Implementation Plan of the CAOFA
Joint Program of Scientific Research and Monitoring (JPSRM)

Central Arctic Ocean Fisheries Agreement (CAOFA)
Scientific Coordinating Group (SCG)

Final version adopted by SCG 9 April 2024

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1. BACKGROUND AND INTRODUCTION

1.1. *Purpose and objectives*

A landmark international agreement was established to promote effective stewardship of Arctic marine living resources: the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean. The Agreement (also known as the "Central Arctic Ocean Fisheries Agreement" or CAOFA) entered into force on June 25, 2021 after ratification by all ten of the Signatories (Canada, the People's Republic of China, the Kingdom of Denmark in respect of the Faroe Islands and Greenland, Iceland, Japan, the Republic of Korea, the Kingdom of Norway, the Russian Federation, the United States of America, and the European Union). The Agreement Area covers the extraterritorial waters in the Arctic and corresponds to 2.8 million km^2.

The Parties to the Central Arctic Ocean Fisheries Agreement (CAOFA) recognized that they lack crucial information regarding the marine ecosystems, fish stocks, and ecological linkages in the Central Arctic Ocean (CAO) as well as a sound understanding of the potential impacts of commercial fishing on CAO ecosystems and Arctic residents, including Arctic Indigenous peoples. Gaining such information was recognized as being essential to managing CAO marine living resources using an ecosystem approach, particularly in light of the effects of climate change on CAO ecosystems and processes. Therefore, the Parties formed the Scientific Coordinating Group (SCG), and charged it with developing the Joint Program of Scientific Research and Monitoring (JPSRM) to fill these information gaps. The Parties agreed that this program should take into account scientific knowledge, Indigenous Knowledge, and local knowledge to help inform this information gathering effort.

The objective of CAOFA (Article 2) is to prevent unregulated fishing in the high seas portion of the central Arctic Ocean through the application of 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. The purpose of the JPSRM is to obtain data and information needed to improve our understanding of the ecosystems in the Agreement Area and, in particular, to determine whether fish stocks might exist in the Agreement Area now or in the future that could be harvested on a sustainable basis, and to assess possible impacts of such fisheries on the ecosystems of the Agreement

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[1] The SCG recognized and expressed its appreciation to the following individuals who made significant contributions to the development and completion of the JPSRM Implementation Plan: Vernae Angnaboogok, Robert Apro, John Bengtson, Dave Benton, Michael Cameron, Sarah Davie, Andrey Dolgov, Alain Dupius, Ashley Ehrman, Elena Eriksen, Lauren Fields, Maria Fossheim, Robert Foy, Ezra Greene, Cyrus Harris, Kevin Hedges, Taqulik Hepa, Yutaka Hiroe, Randi Ingvaldsen, Birgitte Jacobsen, Uma Branner Jespersen, Vivian Korthuis, Libby Logerwell, Shigeto Nishino, Bengamin Pungowiyi, Chris Rooper, Leandra Sousa, Kenji Taki, and Yong Yu.

Area. The JPSRM will follow an ecosystem approach to assess: 1) marine ecosystem structure and function in the Agreement Area and adjacent waters, and identify gaps in knowledge of ecosystem components and functions; 2) the prospects and potential sustainability of commercial fisheries in the Agreement Area; 3) the potential impacts of such commercial fisheries on the marine ecosystems of and linked to the CAO; and 4) the potential impacts of commercial fisheries on Arctic Indigenous peoples and potentially on local communities, that depend on marine ecosystems for culturally sustainable harvests.

Article 4 of the Agreement calls for the creation of the JPSRM as follows:

A. The Parties shall facilitate cooperation in scientific activities with the goal of increasing knowledge of the living marine resources of the central Arctic Ocean and the ecosystems in which they occur.
B. The Parties agree to establish, within two years of the entry into force of this Agreement, a Joint Program of Scientific Research and Monitoring with the aim of improving their understanding of the ecosystems of the Agreement Area and, in particular, of determining whether fish stocks might exist in the Agreement Area now or in the future that could be harvested on a sustainable basis and the possible impacts of such fisheries on the ecosystems of the Agreement Area. The Parties shall guide the development, coordination and implementation of the Joint Program of Scientific Research and Monitoring.
C. The Parties shall ensure that the Joint Program of Scientific Research and Monitoring takes into account the work of relevant scientific and technical organizations, bodies and programs, as well as Indigenous Knowledge and local knowledge.
D. As part of the Joint Program of Scientific Research and Monitoring, the Parties shall adopt, within two years of the entry into force of this Agreement, a data sharing protocol and shall share relevant data, directly or through relevant scientific and technical organizations, bodies and programs, in accordance with that protocol.
E. The Parties shall hold joint scientific meetings, in person or otherwise, at least every two years and at least two months in advance of the meetings of the Parties that take place pursuant to Article 5 to present the results of their research, to review the best available scientific information, and to provide timely scientific advice to meetings of the Parties. The Parties shall adopt, within two years of the entry into force of this Agreement, terms of reference and other procedures for the functioning of the joint scientific meetings.

As outlined in the JPSRM Framework (Annex 1), a principal goal of the JPSRM is to provide the key information needed to provide meaningful advice to the Conference of the Parties (COP) of CAOFA. The JPSRM mapping and monitoring phases will enable the SCG to acquire and evaluate the information needed to provide advice to decision makers to support the goals of CAOFA with respect to the management, sustainable use, and conservation of marine living resources in the CAO.

The purpose of this implementation plan is to provide additional details guiding the planning, coordination, and execution of research to provide the SCG with information it needs to provide advice to the COP to develop appropriate conservation and management measures within the Agreement Area. It will be necessary to develop directed research conducted collaboratively within the JPSRM, through national and international programs, and exploratory fishing that may be authorized in the Agreement Area in the future to collect scientific data and information, while it is also expected that some of the needed information will be available from published literature and external collaborators.

The JPSRM comprises an initial mapping phase that is envisioned to occur over a three-year duration followed by a monitoring phase (FiSCAO 2015). The major goals of the mapping phase are to develop an understanding of baseline conditions and to test and evaluate different approaches, biological and ecological indicators, protocols, methods, Indigenous Knowledge, and local knowledge to be used during the monitoring phase. The mapping phase of the JPSRM will provide a current understanding of species distributions, relative abundances, and population structure in relation to biotic and abiotic factors (gathering retrospective and current information over 2-3 years). The monitoring phase of the JPSRM will focus on identifications of temporal variability or trends in species distributions or ecosystem productivity (utilizing longer-term monitoring of selected species and parameters). Both phases of the JPSRM will utilize diverse sources of information including data collected by the Parties' national research programs, Indigenous Knowledge, local knowledge, as well as data and reports obtained through published literature and collaborators external to the SCG.

1.2. *Research and monitoring questions*

The COP posed a series of research and monitoring questions (Table 1) to the SCG, broadly identifying the highest priority information needs at present. A second set of focused questions regarding exploratory fishing was asked of the SCG (Table 2). These questions identify a wide range of information needs that are central to understanding the biota, physical processes, and ecological linkages at work in CAO marine ecosystems. They underscore the need for field research in the CAO to fill crucial data gaps. The questions also help inform the development of conservation and management measures for potential exploratory fishing as well as potential commercial fishing in the high seas of the CAO. To begin addressing the exploratory fishing questions, at its June 2023 meeting, the COP established the Exploratory Fishing Questions Working Group (EFQ-WG) under the SCG to develop answers to these questions, to inform the COP's development of exploratory fishing measures, and to identify information on this topic available now and needed in the future.

It is important to note that these questions draw on the expertise of scientists, Indigenous Knowledge and local knowledge holders, and other experts. Valuable input for developing these questions was also available from recent work and syntheses of existing CAO data including the SCG, Provisional SCG (PSCG), Scientific Experts on Fish Stocks in the Central Arctic Ocean (FISCAO), ICES/PICES/PAME Working Group on Integrated Ecosystem Assessment of the Central Arctic Ocean (WGICA), ICES, PICES, and others. Many of those syntheses drew heavily on either extrapolations from adjacent seas, or the limited field research conducted in the CAO prior to the signing of the Agreement. Results from more recent field programs conducted in the CAO are likely to further benefit the implementation of the JPSRM, including results from the MOSAiC program, Synoptic Arctic Survey (SAS), CHINARE, and other syntheses identified in the JPSRM Framework document. Updating previous syntheses with the results from these more recent field programs would assist in focusing future research programs in the CAO Agreement Area.

Answering the research and monitoring questions presented in Table 1 will require focus on specific information needs (e.g., geographic areas and scales, seasonality and temporal scales, species, parameters to measure, existing information gaps). Those information needs cover many diverse topics whose relative importance and urgency will need to be evaluated as programmatic priorities are established and implemented. In the Mapping and Monitoring phase, the specific information needs will result from information gaps (e.g., geographical coverage and use of different sampling gear types).

Fishery-independent surveys are needed to collect ecosystem-wide data, particularly during the mapping phase of the JPSRM. Data for all trophic levels needs to be collected using consistent methods throughout the Agreement Area, and in ways that have the least impact on the ecosystem.

Table 1. Research and monitoring questions guiding the work of the Joint Program of Scientific Research and Monitoring (JPSRM).

Overarching question	Specific questions
1. What are the distributions of species with a potential for future commercial harvests in the Central Arctic Ocean?	a. What fish species are currently present in the high seas? b. Do fishable concentrations of commercial species exist in the high seas? c. What are their distributions and abundance patterns? d. What are their local life-history strategies, habitat associations, and demographic patterns? e. Do these strategies, associations, or patterns differ among regions of the Arctic?
2. What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?	a. What are the trophic linkages among fishes and between fishes and other taxonomic groups (i.e. quantify food webs, including identifying keystone forage species)? b. How do fish species abundances and distributions vary in response to climate variability (e.g., time scale of change, extreme events, declining sea ice, and biogeochemical changes)? c. Can the species be harvested sustainably with respect to both target fish stocks and dependent parts of the ecosystem? If not, what are the prospects for the development of fisheries in the future?
3. What are the likely key ecological linkages between potentially harvestable fish stocks of the central Arctic Ocean and the adjacent shelf ecosystems which includes support for Indigenous communities and local communities?	a. What are the connections between fish in the High Seas and those in the adjacent regions? b. What are the mechanisms that establish and maintain these linkages? c. How might fisheries in the High Seas and that in the adjacent and congruent portions of the shelf ecosystems interact, including fish stocks, fishable invertebrates (crabs, shrimp, mollusks), marine mammals, birds, and fisheries-dependent communities (which include those communities that are dependent on subsistence harvests of fish, invertebrates, and mammals)?
4. Over the next 10-30 years, what changes in fish populations, dependent species and the supporting ecosystems may occur in the central Arctic Ocean and the adjacent shelf ecosystems?	a. Which marine species will likely increase and decrease in population size and/or productivity in the central Arctic Ocean in the next 10-30 years? b. What changes in production and key linkages are expected in the coming 10-30 years? c. What northward population expansions are expected in the next 10-30 years? d. What are the anticipated impacts of change in ocean acidification in the next 10-30 years? e. How will existing and increased human activity and pressures in the region likely affect fish populations and ecosystems, which includes support for Indigenous communities and local communities, in the next 10-30 years? f. How could increased fishing activity affect bycatch species, seabirds, migratory and wide-ranging marine mammals, and Indigenous communities and local communities that depend upon these species to sustain their ways of living?
5. What Indigenous Knowledge and local knowledge is available, and how can it be taken into account, to inform ecological baselines?	

Noting that knowledge on the structure and biology of living resources in the CAO is much needed, and recalling that exploratory fishing is defined as “fishing for the purpose of assessing the sustainability and feasibility of future commercial fisheries by contributing to scientific data relating to such fisheries”, as per Article 1(e), exploratory fishing could play a role in addressing scientific questions and collecting scientific data for the JPSRM. Exploratory fishing could supplement fishery-independent scientific surveys once conservation and management measures (CMMs) for exploratory fishing have been established as per Article 5(1)(d). The CMMs for exploratory fishing shall be appended to the JPSRM Implementation Plan once they are adopted.

Therefore, when developing the JPSRM Implementation Plan and answers to questions regarding CMMs for exploratory fishing, the SCG considered the data priorities and types of data that could be collected through fishery-independent surveys or exploratory fishing. Section 2 (Priority Species and Dependent Ecosystem Components) and Section 4 (Priority Parameters), provide guidance for planning of fishery-

Table 2. COP-approved questions in order of agreed priority with estimates of approximately how long it will take the SCG to provide answers to the "Scientific and Indigenous Knowledge Questions for the SCG on Exploratory Fishing under Article 5 of the CAOFA." Time categories: 1=2 months; 2=1 year; 3=1-5 years (two time categories indicate that a partial answer will be available first, followed by a fuller answer later). [Re-ordered priority key: A=3+ parties; B=2 parties; C=1 party; D=next highest priority; E=identified by COP as lower priority]

No.	Question	Time
2-A	What ecosystem information is currently available or needed to establish conservation and management measures for exploratory fishing in order to minimize its ecosystem effects?	2
15-A	What measures should be considered for avoiding, minimizing or mitigating impacts of exploratory fishing on the Agreement Area and adjacent areas including on Arctic Indigenous peoples and local communities whose livelihood depend on Arctic ecosystems?	2
17-A	Please identify which questions in this list need to be answered and what additional information is needed prior to authorizing exploratory fishing to avoid, minimize or mitigate ecosystems impacts and otherwise meet the requirements of the Agreement.	1
14-A	How will the Parties ensure that exploratory fishing is duly limited in duration, scope and scale to minimize impacts on fish stocks and ecosystems?	2
7-B	What components of the CAO ecosystems are vulnerable to perturbations from fishing gear and therefore should be avoided by exploratory fishing efforts using that type of gear? Alternatively, how could impacts from such perturbations be sufficiently minimized?	2
8-C	How do we define non-target and dependent species? How should non-target and dependent species be considered in exploratory fishing plans?	1, 2
1-D	Including the results of the FiSCAO meeting and the mapping phase, what baseline data currently exist for and related to the Agreement Area?	1
3-D	How will the Parties collaborate to collect information on fishery-independent surveys, fishery dependent data collection, other platforms, and inclusion of Indigenous Knowledge and local knowledge?	1, 2
5-D	What is the estimated timeframe needed to provide existing and future data and information described in this list to conduct necessary evaluation of exploratory fishing by the SCG?	1
10-D	What parts of the Agreement Area and seasons may have favorable oceanographic conditions to support potential commercially viable species and may thus be prioritized for exploratory fishing?	2, 3
13-D	How will exploratory fishing in a changing marine ecosystem affect the production and abundance of fish and invertebrates?	2, 3
4-E	What communication regarding scientific knowledge, Indigenous Knowledge and local knowledge with Arctic Indigenous peoples is needed to support COP exploratory fishing decisions?	1, 2
4a-E	How will Indigenous Knowledge and local knowledge be incorporated with national research programs and the JPSRM to develop the knowledge base for this region that contributes to decision-making regarding exploratory fishing? How will multiple knowledge systems be evaluated?	2
4b-E	What type of Indigenous Knowledge and geographical coverage is available?	2
6-E	How do we define and identify vulnerable species and ecosystems in the context of the Central Arctic Ocean, in light of existing guidelines, including the FAO Deep-Sea Fisheries in the High Seas Guidelines?	1, 2
9-E	In accordance with the requirements of the Agreement, including those in Article 5(1)(d)(ii) and (iii), what criteria should the CAO Parties consider when defining potential future commercial fisheries that may be the focus of exploratory fishing, for example: species, abundance, distribution, ecosystem role and interactions, cultural significance, gear, economics, etc.?	2
9a-E	What type of data and information, including scientific knowledge, Indigenous Knowledge and local knowledge is needed or could be collected from exploratory fishing, noting that information from all 3 knowledge systems may not be collected on each exploratory fishing trip? What sort of sampling design and data collection is needed by exploratory fisheries to improve our understanding of relative abundance and distribution of target species?	2
9b-E	What bounds should be set on types of gear used, how that gear is used and seasonal restrictions in exploratory fishing to ensure precautionary exploratory fishing activity (examples: limitations on types of gear, fishing depth, limitations on operation of gear, etc.)?	2
11-E	What aspects of exploratory fishing should be the focus of data collection associated with impacts to Indigenous communities and local communities, including data collection related to pollution and emissions, noise, sea ice, for the evaluation of possible impacts, including cumulative impacts, to Indigenous and local subsistence activities and marine mammal populations in the Pacific and Atlantic Gateways? How can these impacts be mitigated?	2
12-E	What specific aspects of climate change should be accounted for to minimize the impact of exploratory fishing on the ecosystems in this rapidly changing region?	2
16-E	What can we learn from the scientific committees of existing RFMOs and other relevant scientific and management bodies that could inform CAOFA SCG and COP best practices in order to avoid mistakes and shortcomings from being repeated in the CAO?	2

independent surveys and for the JPSRM research program. CMMs developed by the COP will establish the role that exploratory fishing will play in the JPSRM, and provide guidance for exploratory fishing by Parties and the coordination of such plans through the SCG to ensure relevance to the JPSRM.

2. PRIORITY SPECIES AND DEPENDENT ECOSYSTEM COMPONENTS

Even as there is a growing understanding of the CAO, it remains true that this is a data poor region that is undergoing dramatic ecosystem shifts as a result of climate change. As such, there is a great need to conduct research in the CAO to improve our knowledge for a wide range of species and ecosystem components. The practical limits of personnel and logistical resources, as well as realistic temporal constraints, require that JPSRM research be focused on the species, ecosystem components and processes, and parameters that are of most relevance. Identifying such priority information needs will provide essential guidance in developing an achievable set of objectives for the JPSRM.

These information needs were identified by the SCG, building on previous work by FISCAO and the PSCG, and incorporating Indigenous Knowledge and local knowledge regarding key questions and issues.

The list of priority species and questions developed through those processes have been fairly consistent over time. In general, priority species and dependent ecosystem components include, but are not limited to:

A. Fish and invertebrate species that may be of commercial interest or interest to Parties wishing to conduct exploratory fishing.
B. Fish, marine mammals, seabirds, and other marine species that are important to the cultural, social, and food security needs of Arctic Indigenous peoples, and local communities.
C. Fish and invertebrate species that might be taken as bycatch during exploratory fishing or commercial fishing.
D. Marine mammals or seabirds that might be affected by exploratory or commercial fishing.
E. Predators or prey (e.g., zooplankton) of fish species, invertebrate species, marine mammals or seabirds that are important for subsistence and/or commercial harvest and are associated with the CAO.
F. Benthic species such as corals, sponges, or other living marine biota that provide structure and habitat or other ecological services to fish, invertebrate species, marine mammals, or seabirds and their prey.
G. Bottom features that provide important habitats for biota and biodiversity such as sea mounts, geothermal vents, ridges and slopes.

Sea ice features that provide important habitat for breeding, rearing, feeding, resting, or as refugia for commercial species and other priority ecosystem components such as forage fish, marine mammals, seabirds, their prey, and productivity indicators.

The terms “subsistence” and “food security” are used throughout this document. It is important to note that the term subsistence has various interpretations among international agreements. For Arctic Indigenous peoples, the term subsistence is one component of food security. Arctic Indigenous peoples place emphasis on food security being an all-encompassing term, where their people, culture, social, spiritual, and economic wellbeing is a part of the ecosystem. This interpretation is adopted for the purposes of the JPSRM.

Arctic Indigenous peoples rely on a number of marine mammals, seabirds, fish, invertebrates, algae and other species for their food security through seasonal hunting, gathering, and preparation of traditional foods, many of which are migratory, ice-dependent species referenced in Table 3. To understand Arctic marine ecosystems and Arctic Indigenous peoples' food security, it is important to understand that multiple, interconnected components make up the ecosystem.

It is important to bear in mind that the distribution, population size or biomass, population structure and productivity of the species listed below will vary among species and regions within the CAO, as well as seasonally and inter-annually. These features will also change over time, especially in light of climate change effects. The listing of species does not necessarily indicate that they are abundant. In addition, as the Arctic ecosystem changes and is better understood, these lists can be revisited by the SCG. Research may reveal that some may not be in the Agreement Area at all, but found in adjacent areas such as the CAO peripheral seas or the Pacific and Atlantic gateways. Similarly, species not included on this list may be present in the CAO. The JPSRM recognizes that the increasing rate of change brought on by climate change only serves to amplify this uncertainty, and further underscores the need to carefully plan and coordinate research in the CAO to provide the robust information needed to make sound decisions about conservation and management of the living marine resources. Table 3 summarizes the species of commercial, subsistence, and ecological interest described in this section.

2.1. *Fish and invertebrate species*

Fish and invertebrate species that may be important commercial resources, or species of particular importance to Arctic Indigenous peoples and their way of life, are identified in Table 3. This list of species provides guidance to future research work conducted under the JPSRM, and products provided by the SCG to the COP.

Some fish and invertebrate species that are important commercial or subsistence resources and may warrant special attention through JPSRM research efforts include:

A. Species confirmed to occur in the High Seas area that are of interest for commercial or subsistence harvest (see "commercial" column X in Table 3).
B. Species confirmed to occur in the Agreement Area that might be relevant to future commercial fisheries.
C. Species that have been identified in adjacent LMEs, are of interest for commercial or subsistence harvest, and have high potential to move into the Agreement Area.
D. Species that have been identified in adjacent LMEs and are of interest for commercial or subsistence harvest but have lower potential to move into the Agreement Area.

In considering such species, it is particularly important to note that future distributions and population dynamics are not well understood, especially given the effects of ongoing climate change impacts. For example, Pacific cod and walleye pollock, which are of commercial interest in the Bering Sea, have been found increasingly more frequently in the Chukchi Sea recently (Cooper et al., 2023; Levine et al., 2023); Greenland halibut, yellowfin sole and Bering flounder are of commercial interest and are found in the Bering and Chukchi seas; and Atlantic cod, redfish and Greenland halibut are commercially valuable species in the Barents Sea. Atlantic cod and (probably) Walleye pollock have been confirmed to occur in the CAO High Seas. Haddock, Redfish and capelin are present at latitudes > 80°N at the Atlantic gateway and may have already expanded into the CAO.

Table 3. Priority species of commercial, subsistence, or ecological interest in and adjacent to the Agreement Area. “Subsistence” species are harvested by Arctic Indigenous communities or local communities (see Section 2.2). “Ecological” species include prey or non-harvests those that interact with commercial or subsistence species (see Section 2.3). The SCG gratefully acknowledges the seabird information contributed to Table 3 by the Arctic Council’s Circumpolar Seabird Expert Group (CBird).

Taxa	**Commercial**				**Subsistence**	**Ecological**
	Occur in CAO and of interest	Occur in CAO and may be of interest	Adjacent, of interest, and high potential to move into CAO	Adjacent, of interest, and low potential to move into CAO	Harvested by Indigenous and local communities	Species related to commercial/ subsistence use
Lower trophic levels						
Euphausiacea (e.g. *Thysanoessa* spp.)		X				X
Copepoda spp.		X				X
Macroalgae: Agarum, Alaria, Laminaria					X	
Phytoplankton: Diatomia, Dinoflagellata, Chlorophyta, Chrysophyta, Cryptophyta, Parasinophyta						X
Microzooplankton						X
Macrozooplankton: Amphipoda (e.g. *Themisto* spp.), Chaetognatha, Pteropoda						x
Ice algae: Diatomea, Dinoflagellata, Chrysophyta						X
Sea ice biota: bacterium, fungus, prokaryote, protozoon, Metazoa						X
Fish						
Arctic cod (*Arctogadus glacialis*)	X				X	X
Polar cod (*Boreogadus saida*)	X				X	X
Greenland halibut (*Reinhardtius hippoglossoides*)	X				X	
Atlantic cod (*Gadus morhua*)	X				X	
Beaked Redfish (*Sebastes mentella*)	X		X		X	
Arctic telescope (*Protomyctophum arcticum*)		X				X
Glacier lanternfish (*Benthosema glaciale*)		X				X
Atlantic capelin (*Mallotus villosus*)			X		X	X
Alaska plaice (*Pleuronectes quadrituberculatus*)			X			
Bering flounder (*Hippoglossoides elassodon*)			X			
Arctic skate (*Amblyraja hyperborea*)		X				
Yellowfin Sole Flounder (*Limanda aspera*)			X			
Alaska Plaice Flounder (*Pleuronectes quadrituberculatus*)			X			
Golden Redfish (*Sebastes norvegica*)				X		
Pacific capelin (*Mallotus catervarius*)				X	X	X
Atlantic herring (*Clupea harengus*)				X	X	X
Pacific herring (*Clupea pallasii*)				X	X	X
Haddock (*Melanogrammus aeglefinus*)				X	X	

Taxa	Commercial				Subsistence	Ecological
	Occur in CAO and of interest	Occur in CAO and may be of interest	Adjacent, of interest, and high potential to move into CAO	Adjacent, of interest, and low potential to move into CAO	Harvested by Indigenous and local communities	Species related to commercial/ subsistence use
Pacific cod (*Gadus macrocephalus*)				X	X	
Walleye pollock (*Gadus chalcogrammus*)				X	X	
Pacific salmon (Chinook, sockeye, pink, coho, chum)				X	X	
Arctic Flounder (*Liopsetta glacialis*)				X		
Agassiz' slickhead (*Alepocephalus agassizii*)				X		
Pacific sand lance (*Ammodytes hexapterus*)				X		
Nawaga (*Eleginus nawaga*)				X		
Saffron cod (*Eleginus gracilis*)					X	X
Smelts (*Osmerus* spp.)					X	X
Whitefish (Broad, Hump back, Bering cisco, Least cisco, Arctic cisco)					X	X
Arctic char/Dolly Varden (*Salvelinus* spp.)					X	
Sculpin (four horn, bright belly)					X	
Lamprey (Petromyzontidae)					X	
Starry Flounder (*Platichthys stellatus*)					X	
Sheefish (*Stendous leucichthys nelma*)					X	
Myctophidae Other spp.						X
Invertebrates						
Armhook squid (*Gonatus fabricii*)	X					
Snow crab (*Chionoecetes opilio*)			X		X	
Red King Crab (*Paralithodes camtschaticus*)				X	X	
Blue King Crab (*Paralithodes platypus*)				X	X	
Shrimp					X	X
Clams (cockle, butter, razor, little neck, geoduck, whelk, mussels)					X	X
Sea urchins and sea squirts					X	
Benthic polychaetes and crustaceans						X
Echinodermata						X
Mollusca						X
Marine Mammals						
Fin whale (*Balaenoptera physalus*)			X			X
Ringed seals (*Pusa hispida*)					X	X
Harp seals (*Pagophilus groenlandicus*)					X	
Harbor porpoise (*Phocoena phocoena*)					X	
Polar bears (*Ursus maritimus*)					X	

<table>
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<tr><td></td><td>Humpback whales (<i>Megaptera novaeangliae</i>)</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td></td><td>Blue whale (<i>Balaenoptera musculus</i>)</td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td></td><td>Killer whales (<i>Orcinus orca</i>)</td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td colspan="8">Seabirds</td></tr>
<tr><td></td><td>Alcids: Puffins, Least auklets, Little auk, Common murres, Thick-billed murre</td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td></td><td>Red-Throated Loons, Commmon Loons, Yellow-billed loon</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td></td><td>Sea ducks</td><td></td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td></td><td>Gulls: Black-legged Kittiwake, Red-legged Kittiwake, Glaucous gulls, Ivory gulls</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td></td><td>Albatrosses: Laysan Albatross, Black-footed Albatross, Steller’s Albatross</td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td></td><td>Petrels: Pacific northern fulmar, Atlantic northern fulmar, sheawater etc.</td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td></td><td>Skuas and Jaegers: Pomarine Jaegers (Skua)</td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td></td><td>Storm-petrels: Fork-tailed Storm-petrels</td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
</table>

2.2. *Subsistence-harvested marine mammal and seabird species*

Marine mammal and seabird species of special significance are also identified in Table 3. These species are important components of the Arctic marine ecosystem, and are of particular importance to Arctic Indigenous peoples as part of their food security, including their culture, and way of life.
Marine mammals play a pivotal role as top predators within Arctic marine ecosystems. Ice seals and whales navigate and hunt in ice-covered waters, integral components of an intricate ice-associated food web. Both seals and whales exhibit a diverse diet, preying upon a mix of fish and invertebrates, often targeting endemic Arctic species such as polar cod (*Boreogadus saida*), Arctic cod (*Arctogadus glacia*lis), and nutrient- and energy-rich *Calanu*s copepods, hyperiids (Hyperiidae), and krill (Euphausiids). In contrast, the primary prey for polar bears is seals.

The same can be said of seabirds, which also exhibit a diverse diet of fish and invertebrates, often targeting Arctic species such as Arctic cod (*Arctogadus glacialis*), polar cod (*Boreogadus saida*), and nutrient- and energy-rich copepods and krill (Euphausiids). The Arctic Council's Circumpolar Seabird Expert Group (CBird) has developed further information on Arctic seabirds that can help inform research efforts under the JPSRM.

Because marine mammals and seabirds are highly migratory it is important to understand the distribution, population size, habitat use, and other ecosystem linkages related to such species both within the CAOFA Agreement Area as well as linkages between the CAOFA Agreement Area and adjacent waters. Research planning, and products of the JPSRM, as described later in this implementation plan, should incorporate Indigenous Knowledge regarding these species and their significance.

2.3. *Other taxa from key trophic levels*

Many key ecological species contribute to marine ecosystems that support subsistence-harvested and potential commercial-harvested species; bycatch species of concern; and vulnerable and protected species.

Important groups of Arctic marine biodiversity include:

A. Primary production: phytoplankton productivity, ice algae productivity.
B. Phytoplankton: Diatom, Dinoflagellate, Chlorophyta, Chrysophyta, Cryptophyte, Parasinophyta.
C. Microzooplankton.
D. Ice algae: diatom, dinoflagellate, chrysophyta, chlorophyta.
E. Zooplankton: Copepods, Chaetognatha, Euphausiids, Amphipoda, Polychaete, Decapods (shrimp), appendicularians.
F. Sea ice biota: bacterium, fungus, prokaryote, protozoon (ciliates, dinoflagellates), metazoan (crustaceans, flatworms, nematodes, rotifers), under-ice fauna (amphipods, copepods).
G. Non-harvested benthic and pelagic fishes: lanternfish and others (see Table 3 "Ecological".
H. Invertebrates: Polychaeta, Crustacea, Echinodermata, Mollusca.
I. Non-harvested marine mammals: hooded seals and killer whales.
J. Non-harvested seabirds.

Priority low trophic level and pelagic ecosystem components are phytoplankton, microzooplankton, mesozooplankton, macrozooplankton and ichthyoplankton. Microzooplankton can be a key intermediary between phytoplankton and zooplankton, sometimes resulting in a longer food chain during periods of elevated ocean temperature (Barnes et al., 2010). Large-bodied, lipid-rich mesozooplankton- and macrozooplankton, such as the copepod *Calanus glacialis,* euphausiids and amphipods, are important prey for planktivorous fish (including Arctic cod and walleye pollock), seabirds and marine mammals (Ashjian et al., 2021; Harrison et al., 1991; Kimmel et al., 2018). In addition to pelagic fish, priority benthic fish and invertebrates represent important prey for marine mammals (Sheffield and Grebmeier, 2009; Stewart et al., 2023), some of which are subsistence resources for US Alaska Indigenous communities (Hovelsrud et al., 2008), endangered sea ducks (Lovvorn et al., 2014), and benthic fish of commercial value (Aydin, pers. com. based on data described in Livingston et al., 2017). *Appendicularia* may become an increasingly important dietary source of Arctic fishes (Jaspers et al. 2023; Snoeijs-Leijonmalm et al. 2023). In addition, methods are included here to measure parameters pertaining to ecological interactions, specifically biological and physical oceanography. In addition to pelagic phytoplankton, sea ice algae are a priority ecosystem component.

2.4. *Ecological linkages, environment, and habitat*

There are limited data on habitat distribution and use by a variety of biota in the CAO. Section 2 identifies priority species and ecosystem components that should be addressed through the JPSRM. Amongst these are habitat-forming biota such as corals and sponges, sea ice, and bottom features. Research is needed on all of these habitat types. Bottom features such as sea mounts, geothermal vents, ridges and slopes provide a variety of ecosystem and habitat functions. Benthic species such as corals, sponges, or other living marine biota provide structure and habitat or other ecological services to fish, invertebrate species, marine mammals and seabirds, and their prey. The function and distribution of these ecosystem components is poorly understood.

Sea ice is the dominant habitat feature of the CAO Agreement Area. Sea ice plays a critical role in primary and secondary productivity in the Arctic Ocean. Sea ice, including under-ice features, polynyas and leads, and other important sea ice features provide critical migratory, resting, rearing, breeding, or feeding habitats for many organisms. Sea ice cavities and brine channels provide habitats for microbial life from viruses, fungi and bacteria to larger algae and grazing microorganisms.

Understanding the distribution and function of habitats in the Agreement Area, and linkages within and between the Agreement Area and adjacent waters, will be important to the development of effective conservation and management measures for future exploratory or commercial fishing activities. Ecological linkages between continental shelf and slope areas within the Agreement Area as well as between the Agreement Area and adjacent peripheral seas that are under national jurisdiction (e.g., Chukchi Sea, Beaufort Sea, Kara Sea, Barents Sea) are important to consider. Linkages could include nutrient transport, movement or transport of key prey species, genetic connectivity, and migration or movement of fish, shellfish, marine mammals or seabirds, etc. between the Agreement Area and nearshore waters. Studies of genetic population structure are essential for key species to clarify linkages through their life history events (e.g., spawning of Polar cod).

Trophic linkages among species, particularly between potential commercial species and species that support subsistence harvests, are critical for assessing potential impacts of commercial and exploratory fishing on Indigenous communities and local communities. Benthic fish and invertebrates (demersal fishes, polychaete, crustacean, Echinodermata, Mollusca) represent important prey for marine mammals, some of which are subsistence resources for Arctic Indigenous communities, endangered sea ducks, and benthic fish of commercial value. Arctic cod and polar cod, are also key predators for many species in the Arctic.

Environmental data are useful for modelling fish-stock abundance in relation to the environment and trophic status. For the JPSRM it would be useful to collect all CTD profiles available in international databases made during the past 30 years as well as all CTD profiles that will become available during the remaining 14 years of the JPSRM.

Research regarding habitat form and function is particularly important for the three priority geographical areas identified under Section 3. Some important research needs regarding habitat distribution and function in these areas to be addressed by the JPSRM, should include both spatial and temporal distribution of sea ice features and how those affect habitat usage by species of interest.

Environmental data that would be most useful include:

A. Hydrology: Depth, Temperature, Salinity (CTD), Current direction, and speed (ADCP).
B. Dissolved oxygen and Nutrient concentrations (e.g. nitrate, nitrite, phosphate, silicate).
C. Carbonate system (pH, dissolved inorganic carbon, total alkalinity, aragonite saturation state).
D. Light-related parameters: Light levels, Chlorophyll a concentration, pigment analysis.
E. Particle concentrations (e.g. particulate organic carbon, particulate nitrogen, and the stable isotopes δ13C and δ15N, UVP, LISST).
F. Dissolved Organic Matter: dissolved organic carbon, dissolved organic nitrogen, CDOM fluorescence.
G. Bottom topography and type.
H. Sea-ice properties: distribution, coverage, density, dynamics, thickness, ice type, porosity.

3. PRIORITY GEOGRAPHIC AREAS

Although CAOFA's authority to regulate fishing is limited to the zone within the boundaries of the Agreement Area, CAOFA's ecosystem approach requires that it consider potential ecological impacts associated with regulations both inside and outside of the Agreement Area. The JPSRM Framework identified three priority geographic areas which are relevant to the JPSRM: the Agreement Area, the peripheral shelf/slope areas adjacent to the Agreement Area, and the Pacific and Atlantic gateways. National and joint research programs and expeditions organized pursuant to the JPSRM should focus on these priority geographic areas.

3.1. *Agreement Area*

Within the Agreement Area, certain geographical features may warrant special consideration. For example the Chukchi Plateau, including its continental shelf and slope areas, should be a focal area of the JPSRM due to its distinctive bathymetric features. This matches up with the Pacific gateway and provides continuity across these priority areas. Ridges, seamounts, and geothermal vents (e.g., Gakkel, Lomonosov, and Alpha ridges) in the Agreement Area would also be priority geographic features for further research. These features include depths where potential exploratory and commercial fishing may be feasible.

It is considered that areas shallower than 2000 m are fishable with demersal trawls in future ice-free high seas of the CAO (Dupuis et al., 2018; Jørgensen and Saitoh, 2020). Among the fishable areas, the Chukchi Borderland (CBL) is a remarkable region, because it is adjacent to the Chukchi Sea where several biological hotspots are maintained by nutrient supplies from the Pacific Ocean (e.g., Grebmeier et al., 2006, 2010). The CBL is thought to be a spawning area of Arctic cod (Skjoldal et al., 2022), and polar cod distribution around the CBL was suggested by eDNA analyses (Kawakami et al., 2023). Both are important fish species in Arctic marine food webs and are of commercial interest. However, among the Arctic high seas the CBL is experiencing the fastest rates of ocean deoxygenation and acidification, which may impact the marine ecosystem in this fishable area, due to the formation of a northward flow that transports anomalously low oxygen and highly acidified water from the East Siberian Sea (Nishino and Jung et al., 2023; Figure 1). The northward flow formation is likely caused by a change in the basin-scale ocean circulation associated with the recent sea-ice loss. Therefore, when introducing appropriate ecosystem-based management under the Central Arctic Ocean Fisheries Agreement, it will become essential to monitor the marine environment and ecosystem in the CBL region.

3.2. *Peripheral shelf/slope areas*

The ecological relationships between the Agreement Area and the adjacent shelf and slope features is poorly understood. The movement of fishes, marine mammals, seabirds, and other living marine resources between the Agreement Area and its peripheral seas is of particular importance to assessing the effects of exploratory and commercial fishing on the cultural, social, and food security needs of Arctic Indigenous peoples, local people, and communities. In addition, understanding the scope and effect of transport mechanisms for nutrients and fresh water from the nearshore to the offshore regions of the Arctic Ocean is a key factor in determining productivity for a wide variety of ecosystem components.

The area around Pt. Barrow, Alaska is one of the biological hotspots located in the peripheral shelf/slope area in the Pacific Arctic region (Grebmeier et al., 2010). Easterly winds over the Pt. Barrow area cause upwelling flows that move krill from the slope onto the shelf, and the upwelling and its subsequent relaxation establish a bowhead whale feeding and Indigenous subsistence whaling site near Pt. Barrow

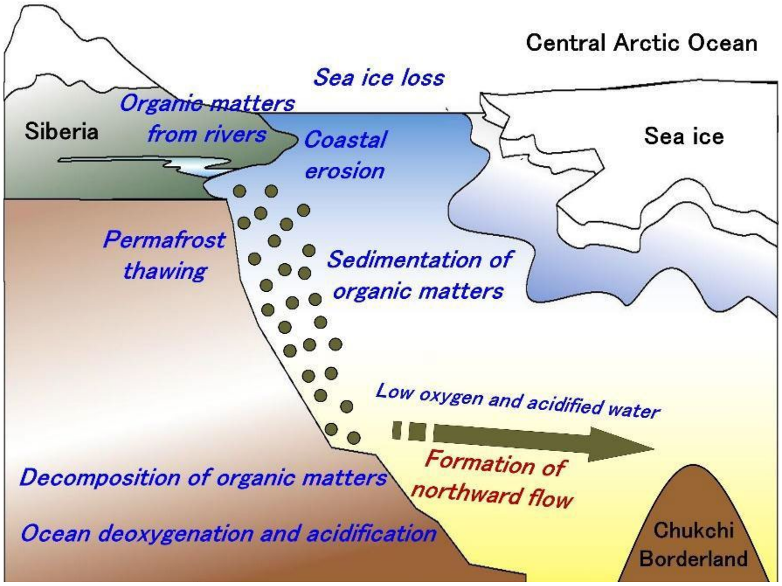

Figure 1. Schematic of the transport of low oxygen and acidified water from the shelf-slope off Siberia to the Chukchi Borderland. Terrestrial/marine organic matters derived from rivers, coastal erosion, permafrost thawing, and biological production are deposited on the seafloor off Siberia. A high quantity of organic matter decomposition produces low oxygen and acidified water. This water is transported to the Chukchi Borderland with a northward flow caused by a change in large-scale ocean circulation related to the sea ice loss (Nishino and Jung et al., 2023). The organic matter supply from each source is expected to increase in the future, resulting in wider areas of generation and spread of the low oxygen and acidified water.
https://www.jamstec.go.jp/e/about/press_release/20231102/

(Ashjian et al., 2010; Moore et al., 2018). Thus, the Pt. Barrow area is not only a priority geographical area but also a socio-economically and culturally focused region. The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has conducted mooring observations in the Barrow Canyon since the late 1990s to monitor flow fields, including the upwelling and heat/freshwater fluxes through the canyon (Itoh et al., 2013). Recently, the mooring measurements were extended to monitor nutrient/oxygen concentrations and phytoplankton biomass/community structures. The mooring system could advance the biophysical and biogeochemical studies in the biological hotspot of the Pt. Barrow area.

The area around Pt. Hope, Alaska, is another biological hotspot located in the Pacific gateway (Grebmeier et al., 2010). Phytoplankton blooms occur not only in spring but also in autumn, with the fall bloom likely triggered by regenerated nutrients associated with the decomposition of particulate organic matter accumulated at the bottom of Hope Valley (Nishino et al., 2016; Figure 2). The zooplankton biomass in the Pt. Hope area also increases in autumn (Kitamura et al., 2017), and bowhead whales use this area for feeding during their fall southward migration (Tsujii et al., 2021). If ocean warming in the Pacific Arctic continues, Pacific cod may expand northward via the Pt. Hope area into the Chukchi Sea, as suggested by observational (Cooper et al., 2023) and model (Alabia et al., 2023) studies. However, the oxygen concentration found at the bottom of Hope Valley during autumn is as low as 100 μmol kg^{-1} (Nishino et al., 2016), which is in a range (< ~130 μmol kg^{-1}) that affects the growth and behavior of some fishes (Ekau et al., 2010). As a result, expansion of Pacific cod into the Chukchi Sea might be inhibited by the low oxygen water. Furthermore, the Pt. Hope area has already been undergoing CaCO3 undersaturation during autumn and the undersaturation duration is expected to increase in the future (Yamamoto-Kawai et al., 2016). Therefore, the Pt. Hope area should be monitored as a bellwether of ecosystem degradation in the Arctic high-seas caused by ocean deoxygenation and acidification.

The Barents Sea and the northern Norwegian Sea are also considered as hot spot areas, as they are stepping stones for Atlantic fish entering the CAO (e.g., Snoeijs-leijonmalm et al., 2023). Several recent

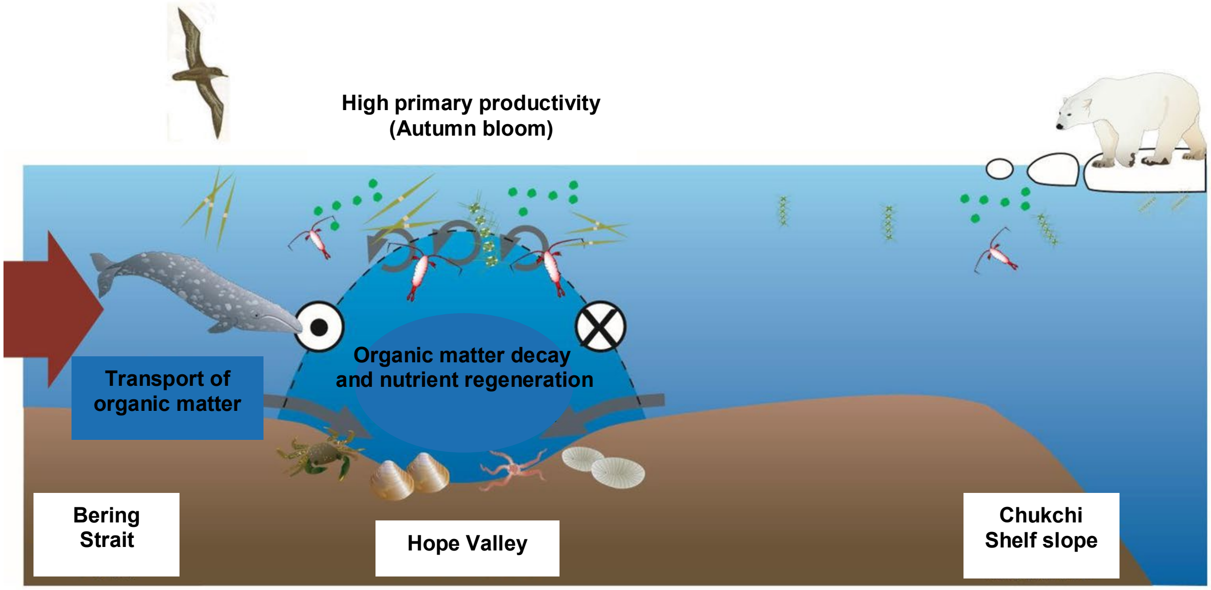

Figure 2. Autumn bloom in Hope Valley in the Chukchi Sea. Circles with a dot and x represent flows from the back to the face of the figure and from the face to the back of the figure, respectively. Over the Hope Valley, there is a dome-like structure of the bottom water, suggesting ocean circulation in a counter-clockwise direction and converge of deep water there. The autumn blooms are, therefore, likely to be associated with particulate organic matters transported into the bottom of the valley, where nutrients such as ammonia are produced to increase phytoplankton with the organic matter decomposition.
https://www.jamstec.go.jp/e/about/press_release/20160429/

papers have described the change in the fish and zooplankton communities in the Barents Sea (e.g. Fossheim et al., 2015; Dalpadado et al., 2020).

3.3. *Pacific and Atlantic gateways*

The Pacific and Atlantic gateways play pivotal roles in the movement of water masses, nutrients, biota, and people into and out of the Arctic Ocean, including the CAO. While they are fundamentally different regions with their own unique characteristics, understanding the mechanisms at work in these two areas will be foundational to understanding the effects of climate change on CAO ecosystems over time.

Of the three priority areas identified in the JPSRM Framework, the gateways are probably the most studied to date and are the regions where relevant data are most available. As such, these regions may require less attention to fill data gaps during the mapping phase than other priority regions. But, predicted impacts of climate change in these gateways include shifts in the spatial distribution of boreal species, a shift from larger, lipid-rich zooplankton to smaller, less nutritious prey, with detrimental effects on fishes that depend on high-lipid prey for overwinter survival, shifts from benthic- to pelagic-dominated food webs with implications for upper trophic levels, and reduced survival of commercially important shellfish in waters that are increasingly acidic (Drinkwater et al., 2021). Thus, given their pivotal role, careful attention during the monitoring phase of the JPSRM is warranted and research programs should be tailored accordingly.

3.4. *Areas of notable change*

The most profound change in the Agreement Area and adjacent areas is sea ice loss and associated changes in the upper water column (e.g., Stroeve and Notz, 2018; Polyakov et al., 2017). The perennial ice-covered Beaufort, northern Bering, and Chukchi seas, as well as north of the Russian shelf seas, are the regions showing largest changes in summer sea ice concentration (e.g., Onarheim et al., 2018), and are thus the regions of most notable change. The disappearance of the sea ice, in combination with warming, has caused increasing primary production (Ardyna and Arrigo, 2020). Further increases in production at the base of the food web might result in higher production also for fish species, but nutrient limitation due to strong stratification have been argued as a limiting factor (e.g., Polyakov et al., 2020). However, recent findings reveal that the primary production in the Arctic Ocean is affected by influx of new nutrients (Lewis et al., 2020), and it has been estimated that around one third of current primary production is sustained by rivers and coastal erosion (Terhaar et al., 2021). Thus, nutrient input from land can be a key process for future evolutions of the Arctic Ocean primary production (Terhaar et al., 2021), and regions with reductions in sea ice and a high degree of riverine delivery and coastal erosion could be relevant priority areas. Recent papers shed additional insight into CAO productivity and implications to food webs due to loss of sea ice (e.g., Wiedmann et al., 2020; Flores et al., 2023).

4. PRIORITY PARAMETERS

A broad set of JPSRM parameters, devices, and methods will be tested during the three-year mapping phase. At the end of the mapping phase, the efficiencies of each of the indicators and the efforts to obtain reliable measurements will be evaluated. For the subsequent 13-year monitoring phase a smaller number of quantitative monitoring indicators will be selected for the JPSRM. During both the mapping and monitoring phases inter-calibration of methods will take place regularly, and other forms of calibration and collaboration, e.g., the exchange of samples, will be facilitated within the JPSRM to maintain data consistency and allow data to be combined in analyses. Table 4 provides a summary of priority parameters and indicators that are used for a variety of species and species groups in the JPSRM.

4.1. *Fish species*

Priority parameters for fishes from the JPRSM outline that are addressed with the methods described here are:

A. Abundance, biomass, and trends.
B. Distribution, spawning areas and seasons, seasonal movements, and migration, range shifts.
C. Size, condition, age composition, maturity, and demography/population structure.
D. Diet (e.g., prey, stable isotopes, fatty acids).
E. Stock identification and population genetics.
F. Key life history features and phenology (e.g., seasonality, trends).

4.2. *Marine mammal and seabird species*

The priority parameters for marine mammal and seabird species are listed below, with brief examples of the types of data that are needed in each category. Subject matter experts within the MM-WG will need to develop specific JPSRM protocols regarding details on the data to be collected (e.g., sampling frequency, statistical power, confidence levels).

A. Abundance, biomass, and trends (e.g., species, number).
B. Distribution, seasonal movements, and migration (e.g., location, habitat, seasonal shifts).
C. Size, condition, and demography (e.g., health and condition, vital rates, age classes).
D. Diet (e.g., prey, stable isotopes, fatty acids, foraging behavior).
E. Stock identification and population genetics (e.g., stock and population differentiation).
F. Key life history features (e.g., reproduction, molting, predation).
G. Timing and schedule (e.g., seasonality, trends).

4.3. *Other taxa from key trophic levels*

Sea ice habitat is a priority indicator in the JPSRM Framework. Information about sea ice (physics and biology) is needed to understand the coupling between fishes, squid, and zooplankton and climate variability through food web and ecosystem modeling. In addition, the methods described below would contribute to understanding two JPSRM priority parameters – ecological linkages and seasonality.

The priority parameters from the JPRSM outline that are addressed with the methods described below (in Section 5) are:

A. Abundance, biomass, trends, stock structure
B. Vertical and horizontal distribution.
C. Condition.
D. Diet.
E. Population genetics.
F. Key life history features.
G. Trophic carbon flux (e.g., using biomarkers, such as fatty acids and stable isotopes).
H. Biomass spectra and trophic transfer efficiency.
I. Biological oceanography.

Table 4. JPSRM priority parameters and indicators in relation to the overarching research questions of the JPSRM.

Overarching question	JPSRM priority parameters and indicators	Ecosystem parameter / knowledge gained
1. What are the distributions of species with a potential for future commercial harvests in the Agreement Area?	**Hydroacoustic with standardized settings** • Area scattering coefficient (NASC), 18, 38, 70, 120 kHz, 0-800 m depth • Collected during open water or through the ice (when ship's engines are turned off)	Fish abundance and biomass
	Catch per unit effort with standardized long lines • Number of fish by species • Age distribution • Length distribution • Weight distribution • Collected during open water or through the ice (when ship's engines are turned off)	Fish species, age and size distributions [+Calibration of acoustic data (target strength)]
	Catch per effort with standardized trawling in larger leads and open- water areas • Number of fish by species • Age distribution • Length distribution • Weight distribution • Collected during open water or through the ice (when ship's engines are turned off)	Fish species, age and size distributions [+Calibration of acoustic data (target strength)]
	Population demographics • Sex • Age • Maturity • Fecundity • Length frequency • Collected during open water or through the ice (when ship's engines are turned off)	Population trends
	Box-core sediment otoliths • Number of fish by species • ^{14}C age • Life-time age distribution • Length distribution(modelled) • Weight distribution(modelled) • Collected during open water	Fish species, age, and size distributions during the Holocene (ca. 10,000 years) [provides fish data with climate variability for modelling studies]
	Deep-sea video cameras • Number of fish, squid and plankton • Species identification • Collected through the ice from stationary ships	Fish and squid presence
	Environmental DNA (eDNA) • Amplicon sequences cytochrome c oxidase subunit 1 (CO1), Cyt b • Amplicon sequences rRNA 12S • Metagenomic sequences • Collected during open water or through the ice from stationary ships	Species distributions of fish, squid, their invertebrate prey, and their mammal and bird predators
2. What other information is needed to provide advice necessary for future sustainable harvests of commercial	**Hydroacoustic with standardized settings** • Area scattering coefficient (NASC), 120, 200, 333 kHz, 0-800 m depth • Collected during open water or through the ice (when ship's engines are turned off)	Fish prey distribution and biomass

fish stocks and maintenance of dependent ecosystem components?	**Fish, zooplankton, marine mammal and seabird samples** • Stomach contents (genomic) • Stable isotopes (delta 13C, delta 15N) • Fatty acids composition • Fish and zooplankton collected during open water or ice camps; marine mammal and seabird samples collected through Indigenous harvests	Trophic linkages among fishes and between fishes and other taxonomic groups Community composition Reconstruction of ambient temperature and metabolic activity during life span Opportunities for interactions among trophic levels
	Distribution/abundance/biomass of dependent ecosystem components • Phytoplankton • Zooplankton • Benthos • Marine mammals • Seabirds • Collected during open water or through the ice (when ship's engines are turned off)	Coupling between fish, squid and zooplankton abundances, distributions and trophic linkages and climate variability (food web modelling)
	Habitat data (water column, sea ice) • Depth • Temperature • Salinity • Current direction and speed • Dissolved oxygen • Nutrient concentrations (e.g. nitrate, nitrite) • Carbonate system • Light levels • CDOM fluorescence • Chlorophyll fluorescence • Chlorophyll a concentrations • Particle concentrations (e.g., particulate organic carbon, particulate nitrogen) • Flow cytometry • Benthos (abyssal community) • Bottom topography and type	Coupling between fish, squid and zooplankton abundances and distributions and ecosystem productivity (modelling)
3. What are the likely key ecological linkages between potentially harvestable fish stocks of the Agreement Area and the adjacent shelf ecosystems that support Indigenous communities and local communities?	Population genetics of fish, squid, other invertebrates, marine mammals and seabirds caught both in the Agreement Area and adjacent regions in all seasons Numbers of seabirds and mammals both in the Agreement Area and adjacent regions	● Connectivity between fish and invertebrates in the Agreement Area and those in the adjacent regions Mechanisms that establish and maintain these linkages ● Abundance and connectivity of seabirds and marine mammals in the Agreement Area and adjacent regions
4. Over the next 10-30 years, what changes in fish populations, dependent species and the supporting ecosystems may occur in the central Arctic Ocean and the adjacent shelf ecosystems?	**Evaluation of the JPSRM parameters & indicators** • Literature studies in relation to the sampled JPSRM indicators and comparison of the JPSRM results with published data from other regions in the Arctic Ocean • Modelling studies of fish, squid, and dependent species abundances and distributions in relation to food web and ecosystem productivity	● Which marine species are likely to be productive in the Agreement Area in the next 10-30 years ● Which changes in production and key linkages are expected in the Agreement Area in the coming 10-30 years ● What northward population expansions into the Agreement Area are expected in the next 10-30 years

	• Evaluation if species can be harvested sustainably with respect to both target fish stocks and dependent parts of the ecosystem • Long-term trends in the nekton community • Long-term changes in the plankton community • Long-term changes in the benthic community	• What are the anticipated impacts of changes in ocean acidification in the Agreement Area in the next 10-30 years • How increased human activity in the Agreement Area (e.g. ship noise, ship traffic, industrial activity, and pollution) is expected to affect fish populations, ecosystem health, and communities in the next 10-30 years • How increased fishing activity in the Agreement Area is expected to affect other species bycatch, migratory and wide-ranging marine mammals, and the Indigenous and local communities that depend upon these species to sustain their ways of living • Evaluation of how fisheries in the Agreement Area might affect adjacent and congruent portions of shelf ecosystems, including fish stocks, fishable invertebrates (crabs, shrimp, mollusks), marine mammals, birds, and fisheries-dependent communities (which include those communities that are dependent on subsistence harvests of fish, invertebrates, and mammals).
5. What Indigenous Knowledge is available to inform ecological baselines?	• Historical and recent changes in harvests, number of animals (i.e., how did the catch of marine mammals and fish fluctuate over the years?), species distributions, movements, behaviors, and habitat associations • Sea ice, ocean currents, tides, weather patterns, and other environmental conditions observed by communities • Movement, distribution, and diet of marine mammals, fish and birds • Species-habitat relationships • Indicators of mercury and microplastic contamination.	• Direct, year-round observations of the ecosystems throughout generations • Abundance, distribution, and trophic linkages of invertebrates, fish, birds and marine mammals • The scope of hunting, and the annual hunting amount (to understand the subsistence-harvesting activities in relationship with fisheries species). • Informs future predictions of species distributions and behaviors.

J. Physical oceanography.
K. Seasonality in species composition, biomass, and vertical distribution.

4.4. *Ecological linkages and impacts*

In an ecosystem, biological and environmental factors are closely related and inseparable. There are many studies of biological responses to climate changes in the Arctic Ocean, especially for the marginal shelf areas that have undergone the most dramatic changes. For example, these changes include borealization (caused by Atlantification and Pacification), ocean acidification, deoxygenation, etc.

Priority parameters of ecological linkages and impacts are listed below:

A. Temperature, salinity, and stratification.

B. Fluxes (heat freshwater, CO2, nutrients and water masses (surface mixed layer, Pacific summer water, Pacific winter water, and Atlantic water)).
C. Sea ice extent, thickness, and ages, sea-ice properties (e.g., ridging, meltponds, drift speed).
D. Ocean acidification and deoxygenation (e.g., pH, dissolved oxygen).
E. Primary production (spring and autumn blooms).
F. Zooplankton transport and potential establishment in the CAO High Seas.
G. Community structure and species composition, migration, and distribution of potential commercial fishes and invertebrate species.
H. Community structure and species composition, migration, and distribution of marine mammals and seabirds.
I. Seasonal food harvest and harvest data by Arctic Indigenous communities.
J. Mortality, including harvesting, research, and natural.
K. Competition and predation.
L. Disease prevalence.
M. Non-native and invasive species.

5. METHODS FOR COLLECTING AND ANALYZING SCIENTIFIC DATA

Each of the three priority geographic areas has distinctive physiognomic, ecological, and habitat features (e.g., corals, sponges, or other vulnerable habitats). JPSRM protocols should give careful consideration to what data collection methods would be best to minimize or avoid potential adverse impacts to sensitive or vulnerable features. For research on fish, the use of hydroacoustic surveys, ROVs, autonomous gliders, and other fishery-independent technologies should be prioritized. For example, in gateway areas where fishing has already commenced, care should be taken to mitigate adverse impacts from the use of fishing gear, grab sampling gear, dredges or other intrusive methodologies. Methods to be utilized for marine mammal and seabird research are well-developed and unlikely to result in any harmful impacts on biota.

5.1. *Standard methods (for collecting priority parameter data)*

Descriptions of appropriate “Standard Methods” recommended for collecting scientific data as part of the JPSRM are summarized in the following series of appendices attached to this Implementation Plan:

- *APPENDIX 1: JPSRM Standard Methods for collecting scientific data - Fish species*
- *APPENDIX 2: JPSRM Standard Methods for collecting scientific data - Marine mammal and seabird species*
- *APPENDIX 3: JPSRM Standard Methods for collecting scientific data - Other taxa from key trophic levels*
- *APPENDIX 4: JPSRM Standard Methods for collecting scientific data - Ecological linkages and impacts*

Although the applications of standard methods are designed specifically for a particular species or species group, there are many basic systems and tools that are used in multiple types of marine science relevant to the JPSRM. Table 5 provides a summary of the principal methods and tools that may be utilized in fieldwork to collect scientific data as part of the JPSRM.

As a standard, research vessels collect oceanographic data with a CTD to measure conductivity (salinity), temperature and depth. CTD rosettes usually carry other instruments as well, such as CDOM fluorescence, chlorophyll fluorescence, UVP and LISST particle concentrations. Water samples are taken to measure basic indicators of ecosystem productivity, such as dissolved oxygen, inorganic and organic nutrients, CO2 (carbonates), chlorophyll a concentration, photosynthetic pigments, particulate organic carbon (POC), δ13C, flow cytometry (cell abundances of bacteria and primary producers), etc. Acoustic Doppler Current Profilers (ADCP) can be used to estimate changes in fluxes and water masses

Table 5. Examples of "Standard Methods" that will be utilized to collect data on priority species and parameters in support of the mapping and monitoring phases of the JPSRM. Ecological linkages includes habitats.

Standard method	**Fish species**	**Marine mammal and seabird species**	**Other taxa from key trophic levels**	**Ecological linkages and impacts**
Acoustic Doppler current profiler (ADCP)				X
Active hydroacoustics	X		X	X
Autonomous Underwater Vehicle (AUV)			X	X
Bottom trawls	X		X	X
Box core sediment otoliths	X		X	X
Buoys	X	X	X	X
Crewed aerial surveys		X	X	X
CTD casts			X	X
Deep-sea cameras	X		X	X
Diet sampling	X		X	X
Environmental DNA (eDNA)	X	X	X	X
Flow cam			X	X
Flow cytometry			X	X
Genetics sampling	X	X	X	X
Grabs and cores	X		X	X
Ice core			X	X
Indigenous Knowledge studies/observations	X	X	X	X
Longlines	X		X	X
Moorings	X	X	X	X
Optical recordings	X	X		X
Passive hydroacoustics		X		X
Pelagic Trawling	X		X	X
Photography, photogrammetry		X		X
Plankton nets			X	X
Radar - ship-born			X	X
Satellite imagery		X	X	X
Satellite telemetry		X		X
Sea chest			X	X
Sediment traps			X	X
Ship and small boat visual surveys		X		X
Subsistence harvest sampling	X	X		X
Tissue sampling	X	X	x	X
Uncrewed Aerial System (UAS)		X		X
Zooplankton imaging			X	X

northward through the Atlantic and Pacific gateways, which may be linked to species range expansions either by affecting environmental conditions or entrainment of individuals. Moorings with ADCPs placed in various locations in the gateway would facilitate monitoring of changes in currents.

For all methods, it would be advisable to store data collected at stations in a relational database so that organism density can be linked to other survey measurements such as oceanography and upper trophic level distribution and abundance. Geographic Information Systems (GIS) and/or spatial modeling (VAST, SDMTMB, etc.) can be used to map the distribution of biomass or abundance and create time series.

5.2. *Analytical methods (for data processing and analyses)*

The following method descriptions and considerations are generally provided in alphabetical order, with methods that collect similar types of data grouped together. These descriptions detail appropriate approaches for collecting data in the Agreement Area. The application of these methods to collect data on particular taxa are detailed in Appendices 1-4.

5.2.1. Acoustic Doppler Current Profiler

Acoustic Doppler Current Profiler (ADCP) (Cokelet and Schall, 1996) measurements can provide an absolute reference for geostrophic currents (units $Sv = 10^6 m^3 s^{-1}$). CTD temperatures and salinities should be averaged over 1-m intervals to calculate density and geopotential height anomalies. Depth bins of data should be determined by pulse length. The first bin can be biased due to ping-to-ping tracking filter misposition and the useable depth range may be around 30-300 m. A ship's gyrocompass and GPS receiver will be necessary for absolute current measurement. Calibrations with CTD temperatures and salinities will improve the accuracy of the currents. Calibrations to compensate for possible misalignment of the ADCP transducers with the ship's centerline should also be conducted. Useful results will require accurate ship velocities. ADCPs can also be used to investigate relative shifts in the vertical distribution of zooplankton, by using their backscatter data.

5.2.2. AUV, Airborne, Ice Cores, Ship Radar

There is a wide array of instruments and methods that can be used on an ice-breaker survey, such as the MOSAiC project (https://mosaic-expedition.org/). Describing the details of these is beyond the scope of this plan. Specific plans should be developed in consultation with Principle Investigators engaged in a monitoring project. For more information, one can access the collection of scientific data from MOSAiC here https://www.nature.com/collections/dcihcgabdc.

5.2.3. Benthic grabs

Replicate grab samples should be taken at each station. Each sample should be sieved on a 1 mm screen and infaunal invertebrates collected and packaged in plastic containers with preservation in 10% seawater formalin, buffered with hexamethylenetetramine. Invertebrates should then be sorted, counted, and weighed (wet weight) to the species or lowest taxon level possible in the lab. The carbon biomass should be calculated from published carbon conversion values (Grebmeier et al., 1989). Samples should subsequently be archived in 50% propanol.

Sediment for grain size and organic carbon and nitrogen content should be collected from the first van Veen grab used for collection of sediment samples, packaged in whirl-pak bags, and frozen for postcruise analyses at land-based facilities. Sediment grain size should be determined in the laboratory after removal of organics and iron oxides following the process of (Gee and Bauder, 1986). Total organic carbon and nitrogen should be determined using an elemental analyzer coupled to a stable isotope mass spectrometer. In addition, replicate surface samples (1 cm3) should be collected with a cut-off 10 cc syringe and subsequently processed for chlorophyll-a content at each station. Sediment chlorophyll-a samples should be extracted and processed shipboard using a fluorometer (Welschmeyer non-acidification method) following a 12-hour in the dark incubation period with 90% acetone at 4°C method (see (Cooper et al., 2013) for further details).

5.2.4. Box-core sediment otoliths

A description of the method and use can be found in (Snoeijs-Leijonmalm et al., 2023).

Fish species distributions in the Agreement Area over a longer time scale (Holocene, ca. 10,000 years) can be assessed from otoliths in deep-sea sediments. To collect enough otoliths a large box core sample is necessary (e.g., surface 50×50 cm, the Holocene layer in the CAO ca. 10-15 cm deep). The geological age of the otoliths is dated with the 14C method, the age of the fish at death is determined from otolith increments. During the Holocene there have been warmer and colder periods, notably the Holocene thermal maximum from around 9000 to 5000 years before present13. Thus, the results can be used for modelling of fish abundance in relation to climate variability. The ambient temperature experienced by the fish is reconstructed with the stable isotope radio δ18O, and metabolic activity by the stable isotope ratio δ13C 13C in the otoliths. The number of otoliths in each layer can be related to temperature and we can predict if fish stocks will increase with climate warming in the future. From the otoliths we can also extract the age of the fish when they died and assess the impacts of temperature on maximum age and age structure of fish stocks.

5.2.5. Buoys

The age, and therefor thickness, of sea ice can be estimated from sea ice motion data from IABP buoys (https://iabp.apl.uw.edu/index.html) and a simple model that tracks a grid of ice parcels as they move (Rigor and Wallace, 2004). A number of other variables are measured from buoys, describing the details of which is beyond the scope of this plan. Specific implementation plans for buoys should be developed in consultation with Principle Investigators engaged in the monitoring project. By adding echosounders to oceanographic and sea-ice buoys, the distribution of zooplankton and fish can be monitored over large areas and time scales (e.g., Flores et al. 2023).

5.2.6. Cores

Duplicate sediment cores for shipboard incubations should be collected. Sediment–flux measurements for dissolved oxygen should follow the methods of (Grebmeier et al., 1989). Bottom water for these experiments should be collected from Niskin bottles on a CTD rosette. Enclosed sediment cores with motorized paddles should be maintained in the dark at in-situ bottom temperatures for approximately 12–24 h. Point measurements should be made at the start and end of the experiment, and flux measurements should be calculated, based on concentration differences adjusted to a daily flux per m2. Sediments should be sieved upon completing the experiment to normalize oxygen fluxes to infaunal biomass and to determine faunal composition.

5.2.7. CTD with Niskin bottles

A CTD Cast Information / Rosette Log should be kept for each cast with a minimum of the following information: the sequential cast number, Latitude and Longitude), GMT date and time, bottom depth, maximum cast depth (NOAA EcoFOCI SOI, S. Bell pers. com.). The sample bottle numbers for each type of sample should be recorded on the log sheet on the line corresponding to the Niskin bottle from which it is drawn. The nominal depth of each Niskin also needs to be recorded on its corresponding line. Minimally salinity samples should be taken on every second to third cast, and those should alternate between near surface (top 5 m) and at depth. If the CTD trace is visible on-screen aboard the ship, the samples taken at depth should ideally be taken from a portion of the water column where the salinity is steady, rather than in a zone of a high salinity gradient. Analytic details for the full list of variables to be measured is beyond the scope of this document and should be established in consultation with scientific survey Principle Investigators during survey planning.

5.2.8. Environmental DNA (eDNA)

Environmental DNA (eDNA) can be used to reconstruct species distributions. A genomic pipeline for Arctic samples focusing on fish and zooplankton was tested by EFICA (the European Fisheries Inventory in the Central Arctic Ocean Consortium). Several methods using whole metagenome and amplicon sequencing are used to construct distribution maps of fish, squid, and key zooplankton, perhaps also birds and mammals. When taking eDNA samples all rules for clean sampling in molecular biology must be used. The method is very sensitive and special care should be taken to not contaminate samples from the water column and the ice with, e.g., fish bait (use obligate freshwater species as bait) or waste water discharge from the ship (forbid any ship discharge before sampling has been terminated at each sampling station).

Some information on sampling in the Arctic Ocean can be found in (Snoeijs-Leijonmalm et al., 2023; Westgaard et al., 2024). Standard methods for eDNA sampling, filter types, extractions, sequencing and bioinformatics should be developed for inter-compatibility of the results. Contamination from humans, and marine fish, squid and shellfish as human food on board or fish bait should be avoided. For bioinformatics analyses the open-source pipelines, including reference databases, designed at SLU can be used. Metagenomic sequencing is preferred since it gives quantitative results.

5.2.9. Flow cam (Krause and Lomas, 2020)

Prefiltered water collected from CTD rosette Niskin bottles should be analyzed soon after the cast (less than 2 hours). Phytoplankton images should be manually classified and biovolume automatically measured using image analysis software. For diatoms, the software can image chains, but it assigns a single biovolume value so this analysis would be conservative.

Imaging flow cytometry, a hybrid technology combining the speed and statistical capabilities of flow cytometry with the imaging features of a flow cam, is rapidly advancing as a cell imaging platform that overcomes many of the limitations of current techniques (Dashkova et al., 2017). For example, flow cytometry lacks the imaging capacity that would allow adequate visualization of cellular morphological features.

5.2.10. Flow cytometry (Lomas et al., 2011)

To assess the biomass of autotrophs, chlorophyll fluorescence can be estimated and converted to carbon, but the errors can be large. A more direct measure can be determined by calibrating cellular carbon content to the geometric mean forward scatter signal, which scales with cell diameter. To measure the biomass of heterotrophic bacteria, one can take advantage of the correlation between the fluorescent intensity of SYPRO-stained cells and cellular protein content which can be converted to carbon biomass using appropriate carbon:protein conversions.

Growth rates for autotrophs can be measured with either esterase activity or photosynthetic electron turnover assays. Both have been shown to correlate well with measured growth rates determined by changes in cell number in culture, but these methods have not been readily incorporated into routine procedures. Growth rates for heterotrophic bacteria can be estimated with Nucleic acid double staining (NADS) which differentiates active, live cells from inactive, dead cells. This approach has been used successfully in marine environments.

Viral infections can be studied using a membrane-impermeant nucleic acid dye (SYTOX green) to detect dead cells and a membrane-permeant dye (calcein AM, which, prior to fluorescent detection, must be hydrolyzed by intracellular esterases (and therefore active cells) into a green fluorescent form).
In addition to quantifying growth of marine microbes, it will be equally important to quantify processes controlling those rates. There are a variety of methods to study nutrient acquisition rates, they are reviewed in (Lomas et al., 2011).

Flow cytometry can separate live from dead particulate organic matter (POM) and thus can be used with mass spectrometry to investigate sources and freshness of POM. One can also use flow cytometry to assess the abundance and importance of marine microgels to dissolved organic carbon (DOC) cycling. Flow cytometry would be particularly suited to this line of investigation because normal filtering procedures either disrupt or remove the microgels from the sample.

5.2.11. Hydroacoustics

Hydroacoustics with 18, 38, 70, 120, and 200 kHz transducers targeting 0-800 m of depth from all ships and drift platforms entering the Agreement Area. Hydroacoustics with a 38 kHz transducer is effective for observing fish with swim-bladders. Hydroacoustics with 70 to 400 kHz transducers have shorter effective observation ranges but can observe smaller organisms (e.g. zooplankton) or fish without a swim-bladder. Broadband hydroacoustics can be used for species discrimination, but methods require further development before use as a standard method in the JPSRM.

In the Eurasian Basin the central Arctic mesopelagic scattering layer occurs in the Atlantic water layer at 100-600 m of depth but this may be lower on the Pacific side. No usable acoustic data can be collected while steaming in ice due to the sound of ice-breaking. Therefore, it is recommended to stop the engines for ten minutes and drift with the ice after a certain time window. For example: steaming 50 min, drifting 10 min. Drift platforms are ideal for collecting acoustic data. Disturbances from the ship can occur (electrical, mechanical, acoustic) and should be avoided while collecting acoustic water-column data. When possible, hydroacoustic measurements should be collected and combined with trawling, but this is only possible if open water is available. It may also be advantageous to use hydroacoustics on smaller platforms, such as submerged moorings, ROVs or autonomous gliders.

Hydroacoustic data collected during steaming should preferably be stored at a horizontal resolution of 1 nautical mile. Hydro acoustic data collected when the vessel is stationary and/or drifting within the sea ice, could be stored on the original temporal resolution.

Nautical area scattering coefficient (NASC, (Maclennan et al., 2002)) should be calculated based on 18 and 38 KHz frequencies, for the 0-800 depth layer. If possible, NASC should also be calculated based on the other available frequencies, for the usable depth layer. The echo integrator threshold in terms of S_v in dB should be set at -90 dB re 1 m^{-1} (for the 38 KHz frequency). The hydro acoustic data should be scrutinized into fish single species (if possible) and plankton.

Zooplankton (e.g., euphausiid) backscatter can be identified by comparing the observed backscatter frequency response at 18, 38, 120, and 200 kHz from acoustic survey transects to a reference data set obtained from trawl-verified measurements of frequency response (e.g., Darnis et al., 2017; Ressler et al., 2012). Volume backscattering strength (Sv, dB re 1 m^{-1}) should be averaged over horizontal and vertical cells, and then all pairwise differences between Sv at different frequencies should be computed for each of these cells and compared to the expectation for various taxa. The signal-to-noise ratio should be used to filter out poor data.

5.2.12. Indigenous Knowledge studies

Indigenous Knowledge utilizes cultural, social, spiritual, and ecological ties that center life and observational experiences to inform a deep knowledge of the Arctic environment. Indigenous Knowledge embodies its own methodologies pertaining to how knowledge is gathered, analyzed, validated, shared, and mobilized holistically to inform decisions. Through ethical, equitable and informed partnerships in knowledge production, when Indigenous Knowledge is combined with science, it results in more robust knowledge production.

Arctic Indigenous Peoples work together with scientists through a co-production of knowledge to study marine mammals, fish, and other species that sustain their people, culture, and way of life. Some examples of research and monitoring programs led by Arctic Indigenous Peoples include the following long-standing monitoring programs and studies: the Inuvialuit Settlement Region Eastern Beaufort Sea Beluga Monitoring Program, Ulukhaktok Seal Monitoring Program, and the Paulatuk and Ulukhaktok Char working groups, which collect harvest data as well as measurements and samples from harvested animals that are used to assess their health, diet, disease and parasites, physical condition, contaminants, and more.

In addition, the North Slope Borough Department of Wildlife Management conducts Inuit-led research on Bering-Chukchi-Beaufort sea bowhead whale (Balaena mysticetus) ecology and population, Eastern Chukchi Sea beluga whale (Delphinapterus leucas) ecology and population, Ice Seals movement and diet in the Bering-Chukchi-Beaufort sea, Polar Cod (Boreogadus Saida) distribution and diet in the Chukchi and Beaufort seas, and Satellite tracked surface ocean currents in the Chukchi and Beaufort seas, under ice observations of zooplankton, fish, and currents in the Beaufort sea.

The Native Village of Kotzebue conducts Inuit-led research including the Ikaaġvik Sikukun project that brought together state-of-the-art geophysical observations from unoccupied aerial systems (UAS) through a community-engaged research approach to bridge scientific and Indigenous understanding of sea ice change in the Alaskan Arctic, as well as satellite tagging projects of young bearded seals, adult bearded seals, and ring seals to understand seasonal movements, habitat selection, foraging and haul-out behavior ice seals in the Chukchi Sea, and a project on Combining Inupiat and Scientific Knowledge: Ecology in Northern Kotzebue Sound, Alaska. Further, in keeping with working together with scientific methods, Inuit knowledge in Nunavik, Canada corresponded to fuzzy logic modelling of Arctic Char spawning habitats, highlighting the benefits of correlating knowledge sources. Many other Inuit-led research projects can inform the JPSRM.

5.2.13. Moorings

Detailed methods for the large number of sensors, instruments and equipment that can be deployed on moorings is beyond the scope of this plan and should be developed by Principle Investigators engaged in the monitoring program.

5.2.14. Optical recordings

Experience on optical recordings, use and processing (using FishCam, MacArtney Germany GmbH, Kiel, Germany) can be found in (Snoeijs-Leijonmalm et al., 2023).

Underwater cameras, ROVs and AUVs currently exist that could be deployed to collect data on fish and invertebrate species both on the benthos and in the water column where sampling is extremely difficult. Combining image collection with automatic detection of moving objects (fish, squid, macrozooplankton) from drifting and moored platforms is a good complement to assess species distributions in the Agreement Area and could potentially be a non-destructive sampling method. Experience has indicated that attaching a camera to a CTD has limited success for fish and squid because a CTD moves fast except during water sampling for very short times at specific depths, and fish actively avoid the moving CTD. Due to the generally low abundance of fish and squid, recording many hours is necessary. Thus, targeted deployments of cameras is likely to result in higher success in capturing abundance and distribution patterns of fishes and squids. There has been considerable research in recent years into combining acoustic and optical surveys for fishes (e.g. deployments of cameras guided by acoustic observations of fish). ROV's and AUV's could both be deployed to target both midwater and benthic species. There is also potential to deploy towed camera systems, drift camera systems or stationary camera systems (e.g. floating in the water column, but anchored to the seafloor) that could cover larger areas and potentially require less cost and technological expertise. Size data for species can also be obtained from either using calibrated stereo cameras or laser systems. Finally, underwater cameras can be combined with other gear types for auxiliary data collection. For example mounting stereo-cameras in trawl nets can allow estimation of gear selectivity or even allow fishing with an open codend that becomes a non-destructive method of capturing abundance and size information.

A variety of methods of image processing and of machine learning procedures exist to identify, quantify and measure plankton in images taken by instruments (e.g., (Bi et al., 2022; Campbell et al., 2020; Corgnati et al., 2016; Li et al., 2022; Maps et al., 2023; Ohman et al., 2019; Pitois et al., 2021; Uusitalo et al., 2016). Describing them is beyond the scope of this report and should be developed with Principle Investigators participating in the monitoring surveys.

5.2.15. Plankton nets

It is recommended to install a flowmeter in each net to record the distance traveled (used to calculate the volume of water filtered). If possible a depth probe such as a SEACAT should also be installed to record the depth profile of the tow. Otherwise the depth of the gear should be estimated from wire out and wire angle (Dougherty et al., 2010).

Samples should be preserved in 5% buffered formalin/seawater. Mesozooplankton, macrozooplankton and ichthyoplankton should then be identified to the lowest taxonomic level and stage possible in the laboratory. Biomass would not typically be measured directly but should be estimated from literature values. Numerical and biomass density should be calculated from the catch and volume filtered. A portion of the sample not preserved for later analysis can be used for specimens.

5.2.16. Population genetics

Population genetic analyses of fish and squid caught both in the Agreement Area and adjacent regions establish connectivity pathways between coastal spawning areas and adults living in the Agreement Area (Crawford and Oleksiak, 2016; Selkoe et al., 2008; Wildes et al., 2022, Snoeijs-Leijonmalm et al. 2022). Principal candidates for such studies (based on the current knowledge) are polar cod *Boreogadus saida* (Maes et al., 2021; Nelson et al., 2020), ice cod *Arctogadus glacialis*, Atlantic cod *Gadus morhua*, Greenland halibut *Reinhardtius hippoglossoides*, Walleye pollock *Gadus chalcogrammus*, Arctic skate *Amblyraja hyp*erborea, Capelins (a complex of *Mallotus* species) and armhook squid *Gonatus fabricii* that all are known to occur in the Agreement Area. Other candidates include haddock *Melanogrammus aeglefinus*, Bering flounder *Hippoglossoides robustus*, Alaska plaice *Pleuronectes quadrituberculatus*, and beaked redfish *Sebastes m*entella. Many species of fish are also relied upon by Arctic Indigenous communities who live adjacent to the Agreement Area.

Microsatellite markers and mtDNA can be developed to be diagnostic for the species of interest. Initially sampling can occur on scales of 100s to 1000s of km. If genetic population structure is found, sampling can be refined. But in general for marine organisms structure is rare on scales < 100 km. 50 samples per site is a good initial sampling effort. Tissues should be stored in ethanol or another buffer that can preserve DNA. If a reference genome is available and the genome is relatively small, whole genome sequencing is recommended. Otherwise, restriction-site associated DNA (RAD) sequencing would be good approach. These approaches will result in thousands to millions of markers to work with for population genetic analysis.

5.2.17. Production

There are rather high uncertainty in Arctic phytoplankton production estimates. Ones of the most accepted methods to evaluate phytoplankton production is semi-analytical algorithms (such as GSM-like models; Matsuoka et al. 2024).

Zooplankton production is a difficult parameter to measure accurately because no direct methods exist (see also Flores et al., 2019). The primary method would be to measure growth rate and multiply by the standing stock biomass. Growth is difficult to measure directly but it can be modeled using temperature, body size and food availability. There are also biochemical methods (Yebra et al., 2017).

5.2.18. Satellites

After downloading % ice cover data at a given spatial resolution (e.g., 25 x 25 km) and temporal resolution (daily or monthly), one can calculate the following indices for the area of interest:

- Ice extent, the proportion of the area covered by sea ice (% ice concentration > 0).
- Ice concentration, average % ice concentration over the area.
- Date of ice formation and retreat, date of daily average % ice concentration (smoothed) that is greater or less than a given threshold (such as 15%).

Note that monthly products are better to use for long-term trend analysis because errors in the daily product tend to be averaged out in the monthly product and because day-to-day variations are often the result of short-term weather.

Satellite data should first be binned and averaged into grid cells, the size of which should be chosen to include enough satellite pixels to assess the spatial variation of the parameter of interest (sea surface temperature SST or Chl-*a*). For Chl-*a*, individual pixels that have more than 10% ice cover should be excluded as this can yield highly uncertain Chl-*a* values. Locations shallower than 20 m bottom depth and near river plumes should also be excluded from Chl-*a*. While satellite data provide unique spatio-temporal coverage, these products often have missing data due to clouds and ice cover, thus to validate parameter estimates it is recommended to compare the satellite data to *in situ* estimates (Chl-*a* derived from factory-calibrated fluorescence sensors), such as from moorings or surveys. Regional Chl-*a* biomass and SST can be calculated from the gridded satellite data. In addition, the timing of the peak of the spring bloom can be estimated from transformed and linearly interpolated data.

5.2.19. Trawls

Latitude, longitude, bottom depth at the start and end of each trawl, and fishing depth should be recorded for all trawl hauls.

Data collected by pelagic trawls include area swept, catch abundance ,catch biomass and biological information. Area swept (km^2) is used to calculate density (a.k.a. catch-per-unit effort, CPUE) from catch biomass and number per species. Area swept would be calculated from the known net width and trawled distance at determined fishing depth. Standard methods for sampling, identifying and quantifying species and biological processing (see below) of pelagic trawl catches can be found in Ingvaldsen et al. (2023) and Eriksen et al. (2017). In addition to sampling the catch, specimens are often preserved (frozen, ethanol or formalin) for subsequent laboratory analyses.

For benthic trawls, area swept would be calculated from the known net width and trawled distance along the bottom determined from acoustic net sensors or a bottom contact sensor and a GPS receiver (Cooper et al., 2023). Area swept (km2) is used to calculate density (a.k.a. catch-per-unit effort, CPUE) from catch biomass and number per species. Standard methods for sampling, species identification, quantifying, and biological processing (see below) of trawl catches can be found in Eriksen et al (2017).

For beam trawl catches, area swept would be calculated from the known net width (fixed by the length of the beam) and distance along bottom determined from acoustic net sensors or a bottom contact sensor and a GPS receiver (Cooper et al., 2023). For otter trawl catches, area swept would be calculated from net width measured with acoustic net sensors and distance along the bottom measured by a bottom contact sensor and a GPS receiver (Stauffer, 2004). Total catch abundance and biomass of invertebrates would typically be estimated from a sub-sample of the catch. The exception would be for rare and/or important taxa such as snow crab where the whole catch would be counted and weighed. Typically the whole catch of fish would be counted and weighed because fish catch is typically relatively low (compared to invertebrates) in the Arctic. Numerical and biomass density (catch-per-unit-effort, CPUE) would be calculated by dividing the catch by the area swept.

5.2.20. Tissue sampling

To analyze lipids and fatty acids (Pinger et al., 2022), specimens should be sorted from the catch and immediately frozen at < −80 °C. Gravimetric methods are used to measure the total mass of lipid in a sample after extraction into an organic solvent. Alternatively, the sulfo-phospho-vanillin (SPV) reaction is a popular method for determining total lipids in a variety of sample types. The SPV assay agrees well with gravimetric analysis and is rapid, high throughput, low cost, precise, sensitive and accurate when calibrated with appropriate standards. Lipid composition can be obtained using chromatographic methods and analysis of total fatty acid composition of lipids can use gas chromatography and mass spectrometry.

5.2.21. Sea chest (continuous)

Periodic salinity, chlorophyll and nutrient samples should be taken from the sea chest water flow to calibrate the sensors.

5.2.22. Sediment traps

It is recommended to use a dense formalin solution to preserve sediment trap samples (Lalande et al., 2020). Use of this preservative facilitates additional analyses by other investigators (e.g., plankton species, fecal pellets). After collection, each cup should be processed using established procedures, including sampling the supernatant, thoroughly rinsing samples to remove the fixative and carefully picking recognizable swimmers (e.g., (Thunell et al., 2000)). To avoid splitting biases the whole contents of each cup should be freeze-dried and weighed to determine dry weight (DW). The first set of fundamental measurements should include organic carbon, nitrogen, phosphorous, inorganic carbon, biogenic silica and aluminum contents (Goñi et al., 2003; Mortlock and Froelich, 1989; Ostermann et al., 1990). To gain additional insights into the provenance of the organic matter collected in traps, pigments should be measured by HLPC (e.g., (Wright et al., 1991)) and selected lipid extractions should be performed to measure taxa-specific lipids, such as highly branch isoprenoids (including IP25) and sterols by gas chromatography-mass spectrometry (Mead and Goñi, 2006).

5.2.23. Trophic linkages

Trophic linkages among fishes and between fishes and other taxonomic groups are studied by analyzing stomach contents, both with microscopy and with metabarcoding and by comparing stable isotope ratios δ13C and δ15N in zooplankton and fish muscle. More accurate methods to identify trophic linkages on longer time scales are fatty acid analysis, and stable isotope compositions of fatty acids and amino acids (e.g., Kohlbach et al. 2017, Vane et al. 2023). An additional method used as a trophic tracer is fatty acid composition in fish (and squid) muscle and liver and in other components of the food web, but this method is more elaborate and expensive. Estimates of phyto- and zoo-plankton relative biomass and numbers will be based upon net catches, as well as from acoustic (AZFP) data. Phyto- and zooplankton species will be determined from plankton net hauls. Sediment traps collect sinking particles associated with the phyto- and zooplankton distributions and carbon cycles. Mooring systems including sediment traps with physical, chemical, and biological sensors can monitor annual and interannual changes in phyto- and zooplankton communities.

Studies testing preservation methods of zooplankton for stable isotopes showed that freezing causes both $\delta^{13}C$ and $\delta^{15}N$ to shift. The best practice should be to analyze directly dried samples (Feuchtmayr and Grey, 2003). However this will be very difficult at sea. The recommended method, adapted from (Pinger et al., 2022) will be to the remove excess water, then flash freeze the samples at -80 °C and never allow to thaw. This method has been successfully used on previous cruises (Pakhomov et al., 2022). Because of this difficulty in preserving samples collected at sea, larger-bodied zooplankton such as *Calanus* and euphausiids are recommended to collect. Stable isotopes should be analyzed in the laboratory following (Miller et al., 2008).

6. INFORMATION SOURCES

6.1. *Scientific information*

For currently available scientific information, the SCG and its working groups will seek opportunities to utilize relevant information from published literature as well as reports and data products from external groups, whenever possible (e.g., national research programs, multilateral research initiatives, and international programs).

However, the Agreement has acknowledged that, "while the central Arctic Ocean ecosystems have been relatively unexposed to human activities, those ecosystems are changing due to climate change and other phenomena, and that the effects of these changes are not well understood." Nevertheless, the CAOFA can create an opportunity to understand the structure and dynamics of CAO ecosystems to help develop management strategies, before the commencement of commercial fishing. Therefore, it has to be kept in mind that data collected through the JPSRM and used to analyze and form the outcome results that contribute to management decisions should be the most important source of data.

Any new scientific information revealed during survey in Mapping and/or monitoring phase and exploratory fishing can be used to support the aim of JPSRM. All data used by the JPSRM must adhere to the SCG Data Management and Sharing Protocol (DMSP).

Sources include:

A. New scientific data to be collected and analyzed.
    a. Data collected from the surveys coordinated by JPSRM during the Mapping phase.
    b. Data collected from the surveys coordinated by JPSRM during the Monitoring phase.
    c. Data and information collected from the Exploratory Fishing.
    d. Data provided from Parties.
    e. Data provided from external groups active in the Arctic.

B. Published literature and reports.
    a. Published literature and result reports of recent research expeditions, from both Parties' national research programs and external groups.
C. Unpublished but available scientific information (needs analysis, publication).
    a. Data collected jointly for the SCG through dedicated efforts by Parties' national research programs.
    b. Data and reports from external groups active in the Arctic, published in international portals and repositories, e.g. GBIF, Pangaea, EMODnet.

6.2. *Indigenous Knowledge*

The ICC has defined Indigenous Knowledge as:

> "Indigenous Knowledge is a systematic way of thinking applied to phenomena across biological, physical, cultural, and spiritual systems. It includes insights based on evidence and acquired through direct and long-term experiences and extensive and multigenerational observation, lessons, and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, and it is passed on from generation to generation.
>
> Under this definition, Indigenous Knowledge goes beyond observations and ecological knowledge, offering a unique way of knowing to identify research needs and apply to research, monitoring, assessments, decision-making, policy and the overall understanding the Arctic – it is our Way of Life" (Inuit Circumpolar Council, 2016).

Arctic Indigenous communities bring a holistic understanding of the Arctic ecosystem, their homeland, which looks at the dynamic relationship between its components that are interrelated and interdependent. Because of this unique understanding, Arctic Indigenous communities have thrived and survived in the Arctic for thousands of years.

To incorporate the interests of Indigenous peoples into the work of JPSRM effectively, it is important to understand the needs of Arctic Indigenous peoples for subsistence-harvesting and their potential interaction with future fishing activities. The JPSRM needs to consider data collected on historical, current, and future harvests including harvested species, harvesting areas, and harvest amounts.

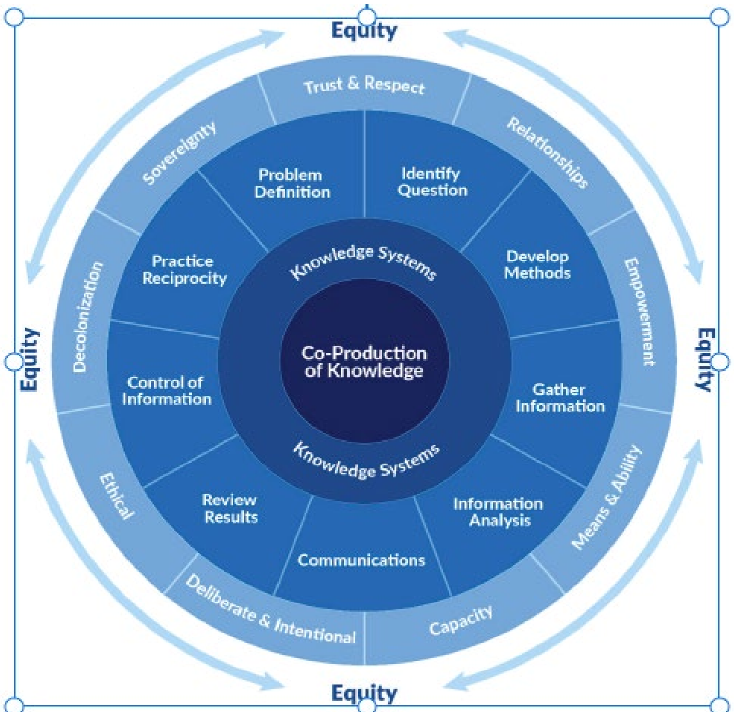

Figure 3. A framework for co-production of knowledge (Ellam Yua, 2022).

Bringing Indigenous Knowledge and science together through a co-production of knowledge can generate new knowledge and understandings of the world that would not be achieved through utilizing only one knowledge system (Figure 3). Co-production of knowledge is founded on an equitable and ethical process for bringing together Indigenous Knowledge and science. Experts from both knowledge systems work collaboratively in identifying research questions. This approach respects the methodologies of both knowledge systems in seeking, analyzing and validating information.

When Indigenous Knowledge is documented, it should meet the standards and protocols developed by Arctic Indigenous peoples, including the Circumpolar Inuit Protocols for Equitable and Ethical Engagement (2022), as referenced in the JPSRM Data Management and Sharing Protocol (DMSP). The DMSP recognizes that data collected from national programs shall respect national and international data policies. Therefore, it is important to note that Arctic Indigenous peoples have ownership and control over their Indigenous Knowledge and information, data, and materials pertaining to their knowledge, people, culture, resources and homelands. (Inuit Circumpolar Council, 2022).

Under a co-production of knowledge, information should be provided, analyzed and interpreted by all knowledge holders. All participants in the knowledge production process should be given the opportunity to review results within a meaningful and mutually agreed upon timeline before results are finalized. Communication between all participants should be open and transparent, culturally acceptable and understandable, and respect the worldviews of both knowledge systems (Ellam Yua, 2022). Implementing the co-production of knowledge is dependent on building strong relationships that take time and mutual participation and effort of all participants. Building this relationship requires learning about and understanding each other’s knowledge systems, motivations, and goals.

Indigenous Knowledge intended for publication or public dissemination under the JPSRM Implementation Plan shall acknowledge the unique nature of interpretation of Indigenous Knowledge, and the SCG shall apply directly to the knowledge provider for review and final decision as to whether to use and publish the knowledge, as directed by the JPSRM Data Management and Sharing Protocol.

Utilizing Indigenous Knowledge within the JPSRM Implementation Plan is a new and developing process within multilateral treaties in the Arctic, which requires institutional support and funding to bring Indigenous Knowledge holders together to inform the steps needed for their contribution to the implementation of the JPSRM and to ensure it is done right.

Sources of Indigenous Knowledge include:

A. New knowledge to be collected and analyzed.
    a. Data collected from the surveys coordinated by JPSRM during the Mapping phase.
    b. Data collected from the surveys coordinated by JPSRM during the Monitoring phase.
    c. Data and information collected from the Exploratory Fishing.
    d. Data provided from Parties.
    e. Data provided from external groups active in the Arctic.
B. Published literature and reports.
    a. Published literature and result reports of recent research expeditions, from both Parties’ national research programs and external groups.
C. Unpublished but available Indigenous Knowledge information (needs analysis, publication).
    a. Data collected jointly for the SCG through dedicated efforts by Parties’ national research programs.
    b. Data and reports from external groups in the Arctic.

6.3. *Local knowledge*

According to FAO (2004), local knowledge is the knowledge that people in a given community have developed over time, and continue to develop. It is:

A. Based on experience.
B. Often tested over centuries of use.
C. Adapted to the local culture and environment.
D. Embedded in community practices, institutions, relationships and rituals.
E. Held by individuals or communities.
F. Dynamic and changing.

When local knowledge is collected or utilized under the JPSRM, it should meet the standards and protocols developed by the DMSP.

7. RESEARCH PLANNING AND COLLABORATION

7.1. *Joint data collection, surveys, and analyses*

The Agreement and the JPSRM acknowledge that the Agreement Area is a data-deficient region and that more data are urgently needed to meet the objective of the Agreement. This section describes the processes to be used by the SCG, national programs, and other external collaborators to plan, coordinate, and implement joint scientific programs in the CAO, peripheral waters, and gateways as part of the JPSRM.

In addition to working together within the SCG, successful implementation of the JPSRM will be strengthened considerably if collaborations can be developed with one or more of the many marine science organizations and initiatives that are conducting research in the Arctic. Partnering with external expert science groups would be an efficient and cost-effective way for the JPSRM to develop information products to the COP that fulfill its specific information needs. The JPSRM Framework provided a list of some of the Arctic science groups that may be interested in collaborating with the JPSRM on an informal or more routine basis in support of JPSRM goals – many of which are likely to be mutual goals shared by both groups. In many instances, Parties to CAOFA are also members of these organizations, which could aid in promoting future collaborations.

As part of the implementation of the JPSRM, the SCG plans to reach out to some of these groups to explore opportunities and mechanisms to develop productive collaborations. The outcome of such partnerships would facilitate the production of analyses and reports that would assist the SCG in providing information and guidance to the COP in response to its specific requests.

7.2. *Planning and coordination among nationally driven Arctic science programs*

The JPSRM Framework identifies the importance of national scientific programs and their role in implementing the JPSRM. There is a need to establish a process outlining the steps to promote consultation, coordination, and implementation with the Parties' nationally driven science programs to meet JPSRM objectives whenever possible. In order to achieve these goals:

- The SCG will develop, for review and approval by the COP, a regular and consistent process to promote coordination between national programs to facilitate collaboration and to meet the data needs identified in the JPSRM Framework and this Implementation Plan. To support this process, the SCG requests that each Party provide its relevant research plans and schedules to the SCG at least six months prior to commencement of research activities.
- The SCG will review these research plans and provide recommendations to the Parties to promote coordination of each Parties' research activities and efforts.
- The SCG shall seek to develop a coordinated plan and schedule whereby SCG Members report on research activities by their Party and contribute to the JPSRM in accordance with the Data Management and Sharing Protocol to avoid duplication and encourage research activities that fill data gaps.
- Information regarding Parties' science programs in areas adjacent to the Agreement Area should also be exchanged to the extent possible through a SCG-led process to annually identify research cruises with potential opportunities for collaboration.

The SCG may seek to liaise with other national and international programs (e.g., see Table 2, JPSRM Framework) to seek opportunities for scientific collaboration.

7.3. *Involving Indigenous peoples, local communities, and Indigenous Knowledge in the JPSRM*

The Agreement recognizes the interests of Arctic Indigenous peoples and local peoples and underlines the importance of involving them and their communities in CAOFA processes. The JPSRM will ensure that Indigenous Knowledge holders and local experts are included in the planning, coordination and implementation of the JPSRM. Section 6.2 describes a structure for the coproduction of knowledge with Arctic Indigenous peoples and provides a critical foundation and guidance for such work in the future.

A. As part of this Implementation Plan, the SCG shall explicitly seek to include participation by Indigenous Knowledge holders and local experts in the planning, coordination, and implementation of Joint Scientific Expeditions organized by the Parties into the CAO and the Pacific and Atlantic gateways, as well as waters adjacent to the CAO in accordance with its Rules of Procedure.
B. The SCG shall seek to establish processes and procedures to bring together scientific knowledge, Indigenous Knowledge and local knowledge into the JPSRM database, methods, analysis, and results.
C. The SCG shall seek to establish guidelines and procedures regarding consultation, acquisition, and ownership of Indigenous Knowledge in line with the Data Management and Sharing Protocol, for approval by the COP. These guidelines and procedures shall be periodically reviewed and updated as necessary to ensure they remain current and appropriate.
D. Parties' science programs operating in the Agreement Area are encouraged to include Indigenous Knowledge holders and local experts in the planning and implementation of such programs and take steps to ensure that Indigenous Knowledge is incorporated into these scientific efforts, analyses, and their results.

8. LOGISTICS COORDINATION

This section details logistic coordination among research focused programs and platforms. Vessels of opportunity should also be considered for JPSRM data collection as available.

8.1. *Fieldwork coordination and implementation*

A top priority for the JPSRM is the planning, coordination, and implementation of joint expeditions into the CAO using existing platforms or platforms of opportunity as may become available. In order to accomplish this goal:

- The SCG shall develop, for review and approval by the COP, a clear process and timeline for consultation among the Parties for scheduling vessels for joint expeditions into the Agreement Area, peripheral seas, and gateways as well as for organizing teams of scientists and Indigenous experts to plan and conduct the research on these joint expeditions.
- The teams organized should be multi-national and multi-disciplinary, and include Indigenous Knowledge holders and local experts when feasible. Teams will be charged with developing specific research plans for each cruise. These plans are to: 1) be informed by the JPSRM Framework and the JPSRM Implementation Plan, 2) include the questions and data needs identified by the SCG and the COP, and 3) provide the ecosystem and fishery information necessary to meet the aims of the JPSRM and the objectives of the Agreement.
- The SCG shall maintain a list of icebreaking and other research vessels that are expected to operate in the CAO and adjacent waters over the next several years and beyond (see 8.2 below). Several ships are owned or operated by the Parties. Parties operating these Arctic research vessels should discuss how planned expeditions could be coordinated through the SCG and how these vessels can participate in the Joint Scientific Expedition process. The SCG shall seek to coordinate annual communication between SCG Members and managers of science programs with Arctic research vessels and other research platforms to discuss coordinated research activities.
- The SCG shall maintain a list of national research programs actively monitoring the Agreement Area and adjacent waters and gateways.

8.2. *Research platforms and coordination*

Vessels and other platforms of opportunity from SCG Members and external collaborators should be used to the extent possible to supplement data collected by the dedicated mapping and monitoring programs. Consideration should be given to establishing a unified observation network (or simply a common-observed section), possibly through a collaborative effort at both national and international levels, could serve as a viable solution to support the mapping and monitoring program.

Planned synoptic/coordinated marine scientific investigations.

- Common goals objectives as reflected in the agreement and JPSRM Framework.
- Common transects.
- Common indicators and parameters contain in the JPSRM Framework and this implementation plan.
- Common protocols and standards.

The following research vessels and icebreakers will be potentially operating in the Agreement Area, peripheral areas, and gateways in the next few years. The coordinators of these vessels should be contacted by the SCG to verify the likelihood that they will be operating in these areas and to evaluate the possibility of using the ship as a vessel of opportunity.

- Amundsen (Canada)
- Araon (Korea)
- Arctica (Finland)
- Kronprins Haakon (Norway)
- Mirai (ice strengthened ship; Japan)
- Oden (Sweden)
- Oshoro-maru (training ship of Hokkaido University, Japan)
- Polarstern (Germany)
- USCGC Healy (United States)
- Sikuliaq (USA)
- Xuelong (China)
- Xuelong2 (China)
- Tara (France)
- Russian drift stations

Japan's first research icebreaker for Arctic sciences is now being built and will be delivered to JAMSTEC in 2026. The ship will be capable of transecting the central Arctic Ocean, and therefore, will largely contribute to pan-Arctic international collaborative studies. Furthermore, the ship is to be equipped with a fish finding echo sounder with advanced onboard instruments capable of withstanding extreme low-temperature conditions, and thus, expected to contribute to scientific surveys related to the Central Arctic Ocean Fisheries Agreement.

The list of research platforms and similar potential vessels of opportunity needs to be maintained and periodically updated.

8.3 *Scientific support from exploratory fishing vessels*

Exploratory fishing as defined in Article 1(e) of the CAOFA is differentiated from commercial fishing by its contribution to scientific information.

As specified in Article 5(1)(d), exploratory fishing shall not undermine the objective of the Agreement, shall be consistent with the JPSRM, and shall be managed such that it is limited in duration, scope and scale to minimize impacts on fish stocks and ecosystems. To aid in this:

- The SCG will define the role exploratory fishing may have in the JPSRM science efforts and identify the types of data that should be collected by exploratory fishing vessels.
- The SCG shall develop processes and procedures to review and provide recommendations on coordination of exploratory fishing to maximize the scientific value and minimize the ecosystem impacts of exploratory fishing and, in particular, meet the requirements of Article 5(1)(d)(ii).
- The SCG shall develop processes and procedures for the review of Exploratory Fishing Plans.
- The SCG shall develop requirements for data collection and reporting by exploratory fishing vessels and operations consistent with the Data Sharing Protocol for review and approval by the COP prior to any exploratory fishing activity in the Agreement Area.

9. ANALYTICAL APPROACH TO ANSWERING THE GUIDING QUESTIONS

9.1. *Analyses, modeling, forecasts*

First, emphasis should be placed on: 1) ensuring that key data are collected and available for JPSRM analyses and modeling, and 2) focusing on data quality control, such as conducting analysis and comparison of the data quality, analyzing appropriate data resolution and scale, and standardizing the data. Second, interpreting the phenomena directly reflected by the data, as well as data mining and analyzing to reveal key phenomena should be priority works. Third, model forecasting could be carried out as a supplement based on clear analytical results and sound scientific evidence, but should not replace the phenomena observed and conclusion of analyzation. Analysts should conduct careful diagnoses of models by using newly acquired data and sensitivity tests to evaluate its robustness.

9.2. *Development of information products and guidance to the COP*

The findings and conclusions of the analysis and research conducted during the mapping and monitoring phases should be provided to the COP in the form of annual reports, interim reports, phase report, and final reports.

10. IMPLEMENTATION TIMELINE

10.1. *Mapping (aspirational milestones and timeline)*

Milestones and timeline for science planning and implementation of joint scientific expeditions by the Parties (referenced within Section 8.1)

Section 8.1 states that a top priority for the JPSRM is the planning, coordination, and implementation of joint expeditions into the CAO using existing platforms or platforms of opportunity as may become available. In order to accomplish this goal the SCG proposes the following:

A. The SCG shall develop a clear process and timeline for consultation among the Parties for scheduling vessels for joint expeditions into the CAO and adjacent seas, and organizing teams of scientists, Indigenous Knowledge holders and local experts to plan and conduct the research on these expeditions.
B. Section 8.2 includes a list of icebreaking research vessels that are expected to operate in the CAO in the next few years. Several are owned or operated by the Parties. The list needs to be updated annually.
C. Section 8.1 states that Parties operating these Arctic research vessels should discuss how planned expeditions could be coordinated through the SCG and how these vessels can participate in the Joint Scientific Expedition process.
D. The SCG shall convene annual meetings to coordinate communication between SCG Members and managers of science programs with Arctic research vessels and other research platforms to discuss planning and coordination of research activities.

Milestones and timeline for planning and coordination among national Arctic marine science programs (referenced within Section 7.2)

Section 7.2 identifies steps to promote the collaboration and coordination among Parties national Arctic science programs, noting that there is a need to establish a process for the orderly consultation, coordination, and implementation of national science programs to meet JPSRM objectives. In order to accomplish this, the SCG shall develop and maintain a process to promote coordination between national programs to facilitate collaboration and meet the data needs identified in the JPSRM Framework and this Implementation Plan. The SCG may invite other international programs to participate, as appropriate.

Milestones and timeline for involving Arctic Indigenous peoples and Indigenous Knowledge in the JPSRM. Milestones and timeline (referenced within Section 7.3)

Section 7.3 notes that the CAOFA recognizes the interests of Arctic Indigenous peoples and local people and underlines the importance of involving them and their communities in CAOFA implementation. Section 6.2.1 provides important guidance regarding Indigenous Knowledge and describes a structure for the coproduction of knowledge with Arctic Indigenous peoples. Sections 6.2 and 7.3 provide a critical foundation and guidance for work going forward, and the SCG proposes the following steps to build on this guidance:

A. As part of this implementation plan, the SCG shall explicitly include participation by Indigenous Knowledge holders and local experts in the planning, coordination, and implementation of the JPSRM, including joint scientific expeditions organized by the Parties into the CAO and the Pacific and Atlantic gateways, as well as waters adjacent to the Agreement Area.
B. The SCG shall convene a meeting to discuss bringing together all relevant knowledge systems under the JPSRM.
C. The SCG shall review processes and procedures whereby Indigenous Knowledge and local knowledge is incorporated into the JPSRM database. The SCG shall review guidelines and procedures regarding consultation, acquisition, and ownership of Indigenous Knowledge and local knowledge consistent with Section 6.2 and the DMSP for approval by the COP with the intent that these guidelines and procedures be periodically reviewed and updated as necessary to ensure they remain up to date and culturally appropriate.

Milestones and timeline for scientific support from exploratory fishing vessels. Milestones and timeline (referenced in Section 8.3)

Section 8.3 identifies steps to incorporate exploratory fishing data collection into the JPSRM. Exploratory fishing as defined in Article 1(e) of the CAOFA is differentiated from commercial fishing by its contribution to scientific information. Currently the COP is developing conservation and management measures (CMMs) consistent with CAOFA Article 3(3) and Article 5(1)(d). The CMMs for exploratory fishing shall be appended to the JPSRM Implementation Plan once they are adopted.

Consistent with Article 5(1)(d), the CMMs, and any additional guidance provided by the COP, the SCG will provide the following:

A. The SCG shall identify the role exploratory fishing may have in the JPSRM, including the types of data that should be collected by exploratory fishing vessels, and the methods and means for collecting such data.

B. The SCG shall develop processes and procedures to review and provide recommendations to the COP for coordination of exploratory fishing operations to minimize duplication, maximize the scientific value of exploratory fishing data collection, and minimize the ecosystem impacts of exploratory fishing including, in particular, the requirements of Article 5(1)(d)(ii).
C. The SCG shall develop processes and procedures for the review of exploratory fishing plans and making recommendations to the COP.

The SCG shall develop requirements for data collection and reporting by exploratory fishing vessels and operations consistent with the CMMs and Data Sharing Protocol.

10.2. *Monitoring (aspirational milestones and timeline)*

Details to be developed following completion of the mapping phase. The monitoring phase will be ongoing after completion of the mapping phase for an indeterminate period of time. The purpose of the monitoring phase is to consistently monitor population or ecosystem indicators in the three priority geographic areas identified in the JPSRM Framework as being relevant to JPSRM implementation: the Agreement Area itself, the peripheral shelf/slope areas adjacent to the Agreement Area, and the Pacific and Atlantic gateways to detect any changes in species or ecosystem components that may warrant a re-examination of SCG guidance to the COP.

10.3. *Products to the SCG and the COP*

Products to the SCG: The SCG shall establish, consistent with the ROP, such working groups as necessary to further the work outlined under 10.1 and 10.2. Timeline and products to be determined following COP approval of the JPSRM Implementation Plan. Following any surveys in the Agreement Area, the SCG will analyze the collected data and provide a report to the COP, including results regarding the composition of the biological community, species distributions and habitat use patterns, and trophic relationships, as possible.

Products to the COP: To provide timely information, advice, and recommendations to the COP, the SCG shall:

A. Report to the COP with recommendations regarding implementation of Section 8.1: Science Planning and Implementation of Joint Scientific Expeditions by the Parties.
B. Report to the COP regarding Section 8.2: coordination of Arctic research vessels. The SCG shall meet in the fall of 2024 to initiate this work with the goal of providing a recommended process to the COP.
C. Report to the COP regarding implementation pursuant to Section 7.2: Coordination and collaboration among Party's national science programs. The SCG shall convene a meeting among the Parties in to facilitate further collaboration and coordination of research activities and efforts and report to the COP.
D. Report to the COP with recommendations regarding Section 7.3: Involving Indigenous peoples and Indigenous Knowledge in the JPSRM. Report to include recommendations for guidelines and procedures regarding consultation, acquisition, and ownership of Indigenous Knowledge, and

procedures for incorporating Indigenous Knowledge into the JPSRM database, methods, and analysis.

E. Report to the COP] with recommendations for implementing Section 8.3: Scientific Support from Exploratory Fishing setting out processes and procedures to meet JPSRM goals consistent with Exploratory Fishing CMMs, and Article 5(1)(d).

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12. LIST OF FIGURES

13. LIST OF TABLES

Appendix 1: JPSRM Standard Methods – fish species

CAOFA JPSRM Standard Methods for Collecting Scientific Data

-- Fish Species --

Central Arctic Ocean Fisheries Agreement (CAOFA)
Scientific Coordinating Group (SCG)

Here we give a description of the standard methods to be used in JPSRM surveys assessing fish (Tables 1-1 and 1-2). These methods do not prescribe in detail the equipment to be used, as that will depend on the vessels and gear available. Prior to a JPSRM survey, the MM-WG must assess how data from different gear with different catchability are to be combined.

1. Trawling

1.1. Benthic (bottom) trawls

Benthic (bottom) trawls can be used to sample epibenthic invertebrates and fishes. Two types of trawls have been deployed in the Northern Bering-Chukchi seas, the small-mesh plumb staff beam trawl (Abookire and Rose, 2005; Cooper et al., 2023) and the large-mesh otter trawl (Cooper et al., 2023; Stauffer, 2004). The beam trawl targets smaller animals than the otter trawl. In the Barents Sea, the Campelen 1800 bottom trawl is in regular use for monitoring benthos and demersal fish (Engås and Ona, 1987). Bottom trawls would be best deployed from a survey vessel in open water.

Data collected by bottom trawls can include area swept, catch abundance and catch biomass. Area swept (km2) would be used to calculate density (a.k.a. catch-per-unit effort, CPUE) from catch biomass and number per species. Specimens can be collected for a wide variety of measurements (see Table 1-2)

1.2. Pelagic (mid-water) trawling

Pelagic (mid-water) trawling in ice-covered waters is challenging because ice floes floating behind the vessel can easily destroy the net during deployment or retrieval. However, modifications of standard fish trawls can function well also in ice covered waters (Ingvaldsen et al., 2023). When possible, mid-water trawling should be conducted in patches of open water and/or leads which occur between ice-floes due to wind forcing. The depth of trawling should be determined by visual inspection on the vessel-mounted echosounder.

Juvenile fish (polar cod) directly under the ice could be caught with a Surface and Under-Ice Trawl (SUIT) (David et al., 2016; Flores et al., 2023).

Appendix 1: JPSRM Standard Methods – fish species

Table 1-1. Methods for collecting data on pelagic fishes (and squid), data to be collected, and which parameters are addressed.

Gear	Data collected	Priority parameter(s)
Pelagic trawls • Mid-water trawls • Surface and Under-Ice Trawl	Trawl • Area swept Catch • Species • number/km^2 • kg/km^2	• Abundance, biomass, trends • Distribution, seasonal movements, and migration
	Specimens • Individual weight, size, sex, maturity • Condition • Stomachs • Stable isotopes • Fatty acids • Population genetics • Otoliths • Gonads	• Size, condition • Diet • Demography • Population genetics • Key life history features • Origins and migration patterns
Longline fishing	Catch • Species • number/hook • kg/hook	• Abundance, biomass, trends • Distribution, seasonal movements, and migration
	Specimens • Individual weight, size, sex, maturity • Condition • Stomachs • Stable isotopes • Fatty acids • Population genetics • Otoliths • Gonads	• Size, condition • Diet • Population structure • Population genetics • Key life history features • Origins and migration patterns
Hydroacoustics	• Nautical Area Scattering Coefficient (NASC) • Target strength (TS) • Species groups	• Abundance, biomass, trends • Distribution, seasonal movements, and migration
Optical recordings	• Species • number/m^2 • kg/m^2	• Abundance, biomass, trends • Distribution, seasonal movements, and migration
Environmental DNA	• Species (presence)	• Stock identification and population genetics
Cores	• Sediment otoliths	• Stock identification and population genetics

Appendix 1: JPSRM Standard Methods – fish species

Table1- 2. Methods for collecting data on benthic fish

Gear	Priority species/ Ecosystem components	Data collected	Priority parameters
Bottom trawls • Small-mesh beam trawl • Large-mesh otter trawl	Epibenthic invertebrates • Bivalves • Crustaceans • Snow crab Benthic fish • Arctic cod • Pacific cod • Walleye pollock • Greenland turbot/halibut • Yellowfin sole • Bering flounder • Atlantic cod • Redfish Ecological linkages	Trawl • Area swept Catch • Species • number/km^2 • kg/km^2	Abundance, biomass, trends Distribution Pelagic-benthic coupling
		Specimens • Individual weight, size, sex, maturity • Condition • Stomachs • Stable isotopes • Lipids • Fatty acids • Population genetics • Otoliths • Gonads	Size, condition Diet Demography Population genetics Key life history features Origins and migration patterns
Longlines	Benthic fish • Greenland turbot/halibut • Pacific cod • Redfish Ecological linkages	Skate • Effort: effective hooks/skate Catch • Species • Catch-per-unit-effort (number, kg)	Abundance, biomass, trends Distribution Pelagic-benthic coupling
		Specimens • Individual length, weight, sex, maturity • Condition • Stomachs • Stable isotopes • Lipids • Fatty acids • Population genetics • Otoliths • Gonads	Size, condition Diet Population structure Population genetics Key life history features Origins and migration pattern
Box core	Benthic fish	Otoliths Species	Distribution

2. Longlines

Longline fishing has proven to be a reliable tool to identify presence of pelagic species in the Central Arctic Ocean (Snoeijs-Leijonmalm et al., 2022). It should be used only when targets with strong backscatter are observed on the ship's echosounder. This method targets single individual of large predatory fish such as e.g., Atlantic cod (Snoeijs-Leijonmalm et al., 2022).

Longlines would also be well-suited to sample benthic fish in relatively deep waters of the continental slope (500 to 1,000 m) and on substrates that are irregular and/or vulnerable to bottom trawls (Fossen et al., 2008). Thus, integration of information from longlines and other gears such as bottom trawls would together provide comprehensive information on species distribution and abundance. Detailed longline methods are found in (Fossen et al., 2008; Sigler and Lunsford, 1997; Siwicke and Malecha, 2022). Longlines would best be deployed from a survey vessel in open water. The basic unit of survey gear is termed a skate. For the US Alaska sablefish survey, a skate consists of 100-m (55-fm) of line with 45 hooks spaced 2-m (6.5-ft) apart and baited with squid or other forage. A longline set consists of 80 skates with weights between each skate. Catch-per-unit effort is the number of fish caught divided by the number of effective hooks per skate (hooks that are not damaged or predated by cetaceans).

Catch biomass can be estimated by converting numbers caught to weight using species-specific length-weight relationships when length data are collected or proxy average weights from longline fisheries when survey length data are not available. Specimens can be collected for a wide variety of measurements (see Table 3-3 in the Benthos and Benthic Habitat section of the "Standard Methods for Other Taxa from Key Trophic Levels" – Appendix 3 – for a recommended list).

It should be noted that longlines function by attracting fish to bait, hence there is a strong selection for predatory and scavenging species. Furthermore, longlines are size-selective, dependent on factors such as bait and hook sizes, bait quality, etc.

3. Hydroacoustics

Hydro acoustical data should be obtained from a vessel-mounted echosounder dedicated to pelagic fish and zooplankton targets. Transducers should be at least 38 kHz (standard for fish), 18 kHz (deeper signals possible) and 200 kHz (standard for mesozooplankton). The echosounder must be calibrated according to standard procedures (Foote, 1983).

Only data from periods when the ship is moving through open water or being stationary and/or drifting within the sea ice, are to be used due to mechanical noise when the vessel is moving through sea ice. When moving through the sea ice, it is useful to make regular stops, and collect good acoustic data for 10 minutes (e.g., every second hour).

Hydro acoustical data could also be collected during open water or ice camps, using mounted/deployed echosounders. It is also recommended to have acoustic equipment on the CTD, like e.g., WBAT 200 or 333 kHz (for zooplankton) and WBAT 38 kHz (for fish, if no ship-mounted echosounder is available). More information on use of WBAT on the CTD can be found in (Snoeijs-Leijonmalm et al., 2023).

Appendix 1: JPSRM Standard Methods – fish species

To assist in interpreting the hydro acoustic data, biological or video sampling should be conducted.

4. Optical recordings

Deep-sea cameras or video systems focusing on fish observations could be used for species identification if biological sampling is not possible. Expertise on the methodology will likely have to be built during the first phase of the sampling. Such sampling (FishCam, MacArtney Germany GmbH, Kiel, Germany) was proved valuable in the Central Arctic Ocean during the MOSAiC Expedition (Snoeijs-Leijonmalm et al., 2022).

5. Environmental DNA (eDNA)

The analysis of extra-organismal environmental DNA (eDNA) can assist in achieving research, management, and conservation objectives for fisheries (Ramírez-Amaro et al., 2022). Recently, this method has also been tested within the Arctic Ocean (Snoeijs-Leijonmalm et al., 2023; Westgaard et al., 2024).

6. Box-core sediment otoliths

Deep-sea sediment otoliths can provide useful data for the JPSRM. A description of the method and use can be found in (Snoeijs-Leijonmalm et al., 2023). The samples can indicate which species have dominated in a specific area in the past and show which species have invaded the area recently. Sampling of deep-sea sediments can be performed during dedicated ecosystem expeditions to the CAO, but also on e.g., geological surveys with no or very limited biological sampling. Furthermore, the geological research institutions of the CAOFA parties likely host a wealth of sediment samples with otoliths that could be used to significantly extend the knowledge on past and present fish distributions in the Arctic Ocean (Snoeijs-Leijonmalm et al., 2023).

Fish sampling methods adapted to the Agreement Area need to be developed further during the mapping phase. Methods need to be evaluated to ensure that vulnerable habitats are not damaged in the long term. Recent surveys have found very low abundance of mesopelagic fishes due to the low productivity of the ecosystem 14, 15; therefore, the sampling effort required to collect specimens is expected to be higher than in comparable surveys in subarctic or temperate waters. In the Eurasian Basin, long-line fishing seemed to be only successful for larger predatory fish species >30-40 cm, while small mesopelagic fish species could not be caught by line-fishing, gill nets, ring nets or traps. On the echosounder, the few fish that occur have been seen fleeing any sampling gear that is lowered in the water column (which proves that fish are present but difficult to sample). Trawling with ice-modified trawls has been successful11; the results have reaffirmed the low densities encountered by previous expeditions. Despite these challenges, the use of multiple fishing gears is encouraged in order to capture as diverse a range of fish samples as possible. In particular, sampling of sympagic fishes (ice-associated polar cod juveniles) in the Agreement Area is possible using a special-designed "Surface- and Under-Ice

Trawl (SUIT) 12 that has proven successful at sampling sympagic fishes under ice cover. Benthic fishes observed in the central Arctic Ocean consist of non- commercial species, except for Greenland halibut (*Reinhardtius hippoglossoides*) of which single (juvenile) specimens have been encountered in the southern part of the Agreement Area during two sampling events. Although bottom trawling can be very disruptive to benthic habitats and should be avoided in sensitive benthic areas such as locations with concentrations of corals and sponges, trawls conducted for scientific purposes corresponding to the JPSRM will be allowed if precautionary measures are taken before trawl operation. Prior to using benthic trawls and other disruptive sampling methods the benthic habitat should be examined using non-disruptive methods such as drop cameras, near-bottom video sleds or ROVs to determine if the area represents a sensitive benthic area. For efficiency forward- looking trawl-mounted cameras could be used if they allow live-video that can be viewed by the captain that provides observation of the seafloor sufficiently far ahead of the sampling gear to allow the captain to abort deployment before the gear makes contact with the seafloor. In addition, benthos, particularly macrobenthos, play an important role in ecosystem functioning and processes. Benthic standing stocks may support key benthic-feeding apex predators, including Pacific walrus (*Odobenus rosmarus divergens*), gray whales (*Eschrichtius robustus*), and bearded seals (*Erignathus barbatu*), thus functioning as a crucial component in the Arctic food-web. Therefore, full considerations should be given to sampling of various benthic invertebrates using box corers or alternate methods.

The methods recommended below are largely based on US surveys in the Northern Bering-Chukchi seas shelves (Baker et al., 2020; Moore and Grebmeier, 2018; Mueter et al., 2017) and the Barents Sea shelf north of Svalbard (Engås and Ona, 1987), so their utility for a CAO survey will need to be tested in pilot projects. The recommended locations for sampling with these methods are shelf areas such as the Chukchi Borderlands, except for cores and longlines, which can be deployed at deeper waters of the slope and basin.

7. Specimen sampling

In addition to sampling the catch, specimens should be preserved (frozen, in ethanol or formalin) for subsequent laboratory analyses (see Appendices 2 and 4 for a list of recommended specimen analyses).

- Individual weight, size (Dougherty et al., 2010). A random sample of up to 150 would typically be measured. With small caches all individuals should be identified and measured. The measured individuals may be preserved for other studies, if requested.

- Lipids and fatty acids (Copeman et al., 2022). Specimens should be sorted from the catch, immediately placed on ice, and then frozen at < −20 ◦C within 6 h of capture. Total lipids and lipid classes can be determined using thin layer chromatography. Total fatty acids would be expressed in relation to whole wet weight (g) to give an index of total acyl lipid storage.

- Condition (Cooper et al., 2023). Individuals collected for condition should be frozen immediately at −20 ◦C and maintained at −80 ◦C at the land-based laboratory and dissected within 6 months of capture. Regressions between log10 (standard length) and log10 (whole wet weight) as well as log10 (standard length) and fatty acid concentrations (mg/g) would be run as indices of morphometric- and lipid-based condition, respectively.

Appendix 1: JPSRM Standard Methods – fish species

- Stomachs (Lamb and Kimmel, 2021). A length-stratified sample of around 25 individuals of differing sizes fish (1 stomach per 5 cm length group for large fish (e.g. cod) and 1-2 cm for small fish), or all individuals from small caches, should be flash frozen in a –80°C freezer and then moved to a –20°C freezer for later diet analysis in the laboratory. It is recommended to use prey-accumulation curves to determine the appropriate number of fish stomachs to analyze per station. Frozen fish selected from each station for stomach contents analysis should be thawed, blotted dry, measured to the nearest 1-mm SL (or total length, as appropriate), and weighed to the nearest 1 mg. All stomachs should then be excised from the fish and placed into vials with a sodium borate-buffered 5% formalin solution. The excised gut should be blotted dry, weighed to the nearest 0.01 mg, and then dissected to determine prey contents. All gut contents should then be identified to the lowest taxonomic level possible and then organized by taxa levels, life-history stage (if possible), and level of digestion. Each prey taxa group should be enumerated, length measured as appropriate, dried (or weighed wet as appropriate), and weighed separately to the nearest 0.01 mg.

- Stable isotopes, bulk and compound-specific (Goldstein et al., 2023). Samples collected at sea should be frozen at -80 °C. In the laboratory, tissues should be dried at 50 °C until a stable weight is maintained. Compound-specific stable isotope analysis requires more tissue than bulk. For bulk analysis, tissues should analyzed with an elemental analyzer in line with an isotope ratio mass spectrometer. Compound specific samples should be prepared with a chloroformate-based method for amino-acid derivatization and analyses should be performed with a gas chromatograph coupled to an isotope ratio mass spectrometer via a combustion interface.

- Population genetics (Crawford and Oleksiak, 2016; Selkoe et al., 2008; Wildes et al., 2022). Specimens should be frozen whole at sea at −80 °C. Microsatellite markers and mtDNA can be developed to be diagnostic for the species of interest. Initial sampling can occur on scales of 100s to 1000s of km. If genetic population structure is found, sampling can be refined. But in general for marine organisms structure is rare on scales < 100 km. 50 samples per sample site is a good initial sampling effort. Some preservation methods include dried DNA from fin clips (for fish), or tissue stored in ethanol or another buffer that can preserve DNA. If a reference genome is available and the genome is relatively small, whole genome sequencing is recommended. Otherwise, restriction-site associated DNA (RAD) sequencing would be good approach. These approaches will result in thousands to millions of markers to work with for population genetic analysis.

- Otoliths (Chapman et al., 2023). To estimate ages of fish, sagittal otoliths should be examined for daily growth increments. After measuring standard lengths, the sagittal otoliths would be removed under a dissecting microscope with fine-tipped forceps. The otoliths would be imaged, where each visible ring is assumed to represent one day of growth. Hatch marks can be identified and validated using otoliths of lab-reared, known-age fish. To ensure accuracy of otolith aging, all sampled otoliths should be aged at least twice and a third time if the first two ages are not within a 5% coefficient of variation (CV). A subsample of the aged otoliths should be examined by a second otolith aging expert to confirm that the images, measurements and ages have no errors.

Appendix 1: JPSRM Standard Methods – fish species

- Gonads (Stark, 2007). Seasonal sampling is recommended to estimate the time of spawning, rate of ovary development, and length- and age-at-maturity. Collected ovaries should be stored in a solution of 4% buffered formaldehyde. Oocytes within each ovary should be classified into histological stages based on previously published criteria. Ovarian development should then be compared across months, by tabulating the proportion of fish classified within each of the five histological stages only for females that had reached the minimum total body length (LT) at maturity, as determined by a length-at-maturity analysis. Maturity as a function of length can be estimated by fitting a logistic function to the maturity data with generalized linear modeling (note that maturity scales have already been developed for many species (e.g., cod, Greenland halibut, redfish). In addition, a gonadosomatic index (IG) can be calculated from the specimens sampled for maturity as the ratio of gonad weight (WG) to body weight (W) with the gonads removed (IG=100 WG/W).

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APPENDIX 2: JPSRM Standard Methods – Marine mammal and seabird species

CAOFA JPSRM Standard Methods for Collecting Scientific Data

-- Marine Mammal and Seabird Species --

Central Arctic Ocean Fisheries Agreement (CAOFA)
Scientific Coordinating Group (SCG)

Methods for collecting scientific data on marine mammals and seabirds can vary considerably depending on the specific data needs, required confidence levels, logistic constraints, and seasonal aspects of the animals being studied and their environment. Given that different research teams from various national programs will be involved in collecting priority information, it is important that some key protocols or methodological standards be established in advance of JPSRM field surveys. Establishing "standard methods" will add power to JPSRM efforts by facilitating the comparison, linking, and sharing of data sets among JPSRM collaborators and conducting joint data analyses and modeling.

Table 2-1 summarizes some of the JPSRM "standard methods" that could be used to collect data on priority parameters of marine mammals and seabirds. Specific protocols describing JPSRM "standard methods" for key measurements such standard methods should be developed and drafted by subject matter experts of the MM-WG to guide key JPSRM data collection for marine mammals and seabirds. Brief preliminary descriptions are presented below for some of the methods likely to be used for JPSRM marine mammal and seabird research:

1. Ship and small boat surveys (as research platforms)

Vessel-based surveys allow scientists to obtain data on marine mammals and their environment. A large vessel provides a viewing platform high above the water line that is ideal for conducting visual line-transect surveys for abundance and density estimation. They also often have the capability of deploying passive acoustic instrumentation, conducting CTD casts for oceanographic data, and deploying zooplankton nets to collect marine mammal prey data. These surveys allow for integrative multivariate data collection from one platform that can be used for ecosystem-wide analyses. Small boat surveys are best suited for work requiring close approaches to marine mammals, given the boats' small size, fast speeds, and maneuverability. Small boats are most often used for collecting photo-ID photographs, collecting skin, tissue, or fecal samples from an individual, as well as deploying satellite tags, all of which require getting close to an animal.

2. Crewed and uncrewed (i.e., drones) aerial surveys (as research platforms)

Aerial platforms are used to collect information on marine mammal and seabird distribution, habitat use, abundance, unique individuals in populations (photo-identification), and body condition (photogrammetry). Survey platforms range from airplanes and helicopters crewed with teams of observers to uncrewed drones operated remotely, typically flown within line of sight of the pilot. These platforms may also be equipped with still or video cameras and thermal sensors to detect and record individuals. Surveys are designed to collect information "on effort" (e.g., tracklines completed, area surveyed), animal location and behavior, weather and visual conditions, and platform altitude and speed.

3. Passive acoustics

Collecting marine mammal passive acoustic data consists of short-term, real-time monitoring using sonobuoys, or long-term, year-round monitoring using autonomous recorders anchored to the ocean floor. Sonobuoys are free-floating, passive listening devices deployed by hand over the side of a vessel. They transmit audio signals in real time back to a receiver on a vessel, allowing scientists to listen in real time for marine mammal sounds. These instruments also provide bearing information, allowing for triangulation of calling whales to assist in locating target species. Long-term moorings record data to an internal hard drive. These instruments remain deployed for a full year of recording data, are retrieved the following year, and are analyzed for the presence of marine mammal sounds and anthropogenic signals.

4. Visual observations

Visual line-transect surveys consist of marine mammal observers looking for and identifying marine mammals from a vessel or aircraft along pre-determined tracklines. Observers use 25x big-eye binoculars or handheld binoculars and report the bearing and distance to a sighting, as well as species and group size. These sighting data allow for obtaining density and abundance estimates of marine mammals, which are essential for effective management. Opportunistic visual observations (i.e., not during dedicated marine mammal surveys), while not suitable for obtaining density or abundance estimates, can be helpful in reporting unusual sightings (e.g., rare species, unexpected behaviors, carcasses), and are often useful sources of sighting information during periods when dedicated vessel surveys are not occurring.

5. Photography, photo identification, and photogrammetry

Marine mammal scientists use high resolution photographs to identify individual cetaceans (whales and dolphins) or pinnipeds using natural markings such as coloration patterns, scratches, scars, and other identifiable markings. Matched photographs are organized into catalogs of individuals with sightings histories that are used for examining movements of individuals, and for estimating abundance or survival through mark-recapture analyses. Lateral identification photographs are collected from boats or from land, and overhead photographs can be collected from uncrewed aerial systems, planes, or helicopters. Photogrammetry uses photographs to measure the length, girth, and volume of cetaceans and pinnipeds, in order to monitor the growth and body condition of individuals.

6. Satellite imagery

Earth-orbiting satellites have the ability to capture optical imagery over any region on the planet. Technical advances in recent decades have resulted in great advances in both the image resolution as well as frequency of images being collected. Tremendous progress has been made, resulting in the ability to use VHR satellite imagery to collect data on the abundance, distribution, density, and habitat use of marine mammals such as large whales. Incorporating advances in cloud computing and machine learning into analyses of satellite imagery may open new opportunities to monitor marine mammals in the JPSRM study area.

7. Satellite telemetry

The use of satellite telemetry to collect movement and behavior information on vertebrate species continues to evolve in complexity, capability, and attachment methods. Researchers are able to use orbiting satellites to track and summarize data collected from externally-mounted transmitters attached to animals. This technique is especially useful for far-ranging marine mammals and seabirds as it can remotely collect location and behavior data from anywhere in the world as well as oceanographic information from sensors imbedded in the instruments. Field methods involve temporarily attaching a transmitter that may last up to several years. Large whales can be tagged by simply using a long pole to place the transmitter.

8. Subsistence harvest sampling

Arctic Indigenous peoples rely on the subsistence harvest of marine mammals and seabirds as a primary food source. In support of the JPSRM, there may be opportunities for collaboration by researchers and Indigenous hunters to coordinate the collection of tissue samples from the harvested animals. Access to healthy, often prime-age samples, provides a unique opportunity to obtain specimen material for research purposes. Such samples can be used for studies of population genetics, diet, and health and condition. Collaboration should be closely coordinated to ensure that sampling does not adversely impact subsistence hunting.

9. Tissue sampling

The collection of biological samples from marine mammals and seabirds is a critical component to understanding the ecology of species and their local environment. A variety of samples (e.g., skin, blubber, blood, other tissue, feces) can be collected from live animals and used to investigate genetics, isotopic status, disease prevalence and exposure, contaminant loads, blood chemistry, and to inform long-term monitoring of biological changes in populations. The methods used for collecting and preserving samples are specific to the research questions but usually follow basic veterinary practices. Archived samples can be stored for years.

APPENDIX 2: JPSRM Standard Methods – Marine mammal and seabird species

Table 2-1. Methods for collecting data on marine mammals and seabirds, data to be collected, and parameters to be addressed.

Collection method	Data collected	Priority parameters
Ship surveys ● Visual observations ● Photo-identification ● Photogrammetry ● Passive acoustics ○ Sonobuoys ○ Towed arrays ● Tissue sampling ● Satellite telemetry (tagging)	● Species, number, behavior ● Distribution, location, habitat use ● Seasonal movements, habitat use ● Size, demography ● Photo-identification ● Health & condition ● Genetics, stock identification ● Foraging behavior ● Diet	● Abundance, biomass, and trends ● Distribution, seasonal movements, and migration ● Size, condition, and demography ● Diet ● Stock identification and population genetics ● Key life history features ● Timing and schedule (e.g., seasonality, trends)
Aerial surveys (crewed) ● Visual observations ● Photographic/photogrammetry	● Species, number ● Distribution, location, habitat use ● Seasonal movements, habitat use ● Size, demography ● Health & condition ● Photo-identification	● Abundance, biomass, and trends ● Distribution, seasonal movements, and migration ● Size, condition, and demography ● Timing and schedule (e.g., seasonality, trends)
Uncrewed aerial systems (UAS) ● Photographic/photogrammetry ● Multispectral imagery	● Species, number ● Distribution, location, habitat use ● Seasonal movements, habitat use ● Size, demography ● Health & condition	● Abundance, biomass, and trends ● Distribution, seasonal movements, and migration ● Size, condition, and demography
Satellite imagery ● Photographic ● Multispectral imagery	● Species ● Distribution, location, habitat use ● Seasonal movements, habitat use	● Distribution, seasonal movements, and migration
Moored passive acoustics	● Species presence, behavior ● Seasonal distribution	● Distribution, seasonal movements, and migration ● Timing and schedule (e.g., seasonality, trends)
Harvest sampling	● Species ● Distribution, location, habitat use ● Size, demography ● Health & condition ● Genetics, stock identification ● Diet	● Distribution, seasonal movements, and migration ● Size, condition, and demography ● Diet ● Stock identification and population genetics ● Key life history features ● Timing and schedule (e.g., seasonality, trends)
eDNA	● Species ● Distribution, location ● Genetics, stock identification ● Seasonal movements	● Distribution, seasonal movements, and migration ● Stock identification and population genetics ● Timing and schedule (e.g., seasonality, trends)

10. eDNA

The field of environmental DNA research is rapidly increasing. Environmental DNA can be collected from multiple types of environmental samples (e.g., fresh or seawater, soil, air) rather than specifically taken from a single organism. Individual organisms shed their DNA into their environment continually. This means that a single sample of eDNA has the potential of having the DNA representative of numerous individuals of multiple species. Samples can serve as a snapshot of the distribution and perhaps abundance of species in local environments. As newer methods of collection, DNA sequencing, and preservation are developed, this technique will likely become even more cost-effective.

CAOFA JPSRM Standard Methods for Collecting Scientific Data

-- Other taxa from key trophic levels --

Central Arctic Ocean Fisheries Agreement (CAOFA)
Scientific Coordinating Group (SCG)

1. Sea ice habitats

Table 3-1 summarizes the methods for collecting data on and under sea ice. The table lists the instrument or method, the priority species or ecosystem components targeted, the data collected and the relevant priority parameters. Priority parameters are ecological linkages and seasonality.

1.1. Satellites

Satellite remote-sensing can be a useful tool for collecting a variety of data related to sea ice at broad spatial scales throughout the year. Parameters that can be acquired or calculated include ice extent, average ice concentration and dates of formation and retreat. Monthly and daily sea ice concentration data at a spatial resolution of 25 x 25 km in GeoTIFF and ASCII file formats can be downloaded from the National Snow and Ice Data Center (https://nsidc.org/data/g02135/versions/3). Temporal coverage of these products is 26 October 1978 to present. Spatial coverage is N:-39.23° to S:-90°, E:180° to W:-180°; and N:90° to S:30.98°, E:180° to W:-180°. In addition to raw data, sea ice extent and concentration images in PNG format can be downloaded that depict trends and anomalies calculated using a 30-year reference period of 1981 – 2010.

NOAA's Polar Watch is also a good source of a variety of satellite data (https://polarwatch.noaa.gov/).

1.2. Buoys

The International Arctic Buoy Program (IABP, https://iabp.apl.uw.edu/index.html) provides a good example of the kinds of measurements that can be taken with instruments deployed on a network of buoys. The network of drifting buoys in the Arctic Ocean provides ice, meteorological and oceanographic data for real-time operational requirements and research projects. Currently, IABP maintains 200 reporting buoys in the Arctic Ocean. Most of the buoys are placed on sea ice, but some are placed in open water as well. These buoys have an average life-span of 18 months. Real time data and data products are available to download from the IABP webpage.

The following describes instruments and methods that can be used on an ice-breaker survey, such as the MOSAiC project (https://mosaic-expedition.org/).

1.3. Ship radar

An ice-breaker vessel's radar can be used to assess floe size distribution.

1.4. Ice cores

Ice cores can be taken at ice stations occupied during the survey. Ice cores can be sectioned and analyzed in shipboard laboratories for a variety of data relating to the physical, chemical and biological characteristics of the ice, including nutrients, primary productivity and plankton biomass (see Table 3-1 Sea ice Methods).

Table 3-1. Methods for collecting data on sea ice habitat and biota.

Instrument/method	Priority species/ Ecosystem components	Data collected	Priority parameter(s)
Satellite	• Sea ice habitat	• Ice extent • Average ice concentration • Date of formation and retreat	• Ecological linkages • Seasonality
Buoys	• Sea ice habitat • Water column properties	• Sea level pressure • Surface air temperature • Sea ice motion • Snow depth • Sea ice thickness • Sea ice temperatures • Ocean temperatures and salinities	• Ecological linkages • Physical oceanography
Ship radar	• Sea ice habitat	• Floe size distribution	• Ecological linkages
Ice core	• Sea ice habitat and biota	• Nutrient concentrations • Particle size spectra and concentration • C uptake and O release • Primary Productivity • Bacterial productivity • Plankton biomass	• Ecological linkages
AUV	• Sea ice habitat	• Upward-looking bathymetric multi-beam sonar • Spectral radiometer	• Ecological linkages • Physical oceanography
Airborne	• Sea ice habitat	• Ice thickness • Surface topography • Visable and IR imagery • Microwave properties	• Ecological linkages

1.5. Autonomous Underwater Vehicle (AUV)

AUVs can be deployed from the vessel to sail under the ice and collect information on sea ice habitat. The AUV can be mounted with an upward-looking bathymetric multi-beam sonar to map sea ice bottom topography. A spectral radiometer can be used to characterize the spatial variability of the light climate under sea ice.

1.6. Airborne platforms

Flying craft such as helicopters can deploy from the ship to measure ice thickness, surface topography, visible and infrared imagery, and microwave properties.

2. Plankton

Table 3-2 summarizes the methods for collecting data on plankton and water column properties together because the two types of information are typically co-collected. The table lists the instrument, the priority species or ecosystem components targeted, the data collected and the relevant priority parameters. Some of the recommendation below are based on U.S. surveys in the Northern Bering-Chukchi seas shelves such as the Distributed Biological Observatory (https://www.pmel.noaa.gov/dbo/), so their utility for a CAO survey will need to be tested in pilot projects. Other recommendations are based on ice-breaker surveys, both embedded (MOSAiC https://mosaic-expedition.org/) and cruising (SAS https://synopticarcticsurvey.w.uib.no/; (Mueter et al., 2019)).

2.1. Satellites

Satellite remote-sensing can assess phytoplankton biomass and provide information on physical oceanography. Data collected by satellites include ocean color and sea surface temperature. NOAA’s Hermes GlobColour (http://hermes.acri.fr/, (Maritorena et al., 2010)) is a standardized merged Chl-a product, combining remote sensing data from SeaWiFS, MERIS, MODIS, VIIRS and OLCI. Sea surface temperature data (C°, 5 km-resolution) are available at https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html. In addition, NOAA’s Polar Watch is a good source of a variety of satellite data (https://polarwatch.noaa.gov/).

2.2. CTD with Niskin bottles

Conductivity-temperature-depth probes with water-collecting Niskin bottles can be used to measure a large number of physical and biological variables in the ocean, including phytoplankton, microzooplankton, temperature, salinity and many more (summarized in Table 3-2 Plankton Methods). Note that effective use of eDNA sampling will require developing a robust protocol to collect eDNA samples and ground truth it with genetics from specimens collected in the net samples. A CTD with bottles (a.k.a. a rosette) can be deployed from vessels in open water and through a hole at ice stations.

2.3. Sea chest

Ship-board sea chests can take continuous measurements of physical and biological variables such as temperature, salinity and chlorophyll fluorescence. They thus can provide valuable information to interpolate between stations data collected with other instruments, such as the CTD with bottles.

Table 3-2. Methods for collecting data on plankton and oceanography.

Instrument	Priority species/ Ecosystem components	Data collected	Priority parameters
Satellite	Phytoplankton Ecological linkages	Ocean color Sea surface temperature	Biomass, trends Distribution Biological oceanography
CTD with Niskin bottles	Phytoplankton Microzooplankton Ecological linkages	Pressure (depth) Temperature Salinity Fluorescence PAR Dissolved O Nutrients Dissolved Inorganic C Total Alkalinity pH $\delta^{18}O$ of H_2O Methane DOC POC Chlorophyll Primary production (incubations) Viruses Bacteria Phytoplankton size composition Microzooplankton eDNA	Biomass, trends Distribution Biological oceanography Physical oceanography
Sea chest (continuous)	Phytoplankton Ecological linkages	Temperature Salinity Fluorescence Nitrate	Biomass, trends Distribution Biological oceanography Physical oceanography
ADCP	Ecological linkages	Current speed and direction	Physical oceanography
Echosounders	Mesozooplankton	Backscattering	Biomass, trends Distribution
Flow cytometry ● Shipboard (continuous) ● Moored	Phytoplankton Microzooplankton Heterotrophic bacteria Viruses	Number/mL Biomass Growth Nutrient acquisition POM, DOM	Biomass, trends Distribution Biological oceanography Seasonality
Flow cam (continuous)	Phytoplankton	Species Number/mL Size	Biomass, trends Distribution Biological oceanography
Moorings	Ecological linkages	Temperature Salinity Fluorescence Currents (ADCP) Oxygen Nitrate PAR	Biological oceanography Physical oceanography Seasonality

		Sea ice cover eDNA	
Plankton nets ● Bongo ● Ring ● Multi-net ● Methot ● CalVET ● Tucker trawl (epibenthic sled)	Mesozooplankton Ichthyoplankton	Tow ● Volume sampled Catch ● Species ● Number/m^3 ● g/m^3	Abundance, biomass, trends Distribution
		Specimens ● Fatty acids ● Lipids ● Stable isotopes ● Genetics ● Production	Condition Diet Population genetics Key life history features
Zooplankton imaging	Zooplankton	Species Number/mL Biovolume/mL Size	Abundance, biomass, trends Distribution

2.4. Acoustic doppler current profiler (ADCP)

Shipboard ADCP can measure current speed and direction which can be a key physical oceanographic parameter for understanding ecosystem drivers and linkages. ADCP data can also give information on zooplankton abundance (e.g., Fielding et al., 2004).

2.5. Echosounders

Echosounders can be used for acoustic detection and quantification of zooplankton distribution and abundance (Ressler et al., 2012). Published methods are for surveys in the Bering Sea and the applicability for surveys in the Arctic needs to be established. They are especially effective for surveying large, fast-swimming species that are difficult to sample in a quantitative way with plankton nets, such as euphausiids. Backscattering data should be converted to biomass density with known target strength parameters. Verification tows with larger pelagic nets, such as the Methot net are recommended.

2.6. Flow cytometry

Flow cytometers can be deployed on ships for continuous measurements; or deployed on moorings for seasonal and interannual data. Flow cytometry can measure a number of parameters of phytoplankton, microzooplankton, heterotrophic bacteria and viruses. See Table 3-2 for a list of data collected.

2.7. Flow cam

Flow cams can be deployed on a ship's flow-through sea-water systems for continuous measurements. They use imaging technology to assess the species, number and size of phytoplankton. Imaging Flow Cytobots combine the functionalities of flow cytometry and flow cams.

2.8. Moorings

Moorings of various designs, sizes, and capabilities can be essential tools for collecting ocean observations in both ice-free and ice-covered seasons/areas. They include a variety of instrumentation and incorporate new and developing technology. (Stabeno et al., 2023) reviews the evolution of long-term biophysical moorings in high-latitude seas. In addition to the standard oceanographic variables (temperature, salinity, chlorophyll fluorescence and currents (measured at multiple depths)), meteorological instruments can be deployed during the ice-free summer, CO2 sensors can be incorporated and other instruments can be added to measure dissolved oxygen, nitrate, passive acoustics, PAR, carbon parameters and eDNA. Other modernizations of mooring design include the Prawler which can provide near-continuous profiles of temperature, salinity, fluorescence and oxygen. The newest design, the RISE mooring (Refloating Ice Sensing), is a Prawler-type mooring that sinks with the arrival of sea ice and refloats the following spring with ice retreat. Some of these instruments can also be deployed on autonomous vehicles, such as gliders or sail drones which can interpolate observations between moorings and stations.

2.9. Plankton nets

Plankton nets can be used to sample zooplankton and ichthyoplankton throughout the water column. They can be deployed from ships in open water or through holes at ice stations. In open water nets such as the bongo and Methot should be towed obliquely at slow speeds (a few knots). Multi-nets have multiple nets that can be triggered to sample at discrete depths. Tucker trawls can target zooplankton near the seafloor. CalVET nets can target smaller species; bongo, ring and multi-nets can target intermediate species; and Methot and Tucker trawls can target the largest species, such as euphausiids. Large ring nets (e.g., 1 m2 mouth area) and CalVET nets can be effective at conducting vertical tows through the ice.

2.10. Zooplankton imaging

Imaging systems such as the PlanktonScope (Bi et al., 2022), Plankton Imager (Pitois et al., 2021) and others (Campbell et al., 2020; Corgnati et al., 2016) can be deployed on vessels to identify and collect data on the number, size and biovolume of zooplankton. They can also be deployed on buoys (Li et al., 2022) or autonomous vehicles (the Zooglider, (Ohman et al., 2019)). Machine-learning algorithms can streamline the identification and quantification of zooplankton in images collected (Culverhouse et al., 2006; Maps et al., 2023; Uusitalo et al., 2016).

3. Benthos and benthic habitat

Table 3-3 summarizes the methods for collecting data on the benthos: epibenthic and infaunal invertebrates and fish; and benthic habitat (sediments). It lists the gear, the priority species or ecosystem components targeted, the data collected and the relevant priority parameters. Understanding ecological linkages is gained by assessing the physical and biological characteristics of sediments, an important component of benthic habitat.

3.1. Grabs and cores

Grabs sample sediments and infaunal invertebrates and would be most effective at 500 m water depth or less. A 0.1m2 van Veen grab is commonly used and can be deployed with the ship's winch in open water or in a hole created by the ship. Cores sample sediments at depths up to 4000 m or greater and can be deployed from a ship. A multi- and single-HAPS benthic corer (133 cm2; Kanneworff and Nicolaisen, 1973), is recommended. Smaller grabs and cores can also be deployed through a hole at an ice station using a portable winch.

Table 3-3. Methods for collecting data on benthos and benthic habitats

Gear	Priority species/ Ecosystem components	Data collected	Priority parameters
Bottom trawls • Small-mesh beam trawl • Large-mesh otter trawl	Epibenthic invertebrates • Bivalves • Crustaceans • Polychaetes • Snow crab Ecological linkages	Trawl • Area swept Catch • Species • Number/km^2 • Kg/km^2	• Abundance, biomass, trends • Distribution • Pelagic-benthic coupling
		Specimens • Individual weight, size • Condition • Stomachs • Stable isotopes • Lipids • Fatty acids • Population genetics • Otoliths • Gonads	• Size, condition • Diet • Population genetics • Key life history features • Origins and migration patterns
Grabs	Infanual invertebrates • Bivalves • Crustaceans • Polychaetes	Catch • Species • number/m^2 • gww/m^2	• Abundance, biomass, trends • Distribution • Pelagic-benthic coupling
	Ecological linkages	Sediment • Grain size • Total organic C, N • Organic C-N ratios • Chlorophyll • Fatty acids • Stable C isotopes	• Benthic habitat
Cores	Ecological linkages	Sediment • Grain size • Total organic C, N • Organic C-N ratios • Stable C, N isotopes • Fatty acids • Biogeochemisty • Dissolved O • Respiration • Chlorophyll a	• Benthic habitat • Pelagic-benthic coupling
Sediment traps	Ecological linkages	Flux • Total biomass • Carbonate • Organic C • N flux • Silicate • Phosporous • Stable isotopes of organic C, N • Pigments	• Benthic habitat • Pelagic-benthic coupling • Seasonality

		● Lipids ● Microfossils (foraminifera and diatoms) ● Sea-ice diatom biomarkers	

Numerical density and wet weight density would be derived from the grab samples. Grabs and cores both sample sediments which would be subsequently analyzed for grain size and other biological and biogeochemical parameters (see Table 3-3 Benthos Methods for a list of recommended measurements).

3.2. Sediment traps

Sediment traps measure flux of material from the pelagic to the benthos and would thus be key for assessing pelagic-benthic coupling (Lalande et al., 2020). Sediment traps can be deployed on surface or sub-surface moorings in ice-covered and open waters. A 21-cup trap, open for two weeks each is recommended for a year-long deployment. Traps can be installed at multiple depths and can be deployed through the ice. Sediment traps measure the flux of a number of particles and parameters (see Table 3-3 for a list of recommended measurements).

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CAOFA JPSRM Standard Methods for Collecting Scientific Data

-- Ecological linkages and impacts --

Central Arctic Ocean Fisheries Agreement (CAOFA)
Scientific Coordinating Group (SCG)

Environmental changes in the CAO originating outside the CAO are frequently discussed in terms of borealization (e.g., Polyakov et al., 2020; see also Table 4-1). Atlantification is part of borealization that is related to progression of anomalies from the Atlantic sector of sub-Arctic seas into the Arctic Ocean. In the western Nansen Basin, inflowing Atlantic water (AW) strongly interacts with the surface mixed layer (SML) above it (Carmack et al., 2015) and weakly stratified AW there undergoes direct ventilation in winter, caused by cooling and convection associated with sea-ice formation (Ivanov et al., 2016). In the past, this winter ventilation of AW did not occur in the eastern Eurasian Basin (EB) because of strong stratification of the cold halocline layer (CHL) below the SML, but now it can be observed in the eastern EB as well, that is Atlantification (Polyakov et al., 2007). This ventilation could lead to the reduction of sea-ice thickness along the continental slope (Ivanov et al., 2012; Onarheim et al., 2014).

Atlantification in the eastern EB accompanies shoaling of the AW layer that potentially uplifts nutrient rich waters closer to the surface and may cause higher primary production, but the observed data did not necessary show the increase in nutrients in the EB halocline (Polyakov et al., 2020). Possible mechanisms of unexpected nutrient decreases in the EB halocline are such as an increased usage of nutrients in the upstream Barents Sea and reduced influences of Siberian shelf water to the halocline, although further studies are needed to elucidate the mechanisms. If the nutrient availability is enhanced in the EB as expected, primary production could increase because of the sea ice loss (improved light conditions) and the temperature increase (increase in metabolic rates) in the surface layer associated with the Atlantification. For example, a recent increase in open water period has prolonged the productive season of phytoplankton (Arrigo and van Dijken, 2015). Under-ice blooms could be enhanced due to the thinning ice cover, proliferation of melt ponds, and frequent lead formation (Arrigo et al., 2012; Assmy et al.,

Table 4-1. Summary of the environmental changes in the Central Arctic Ocean and adjacent seas. Potential increases (decreases) of environmental parameters are indicated by + (-) based on the observations described in Appendix 4.

Environmental parameters	**Atlantic side**	**Pacific side**
Sea ice	-	-
Temperature (upper ocean)	+	+
Salinity (upper ocean)	+	-
Stratification (upper ocean)	-	+
Nutrients (upper ocean)	+	-
Primary production	+	?
Fall bloom	+	+
Ocean acidification	+	+
Zooplankton (boreal species)	+	?
Fishes (boreal species)	+	+
Seabirds	+	?
Marine mammals	+	?

2017). The sea ice loss in the Arctic Ocean triggers novel fall phytoplankton blooms with a promotion of further primary production (Ardyna et al., 2014). The Arctic Report Card (Frey et al., 2022) shows that the steepest trend in primary productivity over the 2003-2022 period is found for the Eurasian Arctic (32.18 gC/m^2/yr/decade, or a ~61.5% increase).

Ocean acidification, which is caused by the absorption of anthropogenic CO_2 from the atmosphere to the ocean, may be accelerated in the EB by the Atlantification. The AW inflow area, e.g., the eastern Fram Strait and north of Svalbard, is a net annual ocean CO_2 sink, mainly caused by biological CO_2 uptake (Chierici et al., 2019), and it could increase with the sea ice loss accompanied by the atlantifcation. In addition to the biological CO_2 uptake, strong ventilation in the winter and high alkalinity of the AW also contribute to a sink for atmospheric CO_2 in the high-latitude North Atlantic, including a portion of the Arctic Ocean (Takahashi et al., 2009). Moreover, dense CO_2-rich brine rejection in winter on the shallow shelf of the Barents Sea and the dense CO_2-rich water transport to intermediate and deep layers of EB could effectively increase the carbon storage there (Chierici and Fransson, 2018). Ulfsbo et al. (2018) estimated that the increases in anthropogenic carbon storage between 1996 and 2015 in the intermediate layers of EB were 0.44-0.73 mol C m^{-2} yr^{-1} in the Nansen Basin and 0.63-1.04 mol C m^{-2} yr^{-1} in the Amundsen Basin. As a result of the increasing anthropogenic carbon storage, seawater pH decreased by 0.020-0.055 units over the last two decades (1996-2015).

Borealization is often used for climate-driven poleward shifts of living organisms such as fishes in the Barents Sea (e.g., Kortsch et al., 2015; Fossheim et al., 2015). Likewise, boreal species of zooplankton have expanded northwards, whereas Arctic species have retreated further north in the Barents Sea (e.g., Orlova et al., 2015; Eriksen et al, 2017). Zooplankton through the Fram Strait is further transported toward the east by AW boundary currents and it has been observed as far east as the East Siberian Sea, although the abundance there is much lower than that of the upstream regions (Ershova and Kosobokova, 2019). The Atlantification is likely to increase the zooplankton abundance in downstream regions of the AW boundary currents. Higher trophic level communities, such as marine mammals, may also extend their biogeographical ranges following the Atlantification and increased productivity at lower trophic levels (Haug et al., 2017). However, recent surveys in the CAO suggest that fish abundance is much lower than the level of commercial fisheries and is expected to remain so even in the future as long as the low productivity continues (Snoeijs-Leijonmalm et al., 2022).

Pacification, which is recognized as the counter part of the Atlantification, is associated with influxes of anomalous Pacific waters into the Amerasian Basin mainly via the Chukchi Sea. The Pacific waters enter the Arctic Ocean through the narrow (85 km) and shallow (50 m) Bering Strait, and transport heat, freshwater, and nutrients into the Arctic Ocean (Coachman and Aagaard, 1966; Stigebrandt, 1984; Walsh et al., 1989). The Bering Strait throughflow has been monitored by mooring observations (e.g., Woodgate et al., 2012, 2015), and it increased 50 % from 2001 (0.7 Sv) to 2011 (1.1 Sv), driving heat and freshwater flux increases. In addition, Tsukada et al. (2018) showed that the solar heating in the Chukchi Sea during summer over 1999-2015 was up to twice the northward heat flux through the Bering Strait. As a result, in the Chukchi Sea, Danielson et al. (2020) found a significant summer and fall warming of 1.4 °C from climatological data over 1922-2018 (0.14 ± 0.07 °C decade^{-1}), and over 1990-2018 the warming rate tripled to 0.43 ± 0.35 °C decade^{-1}. In the Barrow Canyon, northeastern end of the Chukchi Sea, mooring observations have been carried out since the late 1990s (Itoh et al., 2013; Williams et al., 2014), and the data indicated a significant increase in temperature of Pacific summer water (PSW) in the 2000s (~4 °C to 8°C). The PSW further spreads into the Canada Basin via the Barrow Canyon. Thus, the recent warming and freshening of the Chukchi Sea (e.g., Danielson et al., 2020) could result in increasing trends in integrated heat and freshwater content in the halocline of the Canada Basin. Timmermans et al. (2018) estimated a near doubling of ocean heat content relative to the freezing temperature in the Canada Basin halocline over the past three decades (1987–2017). A significant freshening is occurring especially in the Beaufort Gyre of the Canada Basin, as a result of freshwater accumulation accompanied by the enhancement of the gyre circulation associated with the recent loss of sea ice (Proshutinsky et al., 2009; Wang et al., 2018). Proshutinsky et al. (2019) estimated an increase of more than 6,400 km^3 of liquid freshwater content in the Beaufort Gyre from 2003 to 2018, a 40% growth relative to the climatology of the 1970s.

Enhanced Bering Strait throughflow likely transports more nutrients (Woodgate, 2018) that may help increase the primary production in the Chukchi Sea where the ice-free season is extended in recent decades (e.g., Arrigo et al., 2008). On the other hand, Yun et al. (2016) hypothesized that significant decreases of 30–50% in nutrient concentrations occurred over recent decades in the Bering Strait and the Chukchi Sea, resulting in a decrease of primary productivity that was actually estimated from in situ measurements. The loss of sea ice and the accumulation of freshwater observed in the Canada Basin cause a deepening of the nutricline and can have negative effects on primary productivity (McLaughlin and Carmack, 2010; Nishino et al., 2011b; Coupel et al. 2015). However, in this region a role of eddies in supplying nutrients laterally and maintaining phytoplankton production seems to be more important than previously (Nishino et al., 2011a; Aguilar-Islas et al., 2013; Watanabe et al., 2014; Yun et al., 2015). On the other hand, in the East Siberian Sea, the delay in fall freezing of its eastern part during the late 2000s compared with the early 2000s might have resulted in the formation of a large water mass through cooling and convection, and the spread of this water into the southern Makarov Basin may have caused shoaling of the nutricline (Nishino et al., 2013). An intrusion of Atlantic-origin cold saline water into the halocline north of the East Siberian Sea (in the southern Makarov Basin) could also shallow the nutricline during a phase of strong cyclonic atmospheric circulation over EB (Jung and Cho et al., 2021). Shelf water in the western part of the East Siberian Sea, containing high nutrient concentrations, also spreads into the central Arctic Ocean, forming a shallower nutricline than that in the Canada Basin (Alkire et al., 2019). These shallow nutriclines could convey an advantage for phytoplankton production under decreasing sea ice conditions.

The uptake of anthropogenic CO_2, river inputs and sea ice melt are factors amplifying the impact of ocean acidification on the saturation states of calcium carbonate ($CaCO_3$) minerals, Ω, and may influence the marine ecosystem in Pacific Arctic regions (e.g., Steinacher et al., 2009; Bates and Mathis, 2009; Yamamoto-Kawai et al., 2009; Mathis et al., 2011a, b). For example, in the Canada Basin, a cover of the sea ice that has prevented the absorption of CO_2 is drastically melting, and thus accelerating the ocean acidification and freshening, both of which reduce Ω to a level < 1 (Yamamoto-Kawai et al., 2009). This level is undersaturated with respective to $CaCO_3$ and the organisms have been exposed to waters that are corrosive for their $CaCO_3$ shells and skeletons. On the other hand, in shelf bottom waters of the Chukchi Sea (Yamamoto-Kawai et al., 2016) and the East Siberian Sea (Anderson at al., 2011; Cross et al., 2018), CO_2 produced by the decomposition of organic matters, which are accumulated at the bottom, promotes the acidification there. Due to an expected future increase in the supply of marine and/or terrestrial organic matters by enhanced primary production and coastal erosions, the bottom water acidification could proceed and might further influence on benthic organisms. Seawater carbonate chemistry including pH and Ω in the Bering Sea with spatial, seasonal and inter-annual variability was well studied by Mathis et al. (2010, 2011a, b) in terms of a number of marine and terrestrial processes. Effects of Pacification on consumer trophic levels are not well studied in the CAO because of a lack of biological time series observations. However, several studies on this topic were conducted in the Pacific Arctic shelf seas. For example, in the Chukchi Sea, significant increases in Pacific zooplankton biomass and abundance were observed with warming and sea-ice decline in recent years compared to historical studies (Ershova et al., 2015). But the hatching success of Pacific zooplankton, such as Pacific copepod *Neocalanus flemingeri*, was extremely low in the Chukchi Sea compared with that in the Pacific, and thus, it is unlikely to establish expatriate Arctic populations in the near future (Matsuno et al., 2015). Pacific zooplankton are also found over the Chukchi and Beaufort shelf slopes (Kosobokova et al., 2011; Smoot and Hopcroft, 2017) and even in offshore waters close to the shelf break of the East Siberian Sea (Ershova and Kosobokova, 2019), but they never be large populations in those regions. As well as zooplankton, changes in species ranges and composition linked to the Pacification have occurred for benthos (Grebmeier, 2012; Grebmeier et al., 2010, 2018; Waga et al., 2020), fishes (Mueter and Litzow, 2008; Nishio et al. 2020), seabirds (Gall et al., 2017) and marine mammals (Moore, 2016).

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Framework of the CAOFA Joint Program of Scientific Research and Monitoring (JPSRM)

Central Arctic Ocean Fisheries Agreement (CAOFA)
Scientific Coordinating Group (SCG)
June 2023

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Annex 1: Framework of the Joint Program of Scientific Research and Monitoring

Framework of the CAOFA
Joint Program of Scientific Research and Monitoring (JPSRM)

Central Arctic Ocean Fisheries Agreement (CAOFA)
Scientific Coordinating Group (SCG)

1 Background

1.1 Introduction

A landmark international agreement was established to promote effective stewardship of Arctic marine living resources: the *Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean* (Appendix 1). The Agreement (also known as the "Central Arctic Ocean Fisheries Agreement" or CAOFA) entered into force on June 25, 2021 after ratification by all ten of the Signatories (Canada, the People's Republic of China, the Kingdom of Denmark in respect of the Faroe Islands and Greenland, Iceland, Japan, the Republic of Korea, the Kingdom of Norway, the Russian Federation, the United States of America, and the European Union).

The objective of the Agreement (Article 2) is to prevent unregulated fishing in the high seas portion of the central Arctic Ocean through the application of 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.

By providing time for the collection of scientific knowledge, Indigenous Knowledge, and local knowledge before the commencement of commercial fishing, the CAOFA creates a rare opportunity to understand the structure and dynamics of central Arctic Ocean (CAO) ecosystems. This understanding is crucial for development of long term management strategies that support sustainable fishing in the CAO high seas and safeguard healthy marine ecosystems that support subsistence resources. As sea ice coverage continues to decline in the CAO and other anthropogenic activities, increase in extent and frequency, assessment of multiple, interacting stressors will be important to support the sustainability of CAO ecosystems in accordance with the objective of CAOFA.

1.2 Objectives, development, and timeline

Article 4 of the Agreement calls for the creation of a Joint Program of Scientific Research and Monitoring (JPSRM) as follows:

1. The Parties shall facilitate cooperation in scientific activities with the goal of increasing knowledge of the living marine resources of the central Arctic Ocean and the ecosystems in which they occur.
2. The Parties agree to establish, within two years of the entry into force of this Agreement, a Joint Program of Scientific Research and Monitoring with the aim of improving their understanding of the ecosystems of the Agreement Area and, in particular, of determining whether fish stocks might exist in the Agreement Area now or in the future that could be harvested on a sustainable basis and the possible impacts of such fisheries on the ecosystems of the Agreement Area.

3. The Parties shall guide the development, coordination and implementation of the Joint Program of Scientific Research and Monitoring.
4. The Parties shall ensure that the Joint Program of Scientific Research and Monitoring takes into account the work of relevant scientific and technical organizations, bodies and programs, as well as indigenous and local knowledge.
5. As part of the Joint Program of Scientific Research and Monitoring, the Parties shall adopt, within two years of the entry into force of this Agreement, a data sharing protocol and shall share relevant data, directly or through relevant scientific and technical organizations, bodies and programs, in accordance with that protocol.
6. The Parties shall hold joint scientific meetings, in person or otherwise, at least every two years and at least two months in advance of the meetings of the Parties that take place pursuant to Article 5 to present the results of their research, to review the best available scientific information, and to provide timely scientific advice to meetings of the Parties. The Parties shall adopt, within two years of the entry into force of this Agreement, terms of reference and other procedures for the functioning of the joint scientific meetings.

At its inaugural meeting in November, 2022, the CAOFA Conference of Parties (COP) highlighted the need for the CAOFA Scientific Coordinating Group (SCG) to conclude its work to develop the JPSRM in a timely manner so that the COP may consider the JPSRM for approval and adoption by the Agreement deadline of June 25, 2023 (Appendix 2). The COP emphasized that the initial document describing the JPSRM should be considered as a framework for the future work of the SCG. That framework may be revised and updated from time to time as new information requires. An associated JPSRM implementation plan will be developed following the COP's approval of the JPSRM framework presented in this document.

The JPSRM comprises an initial mapping phase that is envisioned to occur over a short time period (e.g., three-year duration) followed by a monitoring phase (FiSCAO 2015). The major goals of the mapping phase are to develop an understanding of baseline conditions and to test and evaluate different approaches, biological and ecological indicators, protocols, methods, Indigenous Knowledge, and local knowledge to be used during the monitoring phase. The appropriate threshold values (triggers) for the indicators need to be developed to determine when to repeat the mapping phase or to re-sample targeted areas during the monitoring phase.

As noted above, the Agreement stipulates that as part of the JPSRM, a data sharing protocol shall be adopted to share relevant data, directly or through relevant scientific and technical organizations, bodies and programs. Two working groups within the SCG were established to help develop the JPSRM: the Mapping and Monitoring Working Group (MM-WG) and the Data Sharing Protocol Working Group (DSP-WG).

1.2.1 Terms of reference: Mapping and Monitoring Working Group

The Mapping and Monitoring Working Group (MM-WG) was established to develop the mapping and monitoring plans for the JPSRM to achieve its aim, building on the draft plans from the 4th and 5th FiSCAO meetings and the 1st PSCG meeting and based on the questions and discussions from the 2nd PSCG meeting with the following Terms of Reference:

a. The MM-WG will consist of multiple representatives from each Party with expertise, including scientific, Indigenous Knowledge, and local knowledge, as well as appropriate external experts, of ecosystem components of the JPSRM (e.g., fish, marine mammals, oceanography, ecosystem production, birds, and lower trophic level species).
b. The MM-WG will meet on a timeline determined by the working group with draft plans available for review and discussion.
c. The MM-WG may form smaller teams to meet separately with similar objectives and products to contribute to the overall draft plans.
d. The MM-WG will focus efforts on scientific, Indigenous Knowledge, and local knowledge activities concerned with:
    i. Mapping requirements in the Agreement Area, Atlantic, and Pacific gateways.
    ii. Monitoring requirements consistent with Article 4 of the Agreement.
    iii. Data collection (e.g., gear type) and data format standardization.
    iv. Prioritization of mapping and monitoring parameters as well as spatial and temporal sampling scales.

1.2.2 Terms of reference: Data Sharing Protocol Working Group

The Data Sharing Protocol Working Group (DSP-WG) was established to develop a data management policy and sharing protocols as part of the JPSRM, for consideration by the SCG and approval by the Parties, building on the draft plan from the 5th FiSCAO meeting and based on the discussions from the 2nd PSCG meeting with the following Terms of Reference:

a. The DSP-WG will consist of no more than three representatives from each Party including a technical expert, and no more than two representatives from any one external group, as appropriate.
b. The DSP-WG will meet on a timeline determined by the working group with a data management policy and sharing protocols plan available for review and discussion at the fall 2022 Provisional Science Coordinating Group (PSCG).
c. The DSP-WG will meet in two phases to: 1) identify the framework and specific policy components to be developed and 2) identify appropriate technical requirements.
    i. The DSP-WG will draft a hybrid framework that recognizes
    ii. A centralized data management system collected specifically for the JPSRM, and
    iii. A distributed data management system for relevant accessible data collected in the JPSRM area.
d. The DSP-WG will consider other international data management policies and sharing protocols to benefit from state-of-the-art agreements already in use.

In summary, the JPSRM will follow an ecosystem approach to assess: 1) the status of knowledge regarding marine ecosystem structure and function in the Agreement Area and adjacent waters, and identify gaps in knowledge of ecosystem components and functions, 2) the prospects and potential sustainability of commercial fisheries in the Agreement Area, 3) the potential impacts of such commercial fisheries on the marine ecosystems linked to the central Arctic Ocean, and 4) the potential impacts of commercial fisheries on Arctic Indigenous communities and local communities that depend on marine ecosystems for sustainable subsistence harvests. The JPSRM mapping and monitoring phases will enable the SCG to acquire and evaluate the information needed to make decisions that support the goals of CAOFA with respect to the management, sustainable use, and conservation of marine living resources in the central Arctic Ocean.

1.3 Geography

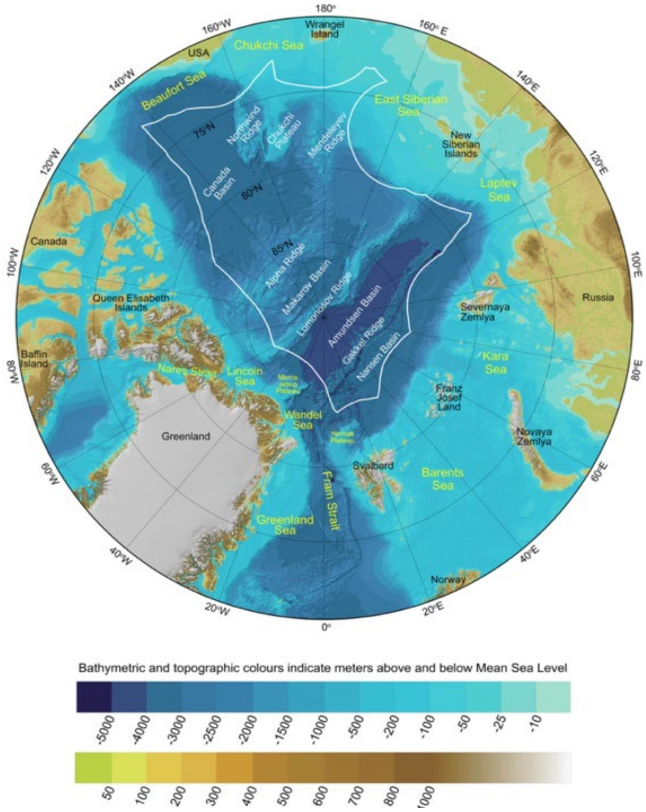


Figure 1. Bathymetric map of the central Arctic Ocean. The Agreement Area is situated within the white line, i.e., the high seas border extending 200 nautical miles from coastal baselines. The background map was extracted from the International Bathymetric Chart of the Arctic Ocean.[2]

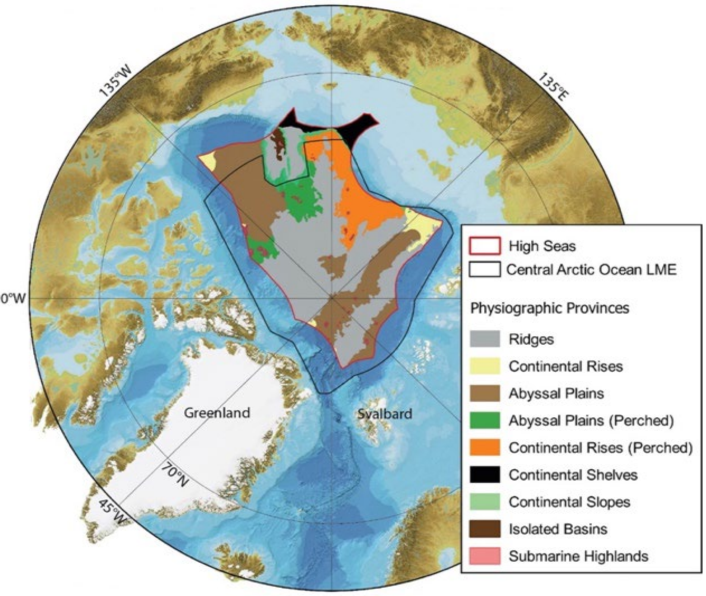


Figure 2. Map of the physiographic provinces in the Agreement Area. The red line is the high seas border cf. Figure 1. The black line is the Central Arctic Ocean Large Marine Ecosystem (CAO-LME) as defined by the Arctic Council.[3] The Physiographic Provinces were calculated by Martin Jakobsson.[4]

Because the issues to be addressed by CAOFA require information about marine ecosystems distributed broadly across the central Arctic Ocean as well as nearby areas, the JPSRM focuses on three ecologically linked zones: 1) the waters within the Agreement Area boundaries, 2) the continental shelf/slope areas peripheral to the Agreement Area, and 3) the Pacific and Atlantic marine gateways. The gateways are defined as the regions of substantial oceanographic flux between marginal seas of the Arctic Ocean and neighboring basins.

The Agreement Area itself comprises the high seas of the central Arctic Ocean, a 2.8 million km^2 area around the North Pole, that is surrounded by waters within which Canada, the Kingdom of Denmark in respect of Greenland, the Kingdom of Norway, the Russian Federation and the United States of America exercise fisheries jurisdiction. (*Figure 1*). The Agreement Area is characterized by several oceanic physiographic provinces (e.g., *Figure 2*). It mainly consists of permanently (winter and summer) ice-covered deep ocean (33.3% abyssal plains, 43.5% submarine ridges, 14.8% continental rises), but also some shallower areas that are not permanently ice-covered (3.3 % continental shelves, 3.2% continental slopes, 1.2% submarine highlands, 0.7% isolated basins). The latter areas could be expected to contain more living marine resources (e.g., fish, squid, crabs, marine mammals, and seabirds) than the permanently ice-covered deep ocean area. For clarity, the Agreement Area is not the same as the Central Arctic Ocean Large Marine Ecosystem (CAO-LME) as defined by the Arctic Council based on ecosystem parameters (*Figure 2*).

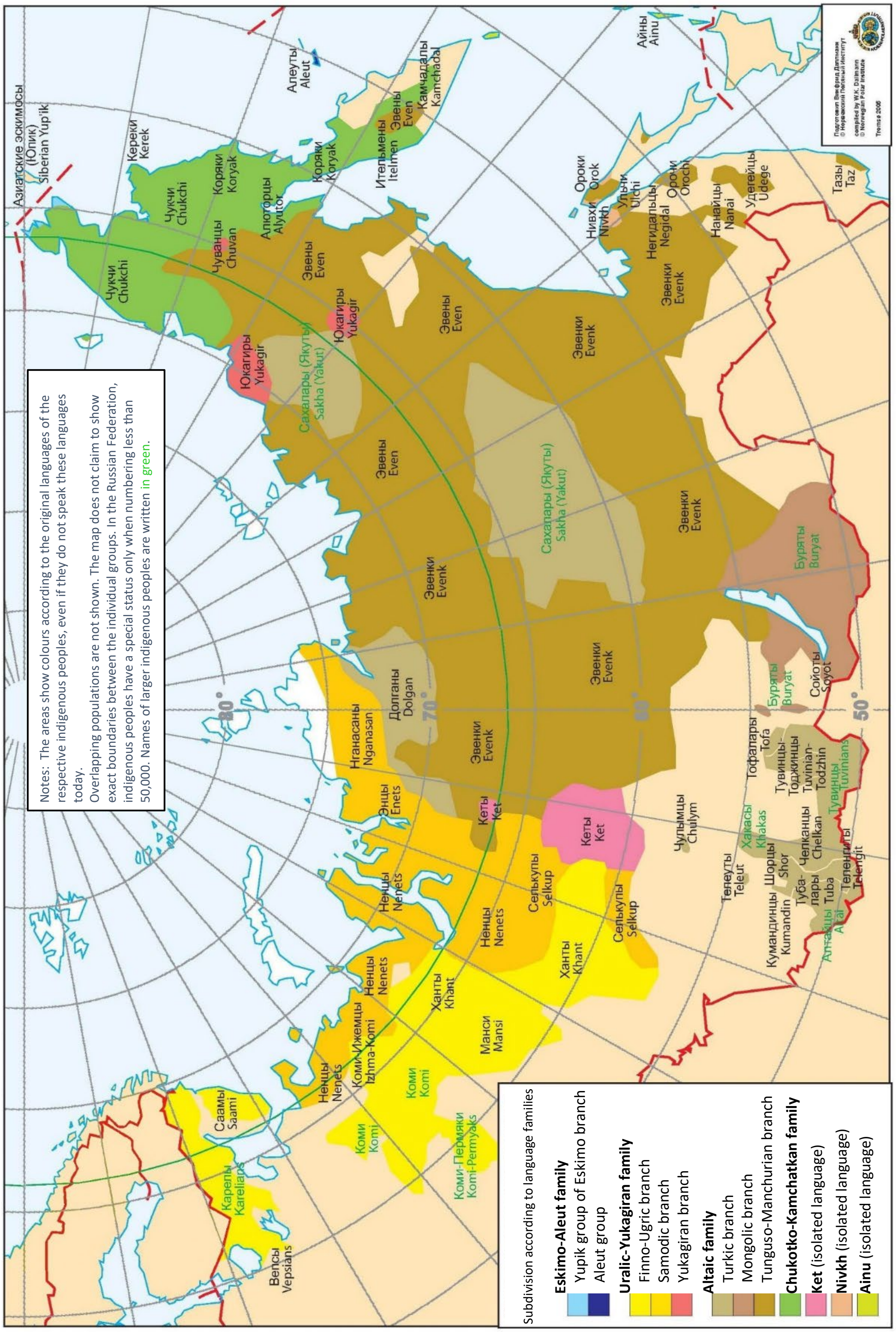
The sea ice cover in the Agreement Area is gradually decreasing as a result of climate change. Today the major effect of warming in the central Arctic Ocean is that the ice is thinning and becoming more dynamic as winds can move thinner ice more easily. Within decades, most of the Agreement Area is expected to be accessible by non-icebreaking vessels, including fishing vessels, in late summer (August-October), but will likely still be covered by sea ice during the rest of the year.

The Agreement Area is not isolated. Its ecosystems are ecologically linked to peripheral Arctic shelf/slope ecosystems (visible as lighter marine zones in Figure 1) and Atlantic and Pacific gateways through physical, chemical, and biological processes intrinsic to ecosystem functioning. Climate change will likely alter the nature of those linkages (e.g., by northward transport of heat and changing distributions of species neighboring subarctic and Arctic areas into the Agreement Area). Such aspects should be covered by the JPSRM as well if they are relevant for the ecosystems of the Agreement Area. The Atlantic and Pacific gateways (and adjacent shelves and slopes) are recognized as priority subareas to monitor because of their strong influences on the Arctic Ocean through the transport of water, heat, nutrients, and plankton from subarctic to Arctic area. These regions are also important seasonal and long-term migration corridors supporting distributional shifts of fish, marine mammals, birds, and crustaceans.

Figure 3. Proximity of the Inuit Homeland to the CAOFA Agreement Area and boundary. Dark gray line indicates the boundary of the CAOFA Agreement Area. Dark green terrestrial areas show the Inuit Homeland as described by the Inuit Circumpolar Council.[1]

The Agreement recognizes the importance of involving Indigenous peoples and local peoples who live in coastal communities that depend on the bordering seas of the Agreement Area. Their involvement together with the science community promotes a holistic approach to incorporating coastal communities into the understanding the Arctic Ocean ecosystems and decisions made under the Agreement. A large portion of the bordering seas of the Agreement Area are offshore of the Inuit Homeland in Greenland, Canada, United States, and Russia (Figure 3). Figure 4 illustrates the distribution of Indigenous peoples in the Russian Federation.

Annex 1: Framework of the Joint Program of Scientific Research and Monitoring



Notes: The areas show colours according to the original languages of the respective indigenous peoples, even if they do not speak these languages today.
Overlapping populations are not shown. The map does not claim to show exact boundaries between the individual groups. In the Russian Federation, indigenous peoples have a special status only when numbering less than 50,000. Names of larger indigenous peoples are written in green.

Figure 4. Indigenous peoples of the North, Siberia, and Far East of the Russian Federation. [This figure is based on information compiled by W.K. Dallmann and published by the Norwegian Polar Institute, Tromsø (2005), but modified here to show only the distribution of Indigenous peoples in the Russian Federation.]

2 *Information Needs*

2.1 Research and monitoring questions of the JPSRM

To guide the development of the JPSRM with a view to achieve its aim, the PSCG drafted a list of questions that were presented to the COP in November 2022 and detailed in the Report of the Third Meeting of the PSCG (*Appendix 7*). Those questions were developed and refined building on the work of two meetings of the Scientific Experts on Fish Stocks in the Central Arctic Ocean (FiSCAO) (*Appendices 3, 4*), three meetings of the Provisional Science Coordinating Group (PSCG) (*Appendices 5, 6, 7*). During its meeting in November 2022, the COP endorsed the two meeting reports of the PSCG report, indicating support for the work of the PSCG on the JPSRM, including the list of questions for the JPSRM developed and revised (Table 1), while also recognizing that different views existed on some questions. In particular, there was not consensus regarding the relevance of some human activities (e.g., ship noise, ship traffic, industrial activity, and pollution) to sustainable fisheries. Some delegations also expressed the need to prioritize the work of the SCG, on the objectives of the Agreement.

2.2 Prioritizing information needs

Answering the research and monitoring questions as presented in Table 1 will require focus on specific information needs (e.g., geographic areas and scales, seasonality and temporal scales, species, parameters to measure, existing information gaps). Those information needs cover many diverse topics whose relative importance and urgency will need to be evaluated as programmatic priorities are established and implemented. In the Mapping and Monitoring phase, the specific information needs will result from information gaps in geographical coverage and use of different sampling gear types.

Recognizing that there are practical limits to how and when such information can be developed into useful products and advice to the COP, the SCG will identify and set priorities for an achievable set of targets in the JPSRM implementation plan. Examples of some of the topics to be considered and assigned priorities in the JPSRM implementation plans are outlined in Appendices 8 and 9.

2.3 Sources of research and monitoring information

Article 4.4 of the Agreement directs Parties to ensure that the JPSRM takes into account the work of relevant scientific and technical organizations, bodies and programs, as well as Indigenous Knowledge and local knowledge. The SCG recognizes that all of these sources of knowledge can provide valuable insights relevant to achieving the aim of the JPSRM.

There are many sources of currently available scientific research and monitoring information relevant to the JPSRM: 1) data collected jointly for the SCG through dedicated efforts by Parties' national research programs, 2) data and reports from external groups active in the Arctic, and 3) published literature and results of recent research expeditions. Whenever possible, the SCG and its working groups will seek opportunities to utilize relevant information from published literature as well as reports and data products from external groups (e.g., national research programs, multi-lateral research initiatives, and international programs).

Annex 1: Framework of the Joint Program of Scientific Research and Monitoring

Table 1. Research and monitoring questions guiding the work of the Joint Program of Scientific Research and Monitoring (JPSRM) (Appendix 2).

Overarching question	Specific questions
1. What are the distributions of species with a potential for future commercial harvests in the Central Arctic Ocean?	a. What fish species are currently present in the high seas? b. Do fishable concentrations of commercial species exist in the high seas? c. What are their distributions and abundance patterns? d. What are their local life-history strategies, habitat associations, and demographic patterns? e. Do these strategies, associations, or patterns differ among regions of the Arctic?
2. What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?	a. What are the trophic linkages among fishes and between fishes and other taxonomic groups (i.e. quantify food webs, including identifying keystone forage species)? b. How do fish species abundances and distributions vary in response to climate variability (e.g., time scale of change, extreme events, declining sea ice, and biogeochemical changes)? c. Can the species be harvested sustainably with respect to both target fish stocks and dependent parts of the ecosystem? If not, what are the prospects for the development of fisheries in the future?
3. What are the likely key ecological linkages between potentially harvestable fish stocks of the central Arctic Ocean and the adjacent shelf ecosystems which includes support for Indigenous communities and local communities?	a. What are the connections between fish in the High Seas and those in the adjacent regions? b. What are the mechanisms that establish and maintain these linkages? c. How might fisheries in the High Seas and that in the adjacent and congruent portions of the shelf ecosystems interact, including fish stocks, fishable invertebrates (crabs, shrimp, mollusks), marine mammals, birds, and fisheries-dependent communities (which include those communities that are dependent on subsistence harvests of fish, invertebrates, and mammals)?
4. Over the next 10-30 years, what changes in fish populations, dependent species and the supporting ecosystems may occur in the central Arctic Ocean and the adjacent shelf ecosystems?	a. Which marine species will likely increase and decrease in population size and/or productivity in the central Arctic Ocean in the next 10-30 years? b. What changes in production and key linkages are expected in the coming 10-30 years? c. What northward population expansions are expected in the next 10-30 years? d. What are the anticipated impacts of change in ocean acidification in the next 10-30 years? e. How will existing and increased human activity and pressures in the region likely affect fish populations and ecosystems, which includes support for Indigenous communities and local communities, in the next 10-30 years? f. How could increased fishing activity affect bycatch species, seabirds, migratory and wide-ranging marine mammals, and Indigenous communities and local communities that depend upon these species to sustain their ways of living?
5. What Indigenous knowledge and local knowledge is available, and how can it be taken into account, to inform ecological baselines?	

Dedicated JPSRM expeditions in the Arctic Ocean may be organized to fill existing data gaps in accordance with the Implementation Plan to be developed. Considering the time and financial cost of such expeditions, the SCG should establish spatial and topical priorities to promote efficient data collection. As needed, the SCG may also encourage and organize coordinated or synoptic surveys, monitoring, and new initiatives implemented with national and international collaborators (Table 2). For example, recent scientific expeditions and projects have collected valuable ecosystem and fish data in the Agreement Area (e.g., the international MOSAiC expedition,[7] 2019-2020; CHINARE Arctic expeditions, 2019-2021; several SAS expeditions, 2020-2022;[8] the INTAROS[9] project that established a Pan-Arctic collaboration between organizations, programs and projects involved in developing Arctic observing systems, 2017-2022; and other recent programs and projects relevant to the central Arctic Ocean[10,11,12,13,14]). Where feasible, information from complementary international science efforts should be leveraged to inform the JPSRM, such as the integration of circumpolar monitoring data on focal ecosystem components in the CAO and surrounding Arctic marine areas by the Circumpolar Biodiversity

Monitoring Program (CBMP),[15] reports by the ICES/PICES/PAME Working Group on the Integrated Ecosystem Assessment for the Central Arctic Ocean (WGICA),[16] monitoring in the Atlantic and Pacific gateways by groups such as the Joint Russian-Norwegian Working Group on Arctic Fisheries[17] in the Barents Sea, the Distributed Biological Observatory (DBO)[18] in the Pacific gateway since 2010, and the joint Iceland-Greenland capelin and ecosystem survey in Iceland sea and Greenland sea on the western side of the Atlantic gateway the Russian–American Long-term Census of the Arctic (RUSALCA) from the Bering Strait to the northwestern Chukchi Sea since 2004, the Joint PICES/ICES Working Group on the Integrated Ecosystem Assessment for the Northern Bering Sea - Chukchi Sea[19], U.S. fish and marine mammal surveys in the northern Bering, Chukchi, and Beaufort Seas, and the North Pacific Research Board's Arctic Program.[20]

In addition to scientific knowledge,[2] Indigenous Knowledge offers an opportunity to develop a holistic understanding of Arctic ecosystems to inform and support the design of the JPSRM. The Inuit Circumpolar Council has defined Indigenous Knowledge as:

> Indigenous Knowledge is a systematic way of thinking applied to phenomena across biological, physical, cultural, and spiritual systems. It includes insights based on evidence and acquired through direct and long-term experiences and extensive and multigenerational observation, lessons, and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, and it is passed on from generation to generation.[1,37]

For example, Indigenous Peoples who live along the U.S. Arctic coast of Alaska hold extensive knowledge of the Pacific Gateway and are involved in guiding the research together with science in the region, especially in the North Slope of Alaska. They possess extensive Indigenous Knowledge of the region, such as related to bowhead whales, other marine mammals, ship strikes, ocean currents, and the arrival of new species in the area. In the Inuvialuit settlement region of Canada, where Inuit and the government of Canada co-manage the resources, Indigenous Peoples living in these areas see first-hand the environmental changes that are occurring, especially when there are extreme events.

3 Scientific Coordinating Group Responsibilities under the JPSRM

3.1 Mapping and monitoring

The CAOFA requires the Parties to establish a JPSRM with the aim of improving the understanding of the ecosystems of the Agreement Area and, in particular, of determining whether fish stocks might exist in the Agreement Area now or in the future that could be harvested on a sustainable basis and the possible impacts of such fisheries on the ecosystem of the Agreement Area. For achievement of goals claimed in Article 4.1 and 4.2, a principal goal of the JPSRM is to provide the key information needed to develop answers to the research and monitoring questions that will enable the SCG to develop useful advice to the COP. The mapping phase of the JPSRM will provide a current understanding of species distributions, relative abundances, and population structure in relation to biotic and abiotic factors. The monitoring phase of the JPSRM will focus on identifications of temporal variability or trends in species distribution or ecosystem productivity. As noted above, the JPSRM's mapping and monitoring phases will utilize

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[2] Scientific knowledge is defined as means knowledge obtained and tested through use of the scientific method. Scientific knowledge may also include the observation and classification of facts with the goal of establishing verifiable knowledge derived through induction and hypothesis.

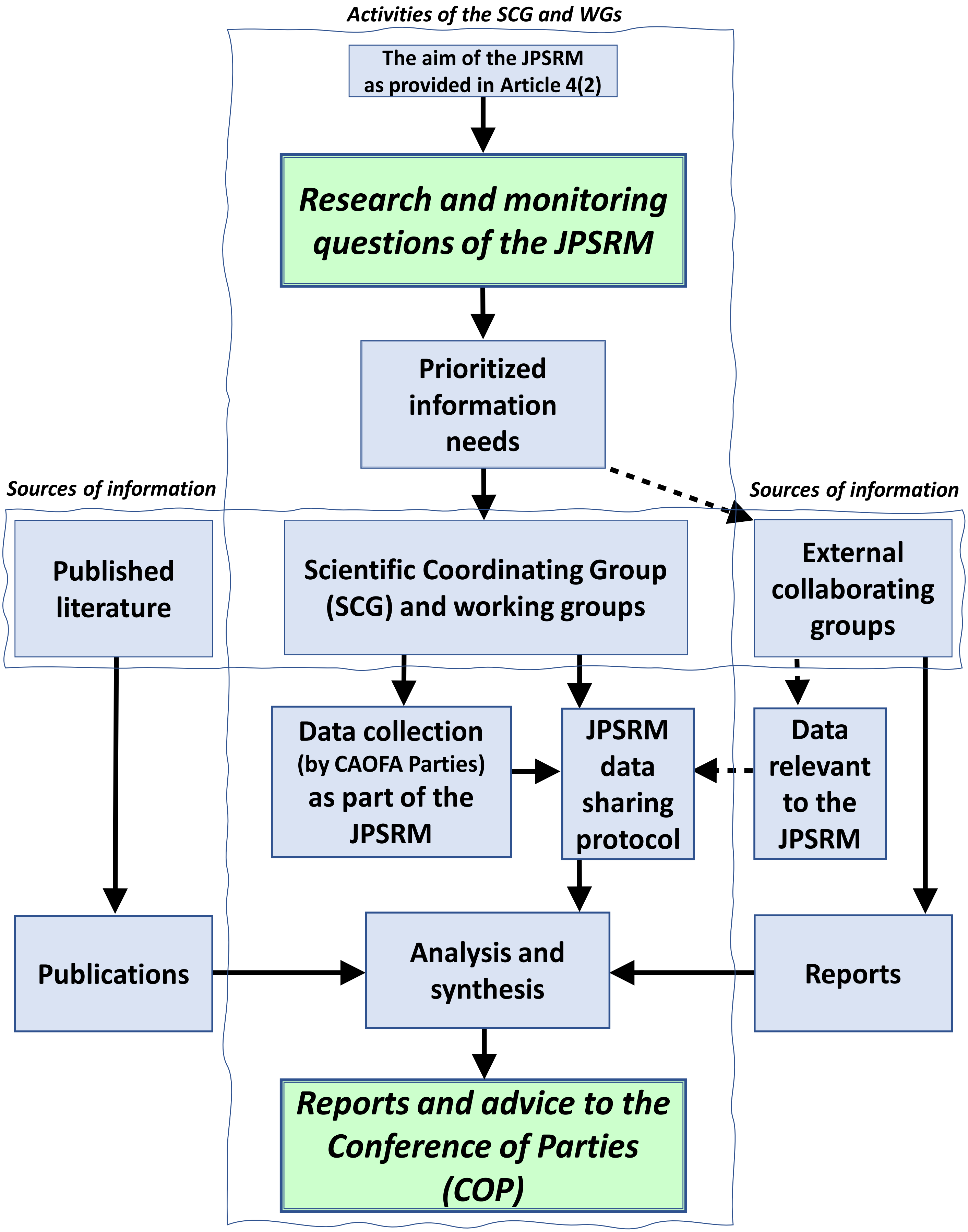
several sources of information including data collected by the Parties' national research programs as well as data and reports obtained through published literature and collaborators external to the SCG. In the monitoring phase, the SCG shall seek deep intervention/participation/collaboration in national and international programs.

As detailed plans are developed for the implementation of the mapping and monitoring phases of the JPSRM, special attention should be given to identifying work relevant to the JPSRM that is already underway by external organizations and research initiatives, including efforts organized and led by Indigenous communities and organizations and local communities. It is clear that the Parties and the SCG cannot accomplish all of the JPSRM goals on their own. The high cost, logistical realities, and geographic breadth of the Arctic mapping and monitoring envisioned by the JPSRM require a collaborative approach. Several excellent research and monitoring programs currently exist that are collecting and analyzing data that are highly relevant to JPSRM goals (e.g., distribution and abundance, stock assessments, population status reviews, trophic interactions, and integrated ecosystem assessments). Therefore, the SCG will strive to encourage and promote the development of productive collaborations (and to avoid duplication) with some of the many external Arctic research groups (Table 2) to share data, logistical platforms, and scientific expertise.

Table 2. Examples of Arctic organizations and research initiatives that may be interested in sharing data and collaborating with the SCG through the JPSRM.

Group type	Group name	Acronym
Inter-governmental and international organizations	Arctic Council – Conservation of Arctic Flora and Fauna[21]	CAFF
	Arctic Council – Protection of the Arctic Marine Environment[22]	PAME
	Arctic Council – Arctic Monitoring and Assessment Program[23]	AMAP
	Arctic Council – Sustainable Development Working Group[24]	SDWG
	CAFF Circumpolar Biodiversity Monitoring Program-Marine[15,25]	CBMP-M
	CAFF Circumpolar Biodiversity Monitoring Program-Coastal[26]	CBMP-C
	ICES/PICES/PAME Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean[27]	WGICA
	International Arctic Science Committee[28]	IASC
	International Council for the Exploration of the Sea[29]	ICES
	Inuit Circumpolar Council[30]	ICC
	Joint PICES/ICES Working Group on the Integrated Ecosystem Assessment for the Northern Bering Sea - Chukchi Sea[19]	PICES WG-44
	North Pacific Marine Science Organization[31]	PICES
	Pacific Arctic Group[32]	PAG
Multi-lateral research initiatives	Distributed Biological Observatory[5] (Pacific and Atlantic)[33]	DBO
	Drift Platform *Severny Polyus*[34]	DPSP
	European Fisheries Inventory in the Central Arctic Ocean[35]	EFICA
	Integrated Arctic Observations System[9]	INTAROS
	Multidisciplinary Drifting Observatory for the Study of Arctic Climate[7]	MOSAiC
	North Pacific Research Board[20]	NPRB
	Pacific Arctic Climate Ecosystem Observatory	PACEO
	Pan-Arctic Observing System of Systems[36]	Arctic PASSION
	Synoptic Arctic Survey[8]	SAS
	Tara Polar Station[37]	TPS

Figure 5. From questions to advice – a framework of prioritized needs, information sources, processes, integration, and collaboration in support of the CAOFA Joint Program of Scientific Research and Monitoring (JPSRM) (solid lines indicate flow of information and products; dotted lines indicate pathways that may be agreed with external collaborators).



Annex 1: Framework of the Joint Program of Scientific Research and Monitoring

To answer key parts of the research and monitoring questions, the SCG will seek to organize dedicated field surveys to collect necessary information relevant to the priorities and topics as outlined in Appendices 8 and 9, which will be incorporated as part of the JPSRM implementation plan. Those efforts will be undertaken, as possible, through collaboration and joint support among the Parties' national research programs. The JPSRM implementation plan(s) will refine the specific information that will be needed (e.g., priority locations and seasons, parameters/indicators to map and monitor, types and frequency of data collection, analytical approaches).

A schematic framework describing the SCG's processes for using the JPSRM to move "From Aim to Questions to Advice" is presented in Figure 5. This framework identifies the JPSRM activities that the SCG and its working groups will conduct directly plus the contributions likely to be made by external groups and sources of relevant information.

3.2 Data management and sharing protocol

In accordance with Central Arctic Ocean Fisheries Agreement (CAOFA) and the *Recommendation of PSCG to Establish a PSCG Data Sharing Protocol Working Group (DSP-WG)* approved by the COP on May 31, 2022, the Data Management and Sharing Protocol shall be part of the Joint Program of Scientific Research and Monitoring (JPSRM), which builds upon the draft plan from the 5th FiSCAO meeting and was informed by the discussions during the PSCG meetings in 2022. This hybrid framework of Data Management and Sharing Protocol consists of a centralized data management system collected specifically for the JPSRM and a distributed data management system for relevant accessible data not directly associated with the JPSRM, also taking into account other international data management policies and sharing protocols and public data portals/repositories.

Objective

1. For the purpose of the CAOFA, this Data Management and Sharing Protocol shall serve as part of the JPSRM to promote data sharing efficiency towards the achievement of the JPSRM aim.

Data management

2. This Data Management and Sharing Protocol adopts a hybrid framework for data management to include the following:
    a. Data collected under the JPSRM are managed in a centralized data archive.
    b. Data collected by national scientific programs, and from sources external to the SCG and the Agreement that are relevant to the review and implementation of CAOFA are recorded and maintained through distributed data archives.

3. The SCG is responsible for the overall coordination of data management and data sharing. Specific responsibilities include:
    a. Identify roles and responsibilities of a Data Management Secretariat who will be responsible to store the JPSRM data managed in the centralized data archive and coordinate metadata of the original data in the distributed data archives.
    b. Identify the content and method of collection and sharing of Indigenous Knowledge and local knowledge.

   c. Adopt and when necessary develop new standards and formats for data collection and management in accordance with international standards and following the internationally mandated principles of FAIR, CARE, TRUST, and EEE.[3]
   d. Consider data submission time for different JPSRM datasets.
   e. Consider potential embargo times for public accessibility of the different JPSRM datasets.

4. Establish a Data Management Secretariat to coordinate the collection, manage, and share the data managed through the centralized data archive.[4] Specific responsibilities of the Secretariat include:
   a. Inform all potential contributors of data to the JPSRM of the data management process under the Agreement and ensure that data will be made available swiftly and reliably, following the principles of the JPSRM data management plan.
   b. Develop and maintain the data management and sharing system.
   c. Ensure that JPSRM data and metadata are complete prior to acceptance.[5]
   d. Facilitate access by Parties of the JPSRM data for the purpose of implementation of the CAOFA.
   e. Facilitate inclusion and sharing of Record metadata for other scientific data relevant to the JPSRM from distributed data archive where appropriate.

5. The centralized data archive shall include the following:
   a. Data collected under the JPSRM.
   b. Indigenous Knowledge and local knowledge collected under the JPSRM.
   b. Metadata collected by national scientific programs.
   c. Metadata from relevant sources external to the SCG and the Agreement.
   d. Citation list of publications related to JPSRM data, Indigenous Knowledge, or local knowledge.

6. The distributed data archives may include the following information relevant to the implementation of CAOFA (harmonized text with 2b):
   a. Other scientific data collected by other national scientific programs and other sources external to the SCG.
   b. Historical data.
   c. Environmental or ecological data.
   d. Indigenous Knowledge and local knowledge as provided by its respective knowledge holders.

7. The data collected under the JPSRM (JPSRM data) and managed by the centralized data archive shall include:
   a. Raw data: the data recorded by observation equipment with minimal processing to remove extraneous values recorded between sampling events, and essential calibrations.
   b. Quality controlled data: the data after quality control that can be directly used for mapping and ecosystem evaluation.

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[3] Added by EU.

[4] Comment from EU: We may consider writing instead: overseeing all data relevant to the JPSRM, including those from external sources.

[5] Comment from Canada: Are we referring to data validation / cleaning / remediation? If so, we would need to discuss how this “quality” will be checked? Further, what if the data transmitted are in such a state that cleaning it/ensuring quality places considerable workload on the individual handling it? Can the individual ask the Party to resend the dataset with corrections?

Annex 1: Framework of the Joint Program of Scientific Research and Monitoring

   c. Data products: the data generated from mapping and evaluation of fish stocks and the ecosystem.

8. The JPSRM data should be submitted in the following time:
   a. The metadata will be submitted within one month after the completion of the data collection.
   b. The raw data will be submitted within 3 months after the completion of the data collection.
   c. The quality controlled data will be submitted within 1 year after the completion of the data collection with consideration for data quality control requirements consistent with section 3d.
   d. Metadata collected by national scientific programs data may be submitted to the centralized data archive within 1 year after the completion of the data collection.

9. The metadata for the centralized data archive will adopt the WMO Core Profile of the ISO 19115: Geographic Information Metadata standard.[6]

10. The JPSRM data shall be quality controlled by the original data observer or the owner of the observation instrument to ensure the quality of the data being processed.

11. Data submitted to the centralized data archive shall be quality checked by the Data Management Secretariat prior to acceptance into the archive.

Data sharing[7]

12. The JPSRM data shall be exchanged among all Parties in a free and unrestricted manner for the purpose of implementing the CAOFA.

13. Data collected from national programs, Indigenous Knowledge,[8] local knowledge, and international organizations shall respect national and international data policies.

14. The maximum duration prior to public sharing of JPSRM data would not exceed two years after the completion of the data collection (e.g., project or cruise). The implementation plan will address the level of data made publicly available.[9]

15. All Parties shall have equal rights and obligations regarding the management and sharing of data generated by the JPSRM.

16. The JPSRM data managed by the centralized data archive before public sharing will be password protected and accessible only by authorized Party individuals.

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[6] Question from EU: Are there more metadata standards to consider?

[7] One example for a data sharing agreement is OBIS: https://manual.obis.org/policy

[8] Users are advised to consult the Circumpolar Inuit Protocols for the Equitable and Ethical Engagement: https://hh30e7.p3cdn1.secureserver.net/wp-content/uploads/EEE-Protocols-LR-WEB.pdf

[9] Suggestion of EU: Consider adding the reference to para 3(d)

17. For the purposes of implementing the CAOFA before public sharing, users shall directly apply to the Data Management Secretariat for access to JPSRM data, and the Secretariat shall directly provide the data upon confirmation.

18. For JPSRM scientific data intended for peer review publication, users shall apply directly to the data provider for review and final decision as to whether to use and publish the data.

19. For JPSRM Indigenous Knowledge intended for publication or public dissemination, acknowledging the unique nature of interpretation of Indigenous Knowledge, users shall apply directly to the knowledge provider for review and final decision as to whether to use and publish the knowledge.

20. For scientific data, Indigenous Knowledge or local knowledge collected under the JPSRM users shall apply directly to the data provider for possible use of the data in publication or any form of public dissemination not directly related to CAOFA, and the data provider has the final decision whether the data can be used and published. This practice is encouraged and should be followed after the two year data embargo (point 14) has ended.

21. The users shall apply directly to the data provider for access to data included in the distributed data archive. The data provider shall decide whether to share and provide data.

22. The JPSRM data will include data Digital Object Identifier (DOI) standards supported by international coordination groups such as the Research Data Alliance (RDA). The Data Management Secretariat shall entrust an existing organization to help data providers develop DOIs if their institutional or national data archive cannot provide the service.

23. When using the JPSRM data, the source of the data should be cited in the report or paper by means of DOI or in the acknowledgments department. If a published report or article uses data from different sources, specify the source of all the data.

24. A report or paper published using the JPSRM data, if the data provider or survey monitor contributed to the report or paper, the author of the paper or report should contact the data provider about whether to list the data provider or survey as a co-author.

25. The centralized data archive will develop a citation list of publications from the submitted citations. Whenever possible, the archive will use DOIs to link to a publication to its data source(s). The shared archive will make the citation list public via the archive website to provide a continuous record of applications and analyses of JPSRM data and JPSRM scientific achievements.

Terminology

26. *Centralized data management system* means that the data collected under the JPSRM are stored at a single physical location.

27. *Distributed data management system* means that the data collected by national program are stored by different programs or Parties.

28. *Metadata* are data that provides information about other data, but not the content of the data, such as the text of a message or the image of itself.

29. *Data provider* is the original entity that collected the information or provider of the information to the JPSRM archive.

30. *JPSRM data* are the scientific data, Indigenous Knowledge, or local knowledge collected under the JPSRM.

3.3 Reports and advice to the Conference of Parties (COP)

As products of the JPSRM, the SCG will submit bi-yearly summary reports to the COP based on JPSRM data collection, analyses, and syntheses. JPSRM participants will also be encouraged to publish their results in peer-reviewed journals to promote broad distribution and public awareness of the evolving ecosystem science occurring in the central Arctic Ocean.

The most important outcome of the JPSRM will be the scientific advice that the SCG will be able to generate and submit to the COP for its consideration. That advice will enable the COP to take science-informed decisions on important issues concerning management of possible central Arctic Ocean fisheries as well as their potential impacts on dependent and vulnerable species, Arctic marine ecosystems, and subsistence of Arctic Indigenous communities. To that end, it is important that the JPSRM collect data on all aspects of the CAO ecosystem to have the information that will be needed to provide advice based on sound science and Indigenous Knowledge.

4 External Sources of Data

4.1 Collaborations and protocols

Providing focused information and advice to the COP will require substantial efforts by many. Foremost will be the research and monitoring activities taken directly by the SCG through the implementation of the JPSRM, while collaborations with relevant Arctic groups external to the SCG will be helpful for the JPSRM to succeed. Wherever possible, the JPSRM will seek to solicit and develop collaborations with international and national expeditions, research projects, and monitoring programs. For example, existing Arctic programs could be encouraged to contribute to the aim of JPSRM. Similarly, it would be very helpful if existing and new research programs operating in Arctic shelf ecosystems and the Pacific and Atlantic gateways would consider incorporating JPSRM objectives into their sampling protocols and sharing of the data.

Collaborations in the Agreement Area and linked ecosystems involving joint expeditions, coordinated ships’ cruise tracks, standardized sampling protocols, cooperative deployments of scientific moorings (e.g., acoustic, optical), and the sharing of samples, data, and analytical expertise will add tremendous strength to the JPSRM. Examples of groups and research initiatives external to the SCG that may be interested in collaborating with the SCG and Parties’ national programs in support of the JPSRM are listed in Table 2. Details and plans for developing such collaborations will be developed as part of the JPSRM implementation plan.

Annex 1: Framework of the Joint Program of Scientific Research and Monitoring

There are many ways that the JPSRM can connect to established international and national expeditions planning research projects, and monitoring programs relevant to the objectives of the JPSRM (*Table 3*). In these cases, most of the costs for infrastructure and research are already financed and could be leveraged to collect additional data relevant for the JPSRM. The disadvantage to this approach is that the area, route, time and other parameters of the expedition will be decided by the expedition organizers and the JPSRM will have to work with the data collected. However, for projects that are still being planned or that will occur for several more years there may be opportunities for the SCG to become a project partner and therefore contribute to joint expedition planning and resourcing.

Table 3. Possible opportunities for external groups to measure JPSRM indicators.

Type of expedition	**Possibilities for the JPSRM**	**Costs for the JPSRM**
1. Dedicated icebreaker or drift platform for JPSRM research in the Agreement Area	Decide upon expedition area, route, time, etc. and collect the complete set of JPSRM indicators	Very high costs for ship/platform infrastructure and for JPSRM equipment and scientists
2. JPSRM owned buoys to be deployed by icebreakers opportunistically	Connect to scientific oceanographic expeditions for deployment	Development of buoys, e.g., ice-tethered buoy for fish and plankton research
3. Any icebreaker or drift platform equipped for scientific research in the Agreement Area	Include as many indicators of the JPSRM as possible in all scientific (geological, oceanographic, atmospheric, biological etc.) expeditions	Extra costs for adding fishery research (acoustics, long lines, ring nets, trawling, box coring, etc.) and JPSRM scientists to the expeditions
4. Any icebreaker or drift platform accessing the Agreement Area for other reasons than scientific research (tourism, etc.)	At least collection of hydroacoustic data for mapping fish distributions	Extra costs for equipping the vessels with acoustic equipment appropriate for JPSRM data collection. JPSRM scientists are only needed before and after the expedition
5. Vessels normally working in and near ice-covered waters in the Arctic and subarctic for scientific research or monitoring	Include as many indicators of the JPSRM as possible in all scientific (geological, oceanographic, atmospheric, biological, etc.) expeditions and extend the cruise track into the Agreement Area when the ice cover allows	Extra costs for adding fishery research (acoustics, long lines, ring nets, trawling, box coring, etc.) and for extending the expeditions into the Agreement Area when the ice cover allows
6. Fishery vessels normally working in the Arctic shelf seas for standard monitoring programs	Include as many indicators of the JPSRM as possible in the standard monitoring programs and extend the cruise track into the Agreement Area when the ice cover allows	Extra costs for extending the expeditions into the Agreement Area when the ice cover allows
7. Indigenous Knowledge	Include Indigenous Knowledge holders in the design and planning of scientific research expeditions as well as on expeditions themselves	Extra costs to support the engagement of Indigenous Knowledge holders
8. Local knowledge	Include expertise of individuals or organizations (e.g., commercial fishing captains, etc.,) who have detailed knowledge of the CAOFA area in design and planning or execution of scientific research expeditions.	Extra costs to support the engagement of local knowledge holders.
9. Exploratory fishing	Collection of data concurrent to exploratory fishing	Costs to outfit exploratory fishing vessels and add observers

Existing national and international monitoring programs in the Arctic shelf seas could be prepared to go further north if ice conditions allow (see *Appendix 5* for a recent compilation). Examples include the Joint Russian-Norwegian monitoring program in the Barents Sea,[11] the Chinese National Arctic Research Expedition in the Chukchi Sea, the Distributed Biological Observatory (DBO) in adjacent regions to the Agreement Area in the Pacific Arctic and complementary efforts developing for the Fram Strait, and the Pacific Arctic Climate Ecosystem Observatory (PACEO), which includes operations in both the Pacific gateway and the Agreement Area.

Examples of other possibilities for the JPSRM are to connect to upcoming scientific icebreaker expeditions and new initiatives. Examples of the latter are a Pan-Arctic Observing System of Systems, Arctic PASSION;[12] a research project organizing a pan-Arctic Observation and Monitoring action including plans for an Arctic-Atlantic DBO (started 2021); the new Russian drift platform *Severny Polyus*[13] designed for 2-years autonomous drifting in thick Arctic sea ice focusing on meteorology and oceanography (started 2022); and the *Tara Polar station*,[14] a research station that is planned to drift in the CAO continuously from 2025 to 2045 collecting on-site biological data.

4.2 Data sharing and reports

The SCG will explore the possibility that some external collaborators listed in Table 4 may be interested in establishing a formal relationship with the SCG to support the JPSRM in their competences. For example, it is anticipated that certain intergovernmental research and monitoring programs (e.g., the Arctic Council's CAFF Circumpolar Biodiversity Monitoring Program (both CBMP marine and coastal groups) and ICES/PICES/PAME Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean (WGICA) may be amenable to providing data or preparing reports to the SCG focused on specific topics that address JPSRM questions and prioritized information needs (Table 4 and as illustrated by dotted lines in Figure 5). Integrating such information into SCG analyses and syntheses would likely be a very effective way to strengthen the JPSRM and the SCG's advice to the COP.

5 Implementation

5.1 JPSRM implementation plan

Although this framework document has outlined a broad vision of how the JPSRM will be structured, a considerable number of details still need to be formulated. Fortunately, discussions by the Provisional Scientific Coordinating Group (PSCG) in recent years raised several important topics and suggestions that may help to guide the development of the implementation plan. During past discussions, there was general agreement on the priorities of the Implementation Plan of the CAOFA JPSRM and a series of topics that should be addressed to provide details and priorities for the JPSRM. Appendix 8 lists the priorities of the Implementation Plan, and Appendix 9 lists some of these topics (as identified in previous meetings of FiSCAO and the PSCG). Additional information that will assist in developing the JPSRM implementation plan will be identified by the SCG and its working groups.

This implementation plan will build on and revise as needed the recommendations in Appendix 8 and Appendix 9 from previous PSCG and FiSCAO meetings.

5.2 Provisional timeline

Annex 1: Framework of the Joint Program of Scientific Research and Monitoring

The SCG will establish milestones and reports aiming for completion of the implementation plan by June 2024. The operational phase of the JPSRM can start immediately after the COP has approved the JPSRM Framework, e.g., by initiatives of single Parties or preferably groups of Parties. This means that data in the context of the JPSRM can already be collected before the Implementation Plan is in place. The Implementation Plan will be revised regularly.

Table 4. Examples of external Arctic groups that may be interested in helping to answer the JPSRM research and monitoring questions through collaboration with the SCG (see Table 2 for additional groups).

Overarching questions	**Specific questions**	**Inter-governmental and international organizations**	**Multi-lateral research initiatives**
1. What are the distributions of species with a potential for future commercial harvests in the central Arctic Ocean?	a. What fish species are currently present in the High Seas? b. Do fishable concentrations of commercial species exist in the High Seas? c. What are their distributions and abundance patterns? d. What are their local life-history strategies, habitat associations, and demographic patterns? e. Do these strategies, associations, or patterns differ among regions of the Arctic?	Circumpolar Biodiversity Monitoring Program-Marine (**CBMP-Marine**) Working Group on Integrated Ecosystem Assessment in the CAO (**WGICA**) International Council for the Exploration of the Sea (**ICES**) N. Pacific Marine Science Org(**PICES**)	Drift Platform *Severny Polyus* (**DPSP**) European Fish. Inventory in CAO (**EFICA**) Multidisciplinary Drifting Observatory for Study of Arctic Climate (**MOSAiC)** Pacific Arctic Climate Ecosystem Observatory (**PACEO**) Synoptic Arctic Survey (**SAS**)
2. What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?	a. What are the trophic linkages among fishes and between fishes and other taxonomic groups (e.g., quantify food webs identifying keystone forage species)? b. How do the abundances and distributions of species of potential commercial interest vary as a function of climate variability (e.g., time scale of change, extreme events, declining sea ice, and biogeochemical changes)? c. Can the species be harvested sustainably with respect to both target stocks and dependent parts of the ecosystem? If not, what are the prospects for the development of fisheries in the future?	Circumpolar Biodiversity Monitoring Program-Marine (**CBMP-Marine**) Working Group on Integrated Ecosystem Assessment in the CAO (**WGICA**) International Council for the Exploration of the Sea (**ICES**) North Pacific Marine Science Organization (**PICES**) Pacific Arctic Group (**PAG**)	European Fisheries Inventory in the CAO (**EFICA**) Pacific Arctic Climate Ecosystem Observatory (**PACEO**) Synoptic Arctic Survey (**SAS**)
3. What are the likely key ecological linkages between potentially harvestable fish stocks of the central Arctic Ocean and the adjacent shelf ecosystems that support Indigenous and local communities?	a. What are the connections between fish in the High Seas and those in the adjacent regions? b. What are the mechanisms that establish and maintain these linkages? c. How might fisheries in the High Seas affect adjacent and congruent portions of shelf ecosystems, including fish stocks, fishable invertebrates (crabs, shrimp, mollusks), marine mammals, birds, and fisheries-dependent communities (which include those communities that are dependent on subsistence harvests of fish, invertebrates, and mammals)?	Circumpolar Biodiversity Monitoring Program-Marine (**CBMP-Marine**) Working Group on Integrated Ecosystem Assessment in the CAO (**WGICA**) International Council for the Exploration of the Sea (**ICES**) North Pacific Marine Science Organization (**PICES**) Pacific Arctic Group (**PAG**)	Distributed Biological Observatory (**DBO**) European Fish. Inventory in CAO (**EFICA**) Integrated Arctic Observations System (**INTAROS**) Multidisciplinary Drifting Observatory for Study of Arctic Climate (**MOSAiC)** Pacific Arctic Climate Ecosystem Observatory (**PACEO**) Synoptic Arctic Survey (**SAS**)
4. Over the next 10-30 years, what changes in fish populations, dependent species and the supporting ecosystems may occur in the central Arctic Ocean and the adjacent shelf ecosystems?	a. What marine species will be productive in the Agreement Area in the next 10-30 years? b. What changes in production and key linkages are expected in the coming 10-30 years? c. What northward population expansions are expected in the next 10-30 years? d. What are the anticipated impacts of changes in ocean acidification in the next 10-30 years? e. How will increased human activity in the region (e.g., ship noise, ship traffic, industrial activity, and pollution affect fish populations, dependent species, ecosystem health, and Indigenous and local communities in the next 10-30 years? f. How will increased fishing activity affect other species bycatch, migratory and wide-ranging marine mammals and birds, and the Indigenous and local communities that depend upon these species to sustain their ways of living?	Circumpolar Biodiversity Monitoring Program-Marine (**CBMP-Marine**) Working Group on Integrated Ecosystem Assessment in the CAO (**WGICA**) International Council for the Exploration of the Sea (**ICES**) North Pacific Marine Science Organization (**PICES**) Pacific Arctic Group (**PAG**)	Distributed Biological Observatory (**DBO**) European Fisheries Inventory in the CAO (**EFICA**) Integrated Arctic Observations System (**INTAROS**) Multidisciplinary Drifting Observatory for Study of Arctic Climate (**MOSAiC)** Pacific Arctic Climate Ecosystem Observatory (**PACEO**) Synoptic Arctic Survey (**SAS**)
5. What Indigenous Knowledge is available to inform ecological baselines?		Inuit Circumpolar Council (**ICC**)	

6 Citations

Citation 1	Inuit Circumpolar Council. 2022. Circumpolar Inuit protocols for equitable and ethical engagement. [https://hh30e7.p3cdn1.secureserver.net/wp-content/uploads/EEE-Protocols-LR-WEB.pdf]
Citation 2	Jakobsson M, et al. 2020. The International Bathymetric Chart of the Arctic Ocean, Version 4.0. Scientific Data 7:176 [https://doi.org/10.1038/s41597-020-0520-9]
Citation 3	PAME. 2013. Large Marine Ecosystems (LMEs) of the Arctic Area: Revision of the Arctic LME Map (Second Edition). PAME International Secretariat [https://www.pame.is/projects/ecosystem-approach/arctic-large-marine-ecosystems-lme-s] and [https://www.pame.is/images/03_Projects/EA/LMEs/Factsheets/13_Central_Arctic_Ocean_LME_.pdf]
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Citation 5	Review of the research knowledge and gaps on fish populations, fisheries and linked ecosystems in the Central Arctic Ocean (CAO). Publications Office of the European Union (2020). [https://data.europa.eu/doi/10.2826/387890]
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Citation 8	Synoptic Arctic Survey (SAS): [https://synopticarcticsurvey.w.uib.no]
Citation 9	Integrated Arctic Observation System (INTAROS): [http://intaros.eu]
Citation 10	Ecosystem mapping in the Central Arctic Ocean (CAO) during the MOSAiC expedition. Publications Office of the European Union (2021) [https://data.europa.eu/doi/10.2926/714618]
Citation 11	Ecosystem mapping in the Central Arctic Ocean (CAO) during the SAS-Oden expedition. Publications Office of the European Union (2022) [https://data.europa.eu/doi/10.2826/958629]
Citation 12	Expedition Report SWEDARCTIC Synoptic Arctic Survey with icebreaker Oden (2022) [https://www.diva-portal.org/smash/get/diva2:1712331/FULLTEXT01.pdf]
Citation 13	The Nansen Legacy Joint Cruise 2-2 2021 – Cruise Report. The Nansen Legacy Report Series 30/2022 [https://septentrio.uit.no/index.php/nansenlegacy/article/view/6413/6498]
Citation 14	Arctic Ocean 2022 Cruise Report IMR Cruise ID 2022710. Norwegian Polar Institute (2022) [https://brage.npolar.no/npolar-xmlui/handle/11250/3013026]
Citation 15	Arctic Council's CAFF Circumpolar Biodiversity Monitoring Program – Marine [https://www.caff.is/marine]
Citation 16	ICES/PICES/PAME Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean (WGICA) [https://www.ices.dk/community/groups/Pages/WGICA.aspx]
Citation 17	Joint Russian-Norwegian Working Group on Arctic Fisheries (JRN-AFWG) [https://www.hi.no/en/hi/nettrapporter?query=&serie=imr-pinro]
Citation 18	Distributed Biological Observatory (DBO): [https://www.pmel.noaa.gov/dbo]
Citation 19	Joint PICES/ICES Working Group on the Integrated Ecosystem Assessment for the Northern Bering Sea - Chukchi Sea [https://meetings.pices.int/members/working-groups/wg44]

Annex 1: Framework of the Joint Program of Scientific Research and Monitoring

Citation 20	North Pacific Research Board Arctic Program [https://nprb.org/arctic-program/#section-1]
Citation 21	Arctic Council's CAFF Working Group (Conservation of Arctic Flora and Fauna) [https://www.arctic-council.org/about/working-groups/caff]
Citation 22	Arctic Council's PAME Working Group (Protection of the Arctic Marine Environment) [https://www.arctic-council.org/about/working-groups/pame]
Citation 23	Arctic Council's AMAP Working Group (Arctic Monitoring and Assessment Program) [https://www.amap.no]
Citation 24	Arctic Council's SDWG Working Group (Sustainable Development) [https://www.arctic-council.org/about/working-groups/sdwg]
Citation 25	CAFF Marine Biodiversity Monitoring [https://www.arctic-council.org/projects/marine-biodiversity-monitoring]
Citation 26	Arctic Council CAFF Circumpolar Biodiversity Monitoring Program – Coastal (CBMP-Coastal) [https://www.caff.is/coastal]
Citation 27	ICES/PICES/PAME Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean (WGICA) [https://www.ices.dk/community/groups/Pages/WGICA.aspx]
Citation 28	International Arctic Science Committee (IASC) [https://iasc.info/]
Citation 29	International Council for the Exploration of the Sea (ICES) [https://www.ices.dk/Pages/default.aspx]
Citation 30	Inuit Circumpolar Council (ICC) [https://www.inuitcircumpolar.com/]
Citation 31	North Pacific Marine Science Organization (PICES) [https://meetings.pices.int/]
Citation 32	Pacific Arctic Group (PAG)[https://pag.arcticportal.org/]
Citation 33	Distributed Biological Observatory (DBO) [https://dbo.cbl.umces.edu/]
Citation 34	Severny polyus: [http://www.energyglobalnews.com/russian-drift-station-severny-polyus-has-started-north-pole-41-expedition]
Citation 35	European Fisheries Inventory in the Central Arctic Ocean (EFICA): [https://data.europa.eu/doi/10.2826/387890], [https://data.europa.eu/doi/10.2926/714618], [https://data.europa.eu/doi/10.2826/958629]
Citation 36	Pan-Arctic Observing System of Systems [Arctic PASSION): [https://arcticpassion.eu]
Citation 37	Tara Polar Station: [https://fondationtaraocean.org/en/schooner/tara-polar-station]

7 List of Figures

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9 Appendices

Appendix 1	Agreement to prevent unregulated high seas fisheries in the Central Arctic Ocean (into force on 25 June 2021) [https://apps-afsc.fisheries.noaa.gov/CAOFA/documents/CAOFA-text.pdf]
Appendix 2	Report of the First Meeting of the Conference of the Parties to the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean, Incheon, Korea, November 23-25, 2022 (CAOFA-2022-COP1-10) [https://apps-afsc.fisheries.noaa.gov/CAOFA/documents/first-meeting-COP.pdf]
Appendix 3	Final Report of the Fourth Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean (2017) [https://apps-afsc.fisheries.noaa.gov/CAOFA/documents/fourth-meeting-FiSCAO.pdf]
Appendix 4	Final Report of the Fifth Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean (2018) [https://apps-afsc.fisheries.noaa.gov/CAOFA/documents/fifth-meeting-FiSCAO.pdf]
Appendix 5	Report of the First Meeting of the Provisional Scientific Coordinating Group (PSCG) of the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean (2020) [https://apps-afsc.fisheries.noaa.gov/CAOFA/documents/first-meeting-PSCG.pdf]
Appendix 6	Report of the Second Meeting of the Provisional Scientific Coordinating Group under the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean (2022) [https://apps-afsc.fisheries.noaa.gov/CAOFA/documents/second-meeting-PSCG.pdf]
Appendix 7	Report of the Third Meeting of the Provisional Scientific Coordinating Group under the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean (2022) [https://apps-afsc.fisheries.noaa.gov/CAOFA/documents/third-meeting-PSCG.pdf]

Appendix 8	Data needed to fulfill the goals of the CAOFA JPSRM (text developed by the MM-WG in February 2023 that is expected to be helpful in developing the JPSRM implementation plan)
Appendix 9	Excerpts from FiSCAO and PSCG meetings providing examples of topics that should be addressed when establishing JPSRM priorities

10 Abbreviations

ABNJ	Areas Beyond National Boundaries
AMAP	Arctic Monitoring and Assessment Program (a working group of the Arctic Council)
AIERP	Arctic Integrated Ecosystem Research Program (a research initiative of the U.S. North Pacific Research Board)
AMAP	Arctic Mapping and Assessment Program (a working group of the Arctic Council)
PASSION	Pan-Arctic Observing System of Systems
CAFF	Conservation of Arctic Flora and Fauna (a working group of the Arctic Council)
CAO	Central Arctic Ocean
CAOFA	Central Arctic Ocean Fisheries Agreement
CBMP	Circumpolar Biodiversity Monitoring Program (a circumpolar program of the Arctic Council's CAFF WG)
CAOFA COP	Conference of the Parties of the Central Arctic Ocean Fisheries Agreement
CDOM	Chromophoric (or Colored) Dissolved Organic Matter
CTD	Oceanographic instrument for measuring conductivity (salinity), temperature and depth in the water column
DBO	Distributed Biological Observatory
DOI	Digital Object Identifier
DPSP	Drift Platform *Severny Polyus*
DSP-WG	Data Sharing Protocol Working Group of the SCG
EEZ	Exclusive Economic Zone
EFICA	European Fisheries Inventory in the Central Arctic Ocean Consortium
EU	European Union
FiSCAO	Scientific Experts On Fish Stocks In The Central Arctic Ocean
IASC	International Arctic Science Committee
ICC	Inuit Circumpolar Council
ICES	International Council for the Exploration of the Sea (intergovernmental)
IEA	Integrated Ecosystem Assessment
IK	Indigenous Knowledge
LK	Local knowledge
INTAROS	Integrated Arctic Observations System
JPSRM	Joint Program of Scientific Research and Monitoring
LME	Large Marine Ecosystem (developed by the USA NOAA to identify ocean areas for conservation purposes)
MM-WG	Mapping and Monitoring Working Group of the SCG
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
NPRB	North Pacific Research Board
PACEO	Pacific Arctic Climate Ecosystem Observatory (a international research initiative of the Pacific Arctic Group)
PAG	Pacific Arctic Group
PAME	Protection of the Arctic Marine Environment (a working group of the Arctic Council)

PICES	North Pacific Marine Science Organization (intergovernmental)
PSCG	Provisional Scientific Coordinating Group
SAS	Synoptic Arctic Survey
SCG	Scientific Coordinating Group
SDWG	Sustainable Development Working Group (a working group of the Arctic Council)
TPS	Tara Polar Station
WGICA	ICES/PICE/PAME Working Group on the Integrated Ecosystem Assessment for the Central Arctic Ocean

Appendix 8: Data needed to fulfill the goals of the CAOFA JPSRM

1. Indicators, devices and methods

A broad set of JPSRM indicators, devices and methods will be tested during the three-year mapping phase. At the end of the mapping phase, the efficiencies of each of the indicators and the efforts to obtain reliable measurements will be evaluated. For the subsequent 13-year monitoring phase a smaller number of quantitative monitoring indicators will be selected for the JPSRM. During both the mapping and monitoring phases intercalibration of methods will take place regularly, and other forms of calibration and collaboration, e.g., the exchange of samples, will be facilitated within the JPSRM to maintain data consistency and allow data to be combined in analyses.

Table 3: JPSRM indicators in relation to the overarching research questions of the JPSRM (cf. Table 1). JPSRM question 5 is not included in the table as it asked about ILK data availability; it was not a question that would be addressed by the JPSRM. Ice camps including shorter or longer periods when an icebreaker is drifting with the ice with engines turned off)

Overarching question	JPSRM Indicator	Ecosystem parameter / knowledge gained
1. What are the distributions of species with a potential for future commercial harvests in the Agreement Area?	**Hydroacoustics with standardized settings** • Area scattering coefficient (NASC), 18, 38, 70 Khz, 0-800 m depth • Collected during open water or ice camps	Fish abundance and biomass
	Catch per unit effort with standardized long lines • Number of fish by species • Age distribution • Length distribution • Weight distribution • Collected during open water or ice camps	Fish species, age and size distributions [+Calibration of acoustic data (target strength)]
	Catch per effort with standardized trawling in larger leads and open-water areas • Number of fish by species • Age distribution • Length distribution • Weight distribution • Collected during open water or ice camps	Fish species, age and size distributions [+Calibration of acoustic data (target strength)]
	Population demographics • Sex • Maturity • Fecundity • Length frequency • Collected during open water or ice camps	Population trends
		Fish species, age and size distributions during the Holocene (ca. 10,000 years) [provides fish

	Box-core sediment otoliths • Number of fish by species • ^{14}C age • Life-time age distribution • Length distribution (modelled) • Weight distribution (modelled) • Collected during open water	data with climate variability for modelling studies]
	Deep-sea video cameras • Number of fish and squid • Species identification • Collected during ice camps	Fish and squid distributions
	Environmental DNA (eDNA) • Amplicon sequences cytochrome c oxidase subunit 1 (CO1), *Cyt* b • Amplicon sequences rRNA 12S • Metagenomic sequences • Collected during open water or ice camps	Species distributions of fish, squid, their invertebrate prey, and their mammal and bird predators
2. What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?	**Hydroacoustics with standardized settings** • Area scattering coefficient (NASC), 120, 200, 333 Khz, 0-800 m depth • Collected during open water or ice camps	Fish prey distribution and biomass
	Fish, zooplankton, marine mammal and seabird samples • Stomach contents (genomic) • Stable isotopes ($^{™13}$C, $^{™15}$N) • Fatty acids composition • Collected during open water or ice camps	Trophic linkages among fishes and between fishes and other taxonomic groups
	Distribution/numbers /biomass of dependent ecosystem components • Phytoplankton • Zooplankton • Benthos • Marine mammals • Sea birds • Collected during open water or ice camps	Community composition Opportunities for interactions among trophic levels
	Ambient and fossil otoliths • Stable isotope $^{™13}$C • Stable isotope $^{™18}$O • Collected during open water	Reconstruction of ambient temperature and metabolic activity during life span
	Habitat data (water column, sea ice) • Depth • Temperature	Coupling between fish, squid and zooplankton abundances, distributions and trophic linkages and climate variability (food web modelling)

	• Salinity • Current direction and speed • Dissolved oxygen • Nutrient concentrations (e.g., nitrate, nitrite) • Carbonate system • Light levels • CDOM fluorescence • Chlorophyll fluorescence • Chlorophyll *a* concentrations • Particle concentrations (e.g., particulate organic carbon, particulate nitrogen) • Flow cytometry • Particulate organic carbon and δ^{13}C • Benthos (abyssal community) • Marine litter (e.g., microplastics, PCBs, Hg, oil) • Bottom topography and type • Collected during open water or ice camps	Coupling between fish, squid and zooplankton abundances and distributions and ecosystem productivity (modelling)
3. What are the likely key ecological linkages between potentially harvestable fish stocks of the Agreement Area and the adjacent shelf ecosystems that support Indigenous and Local Communities?	• Population genetics of fish, squid, invertebrates, marine mammals and seabirds caught both in the Agreement Area and adjacent regions in all seasons • Numbers of seabirds and mammals both in the Agreement Area and adjacent regions	Connectivity between fish in the Agreement Area and those in the adjacent regions Mechanisms that establish and maintain these linkages Abundance and connectivity of seabirds and marine mammals in the Agreement Area and adjacent regions
4. Over the next 10-30 years, what changes in fish populations, dependent species and the supporting ecosystems may occur in the central Arctic Ocean and the adjacent shelf ecosystems?	**Evaluation of the JPSRM indicators** • Literature studies in relation to the sampled JPSRM indicators and comparison of the JPSRM results with published data from other regions in the Arctic Ocean • Modelling studies of fish and squid abundances and distributions in relation to food web and ecosystem productivity • Evaluation if species can be harvested sustainably with respect to both target fish stocks and dependent parts of the ecosystem • Long-term trends in the nekton community • Long-term changes in the plankton community	Which marine species are likely to be productive in the Agreement Area in the next 10-30 years Which changes in production and key linkages are expected in the Agreement Area in the coming 10-30 years What northward population expansions into the Agreement Area are expected in the next 10-30 years What are the anticipated impacts of changes in ocean acidification in the Agreement Area in the next 10-30 years How increased human activity in the Agreement Area (e.g., ship noise, ship traffic, industrial activity, and pollution) is expected to affect fish populations, ecosystem health, and communities in the next 10-30 years

	• Long-term changes in the benthic community	How increased fishing activity in the Agreement Area is expected to affect other species bycatch, migratory and wide-ranging marine mammals, and the Indigenous and local communities that depend upon these species to sustain their ways of living Evaluation of how fisheries in the Agreement Area might affect adjacent and congruent portions of shelf ecosystems, including fish stocks, fishable invertebrates (crabs, shrimp, mollusks), marine mammals, birds, and fisheries-dependent communities (which include those communities that are dependent on subsistence harvests of fish, invertebrates, and mammals)
5 What Indigenous Knowledge is available to inform ecological baselines?	• Historical and recent changes in harvests, number of animals (i.e. how did the catch of marine mammals and fish fluctuate over the years?) • Sea ice, ocean currents, tides, weather patterns, and other environmental conditions • observed by communities • Movement, distribution, and diet of marine mammals, fish and birds	• Direct, year-round observations of the ecosystems throughout generations • Abundance, distribution, and trophic linkages of invertebrates, fish, birds and marine mammals

2. *Hydroacoustic data collection*

Hydroacoustics with 38, 70 and 120 kHz transducers targeting 0-800 m of depth from all ships and drift platforms entering the Agreement Area. Hydroacoustics with a 38 kHz transducer is effective for observing fish with swim-bladders. Hydroacoustics with 70 or 120 kHz transducers have shorter effective observation ranges but can observe smaller organisms (e.g., zooplankton) or fish without a swim-bladder.

In the Eurasian Basin the central Arctic mesopelagic scattering layer occurs in the Atlantic water layer at 100-600 m of depth[10,11], but this may be lower on the Pacific side. No usable acoustic data can be collected while steaming in ice due to the sound of ice-breaking. Therefore, it is recommended to stop the engines for ten minutes and drift with the ice after a certain time window. For example: steaming 50 min, drifting 10 min. Drift platforms are ideal for collecting acoustic data. Disturbances from the ship can occur (electrical, mechanical, acoustic) and should be avoided while collecting acoustic water-column data. When possible,

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[10] *Snoeijs-Leijonmalm P, et al. (2021) A deep scattering layer under the North Pole pack ice. Progress in Oceanography 194:102560 [*https://doi.org/10.1016/j.pocean.2021.102560*]*

[11] *Snoeijs-Leijonmalm P, et al. (2022) Unexpected fish and squid in the central Arctic deep scattering layer. Science Advances 8:eabj7536 [*https://www.science.org/doi/10.1126/sciadv.abj7536*]*

hydroacoustic measurements should be collected and combined with trawling, but this is only possible if open water is available. It may also be advantageous to use hydroacoustics on smaller platforms, such as submerged moorings, ROVs or autonomous gliders.

3. Sampling of fishes and benthos

Fish sampling methods adapted to the Agreement Area need to be developed further during the mapping phase. Methods need to be evaluated to ensure that vulnerable habitats are not damaged in the long term. Recent surveys have found very low abundance of mesopelagic fishes due to the low productivity of the ecosystem[14,15]; therefore, the sampling effort required to collect specimens is expected to be higher than in comparable surveys in subarctic or temperate waters. In the Eurasian Basin, long-line fishing seemed to be only successful for larger predatory fish species >30-40 cm, while small mesopelagic fish species could not be caught by line-fishing, gill nets, ring nets or traps. On the echosounder, the few fish that occur have been seen fleeing any sampling gear that is lowered in the water column (which proves that fish are present but difficult to sample). Trawling with ice-modified trawls has been successful[12]; the results have reaffirmed the low densities encountered by previous expeditions (*Annex 14-15*). Despite these challenges, the use of multiple fishing gears is encouraged in order to capture as diverse a range of fish samples as possible. In particular, sampling of sympagic fishes (ice-associated polar cod juveniles) in the Agreement Area is possible using a special-designed "Surface- and Under-Ice Trawl (SUIT)[13] that has proven successful at sampling sympagic fishes under ice cover. Benthic fishes observed in the central Arctic Ocean consist of non-commercial species, except for Greenland halibut *Reinhardtius hippoglossoides* of which single (juvenile) specimens have been encountered in the southern part of the Agreement Area during two sampling events (*Annex 04 and 14*). Although bottom trawling can be very disruptive to benthic habitats and should be avoided in sensitive benthic areas such as locations with concentrations of corals and sponges, trawls conducted for scientific purposes corresponding to the JPSRM will be allowed if precautionary measures are taken before trawl operation. Prior to using benthic trawls and other disruptive sampling methods the benthic habitat should be examined using non-disruptive methods such as drop cameras, near-bottom video sleds or ROVs to determine if the area represents a sensitive benthic area. For efficiency forward-looking trawl-mounted cameras could be used if they allow live-video that can be viewed by the captain that provides observation of the seafloor sufficiently far ahead of the sampling gear to allow the captain to abort deployment before the gear makes contact with the seafloor. In addition, benthos, particularly macrobenthos, play an important role in ecosystem functioning and processes. Benthic standing stocks may support key benthic-feeding apex predators, including Pacific walrus (*Odobenus rosmarus divergens*), gray whales (*Eschrichtius robustus*), and bearded seals (Erignathus barbatu), thus functioning as a crucial component in the Arctic food-web. Therefore, full considerations should be given to sampling of various benthic invertebrates using box corers or alternate methods.

4. Holocene otoliths

Fish species distributions in the Agreement Area over a longer time scale (Holocene, ca. 10,000 years) can be assessed from otoliths in deep-sea sediments (*Annex 12-13*). To collect enough otoliths a large box core

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[12] *Ingvaldsen, R.B., Eriksen, E., Gjøsæter, H. et al. (2023). Under-ice observations by trawls and multi-frequency acoustics in the Central Arctic Ocean reveals abundance and composition of pelagic fauna. Scientific Reports 13, 1000. [https://doi.org/10.1038/s41598-023-27957-x]*

[13] *Van Franeker JA, et al. (2012). The Surface and Under Ice Trawl (SUIT). Technical Report [*https://www.researchgate.net/publication/297794282*]*

sample is necessary (e.g., surface 50×50 cm, the Holocene layer in the CAO ca. 10-15 cm deep). The geological age of the otoliths is dated with the ^{14}C method, the age of the fish at death is determined from otolith increments. During the Holocene there have been warmer and colder periods, notably the Holocene thermal maximum from around 9000 to 5000 years before present[14]. Thus, the results can be used for modelling of fish abundance in relation to climate variability. The ambient temperature experienced by the fish is reconstructed with the stable isotope radio $\delta^{18}O$, and metabolic activity by the stable isotope ratio $\delta^{13}C$ 13C in the otoliths. The number of otoliths in each layer can be related to temperature and we can predict if fish stocks will increase with climate warming in the future. From the otoliths we can also extract the age of the fish when they died and assess the impacts of temperature on maximum age and age structure of fish stocks.

5. *Environmental DNA*

Environmental DNA (eDNA) can be used to reconstruct species distributions. A genomic pipeline for Arctic samples focusing on fish and zooplankton is being tested by EFICA (the European Fisheries Inventory in the Central Arctic Ocean Consortium) and results will be evaluated by 20 February 2023 (*Figure 3*). Several methods using whole metagenome and amplicon sequencing are used to construct distribution maps of fish, squid, and key zooplankton, perhaps also birds and mammals. When taking eDNA samples all rules for clean sampling in molecular biology must be used. The method is very sensitive and special care should be taken to not contaminate samples from the water column and the ice with, e.g., fish bait (use obligate freshwater species as bait) or waste water discharge from the ship (forbid any ship discharge before sampling has been terminated at each sampling station).

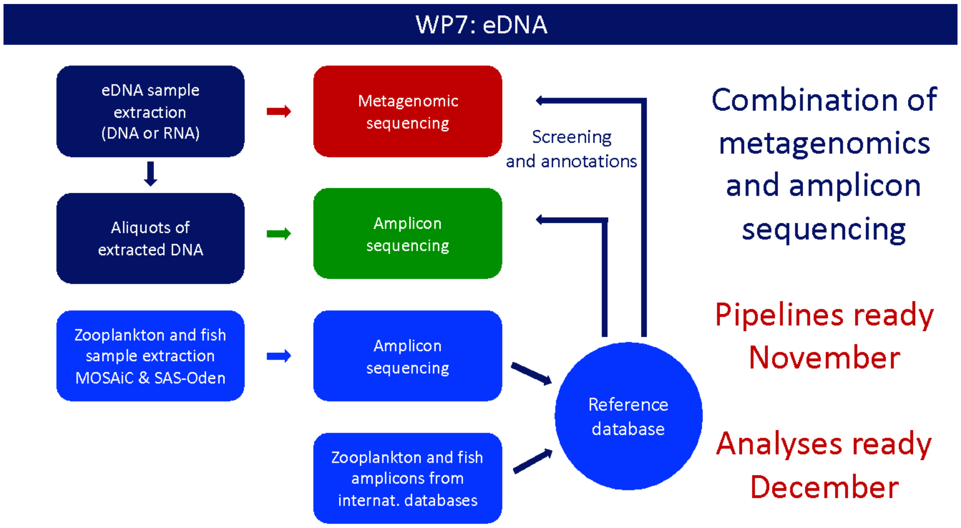

Figure 3: EFICA pipelines for eDNA analyses.

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[14] *Park HS, et al. (2019) Mid-Holocene Northern Hemisphere warming driven by Arctic amplification. Science Advances 5:eaax8203 [https://www.science.org/doi/10.1126/sciadv.aax8203]*

6. Deep-sea cameras

Underwater cameras, ROVs and AUVs currently exist that could be deployed to collect data on fish and invertebrate species both on the benthos and in the water column where sampling is extremely difficult. Combining image collection with automatic detection of moving objects (fish, squid, macrozooplankton) from drifting and moored platforms is a good complement to assess species distributions in the Agreement Area and could potentially be a non-destructive sampling method. Experience has indicated that attaching a camera to a CTD has limited success for fish and squid because a CTD moves fast except during water sampling for very short times at specific depths, and fish actively avoid the moving CTD. Due to the generally low abundance of fish and squid, recording many hours is necessary. Thus, targeted deployments of cameras is likely to result in higher success in capturing abundance and distribution patterns of fishes and squids. There has been considerable research in recent years into combining acoustic and optical surveys for fishes (e.g., deployments of cameras guided by acoustic observations of fish). ROV's and AUV's could both be deployed to target both midwater and benthic species. There is also potential to deploy towed camera systems, drift camera systems or stationary camera systems (e.g., floating in the water column, but anchored to the seafloor) that could cover larger areas and potentially require less cost and technological expertise. Size data for species can also be obtained from either using calibrated stereo cameras or laser systems. Finally, underwater cameras can be combined with other gear types for auxiliary data collection. For example mounting stereo-cameras in trawl nets can allow estimation of gear selectivity or even allow fishing with an open codend that becomes a non-destructive method of capturing abundance and size information.

7. Trophic linkages

Trophic linkages among fishes and between fishes and other taxonomic groups are studied by analyzing stomach contents with metabarcoding and by comparing stable isotope ratios $\delta^{13}C$ and $\delta^{15}N$ in zooplankton and fish muscle. An additional method used as a trophic tracer is fatty acid composition in fish (and squid) muscle and liver and in other components of the food web, but this method is more elaborate and expensive. Estimates of phyto- and zooplankton biomass and numbers will be based upon net catches, as well as from acoustic (AZFP and ADCP) data. Phyto- and zooplankton species will be determined from plankton net hauls. Sediment traps collect sinking particles associated with the phyto- and zooplankton distributions and carbon cycles. Mooring systems including sediment traps with physical, chemical, and biological sensors can monitor annual and interannual changes in phyto- and zooplankton communities.

8. Physical and biogeochemical data

As a standard, research vessels collect oceanographic data with a CTD to measure conductivity (salinity), temperature and depth. CTD rosettes usually carry other instruments as well, such as CDOM fluorescence, chlorophyll fluorescence, UVP particle concentrations. Water samples are taken to measure basic indicators of ecosystem productivity, such as dissolved oxygen, inorganic and organic nutrients, CO_2 (carbonates), chlorophyll *a* concentration, photosynthetic pigments, particulate organic carbon (POC), $d^{13}C$, flow cytometry (cell abundances of bacteria and primary producers), etc. Acoustic Doppler Current Profilers (ADCP) can be used to estimate changes in fluxes and water masses northward through the Atlantic and Pacific gateways, which may be linked to species range expansions either by affecting environmental conditions or entrainment of individuals. Moorings with ADCPs placed in various locations in the gateway would facilitate monitoring of changes in currents.

All these data are useful for modelling fish-stock abundance in relation to the environment and trophic status. For the JPSRM it would be useful to collect all CTD profiles available in international databases made in the Agreement Area during the last 30 years as well as all CTD profiles that will become available during the 14 years of the JPSRM.

9. Population genetics of fish and squid

Population genetic analyses of fish and squid caught both in the Agreement Area and adjacent regions establish connectivity pathways between coastal spawning areas and adults living in the Agreement Area. Principal candidates for such studies (based on the current knowledge) are polar cod *Boreogadus saida*, ice cod *Arctogadus glacialis*, Atlantic cod *Gadus morhua*, Greenland halibut *Reinhardtius hippoglossoides*, Walleye pollock *Gadus chalcogrammus*, Arctic skate *Amblyraja hyperborea*, and armhook squid *Gonatus fabricii* that all are known to occur in the Agreement Area. Other candidates include haddock *Melanogrammus aeglefinus, Bering flounder Hippoglossoides robustus, Alaska plaice Pleuronectes quadrituberculatus,* and beaked redfish *Sebastes mentella*. Many species of fish are also relied upon by Arctic Indigenous communities who live adjacent to the Agreement Area.

10. Distribution of birds and mammals

Distributions of marine birds and mammals both in the Agreement Area and adjacent regions are necessary to assess the abundance and connectivity of fish predators in the Agreement Area. Marine mammals, migratory birds and seabirds, their flyways and nesting colonies, are also significant and new to be understood, especially with increasing changes in Arctic ecosystems. Many migratory birds, seabirds and marine mammals are relied upon by Arctic Indigenous who live adjacent to the Agreement Area; an important goal of the JPSRM is understanding potential impacts from fisheries on the ecosystem to ensure CAO ecosystems remain healthy and productive, including maintaining healthy marine mammal and bird populations that sustain ongoing harvests. Very few data exist from the Agreement Area and they are mainly anecdotal. It is anticipated that bird and marine mammal densities are currently low in the Agreement Area, with the exception of the Chukchi Sea. A possible task for the JPSRM could be to compile data from as many previous expeditions to the Agreement Area as possible, e.g., using photographic documentation by cruise participants.

11. Indigenous Knowledge and Local Knowledge

The ICC has defined Indigenous Knowledge as:

> “Indigenous Knowledge is a systematic way of thinking applied to phenomena across biological, physical, cultural, and spiritual systems. It includes insights based on evidence and acquired through direct and long-term experiences and extensive and multigenerational observation, lessons, and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, and it is passed on from generation to generation.

> Under this definition, Indigenous Knowledge goes beyond observations and ecological knowledge, offering a unique way of knowing to identify research needs and apply to research, monitoring, assessments, decision-making, policy and the overall understanding the Arctic – it is our Way of Life."

Inuit bring a holistic understanding of the Arctic ecosystem, our homeland, which looks at the dynamic relationship between its components that are interrelated and interdependent. Because of this unique understanding, Inuit have thrived and survived in the Arctic for thousands of years.

12. Local Knowledge

Local knowledge is the knowledge that people in a given community have developed over time, and continue to develop[15]. It is:

- Based on experience
- Often tested over centuries of use
- Adapted to the local culture and environment
- Embedded in community practices, institutions, relationships and rituals
- Held by individuals or communities
- Dynamic and changing

13. Modelling studies

Data regarding species distributions, particularly in relation to oceanographic conditions, water depth and benthic morphology and substrate (for benthic species), and results of diet studies and trophic analyses can be combined to develop models of CAO populations and communities. Given expected low abundances for most species and the relatively short duration of the mapping phase (3 years) local data on reproductive rates and other demographic parameters will be limited and likely will need to be borrowed from other populations for model development. The monitoring phase of the JPSRM will provide an opportunity to estimate demographic variables and patterns within the CAO to support model refinement prior to fishery development.

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[15] FAO (2004). Training Manual "Building on Gender, Agrobiodiversity and Local Knowledge". [What is local knowledge? (fao.org)]

ANNEX 1: Framework of the Joint Program Scientific Research and Monitoring

Appendix 9. *Excerpts from FiSCAO and PSCG meetings providing examples of topics that should be addressed when establishing priorities for the JPSRM implementation plan. These examples are not listed in priority order, and they comprise only a partial list of relevant topics to be considered in the implementation plan.*

Sampling information from subareas of the CAO High Seas and adjoining marine areas.
Criteria for prioritizing subareas in concerning the relative availability (or lack) of information, degree of sea ice loss, and water depth. Examples of potential demersal areas include the East Siberian Sea including the Chukchi Borderlands and waters northwest of Wrangel Island.
Refuge areas for polar fishes from climate change effects, both physical and biological, within which species can complete their lifecycles are of particular ecological importance.
Synoptic mapping surveys conducted over as much of the High Seas CAO as possible following standardized sampling protocols and the use of consistent data formats.
Historic and contemporary baseline data that may be available through indigenous and local knowledge holders regarding species distributions and abundances, and environmental conditions in waters adjacent to the High Seas CAO, and to a lesser extent within the High Seas CAO.
Data from previous data collection programs to be identified and prioritized for the Pacific and Atlantic gateways.
Pelagic surveys conducted in areas where there have been documented, observed, or expected northward range expansions by potentially harvestable species.
Surveys in areas where environmental changes have been documented or are expected to occur.
Identifying which indicators are most important for detecting change in the current and future status of commercial fish stocks and dependent (subsistence harvested and protected) species.
The extent to which the JPSRM should focus on marine species that are: 1) potential targets of commercial fisheries, 2) harvested for subsistence purposes, or 3) already protected by governmental or intergovernmental conservation measures.
Data collection priorities focusing on: 1) identifying fish species distributions and relative abundances, 2) understanding population structure and the factors affecting species distributions and productivity.
Assessing the availability and viability of data for species of commercial and subsistence interest, including: 1) distributions of potential commercial fishes and invertebrates, 2) fishing vessel activity in waters adjacent to the High Seas CAO, and 3) marine mammal and seabird abundance, distributions, diets, condition or foraging behaviors.
Cumulative impacts on ecosystems due to anthropogenic activities in addition to potential impacts of commercial fisheries (e.g., shipping, energy).
Understanding broad ecosystem components, including: zooplankton transport and potential establishment into the High Seas CAO, deep scattering layer, primary productivity and associated variables, sea ice, ocean currents, sea temperature, ocean acidification.
Current physical, chemical and biological oceanographic conditions and the distributions and abundances of marine invertebrates, fishes, mammals, and birds in the High Seas portion of the central Arctic Ocean and surrounding waters.