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Development of Indicators for Arctic Marine Biodiversity Monitoring in Canada

Élaboration d'indicateurs pour la surveillance de la biodiversité marine dans l'Arctique canadien

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ABSTRACT

Biodiversity underpins stable and productive marine ecosystems which provide a range of goods and services. Monitoring of the status and trends of marine biodiversity in the Arctic is needed to allow for informed decision making around issues of sustainable resource use, environmental protection, and adaptation to changing conditions in the North. The development of such an arctic marine biodiversity monitoring strategy in Canada builds on the Circumpolar Biodiversity Monitoring Plan- Marine Plan (CBMP-MP) which calls for an indicator-based approach. It is necessary to tailor the indicators presented in the CBMP-MP to those that are relevant and logistically feasible in Canada. To this end, biodiversity indicators based on historical data and ongoing research are recommended for microbes, zooplankton, fishes, sympagic and benthic organisms as well as marine mammals. These indicators will be useful for biodiversity monitoring in Canadian marine arctic waters and will serve as Canada's position on indicators for the CBMP-MP.

RÉSUMÉ

La biodiversité est essentielle aux écosystèmes marins stables et productifs qui fournissent une gamme de biens et de services. Il faut surveiller l'état et les tendances de la biodiversité marine dans l'Arctique pour permettre la prise de décisions avisées au sujet d'enjeux sur l'utilisation des ressources durables, la protection de l'environnement et l'adaptation en fonction des conditions changeantes dans le Nord. L'élaboration d'une telle stratégie de surveillance de la biodiversité marine au Canada est axée sur le plan marin du Plan de surveillance de la biodiversité circumpolaire (PSBC-PM), qui requiert une approche utilisant des indicateurs. Il faut adapter les indicateurs présentés dans le PSBC-PM à ceux qui sont pertinents et réalisables sur le plan logistique au Canada. Pour ce faire, les indicateurs de biodiversité s'appuyant sur des données historiques et de la recherche en cours sont suggérés pour les microbes, le zooplancton, les poissons, les organismes sympagiques et benthiques ainsi que les mammifères marins. Ces indicateurs seront utiles pour surveiller la biodiversité des eaux arctiques canadiennes et constitueront la position du Canada relativement aux indicateurs du PSBC-PM.

INTRODUCTION

Biodiversity underpins a range of ocean ecosystem goods and services (Worm et al. 2006). Government managers, industry, and stakeholders require access to current and meaningful information regarding the status and trends of arctic marine biodiversity (including key ecosystem components) to allow for informed decision making around issues of sustainable resource use, environmental protection, and adaptation to changing conditions (e.g., Bowron and Davidson 2011). In recognition of this, the six arctic coastal nations (Canada, Denmark/Greenland, Iceland, Norway, Russia and USA) have agreed to coordinate efforts to detect and understand long-term change in arctic marine ecosystems. The Circumpolar Biodiversity Monitoring Program-Marine Plan (CBMP-MP) (Gill et al. 2011) is a significant milestone towards the realization of this goal. Prior to the publication of the CBMP-MP, Gill and Zockler (2008) assembled a high-level list of indicators that comprehensively covered marine and terrestrial taxa and habitats. These are presented as "themes" in the CBMP-MP and include: species composition, ecosystem structure, habitat extent, habitat quality, ecosystem function and services, human health and well-being, and policy responses. The only such theme addressed in this paper is that of "species composition". The CBMP-MP calls for an "indicator-based" approach to monitoring arctic biodiversity that combines existing biotic data with that from ongoing research efforts to track the status of biodiversity across the entire taxonomic spectrum. This paper aims to tailor the list of indicators provided in CBMP-MP to those that are relevant and logistically feasible in Canada.

It is becoming increasingly clear that systems with high biodiversity are more resilient to change and have an increased likelihood of providing stable ecosystem products and services (see Palumbi et al. 2009). The assessment of biodiversity is a way to measure ecosystem health and inform management aimed at gaining and maintaining long-term benefit from arctic marine ecosystems. Ecosystems will reorganize in terms of abundance, distribution, phenology and productivity of individual components in response to natural and anthropogenic forcing. When an individual species' ecosystem role is understood, tracking changes in its phenology, abundance and distribution provides the means to understand wider ecosystem effects, as for example, in a predator-prey relationship. Understanding how abiotic drivers (both natural and anthropogenic) influence individual taxa and ecosystem function will contribute to forecasting the biological responses to abiotic forcing and the evaluation of trade-offs among different resource management and development options; this important facet of the management picture is outside the purview of this paper.

As a basis from which to explore the effect of natural and human-driven impacts as well as manage living resources wisely, we must first be able to measure and produce accessible reports on the status and trends in arctic biodiversity. Such monitoring efforts will rely on a small number of indicators that can be calculated from historical data and tracked via ongoing research and monitoring programs. Biodiversity is defined as any level of biological variation including genetic, species, and ecosystem level variation. This report focuses on the species and population levels of biodiversity with the organisms or Focal Ecosystem Components, (FECs) themselves being the subject of measurement. Accordingly, attributes or characteristics of FECs are assessed through field and laboratory analysis to produce data. (These are defined as "parameters" in the CBMP-MP.) The data regarding the attributes of a FEC is used to calculate an "indicator", which is defined here broadly as an information tool that is calculated or determined and that provides information on status of or trends in biodiversity. The objective of this paper is to provide a suite of parameters and indicators for monitoring arctic marine biodiversity in Canada.

The CBMP-MP set forth a framework for monitoring of arctic marine biodiversity as a component of an overarching ecosystem-based monitoring framework that incorporates information regarding terrestrial, freshwater, and marine systems (see Gill and Zockler 2008). The CBMP-MP has several key aspects fundamental to the development of an arctic marine monitoring plan for Canadian waters. Of direct relevance to this paper is Section 5.4 “Priority Parameters and Indicators”, which will be refined to this paper for application to Canadian arctic marine waters. Besides this work, there are other processes ongoing aimed at developing and implementing biodiversity indicators in Canadian arctic marine waters including the Nunavut General Monitoring Plan and the development for the Tarium Niryutait Marine Protected Area monitoring scheme (Loseto et al. 2010). One of the considerations for the selection of indicators here is their compatibility with indicators used globally such as, for example, the Convention on Biological Diversity (see http://www.cbd.int/convention/) is a multinational effort aimed at development and implementation of biodiversity indicators globally.

Nationally and globally the development and application of biodiversity and ecosystem health indicators is an area of active discussion and research (see Rice and Rochet 2005; DFO. 2008; Samhouri et al 2009; Heink and Kowarik 2010; Kershner et al. 2011). There are numerous criteria that could be applied to choosing biodiversity indicators for use in monitoring Canada’s arctic marine biodiversity and much literature describes rationales for indicator choice. Given the diversity of stakeholder interests, regional habitat heterogeneity and differing issues regarding natural and human impacts and management concerns, biodiversity indicator selection at the local level should follow a framework such as that laid out in Rice and Rochet (2005), for example.

The intent of this work is to provide background information and propose core indicators with as wide an application as possible for assessing changes in biodiversity that will feed into the CBMP-MP, and serve as a basis for development of regionally specific biodiversity and ecosystem health indicators across Canada. Further development and implementation of a monitoring program will be carried out under the management of the Marine Expert Network (see CAFF 2012). The indicators proposed here will likely be quite locally relevant, particularly those concerning exploited marine resources but I do not presuppose to fully assess and address local and regional concerns directly.

It must be stressed that the measurement of the parameter (i.e. data gathering), either by field and laboratory work or remote sensing is the limiting factor because without input of data from ongoing research or monitoring efforts, there can be no calculation of indicators and no monitoring program. This paper aims to provide a framework from which to build a viable monitoring program by identifying current researcher efforts that could be incorporated into such a program. Central entities in the development and implementation of Canada’s marine biodiversity plan include programs within ArcticNet, DFO (in particular, Canada’s Three Oceans) and regional governments. Logistical considerations will, therefore, figure prominently in choosing indicators going forward to the implementation stage of the biodiversity monitoring program; thus, not all indicators can be given equal weight. Seabird and polar bear monitoring programs are already established or well forward in the process of development and will not be assessed here.

Besides logistical considerations, criteria for indicators applied here follow those put forth by O‘Connor and Dewling (1986) (below) in the context of the assessment of arctic marine biodiversity.

1. Relevant
   - Must be sensitive to drivers and assess an important ecosystem component(s)
2. Simple and easily understood
   - Because indicators will be widely employed and interpreted by a range of end users, they must be easy to calculate and understand.
3. Scientifically sound
4. Quantitative
   - Allows for objective assessment and comparisons
5. Cost effective

The Canadian arctic marine habitat has been delineated into five biogeographic regions: Hudson Bay Complex, Eastern Arctic, Western Arctic, Arctic Basin and Arctic Archipelago (see DFO 2009). These five regions have been recently further subdivided into 38 ecologically and biologically significant areas (Cobb 2011). Additionally, the Canadian Expert Group compiled a list of focal marine areas and priority sub regions where stress in biodiversity is expected to be high, that are of ecological importance across taxa, and have ongoing research activity and historical data (Figure 1). The priority sub regions are: Beaufort Sea shelf, Lancaster Sound, Northwater Polynya and northern Baffin Bay, Hudson Bay, Hudson Strait, and southern Davis Strait.

The scale and diversity of Canadian arctic marine habitat makes the selection of indicators that are relevant Canada-wide challenging and raises the question as to what spatial resolution is required. For example, an indicator that calculates the ratio of subarctic to arctic plankton may be very relevant to southern areas, especially those that are on the frontier between the two large ecozones, but not useful for the arctic interior for which the transport time of Pacific or Atlantic waters is measured in years. On the other hand, a subarctic to arctic indicator may be very relevant all across the region for highly mobile taxa such as fishes, marine mammals and seabirds. Further to this issue, the relevance of indicators assessing taxonomic groups with patchy distributions (e.g. seabirds) will be relevant across the range of habitats they utilize but not everywhere in Canada’s Arctic. Given the diversity of marine habitats across Canada, ultimately each region would likely have unique management and conservation goals, and its own set of specific locally relevant indicators. For example, Loseto et al. 2010 present 82 indicators for the Tarium Niryutait Marine Protected Area. The 2010 Marine Ecosystem Status and Trends Report (DFO 2010) outlines findings and emerging issues for Canadian arctic marine ecosystems. The types of local issues and drivers presented in this report along with the establishment of relevant conservation and management goals would underpin the development of indicators specific to each region. This level of detail is not possible here.

The CBMP-MP partitions arctic biota into 11 FECs (not necessarily mutually exclusive): microbes, phytoplankton, ice flora, ice fauna, macroalgae, zooplankton, benthic meio-macro-mega fauna, pelagic fishes, demersal fishes, seabirds, and marine mammals. Some FECs have previously developed indicator frameworks and some have no precedents (e.g., microbes). For the purposes of this report, these FECs have been consolidated into six groups: microbes, metazoan zooplankton, sympagic (ice associated) organisms, benthic organisms, fishes, and marine mammals. For each of these groups, ecological importance and response to drivers, historical data and current activities are summarized, followed by recommendations for field sampling, analysis, core indicators, and a description of gaps where applicable

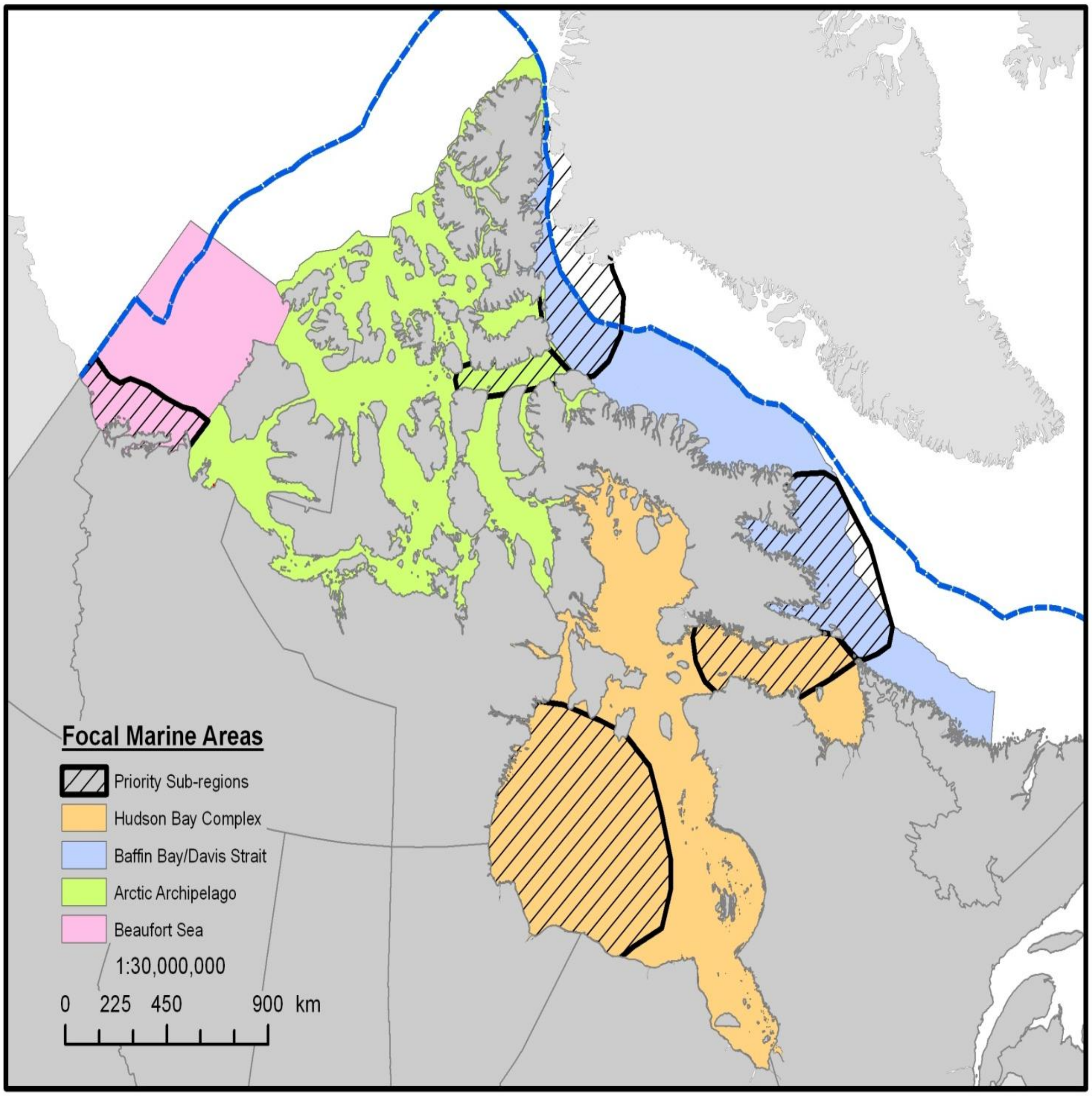

Figure 1. Focal Marine Areas with Priority Sub regions.
Focal marine areas defined as follows: Beaufort Sea-pink, Canadian Arctic Archipelago- green, Hudson Complex-orange, and Davis Strait/Baffin Bay-blue. Priority sub regions are outlined in black.

INDICATOR DEVELOPMENT

MICROBES

Importance and response to drivers

Microbes (viruses, archaea, bacteria and protists) are distributed throughout the Arctic and perform an array of essential functions in arctic food webs (see Lovejoy et al. 2011). They are found in and on every substrate (water column, benthos, ice, and in and on plants and animals). Less is known about this group than any other FEC. This is due to their immense diversity and, until just recently, a lack of tools to explore the taxonomic identity of the majority of species. Because of this, historical data sets are mostly lacking with a few exceptions (see

W. Li et al. 2009). Being poikilothermic mostly with limited mobility, there is little doubt that changes in the water column will strongly affect these creatures and such reports from the field are accumulating. For example, Wassmann et al. (2010) describe temperature effects on production and respiration of arctic bacteria, Li et al. 2009 document community composition shifts driven by water column freshening and deepening of the nitricline in the Canada Basin due to increased freshwater input, which has also increased the depth of the subsurface chlorophyll maximum (McLaughlin and Carmack 2010; Martin et al. 2010), and other effects of climate change on autotrophs can be expected. Microbes with the capacity to reduce CO_2 (autotrophs) are the foundation of life producing both reduced carbon compounds (food) and oxygen. The production of reduced carbon and oxygen is, of course, strongly influenced by light; given recent reductions in ice extent, thickness and duration, the potential for changes in the community production and composition of arctic microbes is significant (see Arrigo et al. 2008). Clearly, primary production has high potential to influence higher trophic level species and its assessment should be given high priority as part of a monitoring program (e.g., see Ware and Thompson 2005; Samhouri et al. 2009).

Historical data

Poulin et al. (2011) compiled a list of arctic microbes across Canada from the 1950s to the present time (see also Archambault et al. 2010). This list is not indexed to specific stations but includes information from Davis Strait, Baffin Bay, Canadian Arctic Archipelago, Beaufort Sea, Canada Basin, Hudson Bay and Hudson Strait. Programs with either recently concluded or ongoing activities have accumulated data from all of the focal marine areas and the plankton monitoring stations put forward by Canada for the CBMP-MP. It is still necessary to establish temporal baselines from historical and recent data sources.

Current Activities

Contact names for current research programs by priority sub region are shown in Figure 2. Recruitment of individual researchers and managers carrying out monitoring-related activities is critical for the successful implementation of Canada’s arctic marine biodiversity monitoring plan.

Field Sampling

Sampling for microbes is via water collection (generally via niskin bottles) and subsequent filtration. Water collection should be associated with basic oceanographic profiling (T, S, chl*a*) and geochemistry. Chl*a* profiling (along with laboratory validation) is important to document the depth of surface chl-max and deep chl-max. The vertical stratification of microbes is becoming increasingly well established as co-varying with water mass structure (Galand et al. 2010) but the majority of the microbial biomass is concentrated in the upper 100 or so metres (see Sherr et al. 2003). Sampling of bacteria, archaea, and protists should follow water mass structure and chl*a*-maxima while sampling targeting the autotrophic community should follow chl-maxima (surface and subsurface).

Analysis

Bacterial and archaeal diversity cannot be characterized by visual inspection and thus necessitates building and sequencing clone libraries (see Galand et al. 2010) or next-generation sequencing of pooled environmental samples (see Barriuso et al. 2011). These genetic approaches have the potential to provide information regarding diversity and relative abundance and thus should allow for calculating diversity indicators such as the Shannon-Weiner and Simpson indices. The Shannon-Wiener index (Shannon and Weaver 1945) emphasizes rarer species while Simpson’s index favors more abundant species (Krebs 1999).

Protist diversity can be characterized visually and by genetic approaches. There is more protist taxonomic data than genetic data so in the short term, this approach should be continued. Genetic approaches have substantial advantage in the longer run because of the lack of specialized taxon-specific expertise needed for this type of analysis. Many commercial labs can process genetic samples and the cost of such analysis is decreasing. There is a need to compare genetic data to taxonomic data to determine how well the genetic approach follows the taxonomy approach. Genetic approaches may not be as sensitive to rare taxa as may be the leading edge of a species boundary shift or accurately reflect abundance. Changes in protest diversity can be assessed via the Shannon-Wiener and Simpson indices.

Flow cytometric and HPLC approaches can be used to characterize prokaryotic and eukaryotic microbes but are too specialized and not widely applied so are not recommended. Use of moorings with acoustic Doppler current profiler (ADCP) and fluorometer capacity can be used to assess zooplankton and phytoplankton. The ADCP and fluorometric approaches do not allow for the identification of species but they can provide valuable insight into shifts in phenology and abundance, and should be promoted. Shipboard measurements of primary production provide very useful information regarding ecosystem status but are not logistically practical across all priority sub regions. An alternative approach would be to employ remote sensing coupled with chl*a* measurements for ground truthing satellite observations. Characterization of viruses is possible with molecular techniques and recent work has begun to characterize abundance and types of viruses in Canada's arctic marine habitat but this field is too new to be recommended as a component of monitoring activities at this time.

The northward boundary shifts of subarctic species are a likely consequence of changes in ice dynamics and water column characteristics. Detecting the establishment of non-native and, potentially, invasive species is an important harbinger of ecosystem boundary shifts and, potentially, of ecological transformation. Thus, analyses of microbial taxonomic diversity, whether by genetic or visual approaches, should be done with full cognizance of the identity of potential invasive species. Table 1 summarizes parameters and indicators for planktonic organisms.

<u>Core Indicators for microbes</u>

- Levels of Chl*a*
- Species richness
- Relative abundance of *Bacteriodetes*, Ciliates, Haptophytes, *Cercozoa* and Type1 Marine Stramenopile
- Ratio of Thaumarchaeota to Euryarchaeota
- Presence / absence of *Synechococcus*
- Clade specific make up of *Micromonas*
- Biomass of key species and total
- Community composition in terms of abundance and biomass
- Small taxa vs. large taxa
- Diversity (Shannon-Weiner and Simpson)
- Presence of non-native, potentially invasive species
- Biogeographic representations of key species and assemblages

<u>Gaps</u>

Further refinement of focal species or communities for monitoring is needed.

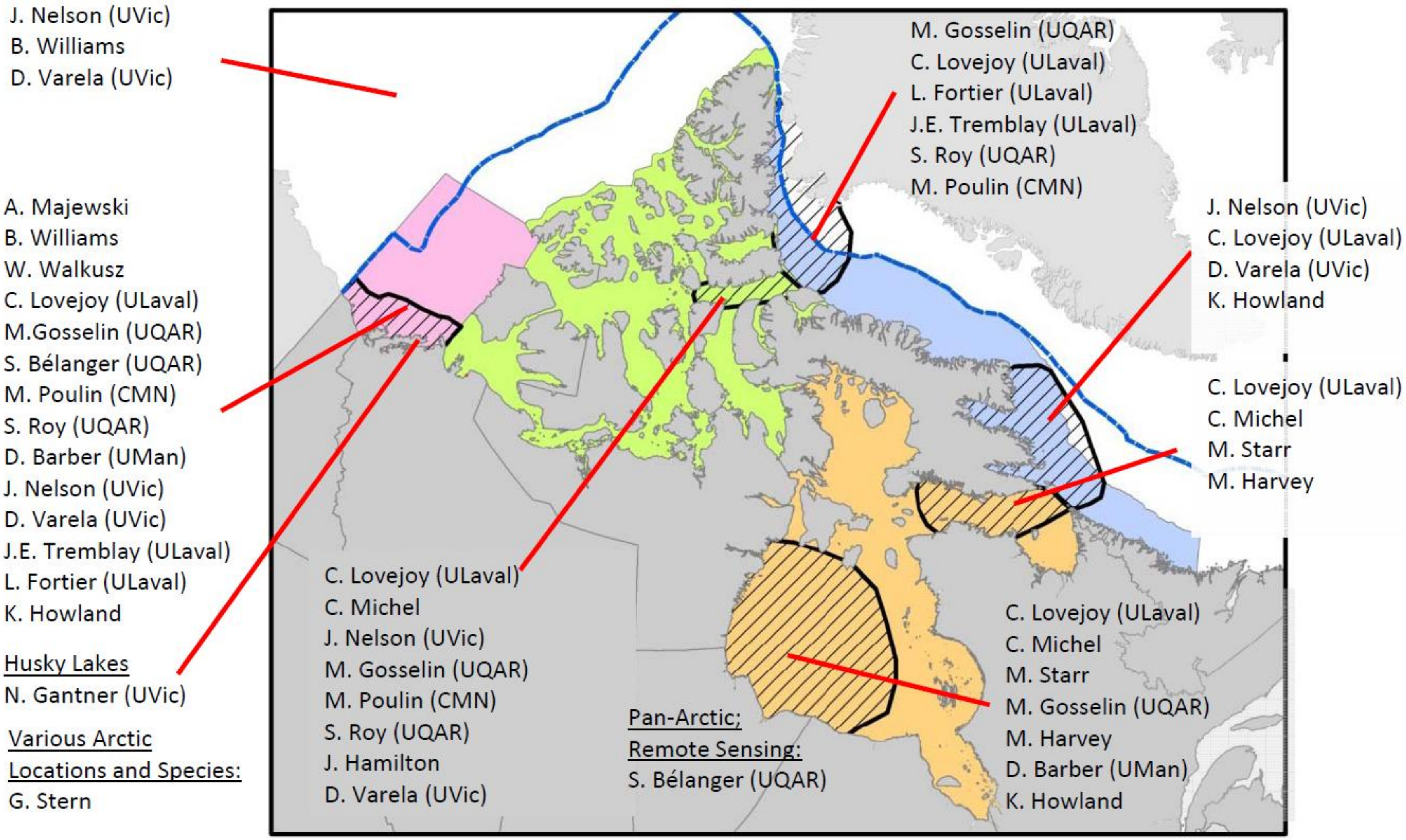

Figure 2. Program and data contacts for water and plankton sampling for Canadian contribution to the CBMP-MP. Fisheries and Oceans Canada (DFO) affiliations unless otherwise indicated. Source: personal communication of those listed.

Table 1. Summary of Parameters and Indicators by Focal Ecosystem Component – Plankton

Category	**FEC**	**Key Parameters**	**Indicators**	**Notes**
Plankton	Phytoplankton	Abundance, biomass & species composition, chlorophyll *a* concentrations (ideally size-fractionated) from visual taxonomy surveys. Chl*a* from direct assays, remote sensing, profiles.	Diversity indices, community/group abundance, ratio small: large, ratio local: invasive, geographical range	Emphasis on chl*a*, top priority. Analysis of environmental associations desirable.
		Primary production	Productivity	Not practical at this time.
	Protists-(other than autotrophs)	Abundance (biomass) & species composition from taxonomy-visual and molecular biology.	Diversity indices, community/group abundance, ratio small: large, ratio local: invasive geographical range	May not be sufficient information for local/ invasive and small /large ratio calculations, analysis of environmental associations desirable.
	Archaea, bacteria.	Abundance, biomass & size structure from molecular biology.	Diversity indices, composition/ group abundance, size spectra, ratio local: invasive	May not be sufficient info for local/ invasive and small /large ratio calculations. Not practical to do flow cytometry. Analysis of environmental associations desirable.
	Zooplankton	Abundance, biomass & species composition from visual.	Diversity indices, community/group abundance, community/group biomass, ratio small: large, ratio local: invasive, geographical range	Molecular biology genomic not practical or necessary now. Local invasive is simply observations of sub-arctic species, analysis of environmental associations desirable.

METAZOAN ZOOPLANKTON

Importance and response to drivers

Metazoan (multicellular) zooplankton are the main link between primary producers and higher trophic level taxa such as fishes, seabirds, and marine mammals. This diverse group also play a fundamental role in nutrient cycling (Buitenhuis et al. 2006) and carbon export to the benthos. The ways in which zooplankton respond to climate forcing have far-reaching ecological effects. The abundance and species composition of zooplankton prey are of high importance to the early survival and population levels of Arctic Cod, which in turn influence the success of vertebrate predators (seals, birds, whales), which feed heavily on this small fish (Welch et al. 1992). In general, less is known about gelatinous zooplankton than other groups and likewise, how they will respond to changes in ice cover and water mass properties. Larvaceans will likely increase in importance (Deibel et al. 2005, Deibel and Daly 2007) and other predatory groups may also increase (Mills 1995, 2001).

There is a distinct possibility of range extensions of southern zooplankters (from both the Atlantic and Pacific oceans) into arctic waters with attendant ecological effects (see Occhipinti-Ambrogi 2007). Ice melt and increased runoff are reducing Ω aragonite saturation to < 1 in some areas of the Arctic (Yamamoto-Kawai et al. 2009; Chierici and Fransson 2009), which is the level at which aragonite-shelled zooplankton fauna are vulnerable to dissolution. Several studies describe the biogeographic structure of zooplankton in the Arctic (Ashjian et al. 2003, Walkusz et al. 2010, Darnis et al. 2008) and reports are starting to emerge describing potential responses of zooplankton to climate-forced change (Darnis et al. 2008; Tremblay et al 2011). However, no studies published to date have sufficient temporal resolution to reach broad conclusions as to how the biodiversity of arctic zooplankton is responding to climate change. This compromises prediction of how change in the zooplankton will affect species that feed on zooplankton and overall ecosystem function.

Historical data

Sampling and study of the metazoan zooplankton community in Canadian arctic waters extends back more than a century (see Shih et al. 1971 for an historical synopsis to 1971). This data is valuable from a species presence/absence perspective but a lack of consistent methodology makes estimation of temporal trends in biomass and abundance problematic. In the last decade, and particularly in 2007-2008 during the International Polar Year, consistent and comprehensive studies were carried out regarding the composition, abundance and distribution of the metazoan zooplankton fauna in Canada's marine arctic waters. Such efforts include the Canadian Arctic Shelf Exchange Study (e.g. Darnis et al. 2008), Canada's Three Oceans program (Carmack 2010), the Circumpolar Flaw Lead program (Barber et al. 2010), and the Joint Ocean Ice Study/Beaufort Gyre Observing System (Proshutinsky et al. 2009). The CBMP-MP holds great promise for promoting international cooperative research with consistent sampling methodology (described herein), wide geographical coverage, and greater temporal sampling, all of which will accelerate the understanding of zooplankton biodiversity. It is necessary to establish a baseline from historical and recent data sources. This will be carried out by members of the Marine Expert Networks.

Current Activities

Contact names for current research programs are shown in Figure 2. Recruitment of individual researchers and managers carrying out monitoring-related activities is critical for the successful implementation of Canada's arctic marine biodiversity monitoring plan.

Field Sampling

Over the years zooplankton gear and sampling methods have varied; this limits the utility of historical data. At a meeting of the CBMP-MP group, it was decided that vertical net hauls with nets of 150-180 µm mesh (150 µm preferred) would be the standard. The size of the opening of the net is not critical except for the larger, faster-moving taxa. Net hauls should be associated with basic oceanographic profiling (T, S, chl*a*) and geochemistry, and go to 100 m or to as close to the bottom as possible (typically wire out to 7 m from bottom) and retrieved at 0.5 to 1 m/sec. In order to estimate abundance and biomass the volume of water filtered must be measured with a flow meter. Net contents are collected and preserved in 5% to 10% buffered formalin.

Analysis

Net contents should be enumerated to the level of species identity and abundance including copepodite stages of copepods. There is a long history of the use of zooplankton biodiversity and range as indicators of ecosystem change (see Hooff and Peterson 2006 and Beaugrand and Ibanez 2004). These studies are a good precedent to follow for development of Canada's Arctic Biodiversity Monitoring Plan. Table 1 summarizes parameters and indicators for planktonic organisms.

Core Indicators for mesozooplankton

- Species richness
- Abundance (key species and total)
- Biomass (key species and total)
- Community composition in terms of abundance and biomass
- Small taxa vs. large taxa
- Diversity (Shannon-Weiner and Simpson)
- Presence of non-native, potentially invasive species
- Biogeographical representation of key species or species complexes

Examination of the distribution of taxa that span the boundaries between oceanic domains is a powerful way to track ecosystem change. These distributions take on increased significance when the taxa tracked are ecologically important. Key metazoan zooplankton species and taxonomic groups to monitor include members of the ubiquitous *Calanus spp*. complex, the amphipod genus *Themisto, and* the pteropod *Limacina helicina* which may be sensitive to aragonite-under saturated water. The Canada Basin has regular zooplankton collections and is, therefore, recommended as a new priority sub-region for this FEC.

Gaps

Further refinement of key focal species and zooplankton communities is needed.

ICE ASSOCIATED FLORA AND FAUNA

Importance and response to drivers

The interplay between sea ice, water, wind and solar input defines arctic ecosystems. Sea ice occurs across the entire Canadian Arctic with differing regional characteristics. Fast ice forms a narrow band along coastlines and pack ice (a combination of first-year and multi-year ice) covers most areas in winter, with the exception of polynyas. Sea ice everywhere is habitat for ice-associated aquatic biota ranging from microbes to fishes. Abundance and taxonomic richness varies but both are generally higher over productive areas (Gradinger et al. 2010). Increased seasonal ice melt (Stroeve et al. 2007) will put pressure on ice-endemic species and reductions in the proportion of multi-year ice in the ice pack (Maslanik et al. 2007) will directly affect biota dependent on the unique structural features of multi-year ice. A general transition to a seasonal rather than multi-year ice ecosystem will not only directly affect sympagic biodiversity but will indirectly affect pelagic and benthic biodiversity as well via changes in light penetration and water mass stratification. Algae associated with sea ice provide an early pulse of reduced carbon into the ecosystem (Michel et al. 2006). Ice structures shelter Arctic Cod. Sea ice is also a critical habitat for seals, walrus, and polar bears (Kovacs et al. 2011) and seabirds; these groups will be affected by changes in ice (see Huettmann et al. 2011). There is little doubt that the changes to sea ice characteristics, dynamics and geographic extent has enormous consequences for arctic marine biota.

Historical data

Poulin et al. (2011) document sympagic unicellular eukaryotes in Canadian arctic waters and Marquart et al. (2011) describe sympagic fauna of the Beaufort Sea (see also Archambault et al. 2010).

Current Activities

Contact names for current research programs by focal marine areas are shown in Figure 3. Recruitment of individual researchers and managers carrying out monitoring-related activities is critical for the successful implementation of Canada's arctic marine biodiversity monitoring plan.

Field Sampling

Sampling of sea ice biota is via the collection of sea ice cores (with the exception of fishes). Ice cores are collected, divided into sections, melted and then the biota preserved both in 10% buffered formalin for taxonomic analysis and ethanol for genetic analysis. Cores should be associated with basic oceanographic profiling (T, S, chl*a*). Specific analyses for microbes (see above) and zooplankton (see above) may be associated with each section. Melt water from the cores should be analysed for basic properties (T, S, etc.) if possible. Meiofauna such as nematodes and amphipods associated with ice will also be encountered and should be enumerated taxonomically.

Analysis

Microbes, metazoan zooplankton, and meiofauna should be identified and enumerated by genetic and/or visual identification (see microbe section for details). Arctic Cod are also associated with sea ice. The systematic study of this species is challenging and may not be viable as part of a continued monitoring program. Study of Arctic Cod during break-up and in times of open water is more feasible and should be a high priority (see section on fishes). Table 2 summarizes suggested parameters and indicators for sympagic organisms.

Core Indicators for sympagic taxa

Species richness
Abundance (key species and total)
Biomass (key species and total)
Diversity (Shannon-Weiner and Simpson)
Community composition in terms of abundance and biomass
Biogeographical representation of key species or species complexes

Gaps

Further refinement of focal species or communities for monitoring is needed.

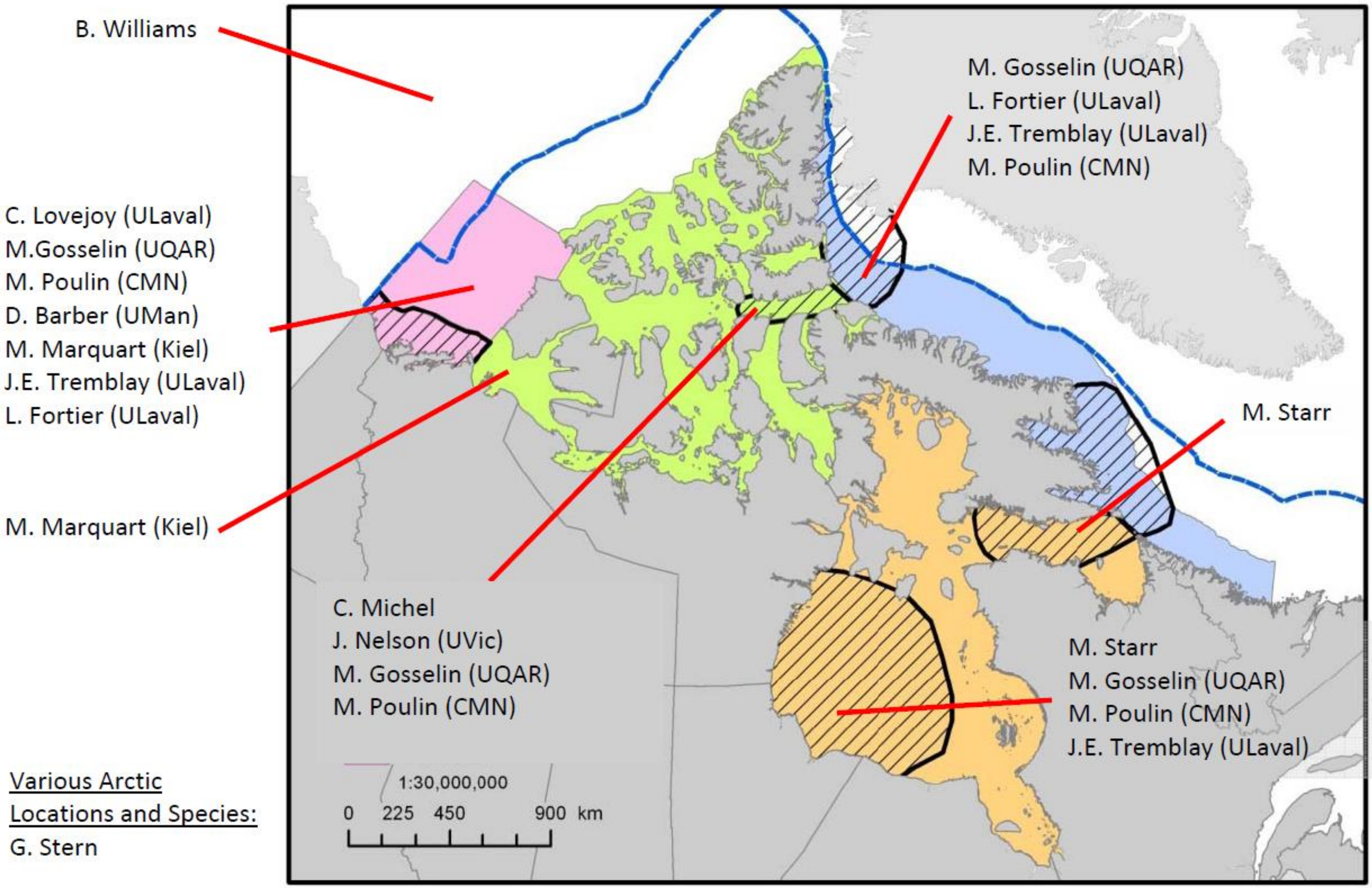

Figure 3. Program and data contacts for sympagic sampling for Canadian contribution to the CBMP-MP. Fisheries and Oceans Canada (DFO) affiliations unless otherwise indicated. Source: personal communication of those listed.

Table 2. Summary of Parameters and Indicators by Focal Ecosystem Component: sympagic

Category	FEC	Key Parameters	Indicators	Notes
Sea-ice microbes	Protists	Abundance, biomass (including Chl*a*), species composition, by taxonomic and molecular genetics methods.	Abundance and biomass- key species and total taxa. Ratio-diatoms: dinoflagellates, diversity indices, presence of sub-arctic species, size ratio.	There may not be sufficient information for local/ invasive and small /large ratio calculations, analysis of environmental associations desirable.
		Primary production	Productivity	No-not practical at this time.
Sea-ice metazoans	Invertebrates	Abundance, biomass & species composition Fauna size structure Key species definition.	Abundance and biomass key species and total taxa, diversity indices, presence of sub-arctic species, size ratio.	Molecular biology and genomics not practical or necessary at present. Invasive is simply observations of sub-arctic species. Analysis of environmental associations desirable.
Fishes	Arctic Cod	Abundance, biomass, size/weight.	Abundance, biomass, size, biogeographical range.	Not feasible consistently during ice cover but should be high priority during ice reduced seasons. Information is lacking regarding *Arctogadus glacialis*.

BENTHIC FLORA AND FAUNA

Importance and response to drivers

A diverse collection of organisms are associated with benthic substrate in Canadian arctic marine habitats. Benthic infauna live embedded in the substrate while epifauna are associated with the substrate surface. Benthic fauna are an important prey base for marine mammals and seabirds and are involved in nutrient cycling. Algae associated with sediments also contribute to primary production where water clarity and depth allow for penetration of photosynthetically active radiation (Wulff et al. 2009). Bacteria associated with sediments are involved in nutrient transformative processes and degradation of organic carbon (H. Li et al. 2009). Among benthic taxa, benthic microbes (including viruses) are the least well-characterized.

Benthic ecosystems of Canada's Arctic are under increasing pressure from a range of potential stressors including: changes in the timing and type of primary production (which will affect the flux of reduced carbon to the benthos), upwelling of lower pH aragonite-under saturated water that may affect calcium carbonate-based taxa; shifts in range of predators; oil and gas development; development of fisheries (see Kenchington et al. 2011). Benthic organisms are excellent candidates for monitoring purposes. Long-lived benthic species can act as multiyear, long-term integrators of a variety of marine processes. Macroinfauna are normally stationary in marine sediments, and thus their community distribution patterns reflect export production from the overlying water column. Some of the strongest signals of climate change in the sub-Arctic have come from the study of benthic infauna (Grebmeier et al. 2006). Methodologically consistent, spatially-focused, long-term sampling of benthic fauna in the Arctic will similarly provide robust monitoring tools.

Historical data

The benthic fauna of Canada's marine arctic habitat has recently been summarized in Archambault et al. (2010); this study does not break down species distribution by region within the Arctic. Kenchington et al. (2011) summarized the status of data sources for Canadian marine benthos and presents summaries of benthic biodiversity; this work indicates that benthic data exist for the focal marine areas of the Northwater Polynya, Beaufort Sea shelf, Lancaster Sound, north Baffin Bay, Hudson Bay, Hudson Strait, and south Davis Strait areas. Benthic biodiversity information collected all around northern North America during the Canada's Three Oceans program and an unpublished MSc thesis (Balsom 2003) that describes benthic fauna ranging from the Beaufort Sea into the Canadian Arctic Archipelago have yet to be incorporated in compilations as described above. It is necessary to establish baselines from these historical and contemporary data sources.

Current Activities

See Figure 4 for contacts relevant to benthic data and sampling in Canada. Recruitment of individual researchers and managers carrying out monitoring-related activities is critical for the successful implementation of Canada's arctic marine biodiversity monitoring plan.

Field Sampling

An array of different gear has been used to sample benthic organisms; these can be broadly defined in terms of their sampling effectiveness in collecting epibenthic and infaunal organisms. Bottom trawls target epibenthos (with some associated infaunal bycatch) while box corers and bottom grab apparatus, such as the Van Veen, sample infauna and epifauna. Image analysis also provides very useful insight into epifauna and some clues to infaunal presence. However, this approach is neither widespread nor standardized so it may be difficult to employ for routine widespread monitoring except in certain highly studied locales. Historical data sets regarding epibenthos of the Hudson and Davis straits (see Kenchington et al. 2010), suggest that sampling of epibenthos (particularly coral and sponges) in these areas could continue into the future and be a key part of biodiversity monitoring in the eastern Arctic. Elsewhere in Canada's Arctic, similar data sets regarding soft coral and sponges do not exist. Use of bottom grab samplers, particularly the Van Veen, appears to be the most widespread approach taken to studying and monitoring benthic fauna and is the recommended standard for shallow water work while for deeper water the box corer is recommended. Sampling should be associated with basic oceanographic profiling (T, S, chl*a*). Substrate analysis as well as sediment Chl*a* analysis would be useful. Substrate from three (at least) replicate grabs (or cores) should be washed from samples over wire mesh and the organisms first placed into 10% formalin and subsequently transferred to 70% ethanol or 50% isopropanol for longer-term storage. If possible, a subsample should be preserved in 95% ethanol (tissue volume not exceeding 25% of final volume) for genetics. Specimen removal should be noted for later calculations of abundance and biomass.

Epibethic bottom trawls to be carried out as per CBMP-MP.

Analysis

Fauna should be identified and enumerated with biomass and abundance standardized to 1 m^2. Taxonomy should be standardized and specimens vouchered and archived for local reference, as well as for comparison between labs. Table 3 summarizes parameters and indicators for benthic organisms.

Core Indicators for benthic fauna

Species richness
Abundance (key species and total)
Biomass (key species and total)
Community composition in terms of abundance and biomass
Diversity (Shannon-Weiner and Simpson)
Presence of invasives

Depending on station density, cluster analysis could be used to group sampling stations into biogeographical units with trends in the above indicators analysed within and between units.

Gaps

Further refinement of focal species or communities for monitoring is needed.

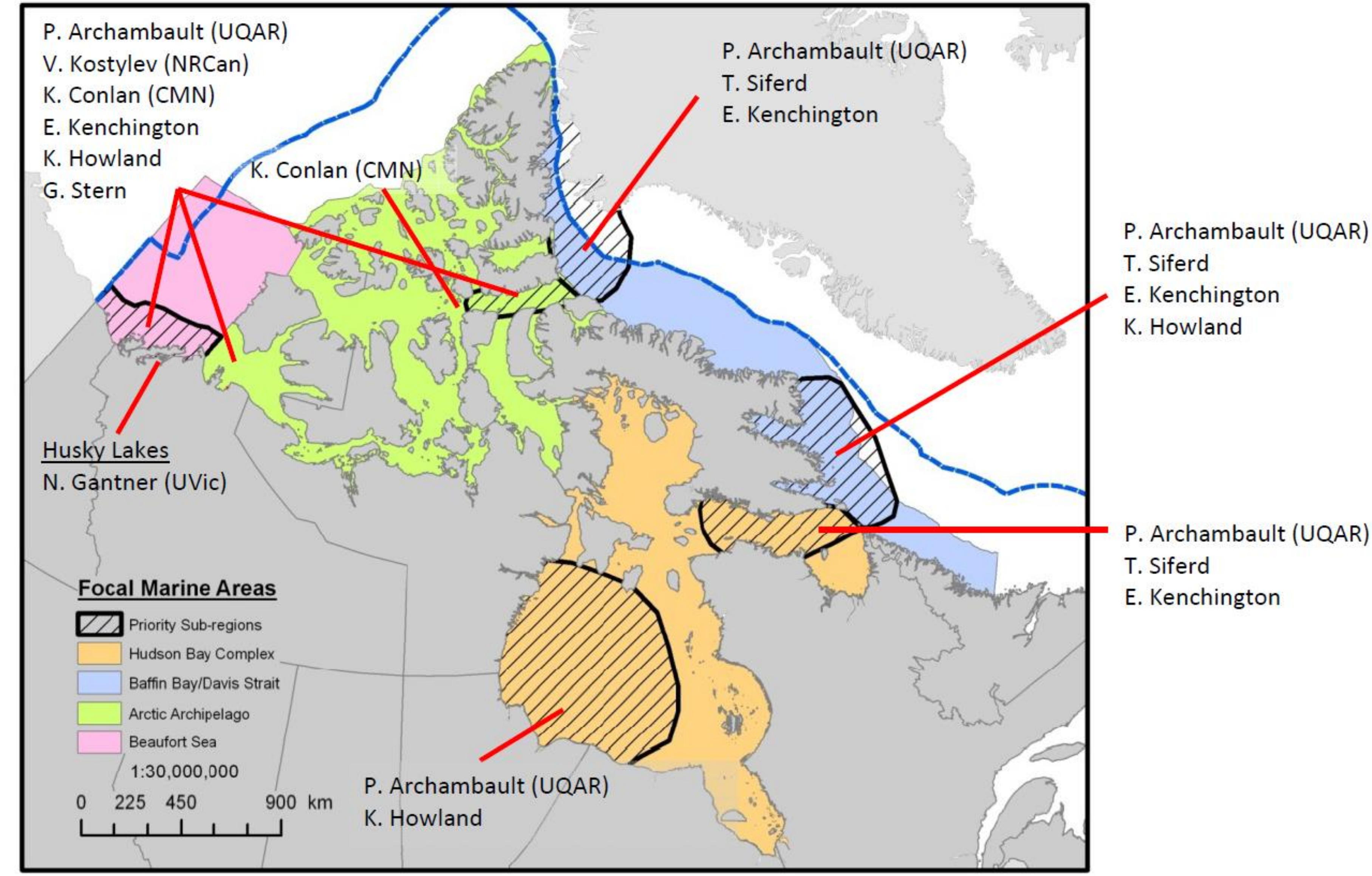

Figure 4. Program and data contacts for benthic sampling for the Canadian contribution to the CBMP-MP. Fisheries and Oceans Canada (DFO) affiliations unless otherwise indicated. Source: personal communication of those listed.

Table 3. Summary of Parameters and Indicators by Focal Ecosystem Component: benthos.

Category	FEC	Key Parameters	Indicators	Notes
Benthic taxa	Benthic infauna epifauna	Species richness Abundance Biomass	Diversity measures (e.g. Shannon, Simpson, Taxonomic redundancy, Beta-diversity, response diversity, taxonomic distinctness)	Means and trends in variance should be presented. Clear reference points should be established using the bioequivalence method.
			Trends in key species (e.g. blue mussel, sea urchins, sea cucumbers, *Corophium* sp. (links to sea birds); clams*, Hyatella arctica, Serripes groenlandicus, Mya truncata*	Should link to higher tropic levels (birds, walrus, bearded seal, etc.). Timing and duration of anomalous events should be noted (links to physical oceanography)
				Timing of phytoplankton/ice algae bloom should be noted (links to microbes)
	Corals and Sponges	Species Richness.	Diversity Measures (e.g. Shannon, Simpson, Taxonomic redundancy, Beta-diversity, response diversity, taxonomic distinctness).	Human activities/impacts should be mapped. Timing and duration of anomalous events should be noted (links to physical oceanography)
		Abundance.		High precision for In situ photographic/video transects (e.g. ROV)
				Low precision for trawl surveys
		Biomass.	Number per m^2	Quantitative grab samples or other equipment (e.g. ROV, small dredge,
				Low confidence in survey data
		Physiological Stress	Live:dead ratio	Expert opinion needed for biomarker indicator identification.
			% zoanthid cover	High precision for In situ photographic/video transects (e.g. ROV)
			Biomarkers in Sponges	Low precision for trawl surveys
		Reproductive Success	Size structure of foundation species	Size structure is considered low priority
			Patch area	Link to genetic diversity
			Patch density	
			Patch isolation/proximity	
			Patch connectivity	
			Patch dispersion	

Macroalgae

Marine macroalgae can serve as spawning habitat and nursery areas for fishes as well as providing a food source for various taxa. The overall distribution of macrophytes in arctic marine waters is a function of sea ice dynamics (ice scouring), light availability, and substrate. In spite of the potential importance of macroalgae to Arctic ecosystems, knowledge of the diversity and distribution of marine macroalgae in the Arctic is poor.

Fundamental ground work regarding distribution and abundance of marine macroalgae in Canadian arctic marine waters is needed to assess the significance of this group of organisms. Traditional knowledge holds the potential to be an important source of information regarding diversity and distribution of macroalgae (see Cobb et al. 2008). The study of kelp beds in the Stefansson Sound Boulder Patch located in the Alaskan Beaufort Sea, may serve as a starting point for the study and monitoring of macroalgae in Canadian arctic marine waters (Dunton et al. 2009).

FISHES

Importance and response to drivers

Fishes are ecologically important as predators and prey, and are harvested by humans for commerce and sustenance. Archambault et al. (2010) gives the number of fishes found in Canada's arctic marine waters at 189 with a possibility of 83 additional species. These species can be divided into either demersal (benthic) or pelagic categories. Increasingly mild conditions will potentially lead to greater direct human impacts (e.g., increased access for fishing) and indirect impacts (e.g., oil and gas exploration and development), and drive a range of biotic responses related to change in water temperatures, primary productivity, etc. Potential response phenomena of fish fauna include range shifts, establishment of invasive species and new diseases, altered productivity, and altered phenology. Development of a biodiversity monitoring strategy for the fishes is complex given the patchy and regional nature of fish distributions, the wide array of fish species, and historical and ongoing stakeholder impacts.

There are two methodological approaches to monitoring icthyodiversity; either a generalized approach using techniques that capture a range of species, such as trawling, or a dedicated species-targeted approach (e.g., gill net surveys for Charr). Species that are currently monitored for fishery management purposes are obvious candidates for monitoring and development of indicators for biodiversity change. Other species that are of high ecological importance but not currently harvested, such as Arctic Cod (*Boreogadus saida*), may warrant special attention because of their foundational ecosystem role and a lack of understanding of the species' biology. Stephenson and Hartwig (2010) present a list of fishes of interest and importance, which was produced from a workshop on arctic fauna, that provides a short list of candidates for development of biodiversity monitoring indicators. Among the species listed are Charr (*Salvelinus* sp.), Whitefish (*Coregonus* spp.), Pacific Herring (*Clupea pallasi*), Arctic Cods (*Boreogadus saida* and *Arctogadus glacialis*), Greenland Cod (*Gadus ogac*), and Greenland Halibut (*Reinhardtius hippoglossoides*). The effect of climate drivers on this collection of species is very species-specific and, generally, not well understood. As an exception to this, however, is a clear summary of the potential of climate driven effects on Charr has been assembled and can be found at http://www.api-ipy.gc.ca/_docs/cvc_e.pdf and see DFO (2010). Similar information could be developed for other fishes that are of monitoring interest. Other salient species for monitoring are salmonids (see Irvine et al. 2009); Pacific salmon abundance in the Beaufort Sea has the potential to increase in the relative short term as do the ranges of Atlantic Salmon and Brook Charr into the Hudson Strait\Foxe Basin area.

Historical data

The extent of fish biodiversity data varies across species and region, and is largely focused around species' of commercial and sustenance importance; this will limit monitoring capacity. One important exception to this is the research that is being conducted on Arctic Cod (*Boreogadus saida*) by DFO, ArcticNet and the Ocean Tracking Network. Basic biodiversity data on arctic fishes are collected when non-target fishes are caught in research fishing activities. This data is generally underutilized and could be recruited into a monitoring framework. DFO data reports could serve as a baseline.

Current Activities

See Figures 5a and 5b for contacts regarding current fish research activities.

Field Sampling

As for all sampling efforts, collections should be associated with basic oceanographic profiling (T, S, and Chl*a*). A range of gear types are used to sample fish populations. These include surface-, mid- and bottom water trawls, gill nets, and seine nets. Sampling in USA waters is moving towards standardized sampling gear (at least for trawling) and efforts should be made to harmonize sampling methodology and gear types. In the eastern Arctic, sampling should be coordinated with fishery work carried out by Greenland. Another consideration for assessment of forage fishes such as Arctic Cod or Capelin is whether seabirds can be used as proxy samplers of populations.

Analysis

Once samples are collected there is a wide range of analyses that can be conducted depending on whether a mixed community is sampled or a targeted species. Mixed samples should be completely enumerated and identified to the lowest taxonomic level possible. This will allow for tracking of basic indicators of biodiversity such as species composition, abundance and diversity. Species of special interest and concern (see below) should be targeted for more in-depth analysis. Basic fish measurements that should be taken include fork length, weight, and gonad condition. Tissue collections made into ethanol or DMSO-NaCl should be made for archiving and for genetic analysis. Table 4 summarizes parameters and indicators for fishes.

Core Indicators for fishes

Species Richness
Abundance (key species and total)
Biomass (key species and total)
Diversity (Shannon-Weiner and Simpson)
Presence of invasive species

Although the diversity of marine fishes in Canada's Arctic is large, historical information and ongoing research is limited to only a few species. These species are good candidates for monitoring. The use of fishery bycatch should be considered, particularly in the Pacific-Arctic and Atlantic-Arctic boundary areas where retreat of arctic fishes and the advance of boreal fishes may be expected.

Target species and areas

Arctic Cod - Beaufort Sea, Amundsen Gulf, Northwater Polynya
Charr - Cumberland Sound, Beaufort Sea
Greenland Halibut - NAFO 0A, 0B
Pacific Herring - Beaufort Sea
Salmonids - Beaufort Sea, Foxe Basin, Baffin Island
Capelin
Shrimp*-NAFO 0A, 0B.

*Shrimp here is included in the fish section because sampling of this species follows the fishery research model and thus would be carried out in much the same manner as for other trawl fisheries.

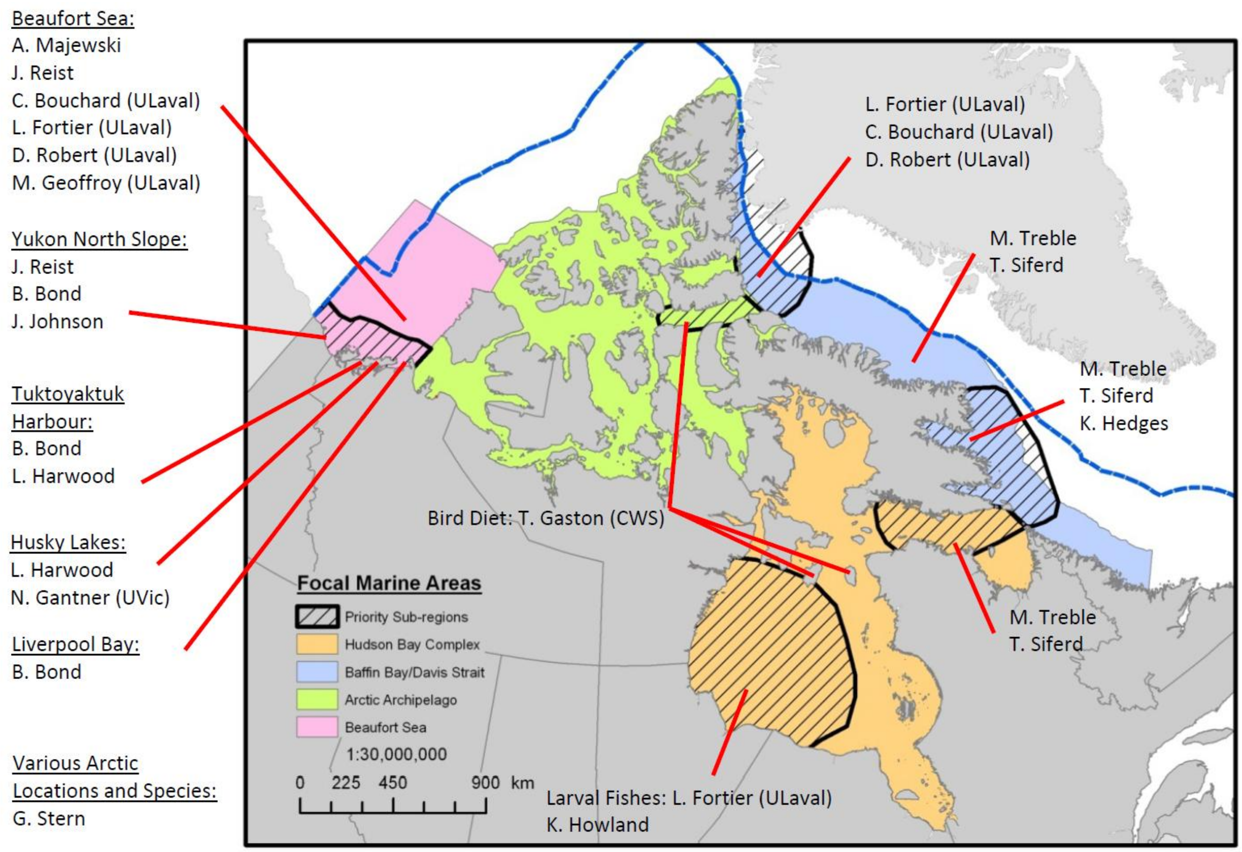

Figure 5a. Contacts information by area for past and ongoing work regarding coastal and marine fishes in Canada. Fisheries and Oceans Canada (DFO) affiliations unless otherwise indicated. Source: personal communication of those listed.

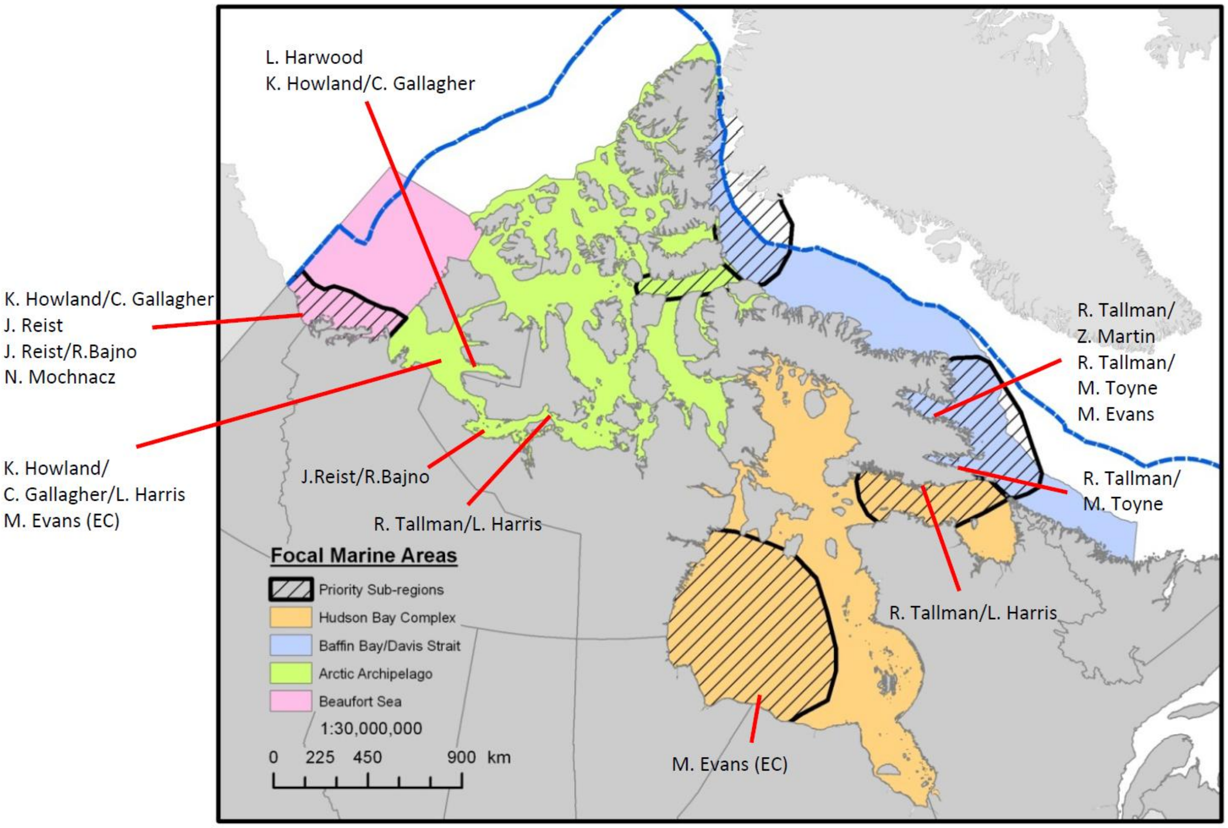

Figure 5b. Contacts information by area for past and ongoing work regarding Arctic Charr and Dolly Varden in Canada. Fisheries and Oceans Canada (DFO) affiliations unless otherwise indicated. Source: personal communication of those listed.

Gaps

Further refinement of species, communities and locations for monitoring is needed.

Table 4. Summary of Parameters and Indicators for fishes.

Key Parameter	**Indicator**	**Rationale**	**Notes**
Species Richness/ Community Composition	Diversity measures (i.e., Shannon-Weiner and Simpson)	Surveys ecosystem resilience and function	Piscivorous fishes and seabirds are efficient samplers and diet information could be utilized.
Abundance	Size-frequency distribution	Surveys ecosystem resilience and function	Survey key species and communities
Biomass	Biomass	Surveys ecosystem resilience and function	Survey key species and communities
Health, Condition and Diet	Condition factor (e.g., weight/length), age, stomach contents, disease?	Important to detect a decline or change in the condition of a population or stock	Some are component of the CBM programs at traditional harvest sites. Also could use analysis of stable isotopes and fatty acids
Genetics	Population or stock delineation	Genetic diversity is an important component for assessing population structure and resilience.	Can also detect hybridization and trans-arctic gene flow
Biogeography and Boundary Shifts	Biogeographical representation of key species or species complexes. Presence of colonizers, vagrants and invaders	As the Arctic climate continues to change there will likely be shifts in species ranges that reflect changes in habitat type or structural properties	
Harvest Statistics	Information regarding timing, rate and location of harvest, age and sex structure, local perspectives on country foods		All or some of these indicators are regularly examined and noted during community harvests.

MARINE MAMMALS

Importance and response to drivers

Climate change has the potential to strongly affect marine mammals, both directly and indirectly (see Huntington and Moore 2008). Marine mammals are long-lived organisms that integrate climate signal over long periods of time. Their responses to change in the environment are not likely to be rapid in terms of changes in demographics but will be relatively rapid in terms of change in range, phenology and behaviour. Indeed, range shifts have been observed (see Ferguson 2009). Over the long term, trends in population size and demographic structure will occur and can be detected; however, these will not happen on the time scales of faster growing R-strategists such as zooplankters. Assessment of condition factors, in particular fat content, will reflect inability to cope with environmental change, and hold potential as powerful monitoring tools.

Simpkins et al. (2009) identified a group of marine mammals for monitoring that spend all of their lives in arctic waters:

Bowhead whale (*Balaena mysticetus*)
Beluga whale (*Delphinapterus leucas*)
Narwhal (*Monodon monoceros*)
Bearded seal (*Erignathus barbatus*)
Ringed seal (*Phoca hispida*)
Walrus (*Odobenusros marus*)
Hooded seal (*Cystophora cristata*)
Polar bear (*Ursus maritimus*)

Among this group, Laidre et al. (2008) identify narwhal and polar bear as being the most sensitive to climate change, making them of high concern and a high priority for monitoring. Polar bear monitoring for the Canadian arctic marine biodiversity monitoring plan will incorporate the plan under development by the international Polar Bear Specialist Group and will not be addressed here. Narwhals are differentiated into semi-distinct populations (Petersen et al. 2010) and this structure must be considered when developing monitoring strategies for this species.

Simpkins et al. (2008) also identified a group of marine mammals for monitoring that have populations that spend at least part of their lives in the Arctic. This group includes:

Gray whale (*Eschrichtius robustus*)
Humpback whale (*Megaptera novaeangliae*)
Fin whale (*Balaenoptera physalus*)
Minke whale (*Balaenoptera acutorostrata*)
Killer whale (*Orcinus orca*)
Hooded seal, (*Cystophora cristata*)
Harp seal (*Phoca groenlandica*)
Ribbon seal (*Histriophoca fasciata*)
Spotted seal (*Phoca largha*)

Among these, gray whale and killer whales have been increasing their ranges into arctic waters in recent years (Ferguson 2009; Stafford et al. 2007). Whether the ranges of other subarctic species are expanding into arctic territory is an important signal of change in biodiversity and should be a monitoring objective.

Historical data

The status of marine mammal monitoring and research activities has recently been compiled; Simpkin et al. (2008) summarize the status of species and subpopulations of marine mammals in the entire Arctic including Canada while DFO (2010) summarizes the status and trends of bowhead and beluga in the Beaufort; bowhead, beluga and narwhal in the Canadian Arctic Archipelago; and beluga in the Hudson and James Bay system. Note that killer whale populations have increased in Hudson Strait and that these marine mammal populations are currently studied and this may provide opportunities for monitoring. The majority of marine mammal research and monitoring in Arctic Canada has focused around five species, bowhead whale, beluga whale, narwhal, ringed seal and killer whale. Because of this, monitoring should focus around these five species.

Current Activities

See Figures 6a and 6b for contacts relevant to sampling in focal marine areas. Recruitment of individual researchers and managers carrying out monitoring-related activities is critical for the successful implementation of Canada's arctic marine biodiversity monitoring plan.

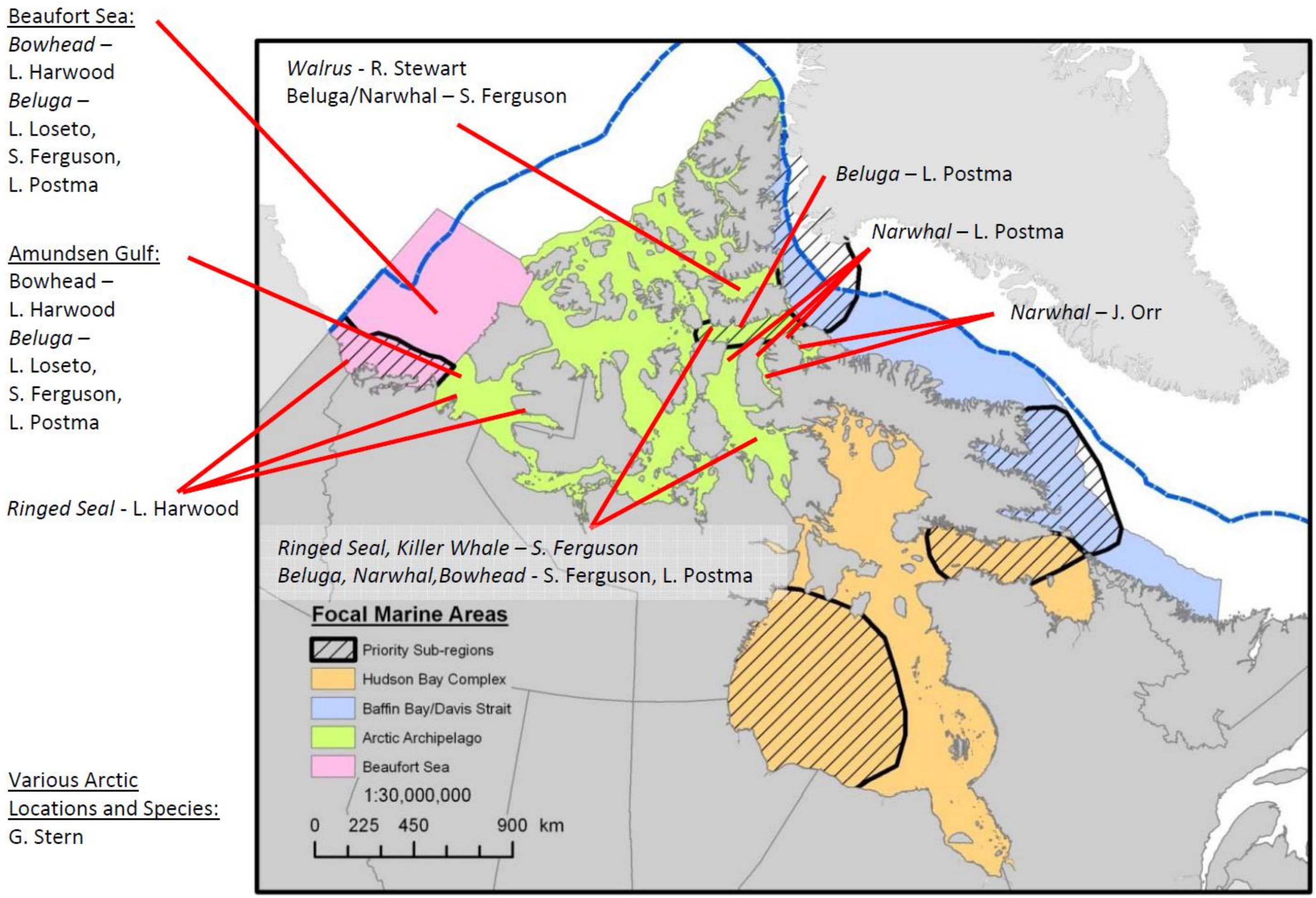

Figure 6a. Contacts information by area for past and ongoing work regarding marine mammals in the Beaufort Sea and Canadian Arctic Archipelago. Fisheries and Oceans Canada (DFO) affiliations unless otherwise indicated. Source: personal communication of those listed.

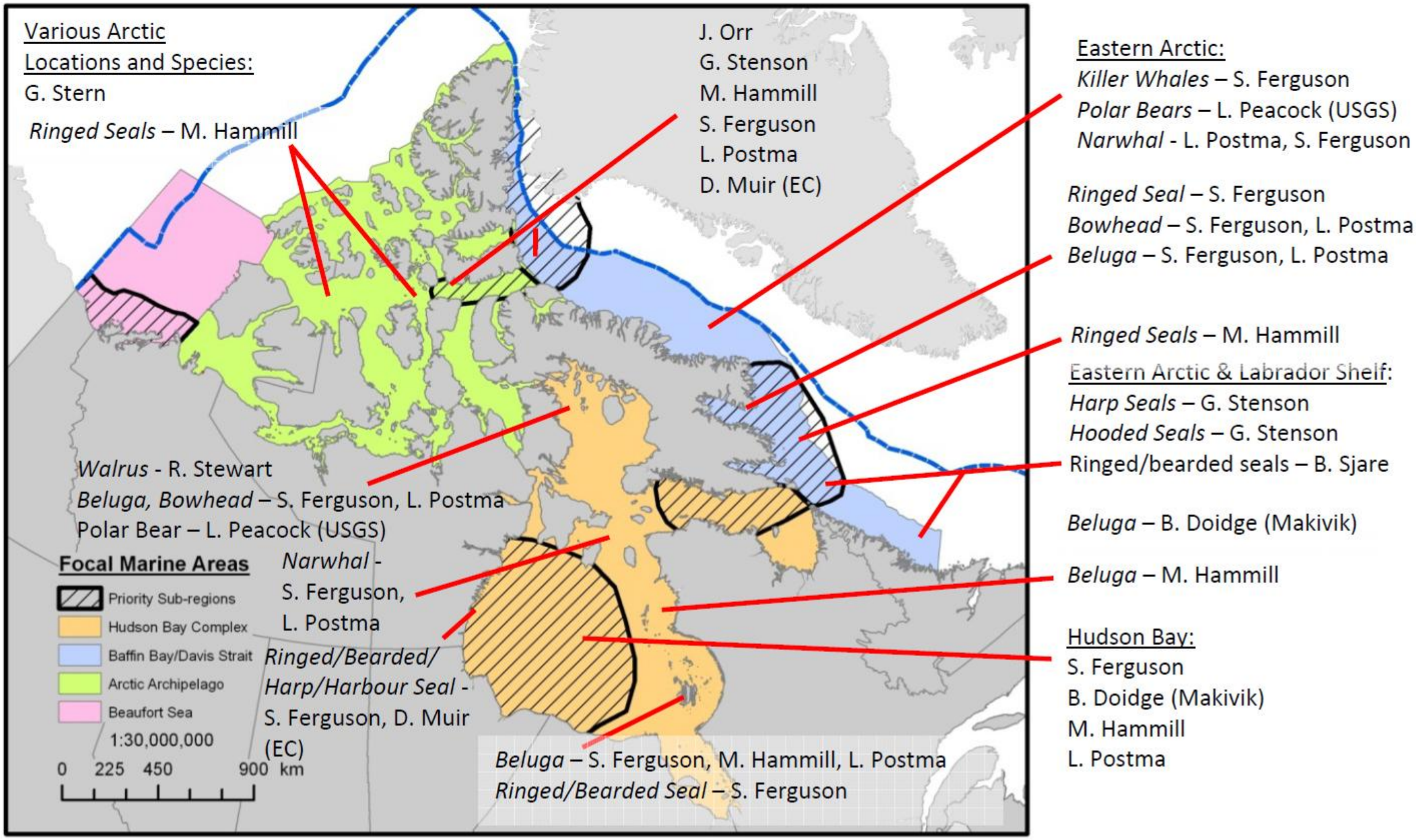

Figure 6b. Contacts information by area for past and ongoing work regarding marine mammals in the Hudson Bay Complex, Labrador Sea and Baffin Bay. Fisheries and Oceans Canada (DFO) affiliations unless otherwise indicated. Source: personal communication of those listed.

Target Species and Areas

Good candidates for monitoring are highlighted in DFO (2011) and include: Cumberland Sound beluga, eastern Hudson Bay beluga, northern Hudson Bay narwhal, Baffin Bay narwhal, western Hudson Bay ringed seal, and Beaufort Sea ringed seal. A more full representation of marine mammal monitoring indicators and opportunities is shown in Table 5 which provides information regarding the rationale for use of particular indicators, and Table 6 which provides suggested indicators for each species broken down by geographical location.

Table 5. Summary of Indicators for marine mammals including polar bear.

Key Parameter	Indicator	Rationale	Notes
Habitat Use	Important feeding areas, migration corridors density distribution, seasonal distribution	Provides a broad range of information with respect to habitat use and timing for highly migratory species	Aerial surveys useful
		Identification of hotspots and habitats which support important life history functions	Telemetry and tracking studies
		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 in the Eastern Arctic).	Should monitor changes in the habitat itself (i.e., pack ice)
Relative Abundance and Population Dynamics	Total or relative abundance, age and sex structure of population, Age specific reproductive rates (i.e., fecundity and maturity)	Changes in relative abundance and population dynamics will reflect response to climate change.	Aerial surveys may be useful. Relative abundance is low priority for some species: it 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 data. Population size available for most polar bear populations.
Harvest Statistics	Information regarding timing, rate and location of harvest, age and sex structure, local perspectives on country foods	Provides information on a range of important parameters	Government of Nunavut (GN) has an extensive harvest monitoring program for polar bears that includes tissue sampling. Focuses on traditionally harvested species and species of interest from DFO and locals perspectives (Valued Ecosystem Components)
Health, condition and diet	Morphometrics, diet, blubber quality/quantity (whales and seals), Body burden of contaminants, incidence of disease and parasites	Important to detect a decline or change in the condition of a population or stock	Techniques include: analysis of fatty acids, stomach and intestine contents, stable isotopes, contaminant, morphometrics
Genetics	Population or stock delineation. Assessment of genetic health.	Genetic diversity is an important component for assessing population structure and resilience.	Genetic diversity
Notable and/or Unusual Events or Observations	Die-offs, Disease, Boundary shifts (i.e., colonizers, vagrants or invaders)	Such events may be quite informative as to potential changes.	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

Table 6. Summary of Indicators by Species and location; marine mammals including polar bear.

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 Ringed seals Bearded seals Beluga Bowhead (limited) Polar Bear (limited)	Beluga Narwhal Bowhead Ringed seals Bearded seals Harbour seals Harp seals Polar Bear	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	Bowhead Narwhal Walrus Ringed seals Bearded seals Harbour seals Beluga Polar bear	Bowhead Walrus Ringed seals Hooded seals Harp seals Killer whales Beluga
Abundance				Harp seals Hooded seals
Relative Abundance	Polar bear		Polar bear	Beluga Polar bear
Health, Condition and Diet	Beluga Ringed seals Polar bear		Ringed seals Bearded seals Beluga Narwhal Walrus Polar bear	Ringed seals Bearded seals Beluga Narwhal Walrus Harp seals Hooded seals Polar bear
Notable/Unusual Events and Observations	Community consultation process Killer whale sightings Seal mortalities	Community consultation process Killer whale sightings Seal mortalities	Community consultation process Killer whale sightings Seal mortalities	Community consultation process Killer whale sightings Seal mortalities
Population or Stock Delineation (Genetic Diversity)	Bowhead	Bowhead	Beluga	Bowhead

Field Sampling

Observations made from land, sea and air, as well as tagging (mark recapture) can be used to track range and to make population estimates, while tracking studies provide information only on habitat use and range. Photo identification is currently used on a select few species to gain habitat and demographic information. Biopsy specimens can be collected from live and dead animals and analysed for contaminant load and for used for genetic analysis. Harvest statistics can be a valuable information source of indicators and examination of blubber and stomach contents can provide valuable information regarding condition and feeding habits.

Analysis

Interpretation of marine mammal information is fundamentally a species-by- species enterprise with a basic goal to understand where animals are located, how many animals there are, and their condition.

Core Indicators for marine mammals

Harvest statistics.
Range and timing of habitat use
Abundance - total and by subpopulation (if identified)
Condition of animals (if possible)

CONCLUSIONS

As a basis from which to explore the effect of natural and human-driven impacts as well as manage living resources wisely, we must first be able to measure and produce accessible reports on status and trends in arctic biodiversity. Such monitoring efforts will rely on a small number of indicators that can be calculated from historical data and tracked via ongoing research and monitoring programs.

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