Informed Decisionmaking for Sustainability

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Building Common Interests in the Arctic Ocean with Global Inclusion

Volume 2

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Informed Decisionmaking for Sustainability

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Cover illustration: Holistic (international, interdisciplinary and inclusive) integration is represented in this figure with the eight Arctic states and six Indigenous Peoples' Organizations in the Arctic Council; biogeophysical features of the Arctic Ocean represented by the 2012 sea-ice mininum; and boundary of the Central Arctic Ocean High Seas established under the international framework of the law of the sea to which all Aprctic states and Indigenous Peoples' Organizations "remain committed." Details of this cover illustration are elaborated in the first figure in Chapter 1.

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Chapter 24 (Research): Maritime Ship Traffic in the Central Arctic Ocean High Seas as a Case Study with Informed Decisionmaking

Paul Arthur Berkman, Greg Fiske, Jacqueline M. Grebmeier, and Alexander N. Vylegzhanin

Abstract This chapter applies the baseline satellite record of maritime ship traffic in the Central Arctic Ocean (CAO) High Seas from 1 September 2009 through 31 December 2018 as a case study with informed decisionmaking to operate across a 'continuum of urgencies'. Starting with questions to generate data as stages of research, the geospatial analyses herein involve cloud-based innovations with the space-time cube and binned queries to interpret the dynamics of maritime ship traffic based on the vessel flag states, types and sizes within the CAO High Seas and surrounding Exclusive Economic Zones (EEZ). These 'big data' are being transformed into evidence for decisions in view of the institutions that produce governance mechanisms and built infrastructure. With science diplomacy, the next level of action is to introduce options (without advocacy), which can be used or ignored explicitly, contributing to informed decisionmaking by the institutions short-to-long term. Objective integration with satellite sea-ice records further reveals ship-ice dynamics in the CAO High Seas – where the highest number and diversity

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of ships are entering from the Pacific Ocean side – introducing urgent questions to generate informed decisions across the Bering Strait Region south to the Aleutian Islands and northward. The holistic (international, interdisciplinary and inclusive) analyses herein of Arctic Ocean satellite records complement the intent of the *"precautionary approach"* embodied in international law, as provided by the 2018 *Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean* that entered into force on 25 June 2021 with ten Arctic and non-Arctic States. In the CAO High Seas, as an area beyond national jurisdictions, maritime ship traffic is highlighted with global inclusion under the Law of the Sea, where all Arctic states and Indigenous peoples *"remain committed"* as they shared in their 2013 *Vision of the Arctic*. These next-generation Arctic marine shipping assessments reflect socioeconomic drivers of change in the Arctic Ocean, as revealed by the ecology of maritime ship traffic in all EEZ and High Seas areas north of the Arctic Circle, with global lessons from the CAO High Seas about balancing national interests and common interests.

24.1 Introduction

24.1.1 Observing Pan-Arctic Maritime Ship Traffic with Satellites

Maritime ship traffic underscores the socioeconomic dynamics of commercial, scientific and other forms of human presence in the Arctic Ocean, which was the overarching rationale to design *Next-Generation Arctic Marine Shipping Assessments* with satellite Automatic Identification System (AIS) records (Table 24.1). AIS signal transmission (NAVCEN, 2016) is mandated by the International Maritime Organization (IMO, 2020a) for ships larger than 300 gross tonnes engaged on international voyages, as implemented globally through the *International Convention for the Safety of Life at Sea,* 1974, as amended (SOLAS, 2020). Accelerating from the Arctic Marine Shipping Assessment report approved by the Arctic Council (AMSA, 2009), with the satellite record of ship movements north of the Arctic Circle from 2009 forward (Berkman et al., 2020a) – this chapter builds on the baseline satellite record of Pan-Arctic maritime ship traffic from 1 September 2009 to 31 December 2016, which can be accessed through the Arctic Data Center supported by the US National Science Foundation (Berkman et al., 2020b). In this chapter, additional satellite AIS data are included through 31 December 2018 for the region north of the Arctic Circle. These maritime ship traffic data provide the framework to generate an objective assessment of the socioeconomic system (associated with science, technology and innovation) coupled with the biophysical system (associated with environmental factors and biological productivity) in the Central Arctic Ocean (CAO) High Seas beyond national jurisdictions under Law of the Sea (see Chap. 1 in this book).

Satellite AIS records enable synoptic patterns, trends and processes with maritime ship traffic to be interpreted on a Pan-Arctic scale objectively in relation to complementary satellite records with the biophysical system, including with sea-ice

Table 24.1 Next-Generation Arctic Marine Shipping Assessments (AMSA)[a]

Attribute	Arctic Marine Shipping Assessments (AMSA)	
	AMSA (2009)	Next-Generation AMSA
Sampling period	2004	2009-present
Data sources	Arctic states individually and with the Arctic Council	Diverse government and commercial Automatic Identification System (AIS) sources
Observation coverage	Point, Regional	Point, Regional and Pan-Arctic
Observation scope	Ground-based	Ground-based and Satellite
Observation frequency	Inconsistent over space and time	Synoptic and continuous (from minutes to decades)
Ship-type designations	Variable national designations	Standardized international designations
Individual ship attributes	Inconsistent and incomplete	Consistent and comprehensive
Analytical capacity	Limited granularity and questions	Open-ended granularity and questions
Science-diplomacy contributions	Scenarios and negotiated recommendations	Holistic evidence and options (without advocacy)
Informed decisionmaking[b]	Governance mechanisms	Operations, Built Infrastructure and Governance Mechanisms

[a]Updated from Berkman et al. (2020a), involving Automatic Identification System (AIS) data collected by polar-orbiting satellites
[b]Informed decisions operate across a 'continuum of urgencies' short-to-long term (Berkman et al., 2020c), as elaborated subsequently (Berkman, 2020a, b)

coverage (NSIDC, 2020) and ocean color patterns as a representation of primary production (Comiso et al., 2020). These maritime ship traffic analyses complement the Synoptic Arctic Survey (Anderson et al., 2018; Ashjian et al., 2019. Paasche et al. (2019) that is underway with international and interdisciplinary inclusion to *"generate a comprehensive dataset that allow for a complete characterisation of Arctic hydrography and circulation, carbon uptake and ocean acidification, tracer distribution and pollution, and organismal and ecosystem functioning and productivity."*

For example, as the sea-ice has been diminishing, the centroid of Arctic maritime ship traffic has shifted 300 kilometers north-eastward based on the continuous satellite AIS record from 2009 to 2016 (NASA Earth Observatory, 2018). This observation enhances the monthly interpretation of satellite AIS data from 2010 to 2014 north of the Arctic Circle (Eguíluz et al., 2016), with Pan-Arctic ship traffic predominating in the Norwegian and Barents Seas. Relationship between sea-ice and ship traffic similarly has been interpreted with the Arctic Ship Traffic Database (ASTD) through the Protection of the Arctic Marine Environment (PAME) working group of the Arctic Council (PAME, 2020a), revealing a 75% increase in the distance sailed by all ships from 2013 to 2019 in the area of the Polar Code (IMO, 2017a), which largely excludes areas in the Norwegian and Barents Seas because they are perennial open water areas. The observed maritime traffic increase appears to be related to destinational shipping, for example, associated with Liquid Natural Gas (LNG) in the Yamal Peninsula and associated logistic chains prior to the COVID-19 pandemic.

Additional assessments with satellite AIS records of Arctic maritime ship traffic also are emerging, as with models of ship emission inventories (Winther et al., 2014) and intercalibration with land-based AIS records (Wright et al., 2019). The goal of this chapter is to demonstrate the fundamental necessity of next-generation Arctic marine shipping assessments (Table 24.1) to implement "precautionary" approaches with decisionmaking for Arctic Ocean management (see Chap. 1 in this book), as established with entry into force of the *Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean* on 25 June 2021 (CAO High Seas Fisheries Agreement, 2018).

24.1.2 Methodology of Informed Decisionmaking

Assessments of maritime ship traffic as well as any other system parameters in the Arctic Ocean – or elsewhere at local-global scales – involves data to answer questions. Diverse methods may be applied to generate the data, including from the natural sciences and social sciences as well as Indigenous knowledge, considering science in an holistic (international, interdisciplinary and inclusive) manner as the 'study of change' (Berkman et al., 2020c). Questions create capacities to consider change short-term to long-term – to make "informed decisions" that operate across a 'continuum of urgencies' (Berkman et al., 2016; Berkman, 2020a, b). For example, the underlying questions with Arctic maritime ship traffic in this chapter relate to patterns of diminishing sea ice in the Arctic Ocean (Thoman et al., 2020), which may be non-linear (Eisenmann & Wettaufer, 2009).

Progressing from questions to data represents stages of research in the *Pyramid of Informed Decisionmaking*, where the apex goal is an informed decision (see Chap. 1 in this book). However, to produce an informed decision requires evidence, which are distinct from data because decisionmaking institutions are involved (Donnelly et al., 2018). The distinction is that data are generated with diverse methods to answer questions with research whereas evidence is for decisions with action, integrating the data in the context of the decisionmaking institutions in a purposeful manner (Berkman et al., 2020a):

$$\text{Data} + \text{Institution} = \text{Evidence} \qquad (24.1)$$

Importantly, evidence is insufficient for decisions, only compelling decisionmaking institutions to act, if they so choose. Beyond evidence – with science diplomacy – options (without advocacy), which can be used or ignored explicitly, are required for informed decisionmaking (Berkman et al., 2016, 2020c;

Berkman, 2020a, b). In this sense, evidence and options represent stages of action, informing decisions about governance mechanisms and built infrastructure as well their coupling to achieve progress with *"sustainable development and environmental protection,"* which are the *"common Arctic issues"* established by the eight Arctic states and six Indigenous Peoples Organizations with the high-level forum of the Arctic Council (Ottawa Declaration, 1996).

In the Arctic Ocean as elsewhere, the challenge is to operate with research and action, building common interests across the data-evidence interface to produce informed decisions. The basic objective of this chapter is to illustrate how satellite AIS data can be integrated into evidence for informed decisionmaking (see Chap. 1 in this book), applying the CAO High Seas Fisheries Agreement as an institutional case study (Vylegzhanin et al., 2020).

24.2 Arctic Ocean Ship Traffic within Law of the Sea Zones

24.2.1 Synoptic Geospatial Analyses with Satellite Big-Data

This chapter continues to elaborate as well as utilize geospatial methodologies with the baseline of satellite AIS data from the Arctic Ocean, involving cloud computing and binned solutions with the space-time cube – based on user-defined polygons – as described with regional lessons from the Bering Strait and Barents Sea in Volume 1 of the Informed Decisionmaking for Sustainability book series (Berkman et al., 2020a). Briefly, the same standardized methods and satellite AIS data are applied herein from 1 September 2009 through 31 December 2018 north of the Arctic Circle with 21,005 ships in total, as interpreted from the Maritime Mobile Service Identity (MMSI) of each unique vessel across more than 173,000,000 AIS records. The cloud-based methods with Google Big Query enable queries to be run across the entire dataset within seconds at $5 USD per terabyte processing costs and $0.02 USD per gigabyte storage costs (Google, 2020).

These cloud-based methodologies accentuate the geospatial questions that can be addressed with user-defined scalability about maritime ship traffic changes over time and space in the Arctic Ocean, applying satellite AIS records north of the Arctic Circle. The framework question to illustrate in this chapter involves the Law of the Sea zones (see Chap. 1 in this book) across the entire Arctic Ocean with its centrality at 90° North latitude, considering the North Pole as a "Pole of Peace" (Gorbachev, 1987):

What is the distribution of maritime ship traffic in the Exclusive Economic Zones (EEZ) of the Arctic states and the High Seas that exist beyond national jurisdictions in the Arctic Ocean (i.e., north of the Arctic Circle)?

Answering this framework question provides the first rendering of maritime ship traffic within, between and beyond national jurisdictions north of the Arctic Circle comprehensively (Fig. 24.1). In addition, this synoptic profile of maritime ship traffic within jurisdictional zones highlights regional granularity in a Pan-Arctic

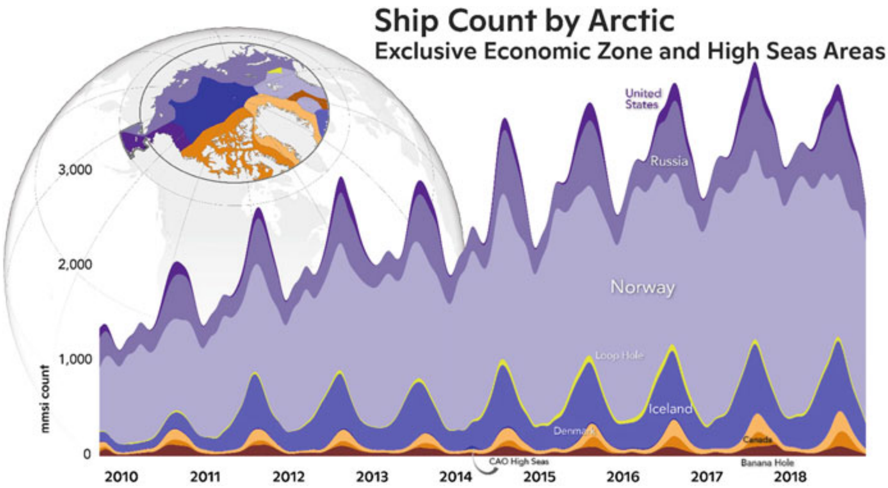

Fig. 24.1 Pan-Arctic Ecosystem of Maritime Ship Traffic among Law of the Sea zones in the Arctic Ocean derived from satellite Automatic Identification System (AIS) big-data with synoptic circumpolar coverage within the Exclusive Economic Zones (EEZ) of Arctic coastal states as well as High Seas areas beyond national jurisdictions from 1 September 2009 through 31 December 2018 north of the Arctic Circle, including the Bering Strait Region as analyzed previously (Berkman et al., 2020a). These data represent more than 173,000,000 AIS records with 21,005 unique ships during the 2009–2018 observation period. Longitudes range from 0°East-West in the Barents Sea with surrounding Norwegian and Russian EEZ to 180°East-West through the Bering Strait with surrounding United States and Russian EEZ. Additional mapping of High Seas areas north of the Arctic Circle is shown in Harrison et al. (2020) for the Banana Hole in the Norwegian Sea and Loop Hole in the Barents Sea as well as the Central Arctic Ocean

context that can be interpreted with new satellite AIS observations, providing an indicator of socioeconomic change that can be integrated objectively with biogeophysical changes continuously across seasons and years in the Arctic Ocean.

The satellite AIS data from 2009 to 2018 reveal seasonality of maritime ship traffic within the EEZ of Arctic coastal states (Canada, Denmark, Iceland, Norway, Russian Federation, United States) as well as within the three High Seas areas north of the Arctic Circle ("Banana Hole" in the Norwegian Sea, Central Arctic Ocean and the "Loop Hole" in the Barents Sea). The high number of ships within the Barents Sea is well known as this region is largely open water throughout the year, further explaining the relatively low-amplitude seasonal variation in maritime ship traffic within the Norwegian EEZ.

As a socioeconomic indicator within Law of the Sea zones, maritime ship traffic reflects the relative change of human presence and interests across the Arctic Ocean. Increasing trends of ship traffic are suggested in all jurisdictional regions, but more clearly in those jurisdictions where there are larger numbers of unique ships (Fig. 24.1). These analyses further reveal the relative dimensions and rates of change with ship traffic across these Arctic maritime jurisdictions from 2009 to 2018 (Table 24.2), noting all regions have increasing maritime ship traffic with the highest increases in the Norwegian EEZ.

Table 24.2 Regional trends of maritime ship traffic within jurisdictions defined by the international framework of the law of the sea, derived monthly from Fig. 24.1

Law of the Sea zone	Arctic ocean area	Monthly number of unique ship days[a]	Regression line[b] [y = rate of change (year) ± constant]
Exclusive Economic Zone (EEZ)	**(areas within national jurisdictions)**		
	Canada	2541	y = 0.012x−474.48 (r^2 = 0.086)
	Denmark	7563	y = 0.169x−638.22 (r^2 = 0.129)
	Iceland	40,644	y = 0.109x−4181.8 (r^2 = 0.322)
	Norway	176,048	y = 0.420x−15928.0 (r^2 = 0.813)
	Russian Federation[c]	43,950	y = 0.088x−3279.1 (r^2 = 0.246)
	United States[c]	6836	y = 0.010x-333.4 (r^2 = 0.023)
High Seas	**(areas beyond national jurisdictions)**		
	Banana Hole	6426	y = 0.012x + 7.7 (r^2 = 0.001)
	Central Arctic Ocean	494	y = 0.002x−89.0 (r^2 = 0.076)
	Loop Hole	3275	y = 0.011x−447.6 (r^2 = 0.306)

[a]Derived with satellite Automatic Identification System (AIS) data north of the Arctic Circle from the monthly totals of unique ships in each area during a daily observation period from 1 September 2009 through 31 December 2018 (i.e., combination of 111 monthly totals), as a measure of relative maritime ship traffic across jurisdictional zones in the Arctic Ocean
[b]Derived from the monthly number of unique ships for 111 months, as shown daily during the observation period (Fig. 24.1), noting the same unique ships may appear in multiple months
[c]The Bering Strait Region with the Russian Federation and United States includes area south of the Arctic Circle (Fig. 24.1), as analyzed and defined previously (Berkman et al., 2020a)

The focus herein with the CAO High Seas involves the jurisdictional zone where there is the slowest increase in maritime ship traffic to date (Table 24.2). Nonetheless, with precaution, the CAO High Seas underlies the potential for a trans-Arctic shipping route when there is open water across the North Pole (Smith and Stephenson, 2013; Stevenson et al., 2019), introducing all manner of questions about *"logistical, geopolitical, environmental, and socioeconomic impacts"* (Bennett et al., 2020).

24.2.2 International Maritime Ship Traffic Patterns and Trends in the CAO High Seas

With maritime ship traffic in an ecological context – studying the home ('eco') – individual ships can be considered as representatives of 'ship species' with known attributes (e.g., flag state, type and size). Similarly, aggregations within a ship species underscore the dynamics of ‘maritime ship traffic populations,’ which are interacting among ‘maritime ship traffic communities’ characterized by their diversities within bounded habitats. These habitats are illustrated regionally by Law of the Sea zones that can be interpreted objectively from satellites over time within the ‘Pan-Arctic ecosystem of maritime ship traffic’ (Fig. 24.1). In an economic context – managing the home – the patterns, trends and processes associated with the Pan-Arctic ecosystem of maritime ship traffic become fundamental to informed decisionmaking about operations, governance mechanisms and built infrastructure in the Arctic Ocean (Table 24.1).

While there are relatively few ships in the CAO High Seas (Fig. 24.1), this jurisdictional region is globally important because it illustrates balancing between national interests and common interests (Berkman & Young, 2009; Berkman & Vylegzhanin, 2013; Berkman et al., 2020c; Berkman, 2010, 2014). This jurisdictional balancing is highlighted by the 2018 CAO High Seas Fisheries Agreement, which is the first North Polar agreement with Arctic and non-Arctic states involving an official translation in an Asian language.

From more than 173,000,000 AIS records with 21,005 unique ships across the Arctic Ocean, in the CAO High Seas there were 185 vessels during the 2009–2018 observation period (Fig. 24.1). As the corpus for the subsequent analyses of this chapter, these vessels were cross-validated in view of their identities and operational characteristics (IMO, 2020b) as well as further confirmed in relation to their transit histories (MyShipTracking, 2020). This dataset of IMO-registered vessels with Class-A transponders (NAVCEN, 2019) is interpreted herein with vessel locations and metadata from 2009 to 2018 (Table 24.3) to generate the first comprehensive assessment about the socioeconomic dynamics of the CAO High Seas, where maritime ship traffic represents human activities, impacts and interests.

The composite maritime traffic pattern in the CAO High Seas from 2009–2018 is shown in relation to vessel flag states (Fig. 24.2), as one of several attributes to quantify ship species’ diversity, providing the granularity to assess the dynamics of the Pan-Arctic ecosystem of maritime ship traffic (Fig. 24.1). Other attributes that are considered herein include ship types (e.g., research, cargo, fishery and enforcement vessels) and their sizes (e.g., tonnage classes). These ship attributes are analyzed individually, but can be combined to address user-defined questions with international and interdisciplinary inclusion. The spatial distribution of ships from all nations is circumpolar, but national activities of Arctic coastal states do seem to predominate adjacent to their respective jurisdictions, notably in parallel with Canada and Russia. Higher diversity of flag states is shown in the CAO High Seas with vessels in the vicinity of the Beaufort and Chukchi Seas.

Different types of ship movements are indicated in Fig. 24.2, as with direct transit lines to the North Pole, where the ‘Barneo Ice Camp’ operated seasonally from 2002 to 2018 (Barneo, 2020). Various shipping patterns (e.g., rectangular zig-zag across extended region, tight zigzag in confined region or two-ship parallel transits) also are revealed, relating to types of maritime activities, as with research or fishing that could be further quantified (Visalli et al., 2020). Moreover, transits of individual ships can be investigated over time as with the 2009–2016 voyages of the German

Table 24.3 Maritime ship traffic attributes to interpret socioeconomic dynamics in the Central Arctic Ocean (CAO) High Seas[a] with surrounding Exclusive Economic Zones (EEZ) shown in Fig. 24.1

Unique ship designation[b]			Ship metadata attribute[c]			CAO High Seas regional visit	
MMSI[d]	Ship name[e]	IMO[f]	Flag[g]	Type[h]	Size[i]	Dates in CAO[j]	Longitudinal Positions[k]

[a]Summary of the satellite Automatic Identification System (AIS) data for the CAO High Seas is available through the Arctic Data Center (https://arcticdata.io/) in conjunction with baseline dataset from September 1, 2009 through December 31, 2016 north of the Arctic Circle (Berkman et al., 2020a), derived from the Aprize satellite constellation launched by SpaceQuest Ltd. (Berkman et al., 2020b); [b]From AIS data file; [c]Selected AIS metadata attributes from among those available (NAVCEN, 2019); [d]Mobile Maritime Service Identity (MMSI) as the unique ship identifier, which is redacted with the Arctic Ship Traffic Database (ASTD) that anonymizes records with access Levels 2 and 3 (PAME, 2020b); [e]Ship names (which may change) were noted, but MMSI (which remains with each ship) was used to identify unique ships; [f]International Maritime Organization (IMO) registered ships with Class-A transponders were used to validate the AIS record; [g]Nation (which may change) at time of each CAO visit; [h]Designation of ship type directly from the AIS data file (Marine Traffic, 2018), recognizing there is a different IMO schema of ship types (IHS Markit, 2017); [i]tonnage size-classes; [j]During period; [k]Longitudinal positions in the CAO High Seas

Polarstern (Berkman et al., 2020a), with its epic MOSAiC (*Multidisciplinary drifting Observatory for the Study of Arctic Climate*) expedition in the CAO High Seas during September 2019 to September 2020 (MOSAiC, 2020).

In addition to patterns of vessel flag states over the CAO High Seas (Fig. 24.2) – across ice-covered and open-water areas with different extents annually (NSIDC, 2020) – the number of nations operating in this international space has been trending upward (Fig. 24.3). Further elaboration of the 30 flag states among the 185 vessels in the CAO High Seas from 2009–2018 are shown in Fig. 24.4, raising questions about the relative number of ships from Arctic and non-Arctic States.

24.2.3 Socioeconomic Trends and Characteristics in the CAO High Seas

The diverse international presence of ships (Figs. 24.3 and 24.4) underlies investments with institutions that enabled their operation in the CAO High Seas. There also are associated questions about risk-management that accompany the decisionmaking. With additional granularity for decisionmaking about built infrastructure (Berkman et al., 2020c; Berkman, 2020a, b), it is clear the number of ship types (Table 24.3) also has been increasing annually in the CAO High Seas (Fig. 24.5), noting a jump in 2014 among the two dozen vessel types recorded from 2009 to 2018 (Fig. 24.6). Independent ASTD analyses (Jon Arve Røyset personal communication October 2020) indicate that many of the unspecified ships are research vessels of different types. The importance of consistent

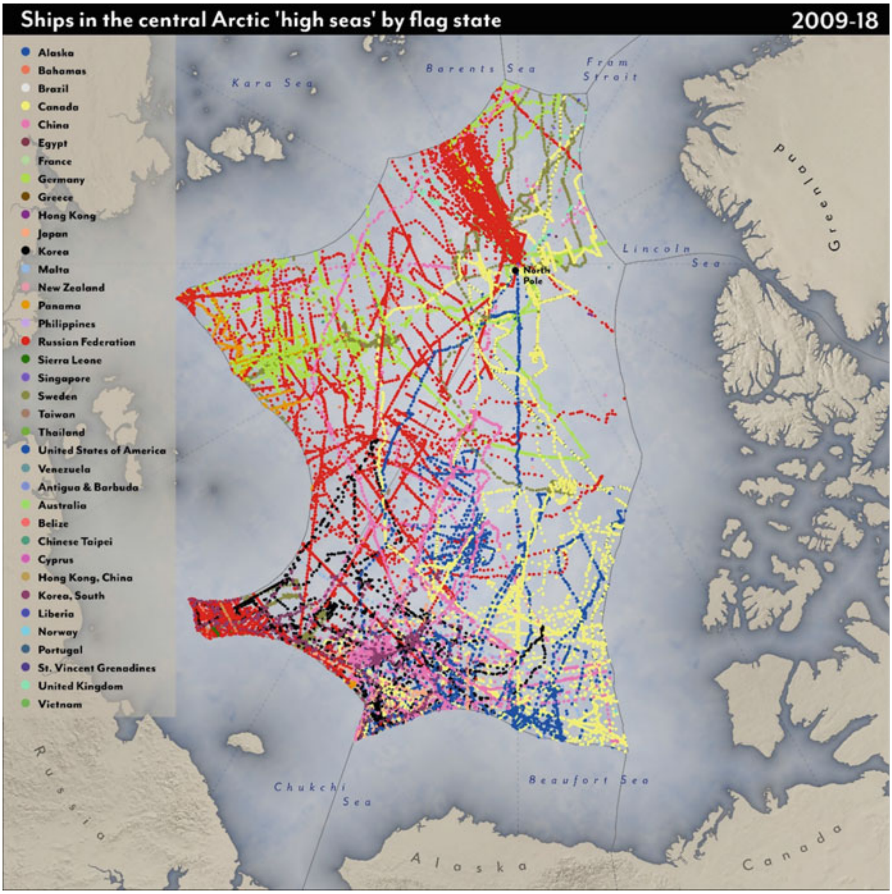

Fig. 24.2 Community of Maritime Ship Traffic in the CAO High Seas based on the composite of vessel flag states (Table 24.3) with distinct ship tracks from 1 September 2009 to 31 December 2018 (see legend). These data have been cross-checked with the Arctic Ship Traffic Database (ASTD) to confirm, for example, that Norwegian flagged vessels were absent in the CAO High Seas until 2019. See Fig. 24.1 for additional East-West orientation around Arctic Ocean longitudes

international strategies with ship-type designations, which is recognized to be a complex challenge (IHS Markit, 2017), are herein highlighted for regional and inter-annual comparisons that contribute to informed decisionmaking.

The socioeconomic dimensions, capacities and dynamics in the CAO High Seas (as elsewhere across the Arctic Ocean) are reflected by ship characteristics (Figs. 24.5 and 24.6) and their national relationships (Figs. 24.3 and 24.4), noting there are "flags of convenience" that complicate any assessments attributed to national activities. It is further noted that additional financial, geopolitical and logistic analyses will be required to produce rigorous socioeconomic interpretations with next-generation Arctic marine shipping assessments (Table 24.1), as interpreted in view of opening of the Transpolar Sea Route (Bennett et al., 2020).

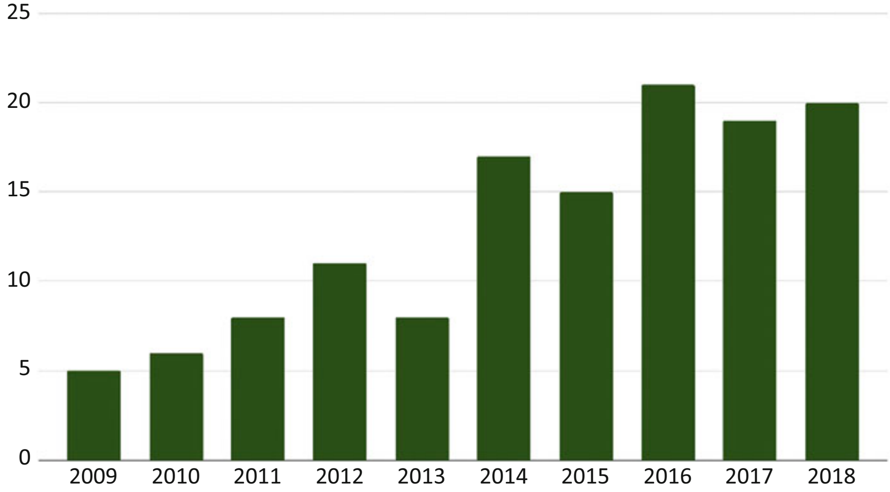

Fig. 24.3 **International Presence and Dynamics** of the maritime ship traffic community in the CAO High Seas (Fig. 24.2) based on the number of flag states among the 185 vessels (Table 24.2) annually from 1 September 2009 to 31 December 2018. These data have been cross-checked and are in close agreement with independent data collected for the Arctic Ship Traffic Database (ASTD). The Y-axis is the number of ships

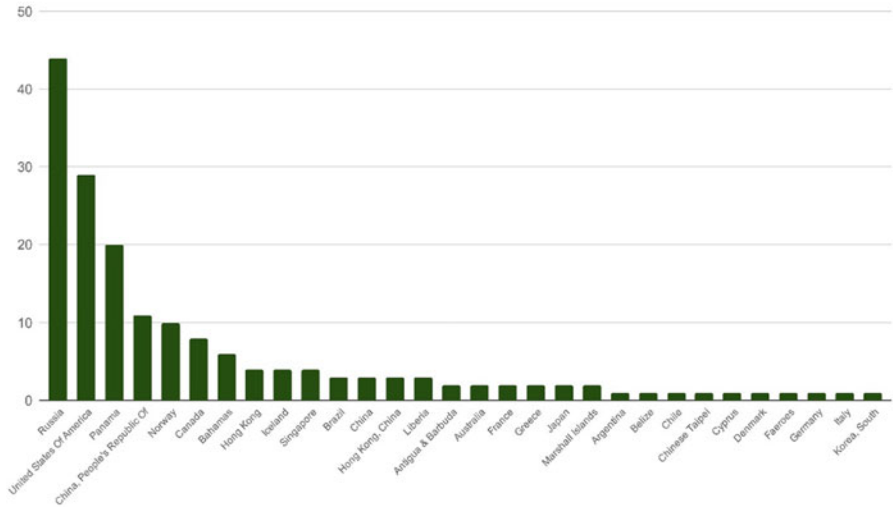

Fig. 24.4 **International Characteristics** of the maritime ship traffic community in the CAO High Seas (Fig. 24.2) based on the diversity of flag states (Table 24.2) among the 185 vessels across the period from 1 September 2009 to 31 December 2018. The Y-axis is the number of ships

A fundamental ship type for the Arctic Ocean is the icebreaker with its various classes, involving an international fleet size of 94 vessels in 2017 (USCG, 2017), indicating about a third of the world icebreaker fleet was operating in the CAO High

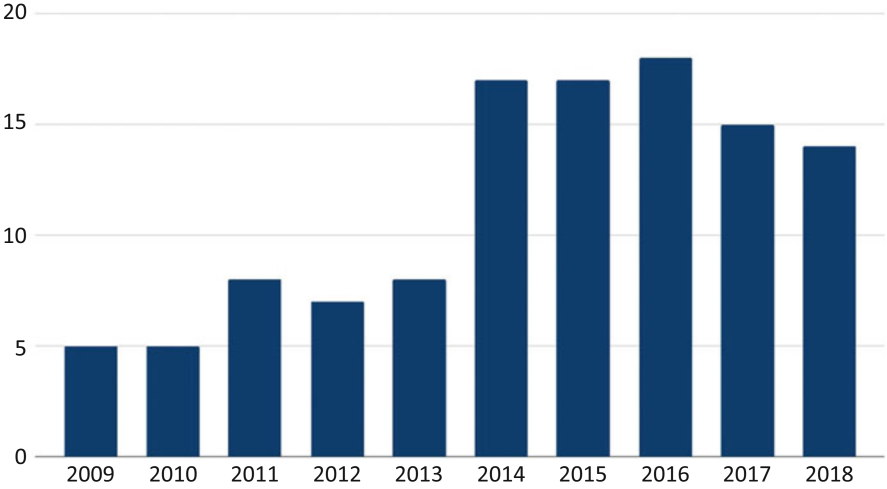

Fig. 24.5 **Socioeconomic Trends** of the maritime ship traffic community in the CAO High Seas (Fig. 24.2) based on the number of ship types (Table 24.3) annually from 1 September 2009 to 31 December 2018. The Y-axis is the number of ships

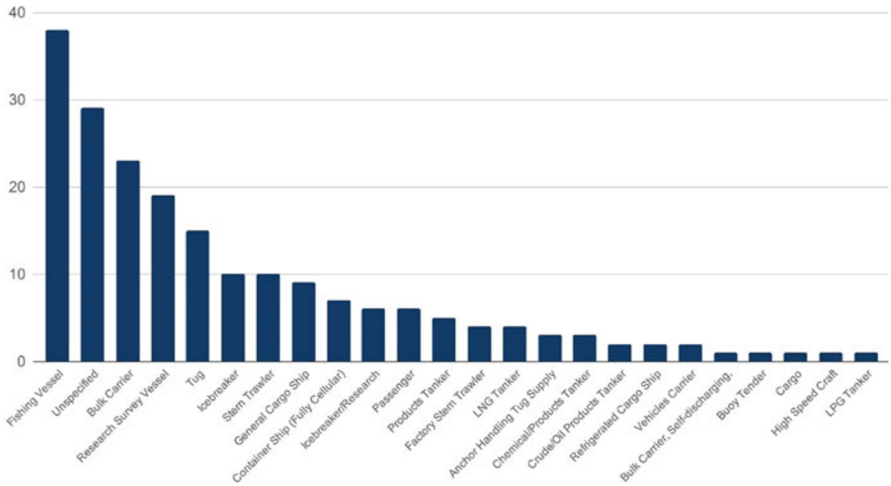

Fig. 24.6 **Socioeconomic Characteristics** of the maritime ship traffic community in the CAO High Seas (Fig. 24.2) based on the diversity of ship types (Table 24.3) among the 185 vessels across the period from 1 September 2009 to 31 December 2018. The Y-axis is the number of ships

Seas during the observation period (Fig. 24.6). Distinct from ice-strengthened vessels, icebreakers are designed for operations that include escorts, search-and-rescue and other emergency responses as well as maritime domain awareness. As the most seaworthy vessels for the Arctic Ocean, can this international icebreaker fleet be better coordinated to implement the emergency-response agreements in force with all of the Arctic states in the Arctic Ocean? Specifically, this question applies to the 2011 *Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic* (Arctic SAR Agreement, 2011) and 2013 *Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic* (Arctic MOPP Agreement, 2013)? Addressing this question also is an example of where data can be integrated into evidence (Eq. 24.1) for decisions in view of relevant institutions in the CAO High Seas as well as elsewhere in the Arctic Ocean.

Satellite AIS data facilitate holistic integration with diverse user-defined questions to transform data into evidence, stimulating research and action that contribute to informed decisionmaking. While it is beyond the scope of this chapter, synoptic analyses based on the characteristics of the vessels and their movements could contribute to informed decisions with next-generation Arctic marine shipping assessment (Table 24.1), identifying questions of common concern to address: black-carbon production; ship strikes on marine mammals; noise pollution; introduction of invasive species; or the effectiveness of existing international agreements generally. Importantly, framing such questions with holistic integration would contribute to common-interest building in the Arctic Ocean, moving beyond self-interests that commonly limit progress with decisionmaking.

In this regard, the CAO High Seas offers a potent case study, as reflected by ambassadorial dialogues on *Building Common Interests in the Arctic Ocean* with the ambassadors of six then twelve nations in 2015 and 2016, respectively (Ambassadorial Panel, 2015, 2016; Pan-Arctic Options Project, 2016). These inclusive dialogues serve as stimulus for this second volume in the Informed Decisionmaking for Sustainability book series, enabled by questions to build common interests beyond the *"concern about a unilateral declaration of five states regarding prevention of unregulated commercial fishing in the Central Arctic Ocean"* (Alfreðsdóttir, 2016). The lesson is that questions of common concern build common interests among allies and adversaries without being prescriptive to enable progress with sustainable development (United Nations, 1987, 2015), which is a "common" Arctic issue (Ottawa Declaration, 1996).

24.3 CAO Ship Traffic Coupling with Sea Ice

24.3.1 Ship-Ice Patterns and Trends in the CAO High Seas

Satellite sea-ice data from the National Snow and Ice Data Center (NSIDC, 2020), covering the same region and period as the satellite AIS data in the CAO High Seas (Fig. 24.2), were integrated into the space-time cube (see above) to analyze ship-ice interactions (Berkman et al., 2020a). These ship-ice interactions represent ship occurrences within 4 km^2 bins that contain ice, quantified on a daily basis. Complementing overall trends with maritime ship traffic north of the Arctic Circle from 2009 to 2016 (Berkman et al., 2020a), ship-ice interactions during this same period increased toward higher latitudes just in the CAO High Seas (Fig. 24.7).

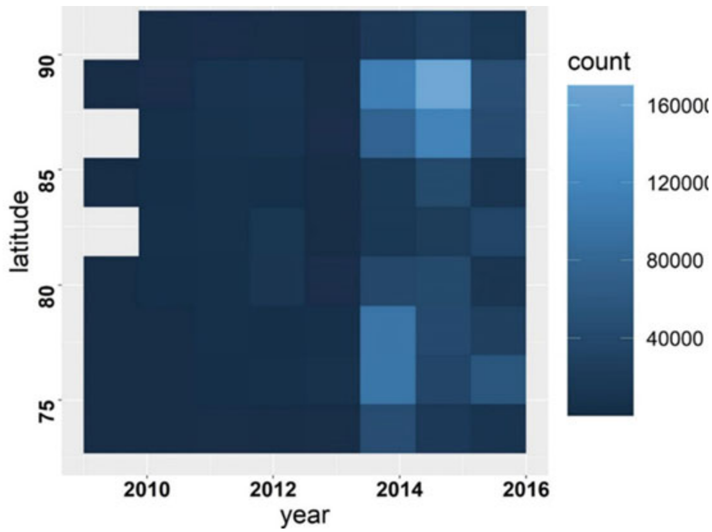

Fig. 24.7 Ship-ice interactions associated with the dynamics of the maritime ship traffic community in the CAO High Seas (Fig. 24.2) assessed within 4 km^2 grids daily from 1 September 2009 to 31 December 2016 based on satellite sea-ice and ship-traffic data, as analyzed previously for the entire maritime region north of the Arctic Circle (Berkman et al., 2020a)

These satellite sea-ice and ship-traffic data further reflect a jump in 2014 (Fig. 24.5) with the coupled biophysical and socioeconomic dynamics of the CAO High Seas system. The three-dimensional pattern of ship-ice interactions in the CAO High Seas (Fig. 24.7) is a space-time representation of the flag-state track lines shown above (Fig. 24.2).

24.3.2 Testing the 'Ship-Ice Hypothesis' in the CAO High Seas

A central contribution of this chapter is applying the CAO High Seas as a regional test of the 'ship-ice hypothesis' that Arctic ship traffic is increasing as sea-ice is diminishing (Berkman et al., 2020a). Without falsifying the hypothesis, assessment in the CAO High Seas (Fig. 24.7) suggests a trend of increasing ship traffic toward higher latitudes in the Arctic Ocean over time, as has been predicted (Smith & Stephenson, 2013; Norwegian Environment, Agency, 2014; Stephenson & Smith, 2015; Stephenson et al., 2018).

However, with the CAO High Seas, the East-West directionality of maritime ship traffic also can be assessed within longitudinal sectors in a circumpolar context surrounding the North Pole. More specifically, the CAO High Seas offers a unique regional test of the ship-ice hypothesis because diminished sea-ice and open-water predominate only in the Beaufort Sea and Chukchi Sea sectors (Thompson et al., 2016; Armitage et al., 2020), adjacent to the 180°East-West meridian. Consequently, a corollary of the 'ship-ice hypothesis' is that maritime ship traffic (i.e., socioeconomic activity) in the CAO High Seas will predominate from the Pacific Ocean rather than from the Atlantic Ocean sectors, even though vessels north of the Arctic Circle predominate in the EEZ connected to the North Atlantic (Fig. 24.1, Table 24.2).

Test of the 'ship-ice hypothesis' is characterized by vessel numbers and diversities within adjacent polygons to reveal 30° sectoral trends during the 2009–2016 period. Within the area of the CAO High Seas, international presence predominates in the Pacific Arctic sectors (Fig. 24.8), centering along the 180° East-West meridian, adjacent to the Bering Strait. This maritime-traffic directionality literally is 180° offset from the majority of shipping north of the Arctic Circle, which is in the Barents Sea (Fig. 24.1), where there is open water, as noted above in view of the *Polar Code* implementation. Concentrated international maritime ship traffic in the Pacific Arctic sectors of the CAO High Seas also is independent of national origin.

The Bering Strait is particularly important as the choke point of maritime ship traffic into and out of the Arctic Ocean (Rothwell, 2017), where the north-south transit gap is only 47 kilometers wide at its narrowest point in the Pacific Arctic

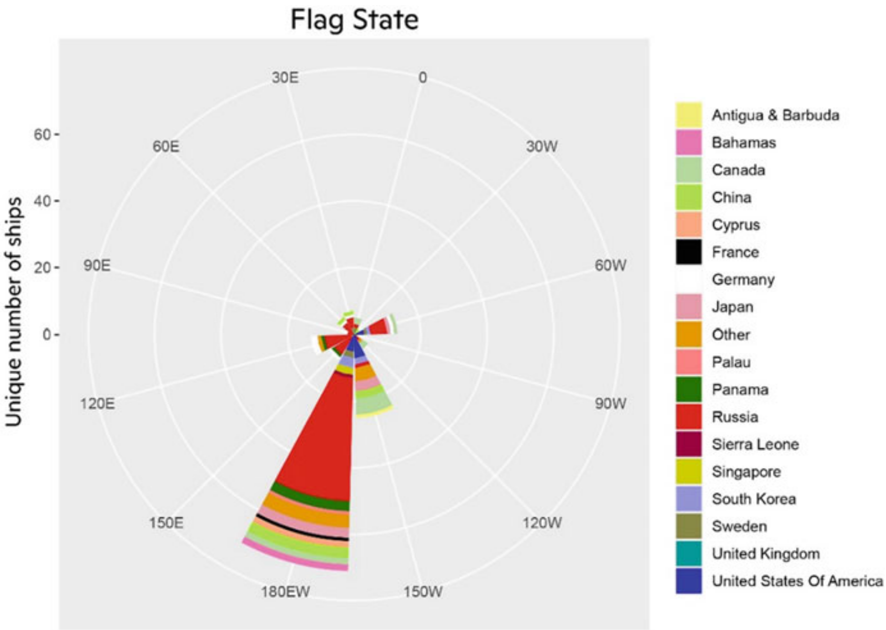

Fig. 24.8 'Ship-Ice Hypothesis' Test (Flag States) with maritime ship traffic populations in the CAO High Seas (Fig. 24.2) based on the distribution of ship flag states (Figs. 24.3 and 24.4) from MMSI records (Table 24.3) across 30° meridional sectors surrounding the North Pole. See Fig. 24.1 for East-West orientation around Arctic Ocean longitudes with 0°East-West in the Barents Sea to 180°East-West through the Bering Strait

sectors along the 180° East-West meridian (WWF, 2020). Along this maritime boundary region with the Russian Federation and United States (Berkman et al., 2016; Young et al., 2020), "two-way routes" and "precautionary areas" have been established for ship traffic (IMO, 2017b). Implications of maritime ship traffic dominating in the Pacific Arctic sectors of the CAO High Seas (Fig. 24.8) also relates to implementation of the "precautionary approach" (Pan & Huntington, 2016; Harrison et al., 2020) intended with the CAO High Seas Fisheries Agreement:

> "*precautionary conservation and management measures as part of a long-term strategy to safeguard healthy marine ecosystems and to ensure the conservation and sustainable use of fish stocks.*"

Transforming these data into evidence (Eq. 24.1) relates to the CAO High Seas Fisheries Agreement (2018) as well as ship-traffic governance mechanisms and built infrastructure that are being considered specifically for the Bering Strait Region (CMTS, 2019).

As shown in a circumpolar context (Fig. 24.9), icebreaker movements exist across all sectors of the CAO High Seas, as would be expected because they are designed to move in ice-covered areas. Conversely, less ice-worthy vessels would be expected to be more restricted in their movements, where sea ice is diminished, which is the case in the CAO High Seas sectors in the vicinity of the Beaufort and

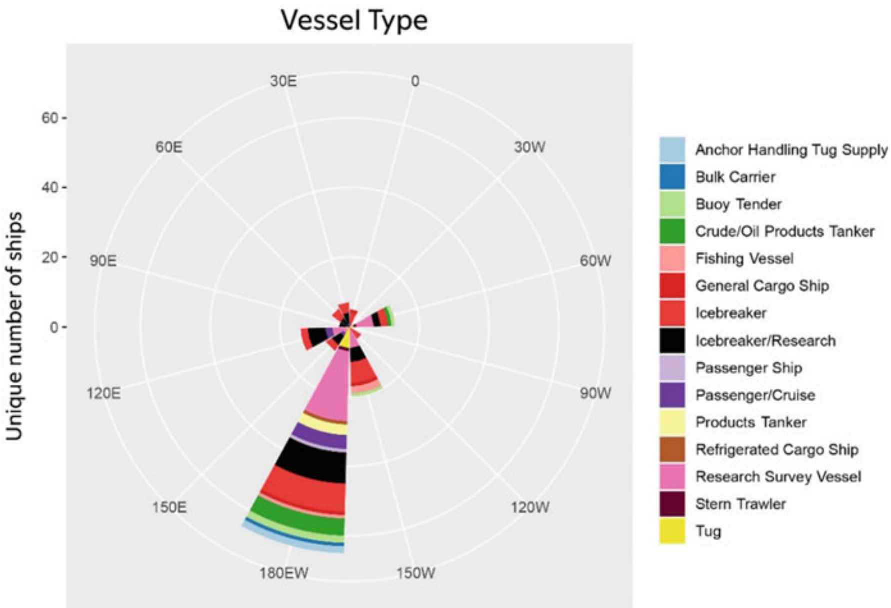

Fig. 24.9 'Ship-ice hypothesis' Test (Ship Types) with maritime ship traffic populations in the CAO High Seas (Fig. 24.2) based on the distribution of ship types (Figs. 24.5 and 24.6) from MMSI records (Table 24.3) across 30° meridional sectors surrounding the North Pole. See Fig. 24.1 for East-West orientation around Arctic Ocean longitudes with 0°East-West in the Barents Sea to 180°East-West through the Bering Strait

Chukchi Seas (Fig. 24.9), supporting the ‘ship-ice hypothesis’ and its corollary above. Moreover, with commercial considerations of harvesting living resources in the CAO High Seas, it also would be expected that fishing vessels may be present in the open water areas, even for exploratory purposes as shown. Ship sizes additionally reveal directionality with small tonnage ships only appearing in the Beaufort Sea region of the CAO High Seas (Fig. 24.10).

Together, ship densities and diversities among meridional sectors (based on the characteristics of the maritime ship traffic) increase with diminishing sea ice in the CAO High Seas surrounding the North Pole (Figs. 24.8, 24.9 and 24.10). As a practical outcome, testing the ‘ship-ice hypothesis’ connects the socioeconomic and biophysical systems of the Arctic Ocean. With such integration, next-generation Arctic marine shipping assessments (Table 24.1) will continue to reinforce the application of a *“precautionary approach”* to produce informed decisions across a

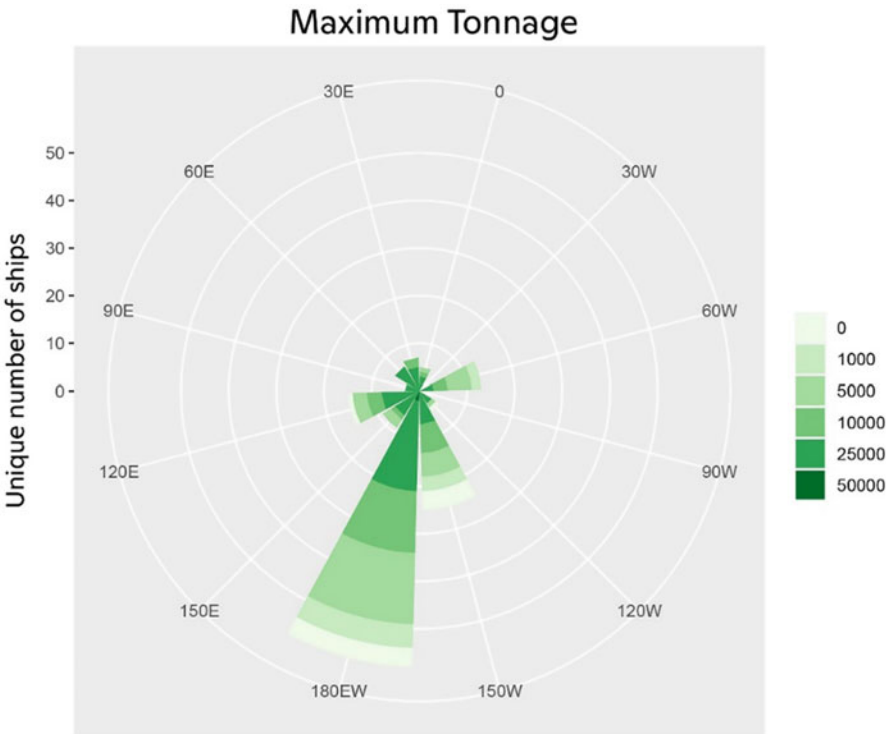

Fig. 24.10 ‘Ship-Ice Hypothesis’ Test (Size-Classes) with maritime ship traffic populations in the CAO High Seas (Fig. 24.2) based on the distribution of ship size-classes from MMSI records (Table 24.3) across 30° meridional sectors surrounding the North Pole. See Fig. 24.1 for East-West orientation around Arctic Ocean longitudes with 0°East-West in the Barents Sea to 180°East-West through the Bering Strait

'continuum of urgencies' with common-interest building (see Chap. 1 in this book) in the CAO High Seas surrounding the North Pole as a "Pole of Peace" (Gorbachev, 1987; Berkman, 2009b, 2012).

24.4 Global Inclusion in the CAO High Seas

24.4.1 Informed Decisionmaking in the CAO High Seas

Understanding the system dynamics of species applies to marine living resources as well as ships. In this ecological context (Crowder & Norse, 2008), ships are analogous to individual fish, which have populations of the same species, involving diverse interactions within communities and ecosystems. Such ship species' interactions are represented, in part, by their feedback and intended interplay with governance mechanisms.

As a research outcome, data to test the 'ship-ice hypothesis' can be transformed into action for informed decisionmaking, considering the integration of evidence in view of Arctic institutions (Arctic Portal, 2020). For example, these maritime ship-traffic data underlie evidence that would apply to the Polar Code (IMO, 2017a), introducing options (without advocacy) to consider with ship design, navigation and monitoring that may be specific to the CAO High Seas in view of the CAO High Seas Fisheries Agreement or the *United Nations Convention on the Law of the Sea* (United Nations, 1982).

As noted above, the interplay with the CAO High Seas Agreement extends to institutions emerging from the International Maritime Organization (IMO, 2017a) and Arctic Council (Arctic SAR Agreement, 2011; Arctic MOPP Agreement, 2013; Arctic Science Agreement, 2017) with applications to the Arctic Ocean. The institutional interplay (Young, 2002, Oberthür & Stokke, 2011) also includes the Straddling Stocks Agreement (1995) and related United Nations codes of conduct (FAO, 1995) as well as existing fisheries agreements that apply to the CAO High Seas (NEAFC, 1980). Integration of Arctic maritime ship traffic data and biophysical data in view of these institutions illustrates who, when, where, what, how and why to create evidence for decisionmaking with governance mechanisms (Eq. 24.1).

With its precautionary approach, the signed CAO High Seas Fisheries Agreement represents a platform for informed decisionmaking in an international space (Vylegzhanin et al., 2020; Young et al., 2020; Berkman et al., 2020a). More specifically, this historic agreement acknowledges the need for a *"long-term strategy to safeguard healthy marine ecosystems,"* addressing *"long-term conservation and sustainable use of living marine resources and in healthy marine ecosystems in the Arctic Ocean."*

Informed decisionmaking in the CAO High Seas involves science broadly as the 'study of change' with biophysical and socioeconomic dynamics interpreted with natural and social sciences as well as Indigenous knowledge, as stated in the CAO High Seas Fisheries Agreement, desiring *"to promote the use of both scientific* *knowledge and indigenous and local knowledge."* Key natural and social science organizations are involved in the CAO High Seas Fisheries Agreement, as had been suggested (Van Pelt et al., 2017), appreciating Indigenous knowledge is being included (Schatz, 2019). Importantly, since 2016, the International Council for the Exploration of the Sea (ICES) and North Pacific Marine Science Organization (PICES) along with PAME have been coordinating the Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean (WGICA). The ICES/PICES/PAME efforts have been generating continuous progress to interpret the rapidly changing biophysical dynamics of the CAO system (WGICA, 2016, 2017, 2018, 2019, 2020). Implications of the 'precautionary approach' with the CAO High Seas are global, especially with precedents that will contribute to sustainable management of biodiversity beyond national jurisdictions (BBNJ, 2019; De Santo et al., 2019). With the CAO High Seas Fisheries Agreement and related institutions, the *"precautionary"* approach or principle (see Chap. 1 in this book) with short-to-long term consideration exemplifies informed decisionmaking under international law.

24.4.2 Common-Interest Building in the CAO High Seas

The *Convention on the High Seas* (1958) established the first international space ever on a planetary scale, promoting peace after the second world war (Berkman, 2009a). Emerging from cooperation among allies and adversaries alike at the height of the cold war – the *Convention on the High Seas* now is awakening lessons from the CAO High Seas that have relevance for humanity, which still is in its infancy as a globally-interconnected civilization (Berkman, 2020a,b), learning to balance national interests and common interests at local-global levels across the spectrum of subnational-national-international jurisdictions (Berkman 2019).

Lessons include socioeconomic dynamics, which can be revealed across the entire Arctic Ocean in relation to maritime ship traffic with objectivity and synoptic scope (Tables 24.1, 24.2, and 24.3; Fig. 24.1), enabling cooperation, coordination and consistency. As an option (without advocacy), next-generation Arctic marine shipping assessments (Table 24.1) can be treated as a fundamental indicator of socioeconomic dynamics in the Pan-Arctic maritime ecosystem, as illustrated with CAO High Seas (Figs. 24.2, 24.3, 24.4, 24.5, 24.6, 24.7, 24.8, 24.9, and 24.10). With the CAO High Seas Fisheries Agreement, these socioeconomic data will help to implement a *Joint Program of Scientific Research and Monitoring* to address questions short-to-long term (Balton & Zagorski, 2020), complementing Pan-Arctic research that is underway with the Synoptic Arctic Survey to understand the biophysical system *"beyond the scope of any single nation"* (Anderson et al., 2018).

At the top of the Earth, the CAO High Seas is unambiguously an area beyond national jurisdictions under the international framework of the Law of the Sea. Building on the initiative of the five surrounding Arctic coastal states (Ilulissat Declaration, 2008), the eight Arctic states and six Indigenous peoples organizations

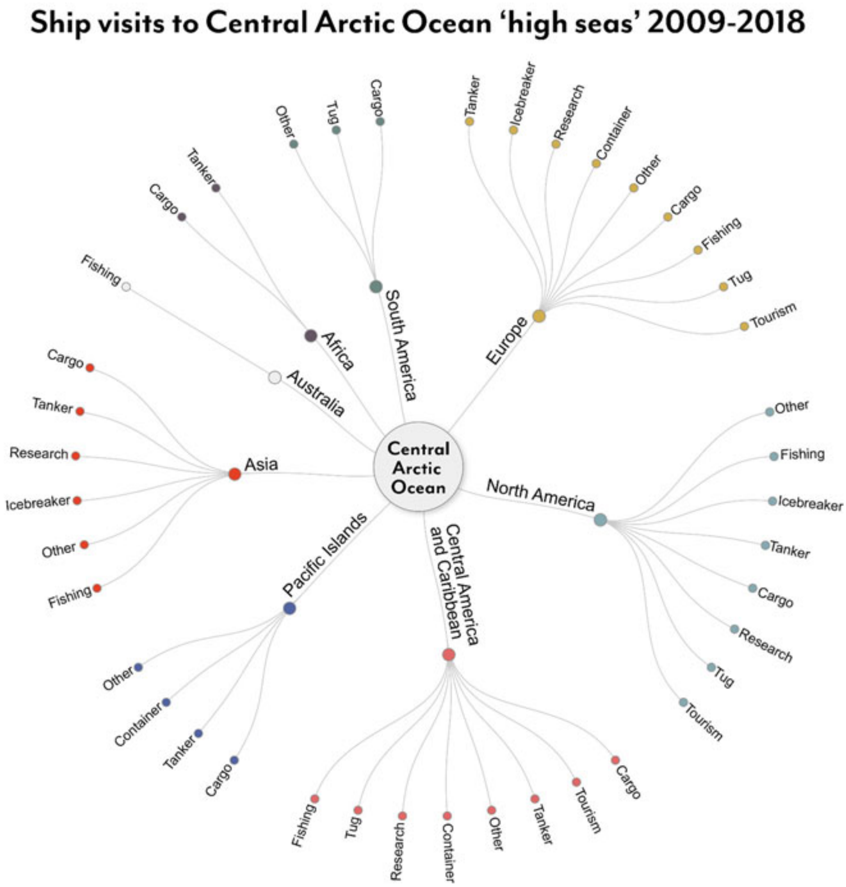

Fig. 24.11 Complex of Attributes (Table 24.3) with the maritime ship traffic community in the CAO High Seas (Fig. 24.2), as an area beyond national jurisdictions (ABNJ), reflecting global inclusion based on ship types flagged from all continental regions on Earth from 2009 through 2018 (Figs. 24.2, 24.3, 24.4, 24.5, 24.6, 24.7, 24.8, 24.9, and 24.10)

together *"remain committed"* to this international legal framework (Arctic Council, 2013). The product of their leadership is global inclusion in the CAO High Seas (Fig. 24.11), where the world has shared rights and responsibilities.

With science diplomacy as an holistic process involving the skills, methods and theory of informed decisionmaking (see Chap. 1 in this book), there is a local-global opportunity to frame questions that build common interests in the CAO High Seas, recognizing the starting point determines the journey of cooperation or conflict. As an option (without advocacy), the journey of humanity in the CAO High Seas can be characterized as an 'Index of Global Inclusion' with hope and inspiration for the benefit of all on Earth across generations.

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