Report on the Status of and Gaps in Knowledge regarding Research and Monitoring for Fish Stocks in the Arctic Ocean

Contents

Short summary of main conclusions

This report focuses on the central Arctic Ocean (CAO) and areas beyond national jurisdiction (ABNJ) while considering adjacent areas under national jurisdiction (national Exclusive Economic Zones or EEZs), and discards, but does not negate, the Protection of the Arctic Marine Environment (PAME; an Arctic Council Working Group) large marine ecosystems (LME) approach. The status report working group (WG) for the Third Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean (April 2015), having produced this report, considers it more realistic to use standard international definitions for the high seas area of the central Arctic Ocean, and management in the national EEZs, as a framework, where national competence and jurisdiction is affirmed towards the central Arctic Ocean. While the LME approach has value in identifying the biogeographical ecosystem, it does not comport with jurisdictional realities.

Baseline information regarding physical, chemical, and biological conditions are lacking for many parts of the Arctic, as shown in the report of the first meeting of scientific experts on fish stocks in the Arctic Ocean in Anchorage, Alaska, June 15-17, 2011 (Anon., 2011). These conclusions were further supported in the contributions to the 2nd Scientific Meeting on Arctic Fish Stocks, Tromsø, Norway, October 28-31, 2013 (Anon., 2013). There are large knowledge gaps concerning the presence, abundance, and distribution of planktonic organisms, fish species, marine mammals, and benthic organisms, and very little is known about the production capacity at the species level, as well as in an ecosystem and changing climate context. Despite the alarming nature of warming and its strong potential effects in the Arctic Ocean the current research effort evaluating the impacts of climate change in this region is limited (Wassmann et al., 2011). However, Hollowed et al. (2013) points at an increasing knowledge base emerging from recent investigations, and, based on these investigations, they predict climate impacts and potential movements of harvestable resources to the north.

The WG is encouraged by the extensive increase in survey activity and the planning of new research and monitoring activity to take place in the near future. Thus, research and monitoring occurring on the shelf areas also appears to be planned to extend into the slope areas of the Arctic Ocean (see Appendix A1 for greater detail on the ongoing projects of many of the nations).

However, taking into consideration that much of the general knowledge of the Arctic marine environment is still model-based and that survey data are lacking for most of the central Arctic Ocean, meeting participants reached the following conclusions regarding the status of and gaps in Arctic research and monitoring, with a focus on identifying actions to be taken based on knowledge gaps.

1. There is a dearth of information as to the species (fish and shellfish in particular) found in the central Arctic Ocean and their geographic distribution. Surveys and research activities in the central Arctic Ocean and adjacent areas should be oriented to produce and report information on all relevant species. Several fish and shellfish atlas

projects are ongoing, and effort should be made to coordinate these atlas projects on a regular basis, as well as coordinating surveys delivering relevant data.

2. Recognizing the potential large effort needed to give a full picture of fish and shellfish in the central Arctic Ocean, should they exist there, it is strongly encouraged that surveys of the central Arctic Ocean focus on potential commercial fish stocks. Due to lack of data relevant to an advice process, in the interim period, we recommend applying precautionary measures on activities impacting living marine resources in the central Arctic Ocean.
3. As the lack of knowledge, in particular on fish and shellfish, is most profound in the waters beyond national jurisdiction of the central Arctic Ocean, it is important for research to focus on these waters and also to focus on linkages with surrounding areas of national jurisdiction in order to respond to the overall question regarding possible presence of commercial quantities of fish and shellfish in the central Arctic Ocean.
4. Data and knowledge on other parts of the Arctic ecosystems (other than fish and shellfish) are obtained to a large extent in the areas of national jurisdiction, and meeting participants expect that this kind of knowledge will be obtained in the central Arctic Ocean in near future. It is therefore important to start developing an appropriate assessment process to synthesize and integrate existing and new knowledge with respect to the ecosystem in the central Arctic Ocean.
5. At present, we observed, there is a preponderance of research and monitoring that focuses on ecosystem structure and processes. It is recommended to continue this effort. Collection of data (stock structure, age / size composition, abundance, growth, diet, natural mortality and reproductive potential) necessary to develop single species and fishery stock assessments is, however, also essential in order to be able to give advice on potential harvesting.
6. We realize it is challenging to conduct comprehensive monitoring of the whole central Arctic Ocean. Therefore, effective coordination among coastal states and other nations is critical with respect to monitoring, research, and survey efforts.
7. Recognizing that the marine ecosystems in the central Arctic Ocean and adjacent waters are changing with respect to climate impacts, focus should be on the need for projecting likely future scenarios with respect to species movements, colonization, and related changes. Appropriate modeling and studies to develop these scenarios are required

Introduction

The five states surrounding the Arctic Ocean (Canada, the Kingdom of Denmark in respect to Greenland, the Kingdom of Norway, the Russian Federation, and the United States of America), the Arctic coastal states, have identified a need for further scientific research and monitoring on the state and nature of living marine resources and associated ecosystems, as well as an increased understanding of the impact of climate change on Arctic ecosystems in general and fish stocks in particular. To satisfy this need, the Terms of Reference for the Third Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean (3rd Arctic Fisheries Meeting) call for a status report on Arctic research and monitoring to identify gaps in information that need to be addressed in future programs of research and monitoring (see the final meeting report and the Framework for a Joint Program of Scientific Research Monitoring for Fish Stocks in the Central Arctic Ocean).

Terms of reference:

1. *Continuing the review of current programs for research and monitoring environmental parameters and patterns of fish distribution and abundance; establishing an inventory of research and monitoring programs and* ***preparing a report on the status of and gaps in knowledge on the distribution and abundance of fish in the central Arctic Ocean****. Such an inventory should include programs occurring in immediately adjacent shelf areas (i.e., within EEZs), which are linked and have relevance to the central Arctic Ocean (high seas).*

Purpose

The status and gaps report on Arctic research and monitoring (SGRM) serves the Arctic coastal states and other interested parties as a means to identify gaps in the information relevant to ecosystem based fishery management (EBFM) of fish stocks in the central Arctic Ocean. Identification of information gaps is fundamental to planning, designing and conducting scientific research and monitoring in support of EBFM in the Arctic. The SGRM is an essential first step in developing scientific research and monitoring in support of EBFM in the Arctic.

General description of the Arctic

The Arctic Ocean is experiencing major transformations. The dramatic reduction in the Arctic sea ice coverage (Comiso, 2012) has already made vast areas of the waters in the Arctic accessible for increased human activity. This development will increase pressures on vulnerable Arctic Ocean ecosystems, and impose new challenges for their sustainable management (AC, 2004). The waters between Greenland and Franz Joseph Land are the main oceanic gateways to the deep Arctic Ocean, channeling the major part of oceanic heat brought to the region by the warm Atlantic inflow through the Fram Strait (e.g., Schauer et al., 2002). Changes in this heat flow have profound implications for the marine environment and the living marine resources in the Arctic. Colonization of new regions by immigrating species is thought to be more likely on this side of the Arctic compared to the Pacific side (Drinkwater, 2011; Hollowed et al., 2013). However, areas north of the Bering Strait, including areas beyond national jurisdiction, are experiencing profound loss of sea ice. Much of this occurs over relatively shallow water, such as the Chukchi plateau, and should be considered in any fishery-related research program for the central Arctic Ocean.

In a pan-Arctic perspective, increasing the scientific knowledgebase and ecosystem understanding, exploring potential options for providing ecosystem-based advice, and establishing long-term monitoring programs in the Arctic Ocean are important both to the Arctic coastal states, as well as non-Arctic coastal nations and other parties interested in the Arctic marine environment.

National approaches to status of Arctic research

As is the case with the Inventory of Arctic Research and Monitoring (IARM), both the geographic scope and the types of biological and physical attributes that are the subject of this report are defined by the principles and practice of EBFM and ecosystem based management (EBM). Ecosystem based management practices are supported by integrated ecosystem assessment (IEA), which are integrative with respect to physical and biological attributes of the large marine ecosystem, and which are also integrative with respect to the human communities, laws, stock assessments, and regulatory approaches of fishery management. The waters under evaluation in this report are the high seas area surrounded by the fisheries jurisdiction of Canada, Denmark with respect to Greenland, Norway, Russia and the United States. The SGRM also acknowledges that this includes the Central Arctic LME and areas of adjacent LMEs that fall under areas of national jurisdiction. Complete descriptions of the research activities underlying the status of research and monitoring summarized here is found in Appendix A1 of this report. Next, we provide short summaries of the national approaches to research and monitoring in the Arctic.

The Norwegian approach to Arctic research

The Research Council of Norway's Research Strategy for the Arctic and Northern Areas, Revision 1, which applies from 2011 to 2016, states that the "Arctic and northern areas are of great strategic importance both globally and to Norway. There is an increasing need for research and new knowledge to ensure the sustainable management of the area's abundant natural resources and to respond to the challenges and opportunities arising from climate change." The national Norwegian HAV21 marine research strategy underlines the Northern area as a main priority and notes that "Marine research in the northern areas should be strengthened as a national research priority."

Also the white paper to the Norwegian Parliament (Melding til Stortinget 10 2010-2011) "First update of the Integrated Management Plan for the Marine Environment of the Barents Sea−Lofoten Area" (Appendix A2) points to the need for further knowledge regarding the Arctic Ocean: "However, it is uncertain whether the productivity of the Arctic Ocean and adjacent seas will increase as the ice retreats and to what extent primary production will be channeled to fish species that are of commercial interest."

The Norwegian Institute of Marine Research (IMR) is a world leading institute in monitoring and advice for ecosystem-based management. Its three main strategic goals are to: 1) explore the environment and biology of the ocean and coastal areas; 2) deliver advice and further develop the advisory capacity towards a sustainable management of the marine ecosystems, the resources and aquaculture; and 3) be the national manager of marine data.

We consider it critical in following up upon the IMR's strategic goals to include the Arctic Ocean in our strategy. It is of utmost importance to increase our knowledge on this "new" ocean and prepare for future requirements for advice. It is also important to optimally take advantage of the existing extensive infrastructure and interdisciplinary scientific manpower of the IMR to maintain the institute in a national and international leading position in marine science in the north including the Arctic Ocean. It is our intent that the knowledge gained through new activities in relation to the Draft Framework for a Joint Program of Scientific Research and Monitoring for the Central Arctic Ocean (including SI_ARCTIC, see Appendix A8) will support the international, national, and institutional goals outlined above and ultimately help strengthen Norway's position in the Arctic.

The Arctic Council's Working Group on Protection of the Arctic Marine Environment (PAME) states: "Increasing human activity in the Arctic Ocean and activities in new areas pose challenges to its health and warrants an ecosystem approach to integrated ocean management to maximize environmental protection and sustainable use of the marine environment". Figure 1 depicts the fishing activity in Norwegian areas, including the resent extension to waters north of Svalbard (see Appendix A5).

Dramatic seasonal changes, low temperatures, extensive permanent and seasonal ice cover, and a large supply of freshwater from rivers and melting ice are key physical factors characterizing the Arctic Ocean ecosystem. The oceanography of the system is influenced by vigorous flow of Atlantic water through the Fram Strait in the West Spitsbergen Current (Ivanov et al., 2009), exchange with the shallow Barents Sea (e.g., Lind and Ingvaldsen, 2012), as well as substantial cooling and mixing (e.g., Steele and Boyd, 1998). Primary production in the Arctic is influenced by the timing of ice breakup and stratification affecting the nutrient and light availability (Wassmann et al., 2006), resulting in a short production season. This will, to a large extent, control the food supply to pelagic and benthic species (Grebmeier et al., 2006). Annual primary production is typically <30 g C m-2 y-1 in the central Arctic Ocean where compact perennial ice dominates, while being between 30 and 100 g C m-2 y-1 in the seasonally ice covered areas around the periphery of the Arctic Ocean (Wassmann, 2011; Reigstad et al., 2011). With less ice due to climate change, the length of the productive period may become somewhat extended, with a moderate increase in the total yearly primary production (Slagstad et al., 2011). However, due to strong stratification that likely prevents nutrient availability (Tremblay and Gagnon, 2009), the central Arctic Ocean will likely remain as a low productive region (Wassmann, 2011). Along the pan-Arctic shelves on the other hand, the response will depend on the regional conditions; removal of ice cover beyond the shelf break can enhance wind and ice-forced shelf-break upwelling, and the resulting increases in both nutrient fluxes and solar radiation can increase new production

(Carmack and McLaughlin, 2011). Another unknown factor in the future production is the recurrence of passing atmospheric lows, generating strong winds that mix nutrient rich water up into the photic zone, after the main spring bloom, an effect important in the Barents Sea proper (Sakshaug, 1997).

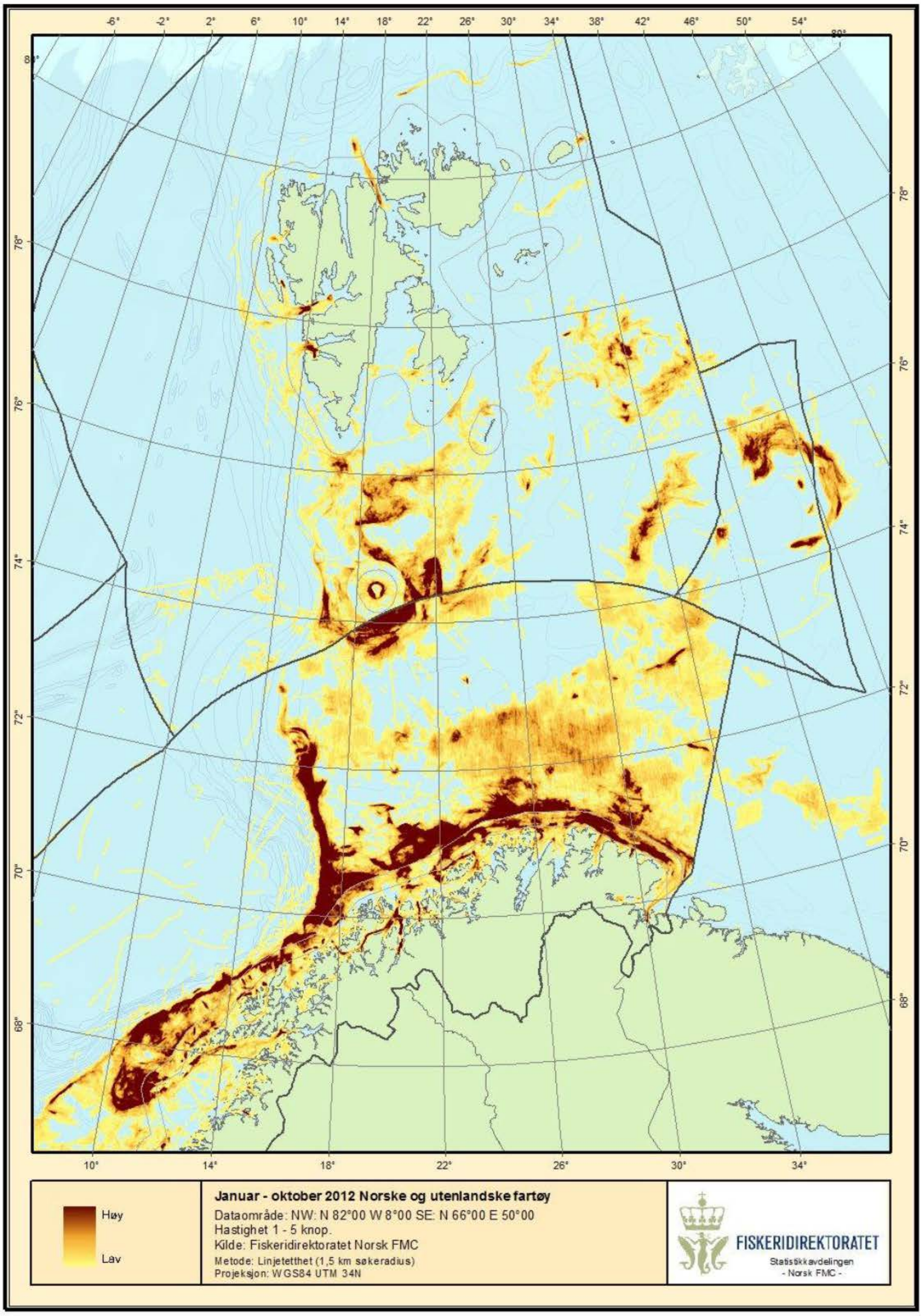

Figure 1. Fishing activity in Norweigan and international waters in the Barents Sea and Arctic Ocean during January-October 2012.

The benthic fauna, which is an integral component of the food web, exhibits a strong association with the overlying primary productivity regime (Tremblay et al., 2011). Close benthic-pelagic relationships in ice-influenced areas have been observed in the Northeast water polynya off Greenland, the Beaufort Sea, and the northern Bering and Chukchi Seas as well as the Barents Sea. The ecosystem importance of the mega-faunal communities in the Arctic has been acknowledged in the Chukchi Sea (Bluhm et al., 2009), the north-east Atlantic (Billett et al., 2001), East Greenland (Mayer and Piepenburg, 1996), the Arctic deep-sea Canadian Basin (MacConald et al., 2010), and the Barents Sea (Anisimova et al., 2011). A shift from an ice-influenced tightly coupled pelagic-benthic system to a less coupled ice-free system can be expected with future reduction in ice cover.

The increase in atmospheric CO_2 and elevated oceanic uptake of atmospheric CO_2 are expected to put stress on marine organisms (i.e., *Calanus*, pteropods and fish), although calcifiers are considered particularly vulnerable. The Arctic Ocean is particularly vulnerable for enhanced freshening and loss of sea-ice cover, which will promote further solubility and amplification of ocean acidification. Changes in the Arctic Ocean are already observed, and presence of aragonite-under saturated waters on the freshwater-influenced shelves of the western Arctic Ocean in summer 2005 has been reported (Chierici and Fransson, 2009). This is substantially sooner than the year 2030 predicted by recent dynamic models (Orr et al., 2005; Steinacher et al., 2009). Given the potential ecological consequences, studies of processes affecting the natural variability of the calcium-carbonate saturation levels in the Arctic Ocean are of great importance in predicting the impact of increased atmospheric CO_2 levels on the vulnerable ecosystem and carbon flow in the Arctic Ocean.

Regional variability of total zooplankton biomass in the Eurasian Basin is mainly related to the circulation patterns with highest biomass in the Atlantic slope current, but local food availability is also important (Kosobokova and Hirche, 2009). Key species associated with the advection of Atlantic slope current are the copepod species *Calanus finmarchicus* and the amphipod species *Themisto abyssorum* (Jaschnov, 1966; Mumm et al., 1998; Kosobokova and Hirche, 2009). *Calanus hyperboreus* and *Metridia longa* are the two dominant larger copepods in the central Arctic Ocean. Timing of ice breakup is probably the single most essential factor deciding the recruitment success or failure in secondary producers which are able to reproduce in the Arctic (Wassmann, 2011). Both too early and too late ice breakup can cause a mismatch between primary and secondary producers, with negative consequences for the entire lipid-based Arctic marine food web (Leu et al., 2011). Another uncertainty associated with ice retreat, is the ability of grazers like ctenophores and scyphomedusae to take advantage of new habitats and resources that could potentially change energy pathways and food-web dynamics, shifting food energy away from fish towards bacteria.

Predicting the responses of commercial fish species to future climate change in the Arctic is of great interest to scientists, managers, and fishers alike. Previous studies have projected shifts in bio-climatic habitats of marine fish species and concluded that new species will colonize polar ecosystems at an accelerated rate relative to other regions of the globe (Cheung et al., 2009). Closer examination of the processes governing fish distributions revealed that range expansions and successful colonization of new regions will depend on a complex suite of factors (Walther, 2010) including habitat suitability, habitat quality, and population size (MacCall, 1990; Auster and Link, 2009). A recent assessment of the potential for fish or shellfish stocks or stock groups to move from the sub-Arctic areas into the Arctic Ocean revealed that several life history factors should be considered when assessing the potential of species moving in response to changing climate conditions (Hollowed et al., 2013). An overview of fish species found in the Barents Sea, including the northern shelf, is given in the "Atlas of the Barents Sea Fishes" (Appendix A3), which is based on the occurrence of these species in the Barents Sea ecosystem survey conducted in cooperation between IMR and the Russian counterpart research institute PINRO in Murmansk.

Reductions in sea ice are reducing the habitat available for ice-associated marine mammals that give birth on sea ice, hide from predators or inclement weather within ice fields, or that eat ice-associated fish and invertebrate prey or other ice-associated marine mammals. Loss of sea ice is already affecting some species, and in the longer term, it is expected that foraging success, fertility rates, mortality rates, etc. will be impacted for additional populations and species of endemic Arctic marine mammals (see Kovacs et al., 2011). Generally speaking, specialist feeders are likely to be more impacted by changes in Arctic food webs that will accompany sea-ice losses compared with generalist feeders, and ice-breeders that require long periods of stable ice late in spring are likely to be impacted more rapidly than late winter ice breeders that require ice for shorter periods of time (Kovacs and Lydersen, 2008). In addition to sea ice loss, combinations of other climate induced changes are likely to have indirect effects on marine mammals, mediated through impacts on their prey. Arctic marine mammals depend on rapid accumulation of energy to restore blubber stores during the short productivity season at high latitudes (Kovacs et al., 2009). With increasing sea temperatures, competition between native prey species and other species from more temperate regions will increase since this strategy for energy storage is not really required or well-developed for these latter forms. This could mean a transition from high-fat to low-fat food ("junk food") for the marine mammals which in turn could affect their ability to deposit the necessary fat resources in their blubber, thereby affecting their ability to produce viable offspring.

Fisheries management regimes with sufficient capacity, in terms of robust science, regulatory frameworks that contribute to reduced fishing effort and maintenance of sustainable stock levels, and enforcement capability, are more likely to respond adequately to the challenges posed by climate change (Harsem and Hoel, 2012). The opening of new areas that until recently have been almost inaccessible for commercial activities are likely to be followed by increased human activity, including ship traffic, petroleum activity, and tourism. This calls for an integrated ecosystem approach to management, which is expected to aid long-term sustainability with respect to exploitation of marine resources, including the fisheries sector (ICES, 2012).

A wider status description on the Barents Sea based on the areas covered by the joint Norwegian and Russian ecosystem surveys since 2003 are given in the "Joint Norwegian-Russian environmental status report on the Barents Sea Ecosystem" (Appendix A4). This report presents an update of Chapter 4 of the "Joint Norwegian-Russian environmental status report on the Barents Sea Ecosystem Part II — Complete report" (Stiansen *et al*., 2009). It updates the original report through 2012 and 2013 with information on ecosystem status with regard to meteorological and oceanographic conditions, phytoplankton, zooplankton, shrimp, fish, and fisheries in both Norwegian and Russian waters of the Barents Sea. In this update, fisheries and other harvesting are the only human activity described and discussed. Overviews of other human activities, and discussion of their impacts, will be provided in future updates. A full update of the Joint Norwegian-Russian environmental status report is scheduled for completion during the summer of 2015.

US Perspective – Arctic Research Activities

Integrated Ecosystem Assessment (IEA)
http://www.noaa.gov/iea/
As developed within the U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA), Integrated Ecosystem Assessment (IEA) is an iterative science-based process that provides products to resource managers who are operating under the principles of ecosystem based management (EBM), and as an application to exploited fish stocks, Ecosystem Based Fishery Management (EBFM). NOAA's National Marine Fisheries Service (NOAA Fisheries), Alaska Fisheries Science Center, is implementing EBFM in four Arctic Large Marine Ecosystems (LMEs) as an active part of the NOAA Integrated Ecosystem Assessment Program. Under the US Arctic Research and Policy Act (ARPA 1982) the waters of the US Arctic occur in the following LMEs: Aleutian Archipelago (10); East Bering Sea (9); Northern-Bering Chukchi Seas (12); and Beaufort Sea (14). The fisheries in the Bering Sea were perhaps the first in the US to be managed under an ecosystem-level annual harvest cap implemented about three decades ago. Under the ecosystem-level cap, the North Pacific Fishery Management Council (NPFMC) limits annual harvests of all fish species to no more than two million metric tons. The NPFMC is also guided in its management decisions by an Alaska Marine Ecosystems Considerations Report, which is an annual snapshot of ecosystem indicators and their time trends. In addition, the report presents estimates of the risks posed to twenty-two types of fish habitats, such as rocky coastal habitats, by twenty risk factors, such as ecotourism. The synthesized ecosystem level information is combined into a written report, which is factored into the decisions on total allowable catch (TAC) made by the NPFMC each year. Observations from physics, through primary and secondary production are also used to estimate the impacts of climate change on fish species in a vertically integrated coupled biophysical model driven by the Intergovernmental Panel on Climate Change (IPCC) climate projections. The upper trophic level component of the biophysical model is known as Forage and Euphausiid Abundance in Space and Time (FEAST). FEAST exchanges information on distribution and abundance of upper trophic level organisms with the lower trophic level model and the economic and spatial fishery predictions model in this vertically integrated series of models. At the base of the models are the IPCC climate scenarios, which drive the physical oceanographic model which in turn drives the lower trophic level model that interacts with FEAST. Work is

continuing to extend FEAST beyond the eastern Bering Sea LME to make predictions about the impact of climate change on other species and other locations.

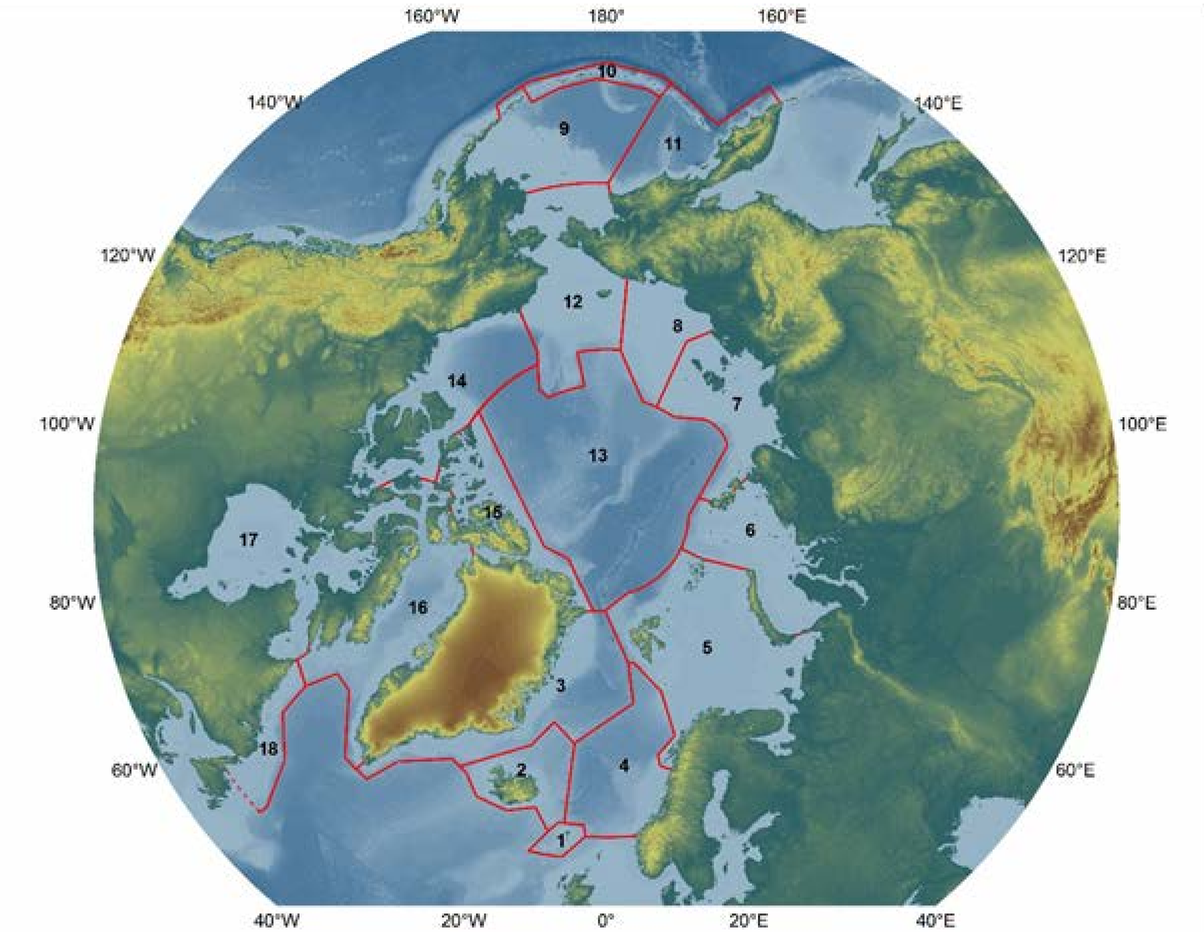

Figure 2. Revised Map of 18 Arctic LMEs (version 17 April 2013). The revisions resulted in 18 LMEs for the Arctic by addition of a new LME in the Bering Sea area: the *Aleutian Archipelago LME*. (The associated table to this figure can be found in Appendix C of the Final Report for the Third Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean.)

Arctic Fishery Management Plan

http://www.npfmc.org/wp-content/PDFdocuments/fmp/Arctic/ArcticFMP.pdf

This Fishery Management Plan (FMP) governs commercial fishing for most species of fish within the Arctic Management Area. The FMP management area, the Arctic Management Area, is all marine waters in the U.S. Exclusive Economic Zone of the Chukchi and Beaufort Seas from 3 nautical miles offshore the coast of Alaska or its baseline to 200 nautical miles offshore, north of Bering Strait (from Cape Prince of Wales to Cape Dezhneva) and westward to the 1990 United States/Russia maritime boundary line and eastward to the United States/Canada maritime boundary. The FMP governs commercial fishing for all stocks of fish, including all finfish, shellfish, or other marine living resources, except commercial fishing for Pacific salmon and Pacific halibut, which is managed under other authorities. The FMP was approved by the Secretary of Commerce on August 17, 2009. Pursuant to Title II of the Magnuson-Stevens Act (MSA), there is no allowable level of foreign fishing for the fisheries covered by this FMP. While fishing vessels and fish processors of the U.S. have the capacity to harvest and process up to the level of optimum yield of all species subject to other Council FMPs, Council policy as articulated in this Arctic FMP is to prohibit all types of commercial harvests of all fish resources of the Arctic Management Area until sufficient information is available to support the sustainable management of a commercial fishery. The FMP implements the principles of EBFM consistent with the missions and policies of NOAA and NOAA Fisheries. Under EBFM, a fish stock may be harvested only to the extent that information is in hand to determine if National Standard One of the MSA (prevent overfishing) is being implemented. The absence of sufficient information on National Standard One may preclude any harvesting, which is the case in the Arctic FMP. Note that EBFM is an integral part of NOAA Fisheries' IEA (see preceding section).

Under the MSA, the NPFMC is authorized to prepare and submit to the Secretary of Commerce for approval, disapproval, or partial approval, an FMP and any necessary amendments for each fishery under its authority that requires conservation and management. The NPFMC's policy is to proactively apply judicious and responsible fisheries management practices, based on sound scientific research and analysis, to ensure the sustainability of fishery resources, to prevent unregulated fishing, and to protect associated ecosystems for the benefit of current users and future generations. As part of its policy, the NPFMC intends to consider and adopt, as appropriate, measures that prevent unregulated fishing, apply the NPFMC's precautionary, adaptive management policy through community-based or rights-based management, apply EBM principles that protect managed species from overfishing and protect the health of the entire marine ecosystem, and where appropriate and practicable, include habitat protection and bycatch constraints. All management measures will be based on the best scientific information available. Given this intent, the fishery management goals are to provide sound conservation and sustainability of the fish resources, provide socially and economically viable fisheries for the well-being of fishing communities, minimize human-caused threats to protected species, maintain a healthy marine resource habitat, and incorporate ecosystem-based considerations into management decisions. This management policy recognizes the need to balance competing uses of marine resources and different social and economic goals for sustainable fishery management, including protection of the long-term health of the ecosystem and the optimization of yield from its fish resources. This policy will use and improve upon the NPFMC's existing open and transparent process of public involvement in decision-making.

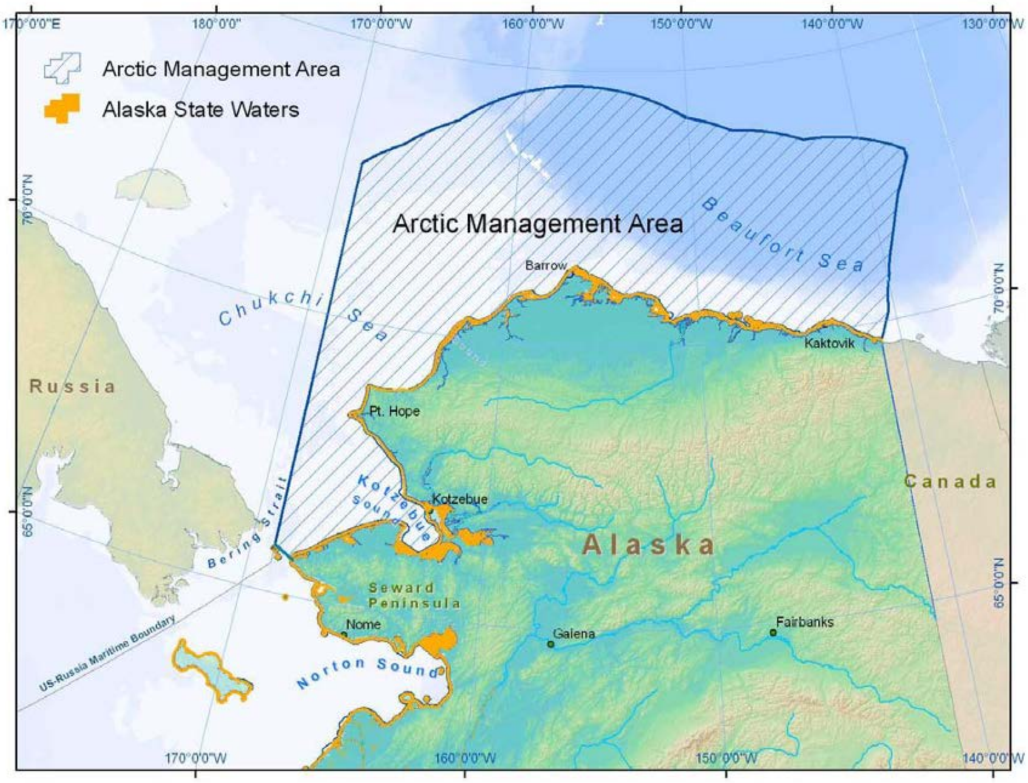

Figure 3. The Arctic Management Area of the FMP.

U.S. Arctic Research

There are at least 14 different Arctic research projects/efforts in the U.S. recently completed or currently underway. They are described in detail later in this document. An important collaborative program involving many of these individual projects is the Distributed Biological Observatory (DBO). The DBO is envisioned as a change detection array along a latitudinal gradient extending from the northern Bering Sea to the Barrow Arc. Data collected at DBO sites includes measurement/samples/observations of physical oceanography, chemical oceanography, production, phytoplankton, zooplankton, benthic fauna, marine mammals, marine birds and fish.

Research and/or funding institutes/agencies for U.S. Arctic research include: University of Alaska Fairbanks; University of Washington; North Pacific Research Board; NOAA Alaska Fisheries Science Center; NOAA Pacific Marine Environmental Laboratory; NOAA National Marine Mammal Laboratory; North Slope Borough; Bureau of Ocean and Energy Management; U.S. Fish and Wildlife Service; U.S. Geological Survey; Community Coastal Impact Assistance Program; Department of Fisheries and Oceans Canada; State Research and Design Institute for Fishing Fleet (Giprorybflot); ConocoPhillips; Shell Exploration; Statoil USA; and Olgoonik Fairweather LLC.

U.S. Arctic field research projects are carried out on the Chukchi Sea and Beaufort Sea shelves. No recent, current, or ongoing studies are conducted in central Arctic Ocean outside the U.S. EEZ. Most of the at-sea projects are conducted in waters > 20 m deep, although a few study the fish communities of the nearshore (< 20 m deep) and lagoons.

Objectives for U.S. Arctic research are several fold. The goal of many studies is to understand the distribution of marine fishes and shellfishes. Some studies are also designed to collect baseline data on the habitat, abundance, distribution, and species composition of fish. A number of studies, supported by BOEM, are to assess the oceanography and ecology of areas of potential oil and gas development. One new project, the Arctic Marine Biodiversity Observing Network, aims to close current gaps in biodiversity observation in the Arctic. Another, the Marine Arctic Ecosystem Study, is designed to identify cultural, historic, and subsistence resources which could be sensitive to human activities.

Focal study organisms for U.S. Arctic research include taxa of potential commercial interest in the Arctic such as Arctic cod (*Boreogadus saida*), walleye pollock (*Gadus chalcogrammus*), flatfish (Pleuronectidae), and snow crab (*Chionoecetes opilio*). Many studies are ecosystem surveys and thus also include collections of data on ocean circulation and physics, water chemistry, microbes, phytoplankton, zooplankton, benthic invertebrates (epi- and infaunal), sediment characteristics, other fish taxa (e.g., capelin, salmon, saffron cod), seabirds, and marine mammals.

There is a substantial U.S. Arctic research effort aimed specifically at marine mammals. The objectives of some marine mammal studies are to document the distribution and relative abundance of whales in areas of potential industrial activity and to relate changes in those variables to oceanographic conditions, indices of potential prey density, and anthropogenic activities. Some studies are conducted to describe the annual migration of bowhead whales across the Alaskan Arctic, significant inter-year differences, and long-term trends in the spatial distribution and timing of the migration. Other studies document the relative abundance, spatial and temporal distribution, and behavior of a suite of marine mammal taxa (cetaceans, ice seals, walruses, and polar bears).

Finally, there are a number of data synthesis projects involving data on physics, fish, and marine mammals. Some projects synthesize recent studies, while others draw on historical data.

Russian Federation Perspectives **on Arctic Research Activities**

The Russian Arctic region can be divided into two sectors: west and east. The west sector includes the Barents and Kara Seas; the east sector includes the Laptev, East Siberian and Chukchi Seas.

Fisheries investigations in the west sector are conducted by the Polar Institute (PINRO). Three surveys are the most important, but only the ecosystem survey covers most of the Arctic areas of the Barents Sea.

1. The joint Russian-Norwegian Winter Survey of demersal fishes (February)

2. The joint Russian-Norwegian Ecosystem Survey (August-September)
3. Russian Autumn-Winter Survey of demersal fishes (October-December)

In 2013-2014 PINRO continued to investigate the Arctic, including the Barents, White, and Norwegian Seas, as well as the Kara Sea and some parts of the central Arctic Ocean. Surveyed areas decreased in 2014 due to lower financial support.

The Russian Autumn-Winter survey is conducted by PINRO in October-December since 1982 and covers mainly the southern Barents Sea and the area near Spitsbergen archipelago. Main attention is paid to oceanography, plankton, and demersal fishes.

In 2013, PINRO conducted one survey in the Kara Sea. Previous surveys were conducted in 2007-2008 only.

One vessel conducted 38 trawling (23 demersal and 5 pelagic). Traditionally, various topics were investigated, such as oceanography, plankton, benthos, fishes, sea birds, marine mammals, etc.

The fishery investigation in the east part of the Russian Arctic is conducted by TINRO.
In recent years, TINRO resumed the periodical investigations in the Chukchi Sea. TINRO conducted pelagic, oceanographic, and plankton surveys in 2003, 2007, 2008, and 2014. TINRO also conducted bottom trawl surveys, oceanographic surveys, and plankton investigations in 1997, 2010, and 2014. The primary purpose of the investigation in 2014 was complex geological exploration, which included research of marine resources.

The data obtained during the expeditions of TINRO indicate that the polar cod is the most numerous species in trawl catches. The polar cod just one of several species with the possibility to form commercially important concentrations.

Researchers also conducted observations of marine mammals in the Chukchi Sea only in recent years. Particular attention is given to the polar bear and traditional aboriginal objects - walrus, gray whale, as well as specially protected species (Red Book species list).

The future plans of research activities in the Russian Arctic region are as follows:

- In the west sector (the Bering and Kara Seas), the main focus is to conduct traditional surveys in the Barents Sea, with no plans for additional surveys in the Kara Sea in the coming years.
- In the east sector, we developed a Program of complex research of biological resources in the seas of the East Sector of the Russian Arctic 2015-2020. This program includes the investigations of the Laptev Sea in 2015, the Chukchi Sea in 2016, 2018 and 2020, and the East Siberian Sea in 2017 and 2019. Particular attention in this plan will be given to the Chukchi Sea.

The Canadian perspective on Arctic research activity

Operational areas in which activities were conducted from 2012-2014 included Canadian Arctic waters as follows (Figure 4): Western Arctic – Beaufort Sea and waters adjacent to the northwestern margin of the Canadian Arctic Archipelago; Central Arctic Archipelago waters; and Eastern Arctic – Baffin Bay and Davis Strait waters south to include Hudson Strait. The former two areas are truly Arctic in circumstances, whereas the latter is a mixture of Arctic and sub-arctic ecological circumstances. In addition to activities in these areas, Canadian marine researchers also conducted activities in the high seas area of the central Arctic Ocean and participated in international missions in other areas. Appendix A1 summarizes the salient activities pertinent to the workshop focused upon finfish and lower trophic levels in Canadian waters, primarily with respect to activities delivered by government; brief mention is also made regarding activities delivered by university consortia, some of which may have relevance here. Where relevant the distinction is made between research and monitoring activities, however, most of this report focuses upon the former. Appendix A1 also provides examples of ongoing synthesis and integrative and data delivery activities. Knowledge acquisition (research) and synthesis activities underpin the provision of advice to environmental managers, and national and international forums. These activities also provide baseline data and advice for development and delivery of monitoring programs.

From the standpoint of the central Arctic Ocean and adjacent shelf seas, the Canadian Arctic marine systems are, for the most part, ‘downstream’ of the system. That is, Coriolis forcings and other physical processes generally move water masses from the northwest central polar region onshore towards the Canadian Arctic Archipelago. These are counter clockwise movements of deep water masses occurring as the Atlantic water mass (~450-900 m depths) and the Arctic Bottom water (1000m depth). Above this and offshore is the Beaufort Gyre, which moves surface waters and ice generally in a clockwise fashion towards areas further west. Between these offshore situations and the continental coast in the west, Pacific Water entering through the Bering Strait, sea-ice summer melt water and freshwater sources are entrained and move generally towards the east (i.e., into Canadian coastal waters). Accordingly, from the Canadian perspective, changes, occurrences, and activities in the central Arctic Ocean have significance in that they may affect domestic seas. Water and ice that enter the western edges of the Archipelago move eastwards to outflow in Baffin Bay and Davis Strait thence southwards along the Canadian coast into the Labrador Sea, thus further influencing processes in these ‘downstream’ areas. Moreover, water and ice flowing from the Arctic basin through Nares Strait between Canada and northern Greenland further influence the eastern regions of the Canadian system, as do North Atlantic inflows along the west Greenland coast. Thus Canada has a vested interest in and is very cognizant of how circumstances and activities in the central Arctic Ocean may affect its Arctic areas. Development and delivery of international and national programs to understand the central Arctic Ocean and its influences are encouraged by Canada.

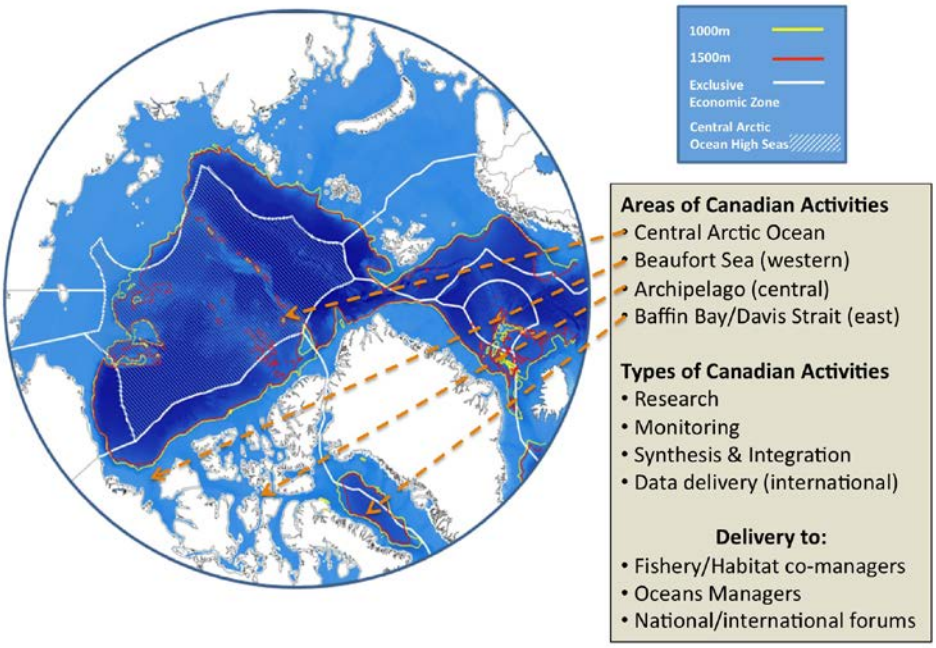

Figure 4. Areas of recent Canadian activity.

The Icelandic approach to Arctic research activities

The Marine Research Institute (MRI) is the main body undertaking oceanographic and fisheries research in Iceland. The main role of the institute is to: 1) conduct research on the marine environment around Iceland and its living resources; 2) provide advice to the government on catch levels and conservation measures for over 30 exploited fish stocks; and 3) inform the government, the fishery sector, and the public about the sea and its living resources. To meet this role, MRI undertakes extensive monitoring in the waters around Iceland. Here is a short overview of this annual and long term monitoring activity.

Since the 1950s, temperature, salinity, and nutrients have been monitored at a grid of 80 stations all around Iceland four times per year while phytoplankton and zooplankton are monitored at the same station grid in spring. These observations have demonstrated marked inter-annual and decadal fluctuations in the waters around Iceland. Since about 1995, a warm period attributed to increased inflow of Atlantic water has been observed.

In order to understand the factors determining the dynamics/variability of this inflow, extensive current measurements have been undertaken for almost two decades in the main inflow off the northwest coast of Iceland. Variability in flow is determined by winds, while it is not known what drives the average flow of the Atlantic water.

Atlantic inflow increases nutrient availability and mixing, which leads to increased primary production, and increased primary production then leads to increased food for zooplankton. Inflow of Atlantic water on to the shelf north of Iceland markedly affects the production process at all levels in that area. Increased Atlantic water also advects more zooplankton from southern waters. Higher temperature Atlantic water further leads to increased growth/production of zooplankton, and increased production/biomss means better feeding conditions for pelagic fish.

Capelin is the only fish stock of Arctic origin exploited by Iceland. The capelin is an important fishable resource, while it is also food for other fish species, seabirds, and whales. The capelin feeds during summer in the sub-Arctic waters to the north of Iceland. When the capelin return to the northern shelf, they are transporting great amounts of energy from the offshore part off the Iceland Sea and into the shelf system as other species feed on them. Exploitation of capelin started in the late 1960s following a collapse of herring stocks in the area and the initiation of a cold climate period around Iceland. The stock size of capelin has been monitored during acoustic surveys in autumn (October/November) and in winter (January) to provide advice for fishing. Since around 2000, the summer and autumn distribution of capelin has shifted farther to the west and north into East Greenland waters. Concurrently, autumn stock assessment surveys were difficult in some years, and the fishing fleet failed to find fishable shoals. These events have been attributed to an increase in the flow of Atlantic water to the areas north of Iceland and increased temperature. In order to try to further understand the changes observed in the capelin stock, MRI undertook extensive studies in the Iceland Sea during 2006-2008.

Since the Norwegian spring spawning herring started to recover in the middle of the 1990s it has been monitored annually in an extensive acoustic survey undertaken under ICES coordination by Faroe Islands, Iceland, Norway, and Russia. In recent years, the EU has also contributed vessels to this survey.

Mackerel in the Northeast Atlantic has shown marked changes in distribution in recent years. During the summer of 2007, a marked change appeared to take place in the distribution of mackerel in Icelandic waters. In 2007, it became more widely and uniformly distributed in the waters east of the country and westward along the south coast. By 2010, mackerel was distributed right around Iceland. An extensive fishery for mackerel within the Icelandic EEZ has developed during recent years, with catches reaching about 150 thousand tonnes in 2011-2014. Since 2009, the stock has been assessed by ICES coordinated pelagic trawl surveys and carried out by Faroes Islands, Iceland, and Norway. Biomass in the Icelandic EEZ during 2010-2014 has been estimated to range from 1.1-1.6 million tonnes. From these surveys and other information, it is evident that distribution of a large part of the mackerel stock has extended by about 1200-1500 miles to the west and 600 miles to the north in recent years.

The demersal fish stocks in Icelandic waters are mainly monitored in the Icelandic groundfish surveys, which have been conducted in March since 1985 and in October since 1996. These projects are based on standardized sampling schemes at about 600 stations and from about 50-500 m using bottom trawls, in which the main aim is to gather fishery independent indices on stock sizes of groundfish species together with information on various biological factors. Routine products for most of the commercially important demersal stocks are changes in stock indices, length frequency distributions, and spatial distribution, together with sexual maturity and age composition. The groundfish surveys also provide very important biological data on less important and non-exploited stocks.

Over 30 fish species have been recorded for the first time in Icelandic waters since 1995. This is believed to be related to and reflect the increase in temperature, which in recent years has occurred in the waters around Iceland.

MRI scientists have regularly (along with colleagues in the North Atlantic) conducted extensive whale sighting surveys since 1987 in order to get information on distribution and abundance of whales in Icelandic and nearby waters. The last and most extensive survey involving many nations took place in 2007 in the whole of the North Atlantic using both ships and airplanes. the current plan is to repeat this survey in 2015, which is considered particularly important in light of environmental changes that are taking place.

All Icelandic vessels fill out detailed reports on each fishing operation. This includes catch/species, position, time, and fishing gear (how long/how). Annually, about 170,000 fishing related operations are registered. All these data are stored in an MRI database and form a part of MRI assessment work and research. Since 2009, the logbooks have been on an electronic form and are sent as such for screening and storing.

MRI has taken part in many international projects that aim to investigate both the environment and biology of Icelandic and nearby waters. Key work is coordinated by ICES, and some of it has already been mentioned. In addition, the following international cooperation is worth mentioning:

- Hydrography: Arctic Subarctic Ocean Fluxes (ASOF), Thermo-Haline Overturning at risk (THOR), North Atlantic Climate (NACLIM);
- Biology/environment: Basin-scale Analysis, Synthesis and Integration (BASIN); and
- Carbon absorbtion and release: Lamont-Doherty Earth Observatory USA, EU framework programs Carbo-Ocean, Carbo-Change).

Finally, several important areas of research call for particular attention or effort in the waters north of Iceland and in Nordic Seas in coming years. These include: continued hydrographic monitoring; research on currents/fronts in relation to mixing processes and production (distribution, interaction, competition); studies on the ability of organisms to adapt to climate changes; effect of climate changes on interactions between predator and prey species; effect of new species with respect to competition; habitat needs of organisms; seabird ecology; ecosystem studies and comparisons of ecosystems; and modelling studies to link physics and biology.

The Korean approach to Arctic fisheries research activity

Most research and monitoring activities in the Arctic Ocean were carried out by the Korea Polar Research Institute (KOPRI) since 2004 with a great deal of qualitative and quantitative achievements. A vast range of polar infrastructures has been successfully constructed including the icebreaker ARAON in 2009 and the status as a permanent observer in the Arctic Council obtained in 2013. The Arctic research projects in Korea are aimed to plan and execute for deriving research outcomes with multilateral international joint research programs.

One example of the international efforts of Korean Arctic research is the DBO workshop, which was held in March 2011 in Seoul, Korea. The workshop was held immediately prior to the international Arctic Science Summit Week. Approximately 90 people attended the one-day DBO workshop in Seoul, including invited speakers who presented ideas for efforts to expand the DBO concept to the Eastern Arctic. In addition, provisional data sets were presented and planning efforts for the 2011 Pilot Study were initiated.

International cooperative Arctic research aboard the Korean icebreaker ARAON were carried out since 2013, including measurement/samples/observations of physical oceanography, chemical oceanography, production, phytoplankton, zooplankton, benthic fauna, etc.. In the 2014 ARAON Arctic cruise, 50 scientists from 10 countries participated in the multi-disciplinary research on Arctic Ocean sea ice, air, and ecosystem variations.

The National Fisheries Research and Development Institute (NFRDI) is beginning an ichthyoplankton study in the Arctic sharing samples by ARAON in 2015 in order to understand the early life history of Arctic fish and crabs. The Arctic fisheries research aims to understand the relationship between oceanographic conditions and biology at upper trophic levels and to contribute to constructing an ecosystem model considering future reactions of marine animals.

NFRDI is seeking an opportunity to participate in cooperative fisheries research by international survey cruises. Based on the accumulated experiences, a fishery survey will be able to be conducted by a second Korean icebreaker with fishery survey gears such as hydroacoustic and mid-water trawl, which is planned to launch in 2020.

The Greenland perspective on Arctic activity

Japanese Arctic research activities

China's approach to Arctic research activities

The key challenges and recommendations

Baseline information regarding physical, chemical, and biological conditions are lacking for many parts of the Arctic (Anon., 2011). Predicting the future of the pan-Arctic ecosystem remains a challenge not only because of the ever-changing nature of both physical and biological processes but also because of a staggering lack of marine ecological knowledge (Wassmann, 2011). There are still large knowledge gaps concerning the presence, abundance, and distribution of planktonic organisms, fish species, marine mammals, and benthic organisms, and very little is known about the production capacity at the species level, hence also in an ecosystem and changing climate context (Anon., 2011). The number of well-documented climate related changes in plankton, fish, and benthos communities in marine Arctic ecosystems is low (Wassmann et al., 2011). Thus, despite the alarming nature of warming and its strong potential effects in the Arctic Ocean, the current research effort evaluating the impacts of climate change in this region is very limited (Wassmann et al., 2011).

Using a multidisciplinary approach and utilizing national expertise and infrastructure, it should be the aim to increase the scientific knowledgebase and understanding of the ecosystem, design a long-term monitoring program to improve our understanding of ongoing processes, and to reveal ecosystem change. Further, there is an urgent need to develop and establish a framework for integrated ecosystem-based advice regarding the marine environment and the marine living resources in the waters under national jurisdiction. This is decisive for sound management of the Arctic Ocean in a national but also international pan-Arctic context. Thus, a key challenge is to extend any development of national research and monitoring into the central Arctic Ocean and to maintain a perspective of international agreement on these efforts.

Working Group evaluations and reporting

Extensive discussions of the Status Report Working Group [WG] at the Third Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean, produced this [more or less] consensus report in response to the Terms of Reference. The major themes are organized and presented below:

1. The WG clarified that it interpreted its primary charge as to review the information available about the distribution and abundance of finfish and invertebrates [snow crab in particular] with commercial importance in the area of the Central Arctic Ocean [CAO] that was beyond the limits of national jurisdiction in the Arctic [ABNJ – areas beyond national jurisdiction in the Arctic].

   In this respect, the WG called attention to the development of Atlases of distribution and abundance under construction by Norway, Canada, Russia and the US [BOEM request], as well as non-governmental organizations like Audubon. It was felt that these efforts would provide fishery managers and others with adequate information on distribution and abundance as is currently available. The expectation, especially with the Norwegian Atlas, is that there would be continuous updates as data are available.

This report focuses on the CAO and ABNJ while considering adjacent areas under national jurisdiction (EEZs), and discards but does not negate the PAME LME approach. The WG considers it more realistic to use standard international definitions for the high seas area of the CAO and management in the national EEZs as a framework where national competence and jurisdiction is affirmed vis a vis the CAO. While the LME approach has value in identifying the biogeographical ecosystem, it does not comport with jurisdictional realities

Recommendation: Surveys and research activities in the CAO and adjacent EEZs should be oriented to produce and report information on all relevant species to the atlas projects on a regular basis. [Look for ways to reorient planned surveys, if possible, to take into account the need to obtain the needed Atlas data].

2. From the standpoint of identifying any "commercial" species of fish and shellfish occurring solely within the CAO the WG considered a fairly wide range of issues.

   First, can we identify any fish or shellfish species occurring solely within the CAO of commercial value? There have not been any systematic surveys for commercial species in the CAO. There have, however, been a number of ad hoc reports [opportunistic] of fish occurrences in the CAO [17 species recorded]. Two surveys are known to have gone into the Chukchi plateau and went into the ABNJ –Rusalka and Xuelong {China}. In the estimation of the WG the primary species that could currently be considered of commercial value from a fisheries perspective was Arctic cod [Boreogadus saida] but that determination was not supported by survey-based stock assessment. Snow crab and Greenland halibut [turbot] are hypothesized to be of possible commercial value in limited geographic areas.

   Second, given the uncertainty cited above, the WG supported precautionary measures to prevent Illegal, Unreported and Unregulated (IUU) fishing in the ecosystems of the CAO. It was seen that the Chairman's report of the Nuuk Meeting called for restraint in regards to fishing in the CAO.

   Third, the WG explored the nature of potential "value" of a CAO fishery. The WG noted that nature and definitions of commercial value is changing constantly. For example, would bioprospecting for genetic resources and other product development be covered by a "commercial" fisheries designation? Similarly, it was considered that a species of potential commercial value might play a key role in the food web/ ecosystem that might prove greater than its market value, e.g., as forage for marine mammals that are critical to the subsistence and cultural values of indigenous peoples in the Arctic. Similarly, value for other ecosystem components like marine mammals and seabirds may be intrinsic, i.e., supporting other ecosystem services.

Fourth, the WG endorses a synoptic survey of the CAO involving the Arctic coastal states and international partners. We are aware that there are proposals being developed that may provide an opportunity for developing such a survey. For the time being, the WG encourages the primary emphasis to do inventory work for benthic commercial species above the current practical limit of demersal fishing [approximately 2000] meters depth given limited resources. In addition, surveys of pelagic fishes and other biota (pelagic food sources, e.g., zooplankton) would be relevant throughout the CAO.

Recommendation: Given the lack of knowledge for the CAO, the WG strongly encourages surveys of the CAO ecosystem focused on potential commercial species. In the interim the WG supports precautionary measures on activities impacting living marine resources in the CAO.

3. The WG reviewed the inventory of surveys and data as reported by all country participants and found that there was a strong need for synthesis and integration of the ecosystem related information coming from the sum of all efforts.

   At present the inventory of surveys and data archiving shows significant efforts, but to understand Arctic ecosystem-wide value of these efforts, there needs to be a major effort to synthesize and integrate these results. With respect to the CAO, in particular, the research and monitoring efforts were very limited; however, the efforts of the Arctic coastal states with respect to continental shelf and slope were more extensive – especially with respect to existing fisheries.

Recommendation: Develop an appropriate assessment to synthesize and integrate existing knowledge with respect to the CAO ecosystem.

4. The WG considered the issues of linkages between the waters in areas beyond national jurisdiction (ABNJ) of the CAO and surrounding areas of national jurisdiction.

   The WG considered it improbable in the short term for there to be an established commercial fishery in the CAO for stocks of species that reproduce in the CAO, have the larvae drift and settlement in the CAO, and juveniles and adults fulfill their life cycle in the CAO. However, stocks in the CAO might develop with some linkage to the continental shelf. Thus, migrations of CAO fish and fish from the continental shelf regimes may have important cross linkages as would be the case in a straddling stock or a trans boundary stock [even one totally between states on the continental shelf]. The WG recognizes high seasonal and spatial variability in these possible relationships [linkages] and encourages appropriate research to understand stock structure, distribution and movement of key biota.

Considerable discussion focused on the current distribution and abundance and also on future distribution and abundance under climate change. For the most part, the WG anticipates considerable change in distribution and abundance, however, the WG is not able to anticipate these trends. How to do this or how to monitor to detect change that would indicate future major shifts is a topic for further evaluation.

Recommendation: The WG found that it was important for research to focus on the international waters of the CAO and linkages with surrounding areas of national jurisdiction.

5. The WG is encouraged by all the research undertaken to investigate the functioning of the ecosystems in the marginal ice zone, the continental slope and into the deep Arctic Ocean, and in the ice covered areas. Technological development, vessel infrastructure and modeling tools provide data and results well suited to give an ecosystem based description of the biology of the Central Arctic Ocean.

   However, traditional fisheries biology and stock assessment may not be in the focus of these activities and thus data necessary to perform a fully integrated assessment may be lacking.

Recommendation: The WG has a preference for research and monitoring that focuses on ecosystem structure and processes. Collection of data (stock structure, age / size composition, abundance, growth, diet, natural mortality and reproductive potential) necessary to develop single species assessments is essential to fishery management within an ecosystem perspective.

6. The WG considered long term monitoring needs for documenting change in the CAO and for expanding and continuing on-going monitoring in the adjacent sea areas

   National presentations at this meeting indicate that plans for future work are fixed 3-5 years out. Thus, the question is what is most important to do from the standpoint of responding to the terms of reference by which the WG asserts that the goal is to identify the most important areas for determining the basis for international cooperation [e.g., CAO treaty if indicated].

   In light of spatial and temporal variability in summer sea ice decline accessibility to certain areas of the CAO will increase. Therefore, prioritization of monitoring, research and survey efforts is required with respect to species, areas, migratory patterns, etc.

Recommendation: The WG realizes that it is challenging to do comprehensive monitoring of the whole Arctic. Therefore effective coordination among the A5 and other nations is critical with respect to monitoring, research and survey efforts.

7. Speculations as to the future situation in the Central Arctic Ocean have been presented at meetings and in publications. It is the concern of the WG that these are not based on empirical data or modeling efforts buildt around reliable data. In order to have fruitful discussions about the future situation in the central Arctic ocean, agreed scenarios and modeling exercises would be an advantage.

Recommendation: Recognizing the marine ecosystem in the CAO and adjacent waters is changing, the WG discussed the need for projecting likely future scenarios with respect to species movements, colonization and related changes. Appropriate modeling and or similar studies to develop these scenarios is required.

References

Arctic Council (AC), 2004. Arctic Climate Impact Assessment: Scientific Report. Oxford: Cambridge University Press, New York.

Anisimova NA, Jørgensen LL, Lubin P, Manushin I, 2011. Benthos. In: T. Jakobsen, V. Ozhigin (Eds.) The Barents Sea Ecosystem: Russian-Norwegian Cooperation in research and management, Chapter 4.1.2.

Anon., 2011. Report of a Meeting of scientific Experts on Fish Stocks in the Arctic Ocean. Anchorage, Alaska, June 15-17, 2011.

Anon., 2013. Report of 2nd Scientific Meeting on Arctic Fish Stocks, Tromsø 28-31 October 2013

Auster PL, Link JS, 2009. Compensation and recovery of feeding quilds in a northwest Atlantic shelf fish community. *Mar. Ecol. Prog. Ser.* 382:163-172.

Bluhm BA, Iken K, Mincks HS, Sirenko BI, Holladay BA, 2009. Community structure of epibenthic megafauna in the Chukchi Sea. *Aquat Biol* 7:269–293.

Billett DSM, Bett BJ, Rice AL, Thurston MH, Galeron J, Sibuet M, Wolff GA, 2001. Long-term change in the megabenthos of the Porcupine Abyssal Plain (NE Atlantic). *Progress in Oceanography*, 50 (2001), pp. 325–348.

Bogstad, B., Gjøsæter, H., Haug, T. and Lindstrøm, U. 2015. A review of the battle for food in the Barents Sea: Cod vs. marine mammals. Frontiers in Ecology and Evolution: in press.

Brey T, 2012. A multi-parameter artificial neural network model to estimate macrobenthic invertebrate productivity and production. *Limnology and Oceanography-Methods*, Vol. 10;581-589

Bucklin A, Hopcroft RR, Kosobokova KN, Nigro LM, Ortman BD, Sweetman CJ, Jennings RM, 2010. DNA barcoding of Arctic Ocean holozooplankton for species identification and recognition. *Deep-Sea Res. II.* 57:40-48

Carmack E, McLaughlin, F, 2011. Towards recognition of physical and geochemical change in Subarctic and Arctic Seas. *Progress in Oceanography* 90: 90-104.

Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, Zeller D, Pauly D, 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Bio*. 16:24-35.

Chierici M, Fransson A, 2009. CaCO3 saturation in the surface water of the Arctic Ocean: undersaturation in freshwater influenced shelves. *Biogeosciences*, 6, 2421-2432.

Comiso JC, 2012. Large decadal decline of the Arctic Multiyear Ice Cover. *Journal of Climate*, 25,4:1176-1193.

Dalen J, Grahl-Madsen M, 2005. Revised plans for "Multi-usage system for towed vehicles" per September 2005. (In Norwegian). Institute of Marin Research and the University College of Bergen, 29 Sept. 2005. Pp. 1-17.

de Lange Wenneck T, Falkenhaug T, Bergstad OA, 2008. Strategies, methods, and technologies adopted on the RV G. O. Sars MAR-ECO expedition to the Mid-Atlantic Ridge in 2004. *Deep Sea Research* II, 2008;55:6-28.

Dickson AG, Sabine CL, Christian,JR (Eds.), 2007. Guide to best practices for Ocean CO2 measurements. PICES Special Publication 3, 191 pp.

Drinkwater KF, 2011. The influence of climate variability and change on the ecosystems of the Barents Sea and adjacent waters: Review and synthesis of recent studies from the NESSAR project. *Progress in Oceanography*, 90:47-61.

Edvardsen A, Zhou M, Tande KS, Zhu YW, 2002. Zooplankton population dynamics: measuring in situ growth and mortality rates using Optical Plankton Counter. *Marine Ecology Progress Series*, 227:205-219

Fransson A, Chierici M, Abrahamson K, Andersson M, Granfors A, Gårdfeldt K, Torstensson A and Wulf A, 2015a. CO2-system development in young sea ice and CO2 gas exchange at the ice/air interface mediated by brine and frost flowers in Kongsfjorden, Spitsbergen. Annals of Glaciology 56(69) 2015 doi: 10.3189/2015AoG69A563

Fransson A, Chierici M, Nomura D, Granskog MA, Kristiansen S, Martma T and Nehrke G. 2015b. Effect of glacial drainage water on the CO2 system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years. Journal of Geophysical Research: Oceans DOI 10.1002/2014JC010320

Gjøsæter H, 1998. The Population Biology and Exploitation of Capelin (Mallotus villosus) in the Barents Sea. *Sarsia* 83:453-496

Grebmeier JM, Overland JE, Moore SE, Farley EV, Carmack EC, Cooper LW, Frey KE, Helle JE, McLaughlin FA, McNutt SL, 2006. A Major ecosystem shift observed in the northern Bering Sea. *Science* 311, 1461–1464.

Harsem Ø, Hoel AH, 2012. Climate change and adaptive capacity in fisheries management: the case of Norway. *Int Environ Agreements*. DOI:10.1007/s10784-012-9199-5.

Heino M, Porteiro FM, Sutton TT, Falkenhaug T, Godø OR, Piatkowski U, 2011. Catchability of pelagic trawls for sampling deep-living nekton in the mid-North Atlantic. *ICES Journal of Marine Science 68*, 377–389.

Hjøllo SS, Huse G, Skogen MD, Melle W, 2012. Modeling secondary production in the Norwegian Sea with a fully coupled physical/primary production/individual-based Calanus finmarchicus model system. *Marine Biology Research* 8:508-26.

Hollowed A, Planque B, Loeng H. 2013. Potential movement of fish and shellfish stocks from the sub-Arctic to the Arctic. *Fisheries Oceanography* 22(5) 353-370.

ICES Advice 2012, Book 1.

Ivanov VI, Polyakov IV, Dimitrenko IA, Hansen E, Repina IA, Kirillov SA, Mauritzen C, Simmons H, Timikhov LA, 2009. Seasonal variability in Atlantic Water off Spitsbergen. *Deep-Sea Research* I 56: 1-14.

Jaschnov VA (1966). Water masses and plankton. 4. Calanus finmarchicus and Dimophyes arctica as indicators of atlantic waters in the Polar Basin (in Russian). Oceanology 6:493-503.

Knutsen T, Melle W, Strand E, Fuglestad A-L, Mjanger M, Harald Fitje H, Ørjansen O, Vedeler T, in press. MESSOR - A towed underwater vehicle for quantifying and describing the distribution of pelagic organisms and their ambient physical environment. *IEEE Journal of Oceanic Engineering*, (in press).

Kosobokova K, Hirche H-J, 2009. Biomass of zooplankton in the eastern Arctic Ocean – A base line study. *Progress in Oceanography* 82:265-208.

Kovacs KM, Haug T, Lydersen C, 2009. Marine mammals of the Barents Sea. *In* Ecosystem Barents Sea, pp. 455-498. Ed. by E. Sakshaug, G. Johnsen and K.M. Kovacs. Tapir, Trondheim.

Kovacs KM, Lydersen C, 2008. Climate change impacts on seals and whales in the Nort Atlantic Arctic and adjacent shelf areas. *Science Progress* 91(2): 117-150.

Kovacs KM, Lydersen C, Overland JE, Moore SE. 2011. Impacts of changing sea ice conditions on Arctic marine mammals. *Marine Biodiversity* 41: 181-194.

Krafft, B.A., Melle, W., Knutsen, T., Bagøien, E., Broms, C., Ellertsen, B., Siegel, V., 2010. Distribution and demography of Antarctic krill in the Southeast Atlantic sector of the Southern Ocean during the austral summer 2008. *Polar Biology* 33, 957–968.

Leu E, Søreide JE, Hessen DO, Falk-Pettersen S, Berge J, 2011. Consequences of changing sea-ice cover for primary and secondary producers in the European Arctic shelf seas: Timing, quantity, and quality. *Progress in Oceanography* 90:18-32.

Lind S, Ingvaldsen R, 2012. Variability and impacts of Atlantic Water entering the Barents Sea from the north. *Deep-Sea Research I* 62:70-88.

Mayer M, Piepenburg D, 1996. Epibenthic community patter non the continental slope off East Greenland at 75 N. *Mar Ecol Prog Ser* 143:151-164.

MacConald IR, Bluhm BA, Iken K, Gagaev S, Strong S, 2010. Benthic macrofauna and megafauna assemblages in the Arctic deep-sea Canada Basin. *Deep Sea Research.* Part II. Vol 57: 136-152.

Melle W, Abrahamsen M, Valdemarsen JW, Ellertsen B, Knutsen T, 2006. Design and performance of a new macro-plankton trawl in combination with a multiple cod-end system. SCOR Working Group 115, Mini Symposium on Standards for the Survey and Analysis of Plankton. Plymouth, England. 19-20 May 2006.

Michalsen K, Dalpadado P, Eriksen E, Gjøsæter H, Ingvaldsen R, Johannesen E, Lindal Jørgensen L, Knutsen T, Skern-Mauritzen M, Prozorkevich DD (2013) Marine living resources of the Barents Sea - ecosystem understanding and monitoring in a climate change perspective. *Marine Biology Research*, 9 (9):932-947, http://dx.doi.org/10.1080/17451000.2013.775459

Mumm, N, Auel H, Hanssen H, Hagen W, Richter C, Hirche HJ, 1998. Breaking the ice: large-scale distribution of mesozooplankton after a decade of Arctic and transpolar cruises. *Polar Biol*. 20: 189-197.

Nejstgaard J, Frischer M, Raule CL, Gruebel R, Kohlberg KE, Verity PG, 2003. Molecular detection of algal prey in copepod guts and fecal pellets. *Limnology and oceanography:Methods*, 1:29-38

Nejstgaard JC, Naustvoll L-J, Sazhin A, 2001. Methods to correct for a common bias in bottle incubation experiments: loss of microzooplankton grazing in bottles with mesozooplankton. *Marine Ecology Progress Series* 221: 59-75.

Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, et al., 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, *Nature*, 437, 681–686, doi:10.1038/nature04095.

Ortman, B. D., A. Bucklin, F. Pages, and M. Youngbluth. 2010. DNA barcoding of the Medusozoa. Deep-Sea Research II 57: 2148 – 2156.

Reigstad, M, Carroll, J, Slagstad, D, Ellingsen, I, Wassmann, P, 2011. Intra-regional comparison of productivity, carbon flux and ecosystem composition within the northern Barents Sea. *Progress in Oceanography* 90:33-46.

Renaud PE, Tessmann M, Evenset A, Christensen GN (2011) Benthic food-web structure of an Arctic fjord (Kongsfjorden, Svalbard). Mar Biol Res 7: 13-26. Doi: 10.1080/17451001003671597.

Sakshaug, E. (1997). Biomass and productivity distributions and their variability in the Barents Sea. *ICES Journal of Marine Science,* 54: 341–350.

Schauer U, Loeng H, Rudels B, Ozhigin VK, Dieck W, 2002. Atlantic Water flow through the Barents and Kara Seas, *Deep- Sea Res. I, 49 (2002)*, 2281-2298.

Slagstad, D, Ellingsen, IH, Wassmann, P, 2011. Evaluating primary and secondary production in an Arctic Ocean void of summer sea ice: An experimental simulation approach*. Progress in Oceanography* 90:117-131.

Steele, M, Boyd, T, 1998. Retreat of the cold halocline layer of the Arctic Ocean. Journal of Geophysical Research, Vol. 103, C5, 10.419-10.435.

Steinacher M, Joos F, Frölicher TL, Plattner G-K, Doney SC, 2009. Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle-climate model*, Biogeosciences*, 6, 515–533.

Tamelander T, Renaud PE. Hop H, Carroll ML, Ambrose Jr WG, Hobson KA (2006) Trophic relationships and pelagic-benthic coupling during summer in the Barents Sea Marginal Ice Zone, revealed by stable carbon and nitrogen isotope measurements. Mar Ecol Prog Ser 310: 33-46.

Tremblay JE, Belanger S, Barber DG, Asplin M, Martin J, Darnis G, Fortier L, Gratton Y, Link Y, Archambault P, Sallon A, Michel C, Williams WJ, Philippe B Gosselin M, 2011. Climate forcing multiplies biological productivity in the coastal Arctic Ocean*. Geophysical Research Letters*. 38.

Tremblay JE, Gagnon J, 2009. The effects of irrandiance and nutrient supply on the productivity of Arctic waters: a perspective on climate change. In: Nihoul CJ,Kostianoy AG (Eds.). Influence of Climate Change on the Changing Arctic and Subarctic Conditions. Springer Science, pp. 73-92.

Utne KR, Hjøllo SS, Huse G, Skogen M, 2012. Estimating consumption of Calanus finmarchicus by planktivorous fish in the Norwegian Sea using a fully coupled 3D model system. *Marine Biology Research* 8:527-47.

Vikebø FB, Husebø Å, Slotte A, Stenevik EK, Lien V, 2010, Effect of hatching date, vertical distribution and inter-annual variation in physical forcing on northward displacement and temperature conditions of Norwegian spring-spawning herring larvae. *ICES Journal of Marine Science*, 67: 1948-1956.

Walther GR, 2010. Community and ecosystem responses to recent climate change. *Phil. Trans. R. Soc*. B 365:2019-2024. Wassmann, P (Ed), 2011. Arctic Marine Ecosystems in an Era of Rapid Climate Change. *Progress in Oceanography*, 90, Issues 1–4, 1-132.

Wassmann P, Duarte CM, Agusti S, Sejr MK, 2011. Footprints of climate change in the Arctic marine ecosystem. *Global Change Biology,* 17, 1235-1249; doi: 10.111/j.1365-2486.2010.02311.x.

Wassmann P, Reigstad M, Haug T, Rudels B, Carroll ML, Hop H, Gabrielsen GW, Falk-Petersen S, Denisenko SG, Arashkevich E, Slagstad D, Pavlova O, 2006. Food webs and carbon flux in the Barents Sea. *Progress in Oceanography* 71:232-287

AMAP. 2007. Arctic oil and gas 2007. Arctic Monitoring and Assessment Programme, Oslo, Norway. 70p. Accessed at http://www.amap.no/oga/.

Conlan, K.E., H.S. Lenihan, R.G. Kvitek, J.S. Oliver. 1998. Ice scour disturbance to benthic communities in the Canadian High Arctic. Marine Ecology Progress Series. 166:1–16.

Craig, P.C., W.B. Griffiths, L. Haldorson, and H. McElderry. 1982. Ecological Studies of Arctic Cod (*Boreogadus saida*) in Beaufort Sea Coastal Waters, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 39:395-406.

Craig, P.C. 1984. Fish Use of Coastal Waters of the Alaskan Beaufort Sea: A Review. Transactions of the American Fisheries Society. 113:265-282.

Duffy, J Emmett, L. A. Amaral-Settler, D.G. Fautin, G. Paulay, T.A. Rynearson, H.M. Sosik, and J.J. Stachowicz. 2013. “Envisioning a Marine Biodiversity Observation Network.” *BioScience* 63 (5): 350-361. doi:10.1525/bio.2013.63.5.8.

Dunton, K.H., T. Weingartner, and E.C. Carmack. 2006. The nearshore western Beaufort Sea ecosystem: Circulation and importance of terrestrial carbon in arctic coastal food webs. Progress in Oceanography. 71: 362–378.

Fechhelm, R.G., B.W. Williams, M.J. Daigneault, and M.R. Link. 2008. Year 25 of the long-term monitoring of nearshore Beaufort Sea fishes in the Prudhoe Bay region, 2007. Report for BP Exploration (Alaska) Inc. by LGL Alaska Research Associates, Inc., Anchorage, Alaska. 80 p.

Jarvela, L.E., and L.K. Thorsteinson. 1999. The Epipelagic Fish Community of Beaufort Sea Coastal Waters, Alaska. Arctic. 52:80-94.

Johnson, S.R., W.J. Richardson. 1981. Beaufort Sea barrier island-lagoon ecological process studies: birds. US Dep. Commerce, NOAA, OCSEAP Final Report 7, pp. 109–383.

Johnson, L. 1983. Assessment of the effects of oil on arctic marine fish and marine mammals. Canadian Technical Report of Fisheries and Aquatic Sciences. Report:1200, viii +15p.

Johnson, S.W., J.F. Thedinga, A.D. Neff, and C.A. Hoffman. 2010. Fish fauna in nearshore waters of a barrier island in the western Beaufort Sea, Alaska. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-AFSC-210, 28 p.

NPFMC (North Pacific Fishery Management Council). 2009. Fishery Management Plan for Fish Resources of the Arctic Management Area. Anchorage, AK: NPFMC, 147 pp.

Rand, K, and E A Logerwell. 2010. “The first survey of the abundance of benthic fish and invertebrates in the offshore marine waters of the Beaufort Sea since the late 1970s.” *Polar Biology* 34: 475-488. doi:10.1007/s00300-010-0900-2.

Appendix A. National Summaries and Review Reports on Arctic Research and Monitoring

Appendix A1: Research activities
Appendix A2: Management plan Barents Sea update
Appendix A3: Atlas of the Barents Sea fishes. Joint IMR PINRO report 1, 2011
Appendix A4: IMR-PINRO Joint Report Barents Sea Update2014-2
Appendix A5: A monitoring strategy for the Barents Sea - HI-rapp_28-2013
Appendix A6: IMR ecosystem activity in the Arctic Ocean - HI-rapp 4-2013
Appendix A7: Survey report from the joint Norwegian Russian ecosystem survey 2013
Appendix A8: Strategic Initiative ARCTIC - WP descriptions
Appendix A9: Final report Joint Russian Norwegian Monitoring Project - Ocean 3 - Npolar 30 2015

Appendix B. Contact Information for Participants and Correspondents

Last Name	First Name	Country	Primary Email Address
Sunnanå	Knut	Norway	knut.sunnanaa@imr.no
Loeng	Harald	Norway	harald.loeng@imr.no
Afanasyev	Pavel	Russia	afanasiev@vniro.ru
Benton	David	USA	davebenton@gci.net
Choi	Seok Gwan	Korea	sgchoi@korea.kr
Fluharty	David	USA	fluharty@uw.edu
Hollowed	Anne	USA	anne.hollowed@noaa.gov
Ichii	Taro	Japan	ichii@affrc.go.jp
Logerwell	Libby	USA	libby.logerwell@noaa.gov
Kelly	Kryc	USA	KrycKA@state.gov
Niemeier	Paul	USA	paul.niemeier@noaa.gov
Rasser	Micael	USA	michael.rasser@boem.gov
Reist	Jim	Canada	Jim.Reist@dfo-mpo.gc.ca
Astthorsson	Olafur	Iceland	osa@hafro.is

Appendix C: Definitive References on the Status of Research and Monitoring by Large Marine Ecosystem

Barents

Jakobsen, Tore, and V. K. Ozhigin. 2011. *The Barents Sea : ecosystem, resources, management : half a century of Russian-Norwegian cooperation* Trondheim: Tapir Academic Press, .

Central Arctic

Grebmeier, Jacqueline M. , and Wieslaw Maslowski. 20014. *The Pacific Arctic region : ecosystem status and trends in a rapidly changing environment* Dordrecht ; New York Springer.

Beaufort

Grebmeier, Jacqueline M. , and Wieslaw Maslowski. 20014. *The Pacific Arctic region : ecosystem status and trends in a rapidly changing environment* Dordrecht ; New York Springer.

East Siberian

Zenkevitch, L. A. . 1963. *Biology of the seas of the U.S.S.R.* . Translated by Translated by Sophia Botcharskaya. London: George Allen & Unwin Ltd.

Laptev

Zenkevitch, L. A. . 1963. *Biology of the seas of the U.S.S.R.* . Translated by Translated by Sophia Botcharskaya. London: George Allen & Unwin Ltd.

Kara

Zenkevitch, L. A. . 1963. *Biology of the seas of the U.S.S.R.* . Translated by Translated by Sophia Botcharskaya. London: George Allen & Unwin Ltd.

Northern Bering Chukchi Seas

Grebmeier, Jacqueline M. , and Wieslaw Maslowski. 20014. *The Pacific Arctic region : ecosystem status and trends in a rapidly changing environment* Dordrecht ; New York Springer.

Wiese, Francis K., Thomas I. Van Pelt, and William J. Wiseman, Jr. 2012. "Bering Sea linkages Introduction." *Deep-Sea Research Part II-Topical Studies in Oceanography* 65-70:2-5. doi: 10.1016/j.dsr2.2012.03.001.

Icelandic waters

Astthorsson, Olafur S., Gislason Astthor, Jonsson, Steingrimur. 2007. Climate variability and the Icelandic marine ecosystem. Deep-Sea Research II, 54:2456-2477.

Astthorsson Olafur S., Hjalmar Vilhjalmsson. 2002. Iceland Shelf LME: Decadal Assessment and Resource Sustainability. In: K. Sherman and H. R. Skjoldal (editors): Large Marine Ecosystem of the North Atlantic. Amst. : Elsevier Science, pp. 219-240.