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Projections for Arctic Marine Accessibility: Risk under Climate Change

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PROJECTIONS FOR ARCTIC MARINE ACCESSIBILITY: RISK UNDER CLIMATE CHANGE

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ABSTRACT

Few transformations in Earth systems are as dramatic as those currently occurring in the Arctic. This Article reveals the emergence of a new route regime in response to the evolving context of climate change and human pressures. This paradigm shift presents both opportunities for Arctic exploration and maritime trade, as well as risks for marine ecosystems and coastal communities. It underscores the need for concerted efforts to recalibrate the associated legal framework.

I. INTRODUCTION

Climate change is exerting a profound impact, unbalancing ecosystems, disrupting societies, and reshaping economic landscapes. The Arctic region, which is believed to contain thirty percent of the world's untapped gas and thirteen percent of its undiscovered oil,[1] is igniting transparent geopolitical aspirations.

The Arctic Ocean presents daunting challenges due to its winter darkness, remoteness, and harsh conditions, but has nevertheless prompted human incursions spanning centuries. The abundant living and mineral resources, the potential for new scientific discoveries and new territories, the opportunities to flourish in long established peripheral homelands—these diverse purposes have supported an Arctic that is far from empty. From the 16th century onward, Arctic Ocean traverses originating in Europe and North America increased—motivated by these opportunities and supported by the emerging legal principles of freedom of navigation. The ability to control the use of the Arctic Ocean became increasingly valuable over time, supporting colonial and strategic developments, along with commercial ones.

Now, Arctic sea ice is in rapid retreat.[2] Summer minimum sea ice extent has retreated to levels not observed since at least 1850.[3] The lowest sea ice extents on record have all been observed within the last 17 years.[4] An ice-free summer is on the horizon. More than any other Arctic trend, this massive transition has raised expectations for both new opportunities and new challenges, in hydrocarbon exploitation, international shipping, infrastructure development, fisheries, tourism, and Indigenous self-determination.[5] However, it concurrently raises concerns about customary

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1. Donald L. Gautier et al., *Assessment of Undiscovered Oil and Gas in the Arctic*, 324 SCIENCE 1175, 1175-1179 (2009).

2. Aiguo Dai et al., *Arctic Amplification is Caused by Sea-Ice Loss Under Increasing CO_2*, 10 NATURE COMMC'NS 1, 2 (2019); Yeon-Hee Kim et al., *Observationally-Constrained Projections of an Ice-Free Arctic Even Under a Low Emission Scenario*, 14 NATURE COMMC'NS 1, 4 (2023).

3. John E. Walsh et al., *A Database for Depicting Arctic Sea Ice Variations Back to 1850*, 107 GEOGRAPHICAL REV. 89, 89 (2017).

4. *Arctic Sea Ice Minimum at Sixth Lowest Extent on Record*, NAT'L SNOW & ICE DATA CTR. (Sept. 25, 2023), https://nsidc.org/arcticseaicenews/2023/09/arctic-sea-ice-minimum-at-sixth/ [https://perma.cc/58Y3-839A].

5. Albert Buixadé Farré et al., *Commercial Arctic Shipping through the Northeast Passage: Routes, Resources, Governance, Technology, and Infrastructure*, 37 POLAR GEOGRAPHY 298, 301 (2014).

and commercial fisheries, strategic postures, and environmental risks tied to the race to the North.[6]

The interactions among geophysical conditions and stakeholder responses pose challenges to our ability to plan adaptive responses across these disparate domains and to forge agreements driven by common interests and grounded in sound science. Furthermore, there is uncertainty regarding the future trajectories. At present, Arctic state responses to the invasion of Ukraine by Russia render polar aspirations complex and difficult,[7] as the typically cooperative Arctic gives way to increasing separation between Russia and the other member states of the Arctic Council.[8] In the context of North Atlantic Treaty Organization's (NATO) response to the Russian invasion of Ukraine, sanction regimes in response to events at lower latitudes have an impact on Arctic operations.[9]

Arctic Ocean navigability is critical for all Arctic operations.[10] The importance of sea routes has typically resided in their ability to transport large volumes of goods more cheaply and safely.[11] But navigability affects all activities in the Arctic, and is an intricate interplay of many factors, including ice retreat under climate change, the threat of polar storms, emergency management, sovereignty and its association with permitting and tariffs, satellite coverage, workforce capacity, insurance, ice breaker technology, port availability, environmental impacts assessments, commodities prices, and more.[12]

Making measured progress in this complex space requires careful attention to what can and cannot be known and with what lead timescales, with particular attention paid to the scientific bases that can have the greatest impact on outcomes. One open question in determining navigability is the impact of evolving climate system characteristics on marine accessibility.

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6. Edward H. Allison & Hannah R. Bassett, *Climate Change in the Oceans: Human Impacts and Responses*, 350 SCIENCE 778, 778-80 (2015).

7. Michael A. Goldstein et al., *Conflict's Impact Raises Costs for Arctic Shipping and the Climate*, 606 NATURE 250 (2022).

8. *See generally* Serafima Andreeva, *Science at Stake–Russia and the Arctic Council*, 14 ARCTIC REV. ON L. & POL. 112, 113, 118 (2023).

9. *See* Michael A. Goldstein et al., *Sanctions or Sea Ice: Costs of Closing the Northern Sea Route*, 50 FIN. RSCH. LETTERS 103257 (2022); Goldstein et al., *supra* note 7.

10. Amanda H. Lynch et al., *The Interaction of Ice and Law in Arctic Marine Accessibility*, PROC. OF THE NAT'L ACAD. OF SCI., June 21, 2022, at 1.

11. *See* Enoil de Souza Júnior et al., *Rotas Marítimas no Ártico* [*Arctic Sea Routes*], 27 CADERNO DE GEOGRAFIA [GEOGRAPHY NOTEBOOK] 748, 748-49 (2017).

12. *See* ARCTIC COUNCIL, ARCTIC MARINE SHIPPING ASSESSMENT 2009 REPORT 16-35 (2009).

II. PROJECTIONS FOR ARCTIC MARINE ACCESSIBILITY

Arctic marine accessibility is derived using the Arctic Transportation Accessibility Model (ATAM),[13] the maritime shipping component of which is based on the International Association of Classification Societies' (IACS) Polar Operational Limit Assessment Risk Index System (POLARIS) decision support system,[14] is the fundamental tool for projecting accessibility.

This model defines a Risk Index Outcome (RIO) metric that quantifies the viability of ship operation encountering a specific ice regime based on the ice thickness and concentration, and the vessel class, which ranges from open water (OW) and Polar Class 7 (summer and autumn operation in thin first-year ice) to Polar Class 1 (vessels approved for year-round operation in all polar waters).[15] The transit speed to safely operate is solved based on the relationship between RIO and recommended speed limits.[16] Optimal routes are identified using Dijkstra's algorithm between the nodes of Rotterdam, Netherlands and the Bering Strait.[17] The optimal (least-time) path and associated travel time of a single transit is realized only when a full transit between the two nodes is possible.[18]

This algorithm is driven by output from the Coupled Model Intercomparison Project, phase 6 (CMIP6),[19] which incorporates the results of around 100 simulations produced by forty-nine different

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13. *See* Xueke Li et al., *Arctic Shipping Guidance from the CMIP6 Ensemble on Operational and Infrastructural Timescales*, 167 CLIMATIC CHANGE 2 (2021); *see* Laurence C. Smith et al., *New Trans-Arctic Shipping Routes Navigable by Midcentury*, PROC. NAT'L ACAD. SCI., Mar. 4, 2013, at 1.

14. Laurent Fedi et al., *Arctic Navigation: Stakes, Benefits and Limits of the Polaris System*, 13 J. OCEAN TECH. 54, 60 (2018); *see* M. A. Stoddard et al., *Making Sense of Arctic Maritime Traffic Using the Polar Operational Limits Assessment Risk Indexing System (POLARIS)*, 34 IOP CONFERENCE SERIES: EARTH & ENVT'L SCI. 1, 1 (2016).

15. International Maritime Organization, U.N. Doc. MSC.1/Circ. 1519, at 4-5 (June 6, 2016) [https://perma.cc/5Q9W-ZV9B].

16. *Id.* at 5-6.

17. Charles H. Norchi & Amanda H. Lynch, *Arctic Navigation and Climate Change: Projections from Science for the Law of the Sea*, 99 INT'L L. STUD. 491, 511 (2022).

18. Xueke Li & Amanda H. Lynch, *New Insights into Projected Arctic Sea Road: Operational Risks, Economic Values, and Policy Implications*, 176 CLIMATIC CHANGE 1, 4 (2023); *see generally* Xueke Li et al., *supra* note 13, at 23.

19. Veronika Eyring et al., *Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) Experimental Design and Organization*, 9 GEOSCIENTIFIC MODEL DEV. 1937, 1938 (2016).

modeling groups for the 20th and 21st centuries.[20] Past simulations are based on observed forcing by solar variability, volcanic eruptions, and atmospheric composition as impacted by aerosol loads and greenhouse gas emissions.[21] Each model is projected into the future according to the changing atmospheric composition implied by a set of Shared Socioeconomic Pathways (SSPs).[22] The SSPs integrate dimensions across population, energy transitions, land-use change, air pollution emissions, and more.[23] Four illustrative emissions scenarios treated as Tier 1 experiments[24] are used in this study (**Table 1**). Notably,

> in the mid-term period (2041-2060), global warming of 2°C relative to the historical level (1850-1900) is very likely to be exceeded under the very high emissions scenario (SSP5-8.5), likely to be exceeded under the high emissions scenario (SSP3-7.0), and more likely than not to be exceeded under the intermediate emissions scenario (SSP2-4.5).[25]

According to the sixth assessment of the Intergovernmental Panel on Climate Change (AR6), the globe is very likely to be on emissions pathways between SSP3-7.0 and SSP2-4.5.[26] Following 2023's research on New Insights into Prohected Arctic Sea Road, we utilize fourteen general circulation models (GCMs) that have sea ice cover well validated for the 20th century (**Table 2**).[27] For models that provide more than one realization, we plan to use one ensemble member from each model for consistency.

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20. *See* Zeke Hausfather, *CMIP6: The Next Generation of Climate Models Explained*, CARBONBRIEF (Feb. 12, 2019), https://www.carbonbrief.org/cmip6-the-next-generation-of-climate-models-explained [https://perma.cc/GV4P-JJ9F].

21. Norchi & Lynch, *supra* note 17, at 511.

22. *Id.*

23. Li & Lynch, *supra* note 18, at 3; Li et al*., supra* note 18, at 4.

24. Brian C. O'Neill et al., *The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6*, 9 GEOSCIENCE MODEL DEV. 3461, 3470-71 (2016).

25. Li & Lynch, *supra* note 18, at 4; *see generally* Li et al., *supra* note 18.

26. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2021: THE PHYSICAL SCI. BASIS, CONTRIBUTION OF WORKING GRP. I. TO THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (Valérie Masson-Delmotte et al., eds., 2021).

27. Li & Lynch, *supra* note 18, at 2; Dirk Notz et al., *Arctic Sea Ice in CMIP6*, 47 GEOPHYSICAL RSCH. LETTERS 1, 1 (2020).

Table 1: *The magnitude of emissions, pollution control and resulting temperature differences for each scenario.*[28] *Global surface temperature differences are relative to that averaged over the period of 1850-1900. Near-term covers the period 2021-2040; mid-term covers 2041-2060. SLCF denotes "short-lived climate forcers."*

	SSP5-8.5	SSP3-7.0	SSP2-4.5	SSP1-2.6
GHG emissions	Very high	High	Medium	Low
Pollution control	Strong	Weak (high SLCF emissions)	Medium	Strong
Best estimate (near-term; °C)	1.6	1.5	1.5	1.5
Best estimate (mid-term; °C)	2.4	2.1	2.0	1.7

Table 2: *List of Coupled Model Intercomparison Project phase 6 (CMIP6) general circulation models (GCMs) by institutional acronym used in the study, with their nominal horizontal resolution.*

CMIP6 Models	Host Institution	Nominal Horizonal Resolution
ACCESS-CM2[29]	Australian Community Climate and Earth System Simulator, Australia	360 × 300

28. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *supra* note 26 at 6.
29. Martin Dix et al., *CSIRO-ARCCSS ACCESS-CM2 model output prepared for CMIP6 CMIP*, EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.CMIP.CSIRO-ARCCSS.ACCESS-CM2 [https://perma.cc/44GW-WFC6].

CMIP6 Models	Host Institution	Nominal Horizonal Resolution
AWI-CM-1-1-MR[30]	Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Germany	Unstructured grid in the horizontal with 830305 wet nodes
BCC-CSM2-MR[31]	Beijing Climate Center, China	360 × 232
CESM2[32]	National Center for Atmospheric Research (NCAR), USA	320 × 384
CESM2-WACCM[33]	National Center for Atmospheric Research (NCAR), USA	320 × 384
CNRM-CM6-1[34]	Centre National de Recherches Meteorologiques, France	362 × 294
IPSL-CM6A-LR[35]	Institut Pierre-Simon Laplace, France	362 × 332

30. Tido Semmler et al., *AWI AWI-CM1.1MR model output prepared for CMIP6 ScenarioMIP*. EARTH SYS. GRID FED'N (2019), https://epic.awi.de/id/eprint/53702/ [https://perma.cc/WK27-TQB3].

31. Xiaoge Xin et al., *BCC BCC-CSM2MR model output prepared for CMIP6 ScenarioMIP*. EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.BCC.BCC-CSM2-MR [https://perma.cc/U8E7-32TF].

32. Gokhan Danabasoglu, *NCAR CESM2 model output prepared for CMIP6 ScenarioMIP*, EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.NCAR.CESM2.ssp245 [https://perma.cc/Q5U8-L2PL].

33. Gokhan Danabasoglu, *NCAR CESM2-WACCM model output prepared for CMIP6 ScenarioMIP*, EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.NCAR.CESM2-WACCM [https://perma.cc/MPE8-PJHY].

34. Aurore Voldoire*, CNRM-CERFACS CNRM-CM6-1 model output prepared for CMIP6 ScenarioMIP*. EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.CNRM-CERFACS.CNRM-CM6-1.ssp585 [https://perma.cc/2HAB-8DKF].

35. Olivier Boucher et al., *IPSL IPSL-CM6A-LR model output prepared for CMIP6 ScenarioMIP*, EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.IPSL.IPSL-CM6A-LR [https://perma.cc/BU6R-SPAJ].

CMIP6 Models	Host Institution	Nominal Horizonal Resolution
MIROC6[36]	Japan Agency for Marine-Earth Science and Technology, Japan	360 × 256
MIROC-ES2L[37]	Japan Agency for Marine-Earth Science and Technology, Japan	360 × 256
MPI-ESM1-2-HR[38]	Max Planck Institute for Meteorology, Germany	802 × 404
MPI-ESM1-2-LR[39]	Max Planck Institute for Meteorology, Germany	256 × 220
MRI-ESM2-0[40]	Meteorological Research Institute, Japan	360 × 364
NorESM2-LM[41]	NorESM Climate Modeling Consortium, Norway	360 × 384

36. Hideo Shiogama at el., *MIROC MIROC6 model output prepared for CMIP6 ScenarioMIP*. EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.MIROC.MIROC6 [https://perma.cc/V8HL-6A24].

37. Kauro Tachiiri et al., *MIROC MIROC-ES2L model output prepared for CMIP6 ScenarioMIP*, EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.MIROC.MIROC-ES2L [https://perma.cc/WLR6-KEYK].

38. Martin Schupfner at el., *DKRZ MPI-ESM1.2-HR model output prepared for CMIP6 ScenarioMIP*, EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.DKRZ.MPI-ESM1-2-HR [https://perma.cc/9DSS-YXT7].

39. Karl-Hermann Wieners et al., *MPI-M MPIESM1.2-LR model output prepared for CMIP6 ScenarioMIP*. EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.MPI-M.MPI-ESM1-2-LR.ssp245 [https://perma.cc/4QHD-NTKP].

40. Seiji Yukimoto et al., *MRI MRI-ESM2.0 model output prepared for CMIP6 ScenarioMIP*, EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.MRI.MRI-ESM2-0 [https://perma.cc/42YU-MMPC].

41. Øyvind Seland et al., *NCC NorESM2-LM model output prepared for CMIP6 ScenarioMIP*. EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.NCC.NorESM2-LM.ssp245 [https://perma.cc/PP8M-E6QK].

CMIP6 Models	Host Institution	Nominal Horizonal Resolution
NorESM2-MM[42]	NorESM Climate Modeling Consortium, Norway	360 × 384

Utilizing this computational framework, we are able to demonstrate that the Arctic is reliably navigable for non-ice-strengthened OW vessels by mid-century under all but the most aggressive emission control scenario (**Figure 1**). The shipping season length grows significantly under all scenarios until 2050.[43] This is consistent with observations of the growing utilization along the Russian-administered Northern Sea Route (NSR), although this enhanced activity is conditioned by geopolitical and economic factors as well. It has been observed that annual tonnage totals increased substantially from around four million tons in 2013 to almost twenty-five million tons in 2018.[44] Cargoes are comprised of dry goods, oil, and gas. Since the inception of the Russo-Ukrainian war and associated sanctions,[45] data reveals an increasing dependence on the NSR for the transportation of oil, particularly domestically within Russia, and between Russia and China.[46] In 2021, nearly twenty-eight million tons of oil, natural gas, petroleum products, coal, and ore concentrate had traversed the NSR.[47] A significant and notable development is Russia's authorization of thin-hulled tankers to navigate through Arctic waters along the NSR. Departing from the Polar Code and conventional practices, this authorization introduces a high level of environmental risk.[48] Thin-

42. Mats Bentsen et al., *NCC NorESM2-MM model output prepared for CMIP6 ScenarioMIP*. EARTH SYS. GRID FED'N (2019), https://www.wdc-climate.de/ui/cmip6?input=CMIP6.ScenarioMIP.NCC.NorESM2-MM [https://perma.cc/LA39-Y8H7].

43. Björn Gunnarsson, *Recent Ship Traffic and Developing Shipping Trends on the Northern Sea Route—Policy Implications for Future Arctic Shipping*, 124 MARINE POL'Y 1, 4 (2021).

44. Xiaoyang Li et al., *Spatial and Temporal Variations of Recent Shipping Along the Northern Sea Route*, 27 POLAR SCI. 1, 1 (2021).

45. Goldstein et al., *supra* note 7, at 250.

46. *See* Li et al., *supra* note 43.

47. IGNA BANSHCHIKOVA, CROSSING THE LINE: HOW THE INCREASE IN SHIPPING TRAFFIC THREATENS THE BERING STRAIT 14 (2022).

48. Jeremy Hsu, *Tanker Surge Raises Risk of Oil Spills*, NEWS SCIENTIST (Oct. 7, 2023), https://www.newscientist.com/article/2394675-surge-of-russian-tankers-in-the-arctic-is-raising-risk-of-oil-spills/ [https://perma.cc/W8XU-8AQU].

hulled tankers now traverse icy waters without the robust oil spill response capabilities typically associated with Arctic operations.[49]

Scenarios in the second half of the 21st century highlight the advantages of high emissions trajectories for international shipping and cabotage in the Arctic. The season length, even for open water vessels, continues to grow under all but the most aggressive emissions control scenarios. This is even consistent with constrained scenarios that project a high likelihood of an ice-free Arctic between July and October (the peak shipping season) after 2050.[50]

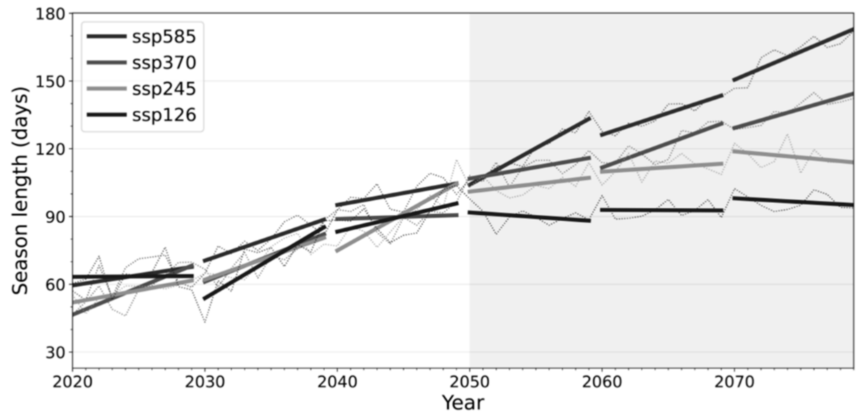

Figure 1: *Projected change in the shipping season length for OW vessels under varying levels of anthropogenic emissions from 2020-2079.*[51]

III. THE EMERGING REGIME

In addition to a lengthening season for open water vessel accessibility, these future scenarios also reveal a new route regime, whereby transpolar routes emerge (**Figure 2**).[52] The emergence of the new regime is likely to bring both opportunities and risks to the Arctic. For example, geographic

49. *Id.*

50. David B. Bonan et al., *Constraining the Date of a Seasonally Ice-Free Arctic Using a Simple Model*, 48 GEOPHYSICAL RSCH. LETTERS 1, 1 (2021); Boucher et al., *supra* note 35.

51. Figure 1 created by authors. The thin dotted line represents interannual variability averaged across 14 CMIP6 GCMs, while the thick solid line represents decadal trend over the corresponding season length. The light grey shading indicates the period during which divergence in scenario trajectories is observed.

52. Norchi & Lynch, *supra* note 17, at 506; Li & Lynch, *supra* note 18, at 7.

shifts across national and political boundaries may create the potential for conflict over newly shared resources.[53]

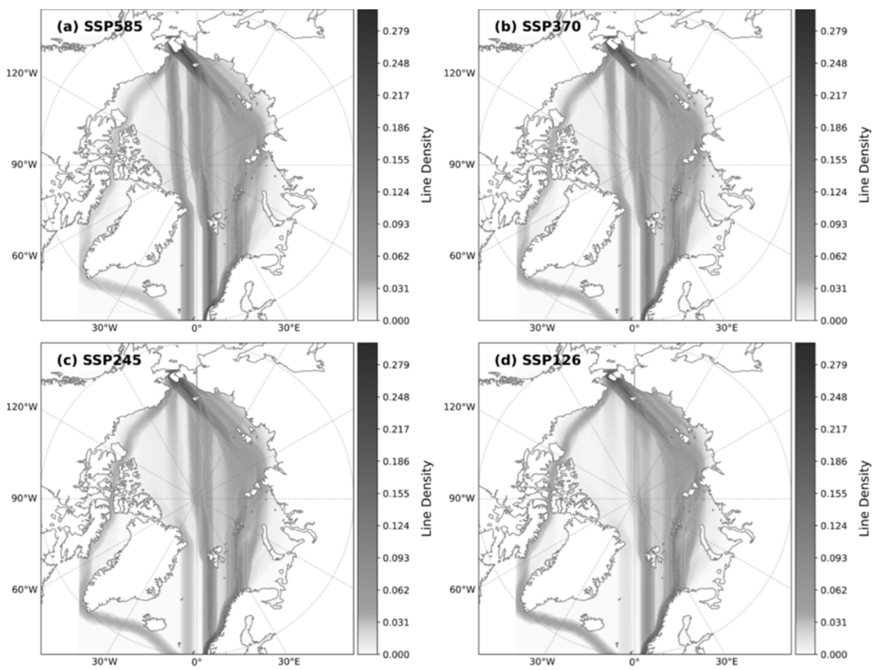

Figure 2: *Projected spatial distribution of navigable trans-Arctic shipping routes over the period 2020-2079.*[54]

IV. Environmental Risk and Legal Framework

The ramifications of the emerging regime are manifold. Firstly, the Arctic is widely perceived as the world's pristine ecosystem. With the emergence of new and faster transpolar routes, the escalating maritime traffic in the Arctic raises concerns about heightened levels of plastic pollution.[55] Once introduced into the Arctic, plastic pollution tends to aggregate in specific areas, adversely affecting local ecosystems through

53. Malin L. Pinsky et al., *Preparing Ocean Governance for Species on the Move*, 360 Sci. 1189, 1191 (2018).

54. Figure 2 created by authors. Transit density is colored based on the proportion of total transits that falls within a defined radius (unit: km). Each transit carries equal weight in the calculation of line density.

55. Melanie Bergmann et al., *Plastic Pollution in the Arctic*, 3 Nature Revs. Earth & Env't 323, 332 (2022).

entanglements and ingestion of marine debris.[56] Despite the presence of marine plastic policies in many Arctic countries, their implementation varies across regions, and there lacks a cohesive pan-Arctic framework to address marine plastic pollution.[57]

Secondly, maritime transport, particularly when utilizing heavy fuel oil (HFO) and operating in environmentally sensitive areas like the Arctic, substantially augments black carbon emissions (commonly known as soot) due to incomplete combustion of fossil fuels.[58] These particulate matters not only induce climate impacts upon deposition on ice and snow, absorbing solar radiation and hastening melting but also contribute to degraded air quality and potential health repercussions.[59] The years 2015 to 2019 witnessed a disconcerting surge in black carbon levels attributed to the intensified shipping activity.[60] Recognizing the urgency of this issue, the International Maritime Organization (IMO) took a significant stride in 2021 by adopting a ban on the use and carriage of HFO in the Arctic.[61] Nevertheless, considerable uncertainty persists in estimating future transpolar shipping, given that even a slight deviation from the traditional routes (e.g., Panama and Suez Canals) has the potential to result in a substantial increase in Arctic black carbon emissions.[62] There is, however, a reduced regulatory friction pertaining to protection against marine pollution in ice-covered seas in accordance with the provisions of the UN Convention on the Law of the Sea (UNCLOS) Article 234.[63]

Thirdly, the anticipated environmental concerns and the projected accessibility in high seas present formidable challenges for marine conservation in areas of marine biodiversity beyond national jurisdiction

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56. *See id.* at 325-30.

57. Jannie F. Linnebjerg et al., *Review of Plastic Pollution Policies of Arctic Countries in Relation to Seabirds*, 6 FACETS 1, 14 (2021).

58. Xueke Li et al., *The Impact of Black Carbon Emissions from Projected Arctic Shipping on Regional Ice Transport*, 57 CLIMATE DYNAMICS 2453, 2454 (2021).

59. Xueke Li et al., *Evaluating the Use of DMSP/OLS Nighttime Light Imagery in Predicting PM2.5 Concentrations in the Northeastern United States*, 9 REMOTE SENSING 1, 1-2 (2017).

60. Sian Prior, *Why Governments Must Cut Shipping's Black Carbon Emissions to Save the Arctic*, HIGH N. NEWS, (Mar. 22, 2022), https://www.highnorthnews.com/en/why-governments-must-cut-shippings-black-carbon-emissions-save-arctic [https://perma.cc/ELB7-WPPW].

61. Li et al., *supra* note 57, at 2455.

62. BRYAN COMER ET AL., PREVALENCE OF HEAVY FUEL OIL AND BLACK CARBON IN ARCTIC SHIPPING, 2015 TO 2025 v-vi (2017).

63. Amanda H. Lynch et al., *The Interaction of Ice and Law in Arctic Marine Accessibility*, 119 PROC. NAT'L ACAD. SCIENCE 1, 1 (2022); Norchi & Lynch, *supra* note 17, at 504-05.

(BBNJ). The environmental conditions of the emerging new transpolar routes are believed to be more favorable for establishment.[64] Consequently, the risk of ship-mediated biological invasions is expected to rise through ballast or wastewater discharges.[65] The seasonally or perennially ice-free conditions projected in the nearshore Arctic Ocean by mid-century or earlier, akin to those of the mid-Pliocene, may facilitate the migration of trans-Arctic invaders from the Pacific to the Atlantic via the Bering Strait.[66]

Lastly, commercial fisheries' interests are intertwined with climate-driven poleward shifts in the distributions of marine species,[67] enabled by the accessibility of the new Arctic regime.[68] Regions characterized by high marine biodiversity often experience more pronounced rates of climate change and seasonal shifts.[69] The number of exclusive economic zones (EEZs) with new transboundary stocks increases with global temperature.[70] Despite this, existing fisheries management and governance are largely predicted on population geographies that have remained static over time.[71] In connection with this, the current legal framework for the international regulation of fisheries does not directly account for fluctuating or changing distributions,[72] introducing a significant level of uncertainty in quantitative predictions.

In summary, the environmental governance of shipping lags behind that of other transportation sectors, necessitating concerted efforts from a multitude of different parties—including climate scientists, environmentalists, legal experts, and agencies such as the IMO—to bring about essential reforms. Our work provides measures for good governance, highlighting special zones for marine protection and conservation amid amplified Arctic warming. This contribution aims to enrich the ongoing dialogue on regulations for new transpolar routes and cooperative management under climate change.

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64. A. Whitman Miller & Gregory M. Ruiz, *Arctic Shipping and Marine Invaders*, 4 NATURE CLIMATE CHANGE 413, 414 (2014).

65. *Id.* at 415.

66. Geerat J. Vermeij & Peter D. Roopnarine, *The Coming Arctic Invasion*, 321 SCI. 780, 780-81 (2008).

67. Allison L. Perry et al., *Climate Change and Distribution Shifts in Marine Fishes*, 308 SCI. 1912, 1912-15 (2005).

68. *See* Li & Lynch, *supra* note 18, at 2 (discussing emergence of new Arctic regime).

69. Michael T. Burrows et al., *The Pace of Shifting Climate in Marine and Terrestrial Ecosystems*, 334 SCI. 652, 652-55 (2011).

70. Pinsky et al., *supra* note 52, at 1189-91.

71. *Id.* at 1189.

72. *Id.* at 1190.