holds unique minerals. Furthermore, the overlapping outer continental shelf extension claims create a legal ambiguity about who can mine in the CAO while also limiting opportunities for non-Arctic states to mine in unclaimed areas of international seabed.

Our other findings are as follows:

- **There are still major uncertainties about the future environment of the CAO** that are likely to remain for at least a decade or two. The likely species mix and volume of future fish stocks are unknown, as are the future wind and general weather conditions of the CAO as sea ice disappears—a factor that is critical to assess the viability of future commercial shipping.[184] Another major uncertainty is the pace of technological advances needed for oil, gas, and mineral exploitation in deeper areas of the Arctic Ocean.
- **Reliable access to the CAO does not mean safe navigation in the CAO.** The fact that cargo shipping companies likely will be able to use a transpolar route seasonally by mid-century—meaning that they can reliably expect to find that route open for a limited window of time—does not mean that they will be willing to risk encounters with other hazards, such as moving ice floes and storms, that will continue to be present in the CAO even as overall sea ice declines. These hazards will make voyages more dangerous, more expensive in equipment and insurance, and more uncertain in terms of the time to travel along the route.
- **Increased activity in the CAO from beyond the Arctic will mean that new actors will also be entering Arctic state EEZs and even territorial waters.** This increase in activity further

[184] Arctic shipping expert, interview with the authors, February 2025.

increases the risk of security and safety hazards close to shore, elevating the need for response capabilities and security presence. Currently, the U.S. Coast Guard maintains a single cutter in the Bering Sea to conduct SAR and law enforcement. A single cutter may be sufficient to conduct security operations given current traffic density patterns, but increases in commercial and illicit activity will require increased law enforcement presence to enforce domestic and international regulations because access through the CAO requires transiting the territorial waters of the United States or Russia.

- **When activities develop in the CAO, the actors best positioned to be first movers will be those that have already planned and developed the capacity to operate in this region.** Ice-capable assets will be necessary to sustain a meaningful presence in the CAO, whether for commercial, safety, or security purposes. Serious environmental hazards to navigation will remain in the CAO for decades even during ice-free periods, and only the stakeholders that adequately planned for these hazards will be able to operate safely in this region.
- **In addition to the Arctic states, non-Arctic parties, such as China, the European Union, Japan, and South Korea, are signaling that they have strategic and economic stakes in the CAO by virtue of being signatories to CAOFA.** Such interest could justify significant allocation of resources for building capacities in Arctic-capable infrastructure. It is reasonable to assume that these actors will be watching developments in the CAO closely in the coming years and weighing whether a renewal of CAOFA in 2037 is in their strategic interest.
- **Not every state stands to gain equally from an opening of the CAO**. Russia would be seriously affected by the creation of a direct competitor to the NSR, which it has sought to develop and promote as a seasonal trade route between Asia and Europe for transit shipping. Avoidance of the NSR in favor of the TSR could allow government vessels from other countries to avoid conflict associated with Russian transport regulations in its EEZ and territorial waters.[185] On the other hand, a reliably accessible TSR, even for limited periods in summer, could encourage Russia to expand its security presence northward for possible interdiction of transiting vessels, particularly if its CLCS submission to claim an extension of its continental shelf into the CAO were to be approved. Regardless, states without ice-capable assets will be least able to respond quickly to changes in the geopolitical landscape of the CAO.
- **Despite these uneven benefits, the risk of resource-driven geopolitical conflict in the CAO is limited, although accidental escalation is always possible.** Given the overall fishing, drilling, mining, and cargo shipping prospects in the CAO and the time horizons on which these activities will be possible, we do not expect a "war for resources" among states in the CAO. The security presence should be commensurate with the overall volume of shipping activity, which we do not expect to be particularly high in the near future. Military assets will be present but limited to these countries that have invested in ice-capable assets. It is true, however, that the combined security and military presence will be higher, which automatically increases the risks of collisions and other incidents that could lead to accidental escalation,

[185] Li and Lynch, 2023.

particularly between states that do not have well established high-level emergency communications.

- **The scenario examined here supposes the absence of a major disaster,** such as a cruise ship accident or oil spill, that could significantly alter the likelihood of any of these activities durably expanding in the CAO. In an area with limited rescue and response capabilities, such disasters have the potential to be particularly devastating and could deter other actors from using the CAO. Also, given the fragility of and lack of knowledge about the marine ecosystem of the CAO, even smaller incidents could cause severe damage to the environment and to the livelihoods of populations living in the Arctic. In other words, the Arctic environment magnifies the consequences of disasters, which could more easily lead Arctic stakeholders to take a precautionary approach when considering whether to operate in the CAO (as they did with CAOFA) or to respond to a disaster with measures that ban or freeze activity altogether.
- **Therefore, sustained activity in the CAO will depend on a robust presence of SAR and disaster response provisions.** Currently, neither are in place. In theory, activity could happen without such precautionary measures, but it would likely be halted after a first major incident occurs. The lack of environmental cleanup provisions could also prompt international or regional measures to seriously limit activity in the CAO following a precautionary principle. Alternatively, a marine casualty could stimulate increased capacity of response assets in the region to match the demand and use of the region. The transnational nature of SAR and disaster prevention and response in the Arctic means that cooperation among Arctic states and non-Arctic actors will be critical for sustaining economic activities in the CAO. Given the high cost of ice-capable assets, Arctic states could consider establishing a regional management system for icebreakers with coastal states providing escorts on a rotating basis and pooling funds generated this way to sustain their operational costs and/or address environmental damage caused by use of the TSR.

Appendix

Methodology for Projecting Future Arctic Maritime Access

The methodology for projecting surface maritime accessibility in the CAO uses the approach described by Stephenson and Smith and by Li and Lynch and is briefly summarized here.[186]

Daily sea ice concentration and sea ice thickness projections for the period 2025 to 2069 were obtained for the area north of 50°N from one ensemble member of the CESM2 global climate system model under the shared socioeconomic pathway 5-8.5 scenario.[187] From these projections, a risk index outcome (RIO) value representing the degree of risk that ice conditions pose to vessels was calculated for each day of sea ice data. RIO is calculated as follows:

$$RIO = \sum_{i=1}^{n} C_i RIV_i$$

where C_i is the ice concentration of ice thickness category i, and RIV_i is the risk index value corresponding to ice thickness category i and the assumed vessel class. RIV is a whole number ranging from −8 to 3 (higher values indicate lower risk), representing the combination of the ice thickness at the location and the vessel's capability in ice (i.e., its Polar Class).[188] In this study, vessels were assumed to be "open-water" vessels with no ice capability. Accessibility of a location to a given vessel class is defined to be possible where the RIO value is greater than 0. Therefore, for a given day of ice projections from CESM2, areas with an RIO greater than 0 were defined as accessible to an open-water vessel on that day.

RIO data were resampled to raster format in a 25-km Lambert azimuthal equal-area projection using nearest-neighbor interpolation. Gridded consecutive "accessible days" per month from 2025 to 2069 were calculated using raster addition of all days within the month, where grid cells with RIO greater than 0 were classified as 1 and all other grid cells were classified as 0. Average and standard deviation rasters of the consecutive accessible days per month were calculated across years in the four periods represented in Chapter 4: 2025 to 2034, 2035 to 2049, 2050 to 2059, and 2060 to 2069. Red-green-blue (RGB) composite images (Figures 4.1, 4.2, 4.3, and 4.4) were created by combining the average and standard deviation rasters to visualize both quantities simultaneously, with the average in

[186] Scott R. Stephenson and Laurence C. Smith, "Influence of Climate Model Variability on Projected Arctic Shipping Futures," *Earth's Future*, Vol. 3, No. 11, 2015; Li and Lynch, 2023.

[187] The atmospheric component of CESM2 used in this research is WACCM6 (Whole Atmosphere Community Climate Model Version 6). For more details, see Danabasoglu et al. (2020). Shared socioeconomic pathway 5-8.5 (SSP585) corresponds to a high-emissions climate scenario in which development driven by fossil fuels is assumed to continue.

[188] For a detailed lookup table of RIV for a range of vessel classes, see Li and Lynch (2023).

the blue band, the standard deviation in the green band, and a zero value in the red band. Access in the CAO was defined as *reliable* in months when the average was high and the standard deviation was low, indicating low fluctuations of a high number of consecutive accessible days from year to year.

To obtain the time-optimal routes minimizing total travel time from Rotterdam, the Netherlands, to the Bering Strait (Figure 2.1), least-cost routes were calculated using Dijkstra's algorithm, where the center point of each adjacent grid cell was considered as a node in a network.[189] Recommended vessel speed limits corresponding to RIO were obtained from IMO guidelines and assigned to locations based on RIO value.[190] Route paths were calculated using a geographic information system.

[189] Dijkstra's algorithm works by iteratively calculating the shortest path, in cost-saving terms (here, time traveled between nodes in a network), between an origin node and every other node that lies between the origin and the destination node. The algorithm stops once the destination has been reached.

[190] IMO, "Guidance on Methodologies for Assessing Operational Capabilities and Limitations in Ice," June 6, 2016.

Abbreviations

AI	artificial intelligence
BBNJ	Biodiversity Beyond National Jurisdiction
CAO	Central Arctic Ocean
CAOFA	Central Arctic Ocean Fisheries Agreement
CLCS	Commission on the Limits of the Continental Shelf
EEZ	exclusive economic zone
GHG	greenhouse gas
IMO	International Maritime Organization
ISA	International Seabed Authority
IUU	illegal, unreported, and unregulated
NATO	North Atlantic Treaty Organization
NSR	Northern Sea Route
NWP	Northwest Passage
OPV	offshore patrol vessel
RFMO	regional fisheries agreement organization
SAR	search and rescue
TSR	Transpolar Sea Route
UNCLOS	United Nations Convention on the Law of the Sea
USGS	U.S. Geological Survey

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