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The missing middle: Central Arctic Ocean gaps in fishery research and science coordination

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ABSTRACT

The warming global climate is reducing sea-ice coverage in the central Arctic, transforming a mostly inaccessible marine region into a 'new' and relatively poorly studied ocean. History shows that exploitation of newly accessible natural resources tends to precede effective research and management measures. But in response to increasing access to the central Arctic, a precautionary approach has been taking hold, with broad political and scientific support culminating in the Oslo Declaration of 2015, which aims to prevent unregulated high seas fishing in the central Arctic. Negotiations toward a full binding agreement are continuing. Formal efforts toward assessing knowledge of the Arctic marine ecosystems and coordinating research are underway, and practitioner-based research coordination and collaboration in the region is also ongoing. Yet broad gaps in our current marine research and coordination exist, and this paper draws attention to the spatial middle, middle trophics, and the middle scale — an Arctic 'missing middle'. Scientific activity in the central Arctic Ocean region is burgeoning in recent years, and a large number of initiatives, projects, and arrangements are meeting some of the need for coordination. But full pan-Arctic scientific coordination does not yet exist. In support of ecosystem-based and precautionary management of the central Arctic Ocean, this paper considers a fully Arctic-focused organization that can both orchestrate and prioritize marine research in the Arctic in view of policy imperatives, and bring emerging scientific understanding of the region directly into the discussion and formation of new policy.

1. Introduction

In the central Arctic Ocean (CAO), multi-year ice has covered the sea for thousands of years (e.g. [1]). But the warming global climate is accelerated in high northern latitudes, due to positive feedback from albedo reductions, among other factors (e.g. [2]), and projections of completely ice-free summer conditions in the CAO focus on a mid-century or earlier timeframe (e.g. [3–5]). Much of the region is already open during summer, particularly in the northern Chukchi and Beaufort seas [6,7]. This is driving alterations in Arctic marine ecosystems (e.g. [8–11]), and what was historically an isolated and largely inaccessible region is transforming within a single generation into a newly accessible ocean. The scale of this change has little precedent in human history [12].

Despite these rapid changes, and despite many past examples of marine resource exploitation outpacing the development of ecosystem-based management regimes (e.g. [13,14]), to date very little research directed at harvestable fish species and related biota has been conducted in the CAO. While several authors have hypothesized that some subarctic fish populations will expand into the high Arctic [15–17], recent meetings of international fisheries experts from the five nations bordering the Arctic Ocean have concluded that commercial fisheries in CAO waters are unlikely in the short term [18]. Yet it is conceivable that commercial fishing in the high seas CAO region could occur in the longer term, and crucially, no existing organization has a mandate to orchestrate fishery-relevant research and management across the entire CAO region, or to unify access to current and historical ecological information for the region.

Partly in response to the prospect of increasing access to the CAO, recent activity among the “Arctic Five” nations sharing marine Exclusive Economic Zone (EEZ) boundaries with the high seas CAO region (Russia, Norway, Denmark/Greenland, Canada, USA) has been

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advancing the prospects of a CAO fisheries agreement, of which marine science and research is a key part (e.g. [19–21]). The 2014 CAO fisheries agreement meeting in Nuuk, Greenland, and the subsequent Oslo Declaration of 2015 call for the establishment of a joint program of scientific research and promotion of "cooperation with relevant scientific bodies" [22].

The Oslo Declaration also described the potential for a broader process that would include "all interested States" [23], and since 2015 other states with Arctic interests have joined the negotiations and strengthened momentum toward coordinated research and monitoring in the CAO. At the June 2016 "Meeting On High Seas Fisheries In The Central Arctic Ocean" in Iqaluit, Canada, delegations from the five Arctic coastal states plus the People's Republic of China, the European Union, Iceland, Japan, and the Republic of Korea (together the "5+5" group) noted the need for further discussion of the scope of the scientific program [24].

In parallel with ongoing policy negotiations, scientific representatives of the 5+5 governments and other interested organizations have been identifying research gaps and needs, refining science questions, and developing terms of reference that focus on a research and monitoring plan. A series of four meetings of this science expert's group have been held to date, with the most recent meeting in Norway in September 2016 [25].

Still, the general priorities and framework of this emerging joint CAO research and monitoring program remain unclear. As one contribution among others toward clarifying these issues, this paper takes a broad look at what is missing in fishery-relevant CAO science and what is needed, scientifically and administratively, to orchestrate research and monitoring among the nations involved. In so doing, this paper aims to contribute towards bringing CAO management policy and science policy together into an overlapping framework.

2. Region and research focus

2.1. CAO region

The CAO region (Fig. 1) is a political designation that encompasses the high seas north of the EEZs of the five Arctic coastal states [21,26]. This paper concentrates on overarching fishery-related marine research issues in the CAO region, but recognizing the oceanographic and ecological interconnectivity in the CAO (e.g. [27]), “adjacent waters” within national EEZs are also considered, including regional shelf seas directly adjacent to the CAO.

2.2. Current regulatory framework

At the broad, global scale, fish resources in the CAO region are currently regulated by the Law of the Sea Convention (UNCLOS) and the United Nations Fish Stock Agreement, which both encompass the CAO [18]. These provide the fundamental high seas regulatory framework upon which other regulatory arrangements are likely to be based. The only formal regional fishery management organization currently in effect in the high seas CAO region is the Northeast Atlantic Fisheries Commission (NEAFC), which covers a slice of the Atlantic sector all the way to the North Pole (Fig. 2). While most of the CAO is deep basin, there are areas less than 2000 m deep north of the Chukchi Sea and along the mid-ocean ridges [28]. In waters adjacent to the CAO, if fish stocks of commercial interest expand along shelf and slope areas that fall within the exclusive economic zones (EEZs) of Arctic coastal nations, national and bilateral fisheries organizations and arrangements are in place to ensure precautionary management. Further detail of fisheries-relevant regulations can be found in several recent publications (e.g. [18,29,30]).

2.3. Fishery and ecosystem research

Traditional fishery research focuses on population dynamics, recruitment, and other biological processes that support stock assessments and have direct application to the establishment and regulation of sustainable harvest levels. Over the past two decades there has been growing interest in ecosystem-based fishery management (EBFM), which aims to apply an integrated approach to fishery management, and to balance a diversity of objectives by considering biotic, abiotic, and human components of ecosystems and their interactions, as well as associated uncertainties [31]. In the context of an ecosystem-based and precautionary approach to potential arctic fisheries, a broad suite of research activities is relevant (e.g. [25,32–36]). Research on the prey and habitat that sustain fish populations, climate and oceanographic influences on fish, the role fishes play as keystone prey species for mammals and birds, marine bird and mammal populations and human communities that depend on fish, and interactions among these factors are all increasingly relevant to managers of extant fisheries, and will be particularly relevant in assessing potential new fisheries such as those in the newly accessible Arctic waters. Less attention has been given to indigenous knowledge about Arctic fishes and fisheries specifically, but especially in the adjacent waters this body of knowledge may offer insights and time depth unavailable from any other sources.

3. Research gaps

3.1. The spatial middle

Despite difficulties in physical access and the extreme conditions found in the far north, the CAO region has seen a remarkable amount of scientific research in the twentieth century, continuing to the present day: Soviet and US drift stations, early icebreakers, modern icebreakers, submarine-based research, remote sensing, and others [9,37]. In addition to geological, atmospheric, and meteorological scientific priorities, past CAO research efforts have largely focused on fundamental aspects of ocean science–sea ice, circulation, biogeochemical cycling, and atmosphere-ocean forcing.

There has been little fishery-focused research in the CAO region, beyond limited taxonomic and biogeographic sampling and opportunistic data collection [38]. This was not surprising during the twentieth century, considering that the region was almost completely ice-covered year-round, blocking or hampering access and making fishery research a low or non-existent priority in competition for limited research funding.

But ice thickness, age, and extent have been changing rapidly in more recent times, and reductions in seasonal ice minima coupled with declines in multi-year ice cover are creating vast openings deep into the non-EEZ, international waters of the CAO (e.g. [39]). Open water in the CAO region during summer and fall is predicted to increase, easing access for commercial and non-commercial use alike, and driving cascades of ecological effects (e.g. [40,41]). In response, multiple observation and research programs are extending north from coastal and shelf areas but have yet to achieve significant coverage in the CAO region.

3.2. Middle trophics

Research in the CAO has to date primarily focused on ice dynamics and on physical, chemical, and biological oceanography and lower-trophic species (benthic species, phytoplankton, and zooplankton). There has also been some focus on upper-trophic marine bird and mammal species that spend time at or above the ocean's surface (whales, seals, seabirds, polar bears). However, relatively little is known about middle-trophic fish species– fish that both prey on lower-trophic zooplankton and are also preyed upon by other fish or by seabirds or marine mammals (e.g. [42,43]). This is largely due to the

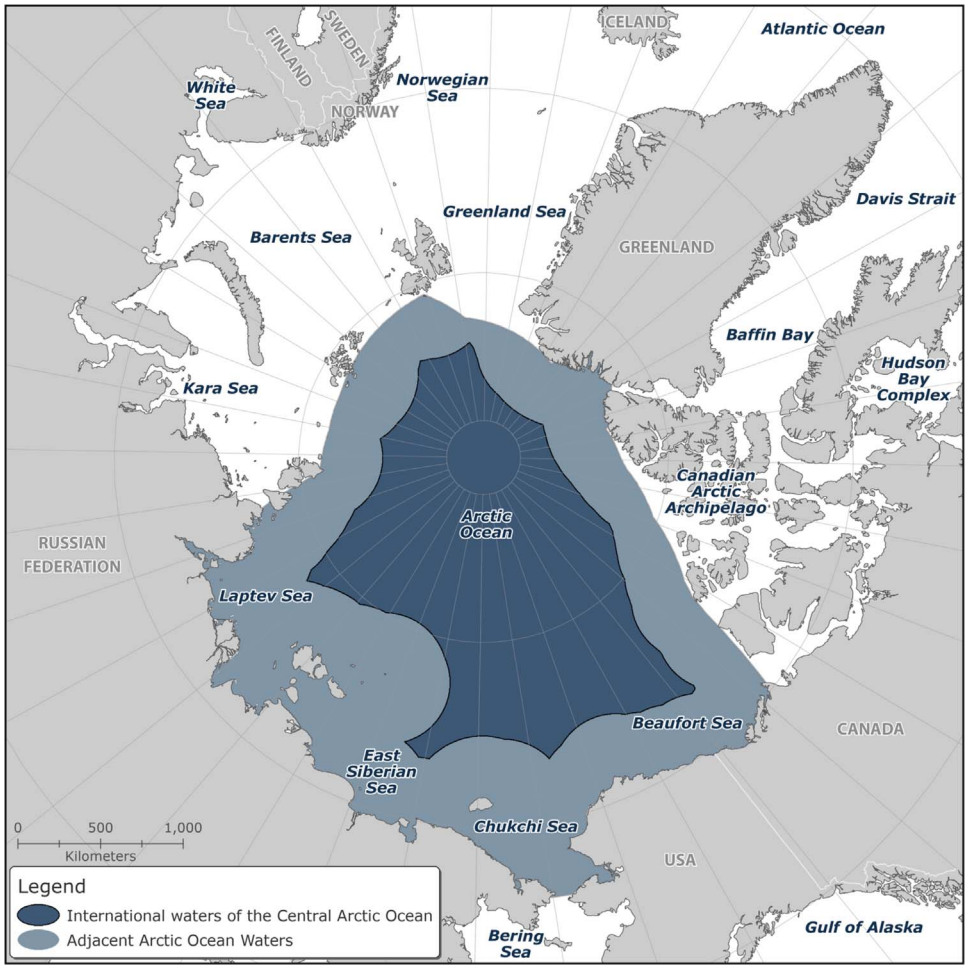

Fig. 1. The international waters of the Central Arctic Ocean (CAO), depicted with adjacent waters. The CAO defined here is a political rather than biogeographic designation, representing the waters north of the Exclusive Economic Zone (EEZ) boundaries of the five arctic coastal states. The 'adjacent waters' polygon includes regional shelf seas directly adjacent to the CAO, but boundaries are based on authors' interpretation and presented for illustration purpose only.

logistical challenge of accessing ice-covered areas and deploying the equipment required for fish research. Plankton, water column, and bottom sampling can be undertaken in broken ice, however towing nets to sample fish is much more restricted by ice (but see [44]). Determined efforts over the past century have led to moderately detailed knowledge on taxonomy and occurrence of fish species, with some 250 species known to occur in Arctic waters [45], but in the CAO very little is known about fish population sizes, movements, stock dynamics and recruitment, or interactions between fish species and their habitat and prey [38].

Recent years have seen an increase in fishery-related field research in waters adjacent to the CAO, bringing opportunity in the sense of potential to inform related work in the CAO, and also showcasing the need for overarching coordination. One focal area for research in adjacent waters is in the Chukchi and Beaufort seas, in part as a response to the US government's 2008 call to take necessary steps to manage migratory and transboundary fish stocks in the Arctic Ocean. Fish-focused scientific surveys have been carried out in the Chukchi and Beaufort seas by NOAA and as part of the 'U.S.-Canada Transboundary Fish and Lower Trophic Communities' project; the 'Arctic Ecosystem Integrated Survey' (Arctic Eis) project is investigating trophic connections to oceanography in the northern Bering and the Chukchi seas [46]; participants in the 'Distributed Biological Observatory' (DBO) framework have undertaken detailed sampling at a set of oceanographic stations in five regions along a gradient from the northern Bering Sea to the Chukchi and Beaufort seas and are now expanding into the Atlantic sector [47]; and the 'Arctic Marine Biodiversity Observing Network' is aiming to pull information together from multiple sources for improved understanding of the Chukchi Sea region and to develop a long-term biodiversity monitoring network [48]. Canadian scientists have pushed net and hydroacoustic sampling into the deeper slope and basin areas of the Canadian Beaufort, where they have documented large aggregations of Arctic cod [49,50]. Norwegian and Russian researchers are similarly extending their "traditional" fishery and ecosystem surveys onto the slope of the Arctic Ocean to the north of Svalbard (e.g. the ‘Strategic Initiative — The Arctic Ocean ecosystem' project; [51]). The circumpolar Ecosystem Studies of the Subarctic and Arctic Seas (ESSAS) program supports a working group on the bioenergetics of subarctic fishes, and also focuses on informative comparisons among subarctic and arctic seas, for example a workshop on the ecology of arctic gadids (*Boreogadus saida* and *Arctogadus glacialis*, referred to ambiguously as "Arctic cod" and "polar cod", saffron cod *Eleginus gracilis*, and navaga *E. navaga)* across the circumpolar north [52]. A further example is the NORCAN project, which contrasted capelin (*Mallotus villosus*) and polar cod populations (among other ecosystem aspects) in the Labrador/Newfoundland region and the Barents Sea/Norwegian Shelf [53].

3.3. The middle scale

Marine research reaching into the CAO region tends to be very broadly oriented. This is perhaps not surprising given how little is known about the region, leading to exploratory research, and also given the unpredictability of access, leading to sometimes opportunistic and reconnaissance science objectives. Studies of this type include international research/monitoring programs such as the 'Nansen and Amundsen Basins Observational System' (NABOS; [54]), the Arctic Ocean 2016 expedition [55], and the 'International Arctic Buoy

Table 1
Selected major marine research and management organizations or programs historically active in the CAO region and adjacent waters, classified by geographic scope and general level of engagement in science coordination, fisheries, and connection to management.

Organization or program	Year of formation	Geographic scope	Science coordination?	Fisheries focus?	Provide management advice?	Use management advice?
Arctic Council	1991 as AEPS; 1996 as full AC	Pan-Arctic	Y			
International Arctic Science Committee (IASC)	1990	Pan-Arctic	Y			
International Council for the Exploration of the Sea (ICES)	1902; full status in 1964	Atlantic Sector	Y	Y	Y	
North Pacific Marine Science Organization (PICES)	1990; full status in 1992	Pacific Sector	Y	Partial		
Joint Norwegian-Russian Fisheries Commission ("JointFish")	1974; first session in 1976	Atlantic Sector	Y	Y		Y
North East Atlantic Fisheries Commission (NEAFC)	1980; entered into force in 1982	Atlantic sector	Y	Y		Y
Intergovernmental Consultative Committee (ICC)	1988	Pacific Sector	Y	Y		Y
Ecosystem Studies of Subarctic and Arctic Seas (ESSAS)	2005; expanded to Arctic in 2013	Pan-Arctic	Y	Partial		
Pacific Arctic Group (PAG)	1999; full status in 2009	Pacific Sector	Y			

Programme' (IABP). And by their nature, coordinated observation programs — recently increasing in number and coverage, in part as a legacy of International Polar Year activities — are broadly focused. These include the European Union's 'Developing Arctic Modeling and Observing Capabilities for Long-Term Environmental Studies' (DAMOCLES) and subsequent 'Arctic Climate Change, Economy, and Society' (ACCESS; [56]) project, Canada's 'ArcticNet' effort [57], and the US-based 'Distributed Biological Observatory' (DBO; [47]), 'Study of Environmental Arctic Change' (SEARCH; [58]), and 'Arctic Observing Network' (AON) projects, and also the Arctic Council's 'Sustaining Arctic Observing Networks' (SAON; [59]) umbrella approach.

Research at a relatively specific, problem-based scale has been common in waters adjacent to the CAO, and less so within the CAO itself. Research of this type may have an ecosystem basis and is often focused on topics of wider public concern, such as particular offshore development sites (e.g. the COMIDA and Hanna Shoal programs in association with Chukchi Sea oil and gas lease sales; [60]); transport routes; species of conservation concern (e.g. bowhead whales, polar bears, walrus; [61]); and/or in relation to important commercial or subsistence harvest species (e.g. [62]).

The 'in-between' or mid-level research focus—proactive, ecosystem-based and policy-relevant research on species or systems that have established importance but are not yet at a crisis point—is not currently well-developed or well-coordinated in the CAO. Middle-scale research examples could include research centered on the two gadid species referred to ambiguously as "Arctic cod" and "polar cod" and an improved understanding of how those species interact with the rapidly changing CAO marine environment (e.g. [52]). Such programs are more prevalent in adjacent waters, especially those connected to subarctic seas that currently support large-scale fisheries (e.g. the Bering Sea; [63]).

4. Gaps in information sharing

Despite many national and international efforts, both grassroots and high-level, CAO marine data accessibility—the ability to visualize and mobilize metadata and data from a unified access portal—remains low. Information sharing among colleagues often remains a personal endeavor, and accessing past and current research in the Arctic is challenging. A wide and complex array of established and more recent initiatives focuses on data and metadata cataloguing and sharing (e.g. [64]), but standardization and interoperability remain nascent. An 'Integrated Arctic Ocean Observing System' emerged as a legacy of the IPY, but remains limited in scope. 2016 and 2017 have seen increasing activity on this front, with SAON among others driving significant progress [65].

Information about the extent and objectives of past and current research programs across the CAO and adjacent seas is usually obtained through regional networks (e.g. the Pacific Arctic Group) or through direct collaborations, complicating broader priority-setting and research coordination efforts in the Arctic. Equally challenging is making information available to a wider range of Arctic stakeholders, not least Arctic residents and indigenous organizations. But at the same time, emerging 'bottom up' or practitioner-driven science organizations like PAG or the DBO, as well as longstanding institutions like ICES, are providing many examples of effective information sharing, and can illustrate a way forward for achieving a similar outcome across the entire CAO area. The current shift within the scientific community, from both funding agencies and researchers, toward publication in open access journals is also broadening the availability of information and perspectives.

5. Coordination gaps

The main research needs in the CAO are transboundary or are in international spaces beyond national jurisdictions, meaning that

actionable research tied to management imperatives or monitoring frameworks must be coordinated among nations. But there is not yet a formal institutional arrangement or commitment by governments to prioritize, plan, coordinate, and implement fishery-related research in the CAO. Currently, international research coordination and cooperation in the Arctic marine environment is accomplished mostly through a mosaic of committees, institutes and universities, informal organizations, bilateral arrangements, or specific multinational programs with limited scope or duration (Table 1). This has provided important information, but as interest in the Arctic grows, as access to the region becomes more available, and as the need for timely scientific information increases, the need for improved coordination has also grown.

Alongside the political track toward a fishery agreement in the CAO, there are currently two new mainstream vectors of international coordination in the CAO. The first is directly linked to the ongoing fishery negotiations, in the form of a series of meetings of “Scientific Experts on Fish Stocks in the Central Arctic Ocean” (or "FiSCAO") that have been supported by the Arctic coastal states. This science-focused process, which began in 2011 in step with the pathway of the political negotiations, has recently expanded into the "5 + 5" group with the inclusion of five additional “cooperating nations” [18,25] as well as other interested organizations. On a related but not directly linked track is the joint Arctic Council and ICES working group on an integrated ecosystem assessment for the CAO region, established in 2016 and called "WGICA" [66]. The WGICA members were originally drawn mainly from the Atlantic sector, but as of 2017 PICES joined the working group and representatives from the Asian Pacific nations (e.g., Republic of Korea, People's Republic of China, Japan) were invited.

In addition to top-down coordination efforts led by governments, i.e. the FiSCAO meetings and the WGICA process, an array of more “bottom up” efforts is growing, in the form of groups that span the

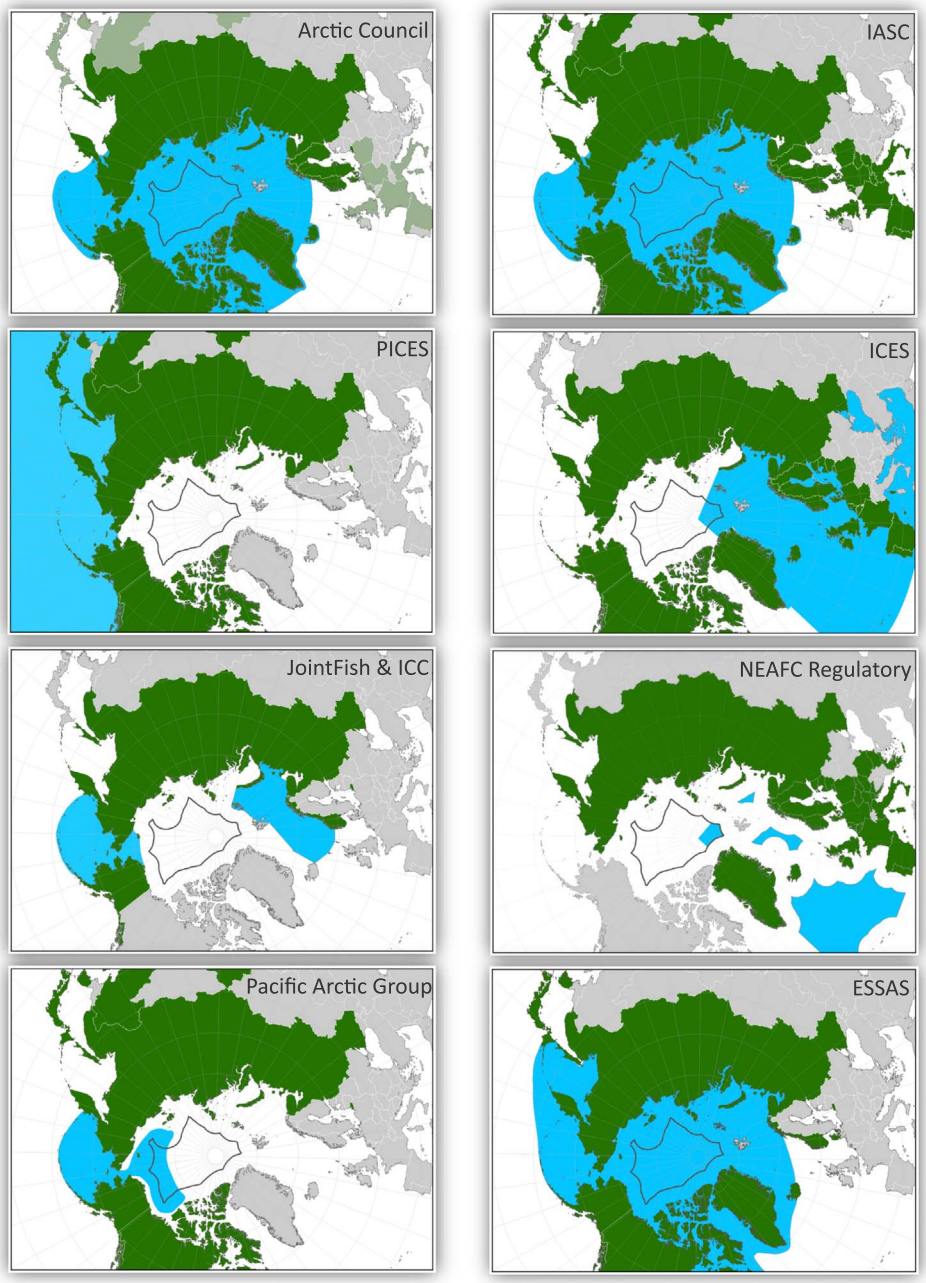

Fig. 2. Maps for each of the major marine research organizations or programs active in the CAO region and adjacent waters, depicting the marine spatial coverage or focus region in blue, and the member states in green. Lighter green represents a secondary tier of membership, e.g. "observer" status for the Arctic Council. See Table 1 for full names. JointFish and ICC are combined in a single panel for convenience; JointFish is the marine area on the right side of panel, with Norway and Russia as corresponding member states, and ICC is the marine area on the left side of panel, with Russia and the USA as member states. Note that depiction of marine coverage is for illustration purpose only– boundaries are not exact.

practitioner scientific level and the coordination level (e.g. the Pacific Arctic Group and the ESSAS program; Table 1). These efforts bring expertise and motivation, and are a significant form of grassroots coordination in leveraging efforts and maximizing the limited resources of vessel time and research funding. However, these groups face significant challenges in coordinating funding for field research across national boundaries due to the lack of international funding mechanisms.

As one avenue for examining the state of activity, coordination, and representation in the CAO prior to development of the FiSCAO and WGICA processes, this paper presents maps that show the geographic focus of the selected organizations listed in Table 1, representing what might be considered the main actors in the CAO in terms of (1) science coordination, (2) fisheries focus, and (3) providing and using management advice. These organizations span the range from the relatively narrow and authoritative (e.g. the only regional fishery management organization active in the CAO, the North East Atlantic Fisheries Commission) to the more grassroots and research-focused (e.g. the Pacific Arctic Group). Other structures are relevant to management and science, e.g. the global regulatory framework noted in Section 2.2, but are less regionally active or focused in terms of science coordination and so are not included in our selection. The maps first depict the general area of interest for each of the nine individual groups, as well as the member representation for each group (Fig. 2). The panels are then overlain, to create a single map that shows the relative density of current coordination coverage across the CAO and adjoining regions, and also shows the relative level of involvement for each nation around the region (Fig. 3). Perhaps not surprisingly, the areas with the highest coverage are the two main inflow shelves, the Barents Sea and the Bering Sea, which are characterized by rapid changes in ice cover and water temperature, the presence of large existing fisheries, and the potential for some of the fished stocks to expand northward into the Arctic. These inflow shelves also provide the most obvious shipping access routes to the Arctic, with the Barents Sea being the gateway to the Arctic for the European nations and the Bering Sea being the only access point for the US and for Asian nations. The distribution of involvement and effort is likely to remain uneven for these and other reasons, but at present there is simply no single mechanisms for pan-Arctic, fisheries-related CAO research and information sharing.

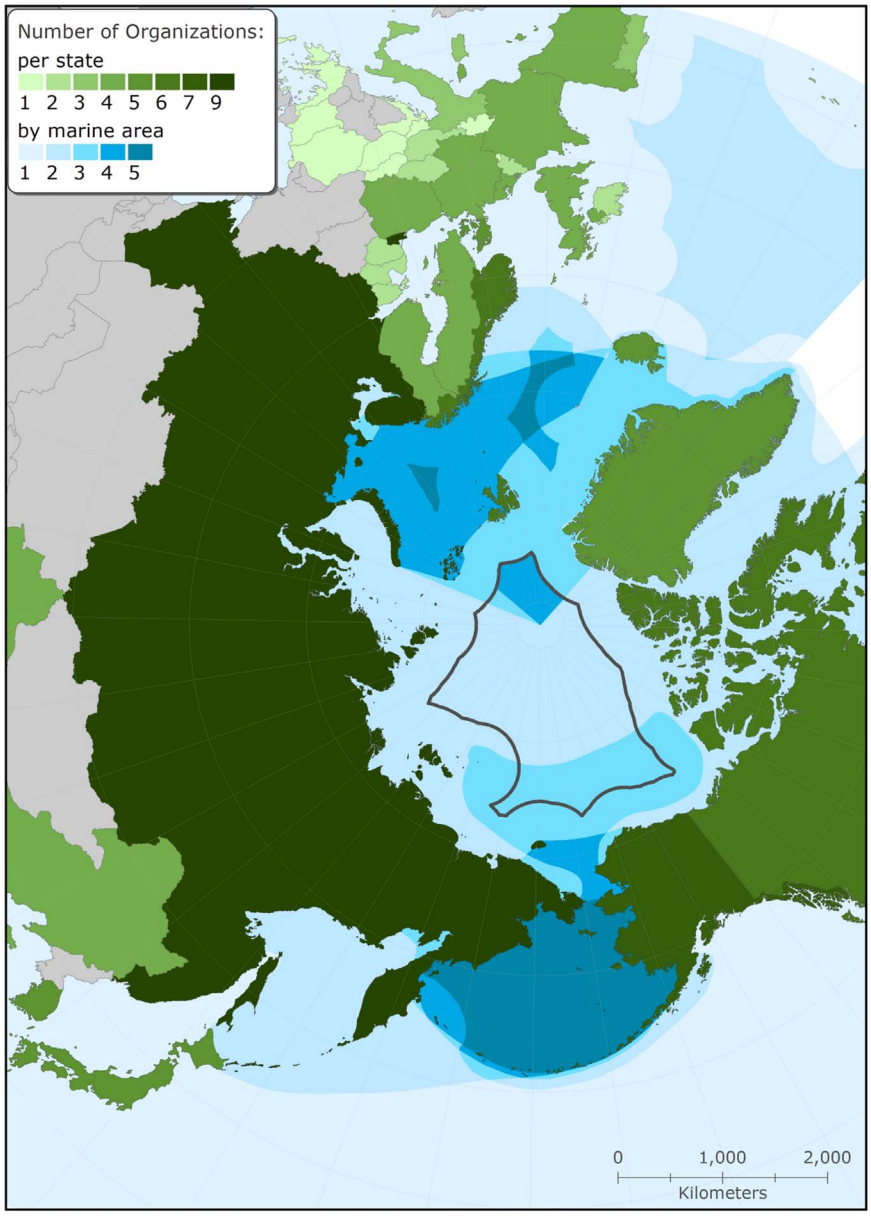

Fig. 3. An illustration of the CAO (polygon outlined in black), adjacent waters, and the north Pacific and Atlantic regions, depicting the relative density of science coordination and management policy coverage at sea and state representation on land. Color density reflects the proportion of the selected organizations listed in Table 1 and shown in Fig. 2 that cover a given area (blue) and the relative level of involvement for each state around the region (green). Note that depiction of marine coverage is for illustration purpose only– boundaries are not exact.

6. A view forward

As noted in the US North Pacific Fishery Management Council's decision to prohibit commercial fishing in US Arctic waters [67], the kinds of information required for sustainable, ecosystem-based fisheries are simply not yet available in coastal and shelf waters—and are even less available in CAO waters. The "joint program of scientific research" with the aim of improving understanding of Arctic marine ecosystems called for by the Arctic coastal states faces significant obstacles in overcoming the issues highlighted here—"missing middle" gaps in spatial coverage and trophic focus, and closing the distance between broad, fundamental research and actionable, policy-focused research.

Such a joint program will require extensive coordination. For marine research, an example of a successful institutional arrangement exists in the North Atlantic under ICES. One important approach for the Arctic is already underway whereby ICES is extending its scope northwards into the Arctic [68], and the Arctic Council– which historically has had little engagement with commercial fisheries topics– is partnering with ICES and PICES to assess the Arctic marine ecosystem [66]. ICES in particular has a long history of Arctic fisheries engagement, with an Arctic Fisheries Working Group in place for over 50 years. Yet ICES and PICES already cover a vast geographic area outside the Arctic, with missions chiefly focused on sub-Arctic and temperate ocean research needs, and the ICES formal membership has no representation from Asian states with interest in the CAO.

The most recent (2016) FiSCAO report [25] suggests that existing scientific bodies working in the region can provide the necessary coordination of science and management. FiSCAO is indeed providing an increasingly capable structure to address the immediate need for scientific advice in support of the 5 + 5 agreement, and partnership with the WGICA will further inform the agreement process.

Yet as illustrated here, despite a broad array of initiatives, projects, and arrangements in recent years, there is still no fully pan-Arctic coordination currently in place. And at the same time, there has been a rapid rise in science activity in the CAO region, driving the need for science coordination higher than ever before. This warrants consideration of a new organization that draws on the tremendous capabilities and knowledge of existing regional organizations, but that is pan-Arctic and entirely Arctic-focused.

Creation of a marine science organization fully focused on the Arctic, with explicit commitments by governments to cooperate on Arctic marine research, could bring immediate benefits in maximizing value of research, and would establish a foundation for collaborative implementation of ecosystem-based, precautionary management in the Arctic. A new 'Arctic Marine Science Organization' that blends bottom-up science coordination with resource management priorities and policy imperatives could address the spatial, trophic, and scale gaps highlighted in this paper and elsewhere, by:

- Prioritizing current and future research and monitoring issues
- Orchestrating marine monitoring and research efforts to address key management questions
- Advising national and international authorities on marine policy and management
- Developing and supporting standard protocols to strengthen practical cooperation
- Developing information sharing to mobilize available and newly-collected data
- Organizing collaborative efforts to interpret and synthesize data

It is therefore suggested that a coordinating organization for the CAO include the following broad criteria that this paper views as necessary for success:

1. Unified coverage of the CAO region
2. Inclusion of all states that are parties to a CAO policy agreement
3. Taking an ecosystem-based and precautionary approach to management
4. Supporting two-way communication between policy and research
5. Ability to manage and mobilize current and historical data for the region

History has taught that the exploitation of natural resources without adequate knowledge commonly leads to unsustainable harvests and negative or unknown effects on ecosystems. Facing the future Arctic and a newly accessible CAO presents an extraordinary opportunity to learn from the past and to "get it right" this time, with an integrated, ecosystem-based, and precautionary approach to fishery science and policy in the CAO. This is a major opportunity, but also a tremendous challenge, and will require new partnerships and new commitments to address current gaps in research, coordination, and information sharing.

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