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28–29 May 2015

Bergen, Norway

ICES
International Council for the Exploration of the Sea
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Conseil International pour l'Exploration de la Mer

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Executive Summary

The joint **ICES/AMAP/CAFF/PAME Workshop on Integrated Ecosystem Assessment (IEA) for the Arctic Ocean** (WKICA) met in Bergen, Norway, 28–29 May 2015. Eighteen participants from five countries (Canada, Iceland, Norway, Russia and USA) attended the workshop.

The purpose of an IEA for the central Arctic Ocean (ToR a) was seen as twofold: 1) provide a holistic and integrated view on the status, trends and pressures, and 2) contribute to implementation of the EA to management of the central Arctic Ocean. Regarding the review of data and information that could be used for an IEA (ToR b), the meeting noted findings from an Inventory of Arctic Research and Monitoring (IARM) resulting from the Third Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean in April 2015.

The geographical scope of an IEA (ToR c) should include the Central Arctic Ocean LME and the slope regions of the adjacent shelf LMEs and also shelf portions where relevant. The fluxes and properties of water through the Atlantic and Pacific gateways need also to be taken into account when addressing physical and biological variability of the basins of the Arctic Ocean.

The thematic scope of an IEA should include three main pressures or human activities: climate change, shipping and fisheries. The Arctic Ocean is undergoing change as part of the global climate change, with extensive loss of summer sea ice (by nearly 75%) since the 'pre-melting' period in the 1970s. An assessment of the current ecological status of the Central Arctic Ocean is to a considerable degree also an assessment of the impacts of climate change. In addition, the IEA could include impacts of continued warming and loss of sea ice towards a potentially ice-free Arctic Ocean in summer based on climate projections. There is a need to identify sensitive and vulnerable areas (with regard to oil spills and shipping) as a basis for considering the needs for measures to regulate shipping activities in the Arctic Ocean. Regarding fisheries the IEA could address questions whether there are fishable concentrations and what is the potential fish production in the central Arctic Ocean. Other topics that could be included in an IEA are pathways of contaminants, pollution effects, and the risk of introduction and spread of invasive species.

WKICA agreed that it would be worthwhile and good if ICES established a working group on IEA for the central Arctic Ocean (WGICA) jointly in collaboration with Arctic Council (AC) working groups. It is suggested that the new group should consider the approach and methodologies for doing an IEA the first year as well as starting to assemble data and information building from IARM. Conducting the IEA could then be done over the next two years including integrated data analyses across datasets and preparing the IEA report.

1 Background and introduction

In the ICES Strategic Plan 2014–2018 it is stated:

"The ICES Strategic Plan commits to building a foundation of science around one key challenge; integrated ecosystem understanding. ICES will produce integrated ecosystem assessments in regional seas as a fundamental link between ecosystem science and the advice required in applying the ecosystem approach."

ICES has signalled a commitment to increase its scientific efforts in the Arctic. ICES is already heavily involved with fishery advice and other activities (e.g. status reports on climate and plankton) in the Subarctic part of the Arctic area in the North Atlantic, and ICES work in the past has included the Arctic Ocean.

The Protection of the Arctic Marine Environment (PAME) working group under the Arctic Council (AC) has led work to promote the use of the Ecosystem Approach to Management (EA) by Arctic States, individually and collectively in the AC. PAME established an expert group on the EA (EA-EG) in 2007, which was broadened to become a joint expert group with participation of other AC working groups in 2011. The EA-EG has produced a revised map of 18 Large Marine Ecosystems (LMEs) in the Arctic (PAME 2013; http://www.pame.is/index.php/document-library/all-documents) and an EA concept paper with a suggested framework for implementing the EA in the Arctic.

The ICES General Secretary (Anne Christine Brusendorff) attended the PAME I-2014 meeting in February 2014. In the Records of Decisions from the meeting, PAME invited the EA-EG to consider possible areas of cooperation with ICES on integrated ecosystem assessments. The present workshop is an activity stemming from follow-on work on this issue, which included consultations with the AMAP and CAFF secretariats. ICES has established working groups for doing Integrated Ecosystem Assessments (IEA) for regional ecosystems such as the Baltic Sea, the North Sea, and the Northwest Atlantic. Two of these groups are for Arctic LMEs: the Barents Sea (WGIBAR) and the Norwegian Sea (WGINOR).

IEA is a core component of the EA. The EA framework suggested by the EA-EG contains six elements:

- **Identify** the ecosystem
- **Describe** the ecosystem
- Set **ecological objectives**
- **Assess** the ecosystem (IEA)
- **Value** the ecosystem
- **Manage** human activities

The present workshop is a scoping and planning step for doing an IEA for the Arctic Ocean. The Central Arctic Ocean with the deep Eurasian and Amerasian basins separated by the Lomonosov Ridge has been identified as one of the Arctic LMEs. This LME is defined according to ecological criteria and does not follow political boundaries (Figure 1). It includes much of the international waters (High Seas) but also parts of the Exclusive Economic Zones (EEZs) of Denmark/Greenland, Norway (Svalbard) and the Russian Federation. On the Pacific side, parts of the High Seas area are included with the Northern Bering – Chukchi Sea and the Beaufort Sea LMEs.

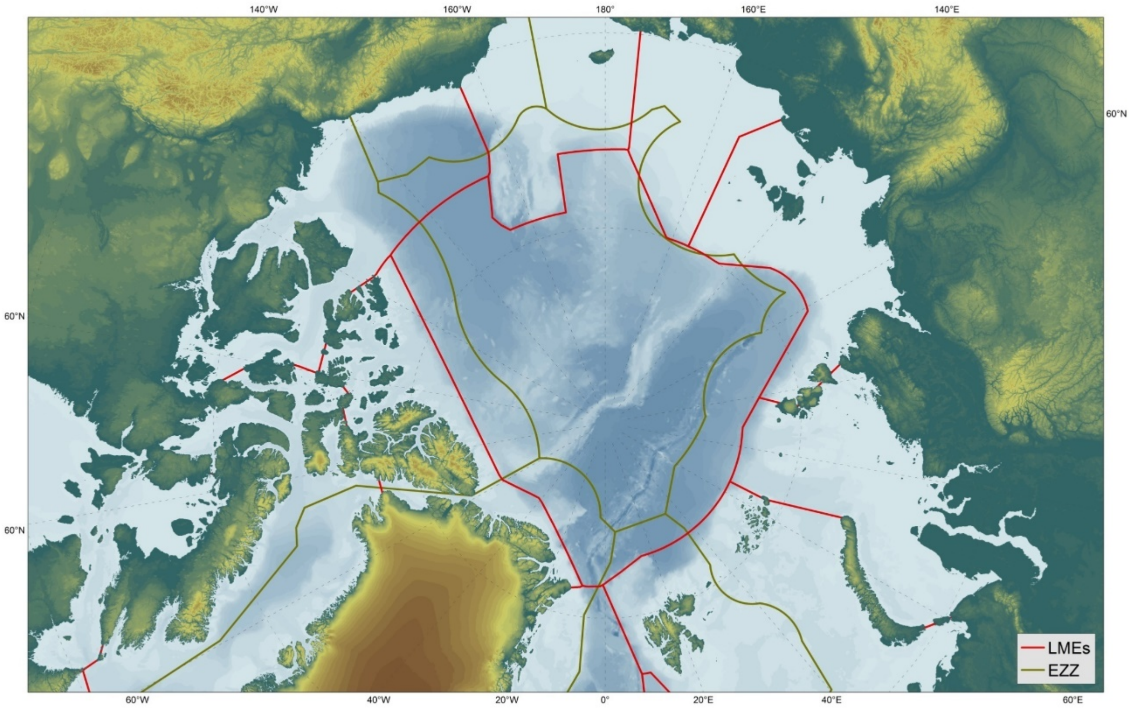

Figure 1. Map of the Central Arctic Ocean LME and adjacent Arctic LMEs (red lines) and political boundaries between national Exclusive Economic Zones and the international waters of the High Seas (green lines).

Preparing an IEA for the central Arctic Ocean can be seen as one step to facilitate an integrated and holistic approach to management of this globally unique ecosystem which now is threatened by global climate change and other (associated) pressures such as transpolar shipping and potential fisheries.

Although not an explicit component of the six-element EA framework given above, **monitoring** is an essential activity to inform an IEA. Once operational, conducting IEA should be a repetitive activity in an iterative management cycle to provide an updated description and analysis of ecosystem conditions and pressures as a basis for scientific advice on any adjustments and new management measures to maintain or achieve defined ecological objectives. Monitoring along with scientific research provide updated information on conditions and improved insight into mechanisms and relationships in the ecosystem including human activities and pressures.

Box – The central Arctic Ocean

The Arctic Ocean consists of two deep basins (Eurasian and Amerasian separated by the Lomonosov Ridge) surrounded by shelves, each consisting of about half the total area. The Central Arctic Ocean (CAO) LME is defined according to ecological criteria and consists of the Eurasian and much of the Amerasian Basin (except the southern part of the Canada Basin, which is part of the Beaufort Sea LME). The CAO LME includes most of the waters outside national jurisdiction (the High Seas) except for portions which are included in the Beaufort Sea and northern Bering-Chukchi Sea LME.

In this report, we use the term 'central Arctic Ocean' to mean a wider area than the CAO LME, including the slope regions around the basins, which constitute parts of the adjacent shelf LMEs. See Figure 1 for the boundaries for the defined LMEs as well as the boundaries between the High Seas and waters under national jurisdiction within EEZs.

2 Terms of reference for the workshop

a) *Consider the purpose and scope of an Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean.*

b) *Review the data and information available from past and ongoing monitoring and research that could be used in and inform the conduct of an IEA.*

c) *Consider the geographical scope for a Central Arctic Ocean IEA, in particular the relationships to the 'up-stream' Atlantic (Barents Sea and Fram Strait) and Pacific (Bering Strait and Chukchi Sea) gateways.*

d) *Consider the thematic scope of an IEA, e.g. impacts from climate variability and change, contaminants and pollution, shipping, and fisheries.*

e) *Suggest practical steps for initiating and carrying out an IEA for the Central Arctic Ocean.*

Supporting information including scientific justification for the Terms of reference (ToRs) given by ICES is included in Annex 1.

3 Participants and agenda

Eighteen participants from five countries (Canada, Iceland, Norway, Russia and USA) attended the workshop. The list of participants is included as Annex 2.

An agenda for the meeting was prepared to address the five items of the ToRs (Annex 3). To provide background for the workshop, four presentations were given in the first part of the program.

Hein Rune Skjoldal presented some background information including the definition of the Central Arctic Ocean LME, the EA framework developed by the EA-EG, and the ToRs for the workshop.

Bodil Bluhm (University of Tromsø) presented (remote via Video) an overview of the physical and biological oceanography of the Arctic Ocean basins based on a paper in press (in Progress in Oceanography) co-authored with Ksenia Kosobokova and Eddy Carmack. The paper was also provided as a background document made available to participants at the workshop SharePoint site prior to the workshop.

Igor Melnikov (Shirshov Institute of Oceanology, Moscow) gave a presentation on the ecology of sea ice biota and changes observed during the last 40 years as the sea ice has melted and changed from predominantly multiyear drift ice to now mainly seasonal ice formed as new ice each winter. Melnikov has worked on the sea ice in the central Arctic Ocean for 40 years and has personally witnessed and documented substantial changes in species abundance and diversity associated with the reduction and changes in sea ice from the 'pre-melting' period in the 1970s to the present situation with much reduced and thinner ice cover in summer.

Yvonne Walter (Sweden and ICES SCICOM Chair) gave a remote presentation on ICES ecosystem work including IEA and engagement in the Arctic.

The presentations are available at the ICES SharePoint site for the workshop.

4 ToR a – Consider the purpose and scope of an Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean

An IEA sits as one of the six elements of the EA framework presented above. There it provides a critical link between ecosystem sciences on the one hand and advice to policy and ecosystem based management on the other. IEAs serve three main purposes: i) reporting on status and trends including human pressures, ii) helping us set ecological objectives, and iii) reporting on progress toward objectives. There is not yet a blueprint for how to do an IEA, and IEA does mean different things to different people. We are basically at the stage of 'learning by doing' as we are progressing in this field.

ICES has established regional working groups to do IEAs for several ecoregions (which are often equivalents to LMEs) including two of the Arctic LMEs: the Barents Sea and the Norwegian Sea. The approach and methodologies used to carry out IEAs differ across regions and groups, and through this work ICES is gaining experience through a collective learning process. This includes considerations of how the outcome of IEAs should be used to provide management advice in the context of the EA to management.

Integration can occur at many levels, from multispecies stock assessments through multi-sectoral impact assessments to fully fledged integrated assessments including socio-economic drivers and consequences back on society. In an operational EA system, IEA would have to be repeated as part of an iterative process that includes gathering observations germane to the attainment of ecological objectives in the ecosystem(s) in question. As we are moving toward this ideal, an IEA is probably best seen as a modular build-up of assessment components, which can be used to construct the overall integrated assessment. Examples of such modular components can be status assessments of species, populations (e.g. commercial fish stocks) and habitats, and various impact assessments, e.g. of climate change, shipping, oil and gas developments, and others. A main challenge lies in the integration; how do we integrate between the status and impact assessments, and how do we address the combined and cumulative effects of various pressures in a scientifically sound manner? An IEA would likely have to include integrated data analyses (e.g. multivariate statistics and mathematical modelling) and integrated scientific analysis across disciplines and sectors.

The purpose of an IEA for the central Arctic Ocean would be twofold:

1) Provide a holistic and integrated view on the status, trends and pressures of the Central Arctic Ocean by building on and drawing together information from past and ongoing assessments and from recent and current research.
2) Contribute to implementation of the EA to management of the central Arctic Ocean (including the High Seas portion beyond areas of national jurisdiction) by providing a better scientific understanding of the current status and trends and the need for management measures (e.g. in relation to transpolar shipping and potential future fisheries).

The scope of an IEA for the central Arctic Ocean in terms of geography and themes is considered in more detail under ToRs c and d, which follow. The overall scope would be to address identified short-term needs to inform policy and management considerations, e.g. in relation to shipping and fisheries, and to summarize the available information on status, trends and pressures to inform policy considerations on more long-term needs under continued climate change and altered (increased) human pressures.

An IEA for the central Arctic Ocean will bring together all relevant information and expertise to examine and elucidate the ongoing changes and pressures on the basins of the central Arctic Ocean. If the assessment is carried out by ICES in collaboration with working groups of the AC, such as AMAP and CAFF, ICES would bring to the table its experience and expertise on doing IEAs and the use of information from such analysis in an advice context as part of the EA. The activity would also serve as an impetus and model for closer coordination and cooperation between AMAP and CAFF within the AC family (which is worthwhile in its own right).

5 ToR b – Review the data and information available from past and ongoing monitoring and research that could be used in and inform the conduct of an IEA

Preliminary findings from an Inventory of Arctic Research and Monitoring (IARM) from the Third Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean in April 2015 presented at this workshop, and information presented by Russia, also at this workshop, indicate that there is a very large body of scientific observation, analysis and modelling on which to base an IEA for the central Arctic Ocean, however gaining access to the information may be problematic. It should be noted that geographic, temporal and disciplinary gaps in the information available could leave the IEA for some locations and topics in the central Arctic Ocean incomplete.

As was concluded by the IARM process, a comprehensive and timely review of the data and information available from past and ongoing monitoring and research relative to an IEA is a formidable and expensive task unto itself. The IARM (available only in draft until June 30, 2015) encompasses extensive reports on the national programs of arctic monitoring and research for Canada, Norway, Russia and the United States pertaining to the geographic area herein called the central Arctic Ocean. Information on arctic research activities of China, Greenland/Denmark, Iceland, Korea and Japan are also presented. The draft IARM identifies a large body of published literature and other written work. In final form, IARM will include lists of key information resources, including notable written references by Large Marine Ecosystem, national websites for metadata and data discovery, arctic research institutes by nation, and other significant information resources.

Further conclusions of IARM relevant to WKCIA with regard to observations, model data and information products (information) relevant to fish stocks and their biological and physical controls in the central Arctic Ocean (artic) are as follows:

- The information and data available from arctic research and monitoring are highly variable in geographic distribution and temporal density.
- Geographic variation in information is pronounced, being generally more available from areas without permanent ice.
- Areas with commercial fisheries adjacent to or nearby the Central Arctic tend to have more biological information than others.
- Physical disciplines (ocean and atmosphere) have more information than biological, economic and human dimensions.
- Physical information on the (atmosphere and) surface is much more dense than in subsurface.
- There are many sources of arctic information.
- Sources of information have not been systematically identified; there is no identifiable starting point for locating arctic information.

- The volume of arctic information is now very large and growing rapidly, nonetheless with respect to arctic information of interest the growth is not necessarily organized or directed toward types of information most suitable to understanding management of fish stocks in the central Arctic Ocean and relevant adjacent areas.

6 ToR c – Consider the geographical scope for a Central Arctic Ocean IEA, in particular the relationships to the 'up-stream' Atlantic (Barents Sea and Fram Strait) and Pacific (Bering Strait and Chukchi Sea) gateways

The boundaries of the Central Arctic Ocean LME to the surrounding shelf LMEs follow the outer slopes on the Eurasian side from the Barents Sea to the Chukchi Sea LMEs. In the Canadian Basin the boundary to the Beaufort Sea is along 76oN leaving the southern portion of the basin as part of the Beaufort Sea LME. The boundary to the Canadian High Arctic-North Greenland LME is along the shelf edge (PAME/Skjoldal and Mundy 2013). The justification for including the upper slope (down to approximately 1.000 m depth) is the large role that the Atlantic (-derived) water flowing as part of the Arctic Circumpolar Boundary Current (ACBC) has on the adjacent shelf LMEs (Barents, Kara, Laptev, East Siberian and Northern Bering-Chukchi LMEs).

In discussion, it was pointed out that processes along the slopes as well as on the shelves have also influences on the basins. Therefore, it was considered important to include the slopes in the geographical scope when focusing on the basins of the Central Arctic Ocean. This would also be the case for relevant processes on the shelves, such as input of freshwater from rivers and reproduction of one of the dominant copepods, *Calanus glacialis*. Thus, the area for the IEA should include the Central Arctic Ocean LME and the slope and relevant shelf regions of the adjacent shelf LMEs.

The Central Arctic Ocean is very much influenced by inflow and through-flow of Atlantic water from the Barents and Fram Strait branches and of Pacific water coming north through the Bering Strait and Chukchi Sea. Due consideration needs therefore to be given in an IEA to the variable flow and properties of Atlantic and Pacific waters flowing into the Arctic Ocean through the Atlantic and Pacific gateways. Information on these flows are available from monitoring and ongoing studies in the Barents Sea, Fram Strait, and Bering Strait and Chukchi Sea regions.

In conclusion, the geographical area for an IEA should include the Central Arctic Ocean LME and the slope regions of the adjacent shelf LMEs and also shelf portions where relevant. The fluxes and properties of water through the Atlantic and Pacific gateways need also to be taken into account when addressing physical and biological variability of the basins of the Arctic Ocean.

7 ToR d – Consider the thematic scope of an IEA, e.g. impacts from climate variability and change, contaminants and pollution, shipping, and fisheries

The chair of this ToR session (Reidar Hindrum) presented a list of topics or themes which was used to frame the discussion on the thematic scope of an IEA for the Central

Arctic Ocean. The list below is given without implying any priority in terms of importance with respect to pressures or impact or with regard to inclusion in an IEA assessment.

1) Impact from climate variability and change (incl. sea ice distribution and change, river discharge)
2) Contaminants and pollution
3) Fisheries
4) Other industrial activities – petroleum (oil and gas) exploration and exploitation, shipping, tourism
5) Conservation, biodiversity issues, habitat change (sea ice)
6) Invasive species transported by ship (ballast water, hull fouling) or spreading due to changing temperature and transport pathways
7) Dynamics in sea ice distribution, currents, ecosystems

The listed topics are to some extent connected. Thus industrial activities such as the petroleum industry and shipping may cause pollution (notably oil spills), and shipping is related to the issue of invasive species. Dynamics of the ecosystem is a general issue that needs to be addressed in an IEA both as part of the general ecosystem description and in relation to climate variability and change and potential impacts of human activities. Conservation and biodiversity issues are related to industrial activities such as petroleum, shipping and tourism through considerations of sensitivity and vulnerability of species and places to factors such as oil spills and disturbances.

A document has been prepared by the Co-Chairs (Skjoldal) on issues and questions that could be used to guide an IEA for the Central Arctic Ocean. The document is structured with a short narrative and some questions under the headings of: climate variability, productivity, fish stocks and potential fisheries, biodiversity and vulnerability, and contaminants and pollution. A revised version of this document is included as Annex 4.

A summary of the discussion on themes to be potentially covered in an IEA for the Central Arctic Ocean is given below.

Climate variability and change

The changes in sea ice and oceanographic conditions over recent decades have been treated in several assessments, notably the Arctic Climate Impact Assessment (ACIA) in 2005 and Snow, water, ice and permafrost in the Arctic, SWIPA in 2011. Updated information is provided in the annual Arctic Report Card produced by US NOAA and AMAP. CAFF is preparing plans to produce a report on the status of Arctic marine biodiversity, including in the Arctic Ocean, in 2017. AMAP is currently producing integrated assessment reports for the three regions Barents, Baffin Bay/Davis Strait and the Bering/Chukchi/Beaufort areas ('Adaptation Actions for a Changing Arctic' - AACA).

The basins of the central Arctic Ocean are an integral part of the Arctic Mediterranean, which also includes the Nordic Seas (Greenland, Iceland, Norwegian Seas) north of the ridge from Scotland via Faroe Isles and Iceland to Greenland. One aspect of assessing climate variability of the Arctic Ocean is to provide a better basis for interpreting and understanding changes taking place in the Subarctic seas adjacent to the Arctic Ocean, which have large fisheries and are core areas for ICES advice.

Climate variability (e.g. variations in sea ice conditions or water circulation patterns) is expected to have major influences on the biology and ecology of the Central Arctic Ocean. Therefore, it is necessary to include effects of climate variability of an IEA as a basis for assessing additional impacts from, or vulnerability to, existing or future human activities, such as shipping (see below).

ACIA and SWIPA have concluded that the Arctic is undergoing change as part of the global climate change. Igor Melnikov in his presentation described the changes from the situation in the 1970s, which he termed the 'pre-melting' period, to the present situation where there has been extensive loss of summer sea ice (by nearly 75%). An assessment of the current ecological status of the Central Arctic Ocean is to a considerable degree also an assessment of the impacts of climate change. An IEA could also have a forward-looking part, assessing the impacts of continued warming and loss of sea ice towards a potentially ice-free Arctic Ocean in summer, based on some future climate projections such as those used in the AACA-C project for the Barents Sea case.

Productivity

The primary production by phytoplankton and ice algae and secondary production by zooplankton and ice-associated crustaceans and other biota are basic characteristics of the central Arctic Ocean. Primary production is strongly limited by light and nutrient availability and is variable and patchy in time sand space dependent on season, ice conditions and oceanography. The secondary production by herbivorous (or omnivorous) zooplankton is similarly dependent on sea ice and oceanographic conditions and on the amount and production of algal food.

An assessment of the magnitude and spatial and temporal variability of primary and secondary production should be a core component of an IEA of the central Arctic Ocean. This would be an important part of the evaluation of biological and ecological effects of climate variability and change, and would be important for evaluating the potential fish production in the Arctic Ocean.

Fish stocks and potential fisheries

There is a concern about unregulated fisheries in a future ice-free and open Arctic Ocean due to climate change. The process on Arctic fisheries by the five coastal states is addressing this concern. For this process, it would be of value if some basic questions could be addressed and answered as far as current knowledge and data allow:

- Are there fish stocks with commercially fishable abundance concentrations in the High Seas portion of the central Arctic Ocean?
- What are the potential production of fish at the trophic levels of planktivores (plankton-feeding pelagic fish) and fish-eaters (carnivorous fish eating small pelagic fish; trophic level 4 or higher)?

The first question can be addressed by summarizing and evaluating observations of fish made from ice-drift stations and research icebreakers. Acoustic recordings with research echosounders from research ships might be one source of information to be used to get information on fish in the water column of the Arctic Ocean.

The second question can be addressed as an extension of the assessment of primary and secondary production. Based on estimated levels of secondary production by the dominant large calanoid copepods (notably *Calanus hyperboreus*, *Calanus glacialis* and *Metridia longa*), which are large enough to be eaten by plankton-feeding fish such as polar cod *Boreogadus saida*, the potential production of plankton-feeding fish at the next tropic level can be estimated from empirical ecological energetics. Assessment of potential fish production needs to take into account energy flow and production of small organisms such as bacteria, protozoans and small copepods (such as the numerically dominant *Oithona, Oncaea* and *Microcalanus* species, which are too small to be eaten by fish).

It is known that polar cod *Boreogadus saida* and Arctic cod *Arctogadus glacialis* are found under the ice in the central Arctic Ocean. An assessment of potential fish production as part of an IEA would help to indicate likely abundance and production of these fish species in the central Arctic Ocean where they in turn form part of the food base for higher trophic level predators such as ringed seals and polar bears.

Vulnerable areas in relation to shipping and oil and gas activities

The AMAP Assessment of Oil and Gas activities in the Arctic (OGA; 2007, 2010) identified oil spills as the most serious environmental threat. The Arctic Marine Shipping Assessment (AMSA) by PAME (2009; which built on OGA for the environmental part) also identified oil spills as the greatest environmental risk. Disturbances from shipping and associated activities carried out from ships (e.g. seismic investigations, eco-tourism, ice-breaking) can also be a threat to wildlife.

One of the recommendations in AMSA (recommendation IIC) called on the Arctic states to "*identify areas of heightened ecological and cultural significance in light of changing climate conditions and increasing multiple marine use …*", with the aim to protect these areas from the impact of Arctic marine shipping. This was followed up in the so-called AMSA IIC report that was prepared by AMAP, CAFF and SDWG and published in 2013 (http://www.amap.no/documents/doc/identification-of-arctic-marine-areas-of-heightened-ecological-and-cultural-significance-arctic-marine-shipping-assessment-amsa-iic/869). In this report, the central Arctic Ocean was considered an area of heightened ecological significance, and four biological features were highlighted in the justification for this: sea-ice biota, polar and Arctic cod, ivory and Ross's gulls, and polar bear of several subpopulations. It was noted that while the whole central Arctic Ocean was identified as being of heightened ecological significance, the area was not homogenous but variable in terms of sensitivity and vulnerability.

The AMSA IIC report was used as the basis for work on the AMSA IID recommendation which was to "*explore the need for internationally designated areas for the purpose of environmental protection in regions of the Arctic Ocean.*" In this work it was felt that more detailed information was required in order to consider appropriate measures under IMO regulations regarding Arctic marine shipping (also taking into account the outcome of a CBD workshop, see below). PAME in 2015 therefore asked AMAP and CAFF for assistance in providing more detailed information on the vulnerability of the central Arctic Ocean to shipping.

The UN Convention on Biological Diversity (CBD) convened a workshop in March 2014 to identify 'Ecologically and Biologically Significant Areas' (EBSAs) in the Arctic Ocean. This workshop identified two variable and geographically overlapping areas as two distinct types of habitats: seasonally ice covered waters and waters with multiyear sea ice (https://www.cbd.int/decision/cop/default.shtml?id=13385).

Further work on identifying sensitive and vulnerable areas (with regard to oil spills and shipping) can be done as part of an IEA. The more detailed analyses of temporal and spatial patterns of primary, secondary, and (potential) fish production can provide one layer of information in an assessment of sensitive and vulnerable areas. There is also a need to take into account information on distribution and migratory patterns of ivory and Ross's gulls, ringed and bearded seals, and polar bears, in relation to sea ice conditions and features of the lower trophic levels (both plankton and ice biota).

Contaminants and pollution

Pollution is when chemical contamination reaches levels where there are deleterious effects on biota and/or human health. Pollution is a very complex issue due to the large multitude of chemical substances (contaminants such as old (classical) and new persistent organic pollutants (POPs), heavy metals (mercury, cadmium, lead), hydrocarbons, radioactive substances, and others) and a wide range of types of biological effects on a variety of organisms with different feeding modes, life histories, etc., etc.

Pollution assessment deals with a sequence of information on sources, inputs, concentrations and biological effects. This includes information on geographical location of source, amount of inputs, transport pathways into and within the Arctic, concentrations in various compartments (water, sediments, biota), and associated effects at various biological (biochemical, physiological, individual, population) and ecological levels. The latter includes uptake and transport in foodwebs with features such as bioaccumulation and biomagnification.

AMAP produced in 2002 a report on contaminant pathways in the Arctic, which highlighted the importance and interactions of physical and biological pathways in causing variations and changes in Arctic pollution in relation to climate variability and change.

An IEA for the central Arctic Ocean could address one or both of two aspects:

1) Changes in pathways of contaminants in relation to climate variability and change and associated changes in spatial and temporal production characteristics at various trophic levels.
2) Exposure and uptake of contaminants and associated effects on biota in the central Arctic Ocean.

Invasive species

Climate change may result in an increased possibility of spread of boreal species into the Arctic Ocean and in particular spread of Pacific species into the Arctic Ocean and from there into adjacent Subarctic seas in the North Atlantic. An IEA could include a risk assessment for such spread of species across biogeographical boundaries.

Increased transpolar shipping represents a way of transport and exchange of boreal and arctic-boreal species between the North Atlantic and the North Pacific. The transport of organism can be in ballast water or attached as fouling organisms to the hull.

8 ToR e – Suggest practical steps for initiating and carrying out an IEA for the Central Arctic Ocean

The meeting agreed that it would be worthwhile/good if ICES established a working group on IEA for the central Arctic Ocean in collaboration with Arctic Council (AC) working groups. It was noted by representatives of AMAP and CAFF that these working groups had approved work plans and heavy workloads during the period of the US Chairmanship and that they could contribute in a substantive manner to new work first after the next ministerial meeting in spring 2017 under the AC Chairmanship of Finland. Participation in a joint working group with ICES would require approval by the working groups and inclusion in their Work Plans for 2017–2019. To cover the Pacific gateway to the Arctic it was considered important also to invite participation from the Pacific sector. The Pacific Arctic Group (PAG) is an active consortium of scientists including from China, Japan and South Korea in addition to Canada and the USA. It is suggested that PAG is invited to take part in the work on an IEA for the central Arctic Ocean.

ICES usually operates with multi-annual Terms of Reference (ToRs) for 3-years periods. If ICES decides to establish a WG on IEA for the central Arctic Ocean (‘WGICA’) for the period 2016–2018, the ToRs should be formulated and planned so that in the first year (2016) the work items would be to consider the methodology to be used in relation to the available data and information. The group could also start a first round of discussion on design considerations for an integrated monitoring program for the CAO LME and adjacent and relevant parts of surrounding LMEs. Other ToR items would be to carry out integrated analyses across datasets (meteorological, sea ice, oceanography, lower and higher trophic levels) including relevant modelling studies, and to prepare an IEA report containing a description and analysis of the current situation and recent and projected trends including effects, potential effects and vulnerability in relation to human activities such as transpolar shipping. A draft set of ToRs is contained in Appendix A.

Appendix A: Draft Terms of Reference for a joint ICES and AC WGs Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean (WGICA)

a) Consider approach and methodology(-ies) for doing an IEA for the CAO (based on the outcome of WKICA).

b) Assemble data and information and carry out appropriate statistical and other types of analyses including mathematical modelling.

c) Prepare an IEA report for the current status of the CAO ecosystem (CAO LME and adjacent slope waters including Atlantic and Pacific inflows and relevant shelf-basin exchanges) and effects, potential effects and vulnerability in relation to climate variability and change and human activities such as Arctic shipping and potential future fisheries.

d) Consider requirements and design of monitoring of the CAO to meet the need for repeated IEA in the near future as well as other types of assessments (which can be modular components of IEAs).

e) Identify priority research issues which, when addressed, can improve the knowledge base for the next iteration of the IEA.

Annex 1: Terms of reference for the Workshop on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean, given by ICES

2014/2/SSGIEA03 The **ICES/AMAP/CAFF Workshop on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean** (WKICA), chaired by Hein Rune Skjoldal, Norway, Phillip Mundy, USA, Alexander Klepikov, Russia, and Reidar Hindrum, Norway will be established and will meet 28–29 May 2015 in Bergen, Norway to:

a) Consider the purpose and scope of an Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean.
b) Review the data and information available from past and ongoing monitoring and research that could be used in and inform the conduct of an IEA.
c) Consider the geographical scope for a Central Arctic Ocean IEA, in particular the relationships to the 'up-stream' Atlantic (Barents Sea and Fram Strait) and Pacific (Bering Strait and Chukchi Sea) gateways.
d) Consider the thematic scope of an IEA, e.g. impacts from climate variability and change, contaminants and pollution, shipping, and fisheries.
e) Suggest practical steps for initiating and carrying out an IEA for the Central Arctic Ocean.

WKICA will report by 29 June 2015 (via SSGIEA) for the attention of SCICOM and ACOM.

Supporting information

Priority	Arctic research is a priority area for ICES from the perspective of better understanding ecological processes and human impacts in this ecosystem. WKICA aims to scope and further develop Integrated Ecosystem Assessments for the Central Arctic Ocean, as a step towards implementing the ecosystem approach.
Scientific justification	Integrated Ecosystem Assessment (IEA) is a core element of the Ecosystem Approach to management (EA). The large basins of the Central Arctic Ocean (CAO) have been identified as a Large Marine Ecosystem, and there is a need now to consider whether an IEA should be carried out for this LME. The CAO is part of the Arctic Mediterranean Sea and is openly connected to the deep basins of the Nordic Seas through the deep Fram Strait. Atlantic water flows into the CAO through the Fram Strait and the Barents Sea, while Pacific Water flows up though the shallow Bering Strait and the Chukchi Sea. These inflows have decisive roles for the circulation and ice conditions in the CAO, and the conditions in the CAO again influence the climate and climate variability of the northern North Atlantic and North Pacific. Better understanding of the role of the CAO in the hemispherical and global climate systems will contribute to better understanding of climate and ecosystem variability of the core ICES area in the North Atlantic as well as in the Bering Sea and Gulf of Alaska in the North Pacific. The sea ice in the Arctic Ocean is diminishing both in area and thickness and the sea ice habitat is threatened by global climate change. Sea ice flora and fauna (e.g. ice amphipods) are to large extent endemic to the Arctic Ocean and there is a need to assess the current and future impacts of climate variability and change on this unique

	biota. The drifting pack ice is also the summer habitat of many polar bears from subpopulations around the CAO (e.g. Barents, Kara, Laptev, Chukchi, Southern and Northern Beaufort subpopulations) which move with the retreating ice into the Arctic Ocean in summer. Climate change represents a threat to these polar bear subpopulations. There are stocks of polar cod (*Boreogadus saida*) around the periphery of the CAO with probable spillover and dispersal under the ice in the CAO. There is also likely to be a relatively large stock of Arctic cod (Arctogadus glacialis) in the Canada Basin of the Arctic Ocean. There is currently an interest by the coastal Arctic states to clarify the prospects of future Arctic fisheries under climate change. Polar and Arctic cod along with ice amphipods and other ice fauna are the food base for ringed seals, beluga whales, narwhals and polar bears which use the drift ice of the CAO in summer. The peripheral area of the drift ice of the CAO is also used by seabirds, notably ivory and Ross's gulls. There is a need to assess the current situation and likely impacts by climate variability and change for the sea ice and pelagic parts of the CAO ecosystem. Contaminants are entering the Arctic through air and water. Climate variability and change will affect the physical and biological transport pathways of contaminants (ref AMAP 'pathway' report from 2002) and their biological effects in the CAO as well as in adjacent and linked ecosystems (e.g. the Barents and Greenland seas). An IEA may include assessment of the current and future pollution status in the CAO. Arctic marine shipping is also an activity that may be included in an IEA for the CAO.
Resource requirements	Assistance of the Secretariat in exchanging information to potential participants.
Participants	The Group is expected to be attended by some 20–25 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	There are no direct linkages with the advisory committees.
Linkages to other committees or groups	Linkages should be established to the other IEA groups (WGIAB, WGINOSE; WGIBAR, WGEAWESS; WGNARS) and the Artic Fisheries Working group (AFWG).
Linkages to other organizations	The work of this group is a joint effort with AMAP, PAME, CAFF.

Annex 2: List of participants

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Annex 3: Agenda for ICES/AMAP/CAFF/PAME Workshop on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean (WKICA)

Bergen, Norway, 28–29 May 2015

Thursday 28 May

09:00	Opening and welcome Introduction Review ToRs
10:00	*Coffee break*
10:20	**Bodil Bluhm** (University of Tromsø) – Tales of two basins
11:00	**Igor Melnikov** (Shirshov Institute of Oceanology, Moscow, Russia) – Changes in sea ice ecosystems
12:00	*Lunch*
13:00	**Yvonne Walter** (Chair SCICOM, ICES) – ICES and the Arctic
13:30–14:30	ToR a – Purpose and scope of an IEA
14:30–15:30	ToR c – Geographical scope
15:30	*Coffee break*
16:00–17:00	Tor d – Thematic scope

Friday 29 May

09:00	Summary from day 1
09:30–10:30	Tor b – Data and information
10:30	*Coffee break*
11:00–12:00	Tor e – Practical steps
12:00	*Lunch*
13:00–14:30	Finalize ToRs a-d
14:30	*Coffee break*
15:00–16:00	Finalize ToR d – Practical steps
16:00–17:00	Agree completion of report
	End of meeting

Annex 4: Background document prepared for the workshop

Issues and questions to guide an Integrated Ecosystem Assessment for the Central Arctic Ocean

Background

The ICES/AMAP/CAFF/PAME Workshop on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean was held in Bergen, Norway, 28-29 May 2015. This is a scoping and planning workshop for the conduct of an IEA for the Central Arctic Ocean LME. An IEA is a process whereby the status of the ecosystem and its components is evaluated in an integrated and holistic manner including pressures and effects of various human activities both individually and cumulatively.

One way to scope and do an IEA is to identify key issues and questions to be addressed in the assessment. In this document, we have identified a number of such issues and questions to serve as a basis for discussion and planning of an IEA for the Central Arctic Ocean. The issues and questions are presented by topical areas below, embedded in a narrative of the scientific background for each topic.

Climate variability

Arctic Mediterranean – the Atlantic gateway

The sea area north of the ridge running from Scotland via the Faroe Isles and Iceland to Greenland is called the Arctic Mediterranean Sea. It consists of two main parts: the Nordic Seas (or the GIN seas -Greenland, Iceland, Norwegian seas) and the Arctic Ocean. Both the Nordic Seas and the Arctic Ocean consist of deep basins (3-4 km deep), and the two parts are openly connected via the deep Fram Strait. Atlantic water (from the Gulf Stream and the North Atlantic drift) flows into the Nordic Seas between Scotland and Iceland and continues north as the Norwegian Atlantic Current on the eastern side of the Norwegian Sea. Here it splits, with one branch flowing into and through the Barents Sea and the other continuing north as the West Spitsbergen Current. The two branches, the Barents branch and the Fram Strait branch, meet at the opening of the St Anna Trough in the northern Kara Sea and continue into the Arctic Ocean as the cyclonic (counter-clock wise) Atlantic Circumpolar Boundary Current system.

The volume flux of Atlantic water into the Nordic Seas is of order 8–10 Sv, of which about half (4–5 Sv) continues into the Arctic Ocean split about equally between the Barents and Fram Strait branches. Around a decade later, (check) the modified Atlantic water (having lost most of its heat) exits through the Fram Strait as part of the East Greenland Current. This key feature of the circulation of Atlantic water connects the two parts of the Arctic Mediterranean into one integral part of the large-scale climate system on the northern hemisphere. What happens in the Arctic Ocean is therefore of importance for understanding what goes on in the Nordic Seas part of the Arctic Mediterranean. Understanding the climate variability which drives and impacts fish stocks and the ecosystems in the Nordic Seas and the Barents Sea (which are core areas for ICES advice) will benefit from better descriptions and understanding of the Arctic Ocean part of the Arctic Mediterranean.

How well do we monitor (through observations and modelling) the fluxes of Atlantic water (and other modified water masses) into and out of the Arctic Ocean?

What are the magnitudes and variability (seasonal, interannual and decadal) in the fluxes of water, salt, freshwater and heat at the Atlantic gateways between the Nordic Seas and the Arctic Ocean?

What are the relationships and feedbacks between the ocean and the atmosphere in the Arctic Mediterranean region?

The Pacific gateway

Pacific water flows north through the Bering Strait and the Chukchi Sea into the Arctic Ocean. The flow is driven by a pressure head from higher sea level in the North Pacific than in the North Atlantic and has a seasonal pattern with stronger flow in summer and lower flow in winter (due to a retarding effect from northerly winds). The annual mean flow is nearly one Sv or roughly 20% compared to the inflow of Atlantic water through the Atlantic gateway. The Pacific water is less salty (by roughly 2 salinity units; S = 32-33 check) and lighter compared to the Atlantic water. Most of the Pacific water originates from the Bering Sea and flows across the slope and up through Anadyr Gulf while a smaller portion flows on the Alaskan side as the Alaskan Coastal Current (containing the input of freshwater from the Yukon River). In addition to the seasonality in flux there is also seasonality in properties, with the water being saltier (from ice formation in the northern Bering Sea) and cold (near freezing point) in winter and less salty (due to ice melt and stronger river flow) and warmer in summer.

The transit time for the Pacific water across the Chukchi shelf is from a minimum of 6 months to more than 12 months dependent on route, winds and seasons. The water mass of the Chukchi Sea homogenizes and cools to freezing temperature due to cooling and ice formation in winter. Pacific water that flows north in early summer can have sufficient time to cross the Chukchi shelf before cooling sets in, thereby maintaining its heat, whereas water that flows north late in the summer season will be affected by winter cooling and loose its heat. There is therefore an interplay between flux, season and meteorological conditions in determining the amount and properties of Pacific water that enters the Arctic Ocean via the Pacific gateway.

How well do we monitor (through observations and modelling) the fluxes of Pacific water transported through the Bering Strait and Chukchi Sea into the Arctic Ocean?

What are the magnitude and variability (seasonal, interannual and decadal) in the flux and properties of Pacific water transported into the Arctic Ocean?

Four vertical layers

There are basically four vertical layers of waters in the Central Arctic Ocean:

1) A top layer (upper mixed polar water) about 50 m thick which is seasonally homogenized by ice formation in winter and stratified by ice melt and spread of river water in summer.

2) A gradient layer including the so-called cold halocline with a strong gradient in salinity between the low salinity upper layer and the salty Atlantic layer below. The gradient layer is located between approximately 50 and 200 m depth.

3) An Atlantic layer between about 200 and 1000 m depth consisting of the Atlantic Circumpolar Boundary Current system and spreading of Atlantic-derived water into the basin interior.

4) Deep water filling the basins below the Atlantic layer.

The circulation of the surface layer of polar water is relatively well known including from ice drift studies. Two main features of the circulation is the clockwise Beaufort Gyre in the Canadian Basin and the Transpolar Drift from eastern Siberia across the Arctic Ocean to the Fram Strait. The circulation of the Atlantic layer is also relatively well known at least in broad terms. It is characterized by the ACBC flowing along the continental margins of the basins with recirculating branches along the ridges between the basins, in particular the Lomonosov Ridge. The circulation of the Atlantic layer and that of the polar surface layer (including the ice drift) are more or less independent and opposite (particularly in the Canada Basin). The circulation in the gradient (halocline) layer in between is less well known and is probably complex. The cold halocline is believed to be formed and maintained by cold water of intermediate densities flowing out from the peripheral shelf areas and spreading along density isopycnals out into the basin interiors. The circulation of the deep waters of the basins is also less well known but there are exchanges between the Amerasian and Eurasian basins across the Lomonosov Ridge as well as with the basins of the Nordic Seas.

How well can we model the vertical structure and circulation in the Arctic Ocean?

What are the long-term changes in the vertical structure and circulation in the Arctic Ocean?

The upper polar layer and the gradient layer (halocline)

The salinity of the upper polar layer decreases from the western Nansen Basin north of the Fram Strait (ca. 34) across the North Pole region to the Canada Basin (30 or less). This decrease reflects the input of freshwater from the major Arctic rivers (Ob and Yenisey into the western Laptev Sea, Lena into the Laptev and East Siberian seas, Yukon into the Chukchi Sea, and Mackenzie into the Beaufort Sea). A consequence of the gradient to lower salinity in the Canada Basin is a stronger salinity gradient in the halocline gradient layer. The weaker gradient (due to higher salinity in the surface layer) in the western Nansen Basin is located relatively deep (around 100 m or more) and lacks the characteristics of the cold halocline; it is defined more like an ordinary pycnocline formed by mixing of two layers (upper polar and Atlantic) with parallel trends in salinity and temperature (straight line in a T-S mixing diagram; Rudels). Further east in the Nansen Basin the cold halocline appears with a strong salinity gradient without a corresponding gradient in temperature (which is cold near freezing and which is why it is called the cold halocline). This feature shows that the halocline is not formed by vertical mixing between two layers, but is taken as evidence that the cold water of intermediate salinities is spreading laterally from the surrounding continental shelf margins.

The cold halocline acts as an insulating layer between the cold upper layer and warm Atlantic layer. Convective mixing of the upper polar layer (due to brine rejection from ice formation) in winter may reach into the upper halocline but will then bring up cold water and not any of the heat contained in the Atlantic water beneath. The position of the cold halocline (the transition between its absence and appearance) has been found to vary, with a retreat eastward in the Eurasian Basin during warming events.

The halocline takes on an even more complex structure in the Amerasian Basin where the Pacific water (of lower salinity and density compared to Atlantic water) becomes layered in the upper part of the halocline above the Atlantic-derived cold halocline portion. The Pacific water in turn is layered with lighter Pacific summer water in the top part of the halocline immediately underneath the upper polar layer (with a temperature maximum at around 50 m), and cold Pacific winter water below (seen in vertical profiles as a local temperature minimum at S about 33.7 at about 100–150 m depth). The Pacific summer water disrupts the insulating function of the cold halocline by being a reservoir of heat that can be brought up by convective mixing of the upper polar layer in winter and thus contribute to ice melt. Despite low salinity (30 or less) of the upper polar water it is still mostly salt water which stems mainly from the underlying Pacific water in the Canada Basin. In contrast, the upper layer in the Eurasian Basin is made up of Atlantic water as the base component.

The anticyclonic (clockwise) Beaufort Gyre is convergent with accumulation of freshwater and a deepening of the upper polar layer in the centre. It has been shown (Proshutinksy *et al.*) that the circulation of the central part of the Arctic Ocean oscillates between anticyclonic and cyclonic modes associated with expanding and relaxing spin of the Beaufort Gyre. This Gyre holds a large reservoir of freshwater from rivers and the Pacific water (relative to a reference salinity) corresponding to thickness of up to 20 m or more in the centre. The variation in the freshwater content between the two main modes of circulation can be of the order of the total annual freshwater input to the Arctic Ocean (Pickart *et al.*). The Beaufort Gyre thus accumulates and releases freshwater in an interannual rhythm that has consequences for the outflow and export of freshwater from the Arctic Ocean as well as for thermohaline processes and circulation in the connected Subarctic seas (the Nordic Seas part of the Arctic Mediterranean as well Baffin Bay and Labrador Sea; Proshutinksy).

What do we know about the mechanisms for formation and maintenance of the cold halocline?

Which geographical areas are the main source regions for maintenance of the cold halocline?

What is the horizontal extent and variability of the distribution of the cold halocline?

How do the Pacific summer and winter waters spread and circulate in the Amerasian Basin?

What is the variability of the geographical position of the Atlantic-Pacific front in the halocline region and how well are such changes documented?

What are the main changes and patterns in the surface circulation in the Arctic Ocean and how are the changes related to atmospheric conditions?

What are the vertical heat fluxes from deeper layers into the polar upper layer and what regulates these fluxes?

The Atlantic layer

The Atlantic water in the ACBC flows relatively quickly along the slope of the southwestern Nansen Basin with slowing speeds as it gets further east (from 15–20 cm s^{-1} northeast of Svalbard to 3–5 cm s^{-1} in the eastern end of the Eurasian Basin). At the base of the Lomonosov Ridge the current splits with one branch diverted north by the ridge and another continuing across the ridge into the Makarov and Canada basins where it follows the basin rims in a anticlockwise manner. The transit time for the Atlantic water to flow from the Fram Strait to the southern Canada Basin is of the order of 5 years.

The ACBC is being diverted with branches along the Alpha-Mendeleyev ridges in the Amerasian Basin and the Gakkel Ridge in the Eurasian Basin, setting up what is depicted as large-scale circulation cells in each of the four sub-basins.

Productivity

Primary production

Rates of primary production by phytoplankton and ice algae are limited by light and nutrients. The light conditions are characterized in general by the low sun-angle (associated with high reflectance) at high latitudes and high prevalence of clouds and fog. Sea ice and snow cover have in addition very strong effects on the amount of light that reaches the under-side of the ice and the upper water column. Thick multiyear ice with snow cover does not transmit enough light for plant growth, which is limited to edges of cracks and leads where there is some light. The light environment is therefore very patchy in space and time in the drifting pack ice. Thinner annual sea ice may let some light through and as the ice-melt progresses through summer there is an improvement in light conditions.

The content of inorganic plant nutrients (most importantly nitrate) in the upper layer is generally low due to the strong permanent stratification in the halocline, which allows limited input from deeper layers into the euphotic zone. The nitrate content is inversely related to the strength of the pycnocline (halocline) and decreases from the western Nansen Basin north of the Fram Strait (6-8 umoles l^{-1} in winter; check) to the central Beaufort Gyre (<1 uM). The Pacific water is much richer in nutrients than the Atlantic water (by a factor of about 3 for nitrate and inorganic phosphate in Bering slope water compared to Atlantic water). High nutrient content is particularly evident in Pacific winter water but even summer water is fairly rich in nutrients. The winter convection which reaches down into the Pacific water brings up nutrients. However, due to the very strong density gradient and the convergent nature of the Beaufort Gyre, the injection of nutrients is of limited magnitude in the Canada Basin. The nutrient input to the surface layer is likely to be patchy and most important in the peripheral parts of the gyre where upwelling along the basin rim may play some role.

The annual rate of total primary production (by phytoplankton and ice algae) is estimated to be of order 15–40 g C m^{-2} in the peripheral areas of mostly seasonal ice cover on the Eurasian side of the Arctic Ocean and in the southern Beaufort Sea. Highest rates may occur in some hot-spot areas such as north of Svalbard, and in the Laptev and Bathurst polynyas. In the central part of the Arctic Ocean the annual rates are probably of order 5–15 g C m^{-2} with lowest rates (<5 g C m^{-2}) in areas with heavy multiyear ice north of Greenland and Canada. A rough estimate of the total primary production in the central Arctic Ocean is of order 50–100 million tons carbon per year (for a total area of 4 million km^2), equivalent to about 500–1.000 million tons of wet weight biomass production per year.

What are typical biomass values and daily rates of primary production of phytoplankton and ice algae under different ice conditions and in leads and open water?

How are rates of primary production of phytoplankton and ice algae distributed in space and time, and are there hot-spot areas of high production, and where?

What are the mechanisms that control the rate of colonization of new sea ice by algae?

What is the total annual primary production of phytoplankton and ice algae in the Central Arctic Ocean?

Zooplankton

Copepods are the main component of zooplankton in the Arctic Ocean making up about 80% or more of the biomass and around 95% of zooplankton by numbers. A handful of species are dominants in terms of biomass or numbers: the large calanoids *Calanus hyperboreus, Calanus glacialis, Metridia longa* and *Calanus finmarchicus* dominate in terms of biomass while *Microcalanus pygmeus, Oithona similis* and *Oncaea* species dominate numerically. The zooplankton distribution is vertically organized with communities corresponding broadly to the four vertical water mass layers, where the two upper layers (polar mixed and halocline) constitute the epipelagic, while the Atlantic and deep layers constitute the meso- and bathypelagic zones. The amount of zooplankton (both as biomass and numbers) declines more or less exponentially with increasing depth. Most of the zooplankton is found in the upper polar layer (upper 50 m) in summer, with one order magnitude decrease into the upper Atlantic layer (200–300 m), and another order of magnitude decline into the upper deep-water layer (about 1.500 m). While there is some seasonal vertical migration, the bulk of the zooplankton remains in the upper 200–300 m during winter.

The zooplankton biomass of the central Arctic Ocean is typically between 1 to 10 g dry weight m^{-2}. There is a zone of relatively high biomass (commonly 5–7 g dw m^{-2}) along the Eurasian continental rim from north of Svalbard to the Chukchi borderland region. The biomass declines by a factor of 2–3 going north into the central part of the Arctic Ocean (1–3 g dw m^{-2}). The three large calanoids *Calanus hyperboreus, Calanus glacialis* and *Metridia longa* make up most of the biomass (50–70%) over the whole Arctic Ocean with *Calanus finmarchicus* contributing to the high biomass in the Nansen Basin. *Calanus finmarchicus* is considered an expatriate not able to reproduce under the cold Arctic conditions. The reproduction of the three other calanoids is also limited and perhaps restricted to zones of higher primary production in the peripheral parts of the Arctic Ocean, such as the northern Barents and Kara seas, the Laptev polynya system, and the Chukchi Borderland region. From these core areas of reproduction, the developing copepods are distributed with the current systems into the central and low productive parts of the Arctic Ocean. The largest species, *Calanus hyperboreus*, can persist and continue to develop but it may require 3–4 years to complete its life cycle in the Arctic Ocean.

The transport of zooplankton into and within the Arctic Ocean is determined by the vertical distribution, migration, the often-opposing flow patterns in the upper polar and Atlantic layers, and the complex pattern in the halocline layer. In addition to *Calanus finmarchiicus* from the Atlantic side, there is also input of expatriate species with the Pacific water through the Chukchi Sea, such as *Neocalanus cristatus, Eucalanus bungeii* and *Metridia pacifica*.

The total biomass of zooplankton in the Arctic Ocean can be estimated to be of the order of 10–15 million tonnes dry weight (corresponding to 5–7 million tonnes of C or 50–70 million tonnes of wet weight biomass; estimated based a mean biomass of 5 g dw m^{-2} over 1.5 10^6 km^2 and 2 g dw m^{-2} over 2.5 10^6 km^2, for a total area of 4 million km^2). The transport of zooplankton with the Atlantic inflow (4–5 Sv) would be about 2–5 million tonnes dw per year (or about 10-25 million tonnes of wet weight biomass; estimated based on concentrations of 10–30 mg dw m^{-3}, corresponding to roughly 5–10 g dw m^{-2} distributed over 300–400 m depth). The input with Pacific water would be lower, perhaps of the order of 1/3 compared to the Atlantic input. The annual input of zooplankton with Atlantic and Pacific waters could represent roughly 25–50% compared to the zooplankton standing stock in the Arctic Ocean.

The zooplankton in the Arctic Ocean is partly an accumulated biomass of large calanoids with multi-annual life cycles and low reproduction and turnover. Assuming annual P/B ratios of 1–2 would give annual production of 100–300 million tonnes wet weight biomass for the Arctic Ocean zooplankton. Compared to the annual primary production (500–1.000 million tonnes) and allowing for energy flow to microbes, microzooplankton and benthos would suggest that zooplankton production is probably in the lower part of this range (100–150 million tonnes per year).

What are the spatial reproduction and production patterns of dominant zooplankton species in the Arctic Ocean (Calanus hyperboreus, Calanus glacialis, Metridia longa, Microcalanus pygmeus, Oithona similis)?

Are there core areas of reproduction for dominant zooplankton species and where are any such areas located?

What are major transport routes of zooplankton within the Arctic Ocean taking into account vertical behaviour and vertical current structure?

What are the rate limiting factors for reproduction, growth, and mortality of dominant zooplankton in the Arctic Ocean?

What are the vital rates (feeding, metabolism, reproduction, production, mortality) of dominant zooplankton in the Arctic Ocean?

How well can we model the spatial and temporal patterns of distribution and abundance of zooplankton species in the Arctic Ocean?

What are the levels of annual production for dominant species and groups of zooplankton?

Sea ice amphipods and other biota

Text and questions to be developed.

Fish stocks and potential fisheries

Around 110 species of fish are able to live in cold Arctic waters with about 70 of them listed as Arctic or predominantly Arctic species based on their distribution (the remaining about 40 species are Arctic-boreal). Eelpouts (family Zoarchidae) make up more than 1/3 of the Arctic species (26 species) followed by snailfish (Liparidae; 17 species) and cottid sculpins (Cottidae; 6 species). Together these 3 families of mostly small fish make up about 70% of the species of Arctic fish.

Two small cod fish (family Gadidae) are found in the Arctic Ocean: polar cod *Boreogadus saida* and Arctic cod *Arctogadus glacialis* (note that the names polar cod and Arctic cod are switched around in North American literature). Polar cod (*Boreogadus*) is found presumably with several large and migratory populations around the rim of the Arctic Ocean: in the northern Barents and Kara seas, in the western Laptev Sea, in the Chukchi Sea, and in the eastern Beaufort Sea. Over the shelves, such as in the Barents Sea, polar cod is found distributed with aggregations in the deeper part of the water column (the species is sometimes considered semi-demersal). Polar cod is found distributed under the ice in the central Arctic Ocean but apparently dispersed in relatively low densities. These fish could represent 'spillover' from the surrounding populations in the peripheral shelf areas of the Arctic Ocean, with individuals living in the under-ice habitat.

There is likely to be a relatively large stock of Arctic cod (*Arctogadus glacialis*) in the Canada Basin of the Arctic Ocean. Based on observations from previous ice drift stations it was suggested that the stock was possibly migratory with a potential spawning area in the Chukchi Borderland region. There is very limited knowledge of population structure and ecology of *Arctogadus* in the Arctic Ocean.

Greenland halibut of the Barents Sea population is found in the slope region north of Svalbard extending east to the northern Kara Sea. Whether the stock is distributed further east along the Laptev slope is not known. Greenland halibut occurs apparently also with a reproducing stock in the Amundsen Gulf region in the eastern Beaufort Sea.

The potential for fish production in the Arctic Ocean depends on the magnitudes of primary and secondary production. Assuming zooplankton production of order 100–150 million tonnes (wet weight) and ecological trophic efficiency of 20% gives a theoretical maximum production of 20–30 million tonnes of pelagic plankton-feeding fish. This estimate is no doubt too high since there are many invertebrate predators such as chaetognaths, amphipods, ctenophores and medusae that are also be consuming the herbivorous and omnivorous zooplankton and thus are competing with planktivorous fish for food. A large fraction of the fish consumption would probably be by the peripheral stocks of polar cod that are living predominantly on the surrounding shelves.

> *What is the geographic structure and phenology of populations of polar cod (Boreogadus saida) living in the Arctic Ocean and on the surrounding Arctic shelves? What is the density and distribution of polar cod under the ice and in the water column in the central Arctic Ocean?*
>
> *What is the geographic structure and phenology of populations of Arctic cod (Arctogadus glacialis) living in the Arctic Ocean and on the surrounding Arctic shelves? Are the Arctic cod (Arctogadus glacialis) found in the central Arctic Ocean migratory, and if so, what is the geographic extent of their distributions?*
>
> *What are the distribution and abundance of demersal fish species such as Greenland halibut along the basin slopes on the Eurasian side and in the Canada Basin?*
>
> *Is there a mesopelagic fish component in the central Arctic Ocean (other than polar and Arctic cod)?*
>
> *What are the production potentials for plankton and fish-eating fish in the central Arctic Ocean?*

Biodiversity and vulnerability

Ringed seal and polar bear

Ringed seal of the main Arctic subspecies (*Phoca hispida hispida*) is widely distributed in the ice covered parts of the Arctic including the Arctic Ocean and adjacent shelf seas. It occurs widely dispersed without a clear population structure due to its solitary and territorial behavior. Ringed seal breeds mainly in fast ice habitats where they give birth to single pups in lairs in snowdrifts. It can also breed on stable drifting pack ice, e.g. in the Baffin Bay, but whether this is the case in the central Arctic Ocean is not known. Ringed seals can migrate 1.000 km or more on a seasonal basis and they are able to move into and out of the pack ice of the central Arctic Ocean where they have been seen regularly even at the North Pole. Ice amphipods and polar and Arctic cod are believed to be the main prey items for ringed seals in the central Arctic Ocean.

Polar bears of several subpopulations (Barents, northern Kara, Laptev, Chukchi, and southern and northern Beaufort) are known to move with the seasonally receding pack ice into the central Arctic Ocean. Some polar bears of the southern Beaufort and Chukchi subpopulations have been found to move north to about 80°N in the Canada Basin in summer. A survey in 2004 suggested that about 2/3 of the Barents Sea polar bear subpopulation was present on the drifting pack ice between about 82 and 85°N in the Nansen Basin in summer. With dwindling sea ice polar bears are faced by the dual challenge of having to leave spring feeding areas (ringed seal breeding areas) early and to follow the rapidly retreated sea ice. There are several reports of bears swimming north in open water with associated exhaustion and mortality. There have been several indications of nutritionally stressed and starving polar bears in the southern Beaufort subpopulation which is considered to be declining due to sea ice loss.

Ringed seals are the main prey for polar bears, and there are tropic links between ice amphipods, polar and Arctic cod, ringed seals and polar bears in seasonal and spatial contexts. Ringed seals and polar bears are venturing into the central Arctic Ocean in summer and there is possibly also some movements of polar cod from the shelves into the basins.

What are the migratory patterns of ringed seals between breeding areas on surrounding shelves and the pack ice of the central Arctic Ocean?

Does ringed seal breed on pack ice in the central Arctic Ocean?

What are the distribution, densities and feeding ecology of ringed seals in the central Arctic Ocean?

What are the seasonal migration patterns of polar bears from different subpopulations between winter and spring habitats on the shelves and summer habitat on the drifting pack ice of the central Arctic Ocean?

What are the population characteristics of the Arctic Basin polar bear subpopulation?

Beluga, narwhal and bowhead whales

Beluga whales are observed in the southern and peripheral parts of the drifting pack ice of the central Arctic Ocean. Belugas of the Eastern Chukchi subpopulation have been tracked as they move through pack ice north to about 80°N in the Canada Basin during the summer migration.

Narwhals occur with one or more subpopulations in the Greenland and northern Barents Seas. They are seen regularly in the Franz Josef Land area where they possibly winter in polynyas. The slope waters into the southern Nansen Basin are potentially important feeding grounds for narwhals where they could find Greenland halibut and the squid *Gonatus fabricii*. Some narwhals venture north into the pack ice.

Bowheads of the critically endangered Spitsbergen population (population size could be of order 100 individuals) are found in the Fram Strait region and the northern Barents Sea. There is limited knowledge of the ecology of this small remnant population but the southern zone of pack ice in the Nansen Basin could be important summer feeding areas for these bowheads. Bowheads from the much larger (about 17.000 individuals) Bering-Chukchi-Beaufort population use the eastern and southern Beaufort Sea and the northern Chukchi Sea as their summer feeding grounds. Some individuals from this population can move west depending on ice conditions as far as the Laptev Sea.

What are the targeted prey items for belugas moving into the central Arctic Ocean, e.g. the Eastern Chukchi population?

What are the feeding and wintering areas for narwhals and Spitsbergen bowheads and are they using habitats in the central Arctic Ocean?

Ivory and Ross's gulls

Two Arctic seabird species have their natural habitat in the Arctic Ocean; they are the ivory gull (*Pagophila eburnea*) and Ross' gull (*Rhodostetia rosea*). Both are adapted to feed in ice-covered waters and both occur with significant parts of their total populations in the central Arctic Ocean during summer. Ivory gull is considered to be **Near Threatened** by IUCN due to recent declines in populations.

Ivory gulls breed on nunataks and other remote sites in northern Russia, Greenland and northern Canada. Severnaya Zemlya and islands in the northern Kara Sea are the main breeding areas for the species with more than 50% of the total global population. During the postbreeding season, ivory gulls from all Northeast Atlantic breeding populations (Greenland, Svalbard and Russia) migrate eastwards and stage in the ice edge zone in the NE Kara and NW Laptev seas in September-October before they migrate to winter either west to the Davis Strait region or east to the northern Bering Sea.

The main breeding area for Ross' gull is on the tundra in northern Yakutia, from the Taymyr Peninsula and east to Kolyma River. After breeding, the Ross's gulls move north to the ice edge and pack ice of the Arctic Ocean. Ross's gulls have been observed to move east through the Chukchi Sea in autumn, presumably to feed in the Beaufort Sea, and then to return west in late autumn.

What are the core feeding areas for ivory and Ross' gulls in the post-breeding, migration and wintering periods?

What are the main prey species for the two gull species and how are they trophically linked to the pack ice system of the central Arctic Ocean?

Sensitive and vulnerable areas

The AMSA IIC report (by AMAP and CAFF) identified the Central Arctic Ocean as an area of heightened ecological significance due to the occurrence of the unique sea ice biota, notably the sea ice amphipods, polar cod and Arctic cod, and the seasonal use of the pack ice area by polar bears, and ivory and Ross's gulls. Ecological importance was related to the occurrence of sensitive fauna components and to vulnerability to oil spills and disturbances from shipping. It was noted that not all areas of the central Arctic Ocean were equally important and sensitive and that the vulnerability therefore would vary among areas and periods.

The UN Convention on Biological Diversity (CBD) convened a workshop in early 2014 on the identification of EBSAs (Ecologically and Biologically Significant Areas) in the Arctic. Two ice EBSAs were identified in the central Arctic Ocean:

1) The Marginal Ice Zone and the Seasonal Ice Cover over the Deep Arctic Ocean
2) Multiyear ice of the Central Arctic Ocean

The two ice EBSAs are dynamic and variable according to ice conditions and are partly overlapping in a static (average) sense.

What and where are the most sensitive and vulnerable areas in the central Arctic Ocean in relation to potential oil spills and disturbances from Arctic marine shipping?

Contaminants and pollution

AMAP produced in 2002 a report on pathways for transports and effects of contaminants in the Arctic. This reported highlighted the importance and interaction between two types of pathways: the physical pathways including atmosphere, sea ice and water, and biological pathways including uptake, bioaccumulation and biomagnifications in the foodwebs. With climate variability and change, the two sets of interacting pathways are likely to change, affecting concentrations and potential pollution effects of contaminants such as persistent organic pollutants (POPs).

There are concerns related to high contaminant levels in species that use the central Arctic Ocean, notably polar bears and ivory gulls.

What are the dominant pathways of contaminants in the central Arctic Ocean?

Which roles does sea ice and biota in the central Arctic Ocean play with regard to concentrations and potential effects of contaminants on predators such as polar bears and ivory gulls?