

RESEARCH ARTICLE

Arctic shipping 2013–2022: the traffic has grown, with big variation between regions, seasons and ship types

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Abstract

This article analyses decadal changes in Arctic ship traffic from 2013 to 2022, using data from the Arctic Ship Traffic Data system (ASTD). Shipping in waters affected by sea ice has grown, but how much depends on geographical definitions. The Polar Code area had an average annual growth of 8.7%, mainly due to more traffic in the Barents Sea, where most Arctic ship traffic occurs. Where analysts set the southern boundary of the Barents Sea significantly influences the statistics, for example, to what extent fishing vessels dominate Arctic shipping. Reports on Arctic shipping should consider the significant intra-Arctic variations in activity levels, growth rates and traffic composition. The Kara Sea experienced the biggest annual growth rate—14% on average—because of petroleum projects that have introduced big oil and gas tankers. In contrast, there is minimal activity and growth in the Large Marine Ecosystems of the Northern Canadian Archipelago and the Central Arctic Ocean. Even though the winter traffic has grown in the Barents Sea, the Kara Sea and Baffin Bay, the activities there remain distinctly seasonal. In other seas, ships almost vanish in winter. Transit shipping over the Arctic is still insignificant in a global context. The standard reports in the ASTD are important for understanding Arctic shipping and should be improved. In particular, the Polar Code area needs to be subdivided to enable consistent reporting on overall pan-Arctic and intra-Arctic developments. Definitions for transit traffic should also be agreed upon and opportunities for automatic reporting accordingly investigated.

Keywords

Arctic Ship Traffic Data (ASTD); Automatic Identification System (AIS); Havbase; Polar Code; Northern Sea Route; Large Marine Ecosystem

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Abbreviations

AIS: Automatic Identification System
ASTD: Arctic Ship Traffic Data
GT: gross tonnage, a measure of ship volume
LME: Large Marine Ecosystem
LNG: liquid natural gas
NCA: Norwegian Coastal Administration
nm: nautical miles
NSR: Northern Sea Route
NWP: North-west Passage
PAME: Protection of the Arctic Marine Environment (Arctic Council working group)
RQ: research question

To access the supplementary material, please visit the article landing page

Introduction

Analyses of shipping in the Arctic have traditionally been constrained by a lack of data on the operations. The Arctic Council's Arctic Marine Shipping Assessment aimed to provide a comprehensive overview of all maritime activities in 2004, on the basis of reporting from the coastal states (Arctic Council 2009). While the assessment offered valuable information, the resulting database had evident shortcomings due to incomplete and inconsistent reporting. When satellites in polar orbits began transmitting signals from AIS transponders on vessels, new opportunities emerged. The NCA was a pioneer in generating automated statistics from AIS signals and making the data available on the internet when it launched Havbase in 2011 (<https://havbase.no/>).

Eight years later, PAME introduced the ASTD system (<https://map.astd.is/>), based on an expanded version of Havbase that incorporated the Arctic. ASTD is now the primary source for obtaining data and statistics related to Arctic shipping.

AIS-based statistics describe traffic patterns, that is, where and when different types of ships operate, which is interesting for many actors and purposes (Svanberg et al. 2019). Maritime administrations can evaluate the needs for routing, better services and infrastructure. Various authorities and industries can use traffic statistics as an indication of issues such as risks for environmental impacts, analyses of logistics and navigability in ice-covered waters. In-depth analyses of many of these issues, however, require supplementary data and modelling (Svanberg et al. 2019).

In this article, we are concerned about the traffic, and the methodology and standard options for reporting about Arctic shipping offered by the ASTD. We focus our analysis on major temporal and spatial trends in areas where sea ice has so far been an obstacle for operations and pose special risks. Motivated by key discourses on Arctic shipping, we have formulated the following five RQs that guide our analysis of the data for the decade spanning January 2013 to December 2022.

Total traffic growth: It is a widely held expectation that reduced sea ice, along with technological advancements and improved infrastructure, will facilitate economic expansion and create more ship traffic (Sander 2016; Ng et al. 2018). This has spurred many governments and commercial actors to position themselves for expected opportunities (Arbo et al. 2012). RQ1 asks for a pan-Arctic overview: To what extent has the traffic increased in waters affected by sea ice?

Intra-Arctic traffic developments: Growth is expected primarily along three routes: the North-east Passage, with the NSR as its most important section in Russian waters (Keupp 2015); the NWP, with several routes through the Canadian Arctic Archipelago (Headland 2023) and the Central Arctic Ocean Route across the North Pole area (Smith & Stephenson 2013). These routes differ in terms of ice conditions, infrastructure and services, and political interest in attracting traffic. RQ2 asks: How has the traffic developed in different Arctic regions, especially along the three major ship routes?

Vessel types and traffic composition: Different vessels serve different purposes. Observing changes in the occurrence of vessel types over time therefore provides an indication of changes in the activities that create traffic. Different vessel types also create different types of impacts and risks in a region where salvage operations are challenging. Accidents involving crude oil or chemical tankers can lead to severe ecological damage, while a cruise ship in distress may endanger hundreds of lives. As a first step towards further analyses of such issues, RQ3 asks: How has the traffic with different vessel types developed?

Seasonal variability: The rough conditions for sailing in the winter season pose a major obstacle for expanding Arctic shipping. With reduced sea ice, more ice-class vessels and icebreakers, as well as improved infrastructure and services, the navigable season may extend beyond a narrow operating period in the Arctic summer. RQ4 asks: To what extent has the seasonal variability of the traffic changed?

Transit-traffic: A major reason for the interest in Arctic shipping lies in the prospect of reliable intercontinental shipping, primarily connecting north-east Asia and northern Europe through the three major routes

described earlier in the text (Meng et al. 2017; Theocharis et al. 2018). Container ships play a pivotal role in international maritime trade. Redirecting a substantial part of this fleet to the Arctic would be needed if the Arctic were to become an important international maritime corridor. However, this is difficult since container ships often adhere to fixed schedules that are vulnerable to delays and cannot easily adapt to seasonal variations and unreliable sailing conditions in the Arctic (Schøyen & Bråthen 2011; Lasserre et al. 2016). The shipping activities in the Arctic are so far dominated by ships that have reasons for travelling to and from destinations in the Arctic. This is referred to as destination shipping. The Arctic Marine Shipping Assessment in 2009 projected that the traffic throughout 2020 would be “overwhelmingly destination, driven by natural resource development, marine tourism, and supply of goods” (Arctic Council 2009). RQ5 tests this projection by asking: Has transit traffic grown, or is the prevailing traffic pattern still destination?

In addressing these questions, we start by presenting statistics solely based on ASTD’s standardized reports. The rationale is that most ASTD users are confined to retrieving statistics based on the system’s predefined geographical and temporal units. Especially the geographic units have significant implications for the understanding of Arctic shipping. Addressing our questions about developments in waters where sea ice may occur, intra-Arctic variability and transit traffic require geographical definitions. If analysts apply different definitions, inconsistent results emerge, as we will illustrate with examples. The ASTD structures data according to areas (polygons), crossing lines and ports. Details on how this is done is presented in the following section, as a background for the presentation of the results. We continue with analyses of temporal and spatial trends according to the RQs for the decade 2013–2022. In the subsequent discussion, we bring in data from other sources to address the issues where the ASTD’s standardized reporting does not enable a good analysis of our RQs. We also suggest improvements for the ASTD. This does not only concern the ASTD but also how developments in Arctic shipping in general could be reported in a standardized manner. In the conclusion, we summarize the answers to the RQs and our main recommendations for better standardized reporting.

Background: from AIS to automated traffic data reporting

In 2000, the International Convention for the Safety of Life at Sea introduced a requirement for AIS on certain ships to enhance ship safety. Vessels were required to install transponders that send information

to nearby ships and coastal base-stations, enabling a real-time overview of ships' positions (IMO n.d.). An AIS transponder sends three types of information every six minutes (NCA n.d.): (1) static information that identifies the vessel; (2) dynamic information about its current position and movement and (3) voyage related information about the ship's destination, cargo and draught. The base stations have limited range, and satellites are therefore needed to extend the coverage to the entire ocean.

In 2010, the NCA launched the first of its four AIS satellites in polar orbits. The motivation was to enhance operational services, but the NCA also saw the potential for acquiring better data for national transport planning. This inspired the development of Havbase, a system that calculates traffic statistics within pre-defined polygons in the North-east Atlantic, over certain crossing lines along the Norwegian coast and calls to Norwegian ports (Barentswatch 2015). Key to its functioning is the coupling of individual ship identities from AIS with data from ship registers, enabling the production of traffic statistics by 15 ship types and seven size groups, and the calculation of emissions to the atmosphere (Mjelde et al. 2014). The users are offered a range of options to select variables of interest and to download tables and diagrams presenting the data, cost-free.

At the Fram Centre in Tromsø, the need for data on Arctic shipping in a research programme on the Arctic Ocean led to cooperation with the NCA to expand Havbase to the Arctic. The authors of this article were tasked with defining the geographic units for what would become Havbase Arctic. The system was launched in 2014 and operated as a separate service for several years until it was replaced by the ASTD. In the context of this article, the important thing to note is that the basic geographical units remain as a heritage in the ASTD.

Establishing the ASTD was a PAME project that followed up a recommendation from the Arctic Marine Shipping Assessment. The objectives were to collect information on shipping activities, make it available for analysis and establish a long-term sustainable solution for such a service (PAME 2016). Having set up Havbase, the NCA was assigned an important role in the project. The ASTD was launched in February 2019 as an improved version of Havbase, with the same types of geographical units as the basis for the production of statistics.

Four different types of areas had been defined (Fig. 1), for which total distance sailed is calculated in nm: (1) management delimitations using the LMEs defined by the Arctic Council (Skjoldal & Mundy 2013);

geographical delimitations using (2) the Arctic oceans and seas as defined by the International Hydrographic Organization (IHO 1953) and (3) the areas defined by 20-degree longitudinal sectors; and (4) jurisdictional areas, using the Exclusive Economic Zones and the High Seas. Moreover, crossing lines were set up to count the number of vessel movements across them, in both directions. The lines were located to record traffic in and out of major seas, bays and fjords, through straits in the NSR and the NWP, and across the Arctic Ocean. Finally, Arctic ports were defined, for which statistics on monthly ship calls according to ship types can be generated.

The Arctic Search and Rescue Agreement (Kao 2012) and the Polar Code (Jensen 2016) had not been adopted when Havbase Arctic was established. The areas according to these treaties have been defined as new polygons in the ASTD. Users may now also create their own polygons, crossing lines and ports or anchoring grounds, and obtain statistics for these. Another significant improvement was introduced when users were given the opportunity to download the complete set of quality-assured data prepared for analysis in GIS (PAME 2020a). This allows GIS experts to use the raw data for any analytical purposes they might have. For instance, it can enable focussing on smaller areas rather than the pre-defined polygons (Stocker et al. 2020) or creating traffic density maps (Eguiluz et al. 2016). With these new opportunities, users can make tailor-made statistics for their own purposes. However, this also implies that we may see more inconsistent reporting of Arctic shipping in the future.

Further developments in the standardized reporting include options to analyse up to 228 ship types, as well as ice-class as a new attribute for vessels. The ASTD is not freely available on the internet, so access for users who are not affiliated with the Arctic Council is contingent on application and payment (PAME 2020b). Level 1 provides access to all data in the database, including on individual ships, and all the 228 ship types. For access levels 2 and 3, individual ships are not identifiable, and the ship types are aggregated into 31 and 15 groups, respectively (PAME 2024b).

Since autumn 2019, the data from the Norwegian satellites have been complemented by data from 16 US satellites (PAME 2019). Many of the limitations on data accuracy and availability were reduced significantly after Norway increased its AIS programme to four satellites; after data from the US satellites were added, these limitations were nearly eliminated. With the extensive satellite coverage and procedures for quality assurance, ASTD data quality is characterized as very high (PAME 2019; Berkman et al. 2020).

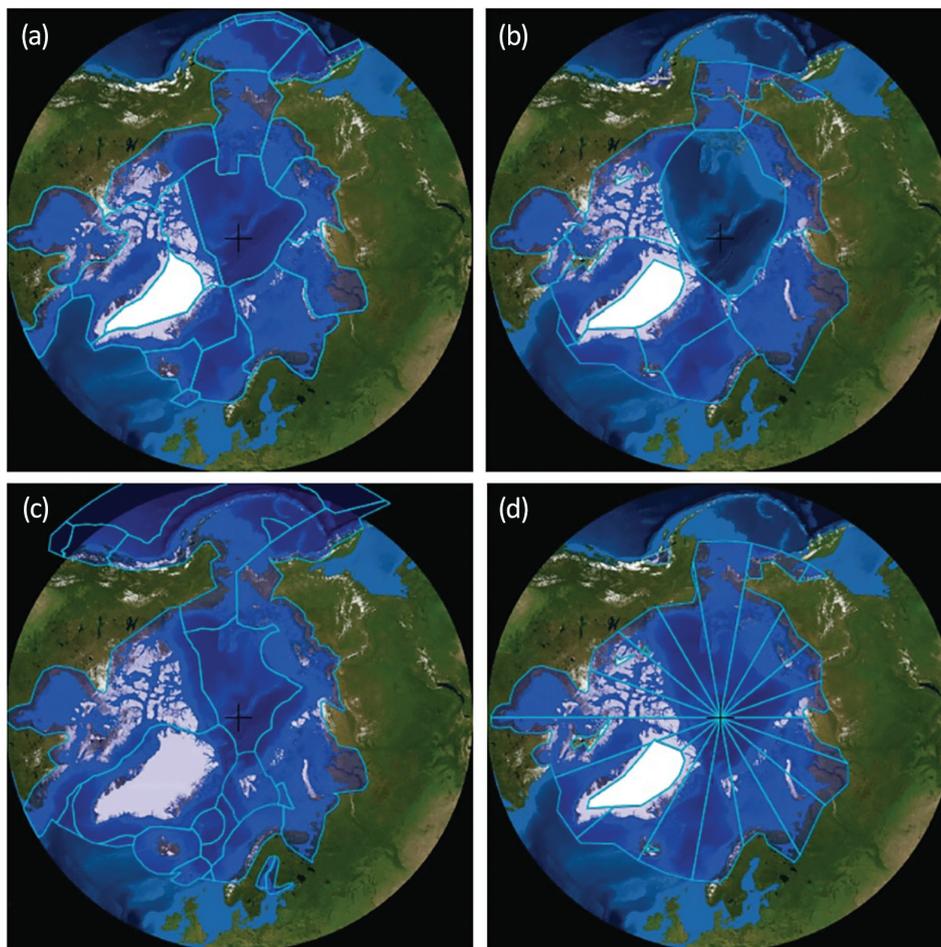


Fig. 1 The four types of areas defined in Havbase Arctic and incorporated in the ASTD: (a) Large Marine Ecosystem (LME); (b) International Hydrographic Organization geographic delimitations; (c) Exclusive Economic Zone (EEZ); (d) 20-degree longitudinal sectors. These area types have later been supplemented by the areas of two international treaties.

Method

The collection and analyses of data from the ASTD were carried out to answer the five research questions. Since 2013 was the first year for which the ASTD has data for all months, our wish to analyse decadal trends led us to choose data from January 2013 to December 2022, which we downloaded in March 2023. We paid for access level 3 for economic reasons and because we expected that 15 ship types would provide a good overview.

The Arctic LMEs were selected as units for presenting statistics on distance sailed because the Arctic Council has endorsed LMEs as important spatial units for the ecosystem approach to management (Skjoldal & Mundy 2013). This requires consideration of all key activities affecting the marine ecosystem, including shipping (Arctic Council 2015). Among the LMEs, we

selected those that are closest to the Arctic Ocean and the major sailing routes where traffic is expected to grow as the sea ice recedes. We call these High-Arctic LMEs (Fig. 2, Table 1).

Defining the southern extent of the Arctic is a recurring challenge in all analyses of Arctic issues (AMAP 1998: 9–19). We were confined to selecting entire LMEs as spatial units. This is problematic, especially for the Barents Sea. The traffic there is high, but the southern part of the LME is ice-free throughout the year, and a high proportion of the traffic is not directed to or from the High Arctic. The Barents Sea LME is therefore sometimes treated separately.

Variables were retrieved as Excel files with monthly statistics for each LME and consolidated into single files for each main data type (distance travelled, crossing line, port calls). We made summary tables using pivot tables in Excel® and calculated absolute and relative changes and

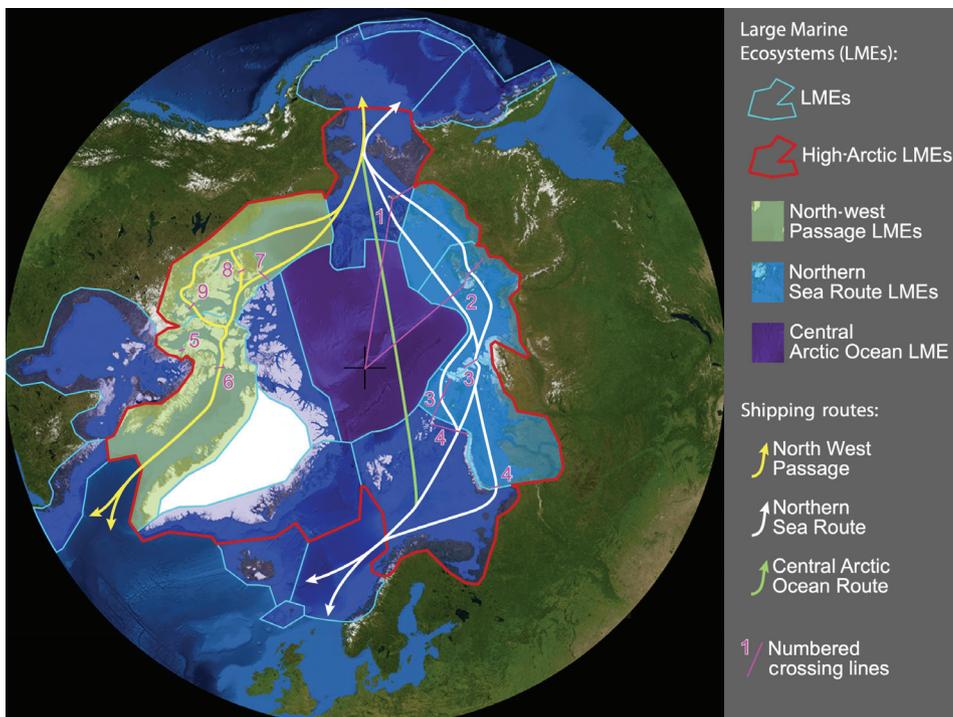


Fig. 2 The selected High-Arctic LMEs, groups of LMEs (see Table 1) and crossing lines that are used for analysing activities along the three main shipping routes. The numbers on the crossing lines correspond to those in subsequent figures and tables.

Table 1 LMEs and their assignment to regions for analysis.

LME	LMEs in ASTD	High Arctic	NSR	NWP
	Aleutian Islands LME			
A	Baffin Bay LME	X		X
B	Barents Sea LME	X		
C	Beaufort Sea LME	X		X
D	Central Arctic LME	X		
E	Chukchi Sea LME	X		
F	East Bering Sea LME			
G	East Siberian Sea LME	X	X	
	Faroe Plateau LME			
H	Greenland Sea LME	X		
	Hudson Bay LME			
	Iceland LME			
J	Kara Sea LME	X	X	
K	Labrador Sea LME	X		
L	Laptev Sea LME	X	X	
M	Northern Canadian Archipelago LME	X		X
	Norwegian Sea LME			
	West Bering Sea LME			

growth rates for the various LMEs, groups of LMEs and seasons. The average annual growth rates for the period 2013–2022 were calculated as the average annual increase of the linear trend lines, which were estimated in Excel by the ordinary least squares method.

In the following sections, we present key results, primarily as figures. The data underlying the figures and additional figures are available as supplementary material.

Decadal trends in Arctic shipping

The presentation in this section starts with an overview for the entire High-Arctic area and continues with sections for the NSR, the NWP and the Central Arctic Ocean LME.

High-Arctic shipping

The total distance sailed in all the High-Arctic LMEs steadily increased from 2013 to 2022, reaching over 22 million nm in 2022 (Fig. 3). The linear trend over the decade showed a 4.6% annual growth (Table 2). With the delimitation we have chosen, it is no surprise that the Barents Sea has the maximum traffic because of its substantial fisheries and traffic to ports in mainland Norway and north-west Russia. However, when we excluded the Barents Sea, meaning that we also omitted traffic in High-Arctic areas around Svalbard, the decadal growth rate was even higher, at 8.2% per year (Table 2).

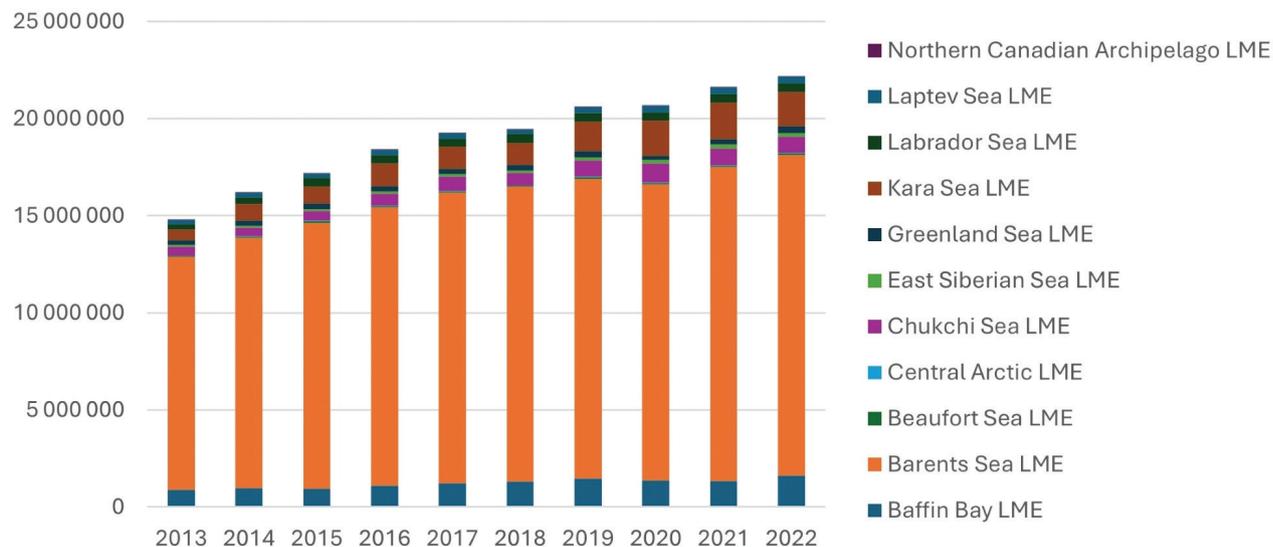


Fig. 3 Distance sailed (nm) per year in the High-Arctic LMEs.

Table 2 Annual distance sailed in the High-Arctic LMEs. The values are in units of 1000 nm, except for two columns showing percentages.

Large Marine Ecosystem	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Share 2022 (%)	Change 2013–2022	Average annual growth (%)
Baffin Bay	896	960	952	1097	1211	1298	1457	1375	1356	1628	7.3	732	6.9
Barents Sea	11 982	12 900	13 675	14 321	14 976	15 197	15 454	15 242	16 157	16 495	74.4	4513	3.6
Beaufort Sea	70	74	101	83	83	55	89	57	64	94	0.4	24	3.4
Central Arctic Ocean	10	31	22	16	9	16	20	29	15	16	0.1	6	4.7
Chukchi Sea	456	423	507	614	751	648	831	1001	881	841	3.8	385	7.1
East Siberian Sea	98	96	87	127	109	121	145	175	199	189	0.9	91	7.5
Greenland Sea	239	272	299	263	271	305	336	228	263	365	1.6	126	4.8
Kara Sea	529	855	869	1180	1137	1092	1509	1783	1892	1727	7.8	1198	14.1
Labrador Sea	298	351	459	414	442	478	472	454	440	463	2.1	165	5.0
Laptev Sea	193	232	216	287	269	239	284	313	343	337	1.5	144	6.4
Northern Canadian Archipelago	1	2	4	5	1	3	5	1	1	3	0.01	2	12.1
Sum all LMEs	14 773	16 195	17 190	18 406	19 258	19 452	20 601	20 657	21 611	22 158	100	7385	4.6
All except the Barents Sea	2790	3295	3515	4086	4283	4255	5147	5416	5454	5662	25.6	2872	8.2
NSR-related LMEs	820	1183	1172	1594	1514	1452	1938	2271	2433	2253	10.2	1433	11.9
NWP-related LMEs	967	1036	1056	1185	1295	1356	1550	1433	1421	1725	7.8	758	6.6

Arctic shipping varies significantly by season. In winter, activities that demand transport are lower and the limited availability of icebreakers and ice-class vessels constrain the supply side. This may explain why the difference between summer and winter traffic is much less

pronounced in the partly ice-free Barents Sea than in the other High-Arctic LMEs (Fig. 4). Yet, for these LMEs with more sea ice, the seasonal variations in traffic have diminished over the decade, as can be seen in Fig. 5. The proportion of the annual distance sailed outside the traditional



Fig. 4 Distance sailed (nm) per month in the High-Arctic LMEs except the Barents Sea, and in the Barents Sea LME (Supplementary Table S7).

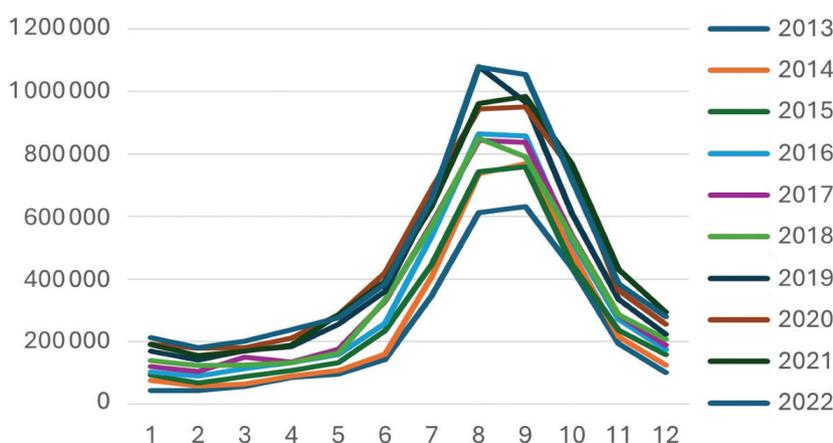


Fig. 5 Distance sailed (nm) per month (1–12: January–December) and year in the High-Arctic LMEs, excluding the Barents Sea (Supplementary Table S7).

peak season between July and October grew from 27% in 2013 to 38% in 2022 (Supplementary Table S1).

In 2022, the ship types dominating sailed distance in the High-Arctic LMEs were fishing vessels (32%), general cargo ships (13%), passenger ships (9%) and “other activities” (20%), which includes icebreakers, tugs, research vessels, yachts and naval vessels (Fig. 6). The “other activities” were the biggest contributors to the 50% growth in traffic, followed by fishing vessels, general cargo ships, gas tankers, crude oil tankers and cruise ships. The rise in petroleum-related transport is remarkable: there were almost no gas tankers operating in 2013, but by 2022, they accounted for a 4% share of the total distance sailed. Similarly, crude oil tankers also reached a 4% share in 2022, reflecting a more than tripling of the distance sailed in 2013. Cruise vessels doubled their activities and also ended up with a 4% share. Interestingly, container ships deviated from the growth, experiencing a steady decline throughout the decade and ultimately contributing only 0.6% of the traffic in

2022. This is contrary to expectations if intercontinental traffic between Asia and Europe were to increase. It is important to note that the volumes and composition of the traffic referred to here—for instance, the high share of fishing vessels—reflect the inclusion of the Barents Sea. When the Barents Sea is excluded, both the total volume of traffic and relative shares of fishing vessels change significantly (Supplementary Table S2, Supplementary Fig. S1).

Considering ship size, the biggest growth is seen in the two smallest size classes, below 5000 GT (Supplementary Fig. S2). On the opposite end of the scale, the emergence of gas tankers larger than 100 000 GT (size class 7) is a remarkable new feature (Supplementary Fig. S3).

The Northern Sea Route

Examining the traffic over the cross-sections along the NSR provides an initial overview of geographic patterns

and developments (Fig. 7). The most striking change is the consistent growth at the western end of the route (crossing line 4), with a fivefold increase from 443 ships in 2013 to 2202 in 2021, followed by a subsequent decline to 1446 in 2022. In contrast, the numbers of ships traversing the crossing lines on the eastern side (line 1 and 2) and in the mid-sections of the route (line 3) have remained relatively stable. The eastern end of the route reached a peak of 294 vessels crossing in 2021 (line 1), while the mid-sections consistently saw about 200 crossings per year.

The developments reflected in Fig. 7 are substantiated by the figures on distance sailed in the three Russian LMEs covering the NSR (Table 2). The traffic tripled from 0.8 million nm in 2013 to a peak in 2021, slightly decreasing the year after, to 2.25 million nm. The Kara Sea, which is key for Russia’s export of petroleum products and other raw materials, experienced the highest traffic (1.89 million nm in 2021) and the biggest growth (3.5 times higher than in 2013). The traffic in the East Siberian Sea LME doubled over the decade, while the growth in the Laptev Sea was slightly lower.

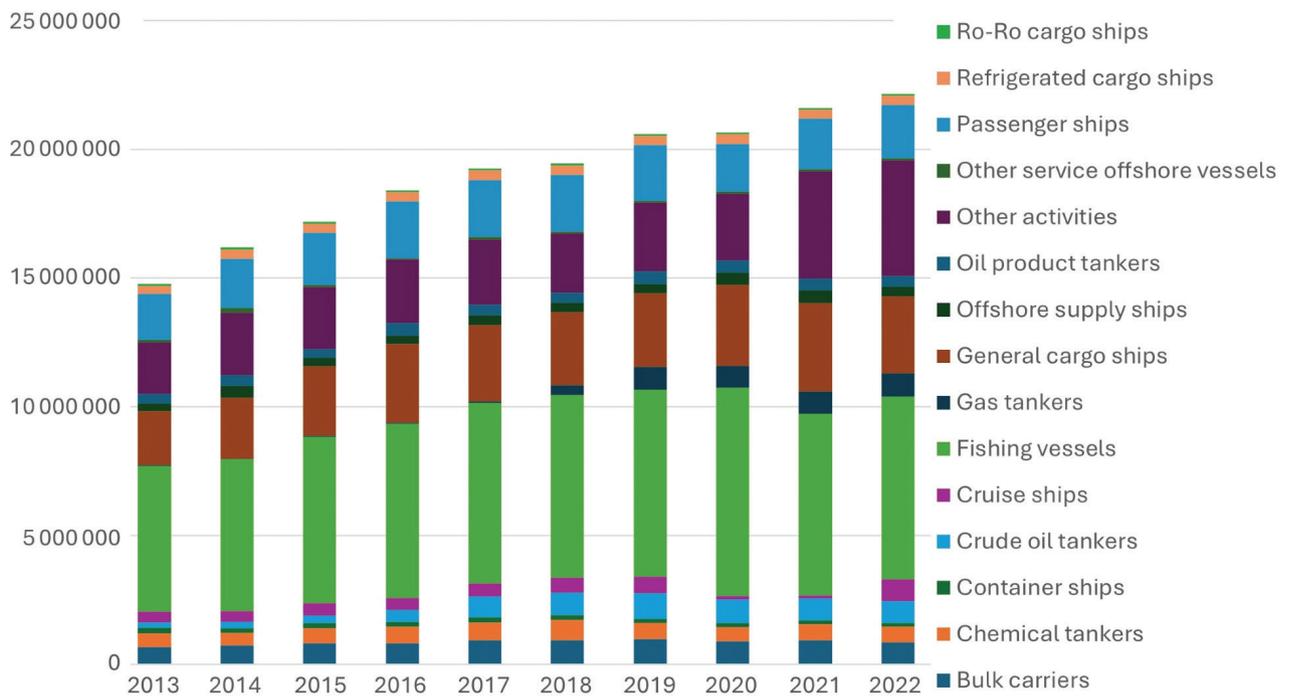


Fig. 6 Distance sailed (nm) by ship type and year for the High-Arctic LMEs (Supplementary Table S8).

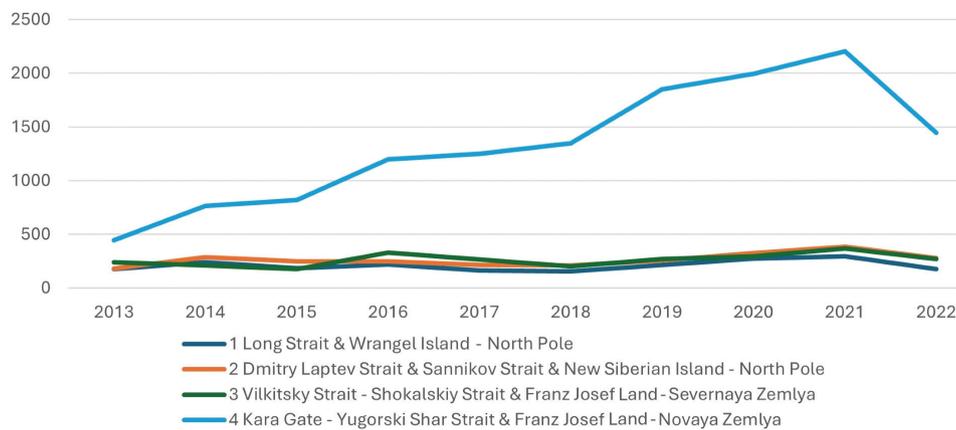


Fig. 7 Number of vessel-crossings in both directions over crossing lines in the NSR (Fig. 2, Supplementary Table S4).

The ship types involved provide a good indication of the primary reasons for the traffic (Fig. 8). In terms of sailed distance in 2022, the following ship types dominated: general cargo ships, vessels undertaking “other activities,” gas tankers and crude oil tankers, all of them increasing significantly (Supplementary Table S3). The crude oil tankers and gas tankers accounted for a remarkable growth in vessels of size classes 5 and 7 (Fig. 9).

The opening of a terminal for year-round oil export from the Novy Port field on the Yamal Peninsula is a key explanation for the large growth of crude oil tankers since 2014 (Moe 2014). Similarly, the introduction of gas tankers from 2017 can be attributed to the opening of the LNG facility and new port in Sabetta, farther north on Yamal (Gunnarsson & Moe 2021; Rajagopal & Zhang 2021). The construction of exploration and transport infrastructure in the years before the opening of these mega-projects required massive deliveries of materials and equipment, which, in turn, explains the initial increase in general cargo shipments. Such shifts in ship traffic from a construction phase to a production phase are typical for petroleum and mineral projects in Arctic regions where land-based transport is not an alternative. However, the continuous development of new industrial and infrastructure projects has sustained the high activity of cargo ships in Russian waters.

There is a distinct seasonal traffic pattern in the NSR (Fig. 10). In the Laptev Sea and East Siberian Sea, there is almost no registered winter traffic. In the Kara Sea, traffic outside the peak season has increased significantly. For instance, traffic in May grew from 12 000 nm in 2013 to 115 000 in 2022. The ice-class tankers built to serve the Yamal LNG project operate in the winter, as do the Russian icebreaker fleet (PAME 2024b). Nevertheless, winter traffic in the Kara Sea also remains significantly lower than the summer traffic.

The ASTD does not contain direct information on transit traffic. However, the number of vessels over crossing lines provide an indication of this (Fig. 7). Although the numbers cannot tell how many ships sailed the entire NSR, the low figures on the Asian side suggest that transit traffic remains very low (Supplementary Table S4). The number of eastbound and westbound crossings are nearly balanced, indicating destination traffic moving to and from Arctic ports. Another clue is the very low occurrence of container ships operating within the Russian LMEs (Supplementary Table S3).

The drop in traffic from 2021 to 2022 can probably be explained by the repercussions of the sanctions imposed on Russia following its full-scale attack on Ukraine in February 2022 (Lasserre & Baudu 2023). Initially, the sanctions targeted financial flows and the

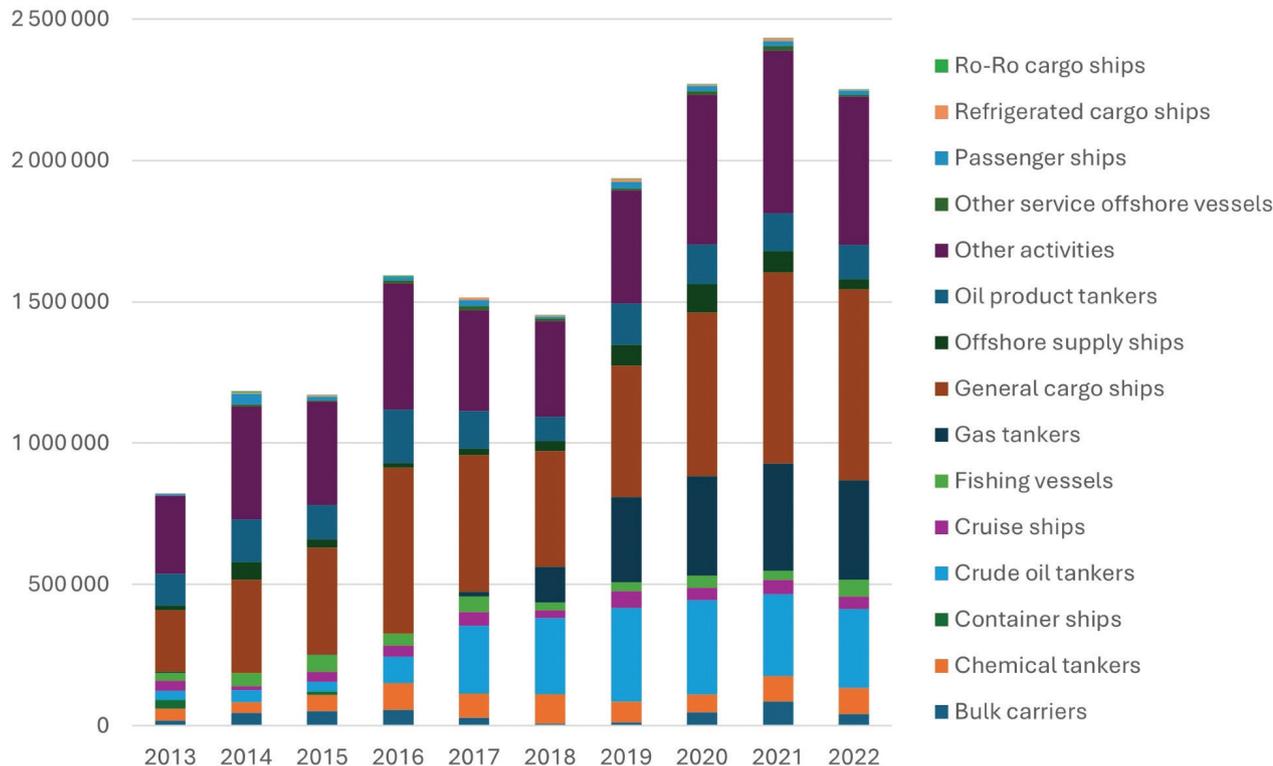


Fig. 8 Distance sailed (nm) in LMEs along the NSR, by ship type and year (Supplementary Table S3).

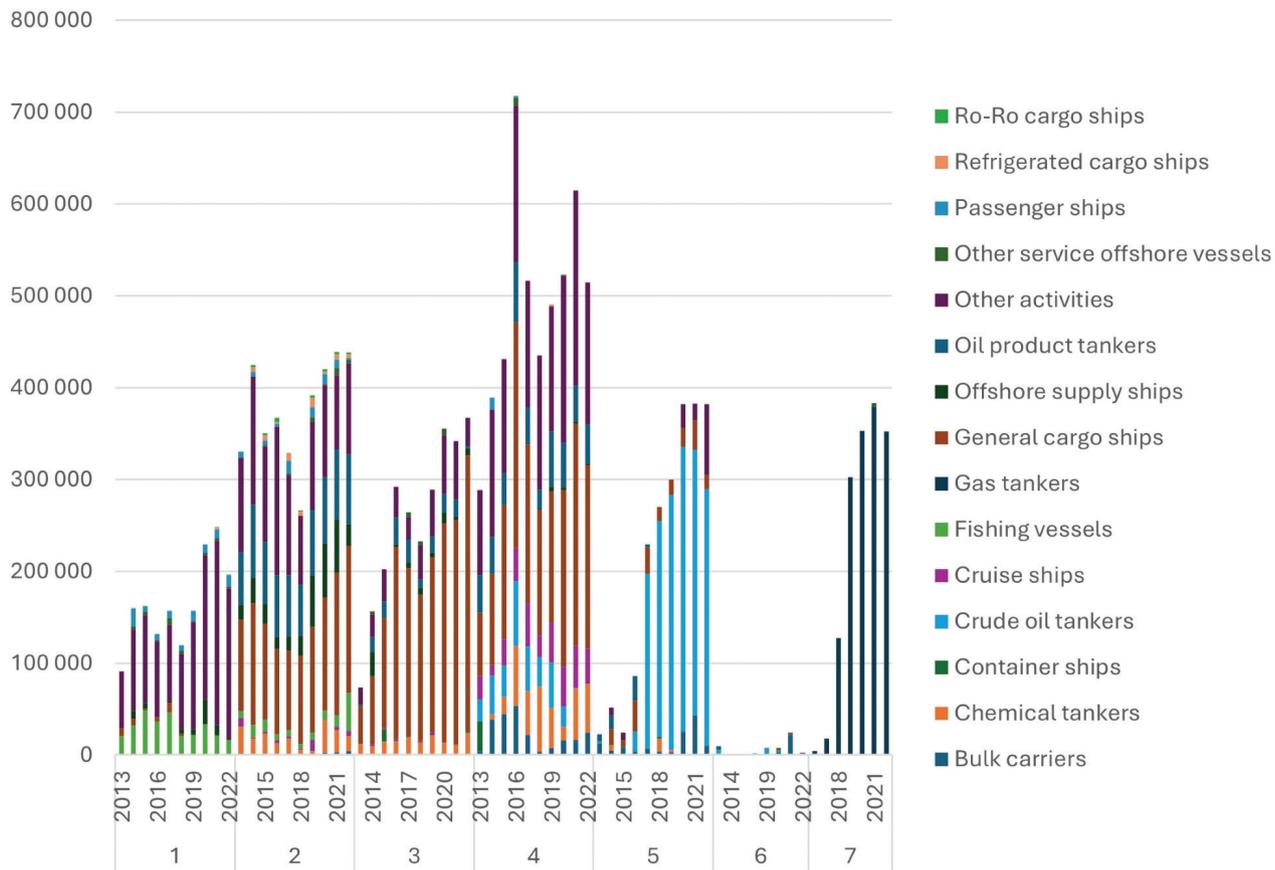


Fig. 9 Distance sailed (nm) in LMEs in the NSR, by ship size (class 1–7), year and ship type.

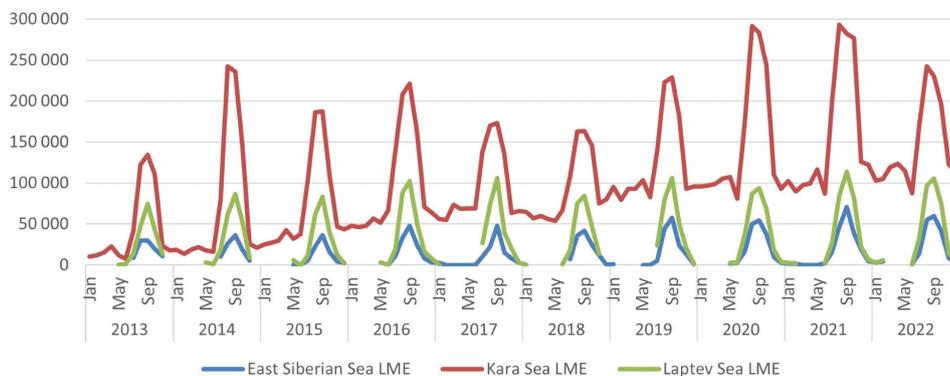


Fig. 10 Distance sailed (nm) per month in the NSR LMEs.

presence of Western companies with their technology and capital. This affected major oil, gas and mineral projects in Siberia which are of great importance for the Russian economy. While oil, refined products and coal were subjected to a complete embargo, gas and LNG were exempted (Lasserre & Baudu 2023). Russia’s export of gas via pipelines to Europe was reduced for various reasons, but Europe partly compensated by

increasing LNG imports, including from Russia. Consequently, 90% of the LNG shipments from Sabetta in 2022 went to Europe (CHNL 2023). Russia has also redirected its exports of oil and other products towards Asian markets, primarily China and India (Lasserre & Baudu 2023). However, this did not lead to more east-bound traffic the first year of the sanctions, as the numbers above illustrate.

The North-west Passage

There are seven alternative routes through the Canadian Arctic Archipelago, which presents complex navigational challenges due to sea ice and the restricted breadth and depth of the straits (Arctic Council 2009; Dawson et al. 2018; Headland 2023). Only a handful of ships are registered over the most relevant crossing lines (Fig. 11). The primary route continues to be the southern one through the Victoria Strait. The northern route through the McClure Strait is hardly in use, despite it being the shortest, deepest and therefore potentially most attractive option for transit traffic. There are no clear trends in traffic volumes over these lines over the decade.

To analyse the traffic more closely, we use three LMEs that cover almost the entire NWP and, unfortunately, also include traffic to and from Greenland (Fig. 2). Together, these LMEs saw a 78% growth in sailed distance since 2013, totalling 1.725 million nm (Supplementary Table S5). Most of the vessel activities take place in the Baffin Bay LME, where there are significant fisheries and ship traffic to and from both western Greenland and north-eastern Canada (Fig. 12). The traffic grew steadily until 2019, followed by a drop the next two years and a renewed peak in 2022 (Table 2). In contrast, the vessel activity is extremely low and variable in the Northern Canadian Archipelago LME, where there are sparse human activities and much sea ice. The distance sailed in the Beaufort Sea LME is between the two others. In the two LMEs with the harshest climate conditions, traffic occurs during the summer and drops to zero in the winter (Fig. 12).

The ship types that sailed the longest total distance in the NWP area in 2022 were fishing vessels (28%), vessels

engaged in “other activities” (26%), general cargo ships (11%), bulk carriers (10%) and cruise ships (9%; Fig. 13). The rapid increase in the bulk carrier activity since 2015 is notable. This is most likely connected to the opening of the Mary River Mine on Baffin Island that year (PAME 2024a). Traffic with “other activities” and general cargo ships also increased significantly. Fishing vessels nearly doubled their sailed distance from 2013 to 2020 but declined in the subsequent two years, resulting in a 41% decadal growth. Cruise ships sailed more than twice as far in 2022 compared to 2013 but were completely absent in 2020 and 2021 because of Canadian covid restrictions. Several vessel groups that account for smaller shares of the traffic decreased the distances sailed.

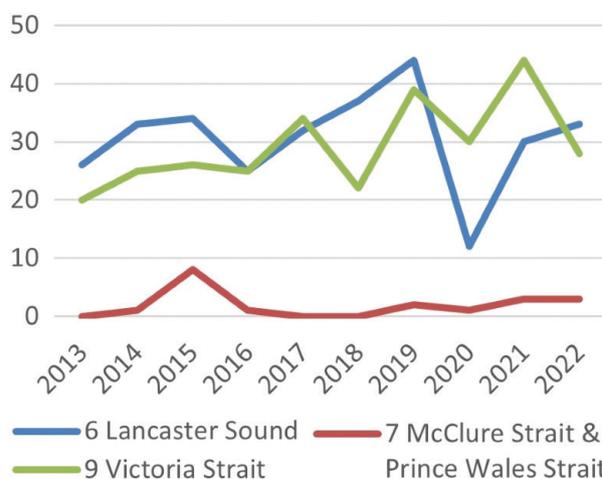


Fig. 11 Number of vessel-crossings in both directions over crossing lines in the NWP (Fig. 2, Supplementary Table S9).

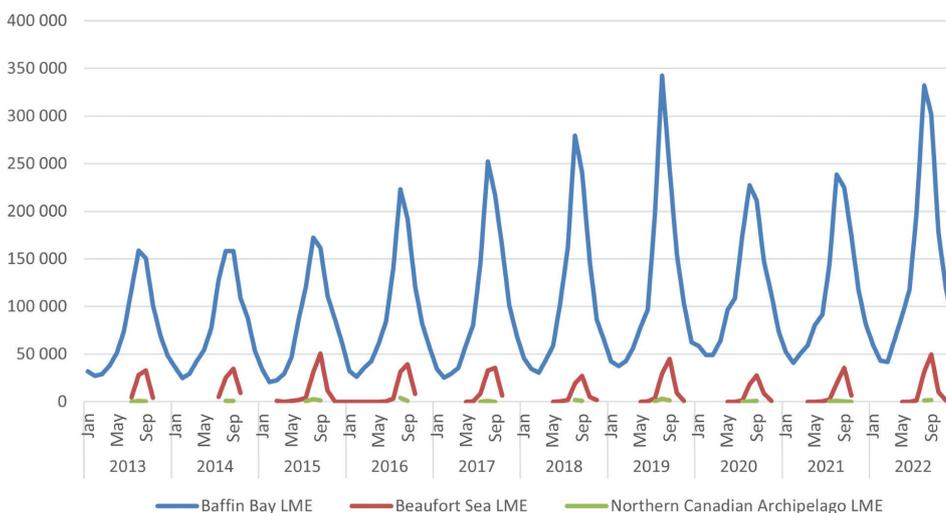


Fig. 12 Distance sailed (nm) per month in LMEs in the NWP.

The traffic in the three NWP-associated LMEs is dominated by fishing vessels smaller than 5000 GT (Fig. 14). The fishing activities almost exclusively occur in the Baffin Bay LME. Container ships create a significant part of the traffic with size class 3 and 4 vessels, and a few even bigger. The growth in bulk carriers has caused an increase in ships between 25 000 and 50 000 GT.

Central Arctic Ocean

Ship traffic in the Central Arctic Ocean LME remains very limited, fluctuating between 9000 and 31 000 nm sailed per year (Table 2). It has a pronounced seasonal pattern, with most sailings concentrated during a brief summer season and virtually no activity during winter (Fig. 15). Ships undertaking “other activities,” such as research vessels, icebreakers and yachts, make up the only category registered with activity every year. Cruise ships were present for seven out of the 10 years, while a few other ship types occurred only in one or two years (Supplementary Table S6). The absence of fishing vessels, except for 2018, indicates that the moratorium on commercial fishing in the high seas portion of the central Arctic Ocean (Calderwood & Umer 2023) is effective.

Discussion

Our analysis of decadal trends, based on data from LMEs and crossing lines in the ASTD, allowed us to address our five RQs but with some challenges. Here, we will discuss some of the problems encountered and supplement the analyses with information on traffic from other sources.

Spatial definitions for Arctic and intra-Arctic analyses

The southern extent of the Arctic is a recurring topic, reflecting different scientific and end-user needs, as well as political interests (AMAP 1998). We wanted to analyse traffic patterns in a High-Arctic area influenced by sea ice (RQ1) but also to investigate internal differences in this area (RQ2). Using the ASTD’s standard reports made it challenging to combine these purposes. The Polar Code area would have been very relevant to answer RQ1 since it is defined exclusively with reference to ship operations in the most hostile Arctic waters, and because the delimitation is the result of international negotiations (Jensen 2016). The problem is that the Polar Code area in the ASTD lacks subdivisions that would enable a consistent analysis of RQ2. Consequently, we were confined to selecting one of the other pre-defined areas, which unfortunately extended

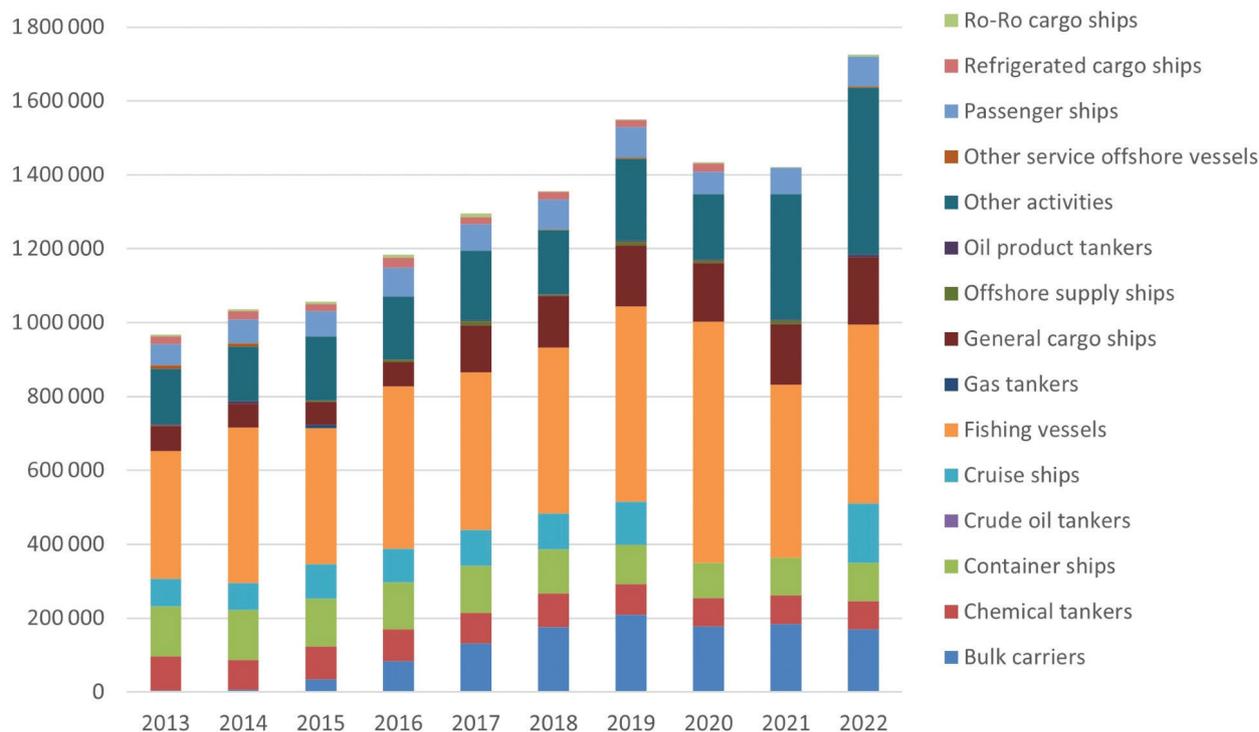


Fig. 13 Distance sailed (nm) in three LMEs in the NWP, by ship type and year (Supplementary Table S5).

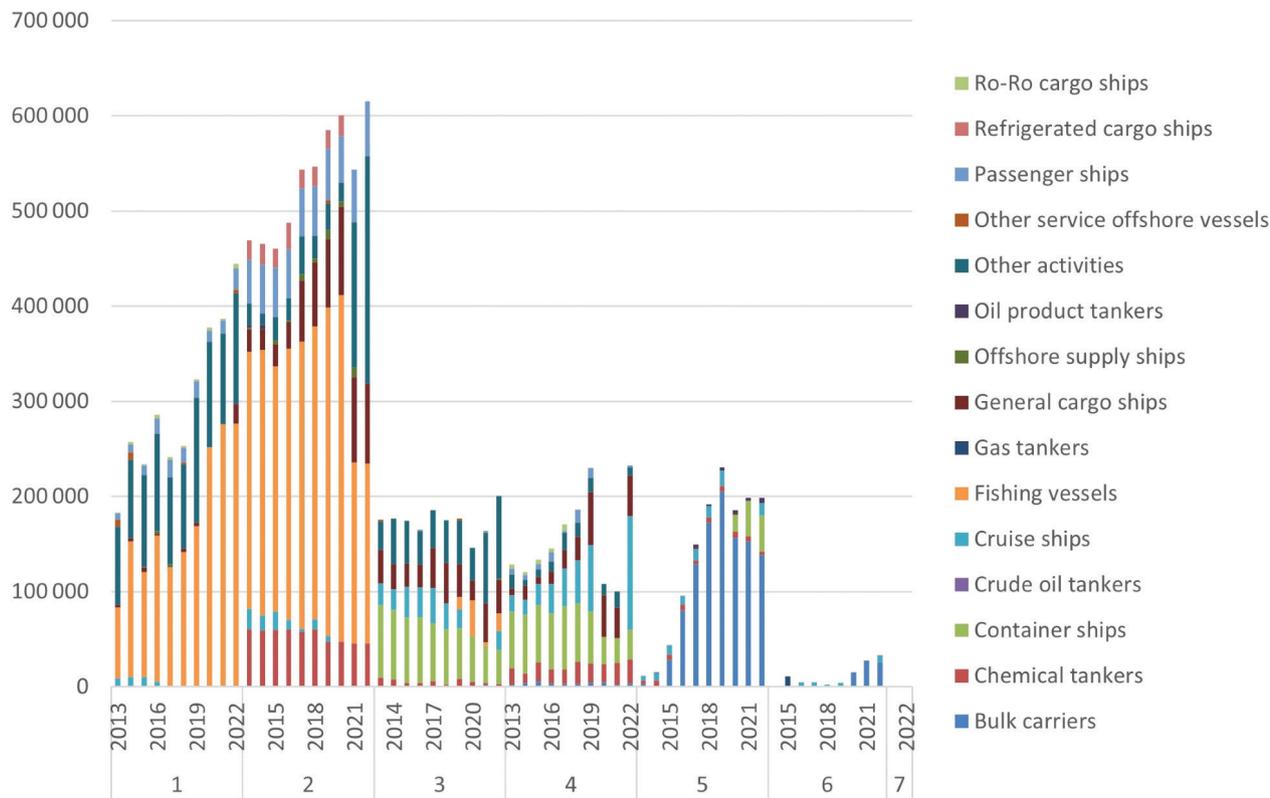


Fig. 14 Distance sailed (nm) in LMEs in the NWP by ship size (class 1–7), year and ship type.

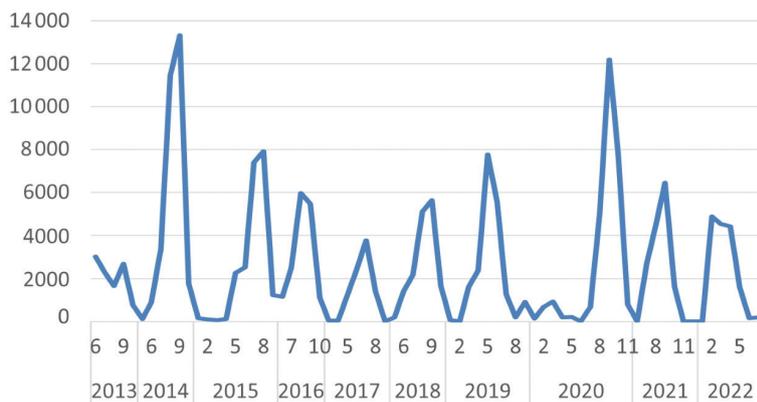


Fig. 15 Distance sailed (nm) per month (1–12) in the Central Arctic Ocean LME.

our analysis beyond areas with sea ice. Selecting LMEs as close as possible to the sea ice was a compromise. If we had chosen any of the other options in the ASTD (oceans and seas, longitudinal sectors or jurisdictional zones; see Fig. 16), we would have encountered the same problem.

Our analysis demonstrates how the inclusion or exclusion of the partly ice-free Barents Sea LME significantly affects the results. The average annual growth in distance sailed for the High-Arctic LMEs was 4.6% when the

Barents Sea LME was included but 8.2% when it was excluded. Thus, the growth rate was higher elsewhere, resulting in the Barents Sea’s share of traffic within the High-Arctic LMEs decreasing from 81% in 2013 to 74% in 2022 (Table 2). Despite the decline, the Barents Sea’s dominating share of the traffic means that the composition and development in this sea will still dominate reporting for the entire region. In absolute rather than relative terms, the traffic in this LME accounted for as

much as 4.5 of the total growth at 7.4 million nm in the High-Arctic LMEs. Similar considerations apply towards other boundary regions: farther south in the Atlantic and the Pacific oceans, there is more and different types of traffic, and the inclusion of such areas may overshadow High-Arctic developments.

PAME consistently uses the boundary of the International Maritime Organization Polar Code in its *Arctic Shipping Status Reports* (PAME 2024a). They found that traffic grew from 6.1 million nm in 2013 to 12.9 in 2022, corresponding to 8.7% average annual growth. While comparison of growth rates can be tempting, the difference between the total traffic volumes between these two approaches is more striking: our LME-based analysis found that traffic in the High-Arctic area grew by 7.4 million nm when the Barents Sea LME is included, 2.9 million nm when it is excluded, as opposed to the 6.8 million nm increase for the Polar Code area.

Müller et al. (2023) also analysed decadal traffic developments for the Polar Code area, applying raw data from the ASTD. They found a 7% annual growth on average. However, their analytical purpose led them to measure activity in shipping days, not in nm. Differences in geographic delimitations as well as units of measurement therefore prevent a direct comparison with PAME’s and our results.

Our findings underscore the fact that there is large intra-Arctic variability that should be carefully considered when analysing Arctic shipping. Comparing the two extremes among our High-Arctic LMEs, the total distance sailed in the Barents Sea during 2022 was 5500 times higher than in the Northern Canadian Archipelago LME (a 74% versus 0.01% share of the total High-Arctic traffic). The Kara Sea and the Baffin Bay LMEs emerge as the next hot spots, accounting for 8% and 7% of the 2022

traffic, respectively. Notably, the growth is also uneven: the Barents Sea, followed by the Kara Sea and the Baffin Bay LMEs, contributed most to the absolute growth in nm (Table 2). The Kara Sea LME exhibited the highest growth rate, averaging 14% per year. We also see clear differences between the LMEs concerning the ship types and size classes involved, reflecting different economic activities in the areas.

To consistently analyse both the overall development in High-Arctic ship traffic and variation within the region, an internal division of the Polar Code area is essential. The boundary of the Polar Code divides the LMEs as well as the other types of polygons defined in the ASTD (Fig. 16 is an example). Consequently, there is a need to make the necessary sub-divisions in all of them.

Transit traffic

Since the ASTD does not provide statistics on transit traffic as such, we could only get indicative information about these voyages. Two other sources that provide regular reports on transit traffic rely on a combination of various Russian sources and AIS data for the NSR (CHNL 2023) and manual reporting for the NWP (Headland 2010, 2023). The Centre for High North Logistics estimated that there were 85 transits of the NSR in 2021, dropping to 43 in 2022. The ships in 2022 all sailed under the Russian flag, carried extremely low cargo quantities and primarily operated between Russian ports. It appears that the Western sanctions following Russia’s full-scale attack on Ukraine halved the already marginal annual traffic, which was comparable to a single day’s traffic in the Suez Canal before the war (Lasserre & Baudu 2023).

The lack of consistent geographical units is a problem for analysing transit traffic too. Headland (2010)

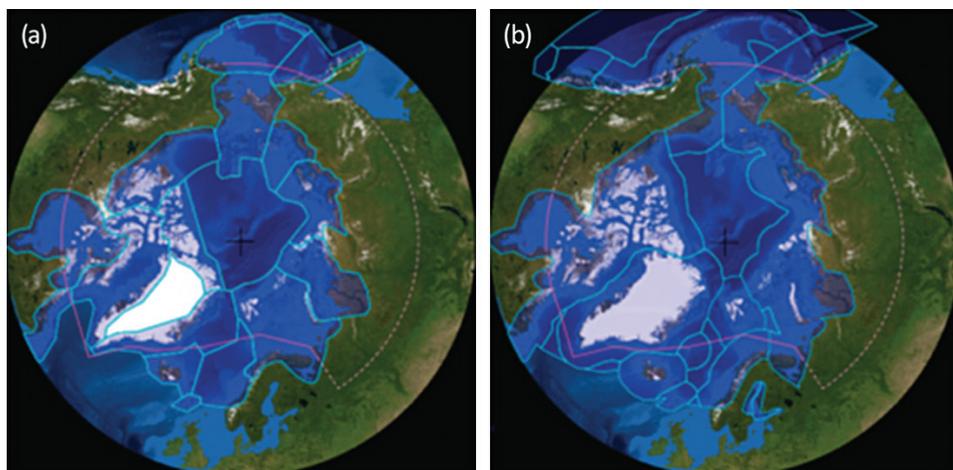


Fig. 16 The Polar Code area (pink line) compared to (a) the LMEs and (b) Exclusive Economic Zones (EEZs), defined in the ASTD.

applies a definition that conforms to the historical concept of a trading route between Europe and Asia, requiring ships to traverse the waters between the Northern Atlantic and the Bering Strait to qualify as a complete transit of the NWP. In 2023, Headland noted a record high of 42 NWP transits, including 18 private vessels, 11 cruise ships and 13 commercial ships, primarily bulk carriers. He excluded “major voyages within but not through the NWP” as incomplete or partial transits. These are becoming so numerous, he claimed, that maintaining an overview with his way of reporting is not possible anymore. On the Russian side, a clear legal definition exists for the NSR. However, differing understandings of what transit means led Gunnarsson & Moe (2021) to propose a nuanced terminology for different sailing patterns. Achieving agreement on such definitions along both passages would be essential for more consistent reporting on transit traffic. This may not be restricted to one definition alone; clear definitions of intercontinental transit traffic, conforming to Headland’s understanding, can be supplemented by any reporting on voyages across smaller sections, such as jurisdictional boundaries. Given the high interest in transit shipping, it should be explored whether it is feasible to automatically generate transit statistics in the ASTD, on the basis of analyses of ship routes derived from AIS.

Temporal resolution

The finest pre-defined temporal resolution of one month allowed us to coarsely demonstrate the variability between winter and summer traffic. However, even for studies of seasonal variability, weekly resolution would allow for earlier detection of changes in patterns and more nuanced analyses. GIS-based analyses of the complete data set with individual ships’ data enable applying weeks, days or even hours as temporal units (Berkman et al. 2020). This may be useful in more detailed analyses of traffic patterns or operational challenges. The work by Müller et al. (2023) is a good example. Interested in the risks created by ships’ exposure to hazardous weather and ocean conditions, they used a temporal resolution of days, which can be compared with metocean parameters on the same and even finer resolution. We recommend inclusion of weeks and days in the ASTD’s standard reports.

Ship type definitions and coverage

The 228 ship types offered to users with access level 1 in the ASTD allows for far more nuanced analyses than the 31 in level 2 and 15 in level 3. A main problem with the 15 ship types in level 3 is the large share of the traffic that is categorized as “other activities.” This merges a diversity

of vessels, including the Russian icebreaker fleet, tugs, naval vessels, yachts and sailing boats. Moreover, not all the 15 ship types seem relevant in an Arctic context. This is not surprising since the aggregation in the ASTD is based on a global system (PAME 2024b). We recommend reconsidering the aggregation of ship types for access level 3 in the ASTD to achieve a manageable number of ship types that are relevant for the Arctic.

Another issue is how representative AIS-based statistics are for the actual traffic (NCA n.d.). This varies with ship types and sizes. There are two types of AIS transponders: class A and B. Havbase and ASTD contain data only from class A, which was required on larger passenger and cargo ships from 2004. Other vessels also started to use AIS class A, either because the system became more common or because their flag states introduced regulations beyond those of the International Maritime Organization, for instance, for fishing vessels above certain lengths (Taconet et al. 2019). Temporal trends derived from AIS class A data may therefore be falsely positive because of more widespread usage. However, for the period we analyse, starting in 2013, there are reasons to believe that most commercial ships in the Arctic were already using AIS class A.

Warships are exempted from the requirement to send AIS signals and may switch off their transmitters. The resulting under-reporting will be particularly significant in areas with high military traffic, such as near the naval bases of the Russian Northern Fleet. Other vessels may also switch off their AIS to conceal illicit activities such as illegal fishing, smuggling or circumvention of the embargo on Russian oil exports (Boerder et al. 2018; Lasserre & Baudu 2023). Such “dark vessels” can be traced by satellite-based detectors other than AIS (KSAT 2020; Government of Canada 2021).

Vessels without AIS, or with AIS class B, are also problematic. Class B is a cheaper option that is often preferred by owners of smaller vessels that are not obliged to carry AIS. The numbers in the ASTD for vessel groups that include few class A ships are therefore an under-representation. For fishing vessels above 24 m, AIS data cover the activities well in the UN’s Food and Agricultural Organization (FAO) areas most comparable to the ASTD area (Taconet et al. 2019). However, the majority of fishing vessels in many Arctic regions are smaller than 24 m and may not use AIS or other traceable electronic systems (Dawson et al. 2018). The limited information about their activities negatively affects analyses of fish catches and safety at sea (Zeller et al. 2011; Pauly & Zeller 2016; Kroodsmas et al. 2018). Pleasure crafts is another group of vessels that is not captured well by AIS data. Reporting to the Canadian Coast Guard demonstrates that traffic with such vessels has grown rapidly, raising concerns about navigational safety. A systematic comparison of how AIS

data and other data sources cover different classes of vessels may enable a better understanding of how the information may be combined to get a better coverage in the ASTD (Svanberg 2019).

Conclusions

Prospects of developing Arctic shipping has been a major reason for increased interest in the Arctic. With the ASTD providing data on ship traffic from 2013, it is now possible to compare expectations with quantitative statistics about actual developments.

There is no doubt that ship traffic in Arctic waters influenced by sea ice has grown in the first decade of ASTD operations (RQ1). The question is how much. The answers are highly dependent on the chosen geography. The Polar Code created a widely recognized delimitation for shipping in Arctic waters. Here, the traffic increased from 6.1 million nm per year in 2013 to 12.1 million nm in 2022, equivalent to 8.7% average annual growth. For the group of High-Arctic LMEs defined in this article, the traffic grew from 14.7 million nm in 2013 to 22.2 million nm in 2022, corresponding to an average annual growth of 4.6%. Vessels in the partly ice-free Barents Sea LME accounted for nearly 75% of these activities in 2022, illustrating that results for the entire Arctic will be very sensitive to the southern boundary drawn in the Barents Sea.

Traffic patterns and developments are very different in various regions of the Arctic (RQ2). In 2022, ships in the Barents Sea LME sailed 5500 times more than those operating in the Northern Canadian Archipelago LME. Over the decade, traffic has grown in all the LMEs but very unequally, both in absolute and relative terms. In the Barents Sea LME, vessels sailed 4.5 million nm further in 2022 than 10 years before, whereas the traffic in the Northern Canadian Archipelago LME increased by only 0.002 million nm. Another remarkable change was the tripling of the sailed distance in the Kara Sea LME, which is explained by Russia's development of petroleum resources assisted by a fleet of ice-class LNG tankers and new icebreakers. The growth rate in the Baffin Bay LME is also above average. Activity in the Central Arctic Ocean LME is very low and variable.

The ship types and sizes in operation (RQ3) also vary significantly between regions. Fishing vessels constitute such a big part of the traffic in the Barents Sea LME that fishing vessels become the dominating ship type for the entire High Arctic. The NSR exhibits large shares of large crude oil and gas tankers, as well as general cargo ships, but low shares of fishing vessels, cruise vessels and container ships. In the NWP area, fishing vessels in the Baffin Bay dominate, while there is also a significant proportion of medium-sized container vessels and larger bulk carriers.

Although the sea ice has decreased, a sharp difference between summer and winter traffic remains (RQ4). Winter sailings have grown and primarily occur in the Barents, Kara and Baffin Bay LMEs. For the other LMEs, there is almost no registered winter activity.

Despite Russia's intention of developing the NSR as a global transport route, the annual transit traffic (RQ5) was lower than one day's traffic in the Suez Canal, even before the sanctions following Russia's full-scale attack on Ukraine. It dropped from 85 voyages in 2021 to 43 in 2022, most likely because of the sanctions. While the war creates high uncertainty on future developments, an analysis of the traffic in 2023 found 79 transits (CHNL 2024). Despite Canada's reluctance to develop its northern waters for international navigation, 42 vessels transversed the whole NWP in 2022. There are absolutely no signs of any transit voyages across the Central Arctic Ocean Route. So, the Arctic Marine Shipping Assessment was right when it predicted that destination traffic would dominate at least throughout 2020.

A key reflection after our analysis is that there are good reasons for using the Polar Code area as a delimitation for High-Arctic shipping. However, sub-division of this area is necessary for enabling consistent analyses of the large intra-Arctic variability. This should be defined and implemented in the ASTD. Similarly, agreement should be reached on geographic definitions for transit voyages, and opportunities for automatically generating statistics for transits in the ASTD should be explored. We also recommend increasing temporal resolution in the standard reporting to weeks and days, as well as reconsidering the aggregation of ship types to be more relevant for the Arctic. PAME should be in a key position to host discussions about such developments, taking diverse user needs into account.

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