Conservation of Arctic Flora and Fauna

CIRCUMPOLAR BIODIVERSITY MONITORING PROGRAM

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Arctic Marine Biodiversity Monitoring Plan

Marine Expert Monitoring Group. Circumpolar Biodiversity Monitoring Program

ARCTIC COUNCIL

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CAFF Designated Area

Conservation of Arctic Flora and Fauna

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Naturally, the authors accept responsibility for any errors or omission in this work.

Executive Summary

Arctic biodiversity is under growing pressure from both climate change and resource development, requiring both managers and users to have access to more complete information to help them make timely and informed conservation and adaptation decisions. Yet existing monitoring programs remain largely uncoordinated, limiting our ability to effectively monitor, understand and respond to biodiversity trends at the circumpolar scale. The maintenance of healthy Arctic ecosystems is a global imperative as the Arctic plays a critical role in the Earth's physical, chemical and biological balance. Maintaining the health of Arctic ecosystems is also of fundamental economic, cultural and spiritual importance to Arctic residents, many of whom maintain close ties to the land and sea.

The Arctic's size and complexity represents a significant challenge towards detecting and attributing changes in biodiversity. This demands an integrated, pan-Arctic, ecosystem-based approach that can effectively identify important trends in biodiversity and identify their underlying causes.

To meet these challenges, CAFF's Circumpolar Biodiversity Monitoring Program (CBMP) is working with partners across the Arctic to harmonize and enhance long-term Arctic biodiversity monitoring in order to facilitate more rapid detection, communication and response to significant trends and pressures. Towards this end, the CBMP is developing four, ecosystem-based Arctic biodiversity monitoring plans (Marine, Terrestrial, Freshwater and Coastal). These umbrella monitoring plans work with existing monitoring capacity to facilitate improved and cost-effective monitoring through enhanced integration and coordination.

The Arctic Marine Biodiversity Monitoring Plan (CBMP-Marine Plan) is the first of the CBMP's four pan-Arctic biodiversity monitoring plans. The overall goal of the CBMP-Marine Plan is to improve our ability to detect and understand the causes of long-term change in the composition, structure and function of Arctic marine ecosystems, as well as to develop authoritative assessments of key elements of Arctic marine biodiversity (e.g., key indicators, ecologically pivotal and/or other important taxa).

The CBMP-Marine Plan integrates existing marine biodiversity monitoring efforts (both traditional scientific and community-based) from across the Arctic and represents an agreement between six Arctic coastal nations and a great number of national, regional, Indigenous and academic organizations and agencies in all six countries on how to monitor Arctic marine ecosystems. More specifically, the Plan identifies agreement on the following:

- A suite of common biological parameters and indicators to monitor and report on change across Arctic marine ecosystems;
- Key abiotic parameters, relevant to marine biodiversity, which should be monitored;
- Optimal sampling schemes (e.g., where, when and how the suite of parameters should be measured and by whom); and,
- Arctic Marine Areas, by which monitoring results will be organized and reported.

The Plan also begins to identify:

- Priority gaps (taxa, spatial, and/or temporal) in monitoring coverage; and,
- Existing datasets and information that can be aggregated to map biodiversity and to establish baselines and retrospective trends in Arctic marine biodiversity.

The creation of the Marine Expert Networks will further the work of identifying priority gaps, identifying existing datasets for aggregation and further refining the suite of biological indicators that will be used to report on the state and function of Arctic marine ecosystems.

The Plan also details the outputs of this effort, or more specifically, how the biological information will be managed, integrated, analyzed and reported on with a focus on:

- Producing long-term datasets that can facilitate a greater understanding of natural variability in Arctic marine ecosystems and the response of these systems to anthropogenic drivers.
- Creating a publicly accessible, efficient, and transparent platform to house and manage information on the status of and trends in Arctic marine biodiversity to facilitate more effective policy responses.
- Providing regular and authoritative assessments of key elements and regions of the Arctic marine system that respond to regional, national, and international reporting requirements.

Finally, Plan implementation timelines and costs over the next 10 years are detailed to ensure appropriate resourcing for this coordinated effort. Implementation of this coordinated Plan will result in improved capacity to detect, attribute and report on biodiversity change in the Arctic marine environment, at a lower cost than multiple, uncoordinated approaches.

Photo by:Lawrence Hislop. http://www.grida.no/photolib

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1. Introduction and Background

Arctic ecosystems host unique assemblages of organisms. The size and nature of arctic ecosystems make them critically important to the biological, chemical, and physical balance of the globe. Dramatic changes, now underway (Figure 1), are threatening arctic biodiversity, the resilience of arctic species, the potential for human use of the Arctic's components, and the overall balance of its ecosystems. Healthy arctic ecosystems are of fundamental economic, cultural, and spiritual importance to arctic residents. Moreover, continued rapid change in the Arctic will have repercussions for the ecosystems and biodiversity of the entire planet.

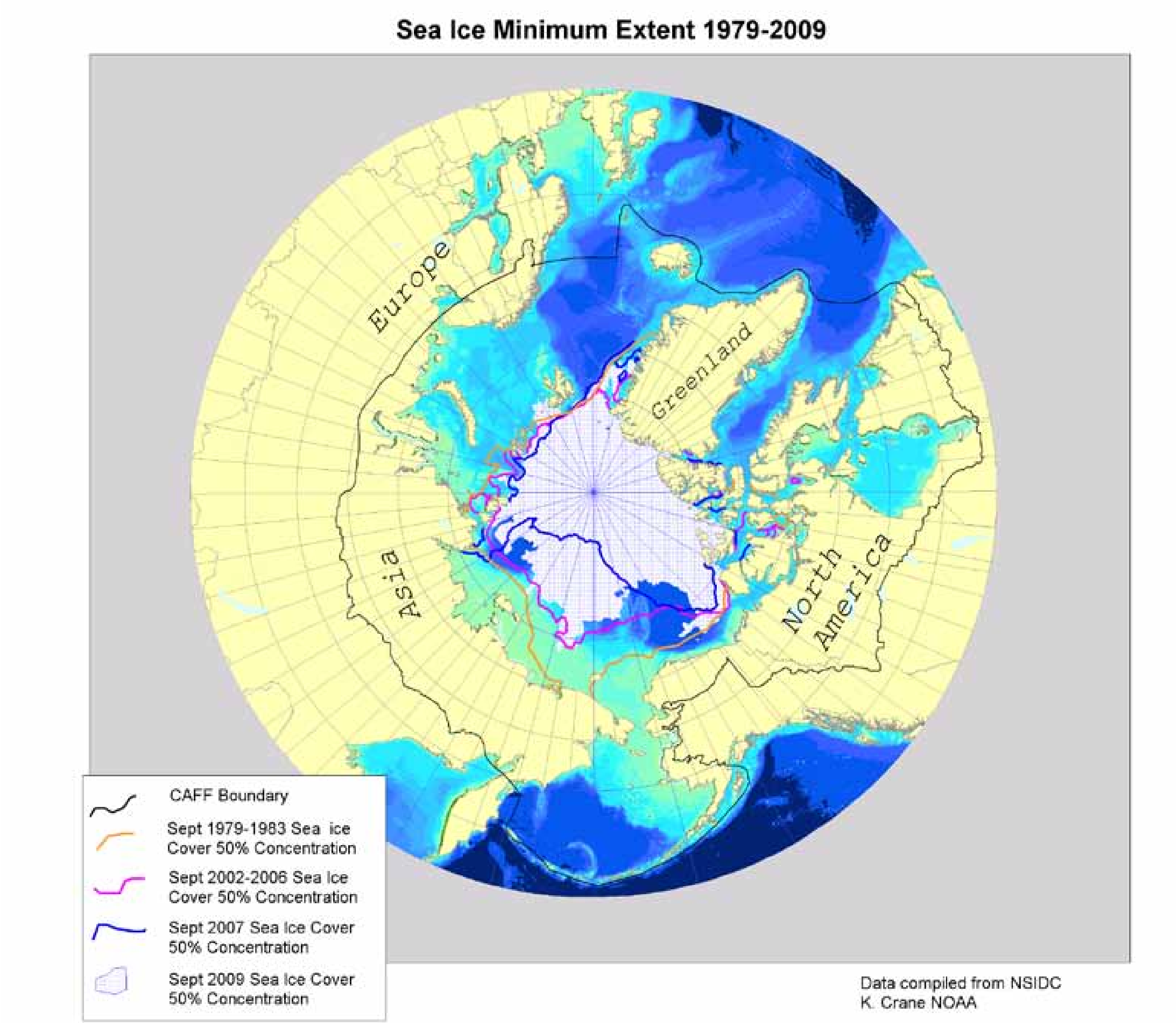

Figure 1 Changes in the September extent of Arctic Ocean sea ice superimposed on bathymetry. Maximum reduction in sea ice has occurred in the Pacific Arctic and the Kara–Laptev Seas regions. Source: National Snow and Ice Data Center (NSIDC)

Currently, Arctic biodiversity monitoring lacks the coordination needed to provide an integrated, pan-Arctic picture of status and trends related to key species, habitats, and ecological processes and services. Improved coordination will improve our ability to detect important trends, link these trends to their underlying causes, and provide this information to decision makers. Information on how the Arctic environment is responding to pressures such as climatic change and human activity is urgently needed to allow decision makers, whether in local Arctic communities, regional or national governments and international venues, to make timely and effective decisions regarding conservation and adaptive management.

In response to these critical needs, the Conservation of Arctic Flora and Fauna (CAFF) Working Group of the Arctic Council created the Circumpolar Biodiversity Monitoring Program (CBMP). CAFF's CBMP is working with scientists and local resource users from around the Arctic to harmonize and enhance long-term Arctic biodiversity monitoring efforts. The Marine Expert Monitoring

Group (MEMG) is one of four Expert Monitoring Groups (EMGs) created by the CBMP to develop integrated, ecosystem-based monitoring plans for the Arctic's major biomes. Each of the groups (Marine, Coastal, Freshwater, and Terrestrial) functions as a forum for scientists, community experts, and managers to promote, share, and coordinate research and monitoring activities, and to use existing data to facilitate improved, cost-effective monitoring that can detect and understand significant trends in Arctic biodiversity. These efforts will be coordinated through integrated, pan-Arctic biodiversity monitoring plans.

The development of the Arctic Marine Biodiversity Monitoring Plan (CBMP-Marine Plan) comes at a critical time. The International Year of Biodiversity has just concluded and governments around the world are faced with the fact that the 2010 goal to reduce the rate of biodiversity loss is largely unmet. In most cases, the rate of loss has not even been adequately measured. The recent report, *Global Biodiversity Outlook 3* (Secretariat of the Convention on Biological Diversity, 2010), noted the need for increased mobilization of resources for the research and monitoring of biodiversity. At the same time, while efforts to reach an international agreement on global climate change continue, there is broad acknowledgement that the polar regions are experiencing and are expected to experience the most rapid and dramatic impacts. The International Panel on Climate Change (IPCC) has concluded that climate change related to increased greenhouse gas concentrations will result in major physical, ecological, sociological, and economic impacts (IPCC 2007).

A number of Arctic Council assessments and reports have called for improved biodiversity information to support effective management of the Arctic environment. The *Arctic Climate Impact Assessment* (ACIA 2004, 2005) recommended that long-term Arctic biodiversity monitoring be expanded and enhanced in the face of a rapidly changing Arctic. A key finding of *The Arctic Biodiversity Trends 2010: Selected Indicators of Change* was that "long-term observations based on the best available traditional and scientific knowledge are required to identify changes in biodiversity, assess the implications of observed changes, and develop adaptation strategies." The *Arctic Marine Shipping Assessment* (AMSA 2009) highlighted the need for information on Arctic marine living resources to facilitate the identification of areas of heightened ecological and cultural significance. Similarly, the *Arctic Oil and Gas Assessment* (Arctic Oil and Gas, 2007) called for "improved mapping of vulnerable species, populations and habitats in the Arctic"

All of these recommendations highlight the increasingly urgent need for improved Arctic biodiversity monitoring to support effective management of the Arctic environment. In addition, Arctic coastal states have commitments through various regulatory regimes and associated legislation to protect their Arctic marine waters and the associated biodiversity. Sub-national governments, including Indigenous governments, also have mandates to ensure the maintenance of a healthy Arctic marine ecosystem. This monitoring plan, a key component of the Conservation of Arctic Flora and Fauna (CAFF) Working Group's Circumpolar Biodiversity Monitoring Program, will result in improved information on the status and trends of the Arctic marine's living resources, thereby directly supporting national and sub-national needs and international recommendations.

1.1 Overall Goals and Objectives of the Arctic Marine Biodiversity Monitoring Plan

The goal of the Marine Expert Monitoring Group (MEMG), formed to develop the Plan, is to promote, facilitate, coordinate, and harmonize marine biodiversity monitoring activities across the Arctic, and to improve ongoing communication amongst and between scientists, community experts, managers, and disciplines both inside and outside the Arctic. The end result will be better data accessibility, improved data management, assessment, and reporting, more efficient monitoring, and more rapid adoption of new technologies and methodologies. The CBMP-Marine Plan is the vehicle through which the MEMG will achieve these results.

The overall goal of the CBMP-Marine Plan is to improve our ability to detect and understand the causes of long-term change in the composition, structure, and function of Arctic marine ecosystems, as well as to develop authoritative assessments of key elements of Arctic marine biodiversity (e.g., key indicators, ecologically pivotal and/or other important taxa). This coordination will result in earlier detection and understanding of change, leading to more effective and timely decision-making.
To meet this goal, the plan has a number of key objectives:

- Identify a suite of common and integrated biological parameters and indicators to monitor change across Arctic marine ecosystems.
- Identify key abiotic parameters, relevant to marine biodiversity, which should be monitored and integrated with biological parameters.
- Identify optimal sampling schemes, making efficient use of existing monitoring capacity.
- Address priority gaps (taxa, spatial, and/or temporal) in coverage.

- Identify existing datasets and information that can be aggregated to map biodiversity and to establish baselines and retrospective trends in Arctic marine biodiversity.
- Provide regular, authoritative and integrated assessments of key elements and regions of the Arctic marine system that respond to regional, national, and international reporting requirements.
- Produce long-term datasets that facilitate a greater understanding of natural variability in Arctic marine ecosystems and the response of these systems to anthropogenic drivers.
- Create a publicly accessible, efficient, and transparent platform to house and manage information on the status of and trends in Arctic biodiversity to facilitate more effective policy responses.

While most existing Arctic biodiversity monitoring networks are national or regional in scope, there is substantial added value in establishing circumpolar connections among monitoring networks. Many, if not most, pressures on Arctic ecosystems operate at large scales. Also, Arctic biodiversity measures are often characterized by high variability due to the extreme nature of the environment. Determining change outside the range of natural variability requires long-term trend data. These conditions demand a pan-Arctic approach to monitoring these systems. Integration of monitoring approaches across the Arctic will lead to enhanced power to detect trends in a given time-frame. Integration will also help identify and eliminate redundancies in sampling effort through the adoption of an optimal sampling framework stratified by ecological rather than political boundaries. The development of a pan-Arctic, long-term, integrated marine biodiversity monitoring plan will facilitate circumpolar connections among national and regional research and monitoring networks. The result will be improved capacity to detect and attribute change and report this change, at a lower cost than multiple, uncoordinated approaches.

1.2 Definition of Biodiversity

The Convention on Biological Diversity (CBD) defines biological diversity, often shortened to biodiversity, as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems" (Article 2). Biodiversity, therefore, must be viewed at the level of the gene, the species, and the ecosystem, ranging in scope from local to regional and, even, global systems.

In the context of Arctic biodiversity, CAFF's CBMP recognizes the integral nature of global and human processes in the Arctic ecosystem. Arctic biodiversity depends, to a large extent, on conditions outside the Arctic, due to a high proportion of migratory species and the interconnections of Earth's systems (e.g., global ocean circulation, contaminant pathways). In addition, humans and their cultural diversity are components of Arctic ecosystems, as well as beneficiaries of essential goods provided by Arctic biodiversity. Monitoring all elements of ecosystems—including species, habitats, ecosystem structure, processes, functions, and stressors to the ecosystems—is necessary to gain a meaningful picture of what is happening to biodiversity in the Arctic.

1.3 Scope of the Monitoring Plan

In keeping with the CBMP's mandate to coordinate Arctic biodiversity monitoring, data management, and reporting, the CBMP-Marine Plan is based, first and foremost, on existing monitoring activities, already active or planned and, wherever possible, circumpolar in scope. Where appropriate, the plan will be coordinated with existing or planned regional, national, or bilateral projects that could contribute to a circumpolar understanding of biodiversity trends. The plan also identifies desired new sampling locations (stations and transects), existing locations where a continuation of observations is desired but not yet certain, and gaps in discipline coverage. The MEMG will encourage the proper administrative/political jurisdictions to facilitate or fund the suggested new monitoring activities, or it will seek funding from external sources. Phase I of the implementation of the monitoring plan (2011-2015) will focus on piloting, testing, and coordinating biodiversity monitoring within the existing monitoring programs and networks operated by Arctic countries. Phase II of implementation (post-2015) will involve refining the monitoring approach and working with integrating marine biodiversity monitoring networks originating from non-Arctic countries.

1.4 Integrated, Ecosystem-based Approach to Arctic Biodiversity Monitoring

The CBMP is adopting an integrated ecosystem-based approach to monitoring in its program design, organization, and operation (Figure 2). The ecosystem-based approach integrates information on land, water, and living resources, and lends itself to monitoring many aspects of an ecosystem within a geographic region. This approach considers the integrity of entire ecosystems and their interaction with other ecosystems. Although the complexity and data/analysis requirements far exceed those of the species approach, the rewards of the ecosystem-based approach are significant. It identifies important relationships, bridging ecosystems, habitats, and species and the impacts of stressors on ecological function. The resulting information contributes directly to adaptive management, enabling effective conservation, mitigation, and adaptation actions appropriate to the Arctic.

1.5 "Network of Networks" Approach

The ecosystem-based approach is achieved through the establishment of four EMGs. Each EMG represents, itself, a network-of-networks approach (linking multiple monitoring networks through an overarching monitoring plan) that will promote standardization and integration of information across biodiversity networks. The resulting biodiversity monitoring plans for each EMG will be integrated to capture the inherent links and influences that marine, coastal, terrestrial and freshwater systems have upon each other (e.g., freshwater downstream effects on coastal and marine systems). The approach also facilitates the establishment of links with other kinds of monitoring networks, including:

- Extra-Arctic: extending beyond the Arctic (e.g., migratory species monitoring).
- Abiotic: concerned with non-living components of the system.
- Umbrella: combining both biotic and abiotic monitoring.

In implementing the CBMP-Marine Plan, the Marine Expert Monitoring Group will draw upon existing species, habitat, ship or aerial-based (transect), and site-based (station) Arctic marine monitoring networks and link, where relevant, to abiotic and extra-Arctic monitoring activities (Figure 2). The CBMP will provide value-added services and tools in the areas of data management, communications, reporting, and decision-making (Figure 2). Of particular relevance is the development of a distributed, web-based data management, access, and analysis system—the CBMP Web-based Data Portal (see Chapter 7)—which will provide a home for the outputs of the integrated monitoring plan.

MEMG Meeting, Washington DC
Photo by: Reidar Hindrum. Norwegian Directorate for Nature Management, Norway

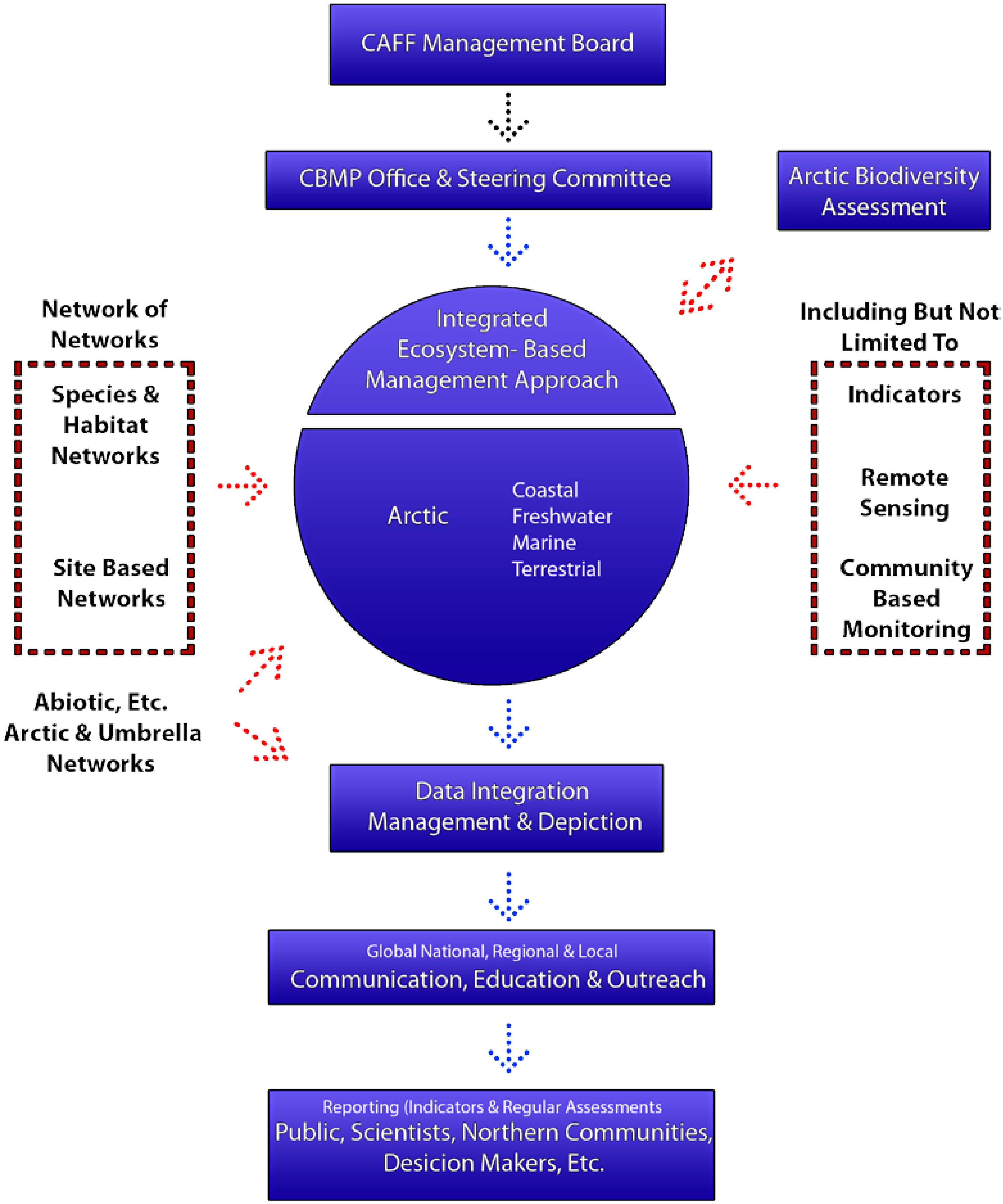

Figure 2. Organizational Structure of the CBMP

1.6 Community-based Monitoring, Citizen Science, and Historical Information

1.6.1 Community-based Monitoring and Citizen Science

The Indigenous peoples of the Arctic developed close connections to the land and sea that are vital for their wellbeing. Based on personal experience, on information shared between community members, and on knowledge passed down over generations, Arctic peoples can often detect subtle environmental changes and offer insights into the causes. Their day-to-day activities make them, in effect, community-based environmental monitors.

In addition to environmental monitoring as a necessity of their normal activities, many Arctic residents, both Indigenous and non-Indigenous, employ—or could employ—standard scientific monitoring procedures as citizen-scientists. This capacity can extend the reach and effectiveness of monitoring programs that otherwise must rely on a limited number of trained scientists who often only visit the Arctic during the summer months.

The CBMP is based on the premise that both community-based monitoring (based on traditional ways of life and practices) and citizen science (based on standard science but conducted by community members) offer important contributions and opportunities to Arctic marine biodiversity monitoring efforts. In return, Arctic communities will benefit from the information the CBMP gathers and disseminates as the information on status and trends in biodiversity can be used to facilitate development, conservation and adaptation decisions. By providing opportunities for the contributions of circumArctic Indigenous peoples and residents to the CBMP-Marine Plan will help ensure that the program is relevant and responsive to local concerns.

The CBMP-Marine Plan will employ conventional scientific methods alongside community-based monitoring and citizen science, dependent upon the parameters and location in question. A number of examples already exist to show how this kind of community involvement can be achieved. They include the Arctic Borderlands Ecological Knowledge Co-operative (Northwestern Canada and the United States, Alaska), the Fisheries Joint Management Committee (Northwestern Canada) and the Bering Sea Sub Network (BSSN) (United States and Russian Federation).

1.6.2 Historical Data

Arctic science began with early explorers who mapped and described Arctic species. The first internationally coordinated Arctic science dates back to the first International Polar Year (IPY) in 1882-1883. A wealth of data on various aspects of the Arctic marine system, including biological measurements, exists in various forms, including scientific publications, gray literature (including industry studies), databases, photo libraries, field books, etc. Museum data collections exist for many Arctic marine species and include voucher collections. These data are often not readily accessible, but they represent, in many instances, cost-effective opportunities for establishing retrospective, long-term datasets. In addition, the Arctic contains a number of abandoned research sites and transects that could be resampled, yielding extended time-series trend data. The CBMP-Marine Plan includes activities to "rescue" existing information and sampling sites that can help us understand past trends and put current trends in context.

1.7 Links and Relevance to Other Programs and Activities

A coordinated monitoring approach for Arctic marine ecosystems serves a variety of mandates at several scales. The Arctic Council will be a direct beneficiary. The outputs of the CBMP-Marine Plan will help populate Arctic Council assessments and identify issues that require a coordinated, pan-Arctic, or even global response. The plan will also benefit scientists directly, by improving cross-disciplinary collaboration and providing greater access to long-term and pan-Arctic datasets. This, in turn, will facilitate advanced research and publications on the mechanisms that drive environmental trends.

To the greatest extent possible, information developed under the CBMP-Marine Plan will be provided at the local scale to serve local decision-making. This will be achieved partly through local-scale, community-based monitoring, but also through interpolation and modeling techniques to provide information that Arctic residents can use to make effective adaptation decisions.

CBMP-Marine Plan outputs will also be of direct value to national governments and organizations charged with monitoring and reporting on the status of Arctic marine ecosystems within their jurisdictions. In many Arctic countries, this responsibility is shared across a number of government agencies. Developing optimal sampling schemes and standardized and integrated approaches to monitoring at a pan-Arctic scale will improve sub-national and national governments' ability to understand trends and the mechanisms driving them and will increase the capacity of individual agencies to respond effectively.

The successful implementation of the CBMP-Marine Plan depends upon effective links to a number of biotic and abiotic monitoring programs and initiatives, including those that are concerned with anthropogenic stressors. Relevant biotic programs are identified within the CBMP-Marine Plan. However, critical information could also be garnered from abiotic programs, umbrella programs, and extra-Arctic programs. These programs could, in turn, use the information generated by the CBMP-Marine Plan and might provide opportunities for coordinated monitoring (e.g. shared sampling sites). Relevant abiotic, umbrella, and extra-Arctic programs, assessments and initiatives include the following:

Arctic Council Working Groups and Activities:

Arctic Biodiversity Assessment (ABA)

The ABA, led by the CAFF Working Group of the Arctic Council, is a three-phase assessment of the status of the Arctic's biodiversity. The first phase, the Selected Indicators of Change report was based on the suite of CBMP indicators and indices. The CBMP-Marine Plan will benefit from the ABA's full scientific assessment report. This assessment involves gathering and analyzing existing data on Arctic marine biodiversity. The development of the ABA marine chapter will provide useful baseline information from which the CBMP-Marine Plan can draw. The CBMP-Marine Plan will use the ABA as the baseline from which it will periodically (every five years) reassess the state of the Arctic's marine ecosystems.

Other CAFF activities as related to the marine environment include work on the sea ice ecosystem and marine sensitive areas. These will also contribute to and benefit from the CBMP-Marine Plan.

Arctic Monitoring and Assessment Programme (AMAP) Working Group of the Arctic Council

AMAP's objective is "providing reliable and sufficient information on the status of, and threats to, the Arctic environment, and providing scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventative actions relating to contaminants." As such, AMAP is responsible for "measuring the levels, and assessing the effects of anthropogenic pollutants in all compartments of the Arctic environment, including humans; documenting trends of pollution; documenting sources and pathways of pollutants; examining the impact of pollution on Arctic flora and fauna, especially those used by indigenous people; reporting on the state of the Arctic environment; and giving advice to Ministers on priority actions needed to improve the Arctic condition."

The information generated by AMAP on pollutants and their impacts on Arctic flora and fauna will be an important data element in interpreting Arctic marine biodiversity trends. Opportunities for monitoring efficiencies between AMAP's monitoring program and the CBMP-Marine Plan should be investigated and, wherever feasible and desirable, coordinated monitoring should be implemented.

AMAP is also involved in climate assessment and leads the Snow, Water, Ice and Permafrost in the Arctic (SWIPA) project. SWIPA was established by the Arctic Council in April 2008 as a follow-up to the 2004 ACIA report, with the goal of assessing current scientific information about changes in the Arctic cryosphere, including the impacts of climate change on ice, snow, and permafrost. Of particular relevance is the assessment of Arctic sea ice as the CBMP-Marine Plan includes monitoring elements of sea-ice-associated biota.

AMAP is also beginning work on an ocean acidification project that will provide relevant information on this emerging environmental driver.

Protection of the Arctic Marine Environment (PAME) Working Group of the Arctic Council

PAME is the focal point of Arctic Council activities related to the protection and sustainable use of the Arctic marine environment. It has a specific mandate to keep under review the adequacy of global and regional legal, policy, and other measures and, where necessary, to make recommendations for improvements that would support the Arctic Council's Arctic Marine Strategic Plan (2004). The information generated by the CBMP-Marine Plan will be useful to PAME in fulfilling its mandate.

The Arctic Marine Shipping Assessment led by PAME includes a recommendation for the identification of environmentally and culturally significant marine environments that can be considered for special management in the light of an expected increase in shipping activity. The outputs of the CBMP-Marine Plan will provide information to support the identification and future monitoring of these areas.

Sustainable Development Working Group (SDWG) Working Group of the Arctic Council

The objective of the SDWG is to protect and enhance the economies, culture, and health of the inhabitants of the Arctic in an environmentally sustainable manner. Currently, the SDWG is involved in projects in the areas of children and youth, health, telemedicine, resource management, cultural and ecological tourism, and living conditions in the Arctic. The work of SDWG—in particular, development of indicators related to human-community response to changes in biodiversity—will be useful to the CBMP-Marine Plan. In turn, it is anticipated that the outputs of the monitoring plan will directly benefit SDWG's indicator development.

Sustaining Arctic Observing Networks (SAON) – An Arctic Council and International Arctic Science Committee(IASC) Initiative

SAON is composed of representatives of international organizations, agencies, and northern residents involved in research and operational and local observing. This initiative is developing recommendations on how to achieve long-term, Arctic-wide observing activities. The goal is to provide free, open, and timely access to high-quality data that will contribute to pan-Arctic and global value-added services and provide societal benefits. CAFF's CBMP is the biodiversity component of SAON. The CBMP-Marine Plan will both facilitate and benefit from the development of an integrated pan-Arctic observing network.

Other Programs:

Group on Earth Observation Biodiversity Observation Network (GEO BON)

GEO BON is the biodiversity arm of the Global Earth Observation System of Systems (GEOSS). Some 100 governmental and non-governmental organizations are collaborating through GEO BON to make their biodiversity data, information, and forecasts more readily accessible to policy makers, managers, experts, and other users. GEO BON is a voluntary, best-efforts partnership guided by a steering committee. The Network draws on GEO's work on data-sharing principles and on technical standards for making data interoperable. This global initiative is closely aligned with the CBMP, and the CBMP is the now the Arctic-BON of the global network. The CBMP's outputs, including the outputs from the CBMP-Marine Plan, will feed directly into the GEO BON effort (the CBMP-Marine Plan is specifically referenced in the GEO-BON Implementation Plan). Correspondingly, pan-Arctic biodiversity monitoring will benefit from the information generated globally, providing context for the patterns and trends detected in Arctic ecosystems.

1.8 Benefits of Contributing to a Circumpolar, Coordinated Effort

The CBMP-Marine Plan will facilitate more powerful and cost-effective assessments of Arctic marine ecosystems through the generation of and access to improved, pan-Arctic datasets. This will, in turn, contribute directly to more informed, timely, and effective conservation and management of the Arctic marine environment. While most Arctic biodiversity monitoring networks are—and will remain—national or sub-national in scope, there is considerable value in establishing circumpolar connections among monitoring networks. The development of a CBMP-Marine Plan will facilitate these connections and encourage standardization amongst national and sub-national research and monitoring networks, increasing their power to detect and attribute change. In addition, the increased power will come at a reduced cost, compared to the cost of multiple uncoordinated approaches.

2. Arctic Marine Areas

*There are a number of ways to divide the Arctic marine region—by ecosystem/ecological characteristics, by administrative criteria, or by some combination of the two (see CAFF programs for other examples). However, effective biodiversity monitoring requires that an ecosystem-based approach be used to identify marine areas. This approach involves delineating areas with similar physical and biogeochemical characteristics to permit useful spatial comparisons across the Arctic. These delineations also provide a framework by which status and trends can be reported across the Arctic.

The MEMG has adopted a set of criteria for choosing areas that blends inputs from MEMG members and builds upon criteria developed at the CBMP Implementation Workshop in Anchorage, November 29-30, 2006.

To be considered an Arctic Marine Area (AMA), significant parts of the region must be seasonally ice-covered at present or must have been so in the recent past. Arctic Council definitions state that marine ecosystems exclude intertidal areas from 0-30 m depth. Shallower areas are included if they are relevant to the overall dynamics in marine areas, and this is the case throughout most of the Arctic.

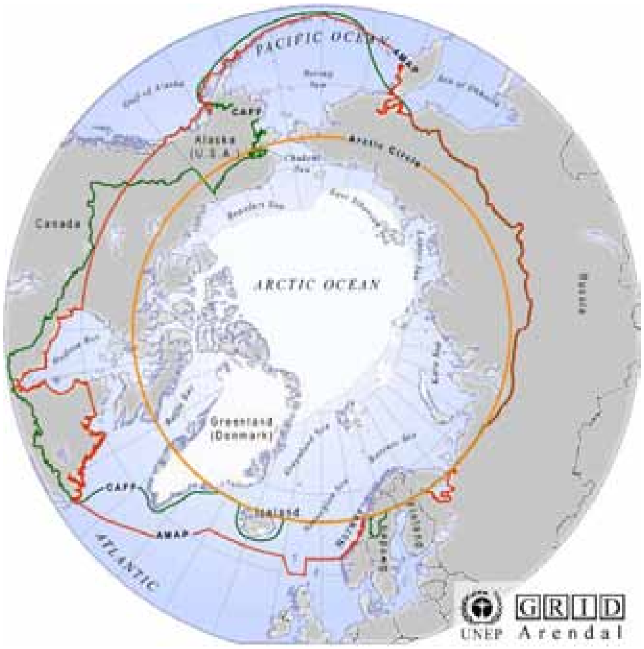

Figure 3 Delineations of the CAFF and AMAP areas

All AMAs selected by the MEMG (Figure 4) are either linked to Large Ocean Management Areas (LOMAs), Large Marine Ecosystems (LMEs), Marine Protected Areas, National Wildlife Areas, Important Bird Areas, or other similar areas, and would benefit from coordinated biodiversity monitoring and its data outputs. The marine areas can link with the Convention on Biological Diversity's Ecologically and Biologically Significant Areas (EBSAs). The areas adjacent to the Arctic coastline will preferably link with the Coastal and Freshwater EMG priorities (e.g., regions important for anadromous fish).

Of note, most Arctic Marine Areas are experiencing, or are expected to experience, development pressures such as oil and gas exploration and extraction, commercial fisheries, and pollution from ships. These areas are also undergoing other changes, in particular due to changes in climate variability and climate extremes (diminishing sea ice, changing freshwater inputs, water temperature, salinity, and acidification).

2.1 Criteria Used to Delineate Arctic Marine Areas

The MEMG developed criteria to identify areas within the Arctic marine system where monitoring should be focused and to delineate physically and biogeochemically distinct AMAs that encompass these important areas. The criteria are listed below, ordered by decreasing significance, with none being mutually exclusive:

1. Marine ecosystems for which we have long-term and high-quality datasets and/or ongoing activities covering all trophic levels from phytoplankton and algae through zooplankton, benthic animals, pelagic fish, seabirds, marine mammals, as well as key supporting biogeochemical data.
2. Biological hotspots (e.g., polynyas, marginal ice zones), since these physically dynamic areas are proven sources of important traditional foods, as well as significant habitat for many marine species.
3. Margins, boundaries, and fronts: monitoring changes in their position that could lead to changes in biodiversity (e.g., ice edge, distinct current circulations, intruding Atlantic or Pacific water that alters vertical structure, river inputs).
4. Gateways, which import and export biogeochemical properties, including biota and invasive species, with seawater.
5. Locations suitable for incorporating and/or developing community-based monitoring approaches.
6. Places with potential for both sections (spatial coverage) and moorings (temporal, especially seasonal, coverage), using new technologies as they become available.
7. Low-productivity systems, because they may change profoundly as a consequence of anthropogenic impact, particularly climate change.
8. Blocking domains, such as sills, which affect migration of biota.

*NOTE: THESE AREAS WILL BE ADJUSTED TO ENSURE THAT THE OUTER BOUNDARIES OF THE ARCTIC MARINE AREAS ALIGN WITH THE ARCTIC LARGE MARINE ECOSYSTEM (LME) BOUNDARIES ONCE THE ARCTIC LME BOUNDARIES ARE FINALIZED IN 2011.

2.2 Arctic Marine Areas

Detailed descriptions of seven of the eight AMAs chosen for focusing coordinated marine biodiversity monitoring efforts are in Appendix B. These AMA boundaries may change over time as bio-physical conditions that define these boundaries change. Figure 4 shows regional divisions of the marine Arctic, as determined by the Marine EMG

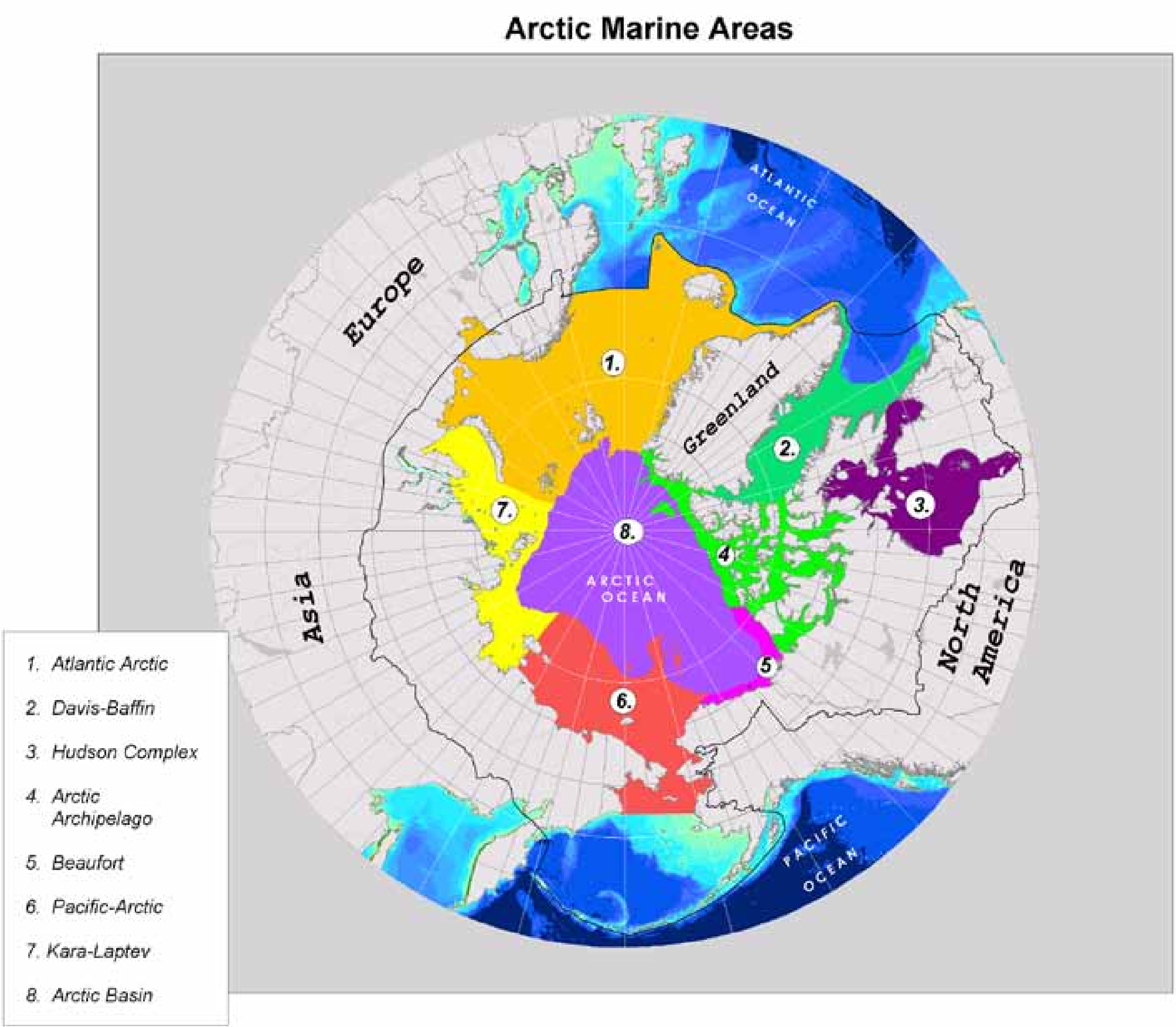

Figure 4 Regional divisions of the marine Arctic, as determined by the Marine Expert Monitoring Group.*

*Note that this map is preliminary and boundaries will be modified to align with the Arctic Large Marine Ecosystem delineations once finalized.

3. Conceptual Model Of Arctic Marine Ecosystems

Conceptual models (Figure 5) were developed to facilitate the selection of Focal Ecosystem Components (FECs), parameters, and indicators, and to identify the relationships between components. These models represent anticipated ecosystem states under four scenarios (normal, moderate temperature increase, overfishing, and ocean acidification). It should be noted that the models are meant to illustrate how different ecological groups might respond under the different scenarios and not necessarily to predict responses of individual species. In addition, the key effects and their magnitude may vary between AMAs, with considerable uncertainty associated with predicting the long-term responses of ecosystems to human impact. The conceptual models are nevertheless useful in ensuring that the resulting suite of FECs, parameters, and indicators captures key elements of the Arctic marine ecosystem. Only that level of coverage will give a balanced plan that can facilitate the detection of trends in important biodiversity elements and also improve understanding of how the ecosystem functions and how its components are related.

The scenarios may operate over different time scales. The depicted impact of fisheries, for example, can take place over a few years or several decades. Indeed, it has already begun in some AMAs (e.g., removal of benthic organisms by bottom trawling in the Barents Sea). The impact of moderate temperature increases may occur over similar time scales, although decadal scales are more likely for major changes. Limited effects of temperature increases are already detectable in some AMAs. Examples include reproductive failure in ice-associated seals on the west coast of Svalbard in the Barents Sea and reduced body condition of polar bears in the Western Hudson Bay sub-population, changes that are linked to declines in sea ice due to climate change. The biological impact of ocean acidification in Arctic waters is still uncertain, as is the time scale on which it might happen.

Photo by:Kathy Crane. National Oceanic And Athmospheric Administration, U.S.A

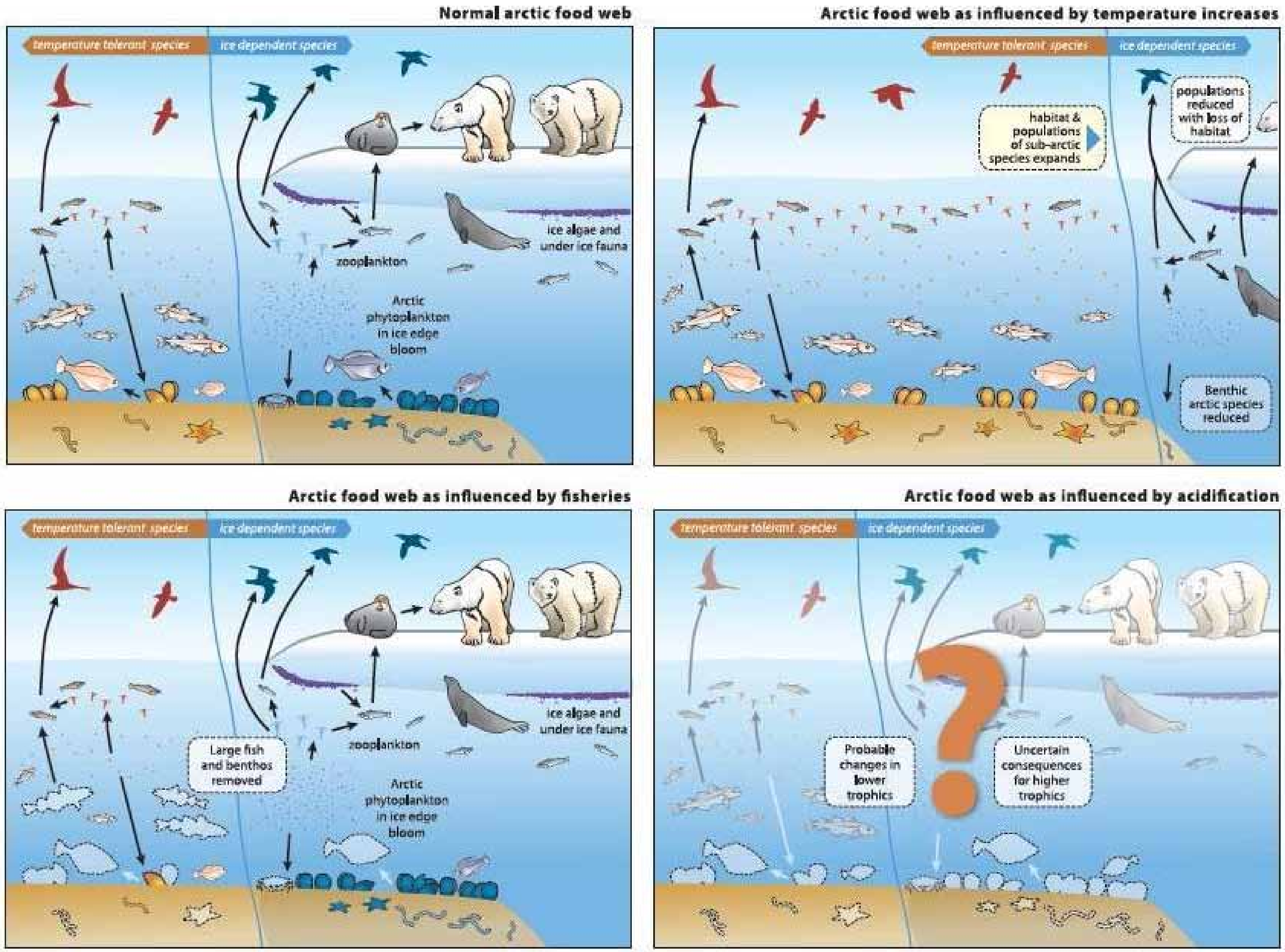

Figure 5 Conceptual models showing potential impacts on Arctic marine ecosystems under different scenarios.

The upper left panel (normal Arctic food web) in Figure 5 gives a schematic representation of a situation with no major anthropogenic impact. The system consists of ice-dependent species and species that tolerate a broader range of temperatures and are found in waters with little or no sea ice. Primary production occurs in phytoplankton (small dots in the figure) in ice-free waters and in ice-attached algae and phytoplankton in ice-covered waters. Phytoplankton (small t-shaped symbols in the figure) and ice algae are the main food sources for zooplankton and benthic animals. The fish community consists of both pelagic and demersal species. Several mammals are ice-associated, including polar bears and several species of seals. A number of sea bird species are also primarily associated with ice-covered waters.

The upper right panel shows responses to moderate temperature increases. In general, populations of ice-dependent species are expected to decline as sea ice declines, and sub-Arctic species are expected to move northwards. Arctic benthic species are expected to decline, especially if their distributions are pushed close to or beyond the continental slope.

The lower left panel shows expected effects from fisheries. Two major effects are reductions in populations of benthic organisms due to disturbance from bottom trawling and removal of large individuals in targeted fish stocks. In addition, the size of targeted stocks, both demersal and pelagic, may be reduced.

The lower right panel illustrates our knowledge status about effects of ocean acidification. Ocean acidification will result in depletion of carbonate phases such as aragonite and calcite. This will alter the structure and function of calcareous organisms, particularly at lower trophic levels. Changes in pH can also alter metabolic processes in a range of organisms. It is not known how these changes will propagate to higher trophic levels, but the effects could be substantial.

It should be noted that two or all three of the types of human impact illustrated here may act cumulatively on an Arctic marine ecosystem. In such a situation, we would be interested in knowing the combined impact of all factors. Acknowledging that this is a complex problem, the models can provide a valuable starting point for analysis.

These models also highlight the importance of monitoring both Arctic marine biodiversity itself and, concurrently, the stressors/drivers in order to understand their impacts Arctic marine biodiversity. This information is critical to identifying adaptive responses.

Photo by:Lawrence Hislop. http://www.grida.no/photolib

4. Selecting Priority Focal Ecosystem Components, Parameters, and Indicators

4.1 Process for Identifying and Selecting Candidate Focal Ecosystem Components, Parameters, and Indicators

4.1.1 Background Paper and Workshop Process

Development of a background paper (Vongraven *et al,* 2009) and two workshops (see Appendix D for participants) were the major steps in developing the CBMP-Marine Plan. The Norwegian Polar Institute led development of the background paper, with contributions from other MEMG members, as part of preparations for the first workshop. Norway convened the first integrated monitoring planning workshop on January 17-18, 2009, in Tromsø, Norway. This workshop (Vongraven, 2009) brought together scientists and community-based experts from across the Arctic to begin identifying the key elements (drivers, Focal Ecosystem Components, indicators, and existing monitoring programs) to be incorporated into a pan-Arctic monitoring plan and within each Arctic Marine Area.

Information from the first workshop was used to assemble a draft integrated marine biodiversity monitoring plan. A second workshop, hosted in Florida by the United States on November 4-6, 2009, completed tasks left from the first workshop, including final selection of key parameters, identifying available and relevant datasets for baseline establishment, and identifying key partners and a process and approach for implementing the monitoring plan.

4.1. 2 Scoping Process

The development of the plan employed an ecosystem-based adaptive management approach, using the concept of Adaptive Environmental Assessment and Management (AEAM), a method developed in the 1970s to address the complexity of biological diversity monitoring.

A major challenge in developing monitoring programs is identifying a limited number of issues to be addressed. This process is called scoping and normally also includes considerations of key questions, measurable objectives, impact factors, or drivers. The AEAM concept is a systematic scoping method aimed at simplifying the ecosystem approach, ensuring its interdisciplinary nature, and mutually sharing knowledge among scientists and other stakeholders. AEAM is a participatory process, based on workshops, which are typically attended by a variety of stakeholders, project holders, scientists, and society representatives.

The AEAM process starts with a description of the ecological and societal status of the area in focus. In each area, there are numerous species, species groups, habitats, and processes that could be monitored. There are also anthropogenic and natural impact factors or drivers that can affect the ecosystem. In a monitoring context, the challenge is to identify priority monitoring objectives and choose which parts of the ecosystem to focus on and the priority of associated drivers. Through systematic scoping, the AEAM method identifies and prioritizes issues (named Focal Ecosystem Components or FECs in the Plan), as well as pressures or drivers. FECs are the basis for the selection of targeted monitoring parameters and indicators in this plan.

In developing the CBMP-Marine Plan, cause-effect charts were constructed, based on a limited number of FECs and drivers, to put the FECs and drivers in context. Impact hypotheses were formulated, based on the cause-effect charts, and the impact hypotheses were explained and described in scientific terms. The impact hypotheses also formed the basis for identifying research needed to support monitoring, specific monitoring objectives, and management actions that the monitoring will need to support. This process identified priority elements to monitor—using, for the most part, existing monitoring capacity—with the goal of integrating monitoring to improve trend detection and attribution.

4.1.3 Criteria for Selecting Parameters and Indicators

Definitions

- **Parameter** is a measure used to determine the state of a particular component of an ecosystem (sometimes referred to as a variable).
- **Indicator** is the result of a parameter or suite of parameters used to report on the state of an ecosystem or a component of that ecosystem.

- **Index/indices** are aggregations or syntheses of indicators used to provide an overall perspective on a trend or change over time. They are used to make finding patterns easier, by either a qualitative or quantitative aggregation of parameters and/or indicators.

To facilitate effective and consistent reporting, CAFF's CBMP has chosen a suite of indices and indicators (Gill and Zöckler, 2008) that provides a comprehensive picture of the state of Arctic biodiversity—from species to habitats, to ecosystem processes, to ecological services. They were chosen through an expert consultation process and reflect existing monitoring capacity and expertise as far as possible.

Criteria used to select these indicators included:

- Sensitivity to natural or anthropogenic drivers.
- Scientific validity.
- Relevance to and resonance with diverse audiences (e.g., local communities, decision makers, global public).
- Ecological relevance.
- Sustainability of monitoring capacity.
- Subject to targets and thresholds.
- Practicality.

The indices and indicators also took into account the following:

- Major Arctic biomes at various scales.
- Known Arctic pressures.
- Major trophic levels, major Arctic biodiversity components (e.g., genes, species, habitat), including humans.
- Critical ecosystem services and functions, using both community and science-based monitoring approaches.

Data generated by the CBMP's expert monitoring groups and networks will underpin these indicators and indices.

The suite of indicators and indices are developed in a hierarchical manner, allowing users to "drill down" into the data from the high-order indices to reach more detailed indicators underpinning a particular index, such as specific population, subpopulation, or regional habitat trend data. This approach will maximize the utility and reach of the information by addressing the varying data needs of end users.

The CBMP indicators and indices will facilitate reporting the Arctic's progress towards the CBD post-2010 targets to measure and reduce the rate of biodiversity loss.

In addition to the overarching CBMP biodiversity indicators, the MEMG identified a suite of key indicators and the parameters needed to support these indicators. The suite of key indicators, which will allow regular assessment reports on the state of Arctic marine biodiversity, was developed through a process that involved:

- Selecting Arctic Marine Areas (AMA) as functional overall marine ecosystems (CBMP Background Paper);
- Prioritizing drivers and FECs within each AMA at Workshop 1.
- Examining available and relevant data and data aggregation within different disciplines and harmonization between AMAs in Workshop 2.

The criteria in this process were based on the overall CBMP criteria for selecting indices and indicators (see above), as well as:

- Finding key indicators to be reported on, based on the data assembled.
- Identifying common parameters that can be implemented across each AMA.

5. Coordinated Arctic Marine Biodiversity Monitoring: Priority Focal Ecosystem Components, Parameters, and Indicators

Arctic marine biodiversity monitoring and reporting will be coordinated across the Arctic, utilizing a suite of common parameters, sampling approaches, and indicators. In some instances (e.g., Arctic Basin), regionally specific parameters are also identified, allowing for a flexible monitoring approach and reflecting the unique nature of Arctic marine ecosystems.

5.1 Focal Ecosystem Components

The plan's FECs are considered either central to the functioning of an ecosystem (and, therefore, likely to be good proxies of underlying changes) and/or of substantial value to Arctic residents (e.g., important caloric and/or spiritual value). The FEC categories identified in developing this plan are listed in the following table:

Focal Ecosystem Components

Focal Ecosystem Component	Applicable Arctic Marine Areas
Microbes	All
Phytoplankton	All
Ice flora (e.g., microalgae)	All
Ice fauna (e.g., meiofauna, amphipods, cod)	All
Macroalgae (coastal)	All (except the Arctic Basin)
Zooplankton (e.g., microzooplankton, copepods, krill)	All
Benthic meio-, macro- and megafauna	All
Benthic/demersal fish (e.g., flatfish)	All
Pelagic fish (e.g., Arctic cod)	All
Seabirds	All
Marine mammals (e.g. polar bear, ringed seal, walrus, beluga, etc.)	All

The FEC categories were used to define six discipline groups (sea-ice biota, plankton, benthos, fish, marine mammals, and seabirds). In the case of seabirds, CAFF's Circumpolar Seabird Group (CBird) is already established, with species and parameters for circumpolar monitoring identified. The work of the CBird group was directly referenced for the seabird elements of this monitoring plan. As well, the CBMP and the Polar Bear Specialist Group (PBSG) of the International Union for Conservation of Nature (IUCN) are currently developing a pan-Arctic polar bear research and monitoring plan. The polar bear plan will be used to coordinate this discipline's monitoring as part of the overall CBMP-Marine Plan. For the other five disciplines, breakout groups were formed to allow for the effective selection of priority parameters, indicators, and sampling approaches to be applied across the Arctic. These five disciplines will become the basis by which pan-Arctic discipline groups (similar to the CBird group) will form (see Chapter 10) to implement core elements of the plan.

A review of existing Arctic marine mammal research and monitoring efforts and recommendations on parameters and sampling approaches can be found in *A Framework for Monitoring Arctic Marine Mammals* (Simpkins *et al*, 2007). This document was used as a foundation in choosing the FECs, parameters, indicators, and sampling approaches for pan-Arctic marine mammal monitoring.

5.2 Drivers

Nine drivers, listed below, were identified as the most important influences on the chosen FECs. It is important to note that the importance and intensity of the drivers vary across the Arctic, and some areas are under greater pressure than others. In many cases, these drivers have several elements. For example, driver #3, Industrial Development, covers a range of sub-drivers, including oil spills, sound disturbance, and habitat loss/alteration. Furthermore, these drivers often act in a cumulative manner, and we have limited knowledge or ability to measure cumulative impacts on species and ecosystems. For example, susceptibility of some vertebrates to disease and/or parasites could increase when persistent, bioaccumulative, and toxic (PBT) contaminant exposure happens in conjunction with climate change affecting food quality/quantity or habitat availability.

Pan-Arctic Drivers and Sub-drivers

1. <u>Climate</u>: Refers to direct and indirect (e.g., ocean acidification) impacts of climate change, either human-induced (from increased atmospheric concentrations of greenhouse gases, increased temperatures) or natural (natural variability, etc.).

2. Harvest: Refers to the direct impacts (mortality, population demographic shifts, etc.) and indirect impacts (bycatch, habitat loss/alteration, reduced prey, etc.) of the harvest of fish, shellfish, seabirds, or marine mammals.
3. Industrial development: Refers to all forms of industrial development and their associated impacts (habitat loss/alteration, disturbance, flotsam, seismic activity, oil spills, other pollution, etc.).
4. Contaminants (persistent, bio-accumulative, and toxic): Refers to the impact of persistent organic pollutants (POPs) and toxic metals (e.g., methyl mercury), originating primarily from non-Arctic sources.
5. Introduced alien species: Refers to species not indigenous to the Arctic that are introduced through human activity (e.g., through ballast water exchange or by natural routes) and persist in the Arctic (invasive species).
6. Tourism: Refers to the impacts caused by tourism activities.
7. Disease/parasites: Refers to the impacts of diseases and parasites in marine populations, exacerbated by human activities and stressors.
8. Scientific research: Refers to impacts resulting from scientific research activities.
9. Shipping: Refers to impacts caused by shipping (e.g., noise, collisions, introduction of alien species from ballast waters and hull foul) as outlined in the *Arctic Marine Shipping Assessment* (AMSA 2009).

5.3 Monitoring Objectives

With the FECs and drivers identified, a number of specific monitoring objectives were laid out in Workshop 1 for each FEC to assist the selection of priority parameters and indicators. The monitoring objectives, while specific for each FEC, can be broadly summarized as follows.

Based on the selection of priority parameters and indicators:

- Develop long-term datasets to allow the estimation of natural variability, assess the status and trends of the FECs in the context of this natural variation, and make this data available to correlate with potential driver datasets (e.g., abiotic or anthropogenic pressures) to assist research in identifying causal mechanisms driving Arctic marine environmental change.
- Develop pan-Arctic data collections to allow comparison of regional trends across the Arctic, thus also facilitating the identification of possible mechanisms driving change.
- Using the FECs and indicators, implement a responsive system for monitoring the status and trends of Arctic marine ecosystems and their biodiversity, which allows for ongoing assessment of the quality and health of the Arctic marine ecosystem.

These overall monitoring objectives, if met, will directly contribute to the overall goal and objectives of the CBMP-Marine Plan (see Section 1.1).

5.4 Priority Parameters and Indicators

Parameters and indicators were selected, based on the monitoring objectives, FECs, and the key drivers influencing the FECs. These parameters and indicators are key to detecting important trends in Arctic marine biodiversity, understanding the mechanisms causing these changes, feeding targeted reporting of Arctic marine ecosystem assessment at multiple scales (e.g. regional, national and international), and thereby informing effective Arctic marine environmental management. The CBMP-Marine Plan identifies biotic parameters and indicators only. However, as mentioned throughout the plan, it is critical that this information be linked to the chemical, physical, and geological environment (e.g., water circulation and chemistry, marine habitats, etc.) to allow an understanding of causal mechanisms driving these trends. As the Plan is implemented, the Marine Expert Networks will have the opportunity to modify and further refine the selected indicators and parameters based on the earlier results and analysis. For instance, if power analysis of the collected data's variance indicates inadequate statistical power to detect a change within a reasonable time-frame, a parameter may be dropped and/or replaced. Also, it may become apparent that the resulting information from parameter measurements is inadequate to allow for development of a specific indicator and/or an indicator may not be deemed to be useful in reporting on the state and quality of Arctic marine ecosystems. As this information becomes available during the initial start-up phase of Plan implementation, indicators will be adjusted and refined so as to end up with a smaller suite by which effective reporting can be based.

5.4.1 Parameters and indicators by discipline

The following tables summarize the priority parameters for the Focal Ecosystem Components (FEC) of each marine biological discipline. They also identify the indicators that may be generated from the data outputs and analysis used to report on the status and trends of key FECs of the Arctic marine environment. While the parameters and indicators are organized by discipline and AMA, it should be noted that the analysis and reporting (see Chapters 8 and 9) will involve cross-disciplinary analysis and indicators (e.g., diversity indices, marine trophic indicators) that involve all disciplines and, thus, trophic levels. As noted above, the discipline groups will further refine the indicators during the start-up phase, determining which ones are the most effective at tracking the state and quality of Arctic marine ecosystems. The goal is to end up with a small suite of the most effective indicators for reporting on the state and quality of Arctic marine ecosystems.

Note: *PAG = Pacific Arctic Gateway; AAG = Atlantic Arctic Gateway; AB = Arctic Basin; DB = Davis Strait-Baffin Bay; HBC = Hudson Bay Complex; AA = Arctic Archipelago; BS = Beaufort Sea*

Plankton

Category	FEC	Key Parameters	AMA	Indicators
Plankton	Phytoplankton	Abundance, biomass & species composition, chlorophyll *a* concentrations (ideally size-fractionated)	All	Diversity indices, community/group abundance, ratio small:large, ratio local:invasive
		Primary production	All	Productivity
		Genomics/barcoding	All	Metagenomics
	Protists (e.g., micro-zooplankton)	Abundance (biomass) & species composition	All	Diversity indices, community/group abundance, ratio small:large, ratio local:invasive
		Genomics/barcoding	All	Metagenomics
	Microbes (archaea, bacteria)	Abundance, biomass & size structure	All	Diversity indices, composition/ group abundance, size spectra, ratio local:invasive
		Genomics/barcoding	All	Metagenomics
	Zooplankton (e.g., meso- and macro zooplankton)	Abundance, biomass & species composition	All	Diversity indices, community/group abundance, community/group biomass, ratio small:large, ratio local:invasive, stage distribution
		Genomics/barcoding	All	Metagenomics

Note: in addition to the listed biological parameters, it is critical that temperature, salinity, *in situ* fluorescence, and macronutrients (NO_3, Si, PO_4) be measured in conjunction with the biological parameters in order to derive accurate interpretations of the data. Also, sea-ice cover data, using both remotely sensed information and local observations, are needed and should be correlated with the biological data.

Sea-ice biota

Category	FEC	Key Parameters	AMA	Indicators
Sea-ice protists	Diatoms Dinoflagellates Flagellates	Abundance, biomass (including Chl *a*), species composition, & productivity Key species definition	All (shelves to basins)	Distribution of Arctic vs sub-Arctic species Ratio diatoms:dinoflagellates Ratio freshwater:marine algae Ratio Arctic:sub-Arctic species Diversity indices (e.g., Shannon, Simpson) Sea ice vs phytoplankton biomass and productivity Size structure of ice algae and phytoplankton communities Biomass indicators (e.g., Chl *a*)
Sea-ice fauna	Interstitial and under-ice layer invertebrates	Abundance, biomass & species composition Fauna size structure Key species definition	All (shelves to basins)	Distribution of Arctic vs sub-Arctic species Ratio Arctic:sub-Arctic species Species invasion:expatriates Diversity indices (e.g., Shannon, Simpson) Partitioning sea ice vs zooplankton biomass and productivity
	Arctic cod	Abundance, composition, stages, reproduction	All (shelves to basins)	Under-ice abundance of two cods (*Boreogadus saida* and *Arctogadus borealis*). *See also Fish table, below*

Note: In addition to the listed biological variables, it is critical that ice thickness and snow depth, sea-ice and water-column temperature, salinity, light (PAR), and macronutrients (N compounds, Si, PO_4) be measured in conjunction with under-ice plankton and water sampling. Satellite data for sea-ice extent, as well as drifting meteorological buoys, is needed to facilitate interpretation of the biological data. Microbiological studies focusing on bacteria and viruses are still at an early stage and should be implemented later. Replicate sampling at each location is crucial to estimating the local small-scale variability that will vary considerably in relation to, for example, snow depth, sediment load and ice thickness.

Benthos

Category	FEC	Key Parameters	AMA	Indicators
Benthic fauna & microbes	Macrofauna & megafauna*	Abundance Biomass (wet weight **) Species composition Barcoding, other genomics	All	Abundance; community composition Biomass; community composition Size-frequency distribution (for selected, mainly pan-Arctic species) Diversity indices (e.g., Shannon, Simpson) Distribution
Benthic flora	Macroalgae	Abundance Biomass (wet weight**) Species composition Barcoding, other genomics	All (except Arctic Basin)	Abundance; community composition Biomass; community composition Diversity indices (e.g., Shannon, Simpson) Distribution
Benthic fauna and microbes	Meiofauna & microbes***	Abundance Biomass Species composition Barcoding, other genomics	PAG, AAG, AB	Abundance community composition/ structure Biomass community structure Diversity indices (e.g., Shannon, Simpson) Distribution

*Megafauna includes both sessile and motile epifaunal organisms > 1 cm (or larger than 4 mm), but this depends on the semi-quantitative trawl-net mesh size used, which is probably different for different programs. Macrofauna is infauna >1 cm and always sampled by quantitative grab.

** Ideally, also dry weight and ash-free dry weight are taken.

***These are current monitoring gaps. Also benthic microflora is not covered in current activities.

Note: Pan-Arctic taxa to focus on for size-frequency distribution: snow crabs, ophiuroids, and bivalves.

Note: In addition to the listed biological parameters, it is critical that temperature, salinity, fluorescence, macronutrients (NO_3, Si, PO_4), and Chl *a* levels be measured. Sediment characteristics (grain size, Chl *a*, and organic carbon content) and satellite data for sea-ice extent are also needed to facilitate interpretation of the biological data. Ideally, benthic stations are sampled in conjunction with plankton and fish stations for best ecosystem integration.

Photo by: Lis Lindal Jorgensen. Institute of Marine Research, Norway

Fish

Category	FEC	Key Parameters	AMA	Indicators
Fish	Pelagic fish	Relative abundance: species caught and effort by gear type Number of each species Age/size distribution Fish length Geographic coordinates and depth Temperature, salinity, substrate Barcoding, other genomics Preservation of voucher specimens	All	Species composition, diversity indices Relative abundance Size ranges Geographic and bathymetric distribution of species Habitat variable associations Taxonomic resolution, species identification Primary documentation for species identifications and distributions
	Salmon (*Oncorhynchus* species in PAG; *Salmo* in AAG)	Relative abundance: species caught and effort by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	PAG, AAG	Size/age-frequency distribution Community structure Disease incidence Geographic distribution and range shifts Life history shifts (e.g., anadromy to non-anadromy as a frequency within populations) indicate shifts in productivity
	Arctic chars (*Salvelinus alpinus* and related taxa)	Relative abundance: species caught and effort by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	All (except AB)	Size/age-frequency distribution Community structure Disease incidence Geographic distribution and range shifts Life history shifts (e.g., anadromy to non-anadromy as a frequency within populations) indicate shifts in productivity
	Capelin (*Mallotus villosus)*	Relative abundance: catch by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	All	Size/age-frequency distribution Community structure Disease incidence Geographic distribution and range shifts
	Benthic and demersal fish	Relative abundance: species caught and effort by gear type Species caught Number of each species Age/size distribution Fish length Geographic coordinates and depth Temperature, salinity, substrate Barcoding, other genomics Preservation of voucher specimens	All	Species composition, diversity indices Relative abundance Size ranges Geographic and bathymetric distribution of species Habitat variable associations Taxonomic resolution, species identification Primary documentation for species identifications and distributions
	Arctic cod (*Boreogadus saida*)	Abundance: catch by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	All	Size/age-frequency distribution Community structure Disease incidence Geographic distribution
	Polar cod (*Arctogadus glacialis*) *See also Sea-ice Biota table, above*	Abundance: catch by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	All	Size/age-frequency distribution Community structure Disease incidence Geographic distribution

	Atlantic cod (*Gadus morhua)* *See also Sea-ice Biota table, above*	Abundance: catch by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	AAG	Size/age-frequency distribution Community structure Disease incidence Geographic distribution
	Walleye pollock (*Gadus chalcogrammus*)	Abundance: catch by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	PAG	Size/age-frequency distribution Community structure Disease incidence Geographic distribution
	Greenland halibut (*Reinhardtius hippoglossoides*)	Abundance: catch by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	All (except AB)	Size/age-frequency distribution Community structure Disease incidence Geographic distribution
	Bering flounder (*Hippoglossoides robustus*)	Abundance: catch by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	PAG	Size/age-frequency distribution Community structure Disease incidence Geographic distribution
	Shorthorn sculpin (*Myoxocephalus scorpius*) and related sculpins	Abundance: catch by gear type Biomass Condition Distribution (geographic) Age/size distribution Life history, phenology, genetic structure	All	Size/age-frequency distribution Community structure Disease incidence Geographic distribution

Notes:

1) Temperature and salinity at fishing depth, depth of capture, and bottom depth should accompany all fish sampling.

2) For assessing species composition and relative abundance, a variety of gear (e.g., surface, midwater, and bottom trawls; gill nets) should be employed.

3) Whole specimens of each species should be archived to document identifications, particularly for multi-species fisheries, char fisheries and sculpins.

4) Above summary is assumed to be mostly research fishing. However, fisheries conducted by Indigenous peoples (i.e., subsistence), commercial fisheries, and recreational (sports) fisheries could be methods of gathering data in a structured fashion. Such fisheries target particular species, whereas research fishing targets all species. For non-research fisheries, the addition of bycatch summaries is required and should include these parameters: species, number of individuals and biomass by species, and, ideally, locality/effort information.

Marine mammals

Discipline	FEC	Key Parameters	AMA	Indicators
Marine Mammals	Walrus & ringed seals	Distribution Abundance Habitat selection Stock structure (genetics/ telemetry) Body condition Contaminants Harvest statistics	PAG, AAG, BS, DB, HBC	Seasonal distribution Number per km^2 Important feeding areas (hotspots) and habitats supporting life functions (sea ice, coastline) Overall condition/disease prevalence Contaminant loads Harvest rates and demographics
	Beluga & bowhead whales	Distribution Abundance Habitat selection Stock structure (genetics/ telemetry) Body condition Contaminants Harvest statistics	PAG, AAG, BS, HBC, DB	Seasonal distribution Number per km^2 Key feeding areas (hotspots), migration corridors and over-wintering areas (MIZ, polynyas) Overall condition/ disease prevalence, blubber quality/quantity Contaminant loads Harvest rates and demographics
	Polar bear	Distribution Abundance Habitat selection Stock structure (genetics/ telemetry) Body condition Contaminants Harvest statistics	All	Seasonal distribution Number per km^2 Important feeding areas (hotspots) and habitats supporting life functions (sea ice, coastline) Overall condition/disease prevalence Contaminant loads Harvest rates and demographics

Seabirds

Discipline	FEC	Key Parameters	AMA	Indicators
Seabirds	Black-legged kittiwake, murre spp., & common eider	Colony size Survivorship Reproductive success Chick diet Harvest statistics Phenology	PAG, AAG, BS, HBC, DB	Abundance, number of active nests Adult and chick survival rates Productivity Diet Harvest rates and demographics Colony arrival dates

Photo by:Kathy Crane. National Oceanic And Athmospheric Administration, U.S.A

5.4.2 Arctic Marine Biotic Indicators and the CBMP's Arctic Indices and Indicators

The following table outlines how the identified Arctic marine biotic indicators relate to the overall CBMP Arctic indices and indicators. The Marine Expert Networks, once formed, will further refine the indicators including the human indicators.

THEME	INDEX	INDICATOR	ELEMENTS	SUB-ELEMENTS	INDICATORS BY DISCIPLINE	KEY PARAMETERS
Species Composition	Arctic Species Trend Index*	Trends in Abundance of Key Species + Trends in other species parameters (e.g. phenology, distribution, productivity, survival, body condition, etc.)	Marine	**Sea-Ice Biota** (protists and fauna) – Diatoms, Dinoflagellates, Flagellates, Interstitial and under-ice layer invertebrates, Arctic cod	Distribution of Arctic vs sub-Arctic species, Ratio diatoms, Ratio freshwater, Ratio Arctic, Diversity indices, Sea ice vs phytoplankton biomass and productivity, Size structure of ice algae and phytoplankton communities, Biomass indicators, Species invasion, Partitioning sea ice vs zooplankton biomass and Productivity, Under-ice abundance of two cods	Abundance, biomass (including Chl a), species composition, productivity, key species definition, & fauna size structure
				Benthic fauna & microbes (macrofauna & megafauna)	Abundance; community composition, Biomass; community composition, Size-frequency distribution (for selected, mainly pan-Arctic species), Diversity indices (e.g., Shannon, Simpson), Distribution	Abundance, biomass (wet weight **), & species composition
				Plankton (Phytoplankton, Protists (e.g., microzooplankton), Microbes (archaea, bacteria), and Zooplankton (e.g., meso- and macro zooplankton)	Diversity indices, community/group abundance, community/ group biomass, ratio small:large, ratio local:invasive, stage distribution, Productivity, Metagenomics	Abundance, biomass & species composition, chlorophyll a concentrations (ideally sizefractionated), primary production, genomics/barcoding

*indices closely related to the Convention on Biological Diversity indicators or a subset of the global indicator

**index suggested for inclusion in the Millennium Development Goals

THEME	INDEX	INDICATOR	ELEMENTS	SUB-ELEMENTS	INDICATORS BY DISCIPLINE	KEY PARAMETERS
				Fish (pelagic fish, Salmon,, Arctic chars, Capelin, benthic and demersal fish, Arctic cod, Polar cod, Atlantic cod, Walleye Pollock, Greenland halibut, Bering flounder, & Shorthorn sculpin and related sculpins)	Species composition, diversity indices, Relative abundance, Size ranges, Geographic and bathymetric distribution of species, Habitat variable associations, Taxonomic resolution, species identification, Primary documentation for species identifications and distributions, Size/age-frequency distribution, Community structure, Disease incidence, Geographic distribution and range shifts, Life history shifts indicate shifts in productivity, Geographic and bathymetric distribution of species, Habitat variable associations	Relative abundance: species caught and effort by gear type, number of each species, age/size distribution, fish length, geographic coordinates and depth, temperature, salinity, substrate, barcoding, other genomics, preservation of voucher specimens, biomass, condition, distribution (geographic), & life history, phenology, genetic structure
				Seabirds (Black-legged kittiwake, murre spp., & common eider)	Abundance, number of active nests, Adult and chick survival rates, Productivity, Diet, Harvest rates and demographics, Colony arrival dates	Colony size, survivorship, reproductive success, chick diet, harvest statistics, & phenology
				Marine mammals (Walrus, ringed seals, Beluga & bowhead whales)	Seasonal distribution, phenology, Number per km^2, Important feeding areas (hotspots) and habitats, supporting life functions (sea ice, coastline) migration corridors, and over-wintering areas (polynyas), Overall condition/disease prevalence, blubber quality/quantity, Contaminant loads, Harvest rates and demographics,	Distribution, abundance, migratory timing, habitat selection, stock structure (genetics/telemetry), body condition, contaminants, harvest statistics
				Polar Bears	Seasonal distribution, Number per km^2, Important feeding areas (hotspots) and habitats supporting life functions (sea ice, coastline), Overall condition/disease prevalence, Contaminant loads, Harvest rates and demographics	Distribution, abundance, habitat selection stock structure (genetics/telemetry), body condition, contaminants, harvest statistics
	Arctic Red List Index**	Change in Status of Threatened Species	Marine Biome			
			Species groupings (e.g. mammals, birds, etc.)			
		Trends in Total Species Listed at Risk	Marine Biome			
			Species groupings			

THEME	INDEX	INDICATOR	ELEMENTS	SUB-ELEMENTS	INDICATORS BY DISCIPLINE	KEY PARAMETERS
Ecosystem Structure	Arctic Trophic Level Index*		Marine Biome			
Habitat Extent	Arctic Land Cover Change Index	Trends in Extent of Biomes, Habitats and Ecosystems	Marine	Sea Ice, Plankton Distribution, Corals		
Habitat Quality	Arctic Habitat Fragmentation Index	Extent of Seafloor Destruction	Marine			
Ecosystem Function & Services		Trends in Extent, Frequency, Intensity and Distribution of Natural and Human induced Disturbances		1. Fish 2. Seabirds 3. Marine mammals 4. Polar Bears	1. Size/age-frequency distribution 2. Harvest rates and demographics 3. Diet 4. Contaminant loads	1. species caught and effort by gear type 2. harvest statistics 3. diet as revealed by stomach contents, isotopic and fatty acid profiles 4. contaminant profiles
Human Health& Well-being	Arctic Human Well-being Index	Trends in availability of biodiversity for traditional food and medicine	Societal			
		Trends in use of Traditional Knowledge in research, monitoring and management				
		Trends in incidence of pathogens and parasites in wildlife				
		Change in Status of Threatened Species	Marine Biome			
Policy Responses		Coverage of Protected Areas	Societal	Coverage according to IUCN categories		
				Overlays with areas of key importance (biodiversity hotspots)		
			Marine Biome	IUCN –Ecologically Important and Vulnerable Marine Areas in the Arctic; World Heritage *Marine* & *Arctic* Thematic Reports		

5.4.3 Existing Monitoring Programs and Their Coverage by Focal Ecosystem Component and Arctic Marine Area

The following tables summarize existing monitoring programs by FEC and AMA that can be used to contribute to the CBMP-Marine Plan's coordinated monitoring approach..

Arctic Basin

FEC	Some Existing Monitoring Programs	Coverage
Abiotic: sea ice and hydrology	RF for Basic Research project: multifunctional analysis of the sea ice and surface water ecosystem dynamic in the Central Arctic Basin	2005-2011; North Pole region, transpolar ice drift
	RF Hydromet/RAS project: PanArctic Ice Camp Expedition (PAICEX)	2007-2012; North Pole region, transpolar ice drift
	RF Hydromet/AARI project: multidisciplinary investigation of the central part of the Arctic Basin (North Pole drifting stations)	2003-recent; Beaufort Gyre and transpolar ice drift
	EU DAMOCLES program: Development of Arctic Modeling and Observational Capabilities for Long-Term Environmental Studies	2006-2009; Nansen and Amundsen basins
	USA Program: orbital remote sensing of the Arctic (NASA)	1978 (daily); pan-Arctic
	USA NSF Project: North Pole Environmental Observatory (NPEO)	2000-2010 mooring (daily); 2000-2015 spring aerial hydrographic surveys; North Pole Region
Abiotic: contaminants	RAS Project: aeolian and ice transport and matter flux (including ecotoxicants) in the High Arctic Basin	2007-2012; North Pole region
	AMAP Project: measurement of standard hydro-chemical indicators in seawater and sediments as well as broad suite of contaminants	Ongoing; Central Arctic Basin
Biodiversity: lower trophics	USA Hidden Ocean (NOAA) Zooplankton and Phytoplankton monitoring with instrumented moorings (Fisheries and Oceans Canada) (abundance only) Climat et écosystèmes des mers glacées (transl. : Climate and ecosystems of the frozen seas) (NSERC) Census of Arctic Marine Zooplankton (Canadian Healthy Oceans Network) C30: Canada's Three Oceans (IPY)	2002, 2005; Canada Basin, Chukchi Plateau, Northwind Ridge
	Canada, Université Laval project: studies of total biodiversity of bacteria and archaea in the deep Arctic Ocean (NSERC/ICOMM)	2007; Canada Basin, Labrador Sea, Beaufort Sea, Nansen Basin
Pelagic fish	USA Hidden Ocean (NOAA)	2002, 2005; Canada Basin, Chukchi Plateau, Northwind Ridge
Marine mammals	Ice seal, beluga and bowhead whale tagging	Since 2008 NOAA/NMML; ice seals (Chukchi shelf & basin) Since 2006 ADF&G; bowhead whale (Beaufort Sea, Chukchi, N. Bering) Since 1998 ABWC; beluga (Chukchi & Beaufort shelf & basin)
Fish	USA Hidden Ocean (NOAA)	2002, 2005; Canada Basin, Chukchi Plateau, Northwind Ridge

Davis Strait-Baffin Bay

FEC	Existing monitoring programs	Coverage
Phytoplankton	Marine Basic Nuuk Diversity and gene expression in Arctic microbes (NSERC) C30: Canada's Three Oceans (IPY) Marine Biological Hotspots: Ecosystem services and susceptibility); The circumpolar flaw lead (CFL) system study (ArcticNet, IPY, NSERC) Census of Arctic Marine phytoplankton and sea-ice algae+protists (Canadian Healthy Oceans Network) Zooplankton and phytoplankton monitoring with instrumented moorings (Fisheries and Oceans Canada) (abundance only)	Godthåbsfjorden, West Greenland Transects up Davis Strait and Baffin Bay (NSERC, C3O, CFL)
Zooplankton	Marine Basic Nuuk Zooplankton in Disko Bay (Torkel G. Nielsen- DTU-Aqua/ Univ. Of Aarhus/NERI), Zooplankton and phytoplankton monitoring with instrumented moorings (Fisheries and Oceans Canada) (abundance only) Climat et écosystèmes des mers glacées (transl. : Climate and ecosystems of the frozen seas) (NSERC) Census of Arctic Marine Zooplankton (Canadian Healthy Oceans Network) C30: Canada's Three Oceans (IPY)	Godthåbsfjorden, W Greenland Disko Bay E Barrow Strait North Water Polynya (N Baffin Bay) Baffin Bay Transects up Davis Strait, Baffin Bay
Benthos	Marine Basic Nuuk (NERO) Disko West EIA (NERI/GINR) Baffin Bay East EIA (NERI/GINR) Environmental impact assessment activities Impact of Climate Change on Arctic Benthos (ArcticNet, CHONe); C30: Canada's Three Oceans (IPY); Multi-species Survey (Fisheries and Oceans Canada) Marine Basic Nuuk (NERO) Disko West EIA (NERI/GINR) KANUMAS West EIA (NERI/GINR Pandalus Surveys	Godthåbsfjorden, W Greenland W of Disko Bay Melville Bay and eastern Baffin Bay Transects along Lancaster Sound (NOW Polynya), and down Baffin Bay and Davis Strait (CHONe and IPY); Baffin Bay, Davis Strait (Fisheries and Oceans Canada) SW Greenland, coastal SW Greenland W of Disko Bay Melville Bay and W Baffin Bay
Benthic/demersal fish and shrimp	GINR fisheries survey cruises Fisheries and Oceans Canada multi-species surveys Cumberland Sound ecosystem and invasive species (Ocean Tracking Network (OTN), Strategic Network Grant)* Fisheries and Oceans Canada multi-species surveys	W coast of Greenland between 59°15'N and 72°30'N from the 3-mile limit to the 600 m depth contour line Baffin Bay and Davis Strait Cumberland Sound S. Davis Strait, Baffin Bay
Pelagic fish	GINR fisheries survey cruises (accidental capture only; capelin and cod are not targeted in monitoring) Climat et écosystèmes des mers glacées (transl. : Climate and ecosystems of the frozen seas) (NSERC Northern Research Supplements Program) Cumberland Sound ecosystem and invasive species (Ocean Tracking Network (OTN), Strategic Network Grant) (capelin)	W coast of Greenland between 59°15'N and 72°30'N from the 3-mile limit to the 600 m depth contour line. North Water Polynya (N Baffin Bay) Cumberland Sound
Seabirds	GINR Seabird Monitoring Program / NERI Seabird database Monitoring of seabirds in Greenland Hunting statistics (Piniarneq) (*GL has some productivity activities associated with the monitoring program, but not part of core monitoring*)	W Greenland
Marine mammals	Fisheries and Oceans Canada GINR Marine Mammal Monitoring Program Catch statistics from the government of Greenland (DFFL) Canada – Greenland collaborative surveys Environment Canada	Lancaster Sound, Baffin Bay, Davis Strait Smith Sound, Baffin Bay, Melville Bay, Davis Strait, SW Greenland, Kane Basin Davis Strait Baffin Bay (North Water Polynya)

* This project has an ecosystem focus rather than a focus on a particular FEC or trophic level.

Atlantic Arctic Gateway

FEC	Existing Monitoring Programs	Coverage
Phytoplankton	Marine Basic Zackenberg Barents Sea Ecosystem (IMR+PINRO) Various (NPI) Various (ARCTOS, CLEOPATRA, Arctic Tipping Points) White Sea Labs (Katesh - ZIN, WSBS -Moscow State)	Zackenberg , E Greenland Barents Sea from 68-80°N, 5°W to Novaya Zemlya Svalbard and MIZ region Barents Sea, Svalbard, MIZ White Sea
Zooplankton	Marine Basic Zackenberg Barents Sea Ecosystem (IMR+PINRO) Various (NPI) Various (ARCTOS, CLEOPATRA, Arctic Tipping Points) White Sea Labs (Katesh - ZIN, WSBS -Moscow State)	Zackenberg , E Greenland Barents Sea from 68-80°N, 5°W to Novaya Zemlya Svalbard and MIZ region Barents Sea, Svalbard, MIZ White Sea
Benthos	Oil company (MOD) BASICC MAFCONS Oil company (Stockman) ZIN MAFCONS	W Barents Sea Central Barents Sea and N Barents Sea up to ice edge E Barents Sea Barents Sea, White Sea
	Oil company (Stockman) ZIN IMR/PINRO Oil Company (MOD) MAFCONS	E Barents Sea Barents Sea, White Sea Barents Sea W Barents Sea
	Gulliksen IMR/PINRO ZERO ZIN Polar Front Transect	Coastal Svalbard and N Norway Barents Sea NE Greenland, coastal E Barents Sea Approx. 76° north
	IMR/PINRO Polar Front Transect	Barents Sea Approx. 76° north
	Gulliksen IMR/PINRO ZERO Polar Front Transect	Coastal Svalbard and N Norway Barents Sea NE Greenland, coastal Approx. 76° north
	IMR/PINRO (partly) Gulliksen	Barents Sea Coastal Svalbard & N Norway
Marine mammals	NPI – Kovacs & Lydersen IPY project w/ Wiig ZERO /GINR monitoring North Atlantic Sighting Surveys. Norway, Iceland, Faroe Islands and NAMMCO	Coastal Svalbard & N. Norway Fram Strait NE Greenland, Haul out site at Sand Island, Young Sound Northeast Atlantic between Greenland and Norway, during summer
Benthic fish	IMR/PINRO; MRI IMR, PINRO (?); MRI GINR	Barents Sea (annually 1970-present); Icelandic waters (1960s-present) Barents Sea; (annually 1970-present); Icelandic waters (1960s-present) East Greenland (annually 1980s-present)
Pelagic fish	IMR/PINRO; MRI IMR, PINRO (?); MRI GINR	Barents Sea (annually 1970-present); Icelandic waters (1960s-present) Barents Sea; (annually 1970-present); Icelandic waters (1960s-present) East Greenland (annually 1980s-present)
Fish species	IMR; PINRO(?) GINR Greenland halibut survey	Barents Sea (annually 1970-present) 2008- present: E Greenland (59N to 67N, 3nm to 600m depth for fish/shrimp and 400-1500m for Greenland halibut)
Shrimps	Joint Annual Ecosystem Cruise GINR Greenland shrimp survey	Barents Sea 2008-present: E Greenland (59N to 67N, 3nm to 600m depth for fish/shrimp) Note: annual surveys of variable design and coverage from 1989-2007

Pacific Arctic Gateway

FEC	Existing monitoring programs	Coverage
Phytoplankton	RUSALCA COMIDA BEST/BSIERP C3O (Canada's Three Oceans) Oil companies (Shell, Conoco Philips, Statoil) BOWFEST BASIS SBI NABOS DBO	Chukchi Sea, E Siberian Sea Chukchi shelf N Bering Sea N Bering Sea, Chukchi Sea, Beaufort Sea Chukchi Sea, Beaufort Sea W Beaufort Sea S Chukchi Sea N Chukchi, W Beaufort Sea E Siberian Sea N Bering Sea, Chukchi Sea, Canada Basin, Beaufort Sea
Protists	BEST/BSIERP C3O (Canada's Three Oceans) BOWFEST SBI	N Bering Sea N Bering Sea, Chukchi Sea, Beaufort Sea W Beaufort Sea N Chukchi, W Beaufort Sea
Zooplankton	RUSALCA COMIDA BEST/BSIERP C3O (Canada's Three Oceans) Oil companies (Shell, Conoco Philips, Statoil) BOWFEST BASIS SBI DBO	Chukchi Sea, E Siberian Sea Chukchi shelf N Bering Sea N Bering Sea, Chukchi Sea, Beaufort Sea Chukchi Sea, Beaufort Sea W Beaufort Sea S Chukchi Sea N Chukchi Sea, W Beaufort Sea N Bering Sea, Chukchi Sea, Canada Basin, Beaufort Sea
Benthos	RUSALCA COMIDA BEST/BSIERP C3O (Canada's Three Oceans) Oil companies (Shell, Conoco Philips) SBI DBO	Chukchi Sea, E Siberian Sea Chukchi shelf N Bering Sea N Bering Sea, Chukchi Sea, Beaufort Sea Chukchi Sea, Beaufort Sea N Chukchi, W Beaufort Sea N Bering Sea, Chukchi Sea, Canada Basin, Beaufort Sea
	RUSALCA COMIDA BEST/BSIERP Oil companies (Shell, Conoco Philips) DBO	Chukchi, E Siberian Chukchi shelf N Bering Sea Chukchi Sea, Beaufort Sea N Bering Sea, Chukchi Sea, Canada Basin, Beaufort Sea
	RUSALCA BEST/BSIERP	Chukchi, E Siberian SE Bering Sea
Marine mammals	BEST/BSIERP COMIDA (MMS/NMML) BOWFEST (MMS/NMML) BWASP (MMS/NMML) Satellite tagging (ADF&G) Tissue Sampling (ADF&G) DBO	SE Bering, Chukchi, Alaskan Beaufort Sea
Seabirds	BEST/BSIERP (USFWS/NPRB)	Bering Sea
Fish	RUSALCA NOAA, AFSC, BASIS	Bering Strait, Chukchi Sea, E Siberian Sea, Chukchi Borderlands N Bering Sea, S Chukchi Sea

Hudson Bay Complex

FEC	Existing monitoring programs	Coverage
Phytoplankton	ArcticNet MERICA	Hudson Bay Complex
Zooplankton	MERICA	Hudson Bay Complex
Benthos	ArcticNet CASES MERICA	Hudson Bay Complex
Marine mammals	Bowhead habitat study/S. Ferguson (also beluga & killer whale, walrus and beluga)	Hudson Bay Complex
Seabirds	Environment Canada Effects of climate change on Canadian seabirds (e.g., how the timing of bird arrival to nesting areas coincides with ice changes over time) (Nunavut Wildlife Management Board, university partners, PCSP)	Hudson Bay Complex Coats Island, N Hudson Bay

Photo by:Peter Prokosch. http://www.grida.no/photolib

Arctic Archipelago

FEC	Existing monitoring programs	Coverage
Phytoplankton	Diversity and gene expression in Arctic microbes (NSERC) C30: Canada's Three Oceans (IPY) Marine Biological Hotspots: Ecosystem services and susceptibility; The circumpolar flaw lead (CFL) system study (ArcticNet, IPY, NSERC) Census of Arctic Marine phytoplankton and sea-ice algae+protists (Canadian Healthy Oceans Network) Zooplankton and phytoplankton monitoring with instrumented moorings (Fisheries and Oceans Canada) (abundance only)	Transects in Lancaster Sound (NSERC, C3O, CFL) E Barrow Strait (Fisheries and Oceans Canada moorings)
Zooplankton	Zooplankton and phytoplankton monitoring with instrumented moorings (Fisheries and Oceans Canada) (abundance only) Climat et écosystèmes des mers glacées (transl. Climate and ecosystems of the frozen seas) (NSERC) Census of Arctic Marine Zooplankton (Canadian Healthy Oceans Network) C3O: Canada's Three Oceans (IPY)	E Barrow Strait Transects in Lancaster Sound (NSERC, C3O, CFL)
Benthos	Environmental impact assessment activities Impact of Climate Change on Arctic Benthos (ArcticNet, CHONe); C3O: Canada's Three Oceans (IPY); Multi-species Survey (Fisheries and Oceans Canada)*	Transects along Lancaster Sound (North Water Polynya)
Seabirds	Environment Canada Effects of climate change on Canadian seabirds (e.g., how the timing of bird arrival to nesting areas coincides with ice changes over time) (Nunavut Wildlife Management Board, university partners, PCSP) Core monitoring - seabirds (thick-billed murre) (Northern Contaminants Program)	Prince Leopold Island, Cape Vera (Devon Island) Prince Leopold Island
Marine mammals	Fisheries and Oceans Canada	Lancaster Sound

* Canada cannot commit to contributing to benthos other than macrofauna.

Beaufort Sea

FEC	Existing monitoring programs	Coverage
Phytoplankton	C3O (Canada's Three Oceans) Canadian Healthy Oceans Network ArcticNet and CFL	
Protists	C3O: Canada's Three Oceans (U. Laval)	Beaufort Sea
Zooplankton	C3O: Canada's Three Oceans, JOIS-BGOS Canadian Healthy Oceans Network	Beaufort Sea
Benthos	ArcticNet-CHONe ArcticNet	Beaufort Sea Beaufort Sea
Coastal fish (anadromous & nearshore)	Coastal Fish Survey (Johnson & Reist)	Yukon North Slope (Shingle Point area; 0-5m) - 2007-2008 repeat of mid-1980's survey
Pelagic & benthic shelf fish	Beaufort Shelf Fish Survey (Majewski & Reist)	Beaufort Sea Shelf (5-150m) – 2004-2009 variable stations and transects; work extended in 2010 to shallower regions near Mackenzie River delta.
Marine mammals	BOWFEST (MMS/NMML) BWASP (MMS/NMML) Satellite tagging (ADF&G) Tissue Sampling (ADF&G) DBO	Canadian Beaufort Sea

Kara/Laptev Seas

Parameters and indicators for the Kara/Laptev Seas AMA have not yet been chosen. The development of a monitoring program in this AMA will occur after the startup phase of the CBMP-Marine Plan and will be aligned and consistent with the monitoring framework applied elsewhere.

Photo by:Peter Prokosch. http://www.grida.no/photolib

6. Sampling Design

The development of common sampling approaches (protocols) and designs (spatial and temporal coverage) will yield more powerful and cost-effective monitoring. The following chapter outlines the sampling approaches and locations by each discipline as well as identifying where multi-disciplinary sampling (e.g., plankton and benthic sampling) can occur at the same location. During the start-up phase (2011-2015), the implementation of common sampling approaches and designs will focus on existing Arctic marine biodiversity monitoring networks run by Arctic nations. Monitoring networks run by non-Arctic sources may be brought into the monitoring plan in the second phase of implementation (2015+). Monitoring handbooks, based on the parameters and sampling approaches chosen, will be developed to assist implementation of the plan and ensure simple and repeatable measures across the Arctic. Community-based, citizen-science, and other scientific sampling approaches will be employed, as appropriate.

As noted in Chapter 8, the start-up phase will allow estimates of variation. These estimates will be used to perform power analyses on the parameters being sampled to determine the optimal sampling approach (i.e., what sample size is needed at what frequency to be able to statistically detect a change). In some cases, particularly for the higher trophic levels, some understanding of sampling effort has already been calculated. However, this is not the case for such taxa as marine fish and for many of the lower trophic organisms.

Refer also to Appendix A for maps depicting existing and optimal sampling locations (e.g., tagging locations, ship transects, plankton stations, etc.) that can contribute to a coordinated monitoring approach across the Arctic marine system. Where appropriate, sampling will be augmented by ships of opportunity that can be equipped with simple equipment for data collection (e.g., plankton recorders). It is assumed and anticipated that existing individual sentinel stations will continue to be supported by the countries that currently operate them. Not surprisingly, there are many gaps in current monitoring coverage. However, among the six countries involved in the start-up phase, only existing monitoring locations can be expected to continue receiving funding in the short-term. It is hoped that, by identifying optimal desired sampling locations that would fill critical gaps, new resources may become available over time, either from sources within Arctic countries or through the engagement of non-Arctic countries in Phase II of implementation (see Chapter 10).

Photo by: Lis Lindal Jorgensen. Institute of Marine Research, Norway

6.1 Plankton

6.1.1 Pan-Arctic Sampling Approach

The sampling of plankton communities will occur annually, with primary data collection in late summer to coincide with historical sampling. This will permit the further development of long-term data time series. If and when additional resources are available, sampling should occur in spring, early summer, and winter (in this order of priority). Where flexibility exists in sampling design, cross-shelf or orthogonal sampling in conjunction with fixed or repetitive mooring stations is most informative.

The most important aspect of a coordinated pan-Arctic approach to monitoring plankton communities will be the use of fixed sentinel stations.

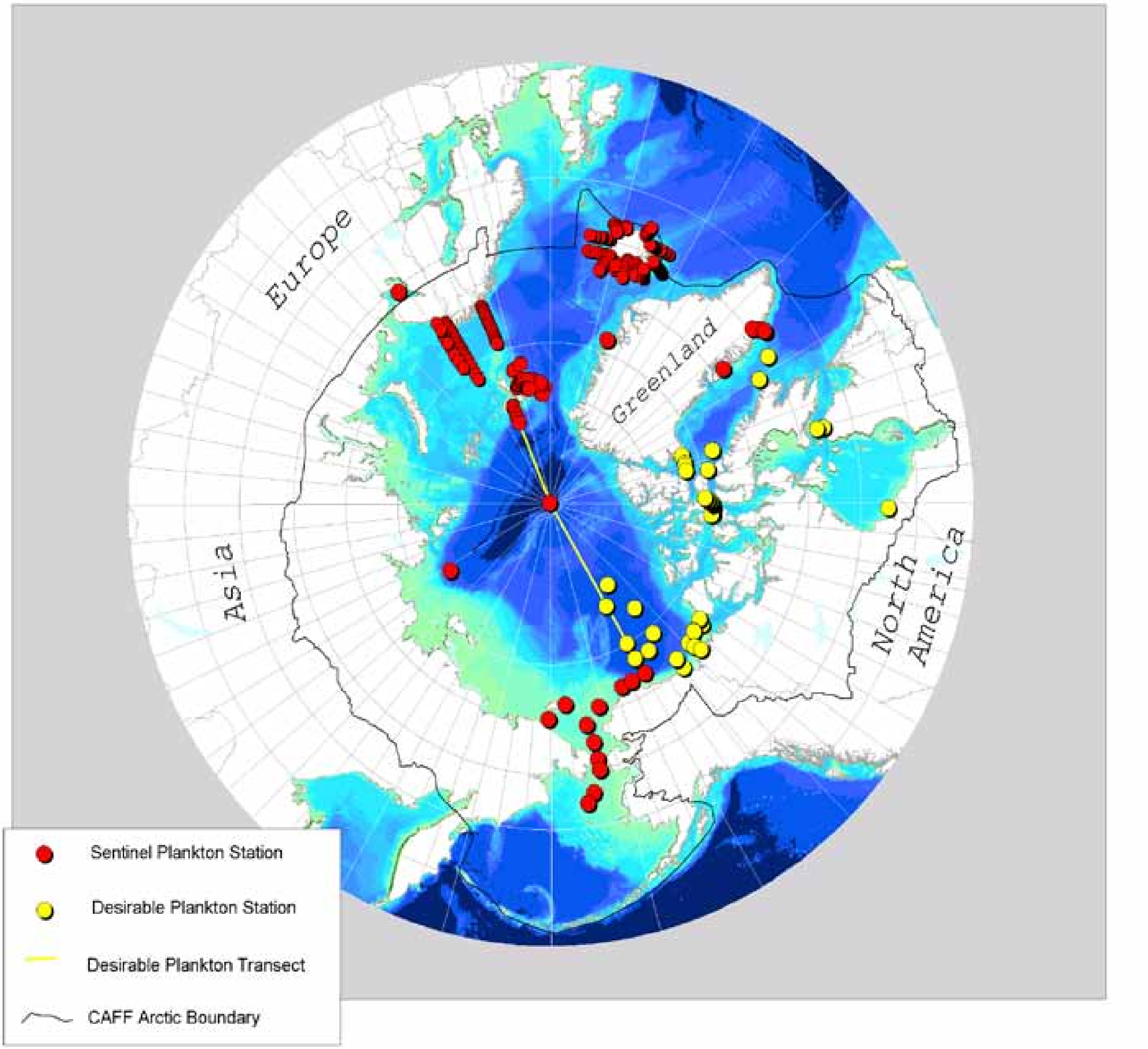

Figure 6 Suggested locations of plankton sentinel stations as part of the CBMP-Marine Plan.

6.1.2 Sampling Protocols

Basic aspects of zooplankton methodology are relatively standardized, although large variation exists in the gear utilized for collection (Harris et al. 2000). To ensure consistent sampling of plankton communities, the following is recommended:

Bottle Sampling

Phytoplankton and other protists

- Essential: Chlorophyll *a* profiles at selected optical depths; if not possible, prioritize at surface and at the deep chlorophyll maximum, and, ideally, size-fractionated. Voucher collections.
- Recommended: Microscopy (species level) at surface and chlorophyll maximum at a subset of stations. Preserved with Lugol's solution (5%) at a minimum, although additional samples in formaldehyde neutralized with hexamethylenetetramine to a final concentration 0.4% or glutaraldehyde (0.5%) will be necessary, depending on additional parameters to be measured. Volume for preserved samples ranges from 250 to 1000 ml depending on productivity.
- Suggested: HPLC (if liquid nitrogen or -80C freezer available) or flow cytometry can reveal high taxonomic groups without microscopic detail. Primary production provides useful ancillary information (several techniques possible).

Microbes (pico-eukaryotes, bacteria and archaea)

- Recommended: Flow cytometry, or microscopy slides if no other techniques (requires liquid nitrogen or -80C freezer), both yield biomass and size structure. Community genomics is the most definitive approach for whole community analysis (taxonomy and functional genes).
- Within a station it is recommended that sampling occur within major water masses.

Net-based sampling (meso- and macro-zooplankton)

Gear

- Essential: Most ongoing programs use vertically deployed 150-180 µm mesh and this should continue. Different net mouth areas and design are of lower concern, since inter-comparison has shown that these factors do not predictably change catch efficiency or composition except for larger crustaceans (i.e., amphipods, krill, and shrimps) and chaetognaths. In deeper waters, stratified sampling is most common, generally using multiple opening and closing net systems. Samples are preserved with 5-10% buffered formalin routinely, or 95% non-denatured ethanol for molecular analysis.
- Recommended: 45 (or 53) µm nets are also common and recommended to allow fuller assessment of the metazoan community (nauplii and other early developmental stages). They can be used in a single deployment package with larger nets. When in ice-free waters, towed 500 µm nets are strongly recommended for larger crustaceans/macro-zooplankton that would otherwise avoid slower nets and/or species that occur in densities too low to be adequately sampled by vertical collections.

Sampling scheme

- Essential: Upper 100 m or to the bottom if in shallower depths than 100 m. In deeper water, add sample to 500 and 1000 m if it is impractical to sample all the way to the bottom.
- Recommended: Stratified sampling valuable, especially in deeper waters. Common strata end at 25, 50, 100, 200, 500, 1000, 2000, and 3000 m and/or the bottom.
- Net speed 0.5-1 m s^{-1}

  All nets **MUST** be metered for volume filtered, and if deployed vertically, the flow-meters must not record during descent.

  Sample analysis

- Essential: Species level detail (as practical). Stage detail in crustaceans provides critical information on population structure and phenology.
- Essential: Vouchering of specimens, archiving of samples.

- Recommended: Genomics/bar-coding to confirm identifications, and examine population structure.
- Suggested: lipid-sac volumes, size/weight at stage, copepod egg production. Gentle examination of samples prior to preservation (using backlighting) is necessary to adequately assess the abundance and biomass of ctenophores.

In situ imaging

Gear

- Suggested: *In situ* imaging (video or still photography) transects provide the only current means to adequately assess the larger, rear, and more fragile zooplankton, particularly at depth. Species-level identification can often be performed for larger species. The added benefit of imaging transects is valuable information of *in situ* distribution patterns at a finer resolution than possible by nets.

6.2 Sea-Ice Biota

6.2.1 Sampling Approach

The sampling of sea-ice biota should include sampling in the nearshore fast-ice regions during the maximum algal bloom, sampling in the marginal ice zone (MIZ), annual summer ice-core sampling with additional spring sampling in deep-sea regions of the Beaufort Gyre and the Transpolar Drift, including the North Pole region. This sampling should also involve cross-section sampling with mesoscale polygons stratified by multi-year and first-year ice. Sampling of multi-year sea ice in regions where it is predicted that it will remain last (e.g., High Canadian Arctic Archipelago) and comparisons with first-year sea ice in neighboring areas is recommended. Concomitant with sea-ice sampling, under-ice sampling of plankton and seawater should occur and include plankton nets and water-bottle sampling in the summer within the 0-300 m water column, in association with Conductivity-Temperature-Depth (CTD) profiling. Further sampling should include sampling melt-water ponds on the ice during the late summer melting season.

Sea-ice cores

Physical/chemical properties

- Essential: Snow depth and sea-ice thickness, temperature, salinity, albedo, and downwelling PAR measurements. For first-year ice, it is essential that biological and chemical measurements are made on the bottom section of the ice where most biological material is present. Depending on the project's objectives and resources, complete ice-core sections can be analyzed. For multi-year ice where the material is more uniformly distributed throughout the cores, it is essential to analyze multiple sections of ice cores.
- Recommended: Divide ice core into equal sections depending on the total length, or use a comparable technique. *Important*: Each ice section needs to be large enough to have a sufficient volume of the melting ice water for all types of physical (temperature) and chemical (salinity) analyses to understand variation throughout the core. If insufficient material is available, multiple sections from replicate cores should be combined.

Sea-ice protists

- Essential: Chlorophyll *a* (fluorescence on extracted Chl *a* samples) biomass assessment, cell abundance, and identification for species distribution within sea-ice thickness.
- Recommended: Divide replicate (n=3 or more depending on amount of material in cores) ice cores into sections and melt core sections separately to analyze for Chl *a*. Melt a second set of replicate (n=3) ice-core sections with the addition of filtered seawater (100 ml filtered seawater for each 1 cm of ice-core section) for biological analyses. Use a known volume of the melted section to analyze ice flora species composition and abundance (Gradinger and Bluhm 2009). Keep the remaining core meltwater for faunal analyses (see below). Preserve with Lugol's or formalin.
- Suggested: Sea-ice flora samples are concentrated (e.g., by settling). Both light and electron microscopy can be used for identification at the species level.

Sea-ice fauna

- Essential: Species-level identification and counts for distribution within sea-ice thickness for biomass and abundance of meiofauna.
- Recommended: Use a known portion of the core sections melted with filtered seawater (see above). Concentrate invertebrate animals on 10-20 µm mesh to 5-10 ml volume and preserved in 4% formaldehyde (=4% formalin) or ethanol (depending on taxon). Counts of organisms are made using Bogorov's device or light microscopy.

Under-ice sampling

Under-ice protists

- Essential: Sea-ice interface sampling and algal aggregations under ice surface (density/biomass/composition)
- Recommended: SCUBA sampling from the bottom ice surface. Continued video monitoring of marine/brackish algal aggregations. Deployment of Remotely Operated Vehicles (ROV)/ Autonomous underwater vehicle (AUV) for larger regional coverage is potentially useful.

Under-ice fauna

- Essential: Ice-associated invertebrate fauna (density/biomass/composition)
- Recommended: SCUBA sampling from the bottom ice surface plus use of ROVs and AUVs

6.3 Benthos

6.3.1 Sampling Approach

Benthic sampling typically occurs as part of targeted research programs, fisheries surveys, established monitoring programs, and, in some cases, as part of industrial development monitoring projects. It is important that all benthic sampling adhere to the following general guidelines to the extent possible:

- Record metadata for all data collections, including surface area sampled, trawl specifications, and sieve/mesh size used;
- Standardize all sampling to a fixed area (1 m^2 for macrofauna, 100 m^2 or 1 km^2 for megafauna; also see "Sample analysis" below);
- Ensure taxonomic consistency to allow for cross-regional comparisons (recommended use of standardized nomenclature under development, and workshops); and,
- Maintain consistency in functional group designations (recommendations under development).

Sampling should be focused on key transition areas based on ice cover, water masses and/or productivity, and running transects across these focal areas, specifically where phase changes occur (e.g., ice edge/polynyas). However, focus areas may differ depending on the driver that is considered most important in a particular region (e.g., climate change, pollution, habitat destruction, harvesting, alien species, etc.). Ideally, a single transect might work to assess several drivers. As well, benthic sampling locations will correspond with plankton and other sampling locations whenever possible to allow for more cost-effective sampling, as well as correlating data.

Small-to large-scale spatial variability is an inherent characteristic of benthic communities and a good measure and understanding of this variability is needed to determine the optimal number of stations per transect or location required to adequately detect trends/signals. Ideally, benthic monitoring should occur every 1-3 years to capture temporal variability. Because of longevity of most benthic organisms and slow response times, a 1-3 year time frame is considered sufficient to capture long-term changes. While benthic monitoring occurs on the whole community level, ongoing monitoring should target regionally and pan-Arctic dominant benthic species. Figure 7 identifies existing and anticipated benthic monitoring locations across the Arctic.

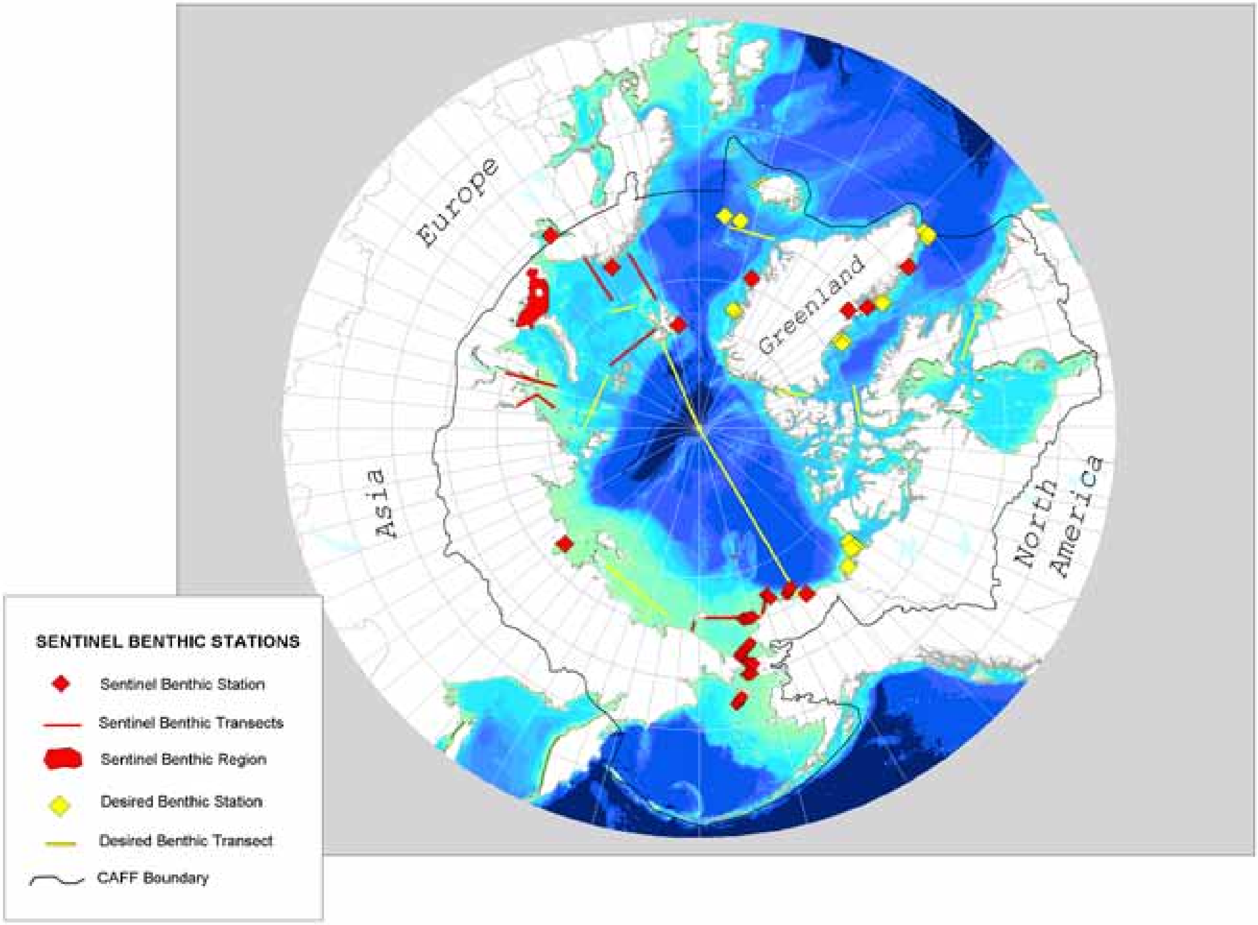

Figure 7 Sentinel and desirable benthic regions, transects, and stations supported by MEMG countries.

6.3.2 Sampling Protocols

Grab sampling (macrofauna)

Gear

- Essential: Most ongoing programs use small quantitative grabs (e.g., 0.1 m^2 van Veen grab) for shelf sampling and larger quantitative box cores for deeper sampling, and this should continue. It is essential that the surface area and gear type be noted in the metadata for each sampling set. Samples are then washed over a defined mesh size (typically 1 mm for shelf samples), and it is essential that the mesh size used is noted. Whole samples (per grab) are preserved with 4% formaldehyde (=10% formalin), and later transferred to 70% ethanol or 50% isopropanol for long-term storage (formalin will erode calcium carbonate structures important for identification).
- Recommended: Preserve subsamples 95% non-denatured molecular-grade ethanol for barcoding and genomics (Integrated Ocean Drilling Program, 2011).

Sampling Scheme

- Essential: 3-5 replicate grab samples are needed to adequately capture local variability of the community. Station depth has to be recorded. Information on grain size has to be taken either from visual categories or through physical sampling from an additional grab sample.

- Recommended: Sample of sediment chlorophyll in addition to grain size. Water properties (salinity, temperature) should be made available from CTD casts. Information on water column chlorophyll (either from direct measurements or from satellite data) should be acquired

- Suggested: Information on other drivers (shipping, development, harvest, etc.) should be acquired from appropriate sources.

Sample analysis

- Essential: Species-level detail desirable (as practical). Abundance counts and biomass (wet-weight, from preserved samples).

- Essential: Standardize sample abundance and biomass to 1 m^2.

- Essential: Vouchering of specimens, archiving of samples.

- Recommended: Genomics/barcoding to confirm identifications, and examine pan-Arctic distribution patterns.

- Suggested: Size-frequency distribution of select target species of regional and/or pan-Arctic relevance.

Trawl and image sampling (megafauna)

Gear

- Essential: Semi-quantitative trawl types, net opening, mesh size, trawl time and tow speed, and depth have to be noted in metadata set. Representative samples are preserved with 4% formaldehyde (=10% formalin), and later transferred to 70% ethanol or 50% isopropanol for long-term storage. Formalin will erode calcium carbonate structures important for identification.

- Recommended: Under-water imaging (video or still photography) transects are recommended to complement trawl samples and can, in some cases, replace trawl sampling. Imaging systems have to be equipped with lasers for scaling so that area covered can be determined for accurate abundance estimates. If trawl and video/still camera observations are available concurrently, biomass in images can be calculated from size-specific measurements of trawl samples. The added benefit of imaging transects is valuable information of *in situ* distribution patterns and habitat features, especially when analyzing trends over time and space.

- Recommended: Preserve subsamples in 95% non-denatured molecular-grade ethanol for barcoding and genomics.

Sampling Scheme

- Essential: Typically, only one trawl per station is taken. Information on substrate type and grain size has to be taken from visual inspection of the trawl catch, from imagery, or from accompanying grab samples. Station depth has to be recorded.

- Recommended: Water properties (salinity, temperature) should be made available from CTD casts. Information about water-column chlorophyll (either from direct measurements or from satellite data) should be acquired. A separate grab sample for quantitative sediment grain-size determination is recommended.

- Suggested: Information on other drivers (shipping, development, harvest, etc.) should be acquired from appropriate sources.

Sample analysis

- Essential: Species-level detail desirable (as practical). Abundance counts and biomass (wet weight from fresh or preserved samples).

- Essential: Vouchering of specimens, archiving of samples.

- Recommended: Genomics/barcoding to confirm identifications and examine pan-Arctic distribution patterns.

- Suggested: Size-frequency distribution of select target species of regional and/or pan-Arctic relevance, invasive species, and species vulnerable to physical stress from trawling.

Nearshore sampling (hard substratum)

The sampling scheme for hard-substratum, nearshore habitats will need to be developed further at a later stage of implementation. Suggestions here are based on ongoing sampling protocols implemented through the Census of Marine Life NaGISA program (Natural Geography in Shore Areas) (Rigby et al. 2007).

Gear

- Sampling is ideally done by diving in the shallow subtidal, or from land in the intertidal._
- Essential: Depth, number of replicates and quadrat size have to be noted in metadata set. Samples are preserved with 4% formaldehyde (=10% formalin), and later transferred to 70% ethanol or 50% isopropanol for long-term storage. Formalin will erode calcium carbonate structures important for identification. Macrophytes are either preserved (herbarium-vouchered) or analyzed fresh (species identification, biomass).
- Recommended: Sampling should be accompanied by quantitative visual percent-cover estimates.
- Recommended: Subsamples should be preserved in 95% non-denatured molecular-grade ethanol for barcoding and genomics

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Sampling Scheme

- Essential: Typically, five replicate quadrats (0.0625 m^2 quadrat size) are sampled at random locations along the high, mid, and low intertidal strata and at 1, 5, 10 and 15 m depth strata. Percent-cover estimates are done from five replicate 1 m^2 quadrats randomly placed at the same depth strata as the smaller quadrat size.
- Recommended: Water properties (salinity, temperature) should be measured and bottom type noted.

Sample analysis

- Essential: Species-level detail (as practical). Abundance counts and biomass (wet weight from fresh or preserved samples).
- Essential: Vouchering of specimens, archiving of samples.

6.4 Fish

6.4.1 Sampling Approach

- Several hundred species of Arctic and sub-Arctic fish are encompassed within the AMAs defined in this plan. These and the subset of species noted explicitly in Chapter 5 are found across four semi-distinct habitats:
- estuaries and mixed waters (e.g., salmons, chars);
- coastal and nearshore euryhaline waters (0-50 m depth) (e.g., sculpins);
- shelf areas (nearshore to 200 m depth) with pelagic (e.g., capelin) and benthic habitats (e.g., Arctic/boreal cods); and,
- slope and abyssal waters (>200 m depth) with pelagic (e.g., herrings) and benthic (demersal) habitats (e.g., Atlantic/ Pacific cods, Greenland halibut).

Sea ice, either as land-fast ice or as pack ice, is an additional factor that provides key habitats for some fish species. The habitats, species of fish, and the nature of the fisheries all determine the best sampling approach. For example, monitoring of anadromous fish re-entering freshwater in the autumn might best be conducted through subsistence fishing. Nearshore monitoring during open-water seasons is best done by gill nets and/or trap nets, especially if conducted through a research monitoring program. Pelagic habitats are best fished using mid-water trawls or floating gill nets. Finally, benthic habitats are best surveyed with bottom trawls, sinking gill nets, or baited set lines. Both habitats might be monitored best through commercial fisheries. Standardization of gear, species (groups of analogous species), and habitat types to be monitored is required to allow for inter-regional comparison of results, which are best analyzed within particular habitat types.

The nature of the platforms from which fishing gear is deployed determines both the type of fish and the nature of the data collected. Research ships often conduct multi-disciplinary cruises and collect information about habitats (e.g., temperature, salinity) as well as fish (e.g., species composition of catch). Fishery vessels tend to focus upon a particular species or small suite of fish species, which represent a subset of the community present. However, they have the advantage of repetitive sampling in areas over long time frames (composition of targeted catch and biological parameters, along with effort, represent some of the best data available for monitoring) and, if combined with bycatch statistics, provide an adequate representation of the fish community. Local subsistence fishers using smaller coastal vessels provide insight into the nearshore and shelf communities.

Within the larger AMAs, particular areas experiencing (or expected to experience) rapid change and/or high levels of stress should be targeted for monitoring. For example, the sub-Arctic fringes of productive polar seas (e.g., Polar Front margin in Barents Sea) could be monitored through a combination of fishery and research activity at a focal site, particularly if they are expected to experience major shifts. Such shifts would likely be signaled by compositional changes in the fish community. Simple parameters, such as the northern-most location of commercial fishing, may signal key changes. Similarly, inshore subsistence fisheries associated with major Arctic estuaries (e.g., Mackenzie River) will possibly experience shifts in the demographics of key anadromous species (i.e., shifting length distributions, timing of key life history events). Monitoring basic biological parameters, such as fish condition (weight/length), provides proxy information regarding the marine ecosystem. Development of appropriate, locally based community fishing programs should be a priority.

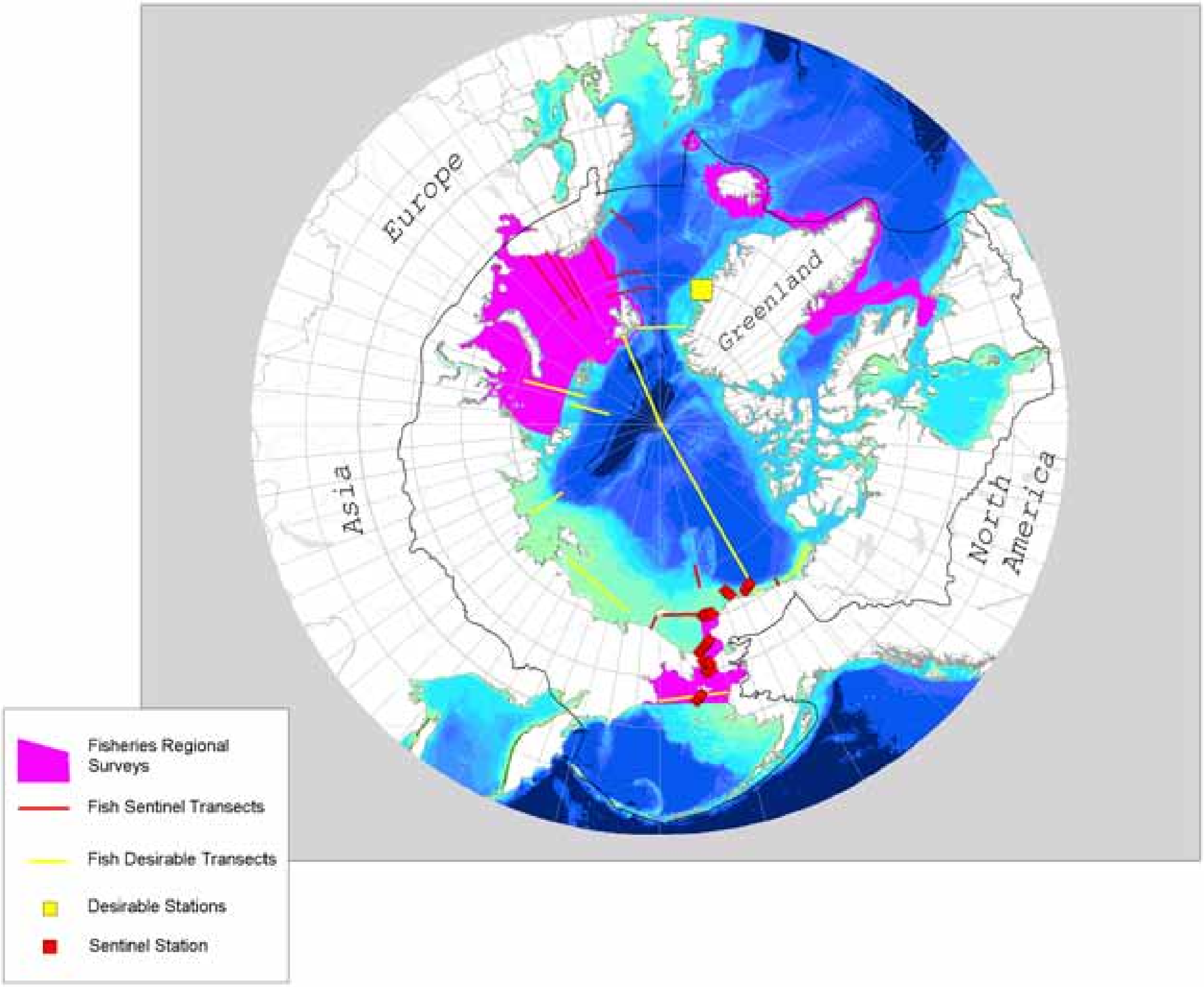

Figure 8 Sentinel and desirable fish-observing regions, transects, and stations supported by MEMG countries.

6.4.2 Sampling Protocols

Sampling protocols are dependent upon gear type, focal species (or habitats), logistical capabilities (e.g., ships capable of trawling), and existing/past data types and availabilities, all of which vary widely across the AMAs and habitats within them. Additionally, transect-based and location-based surveys provide somewhat different information, so the merits/limitations of each require consideration. Existing and idealized locations are shown in Figure 8. Development of sampling protocols and completion of a minimal agreed-upon pan-Arctic suite of transects and sentinel stations is a topic for future consideration by a specialist group.

Linkages of fishing programs with multi-disciplinary research programs (e.g., plankton and benthic surveys) would provide benefits in regards to cost-saving, inter-disciplinary linkages and "value-added" correlational understanding, and also provide information regarding abiotic determinants of habitats (e.g., oceanographic properties).

Capture of a suite of fish species is the initial step in "sampling." Processing the fish according to standardized protocols and analysis of the resulting data provide additional information relevant to monitoring at several levels. Finally, further analysis of sub-samples through specialized techniques (e.g., genetics, stable isotopes) provides added insight to both structural and functional shifts in populations, species, and ecosystems. Examples at various ecosystem levels include the following, which are not exhaustive nor mutually exclusive:

- Community level: occurrence, composition, relative abundance, endemic/vagrant, and size spectra of species present diversity/richness indices trophic indices.
- Species level: distribution (geographical, ecological, and temporal); population structure; life history patterns, phenologies, types.
- Population level: abundance, biomass, distributions of key parameters (age, size); growth; phenologies, such as matches/mismatches to key events.
- Individual level: habitat use; diets; developmental anomalies.

Biodiversity measures and parameters are emergent attributes of species and ecosystems. Shifts in these may reflect natural variability, anthropogenically induced change, or both, in either the biological system or its abiotic underpinnings. Understanding of both natural variation in key biodiversity parameters of fish and variation induced by anthropogenic factors is required. Research is required to understand the causal effects of stressors upon specific fish parameters, particularly those that underpin key indicators. For some stressors (e.g., fisheries), the immediate effect upon some parameters is known (truncation of length and age classes). For others, such as climate change, the effects are less well understood and may be complex, consisting of both direct and indirect changes (e.g., growth shifts and alteration of prey availability, respectively). Understanding the links between fish biodiversity parameters and stressors is essential to understanding causation and developing adaptive responses.

6.5 Seabirds

6.5.1 Sampling Approach

The following is based on CAFF's Circumpolar Seabird Group's (CBird) *Framework for a Circumpolar Arctic Seabird Monitoring Network* (Mosbech *et al*, 2008).

Monitoring of seabird species that are widely distributed across the circumpolar Arctic (e.g., black-legged kittiwakes) should include relative abundance, survival, diet, phenology, and productivity. These data are essential to explaining observed changes in populations, but abiotic environmental factors also need to be taken into account. Currently, black-legged kittiwakes are monitored at varying intervals at 197 colonies and common eiders at 114. The circumpolar distribution of this monitoring lends itself well to the CBMP-Marine Plan. In addition, black-legged kittiwakes are monitored for contaminants as part of AMAP, thus providing the potential for coordinated monitoring between the two programs.

Black-legged kittiwakes, common eiders, and murre species (thick-billed and common) were chosen as priorities for circumpolar monitoring based on rankings done by the CBird group. CBird considered factors such as circumpolar distribution, Arctic responsibility, conservation importance, societal importance, scientific importance, importance as ecological indicators, and national priorities. These rankings, along with other criteria, resulted in 22 species being chosen. Further input reduced this number to the top three seen in this plan. The three groups chosen also represent distinct feeding strategies (i.e., black-legged kittiwakes are surface-feeders, murres are piscivores, and common eiders are bottom feeders).

To cover different stages of the birds' life cycles, at various times of year and at individual areas of importance for their continued survival, it is important to employ different approaches to seabird monitoring. The main components of the Circumpolar Seabird Monitoring Framework network approach are identified as:

- Colony monitoring, with three sub-components: (a) colony registry, (b) total colony counts, and/or (c) partial colony counts (plots, transects).
- At-sea surveys.
- Harvest statistics.
- National lists of breeders and non-breeders.
- National Endangered Species lists; and.
- Banding.

Local, community-based observations are of particular relevance to the monitoring of Black-legged Kittiwake, Murre and Common Eider colonies that are proximal to local communities, particularly communities that harvest seabirds. The year-round presence of Arctic residents and the close connections, including harvest of seabirds, maintained by many Arctic coastal communities presents a cost-effective opportunity for collecting valuable information on the status and trends at colonies proximal to these communities.

Colony monitoring

Of the six components listed above, colony monitoring is particularly complicated and needs to be discussed in some detail. One aspect is selecting which parameters to be monitored and the other is selecting which colonies should be part of an ongoing circumpolar monitoring effort. In general, colony monitoring should involve the following parameters:

- Numbers.
- Productivity (recruitment).
- Survival.
- Diets.
- Phenology.

As part of further development of the Circumpolar Seabird Monitoring Framework, the CBird group will identify which colonies will be part of the circumpolar monitoring effort.

At-sea surveys

Birds at sea are proxies for ecosystem health and, as such, represent important environmental indicators. In at-sea surveys, the full scale of seabird biodiversity in a particular area at a given time of year is covered. Censuses can, in theory, be carried out at any time of year. The distribution of seabirds at sea changes as water masses change, so the census results need to be compared to physical characteristics of the water (e.g., sea surface temperature and salinity) and biotic factors (e.g., primary production and zooplankton data). At-sea monitoring allows population trends and changes in distribution to be determined for many species simultaneously.

Winter surveys of seabirds are inevitably carried out at sea, but can sometimes be difficult to execute due to poor weather conditions, limited light conditions, and few working research vessels. We suggest concentrating monitoring transects on high-density areas, which are often coastal and which, in some locations, can be surveyed from small boats or even from shore. We also suggest aerial surveys, which are even more weather-dependant, but have shorter sampling times and much larger coverage than vessels.

The following ideas have been put forward for at-sea surveys:

- Start with 10 to 15 pilot areas.
- Monitor every year to three years.

- Monitor selected coastal and open-sea areas.
- Use local ferries and research vessels for permanent transects.
- Use vessels of opportunity for one-time transects.
- Use observers on vessels with continuous plankton recorders.
- Liaise with existing global monitoring programs.

In some countries, the so-called Christmas Bird Counts have been carried out for decades along set coastlines. Such counts are differentially relevant to seabird species and monitor primarily those found relatively inshore, such as cormorants, eiders, gulls, and guillemots.

Harvest statistics

Harvest data can give a measure or index of the local abundance of species and of population trends over time. Data are obtained from local or national government programs, and trends in numbers can be derived as with other monitoring data. Harvest data also help interpretation of possible effects of hunting on the respective populations. Such data need interpretation, since many human-related factors can influence the results. Harvest data are open to ambiguities, such as differences in reporting by hunters, distribution of humans, etc. Bird populations in countries and areas without seabird harvests could be used for comparison with hunted populations. For interpretation of harvest data, effort should be measured in some manner (e.g., season length, number of harvesters, total number of harvest days) to allow catch per unit effort (CPUE) to be calculated.

National lists of breeders and non-breeders

As climate changes, species' ranges will change. Simple national lists of breeders in an area or country will, with time, show changes in species composition. Extinct breeding species should be included in such a compilation. The species composition of non-breeders occurring in an area may also change. Therefore, simple lists of regular winter visitors, regular through-migrants, and vagrants are of monitoring value. Species lists for countries are inexpensive indicators, which are normally compiled by bird enthusiasts, but are often thwarted by not providing information about effort. Climate change modeling is a more elaborate methodology, which gives various opportunities to try out hypotheses.

Photo by:Flemming Merkel

Banding

Banding as a methodology is essential for certain aspects of monitoring. In well-structured programs, banding can augment productivity information and increase the sample available using the network of large numbers of amateur banders. More importantly, banding is crucial for survival analyses. Survival of adult breeding birds is one of the most important parameters for the population dynamics of seabirds, most of which are long-lived, but can vary according to life-history traits of the different species. For some species, it may be more important to monitor than productivity, for example, even though survival data are much more difficult to come by.

Other relevant parameters

A suite of other parameters, physical and biotic, is needed to interpret monitoring results. These include the following:

- Climate data (air temperature, winds, etc.).
- Oceanographic data (salinity, depth, sea temperature, currents, sea ice, etc.).
- Climate change models (including North Atlantic Oscillation (NAOs), subpolar gyres, etc.).
- Plankton distributions and magnitudes, both phyto- and zooplankton.
- Contaminants (of which there is a whole suite).
- Fisheries and fish stock data.
- Oil spill data.

More information on the recommended sampling approach for monitoring Arctic seabirds can be found in *Framework for a Circumpolar Arctic Seabird Monitoring Network* (CAFF CBMP Report No. 15).

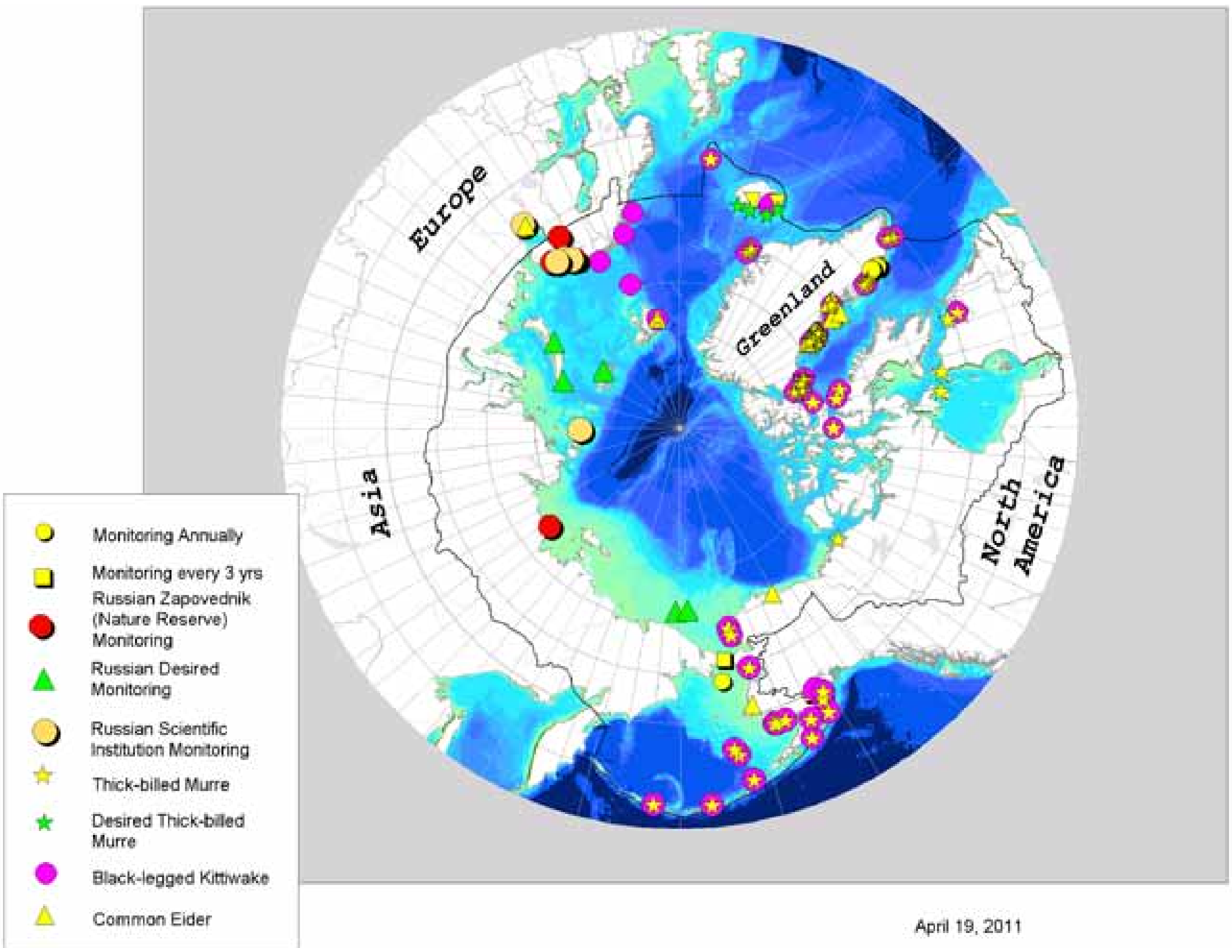

Figure 9 Sentinel and desirable seabird sampling locations supported by MEMG countries.

6.6 Marine Mammals

Marine mammal sampling is conducted using a variety of tools including:

- Visual surveys from shore, vessels or aircraft.
- Passive acoustic surveys for calls from short (hours) to long-term (year) hydrophone deployments.
- Tracking of animals equipped with satellite-linked tags.
- Remote sensing via infra-red imagery from aircraft and satellites.
- Analysis of tissues obtained via biopsy dart or from harvests, along with overall health assessments.

In addition, polar bears are often monitored with basis of mark-recapture using ear-tags or under-lip tattoos. Local, community-based observations are of particular relevance to the monitoring of marine mammals due to the year-round presence of Arctic residents and the close connections, including harvest of marine mammals, maintained by many Arctic coastal communities.

6.6.1 Sampling Approach

Means to sample marine mammals fall into eight categories:

1. Local to broad-scale aerial and ship-based visual surveys (10-1000s km).
2. Local to broad-scale remote sensing from aircraft and satellites.
3. Short- to long-term passive acoustic surveys.
4. Satellite tagging.
5. Tissue sampling (biopsy).
6. Stomach and tissue sampling (harvest).
7. Ice-based census (bowhead whales).
8. Mark-recapture census of natural marks (photo identification of bowhead whales) or ear tags/tattoos (polar bears)

The sampling approach varies with the objectives of the research program. Where possible, multiple approaches may be applied. Justification for the sampling approach used is generally given in the introduction and methods section of research planning documents.

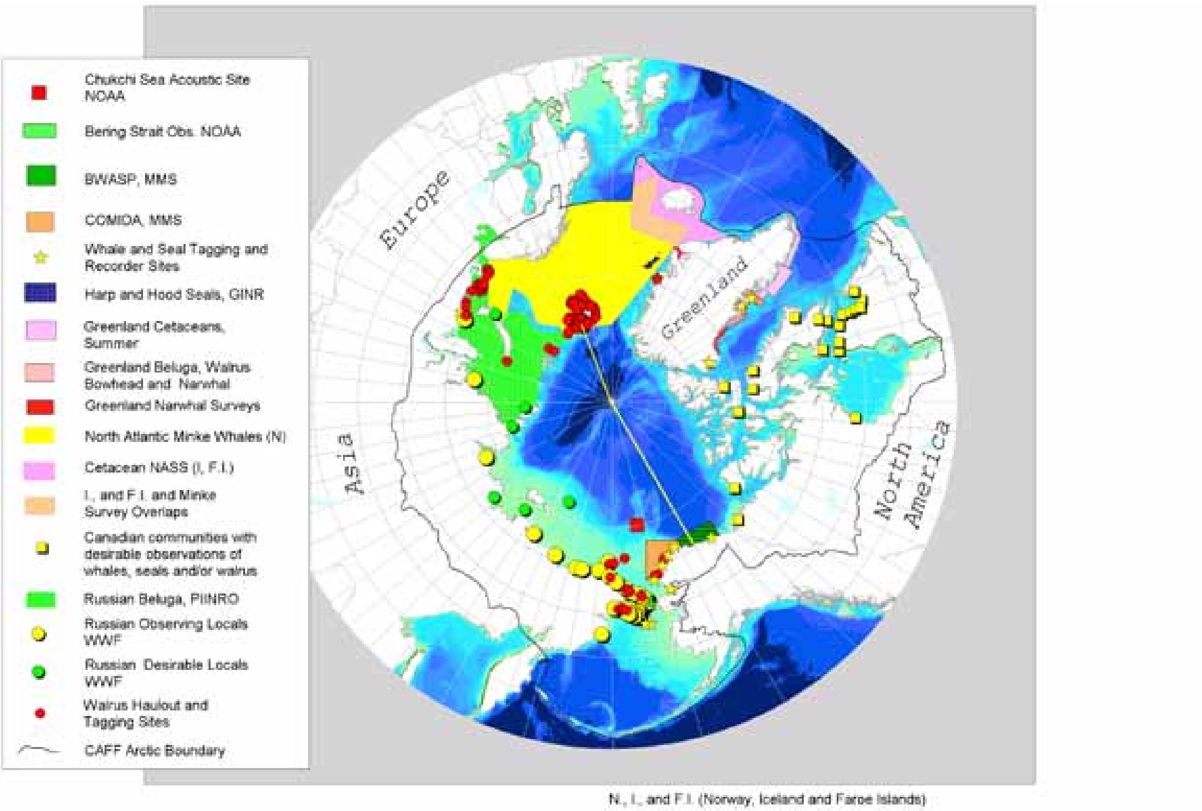

Figure 10 Sentinel and desirable marine-mammal-observing regions and tagging sites suggested by MEMG countries.

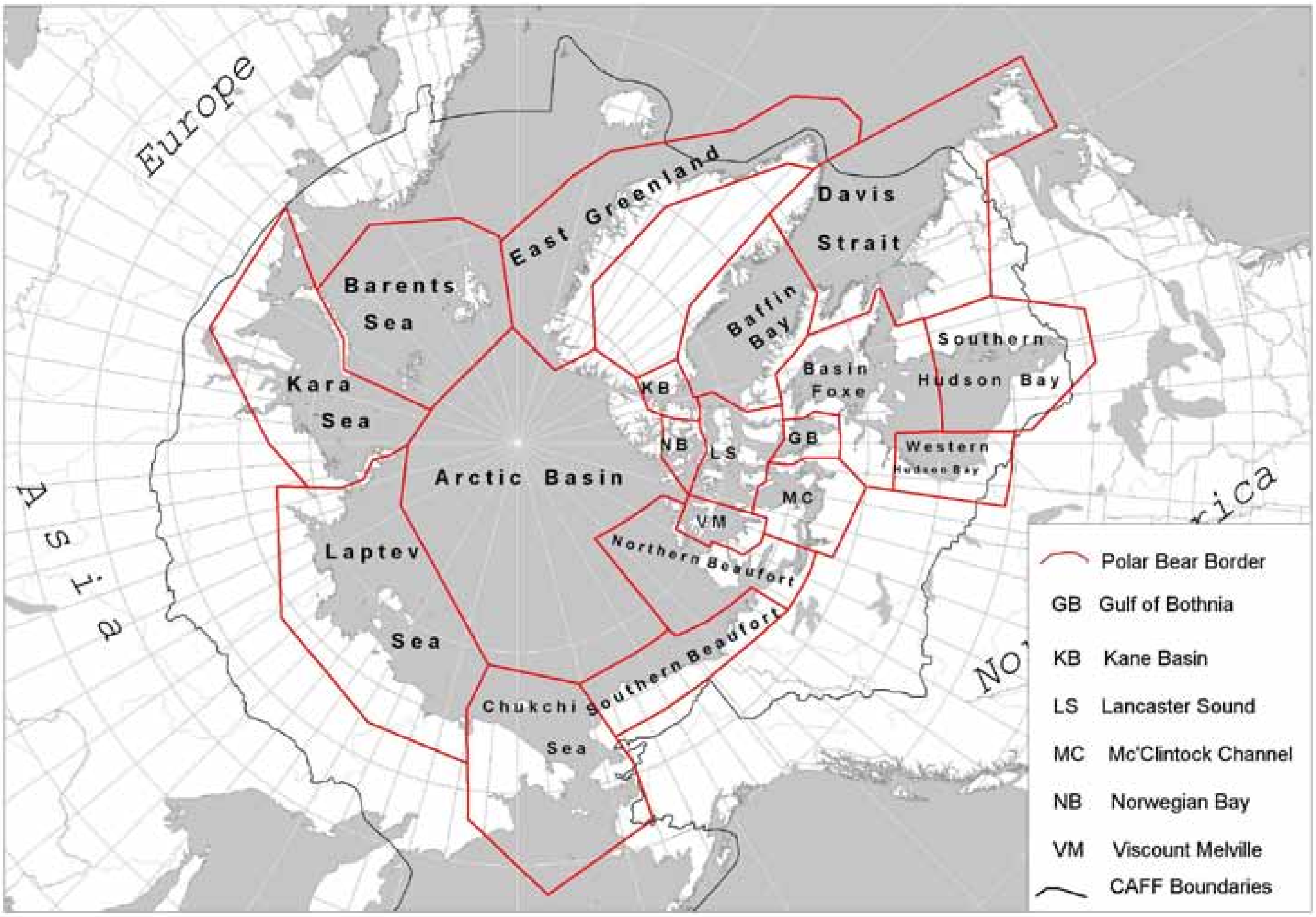

Figure 11. Polar bear regions of the Arctic.

6.6.2 Sampling Protocols

Sampling protocols for each of the eight categories are:

1. Transect surveys with pre-designed start and end points, on-station visual scans, and focal-animal follows.
2. Use of satellite and infra-red imagery to detect hauled-out pinnipeds.
3. Dipping hydrophones (hours and autonomous recorders (year-round) detection of calling animals).
4. Satellite-linked tags to define movement patterns, stock structure, and habitat selection.
5. Hollow-tipped crossbow or air rifle to recover "plug" of skin and blubber.
6. Recovery of stomach volume and tissue from skin-to-muscle layer, and organ sampling.
7. Double-perch visual tracking with theodolites to derive population estimate.
8. High-resolution digital images obtained during aerial surveys conducted from an aircraft outfitted with a belly-port window to enable (re)identifications of individual whales.
9. Mark of sedated bears with plastic ear tags and under-lip tattoos. Recapture either on subsequent field seasons or via legal harvest, handling of problem bears or self-defense /illegal kills.

As with the sampling approach, sampling protocols vary with the objectives of the research program, with specifics of the methodology provided in research planning documents.

7. Data Management Framework

7.1 Data Management Objectives for the CBMP

A key objective of the Circumpolar Biodiversity Monitoring Program is to create a publicly accessible, efficient, and transparent platform for collecting and disseminating information on the status of and trends in Arctic biodiversity. This objective will be instrumental in achieving the Program's mandate to report on trends in a timely and compelling manner so as to enable effective policy responses. The CAFF's CBMP data management objectives are focused on the *art of the possible*—developing data-management systems that facilitate improved access to existing biodiversity data and integration of this data between disciplines, while maintaining the data holders' ownership and control of the data. It is expected that each country would still be responsible for supporting data management (e.g. QA/QC of data and compilation of existing national datasets) and contributions from their individual monitoring networks (i.e., the data holders), whereas the CBMP will focus its efforts on building the mechanisms to access and integrate this data across countries and networks, as well as promoting a common, standardized data-management approach among the countries. For this approach to be successful, it is imperative that national datasets are made available.

Data sources, formats, and subjects vary widely across the Arctic biodiversity research and monitoring community. One challenge is to access, aggregate, and depict the immense, widely-distributed, and diverse amount of Arctic marine biodiversity data from the multitude of contributors involved in this monitoring plan. A related challenge is to integrate and correlate this information with other relevant data (e.g., physical, chemical, etc.) to better understand the possible causes driving biodiversity trends at various scales (regional to global) and thereby facilitate management responses and research. Furthermore, it is critical to deliver this information in effective and flexible reporting formats to facilitate decision making at a variety of scales from local to international. Meeting these challenges will significantly improve policy and management decisions through better and timelier access to current, accurate, and integrated information on biodiversity trends and their underlying causes at multiple scales.

In some cases, especially for the higher trophic levels, biodiversity data and relevant abiotic data layers are already available and can be integrated into the CBMP's Data Portal system (www.cbmp.is). However, the task of aggregating, managing, and integrating data for the lower trophics (e.g., plankton data and benthic invertebrates) is arduous, and it may be some time before such information can be accessed readily via the CBMP Data Portal. The establishment of Marine Expert Networks (see Chapter 11) for the various trophic levels, as well as support from each nation and from the CAFF Data Manager, will facilitate this process through the adoption of common data and metadata standards and the development of common database structures.

The following sections provide an overview of the data-management framework to be used for managing the outputs of the CBMP-Marine Plan. Such a framework is essential to ensure effective, consistent, and long-term management of the data resulting from coordinated monitoring activities. Timelines for implementing this approach to data management are found in Chapter 10.

7.2 Purpose of Data Management

Effective and efficient data management is fundamental to the success of the CBMP and this monitoring plan. A key measure of success will be the ability to effectively connect individual partners, networks, and indicator-development efforts into a coordinated data-management effort that facilitates data access and effectively communicates Arctic biodiversity status and trends to a wide range of audiences and stakeholders. Executed correctly, data management can fulfill the following functions:

- Quality assurance: ensures that the source datasets and indicator development methodologies are optimal and that data integrity is maintained throughout processing.
- Consistency across parameters and networks: encourages the use of common standards and consistent reference frames and base datasets.
- Efficiency: reduces duplicate efforts by sharing data, methodologies, analysis, and experience.
- Sustainability: ensures archiving capability and ongoing indicator production.
- Enhanced communications: produces and distributes information through integrated web-based services, making indicator methodologies accessible and providing source metadata.
- Improved linkages: ensures complementarities between various networks and partnerships and with other related international initiatives, other indicator processes (national, regional, and global), and global assessment processes (e.g., the Global Biodiversity Outlook and Millennium Ecosystem Assessment).
- Enhanced credibility: provides transparency with respect to methodologies, datasets, and processes.

Implementation of the CBMP-Marine Plan relies on participation from many partners. An efficient and user-friendly metadata and data management system will facilitate this collaboration, providing multiple benefits as outlined above. It will offer unique opportunities for monitoring networks to exchange data, draw comparisons between datasets, and correlate biodiversity data with data derived from other networks, using a common, web-based platform. A roadmap for data management, the CBMP Data Management Strategy (Zöckler 2010 *unpublished*) has been developed to guide the management and access of metadata and data amongst and between the CBMP networks.

7.3 Coordinated Data Management and Access: the CBMP Web-based Data Portal

Arctic biodiversity research and monitoring involves a multitude of networks producing information in diverse formats with minimal integration. While much information is produced by these networks, much of it is inaccessible, not reported, or in user-unfriendly formats. New, web-based data management tools and new computational techniques have provided an opportunity for innovative approaches to data management, critical for a complex, international initiative such as the CBMP.

CAFF's CBMP has developed a state-of-the-art data portal (www.cbmp.is): a simple, web-based and geo-referenced information network that accesses and displays information on a common platform to encourage data sharing and display over the Internet. The data portal represents a distributed data management structure where data holders and publishers retain ownership, control, and responsibility for their data. Such a system provides access to immediate and remotely distributed information on the location of Arctic biological resources, population sizes, trends, and other indicators, including relevant abiotic information. As well as providing a point for Arctic biodiversity information, the data portal provides a simple approach for experts to share information through the web and allows for the integration and analysis of multiple datasets (see Chapter 8).

The CBMP's data portal requires the establishment of a series of data nodes, with each data node representing a data type or discipline (e.g., seabirds, plankton, fish). Each data node will be established and supported nationally. The CAFF Data Manager will interact with the national nodes to ensure inter-operability and data aggregation and will provide overall maintenance and management of the resulting pan-Arctic aggregated data. Where appropriate, the CBMP will establish web-based data-entry interface systems (web services) tailored to each data node/discipline, allowing researchers in each country to enter their data on an annual or semi-annual basis (depending on the frequency of data collection) via the Internet. This information will be aggregated, automatically populating a database established at an organization of the Expert Network's choosing. The Marine Expert Network leads will have overall administrative privileges (password-controlled) to view, maintain, and edit the database. Each expert within a discipline group will have access (via a password) to enter and maintain their own data. Each Marine Expert Network will be responsible for defining and implementing the analytical approaches to generating the indicators (see Chapter 8). The CBMP will work with each Marine Expert Network to establish analytical outputs, via the Data Portal, tailor-made for the data collected and housed at the data node. Priority indicator data will be managed via the web portal whereas other dataset compilations can be directly archived at the CAFF Secretariat or through an agreement with an existing data center (e.g. World Data Center in Oceanography).

Users (e.g., scientists, decision-makers, and the public) will have password controlled access to the data outputs via the CBMP Data Portal. Users will be able to perform set analyses (defined by the Expert Networks) on the Portal, which will immediately access the most current data at the data node (using XML Internet language) and display the output of the queried analysis (Figure 12). Much of the initial work in the implementation phase of the CBMP-Marine Plan will involve aggregating existing datasets to create pan-Arctic data layers. The life cycle of the data, from collection to presentation, is shown in Figure 13.

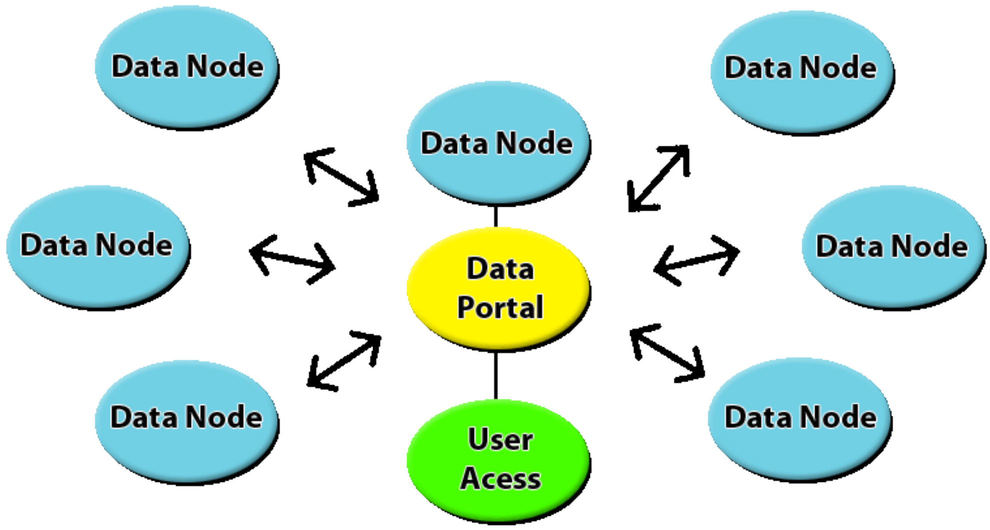

Figure 12 Illustration of the CBMP network of data nodes and their integration via a common platform, the CBMP Web-based Data Portal.

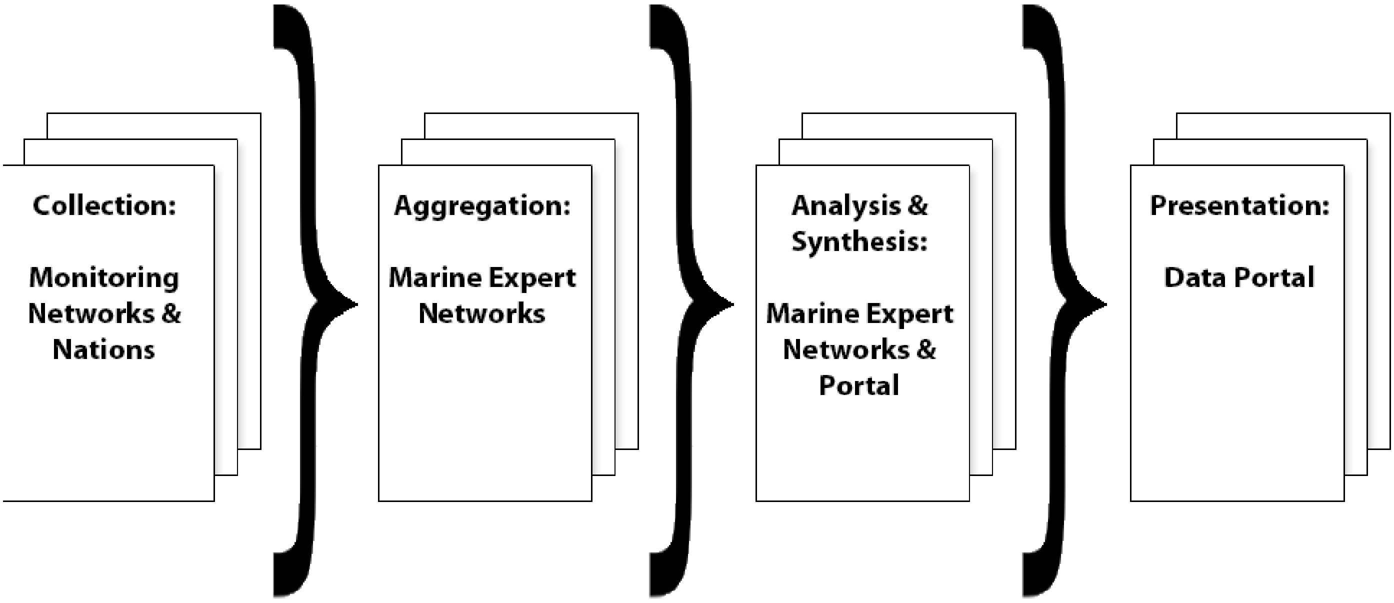

Figure 13 A simplified overview of the steps involved in accessing, integrating, analyzing, and presenting biodiversity information via an interoperable web-based data portal and an indication of the responsibilites at each step.

The CBMP Data Portal will be flexible, password driven, and customizable to serve a diversity of clients (Figure 14). The general public will have access to broad indicators and general information on Arctic biodiversity data trends. National and sub-national governments as well as the Expert Networks will have the opportunity to customize the Portal for their own purposes (e.g. display only the geographic scope of relevance to them, etc.). Both governments and Expert Networks will have the option of choosing the data layers they are willing to have publicly available while having their own password-controlled domain to allow the inclusion of other data layers that they may not want to go public (e.g., unpublished data, data on threatened species) but that they would like to use for their own analyses.

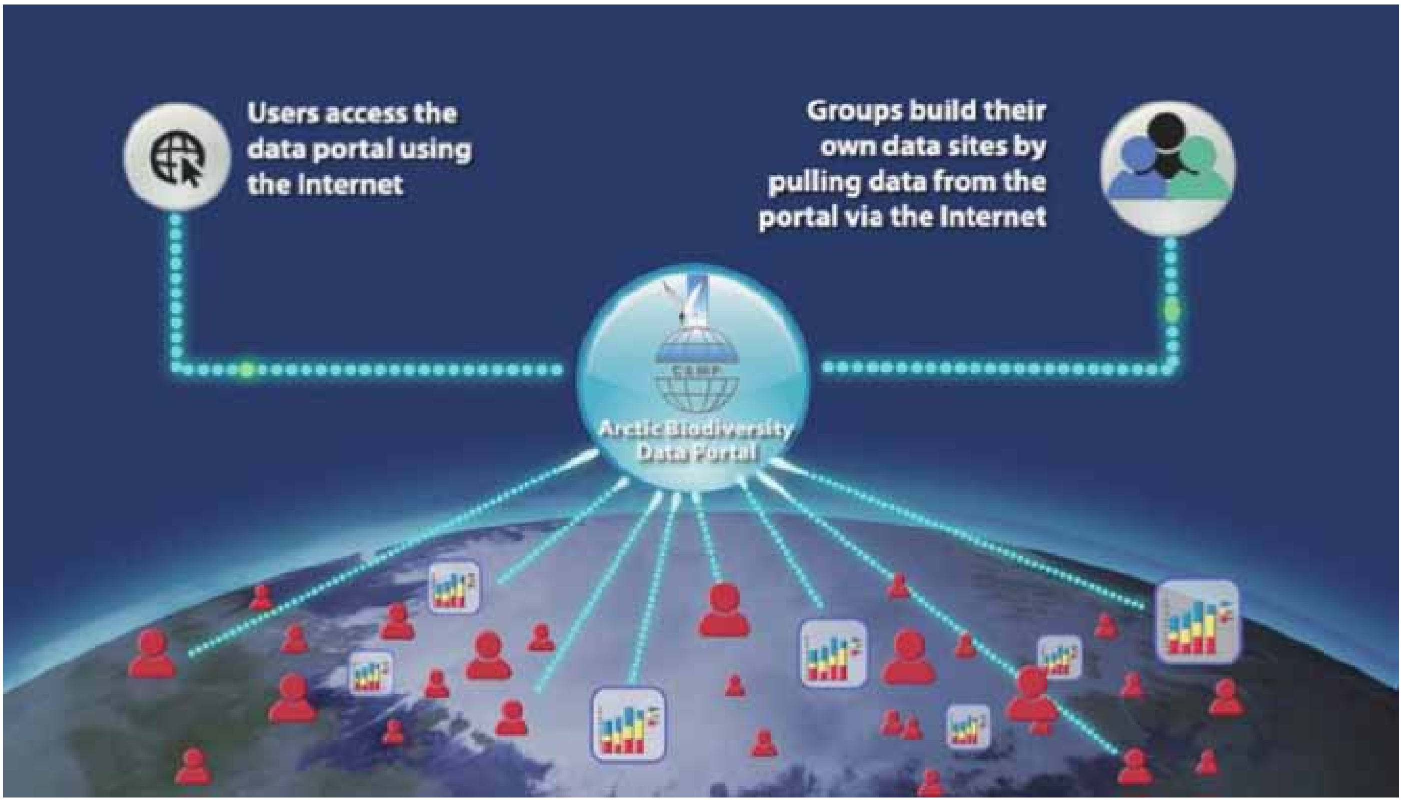

Figure 14 Illustration depicting the Data Portal concept and how clients can utilize the system to meet their specific needs.

This model of operation allows for user involvement at a variety of stages and can accommodate a large number of participants. The aim is to facilitate complete access to the collective knowledge, analysis, and presentation tools available from the many participants and stakeholders both within and outside the Arctic community.

Web-based portals provide a convenient common entry point that allows for a broad spectrum of users worldwide (scientists, decision-makers, and the public) controlled access to data outputs. The web-based portal will serve two purposes for the CBMP. First, it will provide access to geo-referenced information from within partner networks, as well as providing a common platform with multiple entry points for controlled data access, integration, harmonization, and delivery. Secondly, it will enable a wide range of user groups to explore trends, synthesize data, and produce reports with relative ease.

Development of this distributed system will necessitate the adoption and use of existing and widely accepted standards for data storage and query protocols, along with high-quality and standardized metadata and web servers (spatial and tabular). The metadata will be housed on an existing meta-database system (Polar Data Catalogue) allowing for simple and efficient access to a large and constantly updated, web-based, searchable, geo-referenced metadata system. The Arctic marine biodiversity monitoring programs identified as core to the implementation of the monitoring plan will be input into this meta-database.

The web-based data portal will generate indicators representing status and trend analyses, which in turn will be reported by the CBMP through a variety of means. These could include turnkey web-based reports and status and trends reports at multi-year intervals.

Geo-referencing will be critical to the successful integration of disparate datasets. Resolving the different spatial recording schemes used between the various data nodes and data holders—as well as the ranges of data volumes and bandwidth—will be key challenges to overcome. Techniques will be devised to convert data into a standard format for integration. These technical issues will be addressed during the implementation phase.

7.4 Data Storage

A decentralized data storage system is proposed for the CBMP web portal since it offers a solution to concerns over data ownership and copyright. Data policies such as the Conservation Commons and the IPY Data Policy address these issues in general terms. Decentralized approaches to data storage are already successfully applied in the Global Biological Information Facility (GBIF), Ornithological Information System (ORNIS), and other data networks worldwide. Although the data are decentralized, access to and depiction of the data is unified, allowing for multiple integrations for the user. Other compiled datasets may, with appropriate permissions, be archived also at the CAFF Secretariat. Options for mirrored archiving of data generated by the CBMP-Marine Plan will be considered such as working with existing data centers.

For all indicators developed under the CBMP, a database of the time series of reviewed and published indicators will be maintained via the data node hosts. All relevant metadata and the time-series data will be consistently available, along with information about the associated methodology, quality, and interpretation. The CBMP Meta-Data Archive will be linked to other clearing-house mechanisms for access and dissemination. Specific datasets will be contributed by partners to the monitoring plans as they are developed and published.

7.5 Data Policy

7.5.1 Ownership and Custodianship

A data node host may act as custodian for individual data collectors, holders and publishers, but this does not automatically confer any rights to those data. **The responsibility for and ownership of the data will always remain with the data collector, publisher and/or holder.** At all times, ownership of the data remains with the original collector, who bears responsibility for any changes or amendments to the data.

Data collectors could transfer their rights to a data archive, or maintain their rights and store their data with a data archive or any other data holder who uses their data. It is also possible to release data conditionally (e.g., based on requested input and acknowledgement). This flexible model embraces all options from free public data to strict data control and is a feature that will likely prove popular with web portal users and contributors.

7.5.2 Intellectual Property Rights

Unless requested otherwise, the data collector will be acknowledged as owner of the intellectual property of the data (or the representative of the organization that is the property owner). This model follows global policies such as Conservation Commons and the IPY Data Policy.

Conservation Commons

The Conservation Commons is characterized by an underlying set of principles that supports open access to and fair use of data and information related to the conservation of biodiversity. The purpose of the *Conservation Commons Principles* is to allow the distribution of and access to biodiversity data among the many databases housed by large organizations. The principles are as follows:

- Open access: The Conservation Commons promotes free and open access to data, information, and knowledge for all conservation purposes.
- Mutual benefit: The Conservation Commons welcomes and encourages participants both to use and to contribute data, information, and knowledge.
- Rights and responsibilities: Contributors to the Conservation Commons have the right to be acknowledged for any use of their data, information, and knowledge, as well as the right to ensure that the integrity of their contribution to the Commons is preserved. Users of the Conservation Commons are expected to comply, in good faith, with terms of use specified by contributors.

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International Polar Year Data Policy

The IPY Data Policy considers data a global resource and promotes free and open access to raw data online in order to stimulate academic progress. IPY's policy adheres to the most up-to-date scientific principles, with requirements for data to be documented with standardized metadata (e.g., Federal Geographic Data Committee (FGDC) and National Biological Information Infrastructure (NBII)). Online posting of well-documented and interpreted versions of the data is also encouraged. The purpose of this policy is to encourage the widest possible exchange of relevant data. This policy is endorsed by the funding agencies of polar nations and viewed as a template by many other countries.

7.5.3 Data Sharing and Access

The data collected by the CBMP will be available continually at a fixed entry point operated by CAFF on the Internet. This point could be mirrored at a data collector/holder's site, at the Web portal site of a data host, or both (e.g., by linking to both websites). The web portal will allow for organized and restricted access to data where necessary.

CAFF's CBMP encourages data providers to comply with the Conservation Commons and IPY Data Policy on the delivery of free biodiversity data to the public. Compliance with accepted data policies and provision of data to the CBMP Data Portal system will result in password access being provided to the data layers found on the Data Portal. This incentive-driven approach should encourage scientists and others to contribute their data to the Portal as it will result in their access to other data layers relevant to them. Arctic Council countries are also encouraged to make their publicly funded datasets available for use in the CBMP Data Portal system.

A condition of project funding or support through CAFF/CBMP should be the guaranteed availability of any resulting data for use by the CBMP. Additional uses are encouraged and should also be specified. This should provide maximum opportunity for synergies that inevitably follow the presentation and availability of new data.

7.5.4 Data Release Code

All CBMP participants will agree to their data being utilized, within specified terms, in broader analyses and collections by identified users within CAFF and the CBMP. All products, including value-added products (e.g., GIS layers, reports, analyses) identified and released under the management of CAFF and the CBMP, will have appropriate acknowledgement secured. This can be achieved by registration of the data user and through a request to sign or agree with basic conditions of use. These protocols should not pose a constraint to free data release to the public.

The CBMP will create a safe and reliable data network, making high-quality digital data available to global users online. Restricted data would be flagged accordingly (e.g., in the metadata) and only released for specific usage or by specific users with password access. The technical set-up implemented will allow achievement of this goal and protection to the data holder. Data collectors, holders, and providers will have full freedom to specify the level of detail that they wish to make available.

7.5.5 Data Use Restrictions

Ultimately, the CBMP wants to optimize the flow of information pertaining to Arctic biodiversity. While the CBMP will strive to provide unrestricted access to data, there are some exceptions that should be considered and accommodated in order to maximize the utilization of data. For example, unpublished data may require either temporary restrictions and/or partial access (i.e., only advanced analytical results available instead of raw data) in order for the data collector/holder to retain publishing rights. As well, data on some endangered or threatened species may require certain levels of protection to prevent destruction of and/or disturbance to these populations.

The IPY Data Policy prescribes a six-month delay before information is released to the public. Depending on the project and publication circumstances, the CBMP suggests a delay of two to four years, according to data type and project history. Funding agencies in several countries already have a two-year data release policy in place. Details will depend on specific situations, but overall the CBMP will strive for timely release of data in order to promote scientific progress and discovery.

Following is a list of access classifications:

- Unrestricted access: freely available to all participants to incorporate within any product and project.
- Permission-based access: Specific acknowledgements/permission statements must be incorporated within the product. The data management structure will account for these restrictions by creating a process for obtaining permissions to use the data. The system will be efficient and simple to navigate. This will be achieved by using metadata to point to data and describe them, and then by controlled access to actual download of these data once the data user agrees with terms of use.
- Password- restricted access: Access to the data set is restricted to those participants who have been given specific access via a password/key. This can be important for raw data management within a network.
- Copyright restrictions: Available for use only by the data collector/holder. This class is likely to apply to dynamic datasets in a state of flux and receiving constant updates. Even with this level of restriction, there might still be opportunities for the data to contribute generic analyses. An example would be the use of simple data summaries to determine if populations are stable, increasing, or decreasing. The copyright issue needs to be clearly identified. (A pilot project is currently underway to test operability for restricted access of generic seabird data).

- Publication delay: These data are being published by the data collector and owner and will be released, ideally, within a six-month period. In some cases, the release could be delayed for up to four years. The exact release date will be specified and negotiated with the provider.

- Protection of endangered species, human rights, and/or national security: These data are not released because release would threaten an endangered species, violate human rights, or pose a risk to national security. Examples include personalized interview information and sensitive human DNA data. Unless the pertinent threat is resolved or clarified, these data will either be unavailable or available only in a coarse or delayed fashion.

7.5.6 Acknowledgements

The database structure and the web-based portal will ensure that the source of every single data set is properly acknowledged. Full acknowledgement requires that each data set carry a unique name and reference. The reference can take any number of forms: publications, organizations' databases, libraries, data archives with multiple entry providers, networks, etc. The precise wording of the acknowledgement will be provided by the data holder/collector, and it is the responsibility of the data provider to ensure the originality of the source.

7.6 Data and Metadata Standards

In order for the various networks involved in implementing the CBMP-Marine Plan to collaborate, input, and share data and metadata, common data and metadata standards need to be chosen.

CAFF's CBMP has chosen the FGDC standard to ensure compatibility with the Global Earth Observation System of Systems (GEOSS) program, along with many other global and regional programs that have adopted this standard (e.g., Ocean Biogeographic information system, Global Change Master Directory, Global biodiversity Information Facility). The FGDC standard is widely embraced by IPY and can be stored and linked with all relevant biodiversity and other data sources. Freely available software allows users to apply these metadata conveniently and post them online with the clearinghouses (e.g., Polar Data Catalogue). Because data that lack metadata can be virtually unusable, both are crucial requirements and thus requested by funding agencies and the data initiatives cited here.

Photo by:Lawrence Hislop. http://www.grida.no/photolib

8. Data, Samples, and Information Analysis

This chapter describes one of the central elements of the CBMP-Marine Plan: the analysis of data, samples, and information to support biodiversity monitoring. Chapters 7 and 10 describe the organizational structures needed for managing the analysis. It is important to recognize that this monitoring plan is built on the premise of adding value to different types of data collected for various, and often different, purposes. The quality and usefulness of the data will vary among, and within, AMAs. While it will be possible to draw conclusions for certain AMAs rich in appropriate, quality data, this will not be true for many of them. Some data are being collected by formal, long-established monitoring programs designed explicitly to establish baselines and to detect and explain changes and trends. Other data will derive from short-term datasets established for research or other purposes, not for monitoring.

To address some of the unevenness among datasets, and to maximize the potential for using different types of data for monitoring purposes, the intention is to use data from locations (transects and stations) that have at least five years of past data and a reasonable likelihood of continued data monitoring for several years into the future. Note that the datasets do not necessarily have to be continuous to provide useful monitoring information (e.g., historical data from past decades might prove useful, even if temporal gaps exist between historic and current data).

The strongest conclusions about changes to arctic marine biodiversity are likely to be obtained for those AMAs that have long datasets obtained for true monitoring purposes. Datasets containing less than five years of data, obtained for non-monitoring purposes, and/or without certainty of continuing may also be able to contribute valuable insights to the monitoring program. Many such datasets are available. Indeed, for some AMAs, these types of data are in the majority.

8.1 Basis for Analysis

8.1.1 Start-Up Phase

The 2011-2015 period (start-up phase) will be the first effort to develop and implement the CBMP-Marine Plan and will establish the foundation for monitoring during subsequent years. After the start-up phase, the plan will be evaluated and adjusted as required, based on the successes and knowledge acquired about Arctic marine biodiversity.

Since a main objective is to monitor changes to Arctic marine biodiversity, the start-up phase will focus on two aspects: establishing baselines utilizing existing datasets, and determining changes that are occurring geographically and over time. This work will be led by the Expert Networks established by the CBMP Marine Steering Group (Chapter 10).

Establishing baselines for each Focal Ecosystem Component in each Arctic Marine Area

To establish baselines, it will be necessary to conduct retrospective analyses of historical data, including proxy data. These data exist in past journal articles, in databases, and in notebooks. There is also a wealth of biodiversity data in national collections of museums with a strong focus on Arctic regions (e.g., Canada, UK, USA, etc). It will be necessary to locate and evaluate some data (including QA/QC), and convert them into a form compatible with recent data (e.g., digitizing).

Most monitoring programs conduct a review process to establish the necessary baselines for their programs. Once established, the Marine Expert Networks will aggregate existing pan-Arctic datasets in order to establish baselines. As well, the Arctic Biodiversity Assessment, with its full scientific report expected in 2013, should be able to contribute some relevant baseline information. Several disciplines have their own specialist groups (e.g., CBird), and they should also be able to provide baseline information for their respective FECs in each AMA. The Expert Networks described in Chapter 10 will be responsible for establishing the baselines and will draw from the marine sections of the Arctic Biodiversity Assessment to facilitate this work.

The baselines will need to have seasonal and short-term signals removed in order to be meaningful and objective. This will not be easy, given that our understanding of such seasonality and short-term variability will be limited for many parameters and geographic locations. Further, the timeframe covered by the baselines may not be the same for all species in a single AMA or even for a single species or community in different AMAs.

The geographical and temporal representativeness of data will also need to be assessed, especially if the data used to create baselines are not co-located geographically or collected during the same year, season, or even day. Can nearby data points within the same AMA be used in the same way as co-located data points, or are they essentially uncorrelated? Can data collected during the summer be compared with data collected in the fall, or is seasonality important? Caution will need to be exercised before calculating each baseline, interpreting its meaning, or drawing conclusions about geographical differences and temporal changes.

Locating and using historical data – particularly that which is not yet in digital form – will require significant resources. Further, some issues (e.g., taxonomic resolution and accuracy for fish and lower trophic organisms) are far from being resolved and will not be addressed through this plan. Disparities or uncertainties will need to be recognized. Priority, therefore, will be given to datasets amenable to aggregation and analysis.

In addition to historical scientific data, Indigenous and community knowledge will be important during this phase, as these knowledge types often extend further back in time than other kinds of Arctic science. They provide continuity over long periods in the same regions, as well as details and other information complementary to the scientific method. To integrate these kinds of knowledge, partnering will be necessary between scientists and communities. This will be done via the Expert Networks, which will include, where relevant, expertise from both scientists and local experts. Care will be taken to receive authorizations from relevant communities regarding the release of any data held by the community or pertaining to the community into the public domain.

Museum and other collections will also be important. Many collections of Arctic marine biodiversity (e.g., various marine species) have yet to be analyzed, but provide insight into Arctic marine biodiversity from decades and centuries ago.

The results of this aspect of the start-up phase will be baseline information about each FEC, as determined by calculating the chosen indicators (e.g., abundance, distribution, various diversity indices, etc., as described in Chapter 5 and defined below in 8.2). For some indicators, baselines will be derived from several decades ago, before the recent period of rapid climate change. These baselines may, therefore, prove to be particularly useful for future work to detect links between changes to biodiversity and human activities.

Comparing current data and information with the historical baselines

Once the baseline conditions have been established, the focus will switch to using current data and information resulting from the coordinated monitoring to determine what changes (if any) have since occurred to the FECs, again based on the chosen indicators[*]. After producing baseline information, the Expert Networks will be responsible for comparing more recent data with the baselines, drawing on information in recent assessments, published papers, and datasets to produce the first trend diagrams and matrices.

It remains to be seen whether changes can be determined for all FECs. It will depend on the amount, quality, and compatibility of the data used to construct the baselines, variability in the FECs, and the nature of recently collected data. Will it be possible to legitimately conduct the "value-added" analysis to document trends confidently, given that it is as yet unknown whether the original data (sampling design, execution, etc.) may permit such analysis? There is a risk of committing a Type I or Type II statistical error (i.e., rejecting a true null hypothesis vs accepting a false null hypothesis). It may not be possible to calculate temporal and spatial changes for all indicators or in all AMAs. How much can be accomplished will become clearer as each Expert Network's work progresses. Adjustments at the end of the start-up phase will be made accordingly.

As part of the program review, the data collected will be used to estimate the variability of each indicator. A power analysis will determine whether the data collections are robust enough to detect change in a reasonable time frame. Where the data collections are lacking, and where feasible, the sampling approach (Chapter 6) will be revised.

8.1.2 Subsequent phases

By 2015, the monitoring plan should be well-established and will have undergone its first program evaluation. After the start-up phase, the focus will shift to incorporating the other important objective of the CBMP-Marine Plan: i.e., establishing what links, if any, exist between changes to Arctic marine biodiversity and human activities. This phase will continue, with analyses that use new data, samples, and information, as they are collected, and that draw linkages between the observed/derived changes and anthropogenic stressors.

To determine what links exist between changes in Arctic marine biodiversity and human activities, it will be necessary to work together with other programs. Our effort will be focused on biodiversity monitoring, and other programs will be approached to provide information on human stressors. One such program could be the Arctic Council Arctic Monitoring and Assessment Programme (AMAP), which produces information on climate change, pollution, and contaminants. Another could be the Sustainable Development Working Group (SDWG) of the Arctic Council, which is developing a suite of indicators on human activities, some of which may be relevant for this program.

* Given the variability in the historical record for different FECs in different AMAs, the baselines may not cover exactly the same timeframe. Comparisons will need to recognize this and best efforts made to making the different data sets comparable.

The outputs of this monitoring effort should contribute to Arctic peoples' efforts to adapt to climate change impacts. In particular, information on changes in the availability and/or quality of subsistence foods may be useful for predicting future changes, and the predictions, in turn, could be used to inform adaptation efforts. For example, remote Indigenous communities that have traditionally harvested ice-associated pinnipeds may need, in future, to develop different harvesting techniques or shift to relying on other sources of protein.

8.2 Analysis Approach

The CBMP-Marine Plan will use scientific data, samples, and local and traditional knowledge to detect temporal and spatial changes to Arctic marine biodiversity. In addition, the plan will test hypotheses that link these changes with human activities.

Data and information will be converted into meaningful information using a variety of analysis methodologies:

- biodiversity indicators—aggregated data on species, other indicators important for biodiversity, proxy measurements.
- techniques to analyze archived samples (e.g., researcher and museum collections).
- techniques for including Indigenous and community knowledge.
- conceptual models of the Arctic marine ecosystem that demonstrate linkages between the physical, chemical, and biological systems in the Arctic marine environment, and between human activities and Arctic marine biodiversity FECs.
- scientific hypotheses about the potential impact of human stressor(s) on Arctic marine biodiversity.
- statistical techniques to determine temporal and spatial differences in biodiversity indicators, including the statistical significance of such differences; spatial and temporal representativeness; confidence levels and uncertainty.
- empirical and other models.
- quality assurance and quality control (QA/QC).

An important objective of this Plan is to detect links that may exist between temporal and spatial changes in Arctic marine biodiversity and human activities. It will be important to test scientific hypotheses about these links. Preliminary hypotheses have already been developed. These will be reviewed and refined further, and others developed, to ensure that the most important potential linkages are captured in this part of the analysis.

8.2.1 Indicators of change: tracking status and trends in Arctic marine ecosystems

*Chapter 5 describes the species and communities covered by this monitoring plan and, in particular, the parameters and indicators that will be used to establish baselines and detect change. The tables below provide an overview of the selected parameters and indicators.

The monitoring plan currently identifies a number of potential indicators that can be used to report on the status of various elements of Arctic marine biodiversity. As part of the start-up phase, the Marine Expert Networks, together with the Steering Group, will identify a priority sub-set of indicators that are believed to be the best proxies for indicating the state, quality, and degree of change of Arctic marine ecosystems and the biodiversity they support. The effectiveness of these indicators will be verified during the start-up phase, and adjustments to the set of indicators will be made, as necessary.

For the parameters selected, the sampling scheme and frequency will be further refined during the start-up phase, based on greater understanding of the variability of the parameters. The goal is to ensure that the CBMP-Marine Plan is optimal and well-coordinated with the monitoring programs it's based on.

*NOTE: THIS SECTION WILL BE MODIFIED TO MATCH 5.1 AND 5.2 AS PRIORITY INDICATORS IN 5.1 AND 5.2 ARE IDENTIFIED.

Key Parameters	**Definition**
Abundance	The number of a individuals of a species that are present in a specified area(Coweeta LTER Glossary of Terms 2011) or volume.
Biomass	The total mass of living matter present in a specified area at a given time (Pinto, 2011)
Chlorophyll biomass	Total mass of chlorophyll found in a specified area3. This is an index of plant biomass.
Fauna size structure	An organization of the species present in specified area into groups according to their size.
Key species definition	Species that are pivotal to a community in that they maintain the structure/stability of the community. If the species is lost, then a large part of the existing community is lost with them. They can be very useful indicator species if they are recognized easily.(Petchey & Belgrano, 2010)
Productivity	A measure of production within a specific species, group or trophic level: e.g., primary production is the rate of production of organic compounds/production of oxygen/ utilization of carbon dioxide per unit time(*)
Reproduction	The number or relative production of fertile offspring produced by an individual (Pinto, 2011)
Species composition	The number of different species that are found in a specified area(Coweeta LTER Glossary of Terms 2011)
Stages	Developmental stage of individual zooplankton in a zooplankton sample. Developmental life stage of individual animals, especially for crustaceans where the number and character of stages may be highly defined.
Indicators	**Definition**
Biomass indicators (e.g., Chl *a*)	Various indicators that provide the total mass of living matter present in a specified area at a given time (Pinto, 2011). With respect to Chl *a,* it is the total mass of chlorophyll found in a specified area(*). This is an index of plant biomass.
Distribution of Arctic vs. sub-Arctic species	The spatial arrangements (geographic locations) of Arctic and sub-Arctic species associated with sea ice.
Diversity indices (e.g., Shannon, Simpson)	Give indication of the number and variety of species present in an area/within a community.6 The Shannon index provides information about the evenness of the populations of various species and reaches a maximum when all species are equally abundant. The Simpson index measures the probability that two individuals randomly selected from a sample will be from the same species (Vongraven, 2009)
Partitioning sea ice vs. zooplankton biomass and productivity	Biomass and productivity of sea-ice biota compared to that of zooplankton in the same geographical location.
Ratio Arctic:sub-Arctic species	A ratio that gives an indication of the number and variety of Arctic vs. non-Arctic species that are present in an area/within a community(Petchey & Belgrano, 2010)
Ratio diatoms:dinoflagellates	A ratio that gives an indication of the number and variety of diatoms vs. dinoflagellates that are present in an area/within a community(Petchey & Belgrano, 2010)
Ratio freshwater:marine algae	A ratio that gives an indication of the number and variety of freshwater vs. marine algae species that are present in an area/within a community(Petchey & Belgrano, 2010)
Sea ice vs. phytoplankton biomass and productivity	Biomass and productivity of sea-ice biota compared to that of phytoplankton in the same geographical location.
Size structure of ice algae and phytoplankton communities	An organization of the species, found in ice algae and phytoplankton communities, that are present in a specified area into groups according to their size.
Species invasion:expatriates	Detection of the presence of expatriate (non-indigenous) species or communities.
Under ice abundance of two cods (*Boreogadus saida* and *Arctogadus borealis*).	The relative representation of the two cods occurring in a specific location

* Given the variability in the historical record for different FECs in different AMAs, the baselines may not cover exactly the same timeframe. Comparisons will need to recognize this and best efforts made to making the different data sets comparable.

Plankton

Key Parameters	**Definition**
Abundance	The relative representation of organisms belonging to the same species that occur in a specific location.
Biomass	The total mass of plankton in a given area(Martin, 1993)
Chlorophyll *a* concentrations (ideally size fractionated)	Concentration of chlorophyll *a* molecules present in a specified quantity of ocean/ saltwater, often separated based on the size of the cells containing them
Genomics/barcoding	The study of the genome of an organism. A short genetic marker (mitochondrial DNA) is used to identify the organism as a particular species. Often Cytochrome Oxidase (CO1) is the gene targeted.(Biology Online, 2011)
Primary production	The production of organic compounds from atmospheric/aquatic carbon dioxide primarily through photosynthesis. Four different methods can measure aquatic primary production: 1) variations in oxygen concentration in a sealed bottle 2) incorporation of inorganic carbon-14 into organic matter 3) using stable isotopes of oxygen 4) fluorescence kinetics Primary production can be calculated if the extinction coefficient, the amount of solar radiation, and the amount of chlorophyll in the aquatic plants is known. Virtually all primary production occurs in the euphotic zone. Nitrogen and iron often limit primary production in the oceans.(Coweeta LTER Glossary of Terms 2011), (Palmer, 2011)
Size Structure (microbes)	An organization of microbes that are present in a specified area into groups according to their size.
Species Composition	The number of different species that are found in a specified area(Southern California Coastal marine Fish Contaminants Survey, 2002-2004) or volume.
Indicators	**Definition**
Community/group abundance	The number of plankton communities that are present in a specified area(Coweeta LTER Glossary of Terms 2011) or volume.
Community/group biomass	Total mass of living matter in a prescribed area or habitat/total mass of living matter of a specific group or communities of plankton(Coweeta LTER Glossary of Terms 2011)
Diversity indices	Various ratios that give indication of the number and variety of species present in an area/ within a community(Jones, 2008)
Metagenomics	The genomic analysis of micro-organisms through direct extraction and cloning of DNA from an assemblage of micro-organisms(Perrin, Würsig and Thewissen, 2009)
Productivity	A measure of production within a specific species, group, or trophic level: e.g., primary production is the rate of production of organic compounds/production of oxygen/ utilization of carbon dioxide per unit time(Coweeta LTER Glossary of Terms 2011)
Ratio local:invasive	A ratio that gives an indication of the number and variety of local (indigenous) plankton vs. invasive organisms that are present in an area/within a community.(Petchey & Belgrano, 2010)
Ratio small:large	A ratio that gives an indication of the number and variety of small vs. large plankton organisms present in an area/within a community(Petchey & Belgrano, 2010)
Size spectra	The relationship between abundance and size of individual planktonic organisms (Vongraven 2009).
Stage distribution	Relative proportions of plankton organisms at various development stages.

Benthos

Key Parameters	Definition
Abundance	The number of individual benthos of the same species found in a particular ecosystem/ specified area(Science-Dictionary.com, 2011).
Biomass	Total mass of living benthos in a given area at a given time(MedicineNet.com, 2011).
Species composition	The number of different species found in a specific area(Phenology, 2011).
Indicators	**Definition**
Abundance	The number of individual benthos of the same species found in a particular ecosystem/ specified area(Science-Dictionary.com, 2011).
Biomass	Total mass of living benthos in a given area at a given time(MedicineNet.com, 2011).
Community composition	The number of different species found in a specific community.
Community structure	Is a combination of both the number of different types of species and the number of individuals of a species that are present in a specified area as well as the interaction between different species and the interaction between different individuals of the same species
Distribution	The spatial arrangement (geographic location) of benthic organisms
Diversity indices (e.g., Shannon, Simpson)	Give indication of the number and variety of species present in an area/within a community. 6 The Shannon index provides information about the evenness of the populations of various species and reaches a maximum when all species are equally abundant. The Simpson index measures the probability that two individuals randomly selected from a sample will be from the same species.(Coweeta LTER Glossary of Terms 2011).
Size-frequency distribution	The relationship between abundance and size of individual benthic organisms(Pinto, 2011).

Fish

Key Parameters	Definition
Abundance: catch by gear type	The number of individual fish that are all the same species that are found in harvests, organized by harvesting gear type (Phenology, 2011)
Age/size distribution	Classifying individual fish into groups based on their size and age to see the total number that fit in each classification
Barcoding, other genomics	The study of the genome of an organism. A short genetic marker (mitochondrial DNA) is used to identify the organism as a particular species. Often Cytochrome Oxidase (CO1) is the gene targeted.(Biology Online, 2011)
Biomass	Total mass of living fish in a specified area at a given time(Perrin, Würsig and Thewissen, 2009)
Condition	Condition of individuals informs on general state of well-being, whereas average condition for a population reflects the general living conditions (e.g., food availability) and other factors affecting well-being of the population.
Distribution (geographic)	The spatial arrangement (geographic location) of a species of fish
Fish length	The total length of the fish from the most anterior part of the fish to the tip of the longest caudal fin ray (Petchey & Belgrano, 2010).
Geographic coordinates and depth	Specific spatial location (e.g., latitude, longitude coordinates) and depth where organism(s) was harvested or collected.
Life history/phenology/genetic structure	Various reproduction-related variables, including age at first reproductive cycle, number of eggs produced/reproductive cycle, frequency of reproduction/time frame for any seasonal biological phenomena/patterns in the genetics of a population
Number of each species	The number of individual fish that are all the same species.
Preservation of voucher specimens	"Voucher specimens ensure that the identity of organisms studied in the field or in laboratory experiments can be verified, and ensure that new species concepts can be applied to past research."(Pinto, 2011)
Relative abundance: species caught and effort by gear type	The abundance of a fish species (by any measure), divided by the total abundance of all species combined, caught in harvests, organized by harvesting gear type (Phenology, 2011). Effort is the amount of activity directed to fishing (e.g., gear type and characteristics, quotas per licence, number of hours spent, number of vessels, etc.).(Petchey & Belgrano,2010) (Southern California Coastal marine Fish Contaminants Survey, 2002-2004)
Species caught	A list of species caught during fish collection.

Temperature, salinity, substrate	Water temperature and salinity measurements collected during fishing. Substrate characterization at the location of fishing.
Indicators	**Definition**
Community structure	Is a combination of both the number of different types of species and the number of individuals of a species that are present in a specified area as well as the interaction between different species and the interaction between different individuals of the same species
Disease incidence	Rate of occurrence of the physiological state of disease
Diversity indices	Give an indication of the number and variety of species present in an area/within a community
Geographic and bathymetric distribution of species	The spatial arrangement of fish species according to geographic location (e.g., latitude, longitude coordinates) and water depth.
Geographic distribution and range shifts	Changes to the spatial arrangement of fish species according to geographic location, and to the ranges of specific fish species.
Life history shifts	Changes to the pattern and/or timing of key life history events – e.g., frequency of changes from anadromy to non-anadromy within populations (may indicate shifts in productivity)
Habitat variable associations	Associations calculated (e.g., via regression, or other measure) between fish species and various variables characterizing habitats.
Primary documentation for species identification and distribution	Documentation for the preservation of voucher specimens.
Relative abundance	The abundance of a fish species (by any measure), divided by the total abundance of all species combined.(Martin, 1993)
Size ranges	The range of sizes of benthic and demersal fish.
Size/age-frequency distribution	Determining how often individual fish of different sizes/ages occur in a population
Species composition	The number of different species found in a specific area(Science-Dictionary.com, 2011).
Species identification	Identification of a particular organism as being a specific species.
Taxonomic resolution	The taxonomic scale (e.g., genus – lower resolution; species – higher resolution) of a biotic assemblage dataset influences our ability to detect ecological patterns, and affects bioassessment outcomes (Palmer, 2011).

Marine Mammals

Key Parameters	**Definition**
Abundance	The number of individual of the same species that are found in a particular ecosystem/ specified area (Phenology, 2011).
Body condition	Physiological state of the mammal with reference to stomach contents, condition of major organs, fat and blubber content, isotopic and fatty acid signatures, etc.
Contaminants	"An impurity; any material of an extraneous nature associated with a chemical, a pharmaceutical preparation, a physiologic principle, or an infectious agent. A substance that contaminates. A foreign species of a given environment where the species is not in its natural habitat, and therefore foreign to the new environment".(Fisheries and Oceans Canada, 2011)
Distribution	The spatial arrangement (geographic location) of a species of mammal(Phenology, 2011)
Habitat selection	Factors that influence the choice of physical or ecological environment to inhabit
Harvest statistics	Number of individuals purposely killed by subsistence hunters
Stock identity	Genetic discreteness of populations of a given species.
Stock structure (genetics/ telemetry)	Distinct groupings of marine mammals – biological stocks – that have no or low levels of genetic exchange, using genetic and/or telemetry techniques (Palmer, 2011).
Indicators	**Definition**
Blubber quality/quantity	The amount and quality/condition of blubber of a marine mammal. Blubber is the thick layer of fat which lies under the skin of marine animals.(Jones, 2008)

Contaminant loads	Levels/amounts of one or more contaminants found in the environment including in wildlife such as marine mammals.
Disease prevalence	Prevalence refers to the number of cases of a disease that are present in a particular marine mammal population (or stock) at a given time.(Biology Online, 2011)
Habitats supporting life functions (sea ice, coastline)	Habitats that have features (ecological, environmental, etc.) that fulfill natural history requirements of the mammal. If these features were lost, then the mammal would no longer be found in that location.
Harvest rates and demographics	The proportion of the total population (e.g., of a species, stock, or other unit) expected to be captured over a certain time period. Demographics refers to the population characteristics (structure, birth and death rates, etc.) of a species or stock.
Important/key feeding areas (hotspots)	Areas important to marine mammals for foraging and feeding.
Migration corridors	Areas used by marine mammals during migration (e.g., from summering to wintering areas).
Number per square km	Abundance by square kilometre
Over-wintering areas (MIZ, polynyas)	Areas important to marine mammals for fulfilling life's functions during the winter.
Overall condition	Overall condition can be determined from assessing several factors, e.g., blubber levels, energy state, general health status.
Seasonal distribution	The spatial arrangement (geographic location) of a species of mammal during different times of the year (Phenology, 2011).

Seabirds

Key Parameters	**Definition**
Chick diet	Food items provided to growing chicks by their parents (e.g. species composition)
Colony size	Number of individuals or breeding pairs in an given area or colony (breeding populations are usually estimated)
Harvest statistics	Quantitative data about the number and characteristics of harvested seabirds.
Phenology	Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate.(Phenology, 2011)
Reproductive success	Reproductive success is defined as the passing of genes onto the next generation in a way that they too can pass those genes on (Reproductive success, 2009).
Survivorship	Levels of survival (e.g., over a season or annually); often calculated separately for adults and chicks.
Indicators	**Definition**
Abundance	The number of individual of the same species that are found in a particular ecosystem/ specified area (Phenology, 2011).
Adult and chick survival rates	Proportion of adult breeding individuals (or chicks) that survive from one breeding season to the next.
Colony arrival dates	The date of arrival of a colony to a particular location (e.g., breeding location).
Diet	Food ingested by seabird individuals.
Harvest rates and demographics	The proportion of the total population (e.g., of a species, stock, or other unit) captured over a certain time period. Demographics refers to the population characteristics (structure, birth and death rates, etc.) of a species or colony.
Number of active nests	Nests used for breeding, laying and raising chicks.
Productivity	Number of chicks raised to independence/fledging by a breeding pair during one breeding season


Photo by: Greenland Climate Research Center

9. Reporting

This chapter describes the reporting requirements associated with the CBMP-Marine Plan. The anticipated schedule for reporting is presented in Chapter 10. Several levels and reporting formats will be required to address the needs of different audiences. Some reports will focus on the scientific results of the plan, while others will focus on implementation or review. The reporting outputs from this CBMP-Marine Plan will include regular assessments, using the 2013 Arctic Biodiversity Assessment as a baseline and an ecosystem-based approach will be employed, drawing from the data generated by the various disciplines within this Plan.

9.1 Audiences

Regular reporting to the Arctic Council will be required, as well as to managers and decision-makers at national and sub-national levels (e.g., by Arctic Marine Area, regional councils, national and regional governments), other international organizations (e.g., Sustaining Arctic Observing Networks, Group on Earth Observations), local community residents in each AMA, the scientific community (e.g., through peer-reviewed scientific publications), and to our partners and collaborators. Reports and/or communications material will also be needed for public audiences, such as non-government organizations and the interested public.

9.2 Types of Reporting

Different reporting formats are anticipated, depending on the audience. Table 9.1 below summarizes reporting formats according to audience. Table 9.2 provides anticipated timelines for producing these reports. Several reports will be useful to several audiences. The results reported will depend, ultimately, on the focus of the start-up and subsequent phases of the CBMP-Marine Plan.

Photo by: Michel Poulin. Canadian Museum of Nature

Type of Report / Primary Target Audience	State of Arctic Marine Biodiversity Report, including AMA status reports	Status of indicators	Independent review of parameters, sampling approaches, data management approach, analysis and reporting	Scientific publications (by discipline, by AMA and across the Arctic)	Scientific publications (multidisciplinary, by AMA and across the Arctic)	Performance reports and work plans	Various summaries and other communications material
Arctic Council	v	v	v			v	
National and Regional Governments	v	v				v	v
Local Communities	v	v					v
Science Community				v	v		
Other International Organizations	v	v					v
Partners and Collaborators	v	v	v	v	v		v
NGOs and the public	v	v					v

Table 9.1 Types of reporting by audience

Type of Reporting	Timing/Frequency
State of Arctic Marine Biodiversity Report, including AMA status reports	Every 5 years, starting in 2015
Status of indicators	Bi-annually, starting in 2012
Independent review of parameters, sampling approaches, data management approach, analysis and reporting	Every 5 years, starting in 2015
Scientific publications (by discipline)	Ongoing, starting in 2013
Scientific papers (multidisciplinary, by AMA and across the Arctic)	Ongoing, starting in 2013
Performance reports and workplans	Annually, starting in 2012
Various summaries and other communications material	Ongoing, starting in 2013

Table 9.2 Anticipated timelines for reporting.

9.3 Reporting Results

9.3.1 State of Arctic Marine Biodiversity Report

The first State of Arctic Marine Biodiversity Report is targeted for production in 2015, five years after the release of the Arctic Biodiversity Assessment full scientific report. It will describe:

1. The baseline conditions for FECs and spatial comparisons, where possible, within and among the different AMAs;
2. Temporal changes that have occurred since the baseline periods, in addition to historical trends, where data permits; and,
3. Differences that have occurred spatially within and between AMAs.

The results (e.g., trends, spatial differences, and changes in variability) will be described and interpreted, to the extent possible, both statistically and from a biophysical perspective. Emphasis will be placed on the implications of these changes for the Arctic marine ecosystem, as well as upstream and downstream within sub-Arctic regions. It will be important to discuss the statistical significance, spatial representativeness, and confidence levels of the results.

Subsequent reports are planned every five years, and will include an analysis of how changes in biodiversity may be linked to human stressor activities.

9.3.2 Status of indicators

The biodiversity indicators used to illustrate the status and trends in biodiversity (see Chapter 5) will be updated bi-annually and published on the CBMP's Data Portal (see Chapter 7). This will allow site users to see changes in biodiversity between State of Arctic Marine Biodiversity reports or scientific publications.

9.3.3 Independent review

After the first five years —the start-up phase— a review will be conducted of the parameters, indicators, sampling, data management, and analysis and reporting used in the CBMP-Marine Plan. The CBMP-Marine Plan will be adjusted and updated on the basis of this review and in response to the results obtained about Arctic marine biodiversity during the first five years.

9.3.4 Scientific publications

It is anticipated that several types of scientific publications will be produced. Scientific articles will be published by discipline (as is traditional), as well as along multidisciplinary lines. For the purposes of the CBMP-Marine Plan, the intention is for these publications to address the baseline status and changes to Arctic marine biodiversity in each AMA, as well as across the Arctic. The multidisciplinary publications, especially, are expected to provide insights into changes occurring in the broader ecosystem, factors driving these changes, as well as linkages between changes to biodiversity at different trophic levels.

9.3.5 Performance reports and work plans

A requirement of the program, once implementation begins, will be to develop and submit annual performance reports and work plans to the Arctic Council for approval. CAFF will deliver these reports and workplans to the Senior Arctic Officials on an annual basis. The performance reports will describe progress in implementing and managing the plan, while the work plans will outline work anticipated for the following year, along with deliverables, budget, etc.

9.3.6 Various summaries and other communications material

A variety of other reporting materials will be developed for non-specialist and non-technical audiences, especially community residents, other northerners, and organizations interested in Arctic marine biodiversity. The CBMP will also use its existing communications network and media (e.g., newsletter, media releases, websites, etc.) to provide regular information on progress and results to these audiences.

Photo by: Greenland Climate Research Center

10. Administration and Implementation of the Monitoring Program

The implementation of this monitoring plan will involve a number of jurisdictions (national, sub-national, and local) across the Arctic, which are already engaged in Arctic marine biodiversity monitoring. While there is a diversity of jurisdictions involved, monitoring capacity is limited and opportunities for new monitoring efforts or establishing new circumpolar expert groups are very limited. The challenge for the Circumpolar Biodiversity Monitoring Program is to develop a simple and cost-effective structure that ensures effective implementation, ongoing data integration, analysis and assessment, and regular review of the monitoring plan, while continually engaging the multiple jurisdictions responsible for Arctic marine biodiversity monitoring. It is also important that the implementation structure is consistent with the CBMP's network-of-networks (ecosystem-based) approach and that it is aligned, as much as possible, with national and other reporting needs.

10.1 Governing Structure

The governing structure for implementation of the monitoring program involves the following entities (Figure 15): the CAFF Secretariat, the CBMP office, a CBMP Marine Steering Group (CBMP-MSG), and seven Marine Expert Networks (plankton, sea-ice, benthos, fish, CBird, IUCN PBSG, and marine mammals), based on the major FECs identified (e.g., fish, plankton, benthos, seabirds, etc.). The CBMP-MSG will be composed of one representative and an alternate from each Arctic marine nation (U.S., Canada, Greenland/Denmark, Iceland, Norway, Russia), as well as representatives from interested Permanent Participants. The CBMP-MSG can also consider including others (e.g. Arctic Council Working Group representatives) as appropriate. Each representative on the CBMP-MSG will be responsible for ensuring that the monitoring program is implemented within their own nations and will, therefore, need to have close connections with the relevant agencies and experts within their countries. They will also play a key role in providing direction to the evolving monitoring program as a whole. Together with the CBMP, the CBMP-MSG will be responsible for the overall coordination and implementation of the monitoring program.

To facilitate the work of the CBMP-MSG representatives, the Marine Expert Networks will be responsible for adopting and implementing the monitoring plan for their specific FECs. This will involve pan-Arctic data aggregation, analysis, and management of the coordinated monitoring (see Chapters 5 through 8). These networks will be comprised of one appointed member from each of the Arctic countries. The Marine Expert Networks (MENs) will meet annually to review program implementation, produce regular reports, publications and assessments, and adjust the monitoring approach, where necessary. Where possible and appropriate, the MEN annual meetings will coincide with other meetings and may even form out of existing structures (e.g. ICES, NAMMCO). These collaborations are expected to result in multi-authored scientific publications that will advance our understanding of these biota groups and their role in Arctic marine ecosystems. National representatives on the CBMP-MSG will work with their respective national members on the seven Expert Networks to ensure that the monitoring program is being implemented consistently for each discipline within their country and particular Arctic Marine Area(s).

CAFF's CBMP will also be responsible for managing the overall output of the CBMP-Marine Plan by providing value-added services and integration through development of and access to data management (web portal and web-based data nodes), communications products, and reporting (regular assessments) tools, and will work with the Expert Networks to establish analysis outputs via the Data Portal (see chapters 7 through 9).

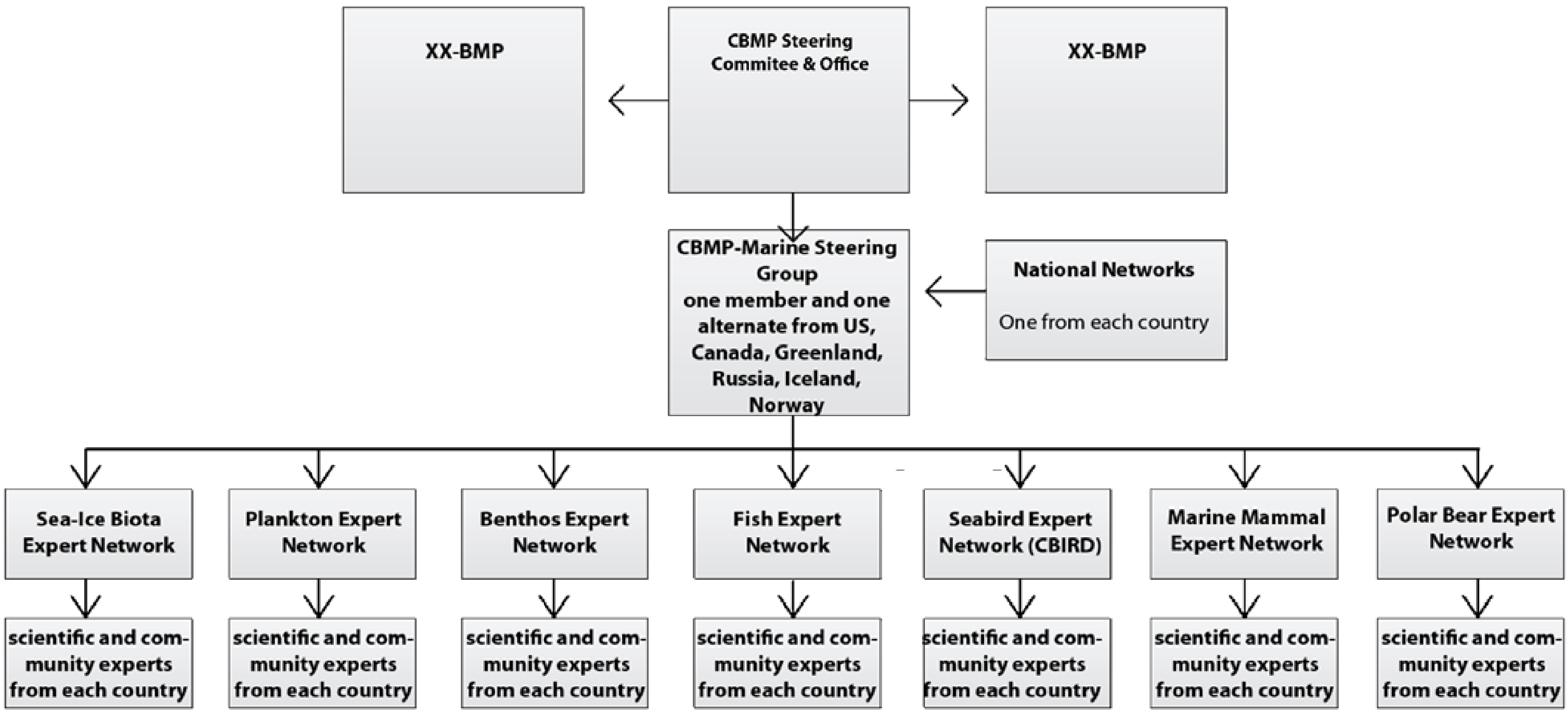

Figure 15 Governing structure for the Arctic Marine Biodiversity Monitoring Plan.

Every five years, one year prior to the assessment, the seven Marine Expert Network leads will meet to discuss circumpolar aggregation and analysis of the resulting datasets to be used to populate the five-year State of the Arctic Marine Environment report.

10.2 Program Review

A full program review will be conducted every five years. This will include a review of the parameters, indicators, sampling approaches, data management, and reporting outputs. Power analysis will be conducted to determine if the sampling approaches are sufficient to detect trends within a specific time frame. The focus of the review will be to determine if the program is meeting its performance objectives and operating optimally and as cost-effectively as possible. Where deficiencies are encountered, adjustments will be made. If adjustments in the sampling approach or data protocols are needed, it will be important to initiate a period of calibration where the new methods are conducted concurrently with the old methods.

Performance measures for determining if the plan's objectives (Section 1.1) have been met are listed in the table below.

Objective	Performance Measure(s)
Identify a suite of common biological parameters and indicators to monitor change across Arctic marine ecosystems.	Common parameters and indicators in use in at least three AMAs by 2015 (Phase I).
Identify key abiotic parameters, relevant to marine biodiversity, that need continual monitoring.	Linkages made between CBMP-Marine Plan and relevant abiotic monitoring networks, and abiotic data is being correlated with CBMP-Marine Plan trends (Phase I).
Identify optimal sampling schemes, making efficient use of existing monitoring capacity.	Optimal sampling schemes and coordinated monitoring in place in at least three AMAs by 2015 (Phase I).
Address priority gaps (elemental, spatial, and/or temporal) in coverage.	Priority gaps identified and raised with national governments (Phase II).
Identify existing datasets and information that can be aggregated to establish baselines and retrospective trends in Arctic marine biodiversity.	Indicators developed and reported on by 2013 (Phase I).
Provide regular and authoritative assessments on key elements and regions of the Arctic marine system that respond to regional, national, and international reporting requirements.	Indicators developed and reported on by 2013. State of the Arctic Marine Biodiversity report produced in 2015 (Phase I).
Produce long-term datasets that facilitate a greater understanding of natural variability in Arctic marine ecosystems and the response of these systems to anthropogenic drivers.	Indicators developed and reported on by 2013 (Phase I) and updated on a regular basis.

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12. Glossary of Acronyms

ABA: Arctic Biodiversity Assessment
ADF&G: Alaska Department of Fish & Game
AFSC: Alaska Fisheries Science Center
AMA: Arctic Marine Area
AMAP: Arctic Monitoring and Assessment Programme
ArcticNet: a Network of Centres of Excellence of Canada
ARCTOS: Arctic Marine Ecosystem Research Network
BASICC: Barents Sea Ice Edge in a Changing Climate
BASIS: Bering Arctic SubArctic Integrated Surveys
BEST: Bering Ecosystem Study
BGOS: Beaufort Gyre Observing System
BOWFEST: The Bowhead Whale Feeding Ecology Study
BSIERP: Bering Sea Integrated Ecosystem Research Program
C3O: Canada's Three Oceans
CAFF: Conservation of Arctic Flora and Fauna
CASES: Canadian Arctic Shelf Exchange Study
CBird: Circumpolar Seabird Group
CBMP: Circumpolar Biodiversity Monitoring Program
CBMP-Marine Plan: Arctic Marine Biodiversity Monitoring Plan CFL: Circumpolar Flaw Lead System Study
CHONe: Canadian Healthy Oceans Network
CLEOPATRA: Climate Effects on Planktonic Food Quality and Trophic Transfer in Arctic Marginal Ice Zones
COMIDA: Chukchi Sea Offshore Monitoring in Drilling Area
CTD: Conductivity-Temperature-Depth
DAMOCLES: Development of Arctic Modeling and Observational Capabilities for Long-Term Environmental Studies
DBO: Distributed Biological Observatory
DFFL: Direktoratet for Fiskeri, Fangst og Landbrug
FEC: Focal Ecosystem Component
FGDC: Federal Geographic Data Committee
GBIF: Global Biodiversity Information Facility
GCMD: Global Change Master Directory
GEOSS: Global Earth Observation System of Systems
GINR: Greenland Institute of Natural Resources
GIS: geographic information system
IABP: International Arctic Buoy Programme
ICEX: Ice Exercise
ICOMM: International Census of Marine Microbes
IMR: Institute of Marine Research
IPCC: Intergovernmental Panel on Climate Change
IPY: International Polar Year
IUCN: International Union for Conservation of Nature
JOIS: Joint Ocean Ice Study
KANUMAS: Kalaallit Nunaat Marine Seismic Project
MAFCONS: Managing Fisheries to Conserve Groundfish and Benthic Invertebrate Species Diversity
MEMG: Marine Expert Monitoring Group
CBMP-MSG: CBMP Marine Steering Group
MERICA: Études des Mers Intérieures du Canada / Monitoring and research in the Hudson Bay Complex
MIZ: marginal ice zone
MMS: Mineral Management Service
MOD: Monitoring Database of the Norwegian Oil Industry Association
MRI: Meteorological Research Institute
NABOS: Nansen and Amundsen Basin Observational System
NASA: National Aeronautics and Space Administration
NERI: National Environmental Research Institute (Denmark)
NERO: Nuuk Ecological Research Operations
NMML: National Marine Mammal Laboratory
NOAA: National Oceanographic and Atmospheric Administration
NPEO: North Pole Environmental Observatory
NPI: Norwegian Polar Institute
NPRB: North Pacific Research Board
NSERC: Natural Sciences and Engineering Research Council of Canada
NSF: National Science Foundation
OBIS: Ocean Biogeographic Information System
OTN: Ocean Tracking Network
PAICEX: PanArctic Ice Camp Expedition
PINRO: Polar Research Institute of Marine Fisheries and Oceanography
PAME: Protection of the Arctic Marine Environment
PCSP: Polar Continental Shelf Program
PINRO: Knipovich Polar Research Institute of Marine Fisheries and Oceanography
RAS: Russian Academy of Science
RUSALCA: US-Russia Census of the Arctic
SBI: Shelf Basin Interactions Program
SHEBA: Surface Heat Budget of the Arctic
SDWG: Sustainable Development Working Group
UNEP: United Nations Environment Programme
UNEP-WCMC: UNEP World Conservation Monitoring Centre
USFWS: United States Fish and Wildlife Service
WSBS: White Sea Biological Station
ZERO: Zackenberg Ecological Research Operations
ZIN: Zoological Institute of Russian Academy of Sciences

Appendix A.
Implementation Schedule and Budget

*While significant investments are made by both Arctic and non-Arctic countries in Arctic marine biodiversity monitoring, very little is currently being invested in coordinating this monitoring, managing the outputs, and providing regular, integrated reporting. As a result, much of the collected information never reaches decision makers or the interested public or, worse, it is lost. Furthermore, statistical power to detect and understand trends is needlessly limited. For an annual average investment of $230 000 USD (average annual cost, 2011 through 2020), we can greatly increase the value of our current national monitoring efforts through a more coordinated, pan-Arctic approach. Even with an improved, coordinated approach, critical gaps in our monitoring coverage will still remain and new resources will be needed to address these gaps. As well, it is critical that monitoring networks that form core components of this monitoring plan receive sustained funding. The following tables outline the implementation schedule and budget for the CBMP-Marine Plan, focusing on the coordination and integration of the monitoring, data management, and reporting. It does not include the costs associated with the actual monitoring.

* Note: The Implementation Schedule and Budget as proposed by the CBMP Marine Expert Monitoring Group is subject to further considerations by the CAFF Management Board and thus, is still pending approval.

Photo by:Lawrence Hislop. http://www.grida.no/photolib

Implementation schedule

Milestone	Activities & Deliverables	Timeline by Quarter																				
		2010				2011				2012				2013				2014				2015+
		Jan	Apr	July	Oct	Jan	Apr	July	Oct	Jan	Apr	July	Oct	Jan	Apr	July	Oct	Jan	Apr	July	Oct	
1. Plan published	a. Final plan endorsed by CAFF Board and published					■																
	b. Executive Summary report published.						■															
2. Governing structure activated	a. CBMP-MSG established						■															
	b. Marine Expert Networks established					■	■	■														
3. Establish coordinated monitoring in each AMA	a. Monitoring manuals for each Arctic Marine Area developed					■	■	■														
	b. Arctic-based monitoring networks adopt parameters and sampling approaches							■	■	■	■	■	■	■	■	■	■	■	■	■	■	
	c. Non-Arctic based monitoring networks adopt parameters and sampling approaches																					■
4. Data management structures established	a. Data nodes and hosts, web-entry and data standards established for each Marine Expert Network					■	■	■	■	■	■	■										
	b. Nodes linked to portal and web portal analysis tools developed							■	■	■	■	■	■	■								
	c. Metadata added to Polar Data Catalogue		■	■	■																	
5. Indicator development	a. Existing datasets identified, aggregated and analyzed to establish indicator baselines								■	■	■	■	■	■	■	■						
	b. Indicators updated with monitoring plan outputs (annually)										■			■				■				■
6. Reporting	a. Annual performance reports and work plans										■			■				■				■
	b. State of the Arctic Marine Biodiversity report (inc. AMA status reports) – every 5 years																					■
	c. Scientific publications (ongoing)													■	■	■	■	■	■	■	■	■
	d. General communications						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
7. Program review & adjustment	a. Independent review of parameters, sampling approaches, data mgmt approach, analysis, and reporting (every 5 years)																					■

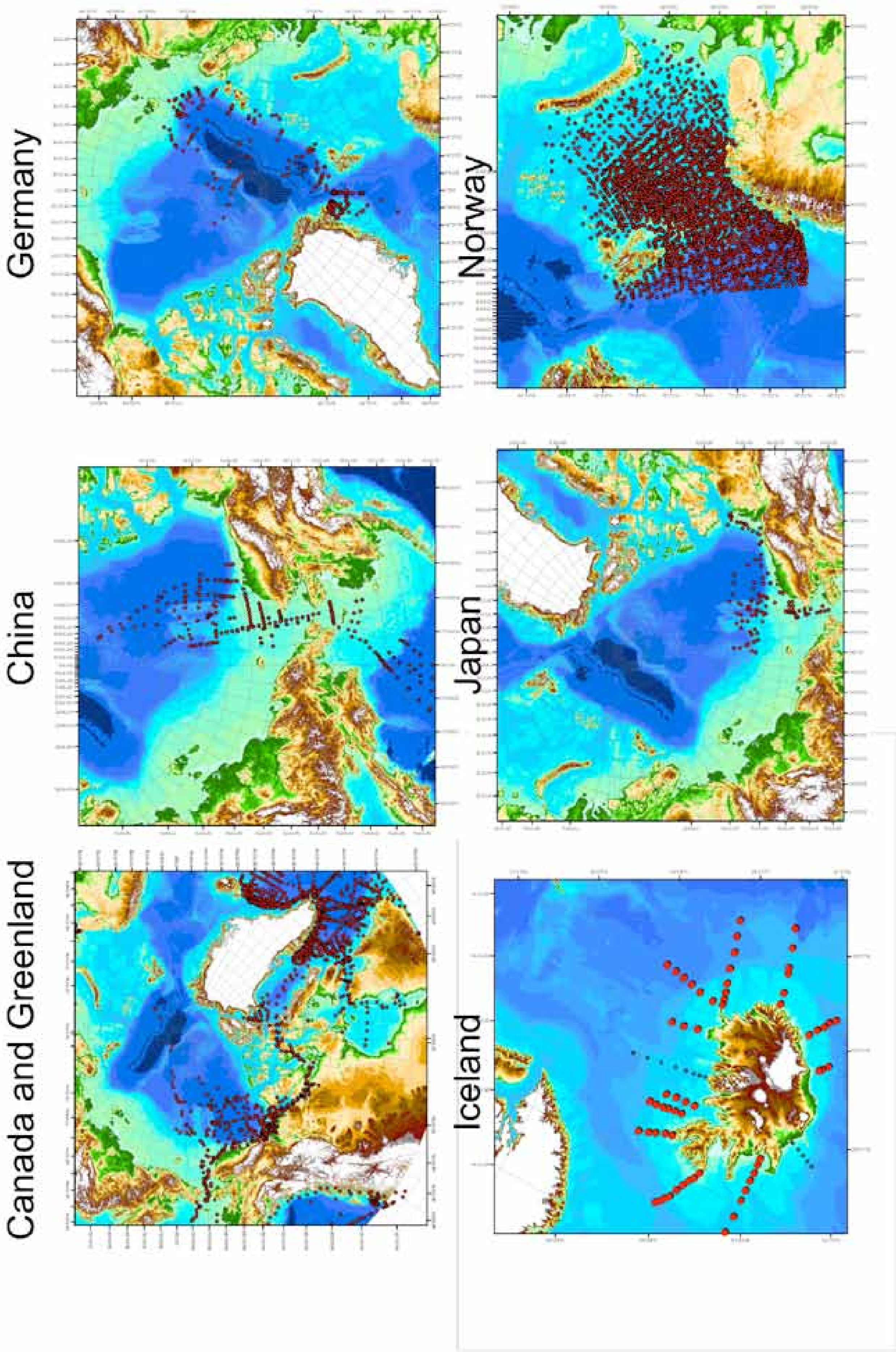
Budget

Note: the costs outlined in the table are focused on new efforts to coordinate and integrate marine biodiversity monitoring, data management and reporting. They do not reflect the actual ongoing monitoring costs and they do not reflect the existing CAFF CBIRD group which is already operational. Some of the costs in the table represent the full cost of establishing some of the data portal platforms. Therefore, these costs will not be duplicated in the other CBMP Arctic monitoring plans.

Milestone	Activities & Deliverables	Total Cost (USD)	Cost Details	Responsibility
1. Governing and operational structure activated	a. 2011 Inaugural meeting of CBMP-MSG and Marine Expert Networks	180K (30k per country)	Meeting costs (travel support for CBMP-MSG leads and alternates and MEN national representatives and venue costs)	Arctic coastal nations for travel support. CBMP for venue costs.
	b. CBMP-MSG – program coordination	2012 onwards: 36K per year (6K per country)	Conference calls, annual meeting costs (travel, venue), coordination.	Arctic coastal nations
	c. Marine Expert Networks	2012 onwards: 150K per year (25K per country).	Conference calls, annual meeting costs (travel, venue), coordination, analysis, and reporting for 5 new expert networks.	Arctic coastal nations
2. Data management structures established	a. Data nodes and hosts, web-entry interfaces, and data standards established	2011: 60K 2012: 60K 2013 onwards: 10K (data node maintenance)	Web-entry interface and web-based databases and nodes and data entry manuals established	CAFF CBMP Office
	b. Data nodes linked to web portal and analytical tools developed	2011: 30K 2012: 60K 2013 onwards: 20K (web portal maintenance)	Data Portal linked to data nodes via XML, and canned analysis tools developed	CAFF CBMP Office
	c. Metadata added to Polar Data Catalogue	2010: 0K	Metadata entry by University of Laval free of charge	CAFF CBMP Office
3. Indicator development	a. Existing data sets identified, aggregated and analyzed to establish indicator baselines	2012: 105K (15K per expert network)) 2013: 105K (15K per expert network) 2017/18: 210K every 5 years to support five year assessment.	Costs for expert network analysis support.	MEN's (CAFF CBMP Office to provide funds)
	b. National dataset compilations, QA/QC and formatting	Varies by nation.	Each nation will need to assign staff to focus on dataset compilation, QA/QC, interaction with CAFF/CBMP Data team and formatting. Costs will vary depending on state of national datasets.	Arctic coastal nations
	c. Dataset compilations archived	Minimal cost. CAFF Data manager staff time.	All datasets compiled and used to be archived at CAFF Secretariat.	CAFF Secretariat
4. Reporting	a. Annual indicator updates	15K per year starting in 2012	Website indicator updates and other media	CAFF CBMP Office
	b. Annual performance reports and work plans	0K per year starting in 2012	Performance report/work-plan layout and digital publication	CBMP-MSG

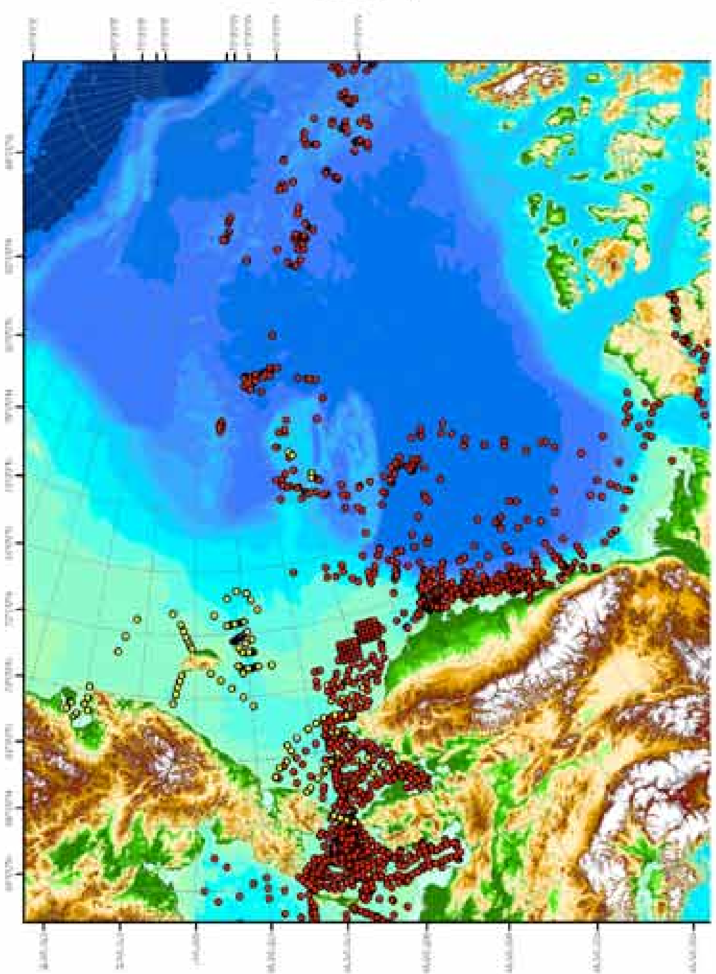
	c. State of the Arctic Marine Biodiversity Report	2015: first initial assessment report. 50K every five years (2015, 2020, 2025, etc.) Note: costs spread over several years to prepare for assessment report.	CBMP-MSG and Marine Expert Network annual meetings coordinated to aggregate & analyze data, and develop report; publishing and communications costs	CBMP-MSG, MEN's and CAFF CBMP Office
5. Program review and adjustment	a. Review of parameters and sampling approaches. b. Independent review of data management approach, analysis, and reporting using performance measures	0K – costs of MEN's reflected above. 30K every ten years starting in 2016	Contract independent review of Monitoring Program	MEN CBMP Office
TOTALS		2011: **270K** (180K Arctic coastal nations; 90K CAFF CBMP) 2012: **436K** (186K Arctic coastal nations: 250K CAFF CBMP) 2013: **341K** (186K Arctic coastal nations; 155K CAFF CBMP) 2014: **231K** (186K Arctic coastal nations; 45K CAFF CBMP) 2015: **281K** (186K Arctic coastal nations; 95K CAFF CBMP) 2016: **261K** (186K Arctic coastal nations; 75K CAFF CBMP) 2017: **336K** (186K Arctic coastal nations; 150K CAFF CBMP) 2018: **336K** (186K Arctic coastal nations; 150K CAFF CBMP) 2019: **231K** (186K Arctic coastal nations; 45K CAFF CBMP) 2020: **281K** (186K Arctic coastal nations; 95K CAFF CBMP)		**Arctic Coastal Nations:** **2011: 180K (30K per country)** **2012 onwards: 186K per year (31K per country per year)** **CAFF CBMP:** **2011: 108K** **2012: 250K** **2013: 155K** **2014: 45K** **2015: 95K** **2016: 75K** **2017: 150K** **2018: 150K** **2019: 45K** **2020: 95K**

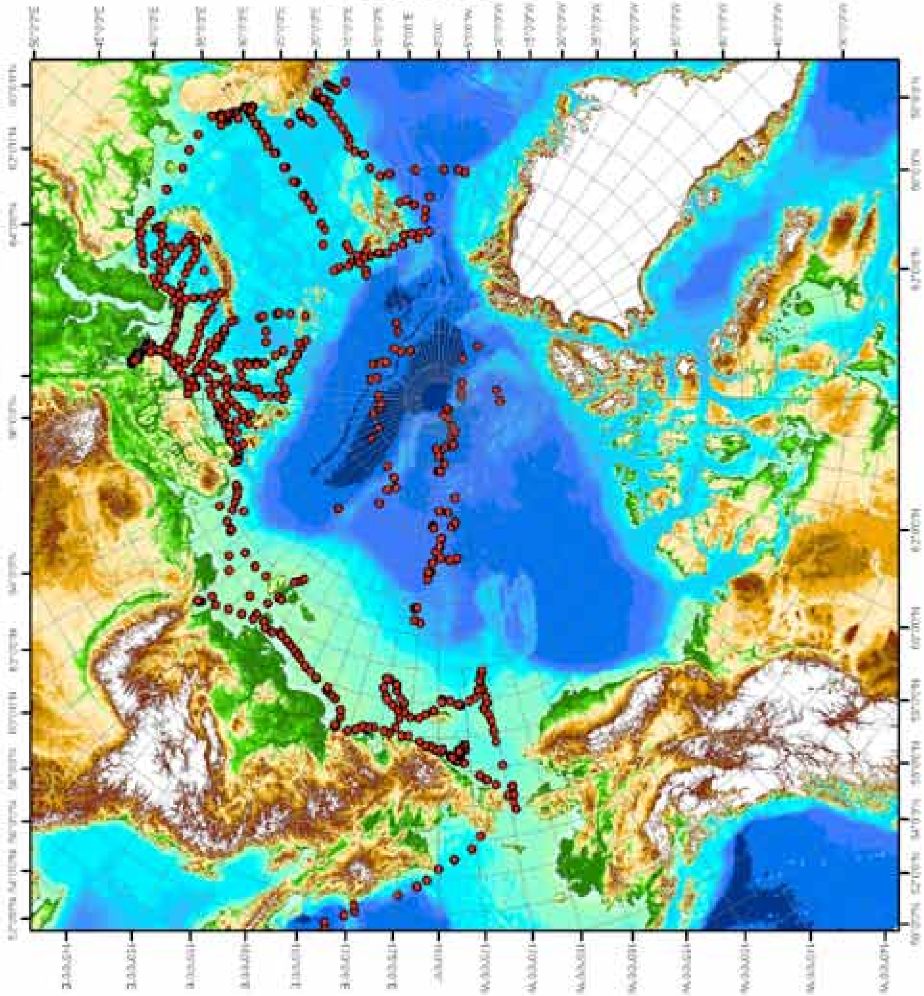
Appendix B.
Current and Historical Sampling Coverage Maps by Discipline



Plankton Stations (a)

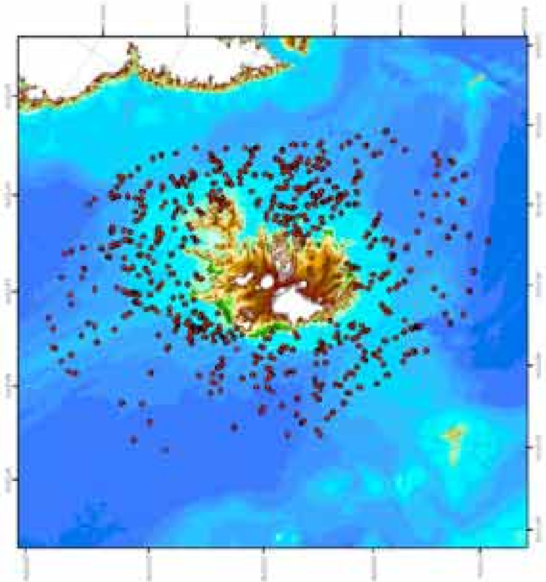
Plankton Stations (b)



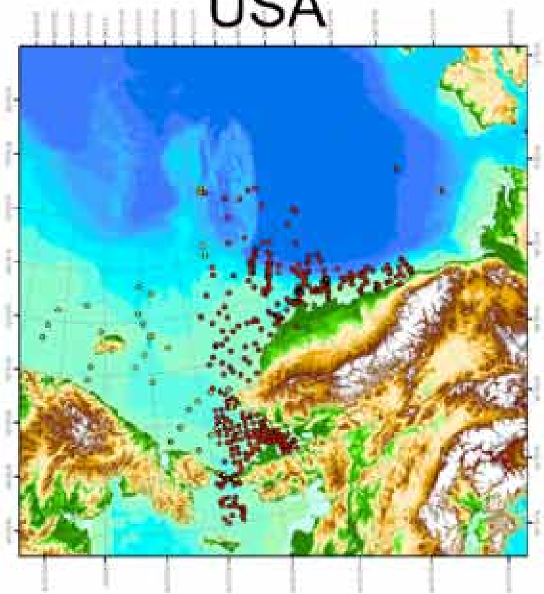


Benthic Marine Life Stations

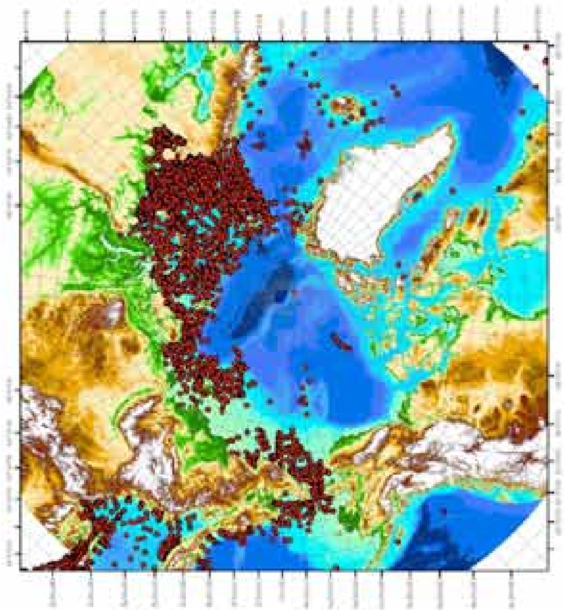
Iceland



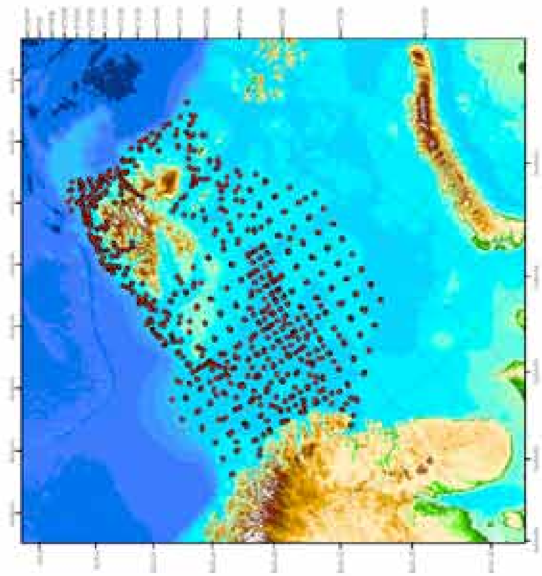
USA



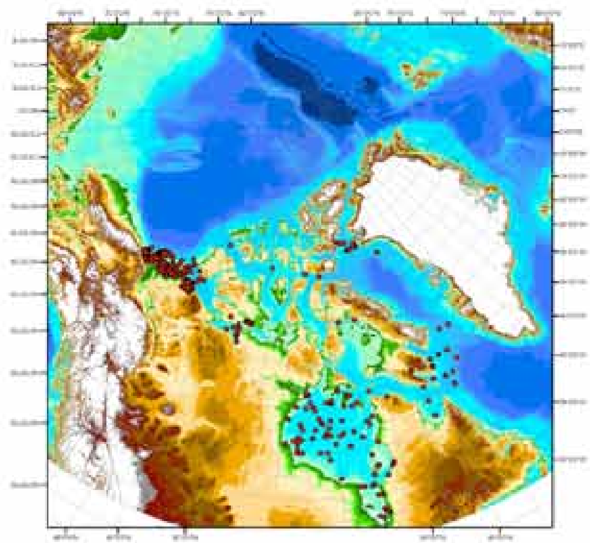
Russia



Norway

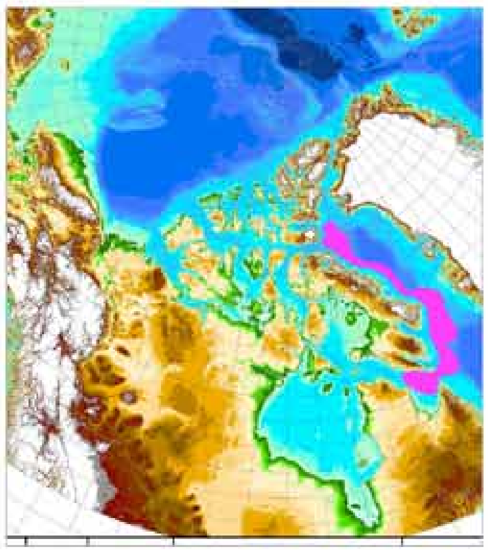


Canada

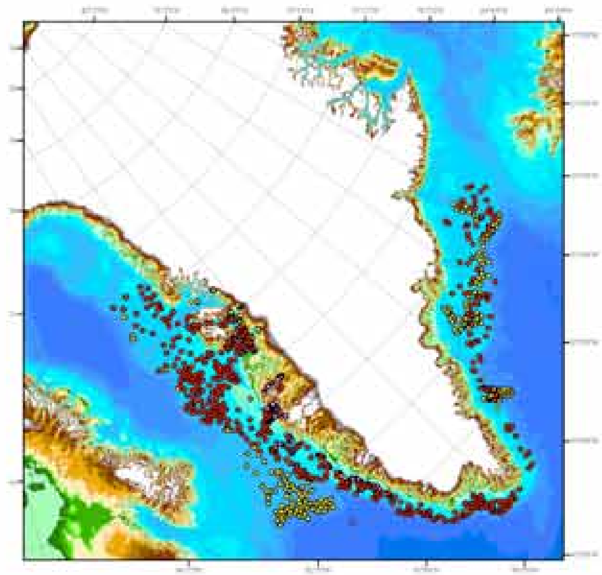


Fish Stations-Regions (a)

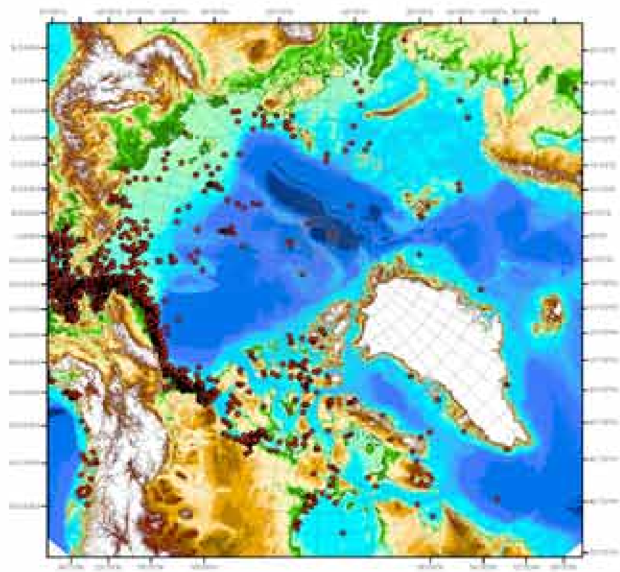
Canada



Greenland

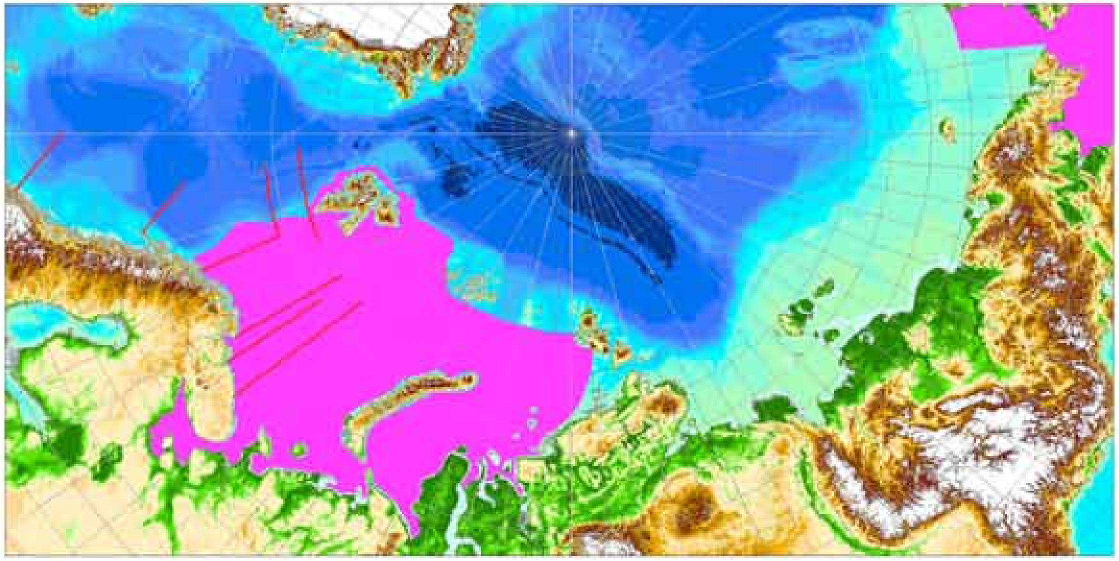


USA

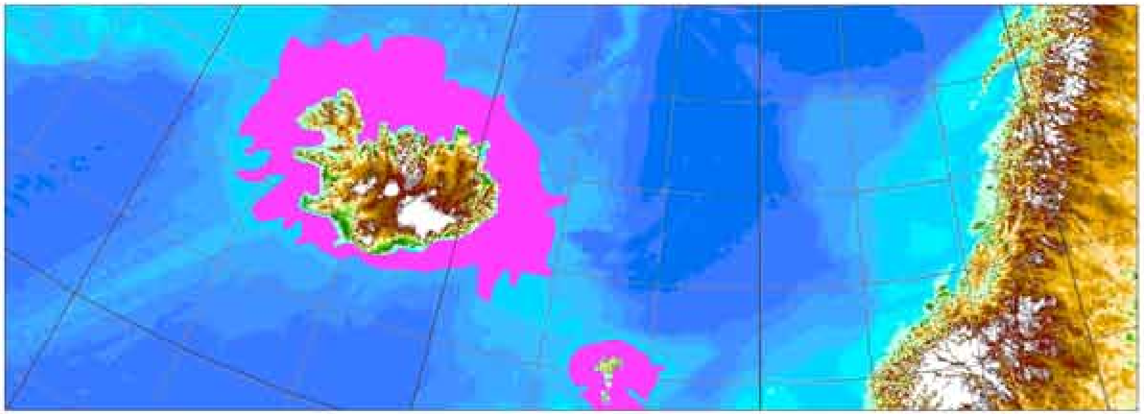


Fish Stations-Regions (b)

Russia and Norway



Iceland and Faroe Islands



Appendix C.
Arctic Marine Areas

*There are many ways to divide the Arctic marine region—by ecosystem/ecological characteristics, by administrative criteria, or by some combination of the two. However, effective monitoring of biodiversity requires that an ecosystem-based approach be used for choosing areas.

The MEMG has adopted a set of criteria for choosing areas that blends inputs from MEMG members and builds upon criteria developed at the CBMP Workshop in Anchorage, November 29-30, 2006.

To be considered an Arctic Marine Area, significant parts of the region must be seasonally ice-covered or, must have been so in the recent past. Arctic Council definitions state that marine ecosystems exclude intertidal areas from 0-30 m depth. Shallower areas are included if they are relevant to the overall dynamics in marine areas. All AMAs selected by the MEMG are either linked to Large Ocean Management Areas (LOMAs), Marine Protected Areas, National Wildlife Areas, Important Bird Areas, or other similar areas, and would benefit from supporting biodiversity monitoring data. These areas can link with the Convention on Biological Diversity's Ecologically and Biologically Significant Areas (EBSAs) and will preferably link with the Coastal and Freshwater EMG priorities (e.g., regions important for anadromous fish).

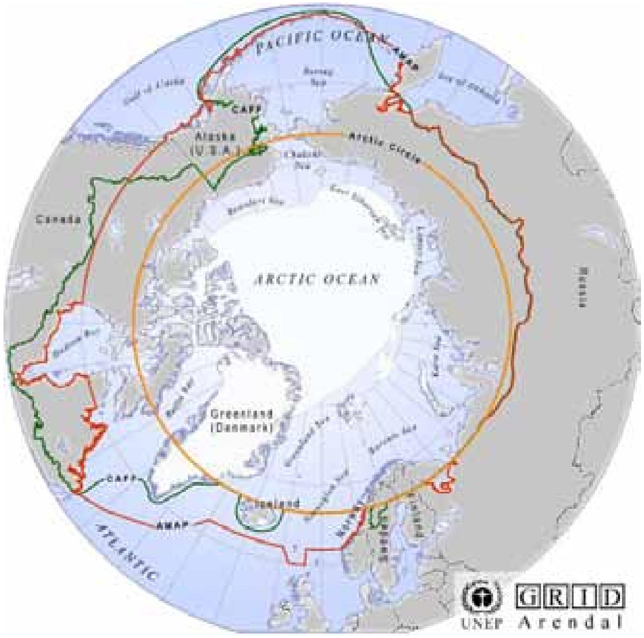


Figure 16 Delineations of the CAFF and AMAP areas

Of note, most AMAs are experiencing, or are expected to experience, development pressures such as oil and gas exploration and extraction, commercial fisheries, and potential pollution from ships. These areas are also undergoing other changes, in particular due to changes in climate variability and climate extremes (diminishing sea ice, changing freshwater inputs, water temperature, salinity, and potential acidification).

The following criteria for AMAs are ordered by decreasing significance, with none being mutually exclusive:

1. Marine ecosystems for which we have long-term and high-quality datasets and/or ongoing activities covering all trophic levels from phytoplankton and algae through zooplankton, benthic animals, pelagic fish, seabirds, marine mammals, as well as key supporting biogeochemical data.
2. Biological hotspots (e.g., polynyas, marginal ice zones), since these physically dynamic areas are proven sources of important traditional foods, as well as significant habitat for many marine species.
3. Margins, boundaries, and fronts: monitoring changes in their position that could lead to changes in biodiversity (e.g., ice edge, circulations, intruding Atlantic or Pacific water altering vertical structure, river inputs).
4. Gateways, which import and export biogeochemical properties, including biota and invasive species, with sea water.
5. Locations suitable for incorporating and/or developing community-based monitoring elements.
6. Potential to conduct both sections (spatial coverage) and moorings (temporal, especially seasonal, coverage), using new technologies as they become available.
7. Low-productivity systems, because they may change profoundly as a consequence of anthropogenic impact, particularly climate change.
8. Blocking domains, such as sills, which affect migration of biota.

The following sections describe the seven AMAs chosen for focusing coordinated marine biodiversity monitoring efforts.

*NOTE: TO BE MODIFIED ONCE ABA MARINE DELINEATIONS ARE FINAL

Pacific Arctic Gateway

Note: The Pacific Arctic Gateway does not include the entire Bering Sea due to the following reasons.

Biophysical features/domains are quite different N-S of ~ 60N (St. Matthew Island) in the Bering Sea. The Aleutian and deep Bering Sea fauna are Pacific in character, not Arctic. Even the ice-covered parts of the Bering Sea shelf are dominated by Pacific fauna year round (until you reach far north) because it warms up too much most summers for fully Arctic species to survive there. There are some species shared between the Arctic and subArctic, however since the general water flow is northward, Arctic species moving southward against the flow are typically not observed, with the exception of the movement of marine mammals.

Notable, the region from St. Matthew northward is driven more by Arctic Oscillation and Arctic atmospheric variability compared to the influence of the Pacific Decadal Oscillation and Aleutian low patterns in the Bering Sea. Also, the movement of Anadyr water into the western side of the northern Bering Sea onto the shelf sets up the major western (high salinity) to eastern (more freshwater influenced) water masses through the summer on a longitudinal basis in this region. The biology in the northern Bering Sea is a transition between sub-Arctic species in the south to Arctic species moving across the Chukchi Sea into the Arctic Basin.

Physical characteristics

The Bering Strait continental shelf complex (northern Bering Sea, Bering Strait and northward to the East Siberian, Chukchi and Beaufort seas) is a major gateway from the perspective of ocean, ice, freshwater, nutrient fluxes, and atmospheric fluxes of heat and moisture, as well as fluxes of biological organisms and organic carbon. Time-series measurements (1990-2004) from the Bering Strait indicate large annual variability transport (~0.4 to 1.2 Sv) and hence heat influx. Furthermore, the Bering Strait provides ~40% of the total freshwater input to the Arctic Ocean, with far-reaching implications for Arctic halocline formation, basin dynamics, and meridional overturning of water on the Atlantic side of the Arctic.
The Pacific Arctic Region is experiencing the greatest seasonal retreat and thinning of sea ice in the Arctic, with 2007 having the lowest minimum ice extent in the 35-year satellite data record and 2008 and 2009 being the second and third lowest. Changes in sea-ice formation and thickness influence albedo feedback, brine formation, and halocline maintenance, so ice-ocean-atmospheric dynamics are extremely critical for regulating climatic conditions in the Arctic and on Earth as a whole.

The shallow and dynamic Bering Strait region and adjacent seas are key locations to monitor ecosystem change. Apparent changes that are being observed in the oceanographic and ice system in this region could lead to dramatic impacts for higher-trophic-level fauna, including benthic-feeding animals such as walrus, bearded seals, and gray whales, and pelagic-feeding bowhead and beluga whales, which are of cultural and subsistence significance to Arctic Indigenous peoples.

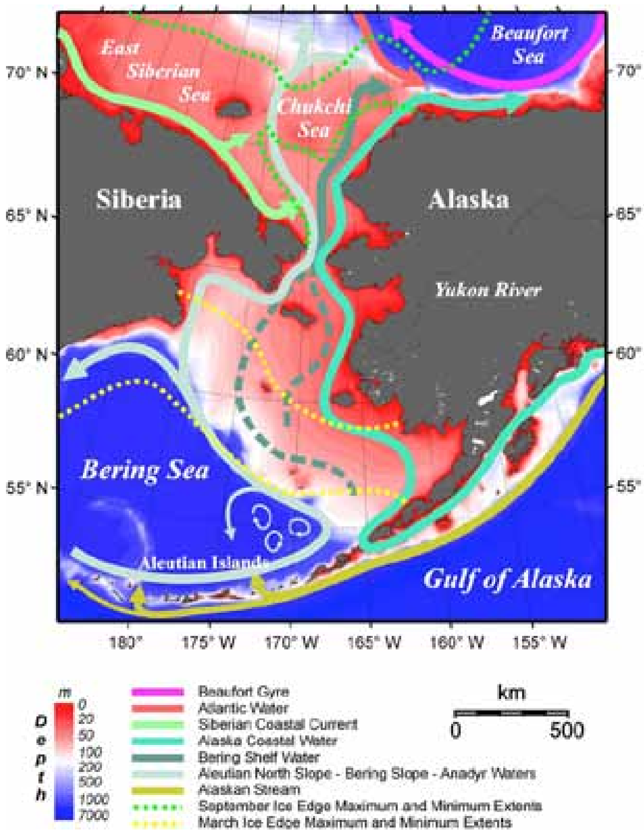


Figure 17. Illustration of the currents through the Bering Strait areas.

Biological characteristics

Large quantities of Pacific heat, nutrients, phytoplankton, and zooplankton enter the region through the Bering Strait in a complicated mixture of water masses (i.e., Alaska Coastal, Bering Shelf, and Anadyr Water: see Figure 17). Each water mass has unique assemblages and quantities of plankton that are diluted by Coastal Arctic waters carried along by the East Siberian Current and water carried in from the deeper waters of the Canada Basin or Chukchi Plateau. Early in the season, the exact timing of the sea-ice breakup, the fate of the sea-ice community, and its match/mismatch with various components of the ecosystem can have profound impacts on this system and change the partitioning between benthic and pelagic productivity. For the most part, the high concentration of nutrients in Anadyr waters stimulates massive sea-ice algal and phytoplankton blooms that cannot be fully exploited by the zooplankton communities. Hence, much of this high production is exported unmodified to the benthos, resulting in impressively high biomass of benthic infauna and epifauna. These rich benthic communities serve as feeding grounds (biological hotspots) for the bottom-feeding Pacific walrus, gray whales, and diving birds. The huge biomass of zooplankton imported to the Bering-Chukchi shelf in the flow of Anadyr Water accounts for the spectacular populations of seabirds, particularly planktivorous auklets, in the Bering Strait region, and undoubtedly supported resident bowhead whales prior to their decimation in the mid-1800s.

Both inter-annual and long-term variations in climate affect the relative transport of the different water masses through Bering Strait and, hence, the composition, distribution, standing stock, and production of sea-ice communities, phyto- and zooplankton, and the tightness of benthic-pelagic coupling in the Chukchi Sea. There is significant concern that the Chukchi Sea may be undergoing an enhancement of energy utilization within its pelagic realm, with a consequent decline in the production made available to the benthic communities. Resulting changes in prey base are likely to have significant effects on population dynamics and survival of upper-trophic-level species.

Pressures

Heat and freshwater flow through Bering Strait have increased significantly in recent years. Visual and passive acoustic surveys suggest that gray whales are occupying the Chukchi and western Beaufort seas longer, potentially competing with bowhead whales for prey and interfering with subsistence hunting of the latter species. Sea-ice decline means that tens of polar bears spend longer time at shore and tens of thousands of walrus must haul-out on land, resulting in increased mortalities and confrontations with Arctic residents. Furthermore, recent dramatic reductions in seasonal ice cover have opened this region to increased oil and gas exploration and to exploratory fisheries, and foster the establishment of trans-Arctic shipping routes in the very realistic scenarios of a seasonally ice-free Arctic.

The Pacific Gateway is a pathway for pollutants into the Arctic from the Pacific and has been shown to be the primary entry point of hexachlorocyclohexane (HCH) within seawater. The region also receives atmospheric deposits of persistent pollutants, including persistent organic pollutants (POPs) and mercury, derived largely from Asia. POPs are found at levels of toxicological significance in predatory marine mammals and seabirds.

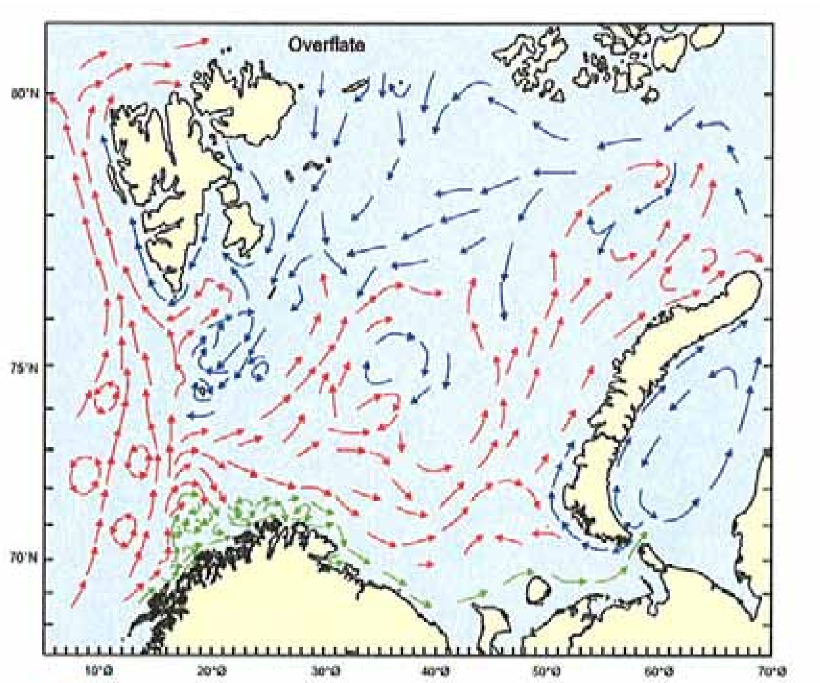
Photo by: Mark Marissink

Atlantic Arctic Gateway

Physical characteristics

Barents Sea

The Barents Sea is a shelf-sea covering an area of about 1.4 million km^2. It is bounded by the coasts of northern Norway and northwestern Russia in the south, Novaja Zemlja archipelago in the east, Svalbard and Franz Josef Land in the north, and the Norwegian Sea in the west (Figure 18). The average depth of the Barents Sea is about 230 m. There are more than 11 shallow (100-200 m) banks and more than 6 deep (300-400 m) basins in the Barents Sea. The banks mainly follow the coastline, but both Central Bank and Stor Bank are localized in the central part of the sea. Two deep channels (500 m) lead into the Barents Sea, one from the west (Beer Island Channel) and one from the north (Franz Victoria Channel). Three main current systems flowing into the Barents Sea determine the main water masses: the Norwegian Coastal Current and the Murman Coastal Current, the Atlantic Current, and the Arctic Currents System. The Atlantic water is warm and saline compared with the Arctic water masses, with the Polar Front formed where they interact. The position of the Polar Front is determined largely by bottom topography in the west and more influenced by prevailing weather and current conditions in the eastern part of the Barents Sea.



Atlantic current
Arctic current
Norwegian coastal current

Figure 18 The Barents Sea and the main current systems.

The Barents Sea is partially covered by ice. The area covered has declined during the last three decades, and recently there have been four years when all sea ice melted during the summer (2001, 2004, 2006, and 2007).

Photo by:Peter Prokosch. http://www.grida.no/photolib

Greenland Sea and adjacent waters

The Arctic Atlantic region includes the whole of the Barents Sea and Greenland Sea, as well as parts of the Norwegian Sea and the waters between the Faroe Islands, Iceland and Southwest Greenland. The Greenland Sea is bounded by Greenland, the Arctic Ocean, Svalbard, the Norwegian Sea, Iceland, and the Denmark Strait/Irminger Sea to the south. The continental shelf extends east from the Greenland coast and has a width of more than 300 km near its northernmost part, becoming narrower further south. Off the shelf, waters reach depths greater than 3000 m.

A submarine mountain ridge, known as the Iceland-Scotland Ridge (IS-Ridge), extends across the North Atlantic from Greenland to Scotland. It forms an efficient barrier between the abyssal basins of the Arctic and the North Atlantic. The water depth at the top of the ridge is around 300-400 m, but it is transected by deeper sills, mainly between the Faroes and Shetlands and, to a lesser extent, between Iceland and Greenland. The bottom water temperature in the Greenland and Norwegian seas, north of the IS-Ridge, remains constant at -1°C from about 600 to 1200 m and down to the greatest depth of 5600 m. However, because of the Norwegian Atlantic Current, the surface water of the greater part of the Norwegian Sea is relatively warm northward from the Faroe Islands towards the northern coast of Norway. Closer to the top, at the northern slope of the IS-Ridge, the bottom water temperature reaches 2° or 3°C. Slightly farther to the southern side, the temperature may increase abruptly to about 5° or 8°C, sometimes within a distance of less than 20 km, as it does off the southeast coast of Iceland.

The Greenland and Norwegian seas are the Arctic Ocean's main outlet to the Atlantic. On the surface layers, the East Greenland Current transports cold and low-salinity Polar Surface Water and sea ice southwards along the Greenland coast. Some surface water branches off eastwards north of Iceland. The deeper layers are crucial to the global seawater circulation, as the waters that have lost heat to the atmosphere change buoyancy, sink, and contribute to the North Atlantic Deep Water. The Arctic water masses of the East Greenland Current meet warmer water from the Irminger Current south of Iceland and continue southwards, rounding the southern tip of Greenland at Cape Farewell, linking the oceanography and ecosystems of East Greenland with Southwest Greenland .

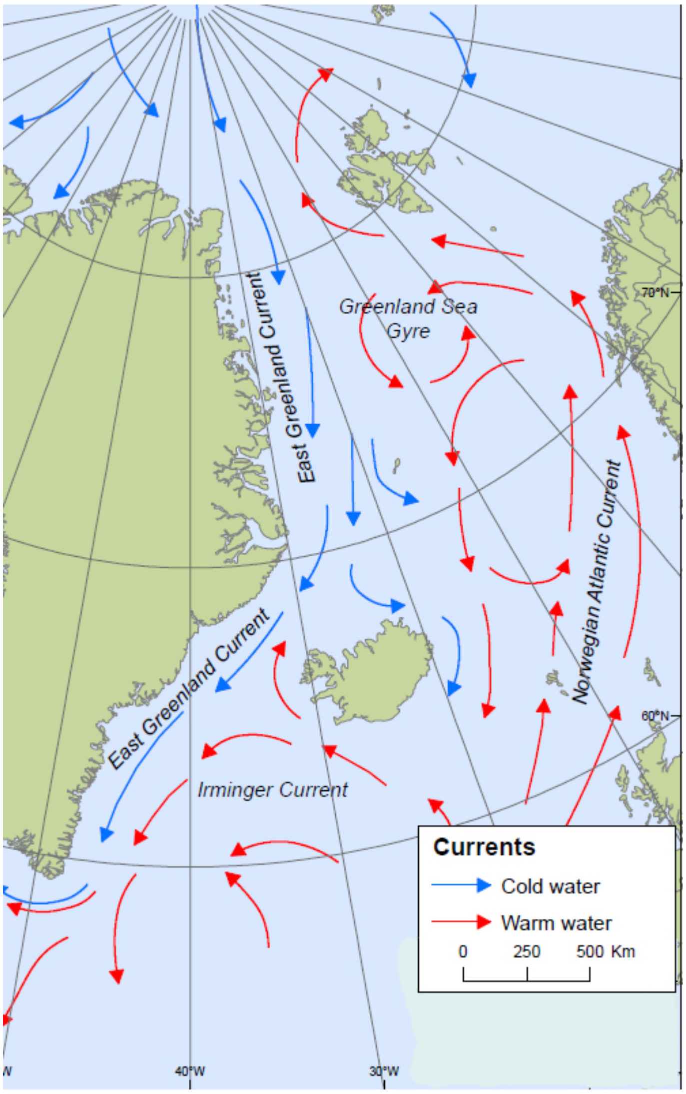


Figure 19 The Greenland Sea and its surface currents

With seasonal and annual variations, ice is present in the Greenland Sea year-round in the form of icebergs, fast ice, and drift ice. Icebergs are released by Greenlandic glaciers. The fast ice is stable and anchored to the coast, covering fjords and the outer coast. In some areas a stationary or semi-permanent shelf made up of fast ice is present year-round. The drift ice consists of a mixture of multi-year and first-year ice floes of various sizes and densities, which are transported southwards by the East Greenland Current. A shear zone with year-round open cracks and leads may occur between the fast ice and the drift ice.
The largest polynyas of the Greenland Sea are the Northeast Water (NEW) off Kronprins Christian Land, the waters off Wollaston Forland, and the mouth of Scoresby Sound.

Biological characteristics

Barents Sea

The Barents Sea is highly productive, particularly so at the Polar Front, the marginal ice zones, and the edge of the continental shelf in the western Barents Sea. The biogeographic boundary between the Atlantic Boreal and the Arctic biogeographic zones is located in the western part of the Barents Sea. The zooplankton community is dominated by *Calanus* species, with different species being important to the south and north of the Polar Front (*C. finmarchicus* in the south and the more lipid-rich *C. glacialis* in the north). The main planktivorous fish are capelin, herring, and blue whiting. The latter is a boreal species that in recent years has been found in large numbers in the Barents Sea. Cod is the most important large predatory fish. Other important fish stocks are haddock and pollock. Greenland halibut, two species of redfish, and coastal cod were once abundant, but are now severely overfished.

The zoobenthos has more than 3000 species in the Barents Sea. Sponges dominate the epifauna in areas influenced by western Atlantic water, while echinoderms (sea stars, brittle stars, sea cucumbers, and sea urchins) make up the main part of the epifauna in central parts of the sea. The southeastern part is dominated by a large carnivore population of red king crab, snow crab, the crangonid shrimp *Sabinea septemcarinata*, the crab *Hyas araneus*, and the sea anemone *Hormathia digitata*. Depth, temperature, available food, and the substrate are important factors influencing the composition of the benthic community. Currents along the shelves of the Barents Sea banks are particularly strong, and large, erect species that filter the water for food particles, the basket star *Gorgonacephalus*, and the sea lily *Heliometra glacialis* are among the dominant species. In the basins, where current speed is low, benthos depend on food particles sinking down to the bottom. The detrivores (animals picking up particles from the substrate), such as the sea cucumber *Molpadia boralis*, the sea star *Ctenodiscus crispatus*, and several bivalves (*Tridonta borealis*, *Astarte crenata*, *Bathyarca glacialis*), dominate, together with a rich infaunal community of polychaetes (*Spiochaetopterus typicus*, *Maldane sarsi, Galathowenia oculata*, *Terebellides stroemi*), amphipods, and bivalves (*Macoma calcarea, Thyasira gouldii*, *Mendicula ferruginosa*).

About 24 marine mammal species regularly occur in the Barents Sea, consisting of 7 species of pinnipeds (seals and walruses), 12 of large cetaceans, and 5 of small cetaceans (porpoises and dolphins). A polar bear population of about 3000 individuals and several species of sea birds are also found in the Barents Sea. A considerable amount of the primary production is channelled through deep-water communities and benthos. Zoobenthos is a good indicator of climate change, and its structure and biomass vary with changes in water temperature.

Greenland Sea and adjacent waters

The key zooplankton species are copepods of the genus *Calanus*. Polar cod is very abundant, both pelagic and in association with the ice, and constitutes a major food resource for seals, whales, and seabirds. Other important fish species in the Greenland Sea are Arctic cod, Greenland halibut, and Arctic char. The Danmark Strait/Irminger Sea, Norwegian Sea and waters around Iceland and the Faroe Islands contain commercially important stocks of capelin, Atlantic cod, blue whiting, herring, and red fish. In the Greenland Sea, several species of seabirds are locally abundant in summer and spring, and several breeding colonies are found close to the polynyas. In spring and autumn, millions of seabirds migrate through the area on their passage from Svalbard and Russian breeding sites to Canadian wintering sites. The most numerous seabird species in the Greenland Sea are common eider, thick-billed murre, little auk, and ivory gull. Iceland and the Faroe Islands are important breeding areas for several seabird species.

Several species of cetaceans feed in the Greenland Sea during the periods with open water. Polar bear, walrus, ringed seal, bearded seal, narwhal, and probably bowhead whale are found in the area throughout the year. Globally important whelping grounds for harp seals and hooded seals are found in the Greenland Sea.

The Iceland-Scotland Ridge marks a well-known biogeographic boundary between the benthic biota of the Arctic and the North Atlantic Boreal Region. This boundary largely coincides with the transition between colder and warmer water masses which cover the sea floor. Characteristic species of the Arctic benthic fauna of the Norwegian and the Greenland seas reach their southern limit at the IS-Ridge: e.g., the molluscan species *Yoldia limatula*, *Thracia myopsis*, several *Buccinum*, *Colus*, and *Boreotrophon*. However, most high-Arctic species, such as *Portlandia Arctica*, *Macoma loveni* and *Pandora glacialis*, do not reach it. Collaterally, the IS-Ridge forms a connection between the European and the American shallow-water faunas, with Iceland and the Faroes as "stepping stones."

Pressures

Barents Sea

Climate

If climate warming continues as predicted by the IPCC, it will have major impacts on the Barents Sea ecosystem and might become the main driver in the sea.

Harvest

The main human driver in the Barents Sea is the fishery. The large fish stocks are at high levels and are harvested sustainably. Some of the smaller fish stocks, however, are at low level because of previous overfishing. The effect of bottom-trawling on large sessile organisms such as corals reefs, sponges and sea pens has been shown, but the impact on other benthic organisms is unknown.

Industrial development

Industrial development in the area is minimal

Contaminants

There is little local-source pollution in the region, but persistent organic pollutants transported from outside the area through ocean and atmospheric currents accumulate in the food chain. High concentrations are found in top predators, such as polar bears and glaucous gulls, and may affect individuals and populations of such species
Introduced alien species

Invasive species such as the red king crab and the snow crab, as well as other species, have an effect on the native systems.
Shipping

To date, there have been few major incidents related to ship traffic and oil and gas activities, and these activities should not be considered primary drivers at present. The risk of accidents in the future may, however, become considerable. In addition, oil and gas activities may affect the system indirectly through the global warming and ocean acidification caused by their products.

Greenland Sea and adjacent waters

In East Greenland, human uses of natural resources, such as fishing and mining, are limited to the southern parts. Subsistence hunting (marine mammals and seabirds) and artisanal fishing take place near Ittoqqortoormiit and Ammassalik. Tourism is a growing industry.

Contaminants, such as hydrocarbons and heavy metals, are transported from other areas and have been documented in the food chain of the Greenland Sea (e.g., in polar bears). There is an ongoing program for oil exploration that can potentially develop into drilling and extraction if suitable hydrocarbon deposits are found in the area.

Fishing, boat traffic, and other anthropogenic pressures are more significant in Iceland and the Faroe Islands than in East Greenland.

Photo by: Lis Lindal Jorgensen. Institute of Marine Research, Norway

Beaufort Sea

Please refer to www.atlas.gc.ca to locate the specific geographic places mentioned.

Physical characteristics

This region is relatively shallow throughout, with an average depth considerably less than 200 m, and has two particularly shallow areas—Queen Maud Gulf and the boundary between Viscount Melville and Lancaster sounds.

Two different patterns of ice cover are present in this ecoregion. The northern part is characterized by the presence of pack ice, whereas the southern part has seasonal ice. Some data suggest that Viscount Melville Sound has a permanent ice cover, but the tracking of marine mammals in this area implies that there are enough gaps in the ice for them to breathe.

Biological characteristics

The most important biological feature in this ecoregion is the shallow-water boundary between Viscount Melville Sound and Lancaster Sound, which is also associated with a permanent plug of ice in Lancaster Sound west of Somerset Island. Combined, the shallow water and the ice plug create a boundary between western and eastern populations of belugas and possibly bowhead whales, and a western boundary to the narwhals from Lancaster Sound. This boundary area and its longitude to the south also correspond to a general boundary for seabirds and waterfowl, dividing populations that migrate in winter to western and eastern areas: e.g., common eider (*Somateria mollissima*), king eider (*Somateria spectabilis*), thick-billed murre (*Uria lomvia*), and northern fulmar (*Fulmarus glacialis*). The northern edge of this ecoregion also represents a boundary for marine mammals and seabirds, as this is where permanent ice cover begins. Both bowhead whales (*Balaena mysticetus*) and beluga whales (*Delphinapterus leucas*) are found in the Beaufort Sea, and belugas migrate into Amundsen Gulf and Viscount Melville Sound. Overall, this region contains a mix of Pacific and true Arctic species.

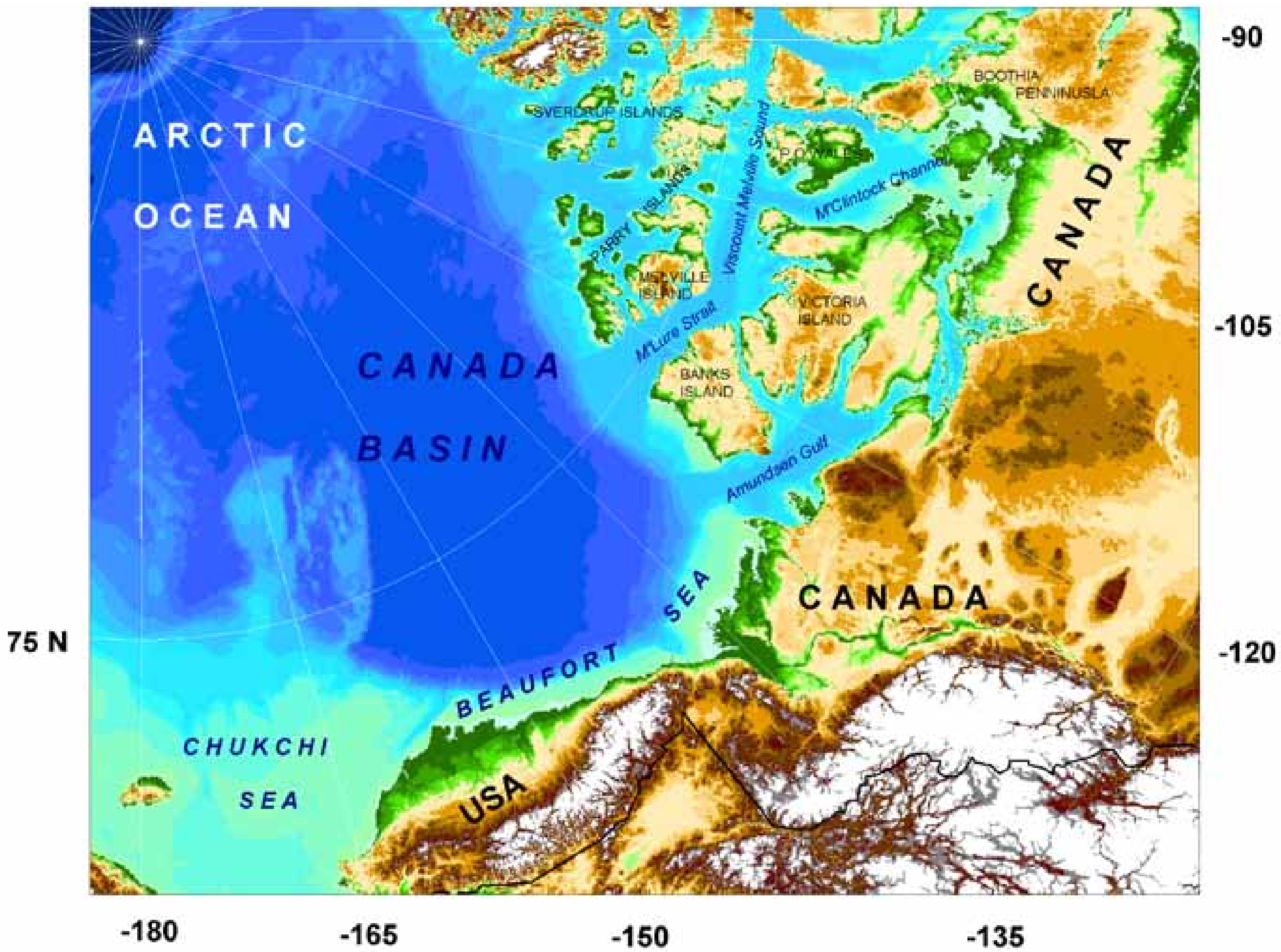


Figure 20 Beaufort Sea

The southern part of this ecoregion can be considered a subregion, based on freshwater influence and primary productivity. The Beaufort Sea is characterized by the presence of a polynya, which coincides with the Mackenzie River freshwater plume and the Beaufort gyre. Queen Maud Gulf also has a strong freshwater influence. High primary productivity in this region coincides with the Mackenzie River freshwater plume in the Beaufort Sea and extends into the Amundsen Gulf and partly into the Dolphin and Union straits.

Pressures

Several anthropogenic pressures affect this marine area in the western Canadian Arctic and these may be delivered in a site-specific or an area-wide fashion. Moreover, these pressures can interact to result in cumulative effects on this ecosystem. Site-specific pressures and their context include items 1-3 below. Area-wide pressures include items 4-6 below.

1. Hydrocarbon development and related infrastructure such as shipping have become an issue after a hiatus of approximately 20 years, with renewed interest in developing nearshore gas wells (and subsea pipelines) in the vicinity of the Mackenzie Shelf. Many ancillary activities causing ecosystem disturbance are expected to accompany increased exploration and development.
2. Nearshore subsistence harvests and fisheries for marine mammals, birds, and fish are of local concern. Overall, harvests are not large, are typically near to community locations, and are generally co-managed in a sustainable manner. At present, stocks of commercially viable species are not known to exist in the area, but this may change.
3. General shipping consists mostly of annual resupply to remote communities. Increased ship traffic associated with ecotourism (e.g., ice-strengthened charter ships) is occurring throughout the area. While so far there have been no serious grounding incidents (despite poorly charted waters) nor appreciable hydrocarbon spills, these could become major future stressors. Development of land-based metal mines and other non-renewable resources in the central Arctic may ultimately drive development of deepwater port construction and increased shipping.
4. Climate change and increased climate variability are perhaps the most significant overall stressors for the area because they are resulting or will result in significant follow-on effects, both directly and indirectly, upon this ecosystem: e.g., shoreline erosion, permafrost degradation, increased precipitation and freshwater inputs to marine areas. Ecosystem restructuring is likely underway in the area and will continue as climate change proceeds.
5. Contaminants and other pollutants are delivered through wide-scale airborne or waterborne mechanisms, and both of these are delivering persistent pollutants from more southerly areas. Land-based effects driven by climate change (e.g., permafrost degradation, slumping into freshwater systems) are likely delivering more nutrients and possibly more heavy metals to freshwater systems and into the marine environment via major north-flowing rivers.
6. Other potential stressors, such as ultraviolet radiation increases, may also be occurring. However, the significance of these stressors for the marine system is currently unknown. Introduction of invasive species (e.g., via ballast water exchange or inadvertent transport) is considered to be a risk. Local development may increase pressures on local renewable resources.

Arctic Basin

Physical characteristics

Geographically, the Arctic Basin is considered a deep basin of the central part of the Arctic Ocean, surrounded by several adjacent seas: the Kara, Laptev, East-Siberian, Chukchi, Beaufort, and Lincoln. It is customary to divide the Arctic Basin along the Lomonosov Ridge into two sub-basins: Eurasian and Amerasian.

The high latitudes are marked by the presence of a polar day and polar night whose duration increases in the direction of the geographical pole. As the Arctic Ocean is not symmetric relative to the pole, the amount of solar radiation (and heat) reaching the underlying surface is different in the Arctic Basin and on its periphery. An important climatic element of the average annual variation in air temperature in the Arctic Basin is its slight fluctuation in the time period from December to March, with no distinct annual minimum. Throughout most of the Arctic Basin, there are no time periods with a steady positive average daily temperature. However, the total time period with positive temperatures is sufficient for annual melting of the snow cover and partial melting of the ice cover.

An important characteristic of the Arctic Basin is the presence of permanent ice that remains after summer ice melting. In winter, seasonal ice returns to ice-free parts of the Arctic seas. At its maximum, sea-ice cover includes the Arctic Basin (4.47 million km^2) and areas of the Lincoln, Beaufort, Chukchi, East Siberian, Laptev, and Kara seas (3.96 million km^2), for a total of 8.43 million km^2. Because of the geographical position of the epicontinental seas of the North Atlantic (Greenland, Norwegian, Barents, and White seas), the Canadian Archipelago, and the North Pacific (Okhotsk and Bering seas), the seasonal sea ice formed in these areas is not part of the sea-ice cover balance in the Arctic Ocean. According to data from ice satellite observations in 1973-76 (NASA, 1987), permanent ice occupied 70-80% of the Arctic Basin area, and the interannual variability of this area did not exceed 2%. Seasonal ice occupied 6-17% (before the melting period of the mid-1970s). During the period of active sea ice melting, in the first decade of the 21st century, the permanent-ice area decreased to 6% in February 2008. However, recently the seasonal-ice area has been increasing rapidly (Figure 21).

There are two general directions of ice drift in the area: the Transpolar Drift, which moves from the western side of the Arctic Basin across the geographical pole and through the Fram Strait, and the clockwise Beaufort Gyre. A current experiment employing drifting-buoys (IABP) points to remarkable changes in direction and rates of ice drift in the Arctic Basin. In addition, the mooring experiment in the vicinity of the North Pole (NPEO) and time-series measurements during the IPY (PAICEX) show substantial variability in the transport of heat from warm Atlantic water to the ice.

Both sea ice and water of the upper Arctic Basin have recently been subject to remarkable climate variations. This leads to a number of important questions. How will recent warming in the Arctic affect the physical, chemical, and biological properties of the low-atmosphere/sea-ice/upper-ocean system? Do the recent remarkable shrinking and melting of permanent sea-ice cover, along with the warming and freshening of surface water in the Canadian Basin, connect with the same processes on the scale of the whole Arctic Ocean? Information about these questions is still insufficient. However, such knowledge is important for assessing the condition of Arctic sea-ice cover and for modeling climatic and ecological processes in the near future.

The North Pole region in the Arctic Basin is a key location for monitoring both environmental and biological change. Long-term science and action plans for the region need to be similar during the research period. In addition, field observations should, if possible, employ the same sampling strategies, field and lab equipment, methods of measurements, scheduled samplings, fixation, etc. The main priorities should be observations of snow, sea-ice cover, and the 0-1000 m water-column dynamic, including albedo measurements, CTD casts, hydrological samplings, and ecosystem studies.

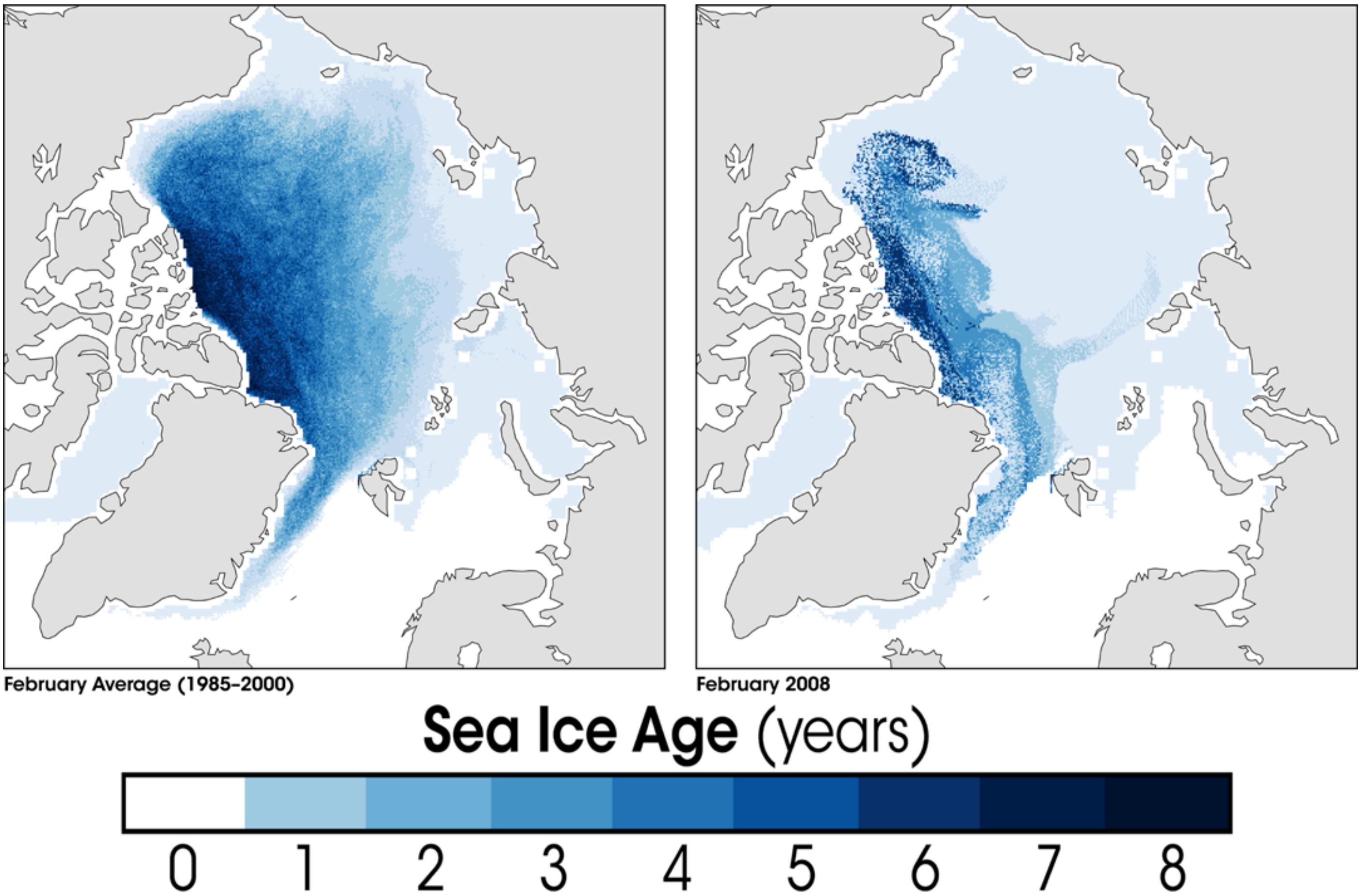


Figure 21 Arctic sea-ice age and extent in February 2008 (right) compared to the average for 1985-2000 (left).

The area and thickness of sea ice that survives the summer have been declining over the past decade. Whereas perennial ice used to cover 50-60% of the Arctic, it covered less than 30% in 2008—down 10% from 2007. The ice that remains is also getting younger. In the mid- to late 1980s, over 20% of Arctic sea ice was at least six years old; in February 2008, just 6% of ice was six years old or older. Source: *http://nsidc.org/data/seaice_index/n_plot.html*

Biological characteristics

Since Fridtjof Nansen's *Fram* expedition, it is well known that the Arctic Basin is inhabited by sea-ice microorganisms, phyto- and zooplankton species, fish, and benthic fauna. In the permanently ice-covered Arctic Basin, the organic energy requirements for the high-trophic-level organisms are supported by sea-ice flora photosynthesis during the short summer. Phytoplankton production is negligible in comparison to the sea-ice biota.

In a stable climate, permanent sea ice represents an integral stable ecological system with a constant species composition of flora and fauna. The system stability persists due to average equilibrium thickness supported by summer ice thawing from above and compensating winter ice growing from below. The ability of sea ice to retain its average equilibrium thickness, referred to as sea-ice-cover homeostasis, is of great ecological significance. On the geographical scale of the Arctic Ocean, the balanced relationship between regions of multi-year ice production and output from the basin, on one hand, and mechanisms maintaining a constant species composition of ice organisms within the vertical crystalline structure, on the other hand, determines the stability of the permanent sea-ice ecosystem in the Arctic Basin.

Observations carried out over the last decade revealed appreciable changes in the qualitative and quantitative composition of sea-ice biota in the Arctic Basin, compared to the mid-1970s. For example, the list of ice algae identified for the 1970s includes more than 200 species. In the most recent decade, the number of species is remarkably reduced. The prevalence of sea diatoms was a significant feature of sea-ice biota in the 1970s, but their domination greatly decreased in the past decade. The sea-ice fauna composition has also changed. Such mass representatives of protozoans and invertebrates as foraminifers, tintinninids, mites, nematodes, turbellarians, rotifers, copepods, and amphipods inhabiting the ice mass in the 1970s were rarely encountered in the last decade.

Recent reduction of sea-ice extent and decreasing ice thickness do not mean the complete disappearance of sea-ice cover in the Arctic Ocean. In fact, a reduction of multi-year ice surface leads to larger seasonally ice-free areas where ice forms in winter. Now, in the Arctic Basin, the structure of sea-ice cover is shifting from domination by multi-year ice to domination by seasonal ice. If this dynamic continues, the Arctic Basin will resemble the Southern Ocean, where seasonal ice is the dominant component, covering more than 80% of the ocean surface (Zwallhy *et al* 1983).

Pressures

Melting of sea ice has increased remarkably in the last decade. This suggests changes in composition, structure, and function of the sea-ice and upper-ocean ecosystems. Field observations in the Arctic Basin during the SHEBA experiment 1997-1998, the "Arctic-2000" expedition, ICEX-2003 ice camp expedition, North Pole-32, 33, 34 ice-drifting stations in 2003-2006, the icebreaker cruises by *Polar Stern*, *Healy*, and *Oden*, as well as observations conducted during the IPY 2007-2008, have revealed many changes at different environmental and biological levels. Such evolution could result in reorganization of the whole lower trophic structure of the ocean and affect the ecology and dynamics of marine ecosystems, including fish, birds, and mammals.

The central part of the Arctic Basin is not a region for fisheries or oil and gas exploration. However, this region has played and will continue to play a very important role in the redistribution of pollutants, due to ice drift and/or currents between coastal and shelf areas and the Arctic Basin peripheries, far from sources of pollution.

Photo by: Lis Lindal Jorgensen. Institute of Marine Research, Norway

Hudson Bay Complex

Please refer to www.atlas.gc.ca to locate the specific geographic places mentioned below.

Physical characteristics

This system is initially characterized by degree of enclosure, with the mouth of Hudson Strait as its eastern boundary and the Fury and Hecla Strait as its western boundary. Depth is approximately 200 m for Hudson Bay and Foxe Basin, with greater depth in Foxe Channel and Hudson Strait.

Figure 22 Hudson Bay Complex

Water flow unites the various parts of this ecoregion. Tides are an important physical oceanographic feature that control mixing in the whole complex. Another strong influence comes from the large input of freshwater from Quebec, with the plume starting in James Bay and following the Quebec coast to the north, all the way to the tip of Labrador. Because of this freshwater influence, stratification in Hudson Bay is from north to south and west to east. Ice cover in this system is seasonal, with the presence of two polynyas, one in northwestern Hudson Bay and another in northwestern Foxe Basin. Foxe Basin and Hudson Bay are characterized by cyclonic circulation systems.

Biological characteristics

One biological property shared throughout the system is high primary productivity. Productivity is low only in the center of Hudson Bay. This high productivity is partly the result of strong tidal mixing. There is also a change in *Pandalus* species at the mouth of Hudson Strait: *P. montagui* in the Strait, and *P. borealis* outside.

Although this system is treated as a single ecoregion, it contains several ecological subdivisions. In terms of species distribution, there is a southern distribution limit for Arctic-specialist waterfowl species, at the mouth of Foxe Basin. There are generally no seabirds in central Hudson Bay and Foxe Basin due to the absence of breeding cliffs, but they are present in Hudson Strait. These seabirds, mostly thick-billed murres, feed primarily on capelin (*Mallotus villosus*), sand lance (*Ammodytes spp.*), and benthic organisms. For marine mammals, bowhead whales are found primarily in Hudson Strait and Foxe Basin, whereas narwhals are found near Southampton Island, and beluga whales in Hudson Bay and Ungava Bay. Rosewellton Strait to the west of Southampton Island was historically an area of high bowhead harvests. Walrus (*Odobemus rosmarus*) are found in Foxe Basin and on the Coats and Mansel islands. Harbour seals (*Phoca vitulina*) are found from the northern shore of Hudson Strait and south into Hudson and Ungava bays. Ringed Seals are found throughout. Polar bears are found in three populations (Western Hudson, Southern Hudson and Foxe Basin). Shrimp (*Pandalus spp.*) and Greenland halibut (*Reinhardtius hippoglossoides*) occur in the Hudson Strait and Ungava Bay. On the basis of these distributions, three subregions could be defined: Hudson Strait, Hudson and James bays, and Foxe Basin. The area surrounding Southampton Island might be considered a fourth subregion.

Pressures

The main human drivers in Hudson Bay have been created by (past) commercial whaling and indirectly by global warming. The bowhead whale population that used the greater Hudson Bay region as a calving area was decimated by 1915. The bowhead population has partly recovered, leaving the ecosystem to respond to the initial removal of considerable living biomass responsible for consuming huge quantities of zooplankton and the current revival of consumption of the basal trophic level. Ecosystem ramifications are unknown.

There is continued loss of sea ice extent, thickness, and duration within the Hudson Bay region due to global warming. Understood ramifications include decreasing fitness of polar bears and seals and the displacement of Arctic cod as the primary forage fish by recent invasive species, sand lance and capelin. Another invasive species, the killer whale (*Orcinus orca*), arrived in the region around 1950 due to the loss of sea ice in Hudson Strait. The growing population of killer whales is thought to be creating considerable predation pressure on marine mammals such as bowhead, beluga, and narwhal whales.

With the loss of sea ice, the port of Churchill may become a significantly greater marine traffic destination. Increased ship traffic and oil and gas activity are considered likely; therefore, the risk of accidents in the future may be considerable.

The region is considered less productive than other sub-polar regions due to the large influx of freshwater and relatively shallow depths. An opportunity for increased primary production may occur in this region with global warming.

Hydroelectric developments in Québec and Manitoba have altered the flow-regime of freshwater to Hudson Bay and have also changed the physical-chemical characteristics of associated estuarine environments. Potential future hydroelectric developments could further alter marine ecosystems.

Davis Strait-Baffin Bay

Physical characteristics

The Davis Strait-Baffin Bay has a counter-clock wise current system, with relatively warm polar water mixed with Atlantic-influenced water flowing from the south along the Greenland coast, and cold water from the north via Nare Strait flowing southwards along the coast of Baffin Island. There are well-defined shelves on both sides of Davis Strait and Baffin Bay.

The Davis Strait-Baffin Bay region is characterized by the presence of seasonal ice, with the duration of the ice cover being longer on the western than eastern parts. During winter, sea ice covers Baffin Bay and the western part of Davis Strait. The limit of the winter sea ice on the eastern parts of the Davis Strait, along the coast of West Greenland is highly variable, but usually reaches south of Disko Island. Baffin Bay includes a large polynya, known as the North Water and located between the Canadian islands of Ellesmere and Devon and the coast of Qaanaaq in northwest Greenland. Sea ice from East Greenland drifts with the current northwards from the southern tip of Greenland in Cape Farewell and along the coast of Southwest Greenland.

The coast of Baffin Island is strongly influenced by tides and the input of freshwater. The southern boundary of Davis Strait is associated with the northern limit of a warm deepwater mass; the boundary was drawn from north of Cumberland Sound (Cape Dyer) to Greenland.

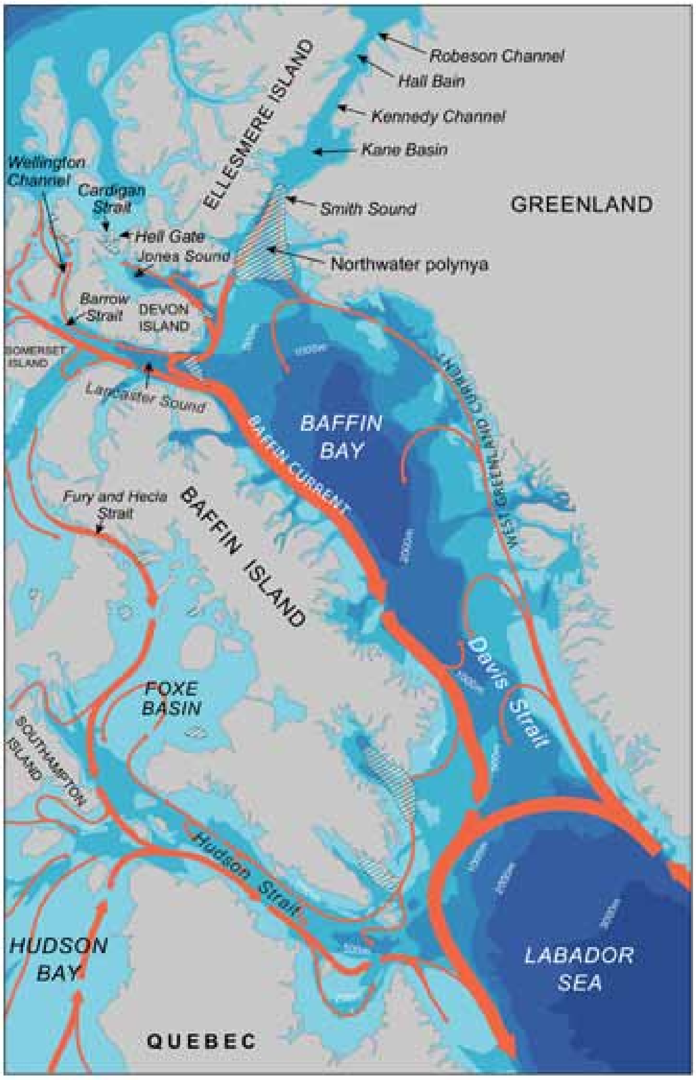


Figure 23 Surface currents west of Greenland and east of Baffin Island.
Source: G. Lichota

Biological characteristics

On the Canadian side, primary productivity is relatively high in Lancaster Sound, Prince Regent Inlet, and at the entrance of Admiralty Inlet, all along the northern and eastern coasts of Baffin Island, and becomes substantially lower offshore. On the Greenland side, primary production is high in several areas over the continental shelf, including Disko Bay and the fishing banks of West Greenland. In the eastern Davis Strait, there are differences in plankton community structure and in chemical and physical gradients between the offshore West Greenland Current system and the inland regions close to the Greenland Ice Sheet. The fishing banks of West Greenland are rich in benthic fauna.

Polar cod (ice-associated) and capelin (ice-free waters) are key species for the transfer of energy from zooplankton to higher trophic levels. Davis Strait and Baffin Bay are home to commercially important stocks of Greenland halibut and shrimp, while along the west coast of Greenland there are locally important fisheries of Greenland halibut, snow crab, Atlantic cod, lumpfish, Greenland shark and capelin.

Seabirds, belugas, and narwhals are present throughout Lancaster Sound. Their western distribution ends at the shallow water/ice plug boundary with the Viscount Melville region. Marine mammals (belugas, narwhals) and seabirds migrate seasonally from Lancaster Sound to the eastern coast of Baffin Island and, further, to the offshore parts of Davis Strait-Baffin Bay and the west coast of Greenland. The presence of seabirds and marine mammals in West Greenland is regulated by the seasonal arrival and retreat of sea ice. Polar bears, walrus, and a number of bowhead whales move with the ice from Baffin Island towards West Greenland during winter and return to Canadian waters during summer. A few polar bears remain in West Greenland during summer. Between Ellesmere Island and Qaanaaq, at the northernmost part of the area, there are polar bears from the Kane Basin subpopulation year-round. There are summering stocks of narwhals in Melville Bay, Inglefield Bredning, and Smith Sund. Other

small cetaceans and rorquals are abundant in West and Southwest Greenland when sea ice is absent. Ringed seals, bearded seals, harp seals, and hooded seals are abundant, either seasonally or year-round, depending on the area.
High concentrations of eider and king eider winter on the North Water polynya and in open waters of mid- and southwest Greenland. During summer, there are globally important concentrations of thick-billed murre and little auk in Northwest Greenland. At least a hundred million (adults and juveniles combined) seabirds utilize the Baffin Bay area in August and early September.

The southwest boundary (i.e., Canada), identified by bottom-water temperature, also corresponds to limits in the distribution of Arctic marine mammals(*) and of large colonies of northern fulmars and black-legged kittiwakes (*Rissa tridactyla*).

Pressures

The distribution of marine fauna could be affected by climate change, including the expansion of ranges northward, and introduction of species. The loss of sea ice associated with climate change may increase shipping in the Arctic, and related activities could have unfavorable environmental impacts. These include the release of substances through emissions to air or discharges to water, accidental releases of oil or hazardous cargo, disturbances to wildlife through sound or sight, collisions with whales or birds attracted to lighted ships, and the introduction of invasive alien species in ballast water and cargo, as well as via hull fouling. Unfavorable environmental effects are also associated with the development of shipping infrastructure, such as dredging shipping lanes and port construction.

Hydrocarbon development and related infrastructure also pose a threat to Arctic ecosystems, as discussed in previous sections. Seismic activity, construction of artificial islands and ice roads in shallower areas, dredging, shipping, and over-wintering of heavy equipment all are anticipated as this activity increases in degree and scope. The nature and consequences of activities in deeper water on the shelf break to the Arctic Basin remain unknown at present. The ever-present threat of an oil spill under ice is an unknown risk.

Commercial fisheries for Greenland halibut and shrimp have the potential to affect the abundance of these species. There are also risks related to bycatch associated with this activity. Trawling and deep-sea gillnets may affect deepwater corals. In West Greenland, cod has been depleted due to overfishing coupled with adverse climatic conditions in the past. The stock may be recovering, but fishing pressure still exists, although more regulated than before.

Potentially unsustainable subsistence harvest of seabirds and marine mammals has been a concern in recent years, especially in West Greenland, where the human population is larger. However, most harvests are now considered sustainable due to increase of hunting regulations, together with intensified monitoring and/or decrease of catches due to climate change or cultural and economical reasons. If the scientific assessments are correct, the combined catches of Canada and Greenland of some shared populations of polar bears and walruses are still unsustainable.

* Bowhead whale, narwhal, beluga, and walrus

Kara and Laptev Seas

Physical characteristics

Kara Sea

The Kara Sea is a shelf sea occupying 883 000 km^2 and bounded by Novaya Zemlja, Franz Josef Land and Severnaya Zemlja archipelagos, Vaygach Island, and the mainland to the south (Figure Figure). The sea has an average depth of 111 m, with maximal depth of 600 m in the Saint Anna Trough in the north. For eight months of the year, the sea is covered by ice and is characterized by highly variable physical and biogeochemical processes. Open water occurs in the form of a polynya that extends as a narrow belt from the southwest nearshore area to the northeast, from Dickson Peninsula to the northern part of Severnaya Zemlja. The two largest Siberian rivers, Ob and Yenisey, as well as a great number of medium and small rivers, bring about 1350 km^3 of water into the sea and more than 150 million tons of suspended and dissolved organic and inorganic matter annually.

The Kara Sea connects with the adjacent Barents and Laptev seas and has an open boundary with the Arctic Basin. The considerable influence of freshwater inflow means that the Kara Sea is well stratified throughout the year. The water-column structure of the sea is very complex and variable. The river-plume area in the central part of the sea constitutes a vast frontal zone where waters of different origin interact and mix. Historical and new data obtained during the Russian-German expeditions have been used to delineate the major water-mass types in the Kara Sea. Earlier suggested classifications list six water masses in the Kara Sea: river waters, surface Arctic waters of the Kara Sea, Barents Sea waters, winter surface waters, deep Atlantic waters, and bottom waters. The word *waters* is a synonym for the term *water mass*, rather than a type of water mass. A great number of water masses in the Kara Sea can be separated into several types according to their position in the structural zones and the places and time of their formation.

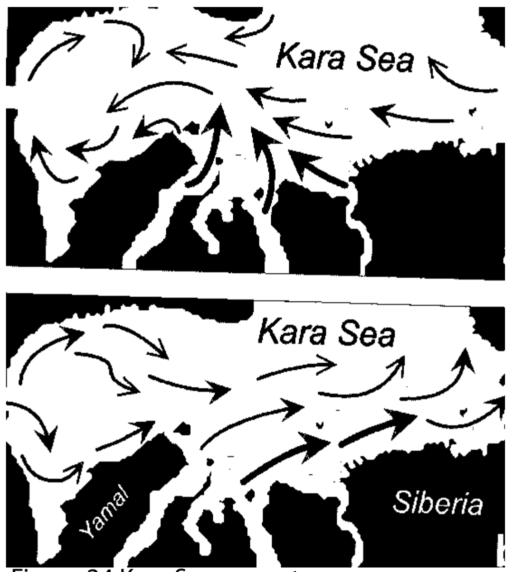


Figure 24 Kara Sea currents

The Kara Sea is characterized by cyclonic circulation in the western part of the sea and by coastal currents in the eastern part. The direction of the coastal current can reverse, depending on the time of year and intensity of freshwater discharge (see Figure).

Laptev Sea

The Laptev Sea is a high-Arctic, epicontinental sea north of Siberia (Russia), comprising 662 000 km^2. The average depth is 553 m, with a maximal depth of 3358 m. It is characterized by a broad shelf plateau and a high influx of river water. Annual discharge to the Laptev Sea from the Lena, Yana, and other rivers is around 600 km^3. The sea is covered by ice from October to May. Formation of a narrow polynya off the fast-ice edge during winter is a typical feature of the Laptev Sea. This polynya extends into the coastal waters of Severnaya Zemlja, the mainland, and Novosibirskiye Islands. The Laptev Sea connects with the adjacent Kara and East Siberian seas by a system of straits and has an open boundary with the Arctic Basin.

The oceanographic regime of the Laptev Sea is characterized by features typical of other marginal Arctic seas. These features include severe climate, ice cover, intensive desalination in summer (due to river run-off and ice melt), and extensive transformation zones between water masses of different origins and considerably different characteristics. The Laptev Sea follows a cyclonic circulation pattern. The oceanographic regime of the Laptev Sea has its own unique features, which are different from the other seas of the Arctic. These features include different water structures in the eastern and western halves (Arctic surface waters and Atlantic deep waters prevail in the western part, while the waters of the continental run-off play a major role in the formation of the hydrological regime in the eastern part), as well as the presence of an extensive water area occupying the largest portion of the sea.

Kara Sea

In general, the productivity of the Kara Sea is low. The exception is the sea's southern coastal area, which coincides with the position of the Great Siberian polynya. In this area, estuarine zones in coastal bays have generally high phytoplankton productivity and biomass. Strong differences in species composition exist between the rivers, estuaries, and the open Kara Sea. The yearly fluctuation of freshwater discharge from both rivers seems to have the strongest influence on the timing and duration of phytoplankton blooms, species composition, and biomass standing stocks during summer. Zooplankton biomass is apparently not related to phytoplankton abundance and follows closely the hydrographic regime. Large *Calanus* species dominate the community in marine waters. Smaller copepods inhabit the brackish-water regions. Neither area is characterized by high secondary productivity. Species number, abundance, and diversity of macrobenthos increase from the estuarine bays in the south towards the open Kara Sea and reach the highest values in the area corresponding to the location of the Great Siberian polynya. Macrobenthic biomass is well correlated with production processes in the overlying water column.

Polar cod is the most biologically important fish species. It forms ecological links between invertebrates, upon which it preys, and mammals and birds. Other species with high ecological importance are the Omul, Muksun, and Siberian sturgeon in the inner reaches of the bays. However, the locations of migration routes, foraging areas, and spawning grounds for many fish species are not yet known.

The most abundant species of marine birds are black-legged kittiwake, ivory gull, and thick-billed murre (Brunnich's guillemot). The largest colonies are located on the coast of the northernmost islands of Novaya Zemlja and Severnaya Zemlja archipelagoes. Also, several species of goose and eiders inhabit coastal areas of the Novaya Zemlja, Severnaya Zemlja, and small islands in the sea.

Polar bear and walrus are found in this region. Both are red-listed species in the Russian Federation's Red Book. Polar bears are distributed over the whole Kara Sea area, with the highest concentrations in the vicinity of Novaya Zemlja and along the polynya zone. The largest walrus populations are found in the northern part of the sea between Franz Josef Land and Severnaya Zemlja. The ringed seal is the most abundant seal species. Abundance estimates range between 2.3 and 7 million individuals. Ringed seals are found across the entire region, with the greatest concentrations located along the coastal areas of Novaya Zemlja and along the Great Siberian polynya. Large numbers of beluga whales are found in most areas of the sea in summer and in the southwestern part of the sea and north of Northern Island of Novaya Zemlja in winter.

Laptev Sea

Three ecological zones are distinguished in the Laptev Sea. Their locations correspond with the distribution of the main water-mass types. The gradients in water characteristics result in gradients in the locations of pelagic and benthic communities. In general, high *Chl a* concentrations in the sediments indicate a tight correlation between pelagic primary production and nutrient supply to zooplankton and zoobenthos. Primary production during the ice-free summer is highest in the southeastern area, which is strongly influenced by the Lena River. Primary production is lower in the western and northeastern Laptev Sea by factors of 2 and 4, respectively. Ecological zones differ by intensity of zooplankton secondary-production formation. The northeastern region has the lower zooplankton biomass. The richest areas for zooplankton are found in places influenced by freshwater discharge. Zoobenthos biomass is relatively low in the northern and eastern parts of the sea. Biomass increases in the areas where polynyas occur. Benthic biomass increases are found in areas influenced by freshwater discharge, which are enriched by allochthonous organic matter.

As in the Kara Sea, polar cod is the most abundant marine fish species. Anadromous whitefish Omul and Muksun are quite abundant in the estuaries of the Lena, Yana, and other rivers, where they are fished commercially. Locations of migration routes, feeding areas, and spawning grounds for many fish species are poorly understood in the Laptev Sea.

The most abundant species of marine birds are black-legged kittiwake, ivory gull, and thick-billed murre (Brannich's guillemot). The largest colonies are located on the Bol'shoy Begichev Island in the southwestern part of the sea and on the Belkovskiy and

Stolbovoy islands in the eastern part of the sea. Several species of goose and eider inhabit coastal areas of the Taymyr peninsula, Severnaya Zemlja and Novosibirskiye Islands, as well as small islands in the sea.

Polar bear and walrus are generally common across the entire region. The ringed seal is the most abundant seal species in the Laptev Sea and is found across the entire region in high concentrations.

Pressures

Kara Sea

The main driver in the Kara Sea is freshwater discharge. River discharge influences vary, most commonly being thermal influx, salinity decrease (freshening), additional import of dissolved and suspended organic and inorganic matters into the sea system, and limitation of energy and matter exchange between different water layers due to pycnocline formation.
Climate change is expected to result in changes in freshwater discharge and suspended matter discharge. The latter is expected to increase due to melting of permafrost and abrasion of coastal areas.

Human impacts on these ecosystems are primarily restricted to shipping traffic related to oil and gas activities. These activities cannot currently be regarded as prime drivers, but future impacts, such as oil spills, may be considerable if intensive exploitation of gas and oil fields continues. At present, the area is relatively pristine with little pollution. The most significant source of pollutants is river discharge.

Laptev Sea

Currently, the main driver in the Laptev Sea is freshwater discharge. River run-off has its greatest influence in the southeastern region of the sea.

Climate change is expected to alter the freshwater discharge into the Laptev and Kara seas. Also, abrasion of coastlines due to melting permafrost will increase the amount of suspended matter, thereby decreasing water transparency and lowering productivity in the coastal zones.

In general, the Laptev Sea is mostly pristine, with the exception of high concentrations of pollutants around Tiksi village. Human impact in the area is largely from shipping traffic.

Photo by: Greenland Climate Research Center

Appendix D.
Research Needed to Support Monitoring

*The successful development and implementation of any ecological monitoring program is totally dependent on a wide and deep knowledge base. Parameters and indicators need to be both precise and robust to feed monitoring programs with information of necessary quality, and precision and robustness are qualities only achievable through good and focused research. Causal chains need to be established with a maximum level of certainty, and uncertainty need to be properly addressed and quantified. And still, once an indicator has been chosen, it requires a constant research effort to support its validity and maintain robustness against conditional changes (e.g., research policies, management regimes, new knowledge or new impact factors). It is the often rigorous, but necessary, requirements to the scientific foundation of indicators that makes long-term and successful monitoring so hard to accomplish.

As CBMP primarily makes use of existing monitoring programs or activities, the program itself escapes the enormous costs and logistical demands associated with establishing monitoring activities that depend on the development of new indicators. Still, as already mentioned, all monitoring programs have to address and facilitate research needed to maintain the quality of the chosen indicators. In this plan, research needs have been identified by Focal Ecosystem Component, Arctic Marine Area, and driver. The following provides a partial overview of the identified research needs. Different research needs for the same component, but different drivers, have been pooled.

FEC Sea-ice, Phyto- and zooplankton

Atlantic Arctic Gateway

Recommended research:

Physical part of the ecosystem

The following requirements, mostly related to funding, were identified through the selection process of indicators for the Management Plan for the Barents Sea:

Needs for data collection/data processing:

- Collection and calculation of data on the latitude of the ice edge need to be secured through long-term funding.
- The time series “Monthly volume flux in the Bjørnøya–Fugløya section” is in need of more regular funding.
- There exist data from numerous research cruises, but calculation of maps showing area coverage of Atlantic/Arctic water masses in the Barents Sea indicates that resources must be allocated before it becomes a regular time series.

Biological part of the ecosystem

The following knowledge gaps and needs for additional funding (compared with the status in 2010) were identified through the selection process of indicators for the Management Plan for the Barents Sea:

Needs for research/monitoring:

- It is necessary to get a better understanding of factors influencing the phytoplankton dynamic, including area-specific variations, before measures of phytoplankton biomass can be used as a management tool in the Barents Sea. However, phytoplankton is important as supplementary information when combined with other indicators.
- A formal analysis is needed to establish the relationship between the timing of the spring bloom and food availability for higher trophic levels. Also, ways in which biomass of phyto- and zooplankton can be used to predict living conditions for higher trophic levels need to be explored.
- Further analysis and research are necessary to establish the relationship between the zooplankton community structure as an indicator and the environment (climate, NAO, AO, current flow). In this regard, species-level identification of the entire community is essential for at least a subset of existing broad-scale programs.
- The use of satellite data as part of an indicator needs to be elaborated, especially how to best combine these data with other parameters. Satellite data also need to be further compared with measured data in order to evaluate their value as predictors for the environmental condition.

Note: the research needs assessment was not comprehensive nor consistent between Arctic Marine Areas. With this in mind, it is important that these lists be seen as preliminary.

- A threshold level to trigger management action is probably not relevant for indicators on phyto- and zooplankton, but time series should allow the establishment of a "normal" range of values once the time series is better understood. However, considerable research will be needed in order to establish more specific threshold levels, if this is at all possible.
- Analyses of the sensitivity and statistical properties of most of the selected indicators will require a dedicated project. It should, as far as possible, be limited to indicators that will actually be used.
- Existing computer models that can provide detailed simulations of hydrographic conditions and production of phytoplankton and zooplankton need to be further developed and validated against historical data before they can prove to be a cost-efficient way both to provide historical data-series and to give almost real-time information about the present situation.

Needs for data collection/data processing

- A more comprehensive sampling program for chlorophyll *a* needs to be established.
- The use of existing remote sensing information on chlorophyll *a*, temperature, salinity, and sea ice should be investigated in order to reconstruct historical series.
- Based on existing data, a time series of the NO_3/SiO_4 ratio in water samples collected from the Bjørnøya–Fugløya section can be constructed back to 1982, and may give information for each year since then about whether diatoms or flagellates dominated in the year's spring bloom. In the future, this should be a regular time series.

Pacific Arctic Gateway

Recommended research:

- Measure phytoplankton production seasonally in relation to hydrographic conditions
- Seasonal progression of community composition, rates of zooplankton production
- Measure ice algal production in relation to ice conditions, ice cores in FY and MY ice, periodically species composition
- Biomass, species composition, sediment composition and carbon/chl tracers, hydrography (macrofauna)
- Experimental studies on temperature tolerance, population genetics (megafauna)
- DNA barcoding to establish species identity and endemism in collaboration with taxonomists

Beaufort Sea

Research needs have yet to be identified, but anticipated to be similar to those for the Pacific Arctic Gateway.
Arctic Basin

Recommended research:

- Measure phytoplankton production seasonally in relation to hydrographic conditions
- Measure zooplankton species composition and community structure under different situations regarding phytoplankton densities and temperature. With special attention to deep water communities in the Central Arctic Basin. DNA barcoding to establish species identity and endemism in collaboration with taxonomists
- Seasonal zooplankton net catches in the vicinity of the North Pole for species identification at standard water depth
- Sea-ice biota: Time-series data on environmental conditions, biodiversity, production and trophic structure of sea ice-upper ocean ecosystem;
- Sea-ice biota: Pollution impact on biota and redistribution of contaminants by drifting ice;
- Sea-ice biota: Standardization and intercalibration methods are needed

Hudson Bay Complex

Research needs have yet to be identified, but anticipated to be similar to those of other FECs.

Davis Strait-Baffin Bay

Recommended research:

- Establish zooplankton community structure and diversity, and nutrient/productivity fluxes; survey communities over space and time;
- Apply new technology (e.g., plankton recorders, acoustic techniques);
- Establish sampling transects in several areas; develop new approaches to monitor diversity of gelatinous zooplankton;
- Apply new technological tools (e.g., molecular biology)

FEC Benthos

Atlantic Arctic Gateway

Recommended research:

- Continue or establish long-term and large-scale data series, particularly coverage of hotspots or lowspots in biodiversity/production,
- Investigation of changes in and on sediments and to benthic communities (pre-and post-crab periods, pre- and post-trawling periods)
- Investigation of the impacts of the main causes of habitat destruction in the AAG area
- Investigation of the impacts of fishing and harvesting on benthic macro/megafauna

Pacific Arctic Gateway

Research needs have yet to be identified.

Beaufort Sea

Recommended research:

- Measure species composition and community structure (e.g., species dominance, proportion of filter vs sediment feeders) + estimate of biomass with respect to ice cover + use also sediment trap to know what reaches the floor and when. This should be done closer to the bottom than has been done so far. Should be coordinated with taking of phytoplankton and zooplankton sampling at the same localities. DNA barcoding to establish species identity and endemism in collaboration with taxonomists (there is lack of expertise in Canada)

Arctic Basin

Research needs have yet to be identified.

Hudson Bay Complex

Research needs have yet to be identified.

Davis Strait-Baffin Bay

Recommended research:

- Establish benthic community structure and diversity and nutrient/productivity fluxes; map and census sessile and vulnerable species and communities (e.g., corals); develop and apply new technology (e.g., increased sediment traps/moorings; benthic video monitoring using remote vehicles); establish benthic sampling transects in several areas
- Establish benthic community structure and diversity; examine effects of trawling; map and census sessile and vulnerable species and communities (e.g., corals); develop and apply new technology (e.g., benthic video monitoring using remote vehicles)

FEC Fish

Atlantic Arctic Gateway

Research needs have yet to be identified.

Pacific Arctic Gateway

Recommended research:

- More sampling on different ice features, distribution in seasonally ice-covered areas (Arctic cod)
- Population genetics of Walleye Pollock
- Population genetics of Salmon

Beaufort Sea

Research needs have yet to be identified.

Arctic Basin

Recommended research:

Under ice observations are needed in seasonally ice-covered areas (Arctic cod)

Hudson Bay Complex

Research needs have yet to be identified.

Davis Strait-Baffin Bay

Recommended research:

- Research regarding the relevant ecosystem structure and function over the diversity and scale of this system
- Research regarding impacts of fishery on targeted and non-targeted spp and habitats. Research on ecosystem structure, function and productivity is required

FEC Seabirds

Atlantic Arctic Gateway

Recommended research:

- Feasibility study for the use of loggers to map seabird dispersal
- To study effect of climate change upon habitat selection and foraging of seabirds
- To study combinted effect of climate change, contamination and pathogens on seabird populations health

Pacific Arctic Gateway

Recommended research:

- Improved sampling of sea ice distribution and of prey-ice associations for chick rearing (i.e., constraints of central-place foragers); information from local communities, stomach content analysis

Beaufort Sea

Recommended research:
Link between nesting and feeding, feeding ecology. Telemetry tracking
Need more research on toxicological endpoints in Arctic species and potentially in this region

Arctic Basin

Recommended research:

- Direct and remote sensing of birds at the ice camp platforms and during the shipping in the High Arctic

Hudson Bay Complex

Research needs have yet to be identified.

Davis Strait-Baffin Bay

Recommended research:

- Research into the areas noted in above box. Lipid content and quality and abundance in main prey organisms. Seabird foraging ecology and linking this to fish ecology during seabird breeding season
- Population delineation and vital rates need to be determined. Disturbance effects require research

FEC Marine Mammals – Polar Bears

Atlantic Arctic Gateway

Recommended research:

- Movements
- Abundance
- Body condition

- Prey (e.g., abundance of prey)
- Population structure
- Analysis of fat, blood and other organs

Pacific Arctic Gateway

Recommended research:

- Improved sampling of movement patterns and habitat selection relative to sea ice from satellite tag tracking, information on bear occurrence in atypical habitats (e.g., beaches) from local communities

Beaufort Sea

Research needs have yet to be identified.

Arctic Basin

Recommended research:

- Improved sampling of movement patterns and habitat selection relative to sea ice from satellite tag tracking

Hudson Bay Complex

Research needs have yet to be identified.

Davis Strait-Baffin Bay

Research needs have yet to be identified.

FEC Marine Mammals: Walrus, Seals, and Whales

Atlantic Arctic Gateway

Recommended research:

- Sea ice monitoring, related to ringed seal condition and reproduction, distribution, movement
- Estimate bowhead whale population size and structure and identify important habitat

Pacific Arctic Gateway

Recommended research:

- Improved sampling of sea ice distribution, and of ice-type requirements from remote sensing and on-site evaluation, continued satellite tag tracking to determine habitat use/selection, information from local communities including body condition, tissue samples & stomach content analysis (Walrus and Ringed seal)
- Improved sampling of sea ice, hydrography & wind influence on regional production and advection re. prey availability (species and abundance), continued satellite tag tracking of seasonal movements and habitat use/selection, information from local communities including body condition, tissue samples & stomach content analysis – Bowhead & belugas

Beaufort Sea

Recommended research:

- Sea-ice, phytoplankton, zooplankton and benthic community structures, trophic structure, whale community structure. Whale migration, distribution and feeding ecology. Whale health, nutritional status (Arctic whales)

Arctic Basin

Recommended research:

- Improved sampling of sea ice distribution, and of ice-type requirements from remote sensing, continued satellite tag tracking, stomach content analysis (Ringed seal)

Photo by: Kári Fannar Lárusson

Hudson Bay Complex

Research needs have yet to be identified.

Davis Strait-Baffin Bay

Recommended research:

- Establish tighter linkages between sea-ice and MM population dynamics; interaction between habitat use and climate change drivers is required. How do sea-ice habitat changes affect individuals, population vital rates and ecosystem structure/function
- Population dynamics in context of harvest levels; interaction between harvest and climate change drivers is required. Population delineation (stock structure) migrations and habitat use require research
- Comparative research across range of communities experiencing differing degrees of regional development

FEC Humans

Atlantic Arctic Gateway

Research needs have yet to be identified.

Pacific Arctic Gateway

Recommended research:

- Research on impacts of decreasing ice on traditional food sources, research on threats to humans of changing sea ice characteristics, research on ability of humans to reach traditional food source under conditions of sea ice loss, including those factors that affect their capacity to get into the marine environment (e.g., cost of fuel, availability means of transportation), research on humans response to and strategies for adapting to and coping with sea ice loss
- Signs of ill health and disease in traditional food sources, time series measuring of traditional foods for mercury, PCBs, POPs, and other metals coordinated with micro-climate, regional-climate, and global-climate changes, bio-monitoring in humans, surveys of human food sources and analyses of why they shift, nutritional content of foods and nutritional status of humans, demographic shifts related to subsistence food problems
- Research on changes in local human communities' diets due to shifts in absence/presence of foods harvested from the marine environment, research on humans strategies for adapting to and coping with changes in available foods

Beaufort Sea

Research needs have yet to be identified.

Arctic Basin

Research needs have yet to be identified.

Hudson Bay Complex

Research needs have yet to be identified.

Davis Strait-Baffin Bay

Recommended research:

- Impacts of changing sea ice conditions on prey availability. Integrating RS data with TK on sea ice conditions at varying scales

Appendix E.
Workshop Participants

Workshop 1

Workshop 1 was held in Tromsø, Norway, on January 17-18, 2009. Following is the list of participants:

Mike Gill	Circumpolar Biodiversity Monitoring Program
Jason Stow	Arctic Monitoring and Assessment Programme
Jill Watkins	Canada
Eddy Carmack	Canada
Jim Reist	Canada
Steve Ferguson	Canada
Grant Gilchrist	Canada
Scot Nickels	Canada
Philippe Archambault	Canada
Sarah Adamowicz	Canada
Connie Lovejoy	Canada
Kathy Crane	USA
Sue Moore	USA
Hajo Eiken	USA
Peter Thomas	USA
Russ Hopcroft	USA
Katrin Iken	USA
Kitty Mecklenburg	USA
James Berner	USA
Andrea Grant Friedman	USA
Jackie M. Grebmeier	USA
Sergei Pisarev	Russia
Igor Melnikov	Russia
Renat Gogorev	Russia
Olga Pronina	Russia
Ksenia Kosobokova	Russia
Nina Denisenko	Russia
Yuri M. Yakovlev	Russia
Maria Gavrilo	Russia
Reidar Hindrum	Norway
Dag Vongraven	Norway
Ingrid Bysveen	Norway
Per Arneberg	Norway
Mats Granskog	Norway
Cecilie von Quillfeldt	Norway
Paul Wassmann	Norway
Hallvard Strøm	Norway
Knut Sunnanå	Norway
Geir Gabrielsen	Norway
Sabine Cochrane	Norway
Hein Rune Skjoldal	Norway
Geir Gabrielsen	Norway
Jon Aars	Norway
Fernando Ugarte	Greenland/Denmark
Aili Labansen	Greenland/Denmark
Morten Frederiksen	Greenland/Denmark
Anders Mosbech	Greenland/Denmark
Doris Schiedek	Greenland/Denmark
Aever Petersen	Iceland

Workshop 2

Workshop 2 was held at the Biltmore Hotel, Coral Gables, Miami, Florida, USA, on November 3-6, 2009. Following is the list of participants:

Kristine Arendt	Greenland Climate Research Centre
Per Arneberg	Norwegian Polar Institute
Carin Ashjian	Woods Hole Oceanographic Institution
Ingrid Bysveen	Directorate for Nature Management
Natalia Chernova	Zoological Institute of the Russian Academy of Sciences
Kathleen Crane	NOAA
Nina Denisenko	Zoological Institute of the Russian Academy of Sciences
Mike Gill	Circumpolar Biodiversity Monitoring Program
Jakob Gjøsæter	Institute of Marine Research
Jackie Grebmeier	University of Maryland
Gudmundur Gudmundsson	Icelandic Institute of Natural History
Reidar Hindrum	Directorate for Nature Management
Russell Hopcroft	University of Alaska
Katrin Iken	University of Alaska Fairbanks
Lis Jørgensen	Institute of Marine Research
Ksenia Kosobokova	Shirshov Institute of Oceanology
Aili Labansen	Greenland Institute of Natural Resources
Gillian Lichota	NOAA
Erlend Lorentzen	Norwegian Polar Institute
Connie Lovejoy	Laval University
Henrik Lund	Greenland Institute of Natural Resources
Catherine Mecklenburg	Point Stephens Research
Igor Melnikov	P.P.Shirshov Institute of Oceanology
Sue Moore	NOAA/Fisheries
John Nelson	Fisheries and Oceans Canada
Clarence Pautzke	North Pacific Research Board
Sergey Pisarev	Shirshov Institute of Oceanology
Loretta Quinn	UCAR/JOSS
Jim Reist	Fisheries and Oceans Canada
Hein Skjoldal	Rune Institute of Marine Research
Jason Stow	Indian and Northern Affairs Canada
Yury Sychev	Polar Foundation
Cecilie Von Quillfeldt	Norwegian Polar Institute
Dag Vongraven	Norwegian Polar Institute
Rik Wanninkhof	NOAA
Jill Watkins	Fisheries and Oceans Canada

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