Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2017/003

Central and Arctic Region

Potential monitoring indicators, protocols and strategies for the Anguniaqvia Niqiqyuam Area of Interest

O. Schimnowski, E. Chmelnitsky, K. Hedges and L. Loseto

Freshwater Institute
Fisheries and Oceans Canada
501 University Crescent
Winnipeg, Manitoba R3T 2N6

January 2017

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Schimnowski, O., Chmelnitsky, E., Hedges, K. and Loseto, L. 2017. Potential monitoring indicators, protocols and strategies for the Anguniaqvia Niqiqyuam Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/003. v + 23 p.

TABLE OF CONTENTS

ABSTRACT

Darnley Bay is located in the western Canadian Arctic within the Beaufort Sea Large Ocean Management Area and the Inuvialuit Settlement Region. A portion of Darnley Bay was nominated as an area of interest and the Cape Parry Offshore Feeding Habitat was identified as the priority area. The Cape Parry priority area was chosen to maintain the integrity of the marine environment offshore of Cape Parry to protect staging sea ducks, feeding seabirds and marine mammals. The conservation objective established for the area guided the selection of appropriate indicators for a monitoring program. Indicators were selected based on their relevance to the conservation objectives and sensitivity to anthropogenic stressors. Indicators were divided into two categories: core indicators and background indicators necessary for establishing baseline levels and interpreting changes in core indicators. Eleven core indicators and three background indicators were identified. Many of the indicators can be monitored through participatory and community-based monitoring, nearshore and offshore sampling, and/or remote sensing and existing weather station data. A monitoring program will need to be developed for the Cape Parry priority area to evaluate how well the conservation objective is being met. This is of particular importance given the potential for increased human activity in the area and climate change, which will likely affect some of the unique characteristics of this productive ecosystem.

Indicateurs, protocoles et stratégies de surveillance possibles pour la zone d'intérêt Anguniaqvia Niquiqyuam

RÉSUMÉ

La baie Darnley se trouve dans la région ouest de l'Arctique canadien, entre la zone étendue de gestion des océans (ZEGO) de la mer de Beaufort et la région désignée des Inuvialuit. Une partie de la baie Darnley a été désignée comme zone d'intérêt, et l'habitat d'alimentation au large du cap Parry a été désigné comme zone prioritaire. La désignation du cap Parry à titre de zone prioritaire sert à maintenir l'intégrité de l'environnement marin au large du cap Parry pour protéger les rassemblements de canards marins et les aires d'alimentation des oiseaux de mer et des mammifères marins. Le choix des indicateurs du programme de surveillance pour cette zone a été fait en fonction de l'objectif de conservation fixé pour cette zone. Les indicateurs ont été choisis pour leur pertinence aux objectifs de conservation et leur sensibilité aux agents de stress de nature anthropique. Ils ont été séparés en deux catégories : indicateurs de base et indicateurs secondaires nécessaires pour établir les niveaux de référence et interpréter les changements dans les indicateurs de base. Onze indicateurs de base et trois indicateurs secondaires ont été sélectionnés. Le suivi de bon nombre de ces indicateurs peut se faire grâce à de la surveillance participative et communautaire, à des échantillons prélevés près et loin des côtes, à la télédétection et aux données existantes tirées de stations météorologiques. Un programme de surveillance devra être élaboré pour la zone prioritaire du cap Parry dans le but d'évaluer dans quelle mesure l'objectif de conservation est atteint. Ceci est d'autant plus important étant donné que l'activité humaine dans cette zone risque d'augmenter et que les changements climatiques auront probablement une incidence sur certaines des caractéristiques uniques de cet écosystème productif.

INTRODUCTION

Indicators are increasingly being used as a tool for sustainable ecosystem management. Environmental indicators provide insight into either the state of the environment or anthropogenic pressures on that environment. Indicators can be used to monitor progress made towards operational objectives and to guide management decision-making. An indicator should relay information in a manner that clearly identifies any need for corrective action. Ideally, values are measurable, cost-effective, concrete, interpretable, grounded-in-theory, sensitive, responsive and specific (Rice and Rochet 2005).

The Government of Canada, along with the provinces and territories, is working to protect and conserve Canada's marine ecosystems through the development of marine protected areas (MPA), along with other conservation measures. The Anguniaqvia Niqiqyuam Area of Interest (ANAOI) is the second area of interest identified/being developed in Canada’s Arctic.

Indicators form the basis of MPA monitoring plans and are used to measure how effectively a conservation objective is being met. Indicators should be reflective of the key components that are identified in the conservation objective for an AOI or MPA and location-specific pathways of effects models. Guidance on the selection of conservation objectives for ecosystem-based management and the need for clear and specific operational objectives have been developed by Fisheries and Oceans Canada (DFO) for MPAs in Canada (e.g., DFO 2007, 2008). Pathways of effects models are tools that provide simplistic representations of the potential effects of anthropogenic activities and key ecosystem components and are necessary for the selection of responsive indicators (DFO 2014).

Assessments, monitoring and scientific research are required to provide a sound scientific basis for indicator selection. Indicator-based monitoring frameworks have recently been developed for several MPAs in Canada (e.g., DFO 2010a, 2012a), including Tarium Niryutait MPA (DFO 2010b, 2013) in the Arctic, and to monitor Arctic marine biodiversity (e.g., DFO 2012b, Gill et al. 2011). Research programs have been carried out in the ANAOI and nearby regions and Traditional Knowledge (TK) is available. These scientific and TK programs were not designed for the purpose of assessing indicators, but they are useful for establishing baseline conditions, directing monitoring efforts and understanding interactions in the ecosystem.

The conservation objective for the Cape Parry Offshore Marine Feeding Habitat is:

> “to maintain the integrity of the marine environment offshore of the Cape Parry Migratory Bird Sanctuary (MBS) so that it is productive and allows for high trophic level feeding by ensuring that the Cape Parry polynyas and associated sea-ice habitat, and the role of key prey species (e.g., Arctic Cod), are not disrupted by human activities.” (DFO 2011a)

When developing a monitoring program, indicators must be sensitive enough to respond adequately and in a timely manner to stressors and drivers. Indicators that provide information on multiple aspects of environmental integrity are considered ideal. The Cape Parry conservation objective focuses on the disruption of species, specifically by anthropogenic activities; therefore indicators need to be sensitive to anthropogenic activities. In the ANAOI, sea-ice and seasonality create habitats that are primarily used by species that visit the region for specific life stages and for short periods of time. Coastal fish and marine mammal species are, in general, more easily monitored; however, in this region some of these species are migratory. The potential influence of anthropogenic forcing outside of the ANAOI must be considered when assessing the appropriateness of these species as indicators, and when developing protocols and/or strategies. A successful monitoring program must be science based and have the support of local communities; sufficient baseline information is needed to distinguish changes that are anthropogenic from natural variation at seasonal and annual scales. Although some baseline data exist, because of a lack of consistent monitoring within the region, this gap will need to be addressed in the development and support of a monitoring program. A goal of the conservation objective is “to maintain the integrity of the marine environment” so that the ANAOI remains a productive foraging area for various species, thus, studies which improve our understanding of trophic dynamics or interactions among trophic levels are key to achieving the conservation objective and developing a relevant monitoring program.

Anthropogenic activities with the potential to impact key ecosystem components in the ANAOI include commercial fishing, dredging, infrastructure, mining, port construction and operation, recreational fishing, scientific research activities, seismic surveys, shipping, subsistence hunting and fishing, and tourism (DFO 2014). Main stressors include effects of artificial lighting, ballast water inputs, biota removal, contaminants, gear loss, habitat alteration and destruction, invasive species introductions, noise, sampling, ship strikes, species disturbance and temporary shore based camps. Advice on the risk (likelihood and impact) of each activity for the region has not been assessed, therefore it is difficult to comment on which activities pose the greatest threat to the marine environment and which should be the focus of a monitoring program. Four pervasive drivers may also cause changes in the ecosystem and a monitoring program for management purposes must understand the influences of these drivers. The four drivers are climate variability and change, contaminant transport, acidification and invasive/colonizing/vagrant species. Synergistic or cumulative effects of multiple stressors on a species or ecosystem are poorly understood and require more scientific study.

This paper reviews past research relevant to the ANAOI and provides a list and scientific discussion of potential indicators for the ANAOI. The selection of indicators provided here is based on an analysis of the conservation objectives developed for the ANAOI and consideration of anthropogenic stresses through an examination of the relevant pathways of effects.

DESCRIPTION OF THE ANAOI

Darnley Bay is located in the western Canadian Arctic within the Beaufort Sea Large Ocean Management Area (LOMA) and the Inuvialuit Settlement Region (ISR). The bay is a large inlet that measures 45 km long and 32 km wide at its mouth. The community of Paulatuk, Northwest Territories (NT) is a hamlet of approximately 300 people situated on the southern extent of Darnley Bay near the Hornaday River (Figure 1). The boundary of the ANAOI extends approximately 15 km north off the shore of Cape Parry and approximately 15 km east offshore of the west side of Darnley Bay (Figure 1). South of Clapperton Island the ANAOI boundary follows the western shoreline roughly 5 to 10 km offshore and extends south to Argo Bay (Figure 1).

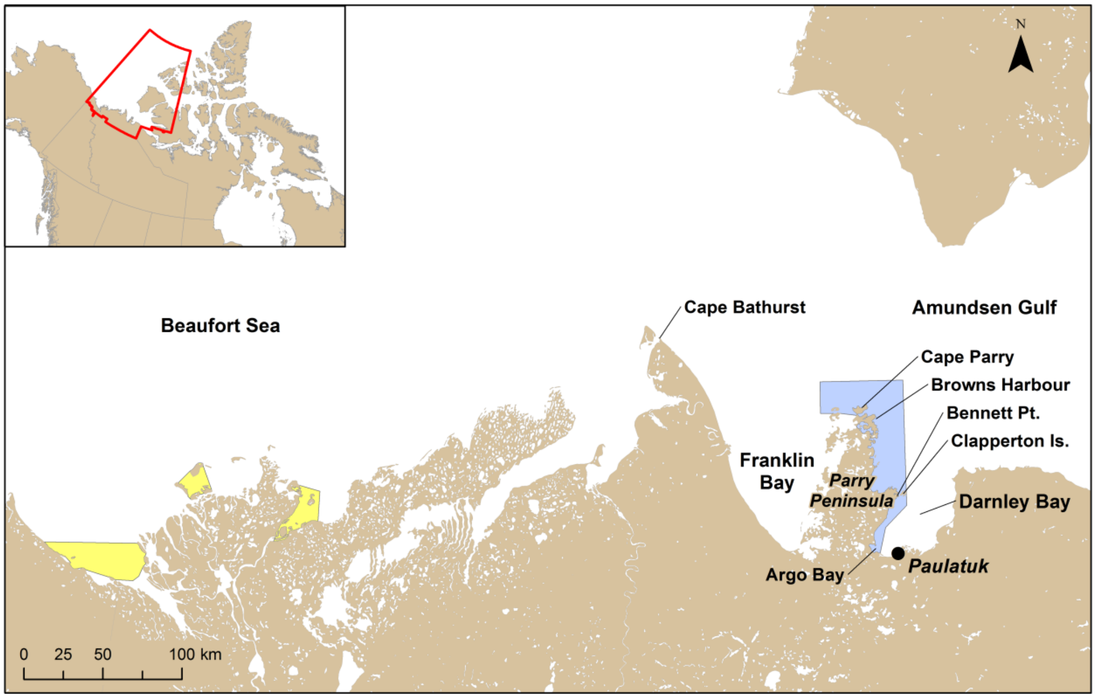

Figure 1. Map showing the location of Darnley Bay and place names as mentioned in the text. The three yellow areas are the Tarium Niryutait Marine Protected Area and the blue area is the Anguniaqvia Niqiqyuam Area of Interest. Insert: Red line indicates the boundaries of the Inuvialuit Settlement Region (ISR); the marine area within the ISR is the Beaufort Sea Large Ocean Management Area.

Darnley Bay is a productive area for a variety of species, including Arctic Char (*Salvelinus alpinus*), Beluga (*Delphinapterus leucas*), Polar Bear (*Ursus maritimus*), Ringed Seal (*Pusa hispida*), Bearded Seal (*Erignathus barbatus*), and a variety of birds. Cape Parry is home to the only Thick-Billed Murre (*Uria lomvia*) colony in the Western Canadian Arctic (Johnson and Ward 1985). This region is culturally important to the Inuvialuit people who use the area for subsistence fishing/hunting, travel, education and recreation (Community of Paulatuk et al. 2008).

The Parry Peninsula has a complex coastline with hundreds of bays and small inlets. At Cape Parry, the most northern point of the Parry Peninsula, limestone outcrops form cliffs 20 m above sea level. The Cape Bathurst polynya is in close proximity to Cape Parry and its associated leads run through the waters off the cape. Enhanced tidal flows exist at Cape Parry and upwellings from currents and bathymetry result in a productive marine environment.

During the open-water season (late spring to early summer) Cape Parry has high densities of key prey species of fishes, marine mammals and birds. The area provides important foraging habitats for a number of species, including Beluga, Bowhead Whale, Ringed Seal, Bearded Seal, Polar Bear and seabirds. Physical features such as land-fast ice and the ice edge, upwelling zones, kelp beds and riverine overwintering habitats often support aggregations of species and important life history functions (e.g., fitness consequences) for these species (DFO 2011b). An understanding of the trophic interactions within the region is necessary for the selection of indicators that best reflect the regions ecological integrity. A schematic diagram of the offshore Beaufort Sea Arctic food web is presented in Figure 2 and provides a simplification of the trophic interactions in the ANAOI.

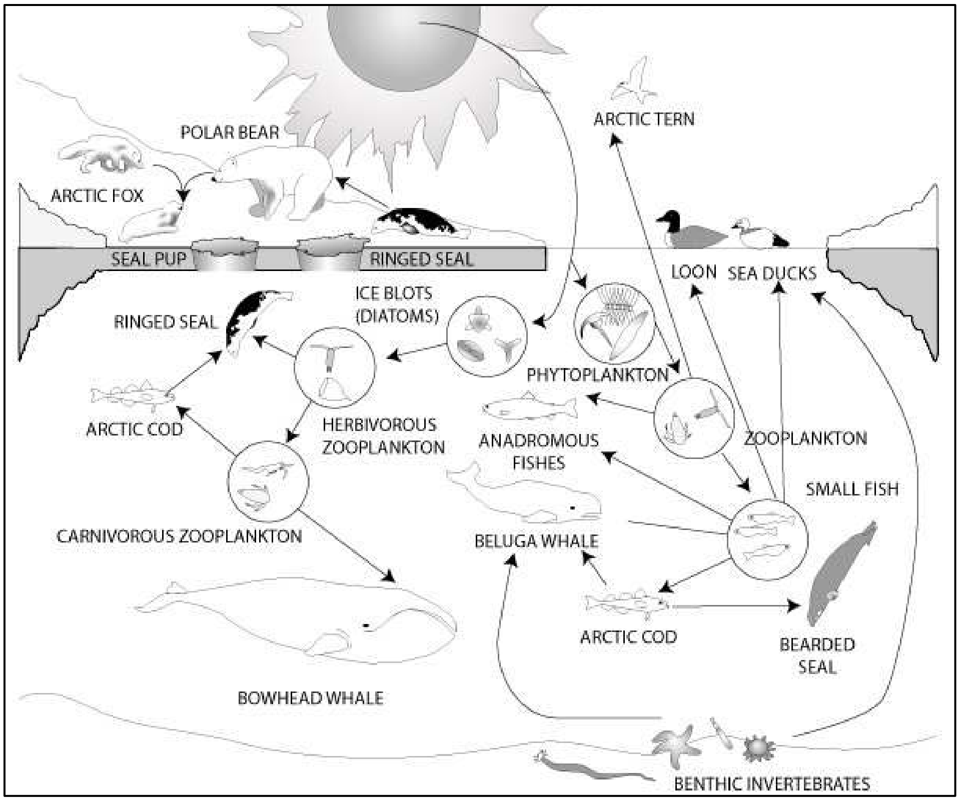

Figure 2. Schematic of the offshore Beaufort Sea Arctic spring food web (modified from Bradstreet et al. 1986).

PREVIOUS RESEARCH AND MONITORING PROGRAMS

SNOW AND ICE

In 1959-1992, the Meteorological Survey of Canada manned a North Warning System station at Cape Parry and collected ice thickness and snow depth data. General findings indicate that ice thickness at the end of winter varies with snow depth, and greater thickness is associated with less snow. This is characteristic of Arctic land-fast ice (Dumas et al. 2005). Winter snow and ice measurements occurred during the overwintering mission of the CCGS Amundsen during the Canadian Arctic Shelf Exchanges Study (CASES) program in 2003-2004 (Barber et al. 2008) and the Circumpolar Flaw Lead System Study in 2007-2008 (Barber et al. 2010).

PHYSICAL OCEANOGRAPHY

The timing and location of sea ice is a key physical determinant of the Cape Parry regional ecology; therefore, changes in characteristics that are predictive of sea-ice conditions could be used as signals of other changes in the ecosystem. Physical oceanography and other physical characteristics, such as marine currents, wind, salinity and temperature, can affect the distribution of sea ice, leads, polynyas and the chronology of freeze-up and break-up (Canadian Ice Service 2002, Hannah et al. 2009).

DFO's Arctic Biological Station conducted fisheries and hydrographic sampling in the Arctic between 1960 and 1979 (Hunter and Leach 1983). Temperature, salinity and dissolved oxygen samples were collected in the ANAOI region by the M/V Salvelinus in 1962, 1963 and 1964. Water property surveys were conducted in Amundsen Gulf by DFO's Institute of Ocean

Sciences (IOS) from the M/V Pandora II in 1977 (Macdonald et al. 1978). DFO's IOS conducted water property surveys in 1982 and 1998-2004 that included temperature, salinity, chlorophyll a fluorescence, water transparency, dissolved nutrients and dissolved oxygen. A mooring was operated at a reference site with sediment traps and current meters during 1999-2002. Since 2005 a reference site in the deepest part of Amundsen Gulf has been visited annually (Humfrey Melling, DFO Sidney, BC, pers. comm.).

The CASES program recorded conductivity, temperature and depth (CTD) data and collected water samples using a CTD–Rosette during 2002-2004 in Franklin Bay, Cape Parry and the Amundsen Gulf, with over-winter sampling in Franklin Bay (Simard et al. 2010a). ArcticNet expeditions collected CTD data, water samples and data from photosynthetically active radiation (PAR) and fluorescence sensors using multiple methods during 2004-2009, mostly in Franklin Bay (Simard et al. 2010b, Simard et al. 2010c, Rail and Gratton 2011, Rail et al. 2011).

Although the focus of data collection during the Northern Coastal Marine Studies (NCMS) program in 2008 was on offshore demersal fish populations, data on physical habitat characteristics, including salinity, temperature and depth, were collected using the CCGS Nahidik (Lowdon et al. 2011). Temperature, salinity and other water properties were collected in Darnley Bay and Cape Parry in 2013 as part of the Beaufort Sea Regional Environmental Assessment (BREA) using the F/V Frosti (Niemi et al. 2015).

Riverine discharge and flow rates were measured on the Hornaday River using a hydrometric water gauging station during 1999-2007. Although it is located outside the ANAOI, discharge from the Hornaday River influences the timing of ocean conditions and productivity in Darnley Bay (Harwood 2009), and the timing of spring melt can influence the distribution and behaviours of species such as Ringed Seals (Harwood et al. 2012b). The discharge range from year to year is high, therefore discharge and timing of freshet should be considered as part of a monitoring program.

LOWER TROPHIC LEVELS

Potential sources of primary production in Arctic waters include phytoplankton, ice algae, benthic micro- and macroalgae, and aquatic macrophytes. Zooplankton are the primary link between phytoplankton and higher trophic levels (i.e., fishes, whales and birds). In the Beaufort Sea, including around Cape Parry, zooplankton are dominated by copepods, which are the main prey of Bowhead Whales (e.g., Darnis et al. 2008, Hop et al. 2011). Benthic invertebrates also provide important links in the food web as the main prey of sea ducks (Dickson and Gilchrist 2002).

Little is known about primary and secondary production in the area of Cape Parry and Darnley Bay, but recent studies conducted using the CCGS Sir Wilfrid Laurier, CCGS Nahidik, CCGS Amundsen, CCGS Pierre Radisson and F/V Frosti in the summers of 2008, 2012 and 2013 provide some baseline data on species richness, biomass and other properties of primary production (Mundy et al. 2009, 2011, Eert et al. 2015, Niemi et al. 2015) and zooplankton (Darnis et al. 2008, Hop et al. 2011, Palmer et al. 2011, Walkusz et al. 2013b). Zooplankton and benthic samples have been collected as part of several scientific programs in Darnley Bay and off Cape Parry, but they have not been analyzed (Wojciech Walkusz, DFO Winnipeg, MB, pers. comm.).

Limited baseline data are available for benthic species in the Cape Parry priority area. Macrobenthic species richness and biomass have been assessed along the Cape Bathurst Peninsula and in Amundsen Gulf (Conlan et al. 2008, 2013). Data on sediment pigment and carbon content in this area were published from the CASES program (CASES, 2003-2004) on the Beaufort Shelf (Renaud et al. 2007, Conlan et al. 2008, Morata et al. 2008) and from the

Circumpolar Flaw Lead study (CFL, 2007-2008) (Renaud et al. 2007, Link et al. 2011, Forest et al. 2011) in the Amundsen Gulf. Total pigments (chlorophyll a + phaeopigments) and organic carbon content in sediments were also collected during ArcticNet-CHONe cruises from 2008 to 2010. During the same cruises, data on benthic remineralization were also collected. Work has also been conducted recently in Darnley and Franklin bays, and Amundsen Gulf (Darnis et al. 2012, Link 2012). During the BREA program in 2012-2013, benthic epifauna and infauna were collected in the Beaufort Sea as far east as Darnley Bay, and community structure is being analyzed (Andrew Majewski, DFO Winnipeg, MB, pers. comm.).

HIGHER TROPHIC LEVELS

The Cape Parry priority area provides important habitat and feeding areas for marine fishes, mammals and birds. Limited information is available for offshore fishes in the Cape Parry area but the predominant fish species caught during the NCMS program in 2008 at Cape Parry was Arctic Cod (*Boreogadus saida*), an important prey species of marine mammals and birds (Lowdon et al. 2011). Arctic Alligatorfish (*Ulcina olrikii*) and sculpins were also caught (Lowdon et al. 2011). Other fish species that may be present in the Cape Parry priority area include flounders, Greenland Cod (*Gadus ogac*) and Capelin (*Mallotus villosus*) as they are present in nearby areas.

In 2008, data collection during the NCMS focused on offshore demersal fish populations, their habitats and prey (Lowdon et al. 2011, Walkusz et al. 2013a). During the 2012 BREA program, similar transects were completed extending to the nearshore zones west of Cape Parry within the priority area (Geoffroy et al. 2012). The predominant species caught in 2012 was still Arctic Cod (Majewski et al. 2015). In 2013, the BREA program included a transect into Darnley Bay near Cape Parry (Andrew Majewski, DFO Winnipeg, MB, pers. comm.). Fisheries sonar and echosounders were used to detect pelagic fishes, with a focus on locating Arctic Cod schools and marine mammals in the Beaufort Sea.

Coastal marine fish sampling was also conducted by DFO near Bennett Point in 2012, approximately half way up the west coast of Darnley Bay and adjacent to the boundary of the Cape Parry offshore priority area. The predominant species caught was Saffron Cod (*Eleginus gracilis)* (Jim Johnson, DFO Winnipeg, MB, unpublished data). Additionally, Greenland Cod, Pacific Herring (*Clupea pallasii*), Capelin, sculpins and flounder species were caught (Jim Johnson, DFO Winnipeg, MB, unpublished data).

Arctic Char spawn and over-winter in the Hornaday River to the east of Paulatuk and are fished for subsistence by the community (Harwood 2009). Arctic Char may be present on the west coast of Darnley Bay and along Cape Parry, but their important feeding habitat is believed to be on the east coast of Darnley Bay and along Pearce Point (DFO 1999, Kim Howland, DFO Winnipeg, MB, pers. comm.).

The Cape Parry area contains important habitat for marine mammals, including Bowhead Whale, Beluga, Ringed Seal, Bearded Seal and Polar Bear (e.g., Community of Paulatuk et al. 2008, Pilfold et al. 2012). Long-term hunter monitoring programs in the community of Paulatuk and throughout the ISR have been established to obtain tissue samples from hunters for various marine mammals, including Beluga and Polar Bear; the tissue samples are used to assess individual age, sex, genetics, stable isotopes, fatty acids and contaminants (Harwood et al. 2000, Community of Paulatuk et al. 2008, Loseto et al. 2008a, McKinney et al. 2011, Routti et al. 2012). The southern Beaufort Polar Bear population has been studied extensively through scientific and community-based monitoring (Regehr et al. 2006, Vongraven et al. 2012) and Polar Bear research was conducted on Cape Parry from 2003-2006 (Regehr et al. 2006, Pilfold et al. 2012). The southern Beaufort population, which includes the Cape Parry area, was nominated for high intensity monitoring in a recently developed circumpolar Polar Bear monitoring framework (Vongraven et al. 2012).

The Cape Parry area contains important habitats for seabirds and sea ducks. Surveys of seabird colonies have been conducted on Cape Parry, and the Thick-billed Murre colony was surveyed by the Canadian Wildlife Services (CWS) in 2002 and 2007 (Johnson and Ward 1985, Latour et al. 2008).

Water bird aerial surveys were flown in 1992 and a review of marine birds in the southeastern Beaufort Sea was conducted in 2002 (Alexander et al. 1993, Dickson and Gilchrist 2002). During the 1992 surveys, Pacific Common Eider (*Somateria mollissima*), King Eider *(Somateria spectabilis*) and Long-tailed Duck (*Clangula hyemalis*) staging areas were located at Cape Bathurst and in the Amundsen Gulf (Alexander et al. 1993). Cape Parry serves as a staging area for male Pacific Common Eiders from mid-July to early October (Dickson 2012).

INDICATORS

Under-ice, ice-associated and open-water biota

Ice-algae are considered a keystone group because they underpin the energetic transfer to higher trophic levels such as sympagic meiofauna, under-ice amphipods and pelagic copepods (Michel et al. 2002). They begin to grow on the underside of ice generally a few months earlier than phytoplankton blooms (Michel et al. 1996), triggered by the addition of light into the system as ice thins and melts. Seasonally, the ice-algae community contributes 70–75% of total primary production (including ice-algae and phytoplankton production) during the spring as the ice melts (Horner and Schrader 1982, Lee et al. 2008). However, they contribute <15% of total primary production over the whole year (Horner and Schrader 1982). The interrelationships among snow cover, ice structure, optical properties and biological activity are of critical importance in understanding the response and behavior in regional ecological systems. Timing, extent and degree of productivity can be indicative of shifts to broader atmospheric and oceanographic conditions which affect timing and extent of ice edge, thickness, snow cover and upwelling events (Carmack and Chapman 2003).

Under-ice, ice-associated and open-water biota can all be monitored to measure ecosystem productivity, if sampling is continuous throughout the productive period. Because certain monitoring methods have drawbacks (e.g., high upfront costs associated with remote sensing and incomplete information from sediment traps), it is important to combine a suite of different methods when monitoring this group of indicators. Available methods include the use of an ocean observatory, sediment traps, remote sensing, moorings, gliders (for ice associated biota), vessels (for open-water and under-ice biota) and biomarkers. There is also the potential for these indicators to be monitored by local community members. Baseline data are not available within the ANAOI but limited relevant data have been collected within a 100 km radius of the ANAOI boundaries through the CASES and CFL studies.

Biodiversity of lower trophic level species

Plankton (zooplankton and phytoplankton) are an important element in the marine ecosystem because they are fundamental to the productivity of higher trophic levels and can be indicative of both environmentally driven changes and anthropogenic disturbance. Overall, the rate of primary production of phytoplankton in Amundsen Gulf is characteristic of low-productivity (oligotrophic) waters. Productivity in the Beaufort Sea is limited by light during the Arctic winter, and then by nutrients, primarily nitrate, in the summer. Changes in species composition and functional diversity can occur in response to changing climatic conditions and hydroclimatic forcing (Planque and Reid 1998). Monitoring changes in species can inform on the introduction of non-indigenous species, possibly through anthropogenic activities such as vessel traffic and/or as a result of environmental changes.

Indicators can be monitored by local community members and/or researchers using research vessels and biomarkers. For example, the Arctic Coastal Ecosystem Study (ACES) program (2010-ongoing) could act as a model for an integrated program in the ANAOI. ACES was developed by DFO to support monitoring within the TNMPA. Baseline data are not available within the ANAOI but limited relevant data have been collected within a 100 km radius of the ANAOI boundaries during the CASES program. Species lists are a suggested indicator for the TNMPA monitoring program and the Circumpolar Biodiversity Monitoring Program (CBMP). Additional information on strategies and protocols for this indicator can be found in DFO (2012b, 2013).

Concentration of nutrients

Relative surface nutrient concentrations characterize the interaction between biological activity and physical processes. Local biological communities are influenced by the local hydrodynamic features which, through their action on surface water temperature, salinity, stratification and mixing conditions, lead to spatial differentiation of the phytoplankton and zooplankton communities. When measured in spring, nutrient levels (nitrates, phosphates, silicates) are indicative of interannual variations in nutrient supply to the eutrophic zone (Harvey et al. 2001).

Nutrient concentrations can be monitored within the ANAOI to measure the productive capacity of the ecosystem. Periodic measurements of nutrient concentrations are sufficient for assessing the productive capacity of the ecosystem and measurements can be taken from vessels or small boats (local monitoring component). Limited baseline data on nutrient concentrations are available within the ANAOI (from the Nahidik program) and within a 100 km radius of the ANAOI boundaries during the Nahidik program, CASES, the CFL study and IOS programs.

Benthic community composition and abundance

Benthic communities and their activities are important to ecosystem processes in the polar marine environment. Benthic diversity and production feeds into higher levels of the food chain, benthic remineralization returns nutrients into the water column usable for primary production and sponge and deep sea coral beds provide structural complexity to habitats and host many associated species (Kenchington et al. 2011). Their abundance and composition can be indicative of both environmental drivers (e.g., climate change, ice scour) and anthropogenic drivers (e.g., sewage, sediment disturbance, toxic inputs) (Lenihan et al. 1995, Hargrave et al. 2000, Ware et al. 2009, Conlan et al. 2010). The condition of bivalve shells can be useful recorders of the ambient hydrographic conditions in which they exist and can indicate trends in freshening of seawater (Torres et al. 2011). The majority of adult benthic species are sessile, sedentary or move over small territorial ranges. Along with their longevity, this makes them good indicators of environmental quality (e.g., Rees et al. 2006) and indicative of changes within the local environment. Understanding life history and community characteristics of benthic species is necessary to guide their determination as indicator species. Research on determining appropriate benthic species for indicators has occurred in other locations, but this has yet to be developed specifically for Darnley Bay and the ANAOI.

Benthic invertebrates are measured using grabs, box cores, drop cameras and remotely operated underwater vehicles (ROVs) from small and large vessels. Normally a dedicated oceanographic program would be required for field collection. Opportunistic sampling from vessels may be possible, however collaborations are not in place and would need to be developed with vessel owners. There is potential for this indicator to be monitored by local community members from small vessels. Given the limited spatial coverage of benthic sampling, proxies such as sediment pigment concentration, strong topographic features and polynyas can be used as indicators for benthic production. The key challenge when using benthic communities/habitats continues to be the lack of historic data with sufficient geographic coverage. Some baseline data are available within the ANAOI and within a 100 km radius of the ANAOI boundaries from the BREA and Nahidik programs.

Offshore and inshore fish community composition, structure, function and energetics

Data on offshore and inshore fish community composition, structure, function and energetics can provide important information on offshore prey species within the ANAOI. Community composition, structure and functional attributes are often linked to static habitat characteristics and dynamic changes can initiate or trigger life history stages in species (Schlosser 1982). For example, wind-driven upwellings have been linked to variability in fish community composition (Jarvela and Thorsteinson 1999). Fish species abundance (Courrat et al. 2009), richness and diversity can be used to evaluate the condition of an ecosystem, but analysis and interpretation can be highly involved. Sub-lethal disturbances can result in changes in activity that can increase susceptibility to predation, elevate energy expenditure and generally disrupt the ecology of a species (Cooke et al. 2000); these effects can be monitored through tagging programs via mark-recapture (for habitat use) or using electronic tags with sensors (e.g., movement rate, physiological state) (Wilson et al. 2015). Structural and functional characteristics of inshore, estuarine and offshore species and communities must be carefully considered because of natural differences in species and community resilience (Elliott and Quintino 2007). Research to develop indicators requires carefully planned and broadly distributed (temporally/spatially) multispecies surveys coupled with the collection of oceanographic/habitat variables to identify ecological subdivisions, identify trophic interactions and calculate energy transfer (food web analysis). Additional research is particularly needed on the ecological resilience of species to stressors. Current baseline conditions could be determined and monitoring could occur through community-based studies, bird forage and marine mammal stomach content observations, or vessel-based surveys.

Reports of odd looking species/individuals and odd behaviours should also be monitored as these characteristics are closely linked to environmental disturbances. This indicator can be monitored using methods similar to those used to monitor offshore fishes but it is important to select a target species.

Some baseline data for both inshore and offshore fishes are available within the ANAOI and within a 100 km radius of the ANAOI boundaries (from the BREA and Nahidik programs). To enhance relevance to the conservation objective, specific fishes should be selected. Opportunistic sampling from offshore vessels may be possible however collaborations would need to be developed with vessel owners. Monitoring of inshore fishes may be better suited to community-based monitoring programs by local community members from small vessels.

Fish diet composition

Fish diet composition can indicate whether fishes are consuming benthic or pelagic prey; this indicator can be monitored by analyzing fish stomach contents, fatty acids, stable isotopes and contaminant tracers. Fishes are mobile consumers that often play a keystone role (top-down and bottom-up control) in the functioning of Arctic aquatic ecosystems (Reist et al. 2006, Roux et al. 2015). Arctic Cod are one of the most abundant species in the Beaufort Sea and occupy a central position in Arctic food webs (e.g., Benoit et al. 2008, Rand et al. 2013). Diet composition and prey size selection by Arctic Cod, or other keystone fish species, can be used to assess food webs and environmental dynamics in coastal and offshore habitats in the ANAOI (Bradstreet and Cross 1982). In both the U.S. and Canadian Beaufort Sea, significant differences in the composition of Arctic Cod diets have been observed between inshore and offshore habitats, and comparative studies have shown that diets vary spatially and temporally across the broader domain of the Beaufort Sea and Canadian Arctic (Loseto et al. 2008b, Rand et al. 2013, Walkusz et al. 2013a). Capelin have a similar diet to Arctic Cod and the respective roles of these two species within food webs can be indicative of climatic changes (Hop and Gjøsæter 2013). Baseline data on fishes in the Canadian Beaufort Sea are currently being collected and some data on fish diet composition are available within the ANAOI and within a 100 km radius of the ANAOI boundaries, from DFO research.

Presence/absence, semi-quantitative abundance and timing of Capelin on beaches

Capelin and Arctic Cod coexist in the ANAOI; both are pelagic, planktivorous forage fishes that occupy similar dietary niches and are the primary prey of marine predators. However, Arctic Cod is an ice associated species and is considered less resilient to changes in the variability and extent of ice (Hop and Gjøsæter 2013). Baseline information on Capelin is essential to determine the potential for competition between or replacement of Arctic Cod due to their influence (top down and bottom up) on ecosystem function (McNicholl et al. 2016). The role of Capelin in ANAOI habitats can be determined by monitoring the presence/absence, semi-quantitative abundance and timing of Capelin on ANAOI beaches.

Visual surveys can be conducted by local community members to obtain data on this indicator. Baseline data on this indicator are available within the ANAOI and within a 100 km radius of the ANAOI, from historic local observations.

Marine mammal presence/absence, timing and group composition

The conservation objective of the ANAOI is focused on conserving forage populations for marine mammals and other predators so that these predators continue to use the ANAOI. Therefore, the presence and timing of habitat use by marine mammals in the ANAOI provides a direct indicator for monitoring the effectiveness of the ANAOI.

Marine mammals such as Ringed Seal, Bearded Seal, Bowhead Whale and Beluga are known to occur in the ANAOI ecosystem. Determining the driving factors of the use of the area (e.g., foraging, mating), timing of migration and other life history functions are needed when considering the selection of indicators for long term monitoring. It is important to note that these marine mammal species differ in their trophic status and function within the ecosystem. Consideration needs to be given to differences in life history, habitat use and physiology when considering the effects of potential disturbances on marine mammals. Stock assessments of harvested marine mammal species have not been performed frequently or at all due to feasibility and logistical constraints. The impacts of climate change-driven changes in sea ice seasonality and properties on Arctic marine mammals have been examined; distribution shifts, compromised body condition and declines in production/abundance are predicted in response to sea-ice declines (Kovacs et al. 2011).

Ice seals are subject to environmental constraints largely in sea ice quality and quantity. They use marine environments for foraging but remain dependent on sea ice to rear their young, rest and mate. The Ringed Seal is the most abundant marine mammal species in the circumpolar Arctic and an important predator, feeding on Arctic Cod and benthic invertebrates (Harwood et al. 2012a). Reproduction and survival are closely linked to sea ice conditions. They periodically undergo changes in abundance and distribution in response to changes in sea ice conditions and life stage (Stirling et al. 1982, Smith 1987, Kingsley and Byers 1998). Initial single-year studies suggest that industrial activities have little influence on the winter activities of Ringed Seal (Harwood et al. 2010), however further study is required. The Bearded Seal shows high inter-annual territoriality for mating and breeding success, feeds almost exclusively on benthic prey and uses a large migratory range for roaming. The long-term mating success of individuals may be altered by yearly fluctuations in ice cover. Effects due to anthropogenic disturbances have yet to be examined.

The Beaufort-Chukchi Bowhead Whale population is one of two cetacean populations that seasonally use the Beaufort Sea during the open water season, spanning into the Amundsen Gulf and areas including the ANAOI, and wintering in the Bering Sea (Quakenbush et al. 2012). Bowhead Whales are mysticedes or baleen whales that filter feed on zooplankton species, including lipid rich copepods, amphipods and euphausids (Walkusz et al. 2012). These groups can be concentrated by oceanic fronts at the estuarine–marine interface on the continental shelf, in the vicinity of troughs and at upwelling locations (e.g. Cape Bathurst) (Walkusz et al. 2012). There is evidence that Bowheads are particularly susceptible to anthropogenic pressures, mainly ship strikes and entanglement in fishing gear (George et al. 1994). Bowhead Whales usually react to approaching vessels by interrupting their normal behaviour and swimming rapidly away (Richardson et al. 1995). They have been observed to interrupt their flight response once a ship is several kilometers away. Individuals usually do not react to ships that are moving slowly and are not moving towards them.

Beluga seasonally occupies the Beaufort Sea, and are widely distributed in Amundsen Gulf, Viscount Melville Sound and on the Mackenzie Shelf, with summer aggregations in the Mackenzie Estuary. With population size estimates of 19,000 (Harwood et al. 1996) to 39,000 (Allen and Angliss 2013), they are considered an important predator in the region that depends on a viable prey stock for sustenance (Hoover 2013). Arctic Cod are thought to be the main prey for adult Belugas feeding in offshore and ice-edge habitats; younger Belugas using shallower inshore habitats also feed on Arctic Cod along with coastal fishes such as Arctic Cisco (Loseto et al. 2009). Although the stomachs of Beluga harvested in the ANAOI and Darnley Bay area are typically empty (Ruben et al. 2015), stomach contents collected from Alaskan harvests contained otoliths from Arctic Cod and other fish species, highlighting their generalist diet (Quakenbush et al. 2015). The distribution of Beluga and habitat selection in terms of sea ice, bathymetry and the use of offshore habitats is hypothesized to be driven by energetic needs, specifically prey availability, such as the distribution of Arctic Cod (Loseto et al. 2006, Asselin et al. 2011, Hornby et al. 2015).

Beluga length data compiled through harvest programs within the Darnley Bay region were recently examined, but low samples sizes, timing and location of hunts and possible hunter bias in size selection raise practical questions about using this harvest statistic as an indicator for the ANAOI. This initial assessment found significant differences in male Beluga mean length among all hunt locations within the ANAOI. A comparison between males harvested at Paulatuk and Hendrickson Island found greater variation in length at Hendrickson Island (DFO unpub. data). The uncertainty associated with this quick examination of data underscores the importance of long-term observation programs within a scientific assessment grounded in an ecosystem context.

Local community members can monitor marine mammal presence/absence, timing and group composition through observations, passive acoustic monitoring and photographs (with the inclusion of standardized information on the date, location, species, etc.). Baseline data on this indicator are available within the ANAOI and within a 100 km radius of the ANAOI boundaries (from surveys and satellite tracking of Bowhead Whales, Belugas and Ringed Seals as well as from historic local observations; although, these observations are not yet compiled or quantified).

Marine mammal prey items

Food web structure, predator–prey dynamics, foraging behavior and consequences of these factors for individual growth, reproduction and survival all need to be examined to understand ecosystem structure and function in the ANAOI. Arctic marine mammal species exploit prey resources close to the sea ice, in the water column and at the sea floor, including lipid-rich pelagic and benthic crustaceans and pelagic and ice-associated schooling fishes such as Capelin and Arctic Cod. Monitoring prey items can provide an indication of why certain migratory marine mammals are key components of the ANAOI ecosystem (e.g., Beluga). Data required to assess trophic relationships and consumer diets are generally not easily or reliably obtained. Direct observations of species interactions and gut contents, in addition to trophic markers such as lipids and fatty acids, can be combined to study food web dynamics (Iverson 2009).

Understanding marine mammal foraging behavior is needed to define habitat use and related energetic consequences. For example, benthic versus pelagic foraging will define the use of specific areas and generalist versus opportunistic feeding strategies help explain population distributions and habitat use. Relationships to environmental parameters, such as advection patterns and the sea ice regime, have been examined, therefore prey items and preferences can inform on broad shifts in increased pelagic primary and secondary production, reduced benthic and pelagic biomass in coastal/shelf areas (due to increased river runoff and consequent changes in salinity and turbidity), or increased pelagic grazing and recycling in open-water habitats at the expense of benthic–pelagic coupling.

Researchers and local community members can monitor this indicator by observing feeding, and/or examining/collecting the stomach contents of marine mammals. Baseline data for marine mammal prey items are available within the ANAOI and within a 100 km radius of the ANAOI boundaries from hunter harvest monitoring programs co-managed by DFO, the community and FJMC for Beluga, and from local observations for Bearded Seals.

Anthropogenic underwater noise

Anthropogenic underwater noise can negatively impact many components of an ecosystem; therefore, it should be monitored to ensure that “the role of the key prey species are not disrupted by human activities” (DFO 2011a).

Anthropogenic noise has the potential to interfere with communication signals, echolocation signals in the case of odontocetes such as Beluga, and sounds from prey and predators (Erbe and Farmer 2000). Odontocetes have varied reactions to vessel noise. Beluga in the St. Lawrence Estuary were shown to adjust the frequencies at which they vocalized, repeated their calls and increased their call duration and amplitude in response to increased background noise from vessels (Lesage et al. 1999, Scheifele and Dare 2005) which may be strategies to reduce the effects of masking. Even if whales habituate to new environmental noise sources, long-term exposure can lead to chronic stress (Wright et al. 2011). Some odontocetes are attracted to large vessels. In the St. Lawrence and Churchill estuaries, Cooke Inlet and the Beaufort Sea, Belugas have been observed to be tolerant of large vessels on a constant course but they have been seen to flee approaching small boats while changing their vocalization patterns, presumably to ensure effective group communication (Lesage et al. 1999) and maintain pod cohesion. Similar reactions to small boats have been seen in Canadian Arctic Beluga, probably because they are hunted from small vessels.

It would be impossible to determine the causality of observed and potential disturbances from anthropogenic noise without monitoring underwater noise from local and distant anthropogenic sources and understanding their direct and indirect effects on individuals, populations and communities. Monitoring of anthropogenic noise was a suggested indicator for the TNMPA monitoring program. DFO (2013) presented information about potential anthropogenic and background noise for the TNMPA region and discussed protocols for a monitoring plan.

Anthropogenic underwater noise can be monitored by local community members through short term instrument deployments or by researchers by means of an ocean observatory, a mooring and/or the use of short term deployments. Underwater cabled observatories are an option and have been deployed recently in Lancaster Sound and Cambridge Bay. To correctly interpret data, underwater noise would need to be compared against natural background variability. At present, baseline data are not available for this indicator; however, initial programs using hydrophones in the region are under development by Oceans North Canada.

Indicators required to determine baseline conditions and interpret change

In order to attribute observed changes in the indicators listed above to manageable anthropogenic or non-manageable natural drivers, the natural variability and pressures relating to climate change and other stressors must be better understood in the ANAOI region.

Data collected as part of research programs such as the Joint Ocean Ice Study (JOIS), ACES or BREA in the Amundsen Gulf, Beaufort Sea or nearby Franklin Bay will likely lack the continuity and spatial extent needed to inform on drivers of changes occurring directly in the ANAOI. Therefore, in order to be informative a monitoring program in this region needs to be considered within the context of a research program to address this need.

A monitoring/research program should include relevant physical variables, including;

(1) oceanographic data, such as temperature, salinity, depth, currents;

(2) benthic habitat, including seabed mapping/distribution; and

(3) ice structures, thickness and breakup timing.

Oceanographic data such as temperature and salinity provide a fundamental description of seasonal and interannual water mass variability as well as estimates of ocean currents and fluxes. Sea level data provide a long-term measure of ocean climate change, seasonal and interannual variability and are a fundamental input to ocean models. Associated variables such as freshwater runoff and release from ice affect stratification, salinity, currents and water properties. These data can be obtained using an ocean observatory and could be monitored by local community members (e.g., the Canadian Rangers Ocean Watch program or CROW). It would be advantageous to collect these data along with biological indicators, such as nutrients and primary productivity, or as a component of a fishing program. Thus far, very limited baseline oceanographic data are available for the ANAOI and surrounding region and no regular monitoring sites are identified in the ANAOI. Limited, baseline data are available within a 100 km radius of the ANAOI boundaries, from the Nahidik, CASES, CFL and other oceanographic programs.

Benthic habitat distribution should be assessed as a prerequisite for understanding benthic community composition. Methods for monitoring benthic habitat distribution can include observations from local community members (e.g., presence/absence of beach erosion and the location of sites selected for repetitive grabs) along with acoustic surveys, the use of bottom grabs, ROVs and drop cameras, and mapping benthic types. Baseline data on benthic habitat distribution are available within the ANAOI and within a 100 km of the ANAOI boundaries from the Nahidik program, ArcticNet, BREA, Natural Resources Canada (NRCan), Canadian Hydrographic Service (CHS) and community observations.

Sea-ice provides important habitats for key species within the ANAOI. Ice provides a dominant control for biological populations and their distributions. However, that control, and its interactions with the ocean and atmosphere, produces a broad range of possibilities for variability. Ice may enable biological growth (ice-edge upwelling, denning locations, ice algae production, stable surface for migration and hunting) and/or limit it (light, vertical mixing by wind, bottom scour, unstable surface). Animals exhibit different degrees of adaptability to short and long term changes in ice and water conditions. Drifting ice and landfast ice must be considered separately, as they are distributed differently, provide different habitats and are subject to change in different ways (Carmack and Macdonald 2002).

Sea-ice structures (as habitat) can be monitored using satellite radar and photographs from local hunters, whereas sea-ice thickness can be monitored using an ocean observatory mooring and ice charts. More intricate details on sea-ice break-up timing can be monitored locally with photographs and reports. Baseline data on sea-ice structures are available within the ANAOI and within a 100 km radius of the ANAOI boundaries, through ongoing Polar Bear and seal research and surveys. A structured program for data analysis is required. Baseline data on sea-ice thickness and sea-ice break-up timing are also available within the ANAOI and within a 100 km radius of the ANAOI boundaries from the Canadian Ice Service (CIS) and related studies.

MONITORING PROTOCOLS AND STRATEGIES

Community based monitoring

Establishing community-based monitoring programs presents an engaging and potentially cost-effective method for data collection. Browns Harbour, near Cape Parry is a seasonal community where a community-based Beluga hunt monitoring program is being developed (Lisa Loseto, DFO Winnipeg, MB, pers. comm). Hunters also currently collect marine mammal tissue samples that are then provided to DFO and analyzed for a variety of parameters including stable isotopes, fatty acids and contaminants (Harwood et al. 2000, Marsha Branigan, Government of Northwest Territories, Inuvik, NT, pers. comm.). Researchers have also used the camp at Browns Harbour as a base to conduct other research programs (e.g., Ringed Seal tagging - Harwood et al. 2012b). Community programs for fish sampling have been conducted with local support (Jim Johnson, DFO Winnipeg, MB, pers comm.) and are beginning to provide relevant baselines of species composition and abundance for the region. A winter program for collecting environmental variables such as sea ice and snow thickness could potentially be integrated into community Polar Bear hunting lines or the CROW program.

Moorings

It is possible to monitor a range of physical, chemical and biological parameters through the strategic placement of a mooring with attached instruments. Data that can be collected on a mooring include conductivity, temperature, salinity, pressure, currents, nitrate concentrations, chlorophyll fluorescence, water, sediment and phytoplankton and other microbes (DFO 2012b). A hydrophone can also be attached to the mooring to record animal and anthropogenic noise using passive acoustic monitoring. Moorings can be deployed year round but the number of instruments attached would depend on the research objectives, funding available and the logistics of deploying the mooring. A small, simple mooring may be deployed, through community involvement, off a small boat but large moorings with many instruments would require a larger boat or Coast Guard vessel for deployment and retrieval.

Vessel-based programs

Major offshore vessel-based programs have the advantage of a multidisciplinary focus and availability of a broad suite of instrumentation. However, these large vessels are not normally in the ANAOI region, except for a very short period of time during the year, so measurements throughout the season are generally not possible. Smaller vessels and near shore programs present a good compromise between costs and capability.

Collaborations

Effective collaboration between DFO and CWS is likely required to monitor this area due to the importance of the area to seabirds and Polar Bears. Polar Bear research was conducted at Cape Parry from 2003-2006 (Regehr et al. 2006, Pilfold et al. 2012) and ongoing monitoring is likely because the southern Beaufort population, which includes Cape Parry, has been identified for high intensity monitoring (Vongraven et al. 2012). For seabirds, CWS surveyed Thick-billed Murres at Cape Parry in the summer of 2013 (Blake Bartzen, CWS, Yellowknife, NT, pers. comm.). There are also well-established Arctic monitoring frameworks for both seabirds and Polar Bears (Petersen et al. 2008, Vongraven et al. 2012).

GAPS AND CHALLENGES

The main challenge in monitoring the ANAOI is data deficiency; there is a lack of baseline data for several indicators. Recent and currently anticipated studies along with TEK (past and ongoing) will address some of these gaps but not all. The BREA program and nearshore fish sampling scheduled for 2014 will provide baseline information[1] for lower trophic level species abundance, fish distributions and habitat use of fishes. However, a gap will still exist for long term studies of some key species as well as sampling in the winter months because most research in the Canadian western Arctic is conducted during the open-water season (summer). Establishing long term monitoring programs will also be difficult because of logistical challenges with the area's remoteness and higher associated costs.

It will also be challenging to monitor the various indicators on appropriate timescales. Monitoring frequency will need to vary by indicator and/or species to be able to separate real change from natural variability. Recommendations have been made for different species or groups (e.g., Gill et al. 2011) but they may not be feasible to implement.

Overlapping jurisdictions over the management of indicators in the area may present a challenge as some coordination will be needed between DFO, CWS and EC to effectively monitor Polar Bears and seabirds. The Inuvialuit have decades of experience with wildlife co-management (e.g., FJMC 2001, Joint Secretariat 2003, Community of Paulatuk et al. 2008), which will help facilitate coordination between federal government departments and the community of Paulatuk.

SOURCES OF INFORMATION

Alexander, S.A., Westover, S.E., and Dickson. D.L. 1993. Spring migration of waterbirds in the Beaufort Sea, Amundsen Gulf, and Lambert Channel polynya, 1993. Can. Wildlife Service Tech. Rep. Ser. 201: xi + 61 p.

[1] Sampling occurred in 2014 and 2015 prior to the publication of this report.

Allen, B.M., and Angliss, R.P. 2013. Alaska marine mammal stock assessments, 2012. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-AFSC-245.

Asselin, N.C., Barber, D.G., Stirling, I., Ferguson, S.H., and Richard, P.R. 2011. Beluga (*Delphinapterus leucas*) habitat selection in the eastern Beaufort Sea in spring, 1975-1979. Polar Biol. 34(12): 1973–1988.

Barber, D.G., Hwang, B., Ehn, J., Iacozza, J., Galley, R.J., Hanesiak, J., Papakyriakou, T., and Lukovich, J.V. 2008. The Ocean-Sea Ice-Atmosphere (OSA) Interface in the Southern Beaufort Sea. *In* On Thin Ice: a synthesis of the Canadian Arctic Shelf Exchanges Study (CASES). Edited by L. Fortier, D. Barber and J. Michaud. Aboriginal Issues Press. pp. 37–68.

Barber, D.G., Asplin, M.G., Gratton, Y., Lukovich, J.V., Galley R.J., Raddatz, R.J., and Leitch, D. 2010. The International Polar Year (IPY) Circumpolar Flaw Lead (CFL) System Study: Overview and the Physical System. Atmosphere-Ocean. 48: 225–243.

Benoit, D., Simard, Y., and Fortier, L. 2008. Hydroacoustic detection of large winter aggregations of Arctic Cod (*Boreogadus saida*) at depth in ice-covered Franklin Bay (Beaufort Sea). J. Geophys. Res. 113, C06S90, doi: 10.1029/2007JC004276.

Bradstreet, M.S., and Cross, W.E. 1982. Trophic relationships at high Arctic ice edges. Arctic. 35(1): 1–12.

Bradstreet, M.S.W., Finley, K.J., Sekerak, A.D., Griffiths, W.B., Evans, C.R., Fabijan, M.F., and Stallard, H.E. 1986. Aspects of the biology of Arctic cod (*Boreogadus saida*) and its importance in Arctic marine food chains. Can. Tech. Rep. Fish. Aquat. Sci. 1491: viii+193 p.

Canadian Ice Service. 2002. Sea Ice Climatic Atlas: Northern Canadian Waters 1971-2000. Ottawa, Canada.

Carmack, E., and D.C. Chapman. 2003. Wind-driven shelf/basin exchange on an Arctic shelf: the joint roles of ice cover extent and shelf-break bathymetry. Geophys. Res. Lett. 30: 1778.

Carmack, E.C., and Macdonald, R.W. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: a setting for marine life. Arctic. 55(Supp1): 29–45.

Community of Paulatuk, Wildife Management Advisory Council (NWT), and Joint Secretariat. 2008. Paulatuk community conservation plan: A plan for the conservation and management of renewable resources and lands within the Inuvialuit Settlement Region in the vicinity of Paulatuk, Northwest Territories. Fisheries Joint Management Council (FJMC), Inuvik, NT. 140 p.

Conlan, K., Aitken, A., Hendrycks, E., McClelland, C., and Melling, H. 2008. Distribution patterns of Canadian Beaufort Shelf macrobenthos. J. Mar. Syst. 74: 864–886.

Conlan, K.E., Kim, S.L., Thurber, A.R., and Hendrycks, E. 2010. Benthic changes at McMurdo Station, Antarctica following local sewage treatment and regional iceberg-mediated productivity decline. Mar. Poll. Bull. 60(3): 419–432.

Conlan, K., Hendrycks, E., Aitken, A., Williams, B., Blasco, S., and Crawford, E. 2013. Macrofaunal biomass distribution on the Canadian Beaufort Shelf. J. Mar. Syst. 127: 76–87.

Cooke, S.J., Schreer, J.F., Wahl, D.H., and Philipp, D.P. 2000. Locomotory dynamics as indicators of stress in fish—remote measures utilizing activity transmitters. *In* Stress in Fish: New Directions. Proceedings of the International Congress on the Biology of Fish, University of Aberdeen, Scotland. pp. 77–86.

Courrat, A., Lobry, J., Nicolas, D., Laffargue, P., Amara, R., Lepage, M., Giradin, M., and Le Pape, O. 2009. Anthropogenic disturbance on nursery function of estuarine areas for marine species. Estuar. Coast. Shelf Sci. 81(2): 179–190.

Darnis, G., Barber, D.G., and Fortier, L. 2008. Sea ice and the onshore–offshore gradient in pre-winter zooplankton assemblages in southeastern Beaufort Sea. J. Mar. Syst. 74: 994–1011.

Darnis, G., Robert, D., Pomerleau C., Link, H., Archambault, P., Nelson, R.J., Geoffroy, M. Tremblay, J.-É., Lovejoy, C, Ferguson, S.H, Hunt, B.P.V., and Fortier, L. 2012. Current state and trends in Canadian Arctic marine ecosystems: II. Heterotrophic food web, pelagic-benthic coupling, and biodiversity. Clim. Chang. 115(1): 1–27.

DFO. 1999. Hornaday River Arctic charr. DFO Science Stock Status Report D5–68.

DFO. 2007. Guidance Document on Identifying Conservation Priorities and Phrasing Conservation Objectives for Large Ocean Management Areas. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/010.

DFO. 2008. Further Guidance on the Formulation, Prioritization, and Use of Conservation Objectives in an Ecosystem Approach to Integrated Management of Human Activities in Aquatic Ecosystems. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/029.

DFO. 2010a. Gully Marine Protected Area Monitoring Indicators, Protocols and Strategies. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/066.

DFO. 2010b. Monitoring indicators for the Tarium Niryutait Marine Protected Area (TNMPA). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/059.

DFO. 2011a. Identification of conservation objectives and boundary delineation for the Darnley Bay Area of Interest (AOI). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/009.

DFO. 2011b. Identification of Ecologically and Biologically Significant Areas (EBSA) in the Canadian Arctic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/055.

DFO. 2012a. Development of a St. Lawrence estuary marine protected area ecological monitoring plan. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/039.

DFO. 2012b. Science advice for identifying indicators for monitoring arctic marine biodiversity in Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/053.

DFO. 2013. Monitoring protocols and strategies for selected indicators in the Tarium Niryutait Marine Protected Area (MPA). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/061.

DFO. 2014. Assessment of stressors, Impacts and Pathways of Effects for the Darnley Bay Anuniaqvia Niqiqyuam Area of Interest for Marine Protected Area designation. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/002.

Dickson, D.L. 2012. Seasonal movement of pacific common eiders breeding in arctic Canada. Can. Wildl. Serv. Tech. Rep. Ser. 521: v + 58 p.

Dickson, D.L., and Gilchrist, H.G. 2002. Status of marine birds of the southeastern Beaufort Sea. Arctic. 55(1): 46–58.

Dumas, J., Carmack, E., and Melling, H. 2005. Climate Change Impacts on the Beaufort Shelf Landfast Ice. Cold Regions Science and Technology. 42: 41–51.

Eert, J., Meisterhans, G., Michel, C., Niemi, A., Reist, J., Williams, W.J. 2015. Physical, chemical and biological oceanographic data from the Beaufort Regional Environmental Assessment: Marine Fishes Project, August-September 2012. Can. Data Rep. Hydrogr. Ocean Sci. 197: vii + 84 p.

Elliott, M., and Quintino, V. 2007. The estuarine quality paradox, environmental homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas. Mar. Pollut. Bull. 54(6): 640–645.

Erbe, C., and Farmer, D.M. 2000. A software model to estimate zones of impact on marine mammals around anthropogenic noise. J. Acoust. Soc. Am. 108(3): 1327–1331.

Fisheries Joint Management Committee (FJMC). 2001. Beaufort Sea beluga management plan - amended Third Printing. Inuvik, NT. iv + 29 p.

Forest, A., Tremblay, J.É., Gratton, Y., Martin, J., Gagnon, J., Darnis, G., Sampei, M., Fortier, L., Ardyna, M., Gosselin, M., and Hattori, H. 2011. Biogenic carbon flows through the planktonic food web of the Amundsen Gulf (Arctic Ocean): A synthesis of field measurements and inverse modeling analyses. Prog. Oceanogr. 91(4): 410–436.

Geoffroy, M., Rousseau, S., and Pyć, C. 2012. 2011 Beaufort Sea active acoustics survey for marine mammal and pelagic fish detection. Final Report prepared for Beaufort Regional Environmental Assessment (BREA), ArcticNet Inc, Kongsberg Maritime AS, BP Exploration Operating Company Limited, Imperial Oil Resources Ventures Limited, and ExxonMobil. viii + 54 p.

George, J., Philo, L., Hazard, K., Withrow, D., Carroll, G., Suydam, R. 1994. Frequency of killer whale (*Orcinus orca*) attacks and ship collisions based on scarring on bowhead whales (*Balaena mysticetus*) of the Bering–Chukchi–Beaufort seas stock. Arctic. 47: 247–255.

Gill, M.J., Crane, K., Hindrum, R., Arneberg, P., Bysveen, I., Denisenko, N.V., Gofman, V., Grant-Friedman, A., Gudmundsson, G., Hopcroft, R.R., Iken, K., Labansen, A., Liubina, O.S., Melnikov, I.A., Moore, S.E, Reist, J.D., Sirenko, B.I., Stow, J., Ugarte, F., Vongraven, D., and Watkins, J. 2011. Arctic Marine Biodiversity Monitoring Plan (CBMP-MARINE PLAN). CAFF Monitoring Series. 3: 138 p.

Hannah, C.G., Dupont, F., and Dunphy, M. 2009. Polynyas and tidal currents in the Canadian Arctic Archipelago. Arctic. 62: 83–95.

Hargrave, B.T., Phillips, G.A., Vass, W.P., Bruecker, P., Welch, H.E., and Siferd, T.D. 2000. Seasonality in bioaccumulation of organochlorines in lower trophic level arctic marine biota. Environ. Sci. Technol. 34(6): 980–987.

Harwood, L.A. 2009. Status of anadromous Arctic charr (*Salvelinus alpinus*) of the Hornaday River, Northwest Territories, as assessed through harvest based sampling of the subsistence fishery, August-September 1990-2007. Can. Manuscr. Rep. Fish. Aquat. Sci. 2890: viii + 33 p.

Harwood, L.A., Innes, S., Norton, P., and Kingsley, M.C. 1996. Distribution and abundance of beluga whales in the Mackenzie estuary, southeast Beaufort Sea, and west Amundsen Gulf during late July 1992. Can. J. Fish. Aquat. Sci. 53(10): 2262–2273.

Hardwood, L.A., Norton, P, Day, B., and Hall, P. 2000. The harvest of beluga whales in Canada’s Western Arctic: hunter-based monitoring of the size and composition of the catch. Can. Stock Assess. Res. Doc. 2000/141.

Harwood, L.A., Smith, T.G., Joynt, A., Kennedy, D., Pitt, R., Moore, S., and Millman, P. 2010. Displacement of whales and seals by seismic and exploratory drilling in the Canadian Beaufort Sea. *In* Presentation made at Canada-United States Northern Oil and Gas Research Forum, Calgary, Alberta, Canada.

Harwood, L.A., Smith, T.G., and Auld, J.C. 2012a. Fall migration of ringed seals (*Phoca hispida*) through the Beaufort and Chukchi Seas, 2001-02. Arctic. 65: 35–44.

Harwood, L., Smith, T., Melling, H., Alikamik, J., and Kingsley, M.C.S. 2012b. Ringed Seals and Sea Ice in Canada's Western Arctic: Harvest-Based Monitoring 1992-2011. Arctic. 65(4): 377–390.

Harvey, M., Therriault, J.C., and Simard, N. 2001. Hydrodynamic control of late summer species composition and abundance of zooplankton in Hudson Bay and Hudson Strait (Canada). J. Plankton Res. 23(5): 481–496.

Hoover, C.A. 2013. Ecosystem Model Indicators for the Beaufort Sea Shelf Region of the Beaufort Sea. Can. Data Rep. Fish. Aquat. Sci. 1249: vi + 14 p.

Hop, H., and Gjøsæter, H. 2013 Polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) as key species in marine food webs of the Arctic and the Barents Sea. Mar. Biol. Res. 9: 878–894.

Hop, H., Mundy, C.J., Gosselin, M., Rossnagel, A.L., and Barber, D.G. 2011. Zooplankton boom and ice amphipod bust below melting sea ice in the Amundsen Gulf, Arctic Canada. Polar Biol. 34: 1947–1958.

Hornby, C. A., C. Hoover, J. Iacozza, D. G. Barber, and L. L. Loseto. 2016. Spring conditions and habitat use of beluga whales (Delphinapterus leucas) during arrival to the Mackenzie River Estuary. Polar Biol. 39(12): 2319–2334.

Horner, R., and Schrader, G.C. 1982. Relative contributions of ice algae, phytoplankton, and benthic microalgae to primary production in nearshore regions of the Beaufort Sea. Arctic. 35: 485–503.

Hunter, J.G., and Leach, S.T. 1983. Hydrographic data collected during fisheries activities of the Arctic Biological Station, 1960 to 1979. Can. Data Rep. Fish. Aquat. Sci. 414: x + 87 p.

Iverson, S.J. 2009. Tracing aquatic food webs using fatty acids: from qualitative indicators to quantitative determination. *In* Lipids in Aquatic Ecosystems. Edited by M.T. Arts, M.T. Brett, and M. Kainz. Springer New York. pp. 281–308.

Jarvela, L.E., and Thorsteinson, L.K. 1999. The epipelagic fish community of Beaufort Sea coastal waters, Alaska. Arctic. 52(1): 80–94.

Johnson, S.R., and Ward, J.G. 1985. Observations of thick-billed murres (*Uria lomvia*) and other seabirds at Cape Parry, Amundsen Gulf, N.W.T. Arctic. 38: 112–115.

Joint Secretariat. 2003. Inuvialuit Harvest Study: Data and Methods Report 1988-1997. Inuvik, NWT. March 2003. 203 p.

Kenchington, E., Link, H., Roy, V., Archambault, P., Siferd, T., Treble, M., and Wareham, V. 2011. Identification of Mega- and Macrobenthic Ecologically and Biologically Significant Areas (EBSAs) in the Hudson Bay Complex, the Western and Eastern Canadian Arctic. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/071. vi + 52 p.

Kingsley, M.C., and Byers, T.J. 1998. Failure of reproduction in ringed seals (*Phoca hispida*) in Amundsen Gulf, Northwest Territories in 1984-1987. NAMMCO scientific publications. 1: 197–210.

Kovacs, K.M., Lydersen, C., Overland, J.E., and Moore, S.E. 2011. Impacts of changing sea-ice conditions on Arctic marine mammals. Mar. Biodivers. 41(1): 181–194.

Latour, P.B., Leger, J., Hines, J.E, Mallory, M.L., Mulders, D.L., Gilchrist, H.G., Smith, P.A., and Dickson, D.L. 2008. Key migratory bird terrestrial habitat sites in the Northwest Territories and Nunavut. 3rd ed. Can. Wildlife Serv. Occ. Paper. 114: 120 p.

Lenihan, H.S., Kiest, K.A., Conlan, K.E., Slattery, P.N., Konar, B.H., and Oliver, J.S. 1995. Patterns of survival and behavior in Antarctic benthic invertebrates exposed to contaminated sediments: field and laboratory bioassay experiments. J. Exp. Mar. Biol. Ecol. 192(2): 233–255.

Lesage, V., Barrette, C., Kingsley, M., and Sjare, B. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. Mar. Mamm. Sci. 15(1): 65–84.

Link, H. 2012. Studying the functioning of benthic hotspot and coldspot ecosystems in the Canadian Arctic. Thesis (Ph.D.) Université du Québec à Rimouski, Rimouski, QC. 212 p.

Link, H., Archambault, P., Tamelander, T., Renaud, P.E., and Piepenburg, D. 2011. Spring-to-summer changes and regional variability of benthic processes in the western Canadian Arctic. Polar Biol. 34: 2025–2038.

Lee, S.H., Whitledge, T.E., and Kang, S.-H. 2008. Spring time production of bottom ice algae in the landfast sea ice zone at Barrow, Alaska. J. Exp. Mar. Biol. Ecol. 367: 204–212.

Loseto, L., Richard, P., Stern, G., Orr, J., and Ferguson, S. 2006. Segregation of Beaufort Sea beluga whales during the open-water season. Can. J. Zoo. 84: 1743-1751.

Loseto, L.L., Stern, G.A., Deibel, D., Connelly, T.L., Prokopowicz, A., Lean, D.R.S., Fortier, L., and, Ferguson, S. 2008. Linking mercury exposure to habitat and feeding behaviour in Beaufort Sea Beluga whales. J. Mar. Syst. 74: 1012–1024.

Loseto, L.L., Stern, G.A., Connelly, T.L., Deibel, D., Gemmill, B., Prokopowicz, A., Fortier, L., and Ferguson, S.H. 2009. Summer diet of beluga whales inferred by fatty acid analysis of the eastern Beaufort Sea food web. J. Exp. Mar. Biol. Ecol. 374: 12–18.

Lowdon, M.K., Majewski, A.R., and Reist, J.D. 2011. Fish catch data from Herschel Island, Yukon Territory, and other offshore sites in the Canadian Beaufort Sea, July and August 2008, aboard the CCGS Nahidik. DFO Can. Data Rep. Fish. Aquat. Sci. 1237: vi + 99 p.

Macdonald, R.W., McFarland, M.E., de Mora, S.J., Macdonald, D.M., and Johnson, W.K. 1978. Oceanographic Data Report Amundsen Gulf August-September 1978. Pac. Mar. Sci. Rep. 78(10): 92 p.

Majewski, A., Walkusz, W., Lynn, B.L., Atchison, S., Eert, J., and Reist, J.D. 2015. Distribution and diet of demersal Arctic Cod, *Boreogadus saida*, in relation to habitat characteristics in the Canadian Beaufort Sea. Polar Biology. DOI: 10.1007/s00300-015-1857-y.

McKinney, M.A., Letcher, R.J., Aars, J., Born, E.W., Branigan, M., Dietz, R., Evans, T.J., Gabrielsen, G.W., Peacock, E., and Sonne, C. 2011. Flame retardants and legacy contaminants in polar bears from Alaska, Canada, East Greenland and Svalbard, 2005-2008. Environ. Int. 37: 365–374.

McNicholl, D.G., Walkusz, W., Davoren, G.K., Majewski, A.R., and Reist, J.D. 2016. Dietary characteristics of co-occurring polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) in the Canadian Arctic, Darnley Bay. Polar Biol. 39(6): 1099–1108.

Michel, C., Legendre, L., Ingram, R.G., Gosselin, M., and Levasseur, M. 1996. Carbon budget of sea-ice-algae in spring: evidence of a significant transfer to zooplankton grazers. J. Geophys. Res. 101(C8): 18345–18360.

Michel, C., Nielsen, T.G., Nozais, C., and Gosselin, M. 2002. Significance of sedimentation and grazing by ice micro- and meiofauna for carbon cycling in annual sea ice (northern Baffin Bay). Aquat. Microb. Ecol. 30: 57–68.

Morata, N., Renaud, P.E., Brugel, S., Hobson, K.A., and Johnson, B.J. 2008. Spatial and seasonal variations in the pelagic-benthic coupling of the southeastern Beaufort Sea revealed by sedimentary biomarkers. Mar Ecol Prog Ser. 371: 47–63.

Mundy, C.J., Gosselin, M., Ehn, J., Gratton, Y., Rossnagel, A., Barber, D.G., Martin, J., Tremblay, J.E., Palmer, M., Arrigo, K.R., Darnis, G., Fortier, L., Else, B., and Papakyriakou, T. 2009. Contribution of under ice primary production to an ice-edge upwelling phytoplankton bloom in the Canadian Beaufort Sea. Geophys. Res. Lett. 36: L17601.

Mundy, C.J., Gosselin, M., Ehn, J.K., Belzile, C., Poulin, M., Alou, E., Roy, S., Hop, H., Lessard, S., Papakyriakou, T.N., Barber, D.G., and Stewart, J. 2011. Characteristics of two distinct high-light acclimated algal communities during advanced stages of sea ice melt. Polar Biol. 34: 1869–1886.

Niemi, A., Michel, C., Dempsey, M., Eert, J., Reist, J., Williams, W.J. 2015. Physical, chemical and biological oceanographic data from the Beaufort Regional Environmental Assessment: Marine Fishes Project, August-September 2013. Can. Data Rep. Hydrogr. Ocean Sci. 198: vii + 144 p.

Palmer, M.A., Arrigo, K.R., Mundy, C.J., Ehn, J.K., Gosselin, M., Barber, D.G., Martin, J., Alou, E., Roy, S., and Tremblay, J.E. 2011. Spatial and temporal variation of phytosynthetic parameters in natural phytoplankton assemblages in the Beaufort Sea, Canadian Arctic. Polar Biol. 34: 1915–1928.

Petersen, A., Irons, D., Anker-Nilssen, T., Artukhin, Y., Barrett, R., Boertmann, D., Egevang, C., Gavrilo, M.V., Gilchrist, G., Hario, M., Mallory, M., Mosbech, A., Olsen, B., Osterblom, H., Robertson, G., and Strøm, H. 2008. Framework for a Circumpolar Arctic Seabird Monitoring Network. CAFF CBMP Report no. 15: 64 p.

Pilfold, N.W., Derocher, A.E., Stirling, I., Richardson, E., and Andriashek, D. 2012. Age and sex composition of seals killed by Polar Bears in the Eastern Beaufort Sea. Plos One. 7(7): e41429.

Planque, B., and Reid, P.C. 1998. Predicting Calanus finmarchicus abundance from a climatic signal. J. Mar. Biol. Ass. U. K. 78(3): 1015–1018.

Quakenbush, L., Citta, J., George, J.C., Heide-Jørgensen, M.P., Small, R., Brower, H., Harwood, L., Adams, B., Brower, L., Tagarook, G., and Pokiak, J. 2012. Seasonal movements of the Bering-Chukchi-Beaufort stock of bowhead whales: 2006–2011 satellite telemetry results. Int. Whal. Comm. Sci. Report. SC/64/BRG1.

Quakenbush, L., Suydam, R.S., Bryan, A.L., Lowry, L., Frost, K. J., and Mahoney, B.A. 2015. Diet of Beluga Whales, *Delphinapterus leucas*, in Alaska from Stomach Conents, March-November. Mar. Fish. Rev. 77(1): 70-84.

Rail, M.E., and Gratton, Y. 2011. Distribution of temperature and salinity in the Canadian Arctic Archipelago during the 2007 and 2008 ARCTICNET sampling expeditions. INRS-ETE, Québec (Qc). 1243: vii + 65 p.

Rail, M.E., Gratton, Y., and Prieur, L. 2011. Distribution of temperature and salinity in the Canadian Arctic Archipelago during the 2009 ARCTICNET sampling expedition. INRS-ETE, Québec (Qc). 1248: vii + 69 p.

Rand, K.M., Whitehouse, A., Logerwell, E.A., Ahgeak, E., Hibpshman, R., and Parker-Stetter, S., 2013. The diets of polar cod (*Boreogadus saida*) from August 2008 in the US Beaufort Sea. Polar Biol. 36(6): 907–912.

Rees, H. L., Pendle, M.A., Limpenny, D.S., Mason, C.E., Boyd, S.E., Birchenough, S., and Vivian, C.M.G. 2006. Benthic responses to organic enrichment and climatic events in the western North Sea. J. Mar. Biol. Ass. U. K. 86(1): 1–18.

Reist, J.D., Wrona, F.J., Prowse, T.D., Power, M., Dempson, J.B., Beamish, R.J., King, J.R., Carmichael, T.J., and Sawatzky, C.D. 2006. General effects of climate change on Arctic fishes and populations. Ambio. 35: 370–380.

Regehr, E.V., Amstrup, S.C., and Stirling, I. 2006. Polar bear population status in the southern Beaufort Sea. U.S. Geological Survey Open-File Report. 1337: 20 p.

Renaud, P.E., Riedel, A., Michel, C., Morata, N., Gosselin, M., Juul-Pedersen, T., and Chiuchiolo, A. 2007. Seasonal variation in benthic community oxygen demand: A response to an ice algal bloom in the Beaufort Sea, Canadian Arctic? J. Mar. Syst. 67: 1–12.

Rice, J.C., and Rochet, M.-J. 2005. A framework for selecting a suite of indicators for fisheries management. ICES J. Mar. Sci. 62: 516–527.

Richardson, W.J., Finley, K.J., Miller, G.W., Davis, R.A., and Koski, W.R. 1995. Feeding, Social and Migration Behavior of Bowhead Whales (Balaena Mysticetus), in Baffin Bay vs. the Beaufort Sea – Regions with different amounts of human activity. Mar. Mamm. Sci. 11(1): 1–45.

Routti, H., Letcher, R.J., Born, E.W., Branigan, M., Dietz, R., Evans, T.J., McKinney, M.A., Peacock, E., and Sonne, C. 2012. Influence of carbon and lipid sources on variation of mercury and other trace elements in polar bears (*Ursus Maritimus*). Environ. Chem. 31: 2739–2747.

Roux, M.J., Harwood, L.A., Zhu, X., and Sparling, P. 2015. Early summer near-shore fish assemblage and environmental correlates in an Arctic estuary. J. Great Lakes Res. 42: 256–266.

Ruben, D., Loseto, L., Ostertag, S., and Hynes, K. 2015. Paulatuk beluga whales: health and local observational indicators. *In* Synopsis of research conducted under the 2014-2015 Northern Contaminants Program. Aboriginal Affairs and Northern Development Canada, Gatineau, Québec. pp. 115-122.

Scheifele, P.M., and Darre M. 2005. Noise levels and sources in the Stellwagen Bank National Marine Sanctuary and the St. Lawrence River Estuary. Marine Conservation Series MSD-05-1. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Marine Sanctuaries Division, Silver Spring, MD. 26 p.

Schlosser, I.J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. Ecol. Monogr. 52(4): 395–414.

Simard, A., Rail, M.E., and Gratton, Y. 2010a. Distribution of temperature and salinity in the Beaufort Sea during the Canadian Arctic Shelf Exchange Study sampling expeditions 2002-2004. INRS-ETE, Québec (Qc). 1187: vii + 128 p.

Simard, A., Rail, M.E., and Gratton, Y. 2010b. Distribution of temperature and salinity in the Canadian Arctic Archipelago during the 2006 ARCTICNET sampling expedition (from August 22nd to November 9th 2006). INRS-ETE, Québec (Qc). 1127vi + 79 p.

Simard, A., Rail, M.E., and Gratton, Y. 2010c. Distribution of temperature and salinity in the Canadian Arctic Archipelago during the 2005 ARCTICNET sampling expedition (from August 5th to October 27th 2005). INRS-ETE, Québec (Qc). 1126: vi + 79 p.

Stirling, I., Kingsley, M., and Calvert, W. 1982. The distribution and abundance of seals in the eastern Beaufort Sea, 1974-79. Can. Wildlife Serv. Occ. Paper. 47. 26 p.

Smith, T.G. 1987. The ringed seal, *Phoca hispida*, of the Canadian western Arctic. Can. Bull. Fish. Aquat. Sci. 216. 81 p.

Torres, M.E., Zima, D., Falkner, K.K., Macdonald, R.W., O'Brien, M., Schöne, B.R., and Siferd, T. 2011. Hydrographic Changes in Nares Strait (Canadian Arctic Archipelago) in Recent Decades Based on δ 18 O Profiles of Bivalve Shells. Arctic. 64(1): 45–58.

Vongraven, D., Aars, J., Amstrup, S., Atkinson, S.N., Belikov, S., Born, E.W., DeBruyn, T.D., Derocher, A.E., Durner, G., Gill, M., Lunn, N., Obbard, M.E., Omelak, J., Ovsyanikov, N., Peacock, E., Richardson, E., Sahanatien, V., Stirling, I., and Wiig, Ø. 2012. A circumpolar monitoring framework for polar bears. Ursus. 23: 1–66.

Walkusz, W., Williams, W.J., Harwood, L.A., Moore, S.E., Stewart, B.E., and Kwasniewski, S. 2012. Composition, biomass and energetic content of biota in the vicinity of feeding bowhead whales (*Balaena mysticetus*) in the Cape Bathurst upwelling region (south eastern Beaufort Sea). Deep-Sea Res. Pt. I. 69: 25-35.

Walkusz, W., Majewski, A., and Reist, J.D. 2013a. Distribution and diet of bottom dwelling Arctic Cod in the Canadian Beaufort Sea. J. Mar. Syst. 127: 65–75.

Walkusz, W., Williams, W., and Kwasniewski, S. 2013b. Vertical distribution of mesozooplankton in the coastal Canadian Beafort Sea in summer. J. Mar. Syst. 127: 26–35.

Ware, S.J., Rees, H.L., Boyd, S.E., and Birchenhough, S.N. 2009. Performance of selected indicators in evaluating the consequences of dredged material relocation and marine aggregate extraction. Ecol. Indic. 9(4): 704–718.

Wilson, A.D., Wikelski, M., Wilson, R.P., and Cooke, S.J. 2015. Utility of biological sensor tags in animal conservation. Conserv. Biol. 29(4): 1065–1075.

Wright, A.J., Deak, T., and Parsons, E.C.M. 2011. Size matters: Management of stress responses and chronic stress in beaked whales and other marine mammals may require larger exclusion zones. Mar. Poll. Bull. 63(1): 5–9.