SCIENCE ADVICE FOR IDENTIFYING INDICATORS FOR MONITORING ARCTIC MARINE BIODIVERSITY IN CANADA

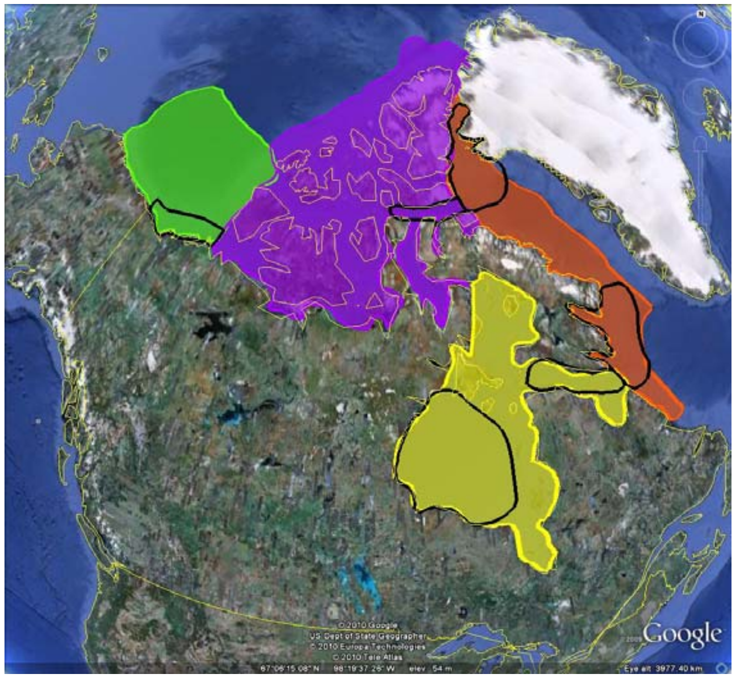

Figure 1: Focal Marine Areas with priority subregions. Focal marine areas defined as follows: Beaufort Sea (green), Canadian Arctic Archipelago (purple), Hudson Complex (yellow), Davis Strait/Baffin Bay (orange). Priority sub regions are outlined in black.

Context:

Arctic marine biodiversity is under growing pressure from climate change and resource development, among other stressors. Under the Arctic Council, the Conservation of Arctic Flora and Fauna (CAFF) working group has agreed to coordinate efforts to detect and understand long-term change in Arctic marine ecosystems and key biodiversity elements. The intent is to develop and recommend a suite of indicators that can be used to monitor changes in Canadian Arctic biodiversity based on current or existing information and monitoring programs, if available. As directed by the CAFF, the Circumpolar Biodiversity Monitoring Program – Marine Plan (CBMP-MP) calls for the construction of marine biodiversity baselines for sea-ice biota, plankton, benthic organisms, fishes, seabirds, marine mammals, and polar bears. Since the mandate for the CBMP program extends beyond Fisheries and Oceans Canada (DFO), Environment Canada experts contributed to this advice. This will serve as one of the initial steps towards the goal of improving our understanding of temporal and spatial changes and variability in biodiversity for the assessment of Arctic marine systems and provide CAFF with future baseline information and periodic status and trends reporting for the Canadian Arctic.

A National peer-review process was held February 6-8, 2012 at the Freshwater Institute in Winnipeg, Manitoba on Identifying indicators for monitoring Arctic marine biodiversity in Canada*. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.*

SUMMARY

- The objectives of this science peer review process were to: 1) refine an existing "long list" of parameters and indicators recommended in the Circumpolar Biodiversity Marine Program - Marine Plan (CBMP-MP) for monitoring of Arctic marine biodiversity, 2) recommend a feasible temporal sampling scheme based on information available for individual indicator analyses, and 3) investigate the availability of existing usable data and identify information gaps which can inform future monitoring and research efforts.

- Biodiversity parameters are identified and marine biodiversity indicators are recommended for each of the following focal ecosystem components (FEC): microbes and phytoplankton, metazoan zooplankton, sympagics (i.e., sea-ice biota), benthic organisms (including corals and sponges), seabirds, fishes, and marine mammals (including polar bears).

- Biodiversity parameters to be monitored for microbes and phytoplankton, metazoan zooplankton, and sympagics (i.e., sea-ice biota) include: species richness, abundance, biomass, community composition, biogeography, and boundary shifts. Proposed indicators are listed for each key parameter.

- Biodiversity parameters to be monitored for benthos include: species richness, abundance and biomass. More specifically, key parameters to be monitored for corals and sponges include: species richness (within habitat), abundance, biomass, physiological stress, reproductive success, and anthropogenic disturbance. Proposed indicators for both benthos and corals and sponges are listed for each key parameter.

- Knowledge of marine macrophytes in the Arctic is poor; however, kelp can provide important habitat for food, spawning, and protection and is therefore potentially important to overall ecosystem structure. Three indicators are being recommended for future monitoring in the Canadian Arctic: species richness, abundance, and biomass; however a working paper outlining current work in this field and further examination of the possible indicators is still necessary.

- Biodiversity parameters to be monitored for fishes include: species richness/community composition, abundance, biomass, health and condition, diet, genetics, notable and/or unusual events or observations, boundary shifts, biogeography, and harvest statistics. Proposed indicators for fishes are listed for each key parameter.

- Biodiversity parameters to be monitored for seabirds include: colony size, survivorship, reproductive success, chick diet, harvest statistics, and phenology. Proposed indicators for seabirds are listed for each key parameter.

- Biodiversity parameters to be monitored for marine mammals (including polar bears) include: habitat use, abundance, harvest statistics, population dynamics, health and condition, diet, genetics, and notable and/or unusual events or observations. Proposed indicators for marine mammals are listed for each key parameter.

- Temporal resolution of reporting on status and trends of indicators cannot be determined until existing data are examined more closely. Trends in indicators may be difficult to interpret when sampling is carried out at different times of the year; this can lead to a mismatch between sampling and phenology. For long-term monitoring, it is advantageous to involve communities scattered across the north because this allows for participatory research and/or monitoring involving community members present in the area year round.

Collaborative monitoring also allows for collection and inclusion of Traditional Ecological Knowledge (TEK).

- The following areas are recommended for inclusion as new priority subregions for monitoring or extensions of the six previously defined areas because of their importance to one or more trophic levels: 1) Canada Basin, 2) Sanikiluaq/Belcher Island area, 3) Labrador Shelf, 4) Ungava Bay, 5) eastern Southampton Island, and 6) Prince Regent Inlet including Creswell Bay, Eclipse Sound, and Admiralty Inlet.

BACKGROUND

Arctic marine biodiversity is under growing pressure from a number of stressors (e.g., climate change and resource development). Managers and stakeholders require access to more up to date, evidence-based information for making decisions about sustainable use, environmental protection, and adaptation to change. In an effort to improve such information, six Arctic Council coastal nations (Canada, Denmark/Greenland, Iceland, Norway, Russian Federation and the United States of America) agreed to coordinate efforts to detect and understand long-term change in Arctic marine ecosystems, including key biodiversity elements. As directed by the Arctic Council working group on the Conservation of Arctic Flora and Fauna (CAFF), the Circumpolar Biodiversity Monitoring Program-Marine Plan (CBMP-MP), calls for the integration of existing long-term data and traditional knowledge to provide information regarding the status and trends of Arctic marine biodiversity (Gill et al. 2011).

The CBMP-MP calls for the construction of marine biodiversity baselines for sea-ice biota, plankton, benthic organisms, fishes, seabirds, marine mammals, and polar bears, based on published material, historical data, and museum collections. Where possible, more recent existing data will be compared to these baselines to detect possible changes or trends in key indicators and interpret the underlying causes of such change. This information will be synthesized and presented in periodic updates. A significant challenge associated with biodiversity monitoring will be distinguishing change from natural variability and determining which changes are caused by anthropogenic stressors such as industrial development. Another challenge will be in reaching definitive conclusions based on incomplete and limited data; most existing data were collected for reasons other than monitoring or biodiversity purposes. Ultimately, the goal is to improve our understanding of changes in Arctic marine biodiversity to provide regular and authoritative assessments that are useful for regional, national, and international decision making processes.

There is a need to identify gaps in data coverage (both temporal and spatial) to guide future Arctic marine biodiversity monitoring efforts. For the CBMP-MP to succeed, it is necessary that the science advice is clear, concise, and easy to understand.

The intent of this science peer review process was to develop and recommend a suite of indicators based on existing data and already existing research programs that can be used to monitor changes in Canadian Arctic marine biodiversity. This is not a monitoring plan *per se,* but serves as one of the initial steps towards the goal of developing a monitoring plan to improve our understanding of variability and changes in biodiversity. This will also provide a basis for national policy development within the context of the Convention on Biological Diversity (CBD).

The objectives of this science peer review process were to:

1) refine the existing “long list” of parameters and indicators recommended in the CBMP-MP for monitoring of Arctic marine biodiversity (Gill et al. 2011);

2) recommend a feasible temporal sampling scheme[1] based on what information is available for individual indicator analyses; and
3) investigate the availability of existing usable data and identify information gaps which can inform future monitoring and research efforts.

INTRODUCTION

Biodiversity is the core of ecosystem function and structure. The CBD defines 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: Use of Terms in the Convention). The CBD has three main objectives: 1) the conservation of biological diversity, 2) the sustainable use of the components of biological diversity, and 3) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

In the coming years and decades a number of changes, due to climate change, will be experienced across the globe. This is especially urgent in the Arctic because the rate of change is greater in polar regions than in lower latitudes. It is important to understand how these changes will affect biodiversity over time. Furthermore, it is expected that the first detection of biodiversity responses to climate change will be in species that are on the edge of the Arctic regions (e.g., species associated with pack ice development along the Labrador coast and Davis Strait).

Indicators, data, and reporting

In choosing appropriate indicators for a biodiversity monitoring program, aside from logistical constraints, indicators should be: 1) relevant, 2) simple and easily understood, 3) scientifically sound, 4) quantitative, and 5) cost effective (O'Connor and Dewling 1986). In some instances, long-term monitoring data themselves can inform which indicators are appropriate to provide information on marine biodiversity. Therefore, it is not always necessary to identify the relationships *a priori*. For indicators that do not have existing data, a trial period would be beneficial to look at the sensitivity of the indicator to change and would also allow for some analysis on the signal to noise ratio (i.e., change relative to variability).

To monitor biodiversity, patterns and trends should be identified within the ecosystem as well as changes at different trophic levels. Also, in interpreting biotic data and associated indicators it is important to identify key abiotic factors and establish links to supporting data (e.g., physical measurements). For example, chlorophyll *a* is used as a proxy of photosynthetic biomass which indicates net productivity of the system.

When interpreting outputs from monitoring efforts, the biological context and importance of the indicator should be considered. Some species are more important economically or as a local food source. Also, changes in keystone or foundational species will have larger effects on the ecosystem and deeper implications for future change. In addition, interpretation and assessment should not be conducted in a purely Canadian context because both species and oceanographic systems have linkages and dependence on systems outside Canadian boundaries. Once indicators are identified, numbers, variability, and trends from data should be

[1] During the meeting it became clear that the phrase "temporal sampling scheme" was confusing, as it implies <u>future</u> data collection. As we are dealing with existing (already collected) data, it was decided to use the phrase "temporal resolution".

reported. To expand on what is reported, researchers conducting the research should be approached.

The criteria for which data can be included in a database for marine biodiversity monitoring are: 1) existing monitoring programs that have at least five years of data (not necessarily continuous) and 2) a high likelihood that the program will continue for several years. However, some of these existing datasets may not be suitable for use in assessing biodiversity because they cannot be adapted to the calculation of biodiversity indictors. In selecting existing data for monitoring Arctic marine biodiversity, three timeframes were considered: 1) current monitoring and reporting (based on existing data), 2) planned/near-future monitoring within 2-5 years (ongoing projects), and 3) future monitoring. Future monitoring can be planned based on spatial, temporal, and trophic level gaps and targeted to monitor biodiversity using the biodiversity indicators identified here.

Biodiversity monitoring program results will be reported for marine ecoregions across the circumpolar Arctic. In Canada, logistical constraints and the paucity of data require a focus on priority subregions where the most useful results and regional comparisons are expected to be obtained. The Arctic marine areas defined in the CBMP-MP were defined by the Marine Expert Monitoring Group (MEMG) using primarily ecosystemic criteria, though political boundaries also came into play. These focal marine areas cover virtually the entire Arctic, including the Canadian Arctic (Figure 1). For the Canadian component of the CBMP-Monitoring Plan to be achievable in practice, the Canadian Expert Group (CEG) evaluated whether particular subregions exist within each of the focal marine areas that might provide a better opportunity to assess biodiversity, in particular changes to biodiversity, across trophic levels. To do this, CEG members were individually asked to list and delineate up to 10 subregions, in priority order, that they considered to be the most ecologically important and with the greatest availability of data. They were also asked to provide rationale based on their species/trophic level expertise in support of their choices. From the information provided, priority subregions were identified as areas that at least two trophic level experts identified as one of the “top 3” priorities. The priority subregions are: the Beaufort Shelf, Northwater Polynya/northern Baffin Bay, Lancaster Sound, southern Davis Strait, Hudson Strait, and western Hudson Bay (Figure 1). These defined subregions will be used to focus efforts during the first period of implementation of the Arctic Marine Biodiversity Monitoring Plan (2010-2015).

Within each subregion and priority area, there is the potential to include community members in monitoring efforts (e.g., sample collection). It is advantageous to have communities scattered across the north because it allows for collaborative or participatory research and monitoring with local community members living in the area year round. Collaborative monitoring also allows for the inclusion of Traditional Ecological Knowledge (TEK). General observations of seasonality, with respect to the biota (e.g., when ice breaks up, when certain species arrive and leave) are valuable TEK information. With appropriate training, more systematic data collection can be obtained.

Information Sources and Process

The identification of indicators for Arctic marine biodiversity monitoring was based on several sources of information. A key source was a working paper prepared for this meeting to be published as a Research Document. The goal of the working paper was to select indicators presented in Gill et al. (2011) which have the greatest potential for reporting on the status and trends of Canadian Arctic marine biodiversity. In support of this and to the fullest extent possible, map-based lists of current and past researchers were prepared by focal marine area and focal ecosystem component (FEC). The indicator lists and rationale in this working paper formed the initial basis for discussion.

Supplementary to the above paper, Kenchington et al. (2012) prepared a second working paper for peer review; this paper reviewed biodiversity indicators for monitoring coral and sponge megafauna in the Eastern Arctic and fills a significant gap regarding monitoring coral and sponge megafauna, which are often considered to be vulnerable marine ecosystems and extremely sensitive to change. Kenchington et al. (2012) prepared a list of indicators to be considered for biodiversity monitoring of sponges and corals and evaluated the performance of a number of these indicators in the context of climate change projections for the eastern Canadian Arctic.

Meeting participants reviewed both working papers and provided additional, more detailed information regarding a number of the indicators. The following information builds on the working papers by incorporating the input gathered from meeting participants.

ASSESSMENT

Diversity at all organizational levels (i.e., gene, species and the ecosystem) contributes to global diversity and the scope of biodiversity can be viewed from local to regional to global scales. This Canadian Science Advisory Secretariat (CSAS) process examined each FEC to the lowest possible level, in some cases to the ecosystem level for species or species groups where there is little information known (i.e., microbes/phytoplankton) and in other cases at the species and gene level (i.e., Beluga and Arctic Char). The scope also varied by FEC and key species.

Kenchington et al. (2012) describe two categories of existing monitoring activities: 1) monitoring ecosystem components to collect information on long-term trends in response to environmental factors, and 2) monitoring threats and stressors to ecosystem components. Both types of monitoring are required to identify change and associated trends but also to understand why change is occurring. The assessment of biodiversity monitoring indicators briefly discussed the differences between these types of monitoring; however, the emphasis was placed on identifying existing ecosystem monitoring indicators. Monitoring of abiotic parameters (e.g., sea-ice, ocean temperature, salinity, currents, etc.) including the timing and duration of anomalous abiotic changes (e.g., ice retreat) are necessary to explain change for any of the FECs. For example, sea ice and polynyas are considered to be key habitats for many Arctic species and should be monitored accordingly in order to explain any future changes in biodiversity.

Among numerous monitoring methodologies available (e.g., remote sensing, satellite tagging etc.), moorings have been used as a reliable sampling tool and can measure a number of abiotic variables; they often have detailed temporal resolution at a fixed location. They can also be used as a platform for other monitoring tools related to biodiversity (see Appendix 2 for an example). For example, fluorescence is an important abiotic parameter used as a proxy for measuring chlorophyll *a*. Other important oceanographic monitoring indicators include temperature, salinity, and nutrients. These variables are all important and are typically included to some degree in any biological monitoring program in order to further understand change in any marine system and should be included in future biodiversity monitoring plan.

This assessment identified indicators based on the aforementioned criteria that will be useful in assessing biodiversity and for which data are currently being collected in the Canadian Arctic; however, there is still uncertainty as to whether the recommended indicators will be sensitive in detecting actual change rather than the extent of variability. Each indicator will require an evaluation based on existing data to:

- Ensure that when a change is detected it is significant and not a false-positive.

- Determine relationships between and among indicators as well as between different trophic levels. This is especially important when conflicting indicators are measured.
- Determine temporal resolution of reporting on status and trends of indicators; however; this cannot be determined until existing data are investigated more closely. The biology of the organisms being monitored must also be considered when determining the temporal resolution. This will also inform future monitoring.

The following is a detailed list of key parameters and indicators and rationale for their use in the Canadian marine biodiversity monitoring plan for each FEC: microbes, metazoan zooplankton, sympagics (i.e., sea-ice biota), benthic organisms (and more specifically corals and sponges), fishes, seabirds, and marine mammals (including polar bears). For some FECs, key species or taxonomic groups and gaps in knowledge (by species or area) were identified. Current monitoring programs and lead researchers referenced on a Canadian Arctic map were presented from one of the working papers and updated at the meeting.

Microbes, Phytoplankton, Metazoan Zooplankton, and Sympagics (i.e., sea-ice biota)

Six key biodiversity parameters and eight indicators were identified for the microbes, metazoan zooplankton, and sympagic FECs (Table 1).

Table 1: Key parameters and indicators for microbes, metazoan zooplankton and sympagics and the rationale for their use in Canadian marine biodiversity monitoring.

Key Parameter	Indicator	Rationale
Species Richness	• Number of species observed in a sample using taxonomic and/or molecular genetics • Diversity indices	• A measure of biodiversity • As new species are 'discovered' using new identification techniques, the list will continue to grow and therefore there may be a false impression of an increase in biodiversity
Abundance	• Abundances of key species and total abundance of key taxonomic or functional groups	• Abundance indicates standing stocks and is useful for comparing among years provided standard caveats are followed. These include time of year or stage of annual production cycle, depth or integrated depths of the samples
Biomass	• Biomass of key species • Total biomass of trophic levels, which provides a food web health indicator	• Same comments and caveats as for abundance, this can provide an overall indication of standing stock of different trophic levels
Community Composition	• Size composition (plankton and sea-ice biota) • Small versus large • Assemblage structure • Ratio diatoms/dinoflagellates • Ratio pennates/centrics • Ratio Arctic/sub-arctic species	• Proportion of species and population sizes relative to total within and among functional trophic levels in a given area
Biogeography	Loss of species or changes in relative dominance of species within geographical regions	• Biogeographical representation of key species or species complexes • Indicate changes in habitat type or structural properties
Boundary Shifts	• Presence of colonizers, vagrants, and invaders • Change in species range	• As the Arctic climate continues to change there will likely be shifts in species ranges

Microbes and phytoplankton

Key microbe species and taxonomic groups that should be monitored based on the existing data from molecular surveys include Gammaproteobacteria and Bacteriodetes versus Alphaproteobacteria, Thaumarchaeota as a percent of total Archaea, and *Micromonas* 2099 versus other *Micromonas* clades. Key species and taxonomic groups that should be monitored based on existing data from microscopy, aided by molecular and flow cytometry surveys, include ciliates, diatoms, dinoflagellates, and large flagellate species distributions.

Monitoring for microbes is conducted regularly in Amundsen Gulf; however, this area is not currently identified as a priority subregion and is, therefore, recommended as a new priority area given that it is one of the few regions with regular data collection and is known to be biologically significant. There is generally a lack of sample collection for microbes in most years and regions elsewhere.

Metazoan zooplankton

Key metazoan zooplankton species and taxonomic groups to monitor based on existing data include *Calanus* spp. complex, hyperiid amphipods *Themisto* spp. (notably *T. libellula and abyssorum)*, and pteropods or other pH sensitive species. The hyperiid amphipods *Themisto libellula* and *T. abyssorum* are important components of Arctic pelagic ecosystems; both species are carnivorous and prey on mesozooplankton. They also represent a substantial food source for marine vertebrates and are a key link between zooplankton secondary production and higher trophic levels. In contrast, *T. compressa* are rare and regarded as subarctic species. Pteropods are a key taxonomic group but are not sufficiently sampled using normal net gear; therefore, there is a knowledge gap for this group. The Canada Basin has regular zooplankton collections and is, therefore, recommended as a new priority subregion for this FEC.

Sympagics (i.e. sea-ice biota) – Microbes and metazoans

Key sympagic species and taxonomic groups to monitor based on existing data that used molecular and microscopy surveys include Cryothecomonas, circumarctic pennate diatom *Nitzschia frigida,* pennate versus centric diatoms, and dinoflagellates: *Polarella glacialis and Heterocapsa arctica*. Other key species include the ice-associated amphipod *Gammarus wilkitzkii* (multi-year ice) and Arctic Cod (*Boreogadus saida)*. Also, extracted chlorophyll *a* can be used as a proxy for biomass.

The Arctic Archipelago multi-year pack ice is under-sampled and represents threatened habitat; therefore, this area is recommended as a new priority subregion. For sympagics, ice characteristics (i.e., habitat) can be used as a proxy of biodiversity and can be measured using methods including remote sensing and community observations for spatial and temporal analysis. Polynyas, which are areas of open water surrounded by ice, are also important and should be considered in future monitoring work.

Benthos

Three key biodiversity parameters and two indicators for benthic fauna (mega-, macro-, meio-, epi-, and infauna) were identified (Table 2). In addition, six key parameters and 15 indicators specific to monitoring coral and sponge biodiversity were also identified (Table 3; see Kenchington et al. 2012).

Table 2: Key parameters and indicators for benthos and the rationale for their use in Canadian marine biodiversity monitoring.

Key Parameter	Indicator	Rationale	Notes
• Species Richness • Abundance • Biomass	• Diversity measures (e.g., Shannon, Simpson, taxonomic redundancy, Beta-diversity, response diversity, taxonomic distinctness) • Trends in key species (e.g., blue mussel, sea urchins, sea cucumbers, *Corophium* sp. etc. (food web links to seabirds); clams, *Hyatella arctica, Serripes groenlandicus, Mya truncata* (food web link to walrus))	• Ecosystem resilience and function • Link to higher tropic level (birds, walrus, bearded seal, etc.)	• Means and trends in variance should be presented, established clear reference points a priori using the bioequivalence method • Timing and duration of anomalous events (link to physical oceanography) • Timing of phytoplankton/ice algae bloom (link to microbes) • Trawling data are not suitable for measuring biomass or abundance due to catchability and recording/reporting issues

Table 3: Key parameters and indicators for corals and sponges and the rationale for their use in biodiversity monitoring.

Key Parameter	Indicator	Rationale	Notes
Species Richness (within habitat)	• Diversity measures (e.g., Shannon, Simpson, taxonomic redundancy, Beta-diversity, response diversity, taxonomic distinctness)	• Ecosystem resilience and function	
Abundance (geo-referenced data)	• Number per m^2 • Patch area	• Ecosystem resilience and function	• High precision for *In situ* photographic/video transects • Low priority for trawl surveys
Biomass (geo-referenced data)	• Weight/unit area	• Ecosystem resilience and function	• Quantitative grab samples or other equipments (e.g., ROV, small dredge) • Trawling data are not suitable for measuring biomass or abundance due to catchability and recording/reporting issues
Physiological Stress	• Live:Dead • % zoanthid cover • Biomarkers in sponges	• Ecosystem resilience and function	• Expert opinion needed for biomarker indicator • High precision for *In situ* photographic/video transects (e.g., ROV) • Low precision for trawl surveys
Reproductive Success	• Size structure of foundation species • Patch area • Patch density • Patch isolation/proximity • Patch connectivity • Patch dispersion	• Ecosystem resilience and function	• Size structure is considered low priority • Link to genetic diversity • Can be calculated from trawl survey data with moderate precision
Anthropogenic Disturbance	• Distribution and aggregation of fishing activities • Areas not impacted	• Trends in fragmentation of natural habitat • Link to potential key drivers for changes	• Vessel monitoring systems (VMS) data required • Similar indicator for oil and gas activities

Macroalgae

Knowledge of marine macrophytes in the Arctic is poor. The overall distribution of macrophytes within the marine Arctic environment is largely influenced by sea ice dynamics (ice scouring), light availability (sea ice and suspended sediments), and suitable substrates for attachment. Detailed studies on macrophytes have been conducted in some Arctic regions (e.g., Stefansson Sound, Alaska and Bridgeport Inlet, Melville Island); however, in general they are under-sampled throughout the Arctic.

Traditional knowledge would be an important tool to start to identify areas where macroalgae occur. For example, in the Beaufort Sea traditional knowledge has indicated a number of potential sites near Argo Bay and Wise Bay and possibly Liverpool Bay and near Sachs Harbour (see Cobb et al. 2008). Other locations include the Boulder Patch in Alaska at Stefansson Sound and areas within the Canadian Eastern Arctic (e.g., Resolute, Igloolik - Chapman and Lindley 1981).

Kelp beds are known to fulfill many diverse habitat functions in other coastal oceans, providing three-dimensional space, protection, and food for potentially unique and/or diverse communities. They may also serve as important spawning habitat or nursery areas for juvenile life stages for some fish species. Therefore, the presence of kelp is potentially important to overall ecosystem structure and function. Włodarska-Kowalczuk et al. (2009) suggest that similar to deforestation, the loss of kelp may result in significant decreases of faunal diversity and abundance.

A long-term monitoring plan currently exists for the Stefansson Sound Boulder Patch in relation to oil and gas development in the region (OCS Study MMS 2009-040). This plan may be a starting point for the development of a monitoring plan for the Arctic. Three indicators are recommended for future monitoring of macroalgae in the Canadian Arctic: species richness, abundance, and biomass; however a working paper outlining current work in this field and further examination of the possible indicators is still necessary.

Fishes

Nine key biodiversity parameters and 23 indicators were identified for fishes (Table 4). Many species currently harvested for subsistence or commercial fishery have relatively consistent and reliable monitoring data; however, important species from an ecosystem functioning perspective have only sporadic and typically incomplete monitoring/data. The difference in knowledge between harvested or commercially important fish species and other species will have implications on reporting of these indicators.

Table 4: Key parameters and indicators for fishes and the rationale for their use in Canadian marine biodiversity monitoring.

Key Parameter	Indicator	Rationale	Notes
Species Richness/ Community Composition	• Diversity measures (e.g., Shannon-Wiener and Simpson) • Marine mammal and seabird diets		• Stomach contents: fish predators are efficient samplers; however, they are selective feeders so data would be affected by a "gear" or sampling bias. Also, consumption depends on its prey densities (its multispecies functional response, or MSFR) and should be considered when using fish predators as samplers (Asseburg *et al.* 2006)
Abundance	• Size-frequency distribution	• Ecosystem resilience and function	• Key species and total
Biomass	• Weight/unit area		• Key species and total
Health, Condition and Diet	• Condition factor (e.g., weight/length) • Age • Size • Stomach contents • Stable isotopes • Fatty acids	• Typically a component of the Community-based Monitoring programs at traditional harvest sites • Non-invasive techniques are available which can provide a range of information on the health of the animals • Important to detect a decline or change in the condition of a population or stock	
Habitat Use	• Feeding areas • Rearing areas • Spawning areas • Migratory pathways		
Genetics	• Population or stock delineation • Hybridization • Trans-Arctic gene flow (char)	• Genetic diversity is an important component in order to determine the health and success of a population	
Notable and/or Unusual Events or Observations	• Die-offs • Disease • Notable species observations	• Scientific/management sampling and monitoring does not occur year-round, events that may not be recorded by researchers but are recorded by locals is a valuable tool in order to interpret field season results or to understand variability and identify change	
Boundary Shifts	• Presence of colonizers, vagrants and invaders • Change in species range	• As the Arctic climate continues to change there will likely be shifts in species ranges.	
Biogeography	• Species association to habitat types	• Biogeographical representation of key species or species complexes • Indicate changes in habitat type or structural properties	
Harvest Statistics	• Timing and location of harvest • Harvest rates • Age and sex structure • Population dynamics • Local perspectives on country foods	• All or some of these indicators are regularly examined and noted during community harvests.	• To be effective in monitoring, the harvest methods have to be consistent and the associated effort data are required.

Key fish species and taxonomic groups to include in this monitoring plan are Arctic Cod, Capelin (*Mallotus villosus*), Dolly Varden (*Salvelinus malma*), Arctic Char (*Salvelinus alpinus*), whitefishes and ciscoes (*Coregonus* spp., *Stenodus* sp.), shrimp, Greenland Halibut (*Reinhardtius hippoglossoides*), and Pacific salmons (*Onchorhynchus* spp.). Arctic Char is a common community country food and therefore, stock assessments and community collected data are readily obtained for this species. When conducting data analyses and determining temporal scale, data quality needs to be determined and considered (e.g., mismatch between sampling and char runs).

Seabirds

Seabirds in the Canadian Arctic have been 'regularly' monitored since the 1970s (Gaston and Nettleship 1981; Gaston 2002; Mallory et al. 2009) with historical data dating back to the 1950s (Tuck 1961). CAFF has had a Circumpolar Seabird Expert Group, known as CBird, since 1993. In 2008 the Framework for a Circumpolar Arctic Seabird Monitoring Network (Petersen et al. 2008) was published as a CBMP product. All of the indicators identified for seabirds in Petersen et al. (2008) are recommended for inclusion in a Canadian monitoring plan (Table 5).

Table 5: Key parameters and indicators for seabirds - adapted from Petersen et al. (2008).

Key Parameter	Indicator
• Colony size	• Abundance, number of active nests
• Survivorship	• Adult and chick survival rates
• Reproductive success	• Productivity
• Chick diet	• Diet
• Harvest statistics	• Harvest rates and demographics
• Phenology	• Time of breeding

CBird recommends a long list of species to be considered as part of the Circumpolar Seabird Monitoring Network (see Petersen et al. 2008). In Canada the key species from this long list include the Black-legged Kittiwake (*Rissa tridactyla*; surface piscivore), murres (diving piscivores) and Common Eiders (*Somateria mollissima*; benthic feeder). However, based on the approach that a species representative of each foraging type be monitored, Canadian seabird monitoring should also include the Northern Fulmar (*Fulmarus glacialis*; pelagic foraging), Ivory Gull (*Pagophila eburnea*; ice-associated and Endangered (COSEWIC)), Glaucous Gull (*Larus hyperboreus*; omnivore, significant contaminant load), and Black Guillemot (*Cepphus grylle*; benthic feeders). This expanded list provides a more complete assessment of the current status of these important populations in the Canadian Arctic. In addition, other data that are important for interpreting seabird trends include:

- climate data (e.g., air temperature, winds, etc.);
- oceanographic data (e.g., salinity, depth, sea temperature, currents and sea ice);
- climate change models (i.e., North Atlantic Oscillation, subpolar gyres);
- plankton distributions and magnitudes (i.e., phyto- and zooplankton);
- contaminants;
- fisheries and fish stock data; and
- oil spill data.

Many of the additional data listed above are also relevant for understanding trends in other species groups including fishes and marine mammals.

In addition to an expanded key species list the following are recommended as extensions or additions to the identified priority subregions in Figure 1:

1) an extension of the western Hudson Bay priority subregion to include East Bay;
2) a new priority subregion at the Sanikiluaq/Belcher Islands;
3) an extension of Lancaster Sound/Barrow Strait subregion southwest into Prince Regent Inlet and Prince Leopold Island as far as Creswell Bay (this area is very important for seabirds and beluga after the ice has cleared from Prince Regent Inlet); and
4) a new priority subregion in Eclipse Sound and Admiralty Inlet (this area is also very important for narwhal, in particular).

Table 6 contains a list of key species currently monitored for each indicator in the Canadian Arctic.

Marine Mammals (including polar bears)

The Canadian Arctic provides seasonal and/or year-round habitat for several species of marine mammals, many of which are important for subsistence purposes. Marine mammal species recommended for monitoring include Bowhead (*Balaena mysticetus*), Beluga (*Delphinapterus leucas*), Narwhal (*Monodon monoceros*), Walrus (*Odobenus rosmarus*), Bearded seal (*Erignathus barbatus*), Ringed seal (*Phoca hispida*), Harp seal (*Pagophilus groenlandicus)*, Hooded seal (*Cystophora cristata*), Killer whale (*Orcinus orca*), and Polar bear (*Ursus maritimus*). Of all the listed species, the least amount of research and monitoring has been conducted on the Bearded seal. Monitoring of this species will first require an evaluation of what data sets are available. Another gap in monitoring includes temperate species being observed in Canadian Arctic waters including a number of whales [Grey (*Eschrichtius gibbosus*), Humpback (*Megaptera novaengliae*), Right (*Eubalaena glacialis*), and Minke (*Balaenoptera acutorostrata*)], dolphins, and porpoises.

Six key biodiversity parameters and 26 indicators were identified for marine mammals (Table 7). At present, the Beaufort Sea and the western Hudson Bay priority subregions have the highest Polar bear monitoring intensity. There is also a high intensity of monitoring in the high Arctic Archipelago.

The multi-year pack ice within the Arctic Archipelago is predicted to be the last remaining multi-year ice in the Canadian Arctic and has been identified as an Ecologically and Biologically Significant Area (EBSA) (DFO 2011). Marine mammal aggregations and current concentrations/densities appear to be low in this area in comparison to the entire Arctic and there are currently no marine mammal monitoring programs here; however, this area is considered to be important regionally and should be monitored accordingly in light of the many anticipated changes in the high Arctic due to climate change.

Table 6: Current and past seabird monitoring in the Canadian Arctic by indicator and focal marine area.

Indicator	Beaufort Sea	Arctic Archipelago	Hudson Bay	Baffin Bay/ Davis Strait
Counts	• Barrow, Alaska (eiders) • Inuvialuit Settlement Region (eiders)	• Prince Leopold Island (Murres, Kittiwakes, Glaucous Gull, Northern Fulmar) • St. Helena Island (eiders, Glaucous Gull) • Tern Island (Arctic Tern, eiders) • Range-wide Ivory Gull surveys	• Digges Island (murres, Glaucous Gull) • Coats Island (murres, Glaucous Gull) • East Bay (eiders) • Sanikiluaq (eiders) • Churchill (eiders)	• Hudson Strait (eiders)
Productivity		• Prince Leopold Island (Murres, Kittiwakes, Glaucous Gull, Northern Fulmar) • St. Helena Island (Glaucous Gull) • Seymour Island (Ivory Gull)	• Digges Island (murres, Glaucous Gull) • Coats Island (murres, Glaucous Gull) • East Bay (eiders) • Churchill (eiders)	
Phenology		• Prince Leopold Island (murres, kittiwakes, Glaucous Gull, Northern Fulmar) • St. Helena (Glaucous Gull)	• Digges Island (murres, Glaucous Gull) • Coats Island (murres, Glaucous Gull) • East Bay (eiders) • Churchill (eiders)	
Chick growth		• Prince Leopold Island (murres)	• Digges Island (murres) • Coats Island (murres)	
Contaminants		• Prince Leopold Island (murres, kittiwakes, Glaucous Gull, Black Guillemot)	• Digges Island (murres) • Coats Island (murres, Glaucous Gull) • Sanikiluaq (eiders)	
Diet		• Prince Leopold Island (murres, Northern Fulmar - stable isotopes, Glaucous Gull)	• Digges Island (murres) • Coats Island (murres, Glaucous Gull) • East Bay (eiders) • Sanikiluaq (eiders)	

Table 7: Key parameters and indicators for marine mammals and the rationale for their use in Canadian marine biodiversity monitoring.

Key Parameter	Indicator	Rationale	Notes (including protocols)
Habitat Use	• Important feeding areas • Calving and pupping areas • Overwintering areas • Density distribution • Migration corridors/pathways • Seasonal distribution • Changes in habitat, e.g., for species with specific habitat needs (i.e. Pagophilic seals) should monitor changes in the habitat itself (i.e., pack ice)	• Provides a broad range of information with respect to habitat use and timing for highly migratory species • Identification of hotspots and habitats which support important life history functions • The first signs of climate change will be detected in changes of the spatio-temporal use of habitats, particularly those at the edges of the Arctic region (e.g., harp and hooded seals, *Cystophora cristata*, in the Eastern Arctic)	• Aerial surveys • Telemetry and tracking studies • Mark/recapture studies
Population Dynamics	• Total or relative abundance • Age and sex structure of population • Age specific reproductive and survival rates (e.g., fecundity, maturity, senescence) • Animal growth rates • Reproduction, mortality and vital statistics • Morphometrics	• For some species, especially bowhead whales, total or relative abundance is difficult to measure or obtain enough data points for an accurate count and/or trends for some species because it is typically calculated based on aerial survey or mark/recapture data • Population size estimates available for most polar bear populations although some estimates are outdated.	• Aerial surveys • Mark/recapture studies
Harvest Statistics	• Timing and location of harvest • Harvest rates • Age and sex structure of harvested animals • Local perspectives on country foods • Struck, landed, and lost rates • Age specific reproductive rates (i.e., fecundity and maturity)	• Focuses on traditionally harvested species and species of interest from DFO and locals perspectives (Valued Ecosystem Components) • Annual hunt sampling • Community-based Monitoring Programs	• Government of Nunavut (GN) and the Government of the Northwest Territories have (GNWT) have an extensive harvest monitoring program for polar bears that includes tissue sampling.
Health, Condition and Diet	• Morphometrics • Diet • Relative condition (e.g., blubber quality/quantity for whales and seals) • Body burden of contaminants • Reproduction, mortality and vital statistics • Incidence of disease and parasites	• Typically a component of the Community-based Monitoring programs at traditional harvest sites • Non-invasive techniques (e.g., biopsy samples) are available which can provide a range of information on the health of the animals • Important to detect a decline or change in the condition of a population or stock	• Fatty acids • Stomach and intestine contents • Stable isotopes • Contaminant tracers • See GN and GNWT polar bear harvest monitoring
Genetics	• Population or stock delineation • Mating system • Social behaviour	• Genetic diversity is an important component in order to determine the health and success of a population	• Genetic diversity • See GN and GNWT polar bear harvest monitoring
Notable and/or Unusual Events or Observations	• Die-offs • Disease • Boundary shifts (i.e., colonizers, vagrants or invaders)	• Sampling and monitoring does not occur year-round, events that may not be recorded by researchers but are recorded by locals is a valuable tool in order to interpret field season results or to understand variability and identify change	• Response program • Stranding program

Table 8 contains a list of key species currently and previously monitored for each indicator in the Canadian Arctic.

Table 8: Current and past marine mammal monitoring in the Canadian Arctic by indicator and focal marine area.

Indicator	Beaufort Sea	Arctic Archipelago	Hudson Bay	Baffin Bay/ Davis Strait
Harvest Location and Timing (includes local perspectives, age and sex structure, population dynamics)	• Ringed seals • Bowhead • Beluga • Polar bear	• Narwhal (limited) • Ringed seals (limited) • Beluga • Bowhead (limited) • Polar Bear (limited) • Walrus	• Beluga • Narwhal • Bowhead • All seal species • Polar Bear • Walrus	• All seal spp. • Bowhead • Beluga • Narwhal • Polar bear
Range and Timing of Habitat Use (telemetry and tracking studies)	• Beluga • Bowhead • Ringed seals • Polar bear	• Narwhal • Walrus • Beluga • Ringed seals (limited)	• Bowhead • Narwhal • Walrus • Ringed seals • Bearded seals (limited) • Harbour seals (limited) • Beluga • Polar bear	• Bowhead • Walrus • Ringed seals • Hooded seals • Harp seals • Killer whales • Beluga
Abundance	• Polar bear		• Ringed seal • Beluga • Narwhal • Bowhead • Walrus • Polar bear	• Harp seals • Hooded seals • Narwhal • Beluga • Bowhead • Walrus • Polar bear
Relative Abundance		• Polar bear		
Health, Condition and Diet (i.e., disease, morphometrics, contaminants)	• Beluga • Ringed seals • Polar bear		• Ringed seals • Bearded seals • Beluga • Narwhal • Bowhead • Walrus • Polar bear	• Ringed seals • Bearded seals • Beluga • Narwhal • Walrus • Bowhead • Polar bear • Harp seals • Hooded seals
Notable/Unusual Events and Observations	• Community consultations process • Killer whale sightings • Seal mortalities	• Community consultations process • Killer whale sightings • Seal mortalities	• Community consultations process • Killer whale sightings • Seal mortalities	• Community consultations process • Killer whale sightings • Seal mortalities
Population or Stock Delineation (Genetic Diversity)	• Bowhead • Beluga • Polar bear • Ringed seals	• Bowhead • Narwhal • Beluga • Walrus • Ringed seals • Polar bear	• Beluga • Narwhal • Polar bear • Ringed seals • Bearded seals • Walrus • Bowhead	• Bowhead • Narwhal • Beluga • Polar bear • Ringed seals • Walrus • Harp seals

Sources of uncertainty

The Canadian Arctic is expansive and can be logistically difficult to access for research and monitoring initiatives. Often, sampling is limited to the open water season or during winter when sea-ice conditions offer, to some extent, a better platform for sampling than during the spring and fall seasons. Difficulties in access to many areas have consequences for data collection:

- In general, there is a widespread lack of data underpinning each of the indicators with some species or groups better represented than others. This creates a situation where trends may be difficult to interpret when there are inconsistent sampling periods in different years which can lead to a mismatch between sampling and phenology. Also, accuracy and precision may vary with the nature of the indicator and the underlying data.
- Sampling is often conducted close to existing communities and camps, creating many geographical gaps in where data are collected. Data collection and reporting on indicators will likely be focused on common geographic locations and/or regions (e.g., priority sub-regions) and not reported uniformly across the entire Canadian Arctic.
- Gear types and/or methods to collect the identified indicators have not been standardized for the Canadian Arctic; however suggested methods and tools for each FEC are identified in the working paper presented at this meeting and in Petersen et al. (2008). Although it is possible in some cases to evaluate indicator data collected using multiple methods this may not be possible in all cases (i.e., historic data sets). Where standardization of methods is difficult or impossible, indicators should be interpreted in ways that enable maximum use and comparison of data (Vongraven et al. 2009).

Another source of uncertainty is inconsistency in taxonomic resolution and species identification techniques used. Many metrics/indicators rely on taxonomic identification. A reduction in available taxonomic expertise especially for the lower trophic levels, other benthos, and fishes, has further amplified the uncertainty. Molecular technology has provided assistance in the identification of these organisms and is now being widely used. These techniques allow for a greater taxonomic resolution, down to species level for many FECs. Because of the greater level of precision, new species that are identified may have actually been previously identified but to a higher taxonomic level or mis-identified. Accurate taxonomic identification to the lowest practicable level is essential in order to determine when boundary shifts and/or new arrivals to an area occur.

CONCLUSIONS AND ADVICE

Overall there is a paucity of marine biodiversity knowledge in the Arctic. It is, therefore, important to outline a systematic approach to measure biodiversity across the Arctic. The information contained within Tables 1-8 will serve as a valuable contribution to a future Canadian Marine Biodiversity Monitoring Plan. Current research and monitoring programs, along with planned programs will contribute significantly to reporting status and trends on biodiversity in Canada.

In addition to the monitoring programs conducted within Canada, we recognize the linkages and dependence that both species and oceanographic systems have on systems outside Canadian boundaries. Therefore, to understand potential changes in biodiversity the geographic scope of monitoring should be extended to include the Canada Basin, Labrador Sea, and Baffin Bay/Davis Strait within Greenlandic waters. International linkages to other Canadian research programs (i.e., Joint Ocean Ice Study (JOIS), Canada's Three Oceans (C3O), Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP) and ice products from the

Canadian Ice Services), which are collected beyond the bounds of these four focal marine areas (Figure 1) should be considered and incorporated into the future monitoring plan.

A majority of the past, existing, and planned research and monitoring programs in the Canadian marine Arctic work towards understanding ecosystem function and structure as well as the management of stocks, although few programs are run solely as dedicated biodiversity monitoring programs. Existing data can be used to refine and evaluate a number of the currently identified indicators but future emphasis should be on establishing dedicated biodiversity monitoring programs or modifying existing programs to ensure elements required to address biodiversity monitoring programs are included. Policy direction can also help guide future monitoring efforts.

As part of this assessment participants identified past and present research and monitoring programs that have data which would contribute to the development of baselines for the above mentioned indicators. It is important to also consider the accessibility of data. This includes knowing where the data are housed and having the data in a usable format (e.g., samples analyzed). This will also be an important step in the future development of baseline data sets and reporting.

The importance of collaborative monitoring is emphasized; however, it should be noted that the information in this Science Advisory Report is the result of a scientific and technical Canadian Science Advisory Secretariat (CSAS) process using the types of information typically central to science processes.

Finally, experts for each FEC determined that although there is still a great deal of work to access, organize, and analyze indicator data, it will be possible to report on some indicators in the near future. Based on the assessment and conclusions above, the following areas are recommended for inclusion as new priority subregions or extensions of previously defined areas (Figure 1): 1) Canada Basin, 2) Sanikiluaq/Belcher Island area, 3) Labrador Shelf, 4) Ungava Bay, 5) eastern Southampton Island, and 6) Prince Regent Inlet as far as Creswell Bay, Eclipse Sound, and Admiralty Inlet. The first two are new areas and the last four are extensions. The Canadian Arctic Archipelago is the largest archipelago in the Arctic and has been identified as an important area for all FECs (Cobb 2011; DFO 2011) but has limited existing long term datasets (DFO 2011). In anticipation of the expected changes to occur in the Arctic due to a changing climate, this area should be a priority subregion for monitoring. Also, a number of long-term monitoring and datasets currently exist outside of the identified priority subregions (e.g., Ulukhaktok Ringed seal monitoring in the Western Arctic). These programs should be continued and contribute to reporting on the status and trends of the identified indicators in this assessment.

Recommendation for future work

Existing and planned programs can work towards collecting data where data gaps exist, as well as, multi-species data collection (within and across trophic levels) as opposed to targeting single species data collection. Identifying indicators emphasizes the need to collect biodiversity monitoring data because while existing data can be used to refine and evaluate indicators, future biodiversity monitoring requires dedicated monitoring programs. Various technologies (e.g., moorings, remote sensing, ship based monitoring, community-based monitoring, etc.) need to be evaluated for the long term collection of biodiversity monitoring data.

An evaluation of the recommended indicators will need to be conducted in order to determine:

- if change can be detected using the identified indicators (i.e., monitoring is conducted in the right geographic locations, at the right time, and in the right way);
- the temporal sampling scale for each indicator by location;
- if it is possible to collect samples/data that will inform multiple indicators using one method;
- if indicator reporting will be representative of all focal marine areas, and more specifically within the priority subregions; and
- if one or more priority sub-regions contain indicator monitoring for all FECs to allow for cross-trophic linkages.

Indicators and parameters are recommended for all trophic levels defined by FECs: microbes and phytoplankton, metazoan zooplankton, sympagics (i.e., sea-ice biota), benthic organisms (including corals and sponges), seabirds, fishes, and marine mammals (including polar bears). For macroalgae, three indicators are being recommended here for future monitoring of macroalgae in the Canadian Arctic: species richness, abundance, and biomass. However, a working paper outlining current work in this field and further examination of the possible indicators is still necessary.

Although TEK was not addressed in the CBMP-MP it is an essential source of knowledge in the Canadian Arctic and should be incorporated in any future Canadian Marine Biodiversity Monitoring Plan.

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This Science Advisory Report is from the Fisheries and Oceans Canada (DFO), Canadian Science Advisory Secretariat, National peer-review process was held February 6-8, 2012 at the Freshwater Institute in Winnipeg, Manitoba on *Identifying Indicators for Monitoring Arctic Marine Biodiversity in Canada*. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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APPENDIX 1: Glossary

Term	Definition
Colonizer	Species new to an area due to a boundary shift in their distribution and is reproducing in that area.
Invader	Species new to an area that has been transported by humans. It may or may not be reproducing in that area and may or may not have adverse effects on indigenous species.
Vagrant	Species new to an area but is an irregular occurrence and is not reproducing in that area.

APPENDIX 2: Ideal Mooring

Existing technology would allow a cluster of three moorings at a biodiversity monitoring site to collect physical, chemical, and biological data to allow some monitoring of the ecosystem and biodiversity. The three moorings are:

1. A physics mooring: This mooring is envisioned to carry temperature, salinity and pressure sensors and Acoustic Doppler Current Profiler (ADCP) current meters which provide both currents and acoustic backscatter. It would also be able to carry autonomous underwater recording devices that can be used to monitor marine mammal sounds, ice noise, and ship and submarine noise.

2. A near-surface sampling mooring: A profiling device such as an Icycler or Arctic Winch would repeatedly profile from approximately 50m deep to the underside of the ice. Moorings in ice covered waters require top-floats at least 30m deep to avoid damage from moving ice keels. The profiler works by actively avoiding the ice and collecting profile data in the strongly stratified and biologically active upper water column. A suite of instruments would be placed on the profiler including: Conductivity, Temperature and Depth (CTD) meter, *In Situ* Ultraviolet Spectrophotometer (ISUS) to measure nitrate concentrations, a pCO2 device, Photosynthetically Active Radiation (PAR) sensor, chlorophyll fluorescence and optical back scatter, and an upward-looking camera.

3. A biological mooring: This mooring would contain sediment traps, pumps to sample phytoplankton and other microbes, and water samplers at three or four levels. Moored pumps and water samplers are relatively new technology and collect samples which allow a wide range of analyses. The mooring would also have a bottom camera for time-lapse images of the seafloor.

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