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Potential ecological monitoring indicators and strategies for the Anguniaqvia niqiqyuam Marine Protected Area and a synopsis of available information

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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.

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ABSTRACT

In 2016, the Anguniaqvia niqiqyuam Marine Protected Area (ANMPA) became the second marine protected area designated in Canada's Arctic under the *Oceans Act*. The ANMPA encompasses marine habitat on the western shores of Darnley Bay near the community of Paulatuk, NT, in the Inuvialuit Settlement Region. Ecological indicators to evaluate the status of the conservation objectives were selected by an expert panel, guided by the latest scientific knowledge for the area, and community priorities provided by the ANMPA Working Group. A three-tiered indicator concept was developed to ensure sufficient data are collected to link potential changes in valued upper-trophic level animals and their habitats to the drivers of change: (a) five indicators are recommended to provide background environmental context required to interpret change in biological indicators, (b) 11 indicators are recommended to monitor biological and food web integrity directly linked to the conservation objectives, and (c) two indicators are recommended to monitor current pressures and threats to the biological system, acknowledging that re-evaluation will be necessary on a regular basis. Information currently available to support each indicator is summarized, and key monitoring strategies and measurement parameters are proposed. Appendix C provides a summary table of recommended measurement parameters and considerations. In some cases, accessing data/information collected at a spatial scale larger than the ANMPA will be vital to increase the reach and contextual value of monitoring data. Most of the indicators can be monitored by community-based monitoring programs, a combination of inshore and offshore sampling, remote sensing, and/or partnering with established research and harvest monitoring programs to optimize the efficiency of data collection. In some cases, follow-on analyses of existing samples and data are required to establish baseline conditions. The information provided herein is an update to science advice previously provided by Fisheries and Oceans Canada, and is intended to support the development of an ecological monitoring plan for the ANMPA through the ANMPA Working Group, Western Arctic MPA Steering Committee, and other relevant partner forums.

ABBREVIATIONS

ADCP: acoustic Doppler current profiler

ANAOI: Anguniaqvia niqiqyuam Area of Interest

ANMPA: Anguniaqvia niqiqyuam Marine Protected Area

BREA MFP: Beaufort Regional Environmental Assessment Marine Fishes Project

BSMFP: Beaufort Sea Marine Fishes Project

CASES: Canadian Arctic Shelf Exchange Study

CBS MEA: Canadian Beaufort Sea Marine Ecosystem Assessment

CCGS: Canadian Coast Guard Ship

CFL: Circumpolar Flaw Lead

CO: conservation objective

CROW: Canadian Rangers Ocean Watch

CTD: conductivity-temperature-depth probe

CWS: Canadian Wildlife Service

DFO: Fisheries and Oceans Canada (previously the Department of Fisheries and Oceans)

EBS: Eastern Beaufort Sea (Beluga population)

FJMC: Fisheries Joint Management Committee

F/V: Fishing vessel

HTC: Hunters and Trappers Committee

ISR: Inuvialuit Settlement Region

MPA: marine protected area

NCMS: Northern Coastal Marine Studies

ROV: remotely operated vehicle

WCS: Wildlife Conservation Society

1. INTRODUCTION

The concept of conservation is challenged in the Arctic by the magnitude and pervasiveness of climate-driven ecological alterations (Wassmann and Reigstad 2011, Timmermans et al. 2018, Griffith et al. 2019, van Kerkhoff et al. 2019). By the end of the century, even conservative climate projection models forecast significant increases in air and ocean temperatures; stronger and larger storms; lower sea surface salinities and stronger stratification; declines in sea-ice concentrations, extent, and thickness; lower pH and nitrate concentrations; earlier ice melt and later freeze-up across the southern Beaufort Sea and Amundsen Gulf (Steiner et al. 2015). In addition to directional shifts in baseline ecosystem variables, larger seasonal and interannual variabilities are expected in the timing, magnitude, and frequency of key events (e.g., storm surges, ice formation and break-up; e.g., Steiner et al. 2015). In such a case, it can take many years of data collection before a trend is teased apart from background variation, and even longer to be able to distinguish “normal” from “extreme” conditions. In the western Canadian Arctic, few ecosystem baseline datasets currently exist, and the available information is not sufficient to characterise or distinguish natural or anthropogenic-driven trends. Understanding biological responses to such physical change is more complex. Species’ responses to environmental changes vary; some populations are likely to benefit from new climate-related opportunities, while others may experience negative consequences (Niemi et al. 2019).

Thus, a broader perspective on conservation is required, in which the goal is perhaps not to maintain the ecosystem in its current physical arrangement, but to protect key species, ecosystem processes, and core characteristics from potentially harmful anthropogenic activities as ecosystems adjust to environmental change. To that end, adopting a “future-oriented” conservation approach (van Kerkhoff et al. 2019) would be beneficial, in which environmental monitoring plans are developed at the outset with the flexibility to adapt to capture both the impacts of anthropogenic activities and inevitable environmental change.

The Anguniaqvia niqiqyuam (pronounced *Ung-u-niak-via ni-kig-e-um*) Marine Protected Area (ANMPA) is the second marine protected area (MPA) to be designated in Canada’s Arctic under the *Oceans Act*. The ANMPA encompasses 2,361 km^2 of marine habitat on the western shores of Darnley Bay and the northern tip of the Parry Peninsula, within the Inuvialuit Settlement Region (ISR) near the community of Paulatuk, NT (Figure 1). In Inuvialuktun, “Anguniaqvia niqiqyuam” translates to “where I hunt for food.” This translation reflects the cultural, socio-economic, and ecological significance of the ANMPA and adjacent waters, which support marine species that are highly valued components of both the local ecosystem and the subsistence diets of the Inuvialuit (Kavik-AXYS Inc. 2012, DFO 2014).

The conservation objectives (COs) of the ANMPA are:

- To maintain the integrity of the marine environment offshore of the Cape Parry Migratory Bird Sanctuary so that it is productive and allows for higher 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;
- To maintain the habitat to support populations of key species (such as Beluga Whales, Arctic Char, and Ringed and Bearded seals).

Notably, the ANMPA COs are not to maintain the ecosystem in its current form, necessarily. The focus is on protecting key functions and core characteristics that, in turn, protect ecosystem services and the upper-trophic level biota valued by Inuvialuit. Management strategies can thus remain adaptable to changing risks from anthropogenic and natural factors, and to evolving states of scientific and Indigenous knowledge.

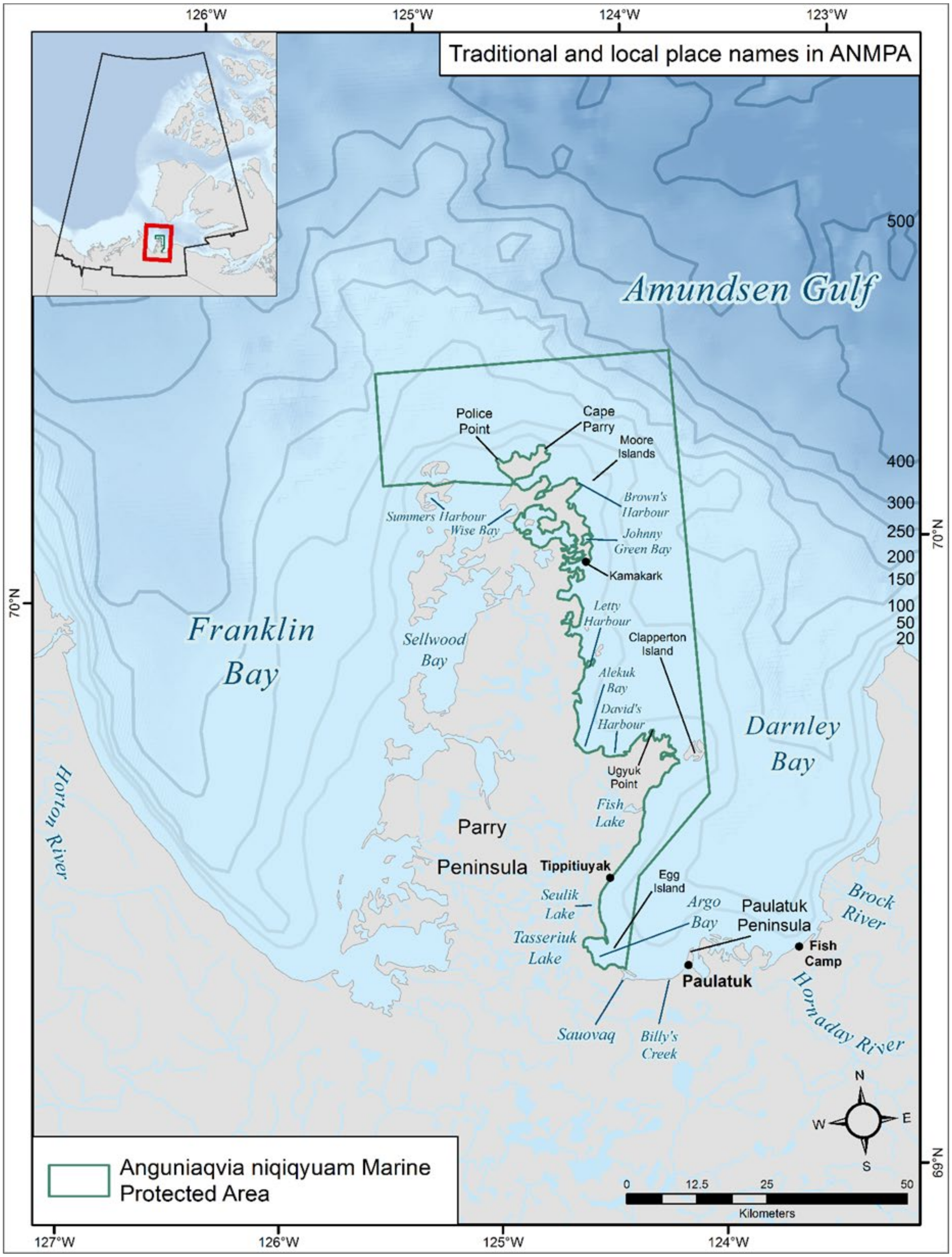


Figure 1. Map of traditional and local place names in the Anguniaqvia niqiqyuam Marine Protected Area. Map created by J. Friesen and local place names provided by the ANMPA Working Group. Bathymetry adapted from the IBCAO by M. Ouellette. Base map obtained from Open Government Portal.

The ANMPA Working Group is currently developing a monitoring plan (including ecological, socioeconomic, and governance indicators), to be implemented at the community level in order to track changes, evaluate whether the conservation objectives are being met, and develop co-management responses as appropriate. Development of the plan is a collaboration between appointed members of the Paulatuk Hunters and Trappers Committee (HTC) and co-management partners Fisheries and Oceans Canada (DFO) and the Fisheries Joint Management Committee (FJMC). Prior to completion, the ANMPA Monitoring Plan will be presented to the Western Arctic Marine Protected Area Steering Committee to ensure guidance from co-management partners, DFO, and Inuvialuit partners is meaningfully included. In 2014, prior to the official designation of the ANMPA, DFO Science provided advice on the selection of ecological monitoring indicators and strategies relevant to informing on the status of the COs (see definitions in Table 1; DFO 2015, Schimnowski et al. 2017). Assessment was only requested for the Cape Parry priority area (Figure 2), and did not address indicators for habitats south of Bennett Point or for adjacent, offshore waters that are inextricably linked to the ANMPA ecosystem. Following the provision of initial science advice (DFO 2015), substantial research and baseline data collection have occurred in the region, and the ANMPA Working Group has identified a set of priorities for ecological monitoring (Appendix A). An update to advice was thus required.

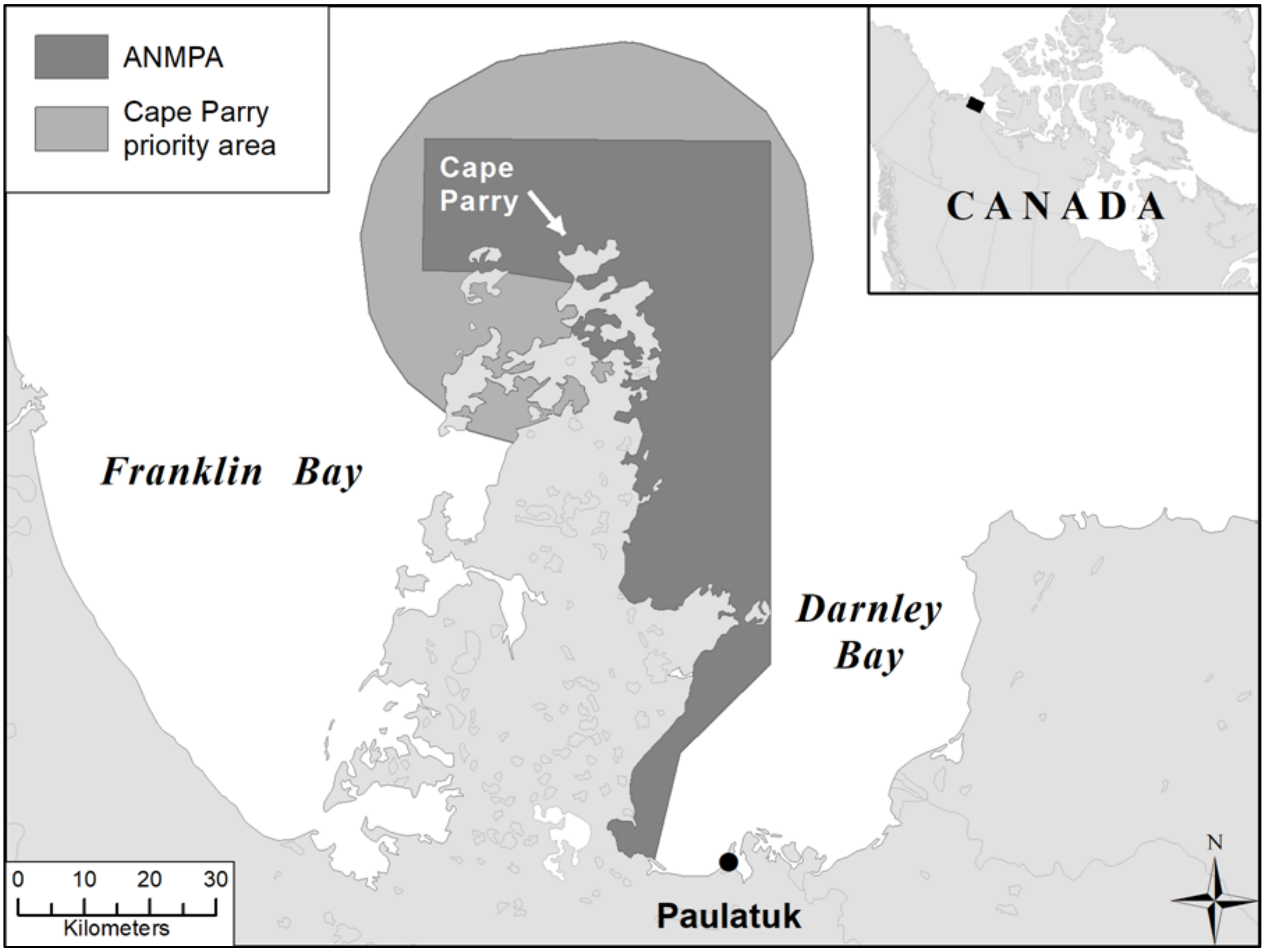


Figure 2. Map of the Cape Parry priority area reviewed during previous science advisory processes on monitoring indicators, protocols, and strategies (DFO 2015), relative to the final boundaries of the ANMPA. Map created by M. Ouellette.

Table 1. Terms and definitions used to describe components of a monitoring program throughout the review. Examples are provided for context.

Term and definition	Example
A ***monitoring indicator*** is the environmental or ecological component that responds to a stressor (anthropogenic) or driver (environmental) in a manner that can be detected, measured, and used to evaluate whether a CO is being met.	• Core oceanographic parameters and nutrient concentrations • Inshore fish community composition, structure, and function • Contaminant concentrations in marine mammals and in the environment
A ***monitoring strategy*** is a broad approach to monitoring an indicator.	• Stratified, random biodiversity assessment of inshore fish conducted annually during summer by community monitors • Local observations of rare species
A ***monitoring parameter(s)*** is one, or an aggregate of, standardized measurements or observations collected regularly to detect the variability, stability, and/or the status of an indicator. Multiple parameters may be used to measure a given *monitoring indicator*, and/or measured as part of a given *monitoring strategy*.	Data collected through the biodiversity assessment can be used to calculate monitoring parameters such as: • Fish catch-per-unit-effort (relative abundance and biomass of each species) • Shannon's diversity index • Species richness
A ***monitoring protocol*** is the specific, standardized procedure that guides data collection and/or calculations required for a particular *monitoring parameter.*	• Specific step-by-step procedures followed to conduct the stratified, random fish biodiversity assessment • Standard equations used to calculate parameters such as catch-per-unit-effort, Shannon's diversity index, and/or species richness • Standard equations used to add local observations to species richness

To that end, the purpose of this review is to:

1. Provide an updated summary of existing baseline data, scientific information, and published local and Indigenous Knowledge relevant to developing an ecological monitoring plan for the ANMPA;
2. Expand the scope of review to include southern portions of the ANMPA and adjacent waters that were not considered in previous science advice (DFO 2015, Schimnowski et al. 2017), and to include priorities outlined by the ANMPA Working Group; and
3. In light of (1) and (2), re-evaluate the monitoring indicators suggested in DFO (2015) to ensure their continued applicability and identify gaps.

As the terminology surrounding environmental monitoring can vary substantially, the definitions used to describe monitoring indicators, strategies, parameters, and protocols throughout this review are defined in Table 1.

2. DESCRIPTION OF THE ANMPA

DFO first sought interest and information regarding a new MPA in the Inuvialuit Settlement Region in 2008. The ISR is one of four regions that collectively constitute Inuit Nunangat (the Inuit homelands) and is governed under the Inuvialuit Final Agreement, a modern land claim agreement signed in 1984. Darnley Bay, which included several ecologically and biologically significant areas (Paulic et al. 2009), was selected as the general area within which the MPA would be designated. In 2010, DFO Science identified areas within Darnley Bay that satisfied the criteria for marine protection under the *Oceans Act*, and provided advice on potential MPA boundaries and conservation objectives (DFO 2011). The science advice was used alongside Indigenous Knowledge and socio-economic considerations to delineate the Anguniaqvia niqiqyuam Area of Interest (ANAOI) and, in 2016, to officially designate the region as the ANMPA.

A full ecological overview of the ANMPA ecosystem is beyond the scope of this review. Readers are instead directed to the detailed ecological information summarized in DFO (2011), Chambers and MacDonell (2012), Kavik-AXYS Inc. (2012), and Paulic et al. (2012).

Briefly, the ANMPA encompasses most of the eastern and northern shores of the Parry Peninsula, from inner Darnley Bay in the south to Amundsen Gulf in the north (Figure 1). The food web is typical of coastal Arctic systems, comprised of four to five trophic levels whose function and connectivity are intimately associated with the seasonal cycles of light availability, ice cover, migration and productivity. The ANMPA and Darnley Bay can be roughly divided into several ecosystem regimes that function to support upper-trophic level feeding. The coastal habitat includes travel corridors for Beluga Whales (Qilalugaq / *Delphinapterus leucas*) and Arctic Char (Iqalukpik / *Salvelinus alpinus*) in the summer, and supports populations of Ringed Seals (*Natchiq / Pusa hispida*), Bearded Seals (Ugyuk / *Erignathus barbatus*), and marine coastal fishes year-round. The southern portions of the ANMPA are typically warmer, less saline, and sandy under the influence of fresh water and sediments discharged from the Hornaday and Brock rivers, and support anadromous fishes seasonally. The ANMPA coastline transitions to steep, rocky bluffs towards the northern tip of the Parry Peninsula, where variable bathymetry promotes enhanced tidal flows and suspected relatively frequent upwellings of nutrient-rich water. Here, waters are colder and more saline than in the south, and typically support higher biological productivity. In the summer, the offshore areas of Cape Parry and Darnley Bay are considered important marine feeding habitat for Bowhead Whales (Arviq / *Balaena mysticetus*) and for unique nesting colonies of migratory Thick-Billed Murres (*Uria lomvia*) and small numbers of Black Guillemots (*Cepphus grille*) occupying the Cape Parry Migratory Bird Sanctuary. A recurring polynya forms off Cape Parry. The ice-edge habitat at the polynya and associated leads is used in spring for foraging by Polar Bears (Nanuq / *Ursus maritimus*), Ringed Seals, and Bearded Seals, and for staging by a large number of migratory waterfowl including several species of sea ducks, gulls, and loons. The offshore area is utilized by thousands of King Eider (Qingalik / *Somateria spectabilis*) and Common Eider (Qaugaq / *Somateria mollissima*) during late summer/early fall for staging and moulting.

3. KEY CONSIDERATIONS FOR SUCCESSFUL IMPLEMENTATION

3.1. INCLUSION OF INDIGENOUS KNOWLEDGE

This document focuses largely on knowledge gained from western science, and indicators were developed within a western science framework (i.e., the collection of data for statistical analyses). Although the document provides discussion about how data collection can be incorporated into a community-based monitoring program in Paulatuk, the monitoring indicators and parameters herein were not explicitly developed based on Indigenous Knowledge. It is recognized that scientific information in support of the ANMPA monitoring plan is meant to complement community values, goals, and Indigenous Knowledge in a collaborative decision-making process for ecosystem co-management. In both western science and Indigenous Knowledge, knowledge generation exists along a spectrum from simple observations to holistic understanding, and contributions from the full spectra of both knowledge systems is needed for a monitoring plan to be successfully delivered.

This document adopts the definition of Traditional Knowledge outlined in the ISR Traditional and Local Knowledge Catalogue as, briefly, “a shared, collective body of knowledge incorporating environmental, cultural, and social elements” (see ISR Traditional and Local Knowledge Catalogue for full definition). The inclusion of published Indigenous Knowledge in this review was specifically limited to documents that were 1) developed by or in collaboration with the Paulatuk HTC, 2) are understood to be broadly approved by the Paulatuk HTC, and 3) which include information documented in forums specifically intended to capture ecological knowledge that could aid in the development of conservation strategies in Darnley Bay. An annotated bibliography of those documents is provided in Appendix B to provide context to the reader. Inuvialuktun species names used in this document were drawn, when available, from the Paulatuk Community Conservation Plan.

3.2. SCIENTIFIC CONSIDERATIONS

For the ANMPA monitoring plan to be successfully implemented, it must be grounded in the best available scientific evidence and Indigenous Knowledge, and must have the support of the local community. Strong partnerships between co-management bodies, Inuvialuit partners, and researchers working in the ANMPA will be essential to meeting conservation goals.

Monitoring and research work hand-in-hand to inform management strategies and meet conservation objectives. Both are most effective when they are hypothesis- or question-driven, but they play different roles. *Research* strives to delineate the connections among ecosystem components and drivers; to understand, predict, and provide advice to mitigate the consequences of potential future changes to the ecosystem. Research is often developed around a hypothesis at the functional level and conducted on a relatively short time scale. Research thus supports monitoring through the choice of key indicators, understanding of the implications of changes in those indicators, and with respect to management options. *Monitoring* collects standardized information at regular time intervals for key components and processes of the ecosystem to evaluate temporal change (or stability), and to report on the state of the MPA. In essence, monitoring is descriptive. Trends observed in monitoring indicators can stimulate targeted research to better understand the implications of change, or be used to develop appropriate strategies for ecosystem management.

The indicators and parameters chosen for monitoring would preferably have known or suspected cause-and-effect responses to a driver or stressor. Thus, a monitoring plan will have a greater capacity for future-oriented conservation if it includes a broad suite of ecological indicators (van Kerkhoff et al. 2019). By monitoring the indicators that are of direct conservation interest (e.g., Beluga presence/absence) alongside the indicators that directly or indirectly support and/or influence them (e.g., prey abundances, ocean temperatures), a monitoring plan stands the greatest chance of capturing, identifying, and understanding ecological change.

An effective monitoring plan should continue to be re-examined on a regular basis in order to re-evaluate the specific hypotheses that will allow co-managers to answer the question “are the conservation objectives being met?” in the face of ongoing ecosystem variability and change, and new local or scientific discoveries. Doing so will ensure indicators are still the most appropriate and effective for detecting shifts/responses relevant to the COs. Moreover, regular evaluation of the monitoring plan can guide research toward addressing knowledge gaps of pressing concern.

In short, to successfully evaluate whether the COs for the ANMPA are being met (from a western science perspective), the ecological monitoring plan should be (DFO 2015):

1. Able to distinguish between anthropogenic-related change and environmental variation (have a high signal-to-noise ratio), such that it is able to recognize the complexity of the system and be sensitive to seasonality;
2. Standardized, long-term, and follow specific established protocols that are adaptable rather than static (e.g., hypotheses should be revisited regularly to incorporate new findings and be modified accordingly), recognizing that changes to protocols/technology must be implemented with overlap between methods to ensure comparability and a cumulative record;
3. Based on a question or hypothesis associated with predictions/expectations at all stages of the monitoring program, which is explicitly linked to data collection methodologies to achieve meaningful outcomes;
4. Assessed on a regular reporting schedule;
5. Incorporated with data analysis, the dissemination of results to both local and scientific communities, and archiving of data/results in a standardized fashion;
6. Community-led and coordinated among co-management groups, government, and scientific partners.

The criteria above do not consider that area-based conservation is challenged by spatial shifts in key ecosystem components likely to occur in response to climate change and climate variability. Species distributions, foraging, movement patterns, and habitat associations are likely to adapt, such that conservation objectives may become a moving target. Adaptability should be built into a monitoring plan as much as possible, with a focus on preserving key functions, while recognizing some challenges will require political solutions (e.g., modifying MPA boundaries).

4. INDICATOR SELECTION

4.1. INDICATOR CRITERIA

At a bare minimum, an ecological indicator must be able to successfully identify changes in the ecosystem that indicate whether the conservation objectives for the area are being met. To do so, an effective indicator should be (DFO 2015):

1. Relevant to the COs (primary criteria);
2. Sensitive and responsive to a natural driver or anthropogenic stressor;

3. Reflective of processes and/or changes to processes within the area;
4. Reflective of natural drivers or anthropogenic stressors within a relevant timeframe;
5. Able to provide information on multiple aspects of environmental integrity (ideally);
6. Most effective with appreciable baseline/historic data;
7. Based on Indigenous Knowledge and scientific information but are not the explicit output of scientific research;
8. Easily developed and delivered in the field (ideally);
9. Easily detected; high signal to noise ratio.

4.2. SELECTION PROCESS

Ecosystem integrity, trophic links, as well as Beluga Whale, Arctic Char, Ringed Seal, Bearded Seal, and their habitats were identified as valued ecosystem components in the ANMPA (DFO 2011, 2014). A list of anthropogenic activities that have the potential to negatively affect these components in the ANMPA, and their pathways of effects, was developed in 2014 (DFO 2014), and used to inform the selection of an initial set of monitoring indicators that considered expected ecosystem responses to anthropogenic activities, climate change, and climate variability while adhering to the criteria listed in *Section 4.1* (DFO 2015, Schimnowski et al. 2017). In 2020, an expert scientific panel re-evaluated the indicator list in light of the monitoring priorities provided by the ANMPA Working Group (Appendix A) and new scientific information. The indicators recommended by the 2020 CSAS review are summarized in the accompanying Science Advisory Report, with detailed information provided in *Sections 5*, *6*, and *7* of this document. Although a wide range of strategy options are discussed, the measurement parameters considered most informative for each monitoring indicator, as well as their relevance to the COs, are summarized in Appendix C.

The monitoring indicators discussed in the following sections were selected based on the best available science for the ecosystem, supported by expert consultation and published Indigenous Knowledge. The existing body of literature on environmental indicator selection and examples from other monitoring programs were also considered. However, explicit research on effectiveness in the ANMPA has not been conducted for many of the recommended indicators. A validation and reporting process should be built into a monitoring plan to ensure that the selected indicators do provide information relevant to the COs.

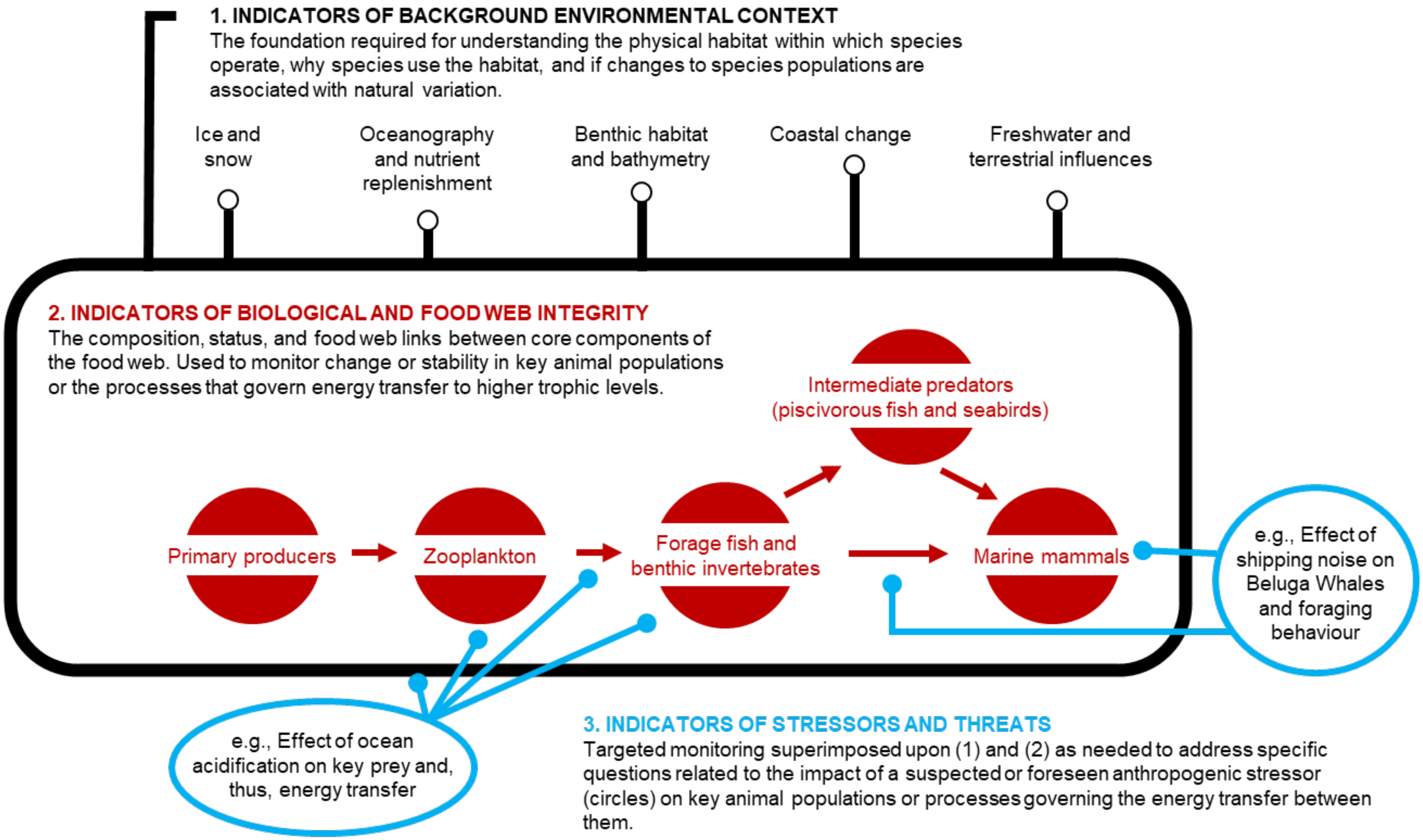
4.3. THREE-TIERED INDICATOR CONCEPT

Indicators discussed in this document are organized into three categories (Figure 3), to capture the data required to link potential changes in valued upper-trophic level animals and their ecosystem to the drivers of change. Indicator categories are as follows:

1. *Indicators that provide background environmental context:* These indicators lay the foundation for an ecosystem-based management approach to understand the physical habitat in which species operate, why species use the habitat, and if changes to species populations are associated with natural variation. Background environmental indicators are especially important to distinguish when a species trend is linked to an anthropogenic stressor that can be actively managed, as opposed to natural environmental variation that is beyond the scope of local management (aside from potential adaptation strategies). As such, background indicators contribute to monitoring both COs. Some background environmental indicators are well-suited to regular monitoring because they are expected to respond to natural drivers or anthropogenic stressors, or they exhibit natural temporal

variability that influences biological communities (e.g., nutrient supply). Other indicators still require basic data collection to provide fundamental habitat descriptions (e.g., bathymetry).

2. *Indicators of biological and food web integrity:* These indicators directly address both COs by providing information on the composition and status of key biological populations that inhabit the ANMPA, as well as the food web processes that govern their interactions, and thus the transfer of energy to higher trophic levels. These indicators are at the “core” of the monitoring program, directly tracking change in the biological communities in each major trophic group. Metrics of whole-community structure (e.g., biodiversity, species richness) as well as population parameters for key species (e.g., relative abundances, distributions) should be selected for monitoring within each major trophic group. It is stressed that data from upper-trophic level species alone will not provide sufficient information to evaluate the COs. Indicators of biological and food web integrity must be placed in the context of processes occurring at lower trophic levels, and in the context of background environmental variation.
3. *Indicators of pressures and threats:* These indicators guide targeted monitoring, superimposed upon (1) and (2), to understand how a suspected or foreseen anthropogenic pressure will (or does) affect the species that inhabit the ANMPA, their habitats, or processes vital to ecosystem integrity. The data may also be used to determine the mechanisms through which an effect is propagated (“pathways of effects”). Indicators of pressures and threats are meant to understand ecosystem responses, and to inform or trigger management actions. Thus, these indicators are selected based on anticipated activities in or near the ANMPA (e.g., shipping), newly discovered potential threats (e.g., invasive species, emerging contaminants), or other questions of specific interest (e.g., impact of ocean acidification). Indicators of pressures and threats are meant to be treated as modular in the monitoring plan design; their applicability should be re-evaluated on a regular basis, and indicators should be added or removed as threats become imminent or resolved. They will have limited usefulness without the data collected through (1) and (2).



1. INDICATORS OF BACKGROUND ENVIRONMENTAL CONTEXT
The foundation required for understanding the physical habitat within which species operate, why species use the habitat, and if changes to species populations are associated with natural variation.

2. INDICATORS OF BIOLOGICAL AND FOOD WEB INTEGRITY
The composition, status, and food web links between core components of the food web. Used to monitor change or stability in key animal populations or the processes that govern energy transfer to higher trophic levels.

3. INDICATORS OF STRESSORS AND THREATS
Targeted monitoring superimposed upon (1) and (2) as needed to address specific questions related to the impact of a suspected or foreseen anthropogenic stressor (circles) on key animal populations or processes governing the energy transfer between them.

Figure 3. Schematic of the three-tiered indicator concept that guided indicator recommendations. (1) Indicators that provide background environmental context lay the foundation for an ecosystem-based management approach to monitoring and are necessary to link observed species trends to natural environmental variation or anthropogenic drivers. These indicators describe the habitat parameters (black box) within which biological communities (red) operate. (2) Indicators of biological and food web integrity are at the "core" of the monitoring program, directly tracking change in the biological communities and key species that occupy each major trophic group (circles), as well as the trophic processes that control energy transfer through the food web (arrows). Note that not all trophic components are pictured. (3) Indicators of stressors and threats are modular indicators superimposed on (1) and (2) that can be added or removed to guide targeted monitoring of how a specific stressor/threat (blue) impacts species (red circles), their habitats (black box), or process that govern energy transfer (red arrows).

4.4. INTEGRATION WITH MPA NETWORKS

The Government of Canada has committed to developing a network of well-connected marine protected areas (Government of Canada 2011), and network-scale monitoring will seek to leverage existing monitoring programs for individual MPAs (DFO 2020). Therefore, indicators identified for monitoring in the ANMPA monitoring plan could proactively be developed with a broader network approach in mind, and create connectivity among MPAs in the Arctic. The indicators recommended in this report were tailored specifically to the COs of the ANMPA, but many are also relevant to the COs of the nearby Tarium Niryutait MPA. During monitoring plan development, best practices would be to identify the selected indicators or parameters that are relevant to conservation objectives in multiple MPAs, and to standardize methods for data collection, analysis and reporting across sites so that monitoring can be integrated at the regional scale. It would also benefit network monitoring if individual MPA monitoring plans included indicators/parameters that could assess connectivity between multiple sites (e.g., tagging, genetics, contaminants, anthropogenic stressors).

5. INDICATORS THAT PROVIDE BACKGROUND ENVIRONMENTAL CONTEXT

5.1. CORE OCEANOGRAPHIC PARAMETERS AND NUTRIENT CONCENTRATIONS

Oceanographic conditions and water circulation affect every aspect of marine life, forming the core habitat within which marine organisms operate. Darnley Bay is a productive embayment that attracts valued wildlife into its waters. However, the state of knowledge regarding *why* wildlife are attracted to the region, and which environmental processes contribute to that attraction, are not yet fully understood. To be productive for upper-trophic level species, the ANMPA must contain favourable habitat for their prey and must support or accumulate the primary production that fuels the entire food web. Ocean characteristics, circulation and energetic events such as upwelling, downwelling, and wind-driven mixing of surface waters are primary factors that determine habitat conditions within the water column, and that together with sea-ice conditions promote or impede primary production. For example, the delivery of nutrients fuels primary production whereas increases in suspended sediments interfere with light penetration and decreases primary production. The amount, location and type of primary production depends on a complex interplay of light and nutrient availability and determines key ecosystem functions such as pelagic-benthic coupling (Juul-Pedersen et al. 2008a,b, 2010, Sallon et al. 2011) and the location of productive hot spots and their response to climate change (Ardyna et al., 2011, Coupel et al. 2015). In turn, these key ecosystem functions determine where lower-trophic level prey congregate and attract upper-trophic level predators (e.g., Bluhm and Gradinger 2008, Williams and Carmack 2008, Walkusz et al. 2012, Majewski et al. 2016, Stasko et al. 2018, Yurkowski et al. 2019). Key marine habitat conditions are influenced by oceanographic, cryospheric and climate forcings, including the seasonal evolution and extent of sea ice, vertical density-driven stratification, and distribution of water masses. In turn, these habitat conditions impart strong influences on productivity (e.g., Tremblay et al. 2012), species' distributions, interspecific interactions (e.g., Geoffroy et al. 2011, Roy et al. 2014, Stasko et al. 2016, Yurkowski et al. 2016, Harwood et al. 2017b, Hornby et al. 2017, Majewski et al. 2017, Smoot and Hopcroft 2017).

Because primary production is at the base of the whole food web, it is important to discern ocean processes that influence its magnitude (productive capacity of the system), seasonality, and the location of hotspots (areas of concentrated biota and/or key processes such as enhanced biological production). Nutrients play an essential role as fuel for primary production, which supports the entire food web, and is therefore a key oceanographic parameter to monitor.

Nutrient supply in the euphotic zone of the Beaufort Sea, during the open water period, is influenced by wind-driven mixing and shelf-break upwelling, which are both increasing due to reduced ice cover, higher air pressure over the Canada Basin, and more persistent easterly winds (Tremblay et al. 2011, 2012, Steiner et al. 2015). In offshore areas, nutrient concentrations in the upper layers of the water column may be significantly affected by accumulation of fresher, warmer waters that strengthen density-driven stratification and suppress vertical mixing (reviewed in Tremblay et al. 2012, AMAP 2017). In a recent review, Steiner et al. (2015) found high spatial variability in historical trends of primary production across the southern Beaufort Sea linked to heterogeneity in nutrient supply. Model projections in Steiner et al. (2015) agreed with previous studies that suggested sea-ice retreat from shelf areas would lead to the promotion of greater primary production due to enhanced wind exposure and upwelling of nutrient-rich waters, whereas primary production in the offshore was projected to remain relatively stable as freshened upper water layers supressed vertical mixing (Tremblay et al. 2011, Coupel et al. 2015). However, it is not yet established which exact mechanisms are active in embayments dominated by landfast ice, such as Darnley Bay, and what their cumulative effect on primary productivity of the system will be.

Measurements of core physical and chemical oceanographic parameters are complementary to each other, and inform primary production and food web processes. It is therefore recommended that core physical and chemical oceanographic parameters are measured together and concomitantly with primary production parameters, to maximize the ecosystem information gained. Core oceanography and nutrient concentrations are fundamental to identifying potential causes of change in indicators of biological and food web integrity (see those in *Section 6*). This is especially true in the context of climate change and climate variability. Climate-induced fluctuations and changes in physical habitat features have demonstrable cascading effects on all levels of the marine food web, including on valued marine mammals, fish, and seabirds (e.g., Carmack et al. 2006, Laidre et al. 2008, Wassmann 2011, Moore and Stabeno 2015, Frainer et al. 2017). Physical and chemical oceanography will be integral to many of the hypotheses that structure the design of the ANMPA monitoring plan, and will help tease apart the influence of manageable anthropogenic stressors from non-manageable natural drivers.

In short, physical oceanography and nutrient concentrations underpin important biological processes that occur within the ANMPA. Information on this indicator is critical for interpreting biological change with respect to large-scale ecosystem change. Monitoring core parameters of physical oceanography and nutrient concentrations is strongly recommended as an integral part to the monitoring program.

5.1.1. Available information

Data on physical and geochemical oceanographic parameters have been intermittently collected in the ANMPA and adjacent waters since 1962, but insufficient information exists to form a systematic baseline. Continuous time series of full oceanographic profiles at fixed locations are scarce in the vicinity of the ANMPA. Water circulation within Amundsen Gulf requires more investigation, and circulation within Darnley Bay is poorly understood (reviewed in Paulic et al. 2012).

As summarized in Schimnowski et al. (2017), historical temperature and salinity profile data were collected by DFO-led expeditions that took place in late summer of 1962–1964 aboard the M/V *Salvelinus*. Surveys were conducted at locations around Franklin Bay, Darnley Bay, and Cape Parry in support of fisheries assessments, with occasional measurements of dissolved oxygen concentrations (Figure 4). All data from the program are tabulated in Hunter and Leach (1983). More systematic water profile surveys of temperature, salinity, fluorescence, water transparency, dissolved nutrients, and dissolved oxygen were conducted by the Institute of Ocean Sciences (DFO) in the offshore Amundsen Gulf in 1977 (Figure 5a; Macdonald et al. 1989), 1982 (winter) and 1998–2004 (H. Melling, DFO, unpublished data; Figure 5b-g). Many stations sampled during the surveys were within 100 km of the ANMPA, but few were in directly adjacent waters (Figure 5). A long-term monitoring station, A1, was established by the Institute of Ocean Sciences (DFO) in 1997 at the deepest point of Amundsen Gulf, northwest of Cape Parry (Figure 5h). Since then, full profiles of physical and geochemical parameters have been measured at Station A1 annually by the Institute of Ocean Sciences, later complemented by measurements taken by ArcticNet beginning in the mid 2000's (H. Melling, DFO, pers. comm.) and by the Canadian Beaufort Sea Marine Ecosystem Assessment (CBS MEA) in 2017 and 2019.

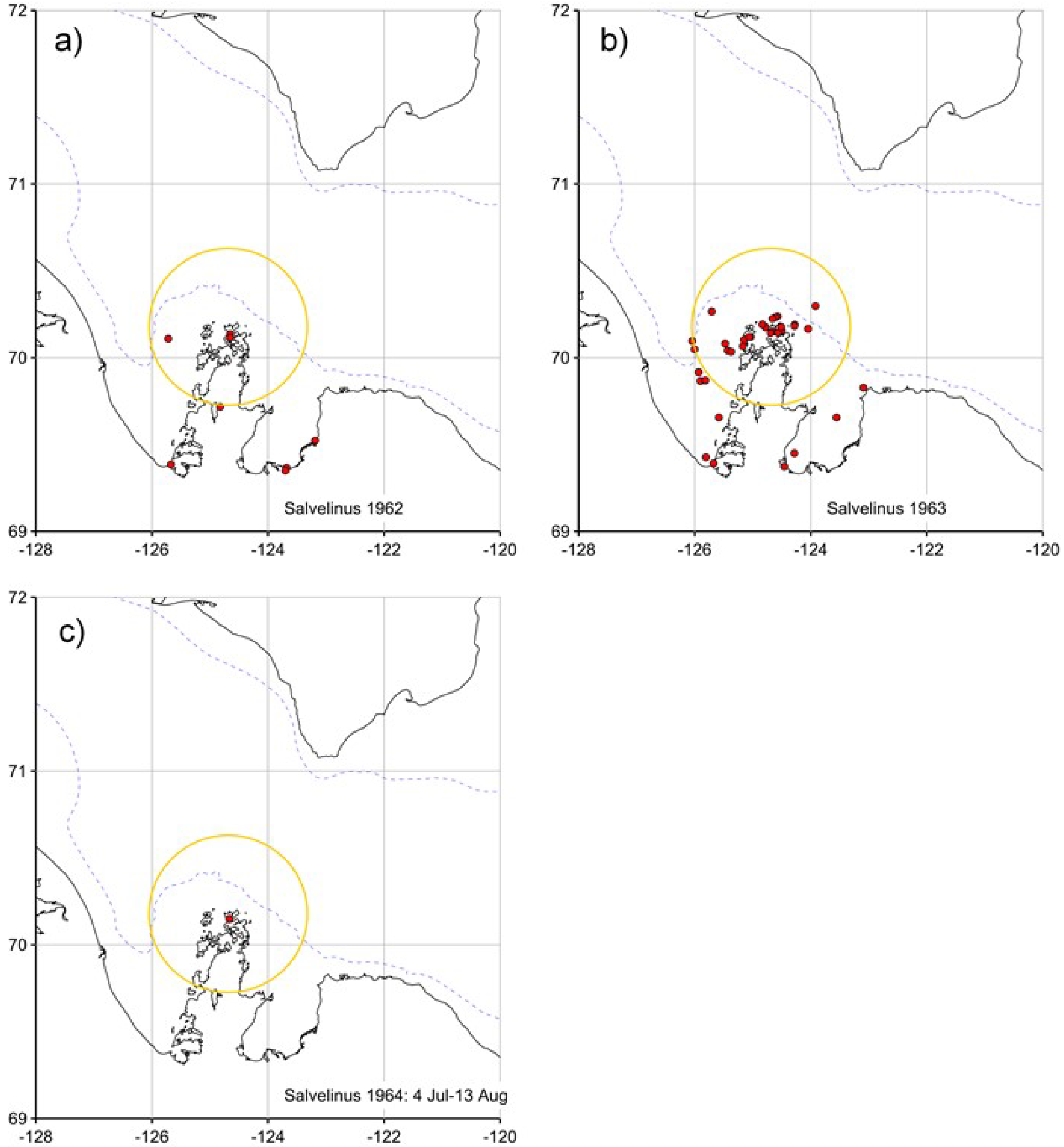


Figure 4. Locations of water profile surveys conducted near the ANMPA by the M/V Salvelinus in a) 1962, b) 1963, and c) 1964. Surveys collected temperature, salinity, and occasionally dissolved oxygen data (Hunter and Leach 1983). Maps provided by H. Melling.

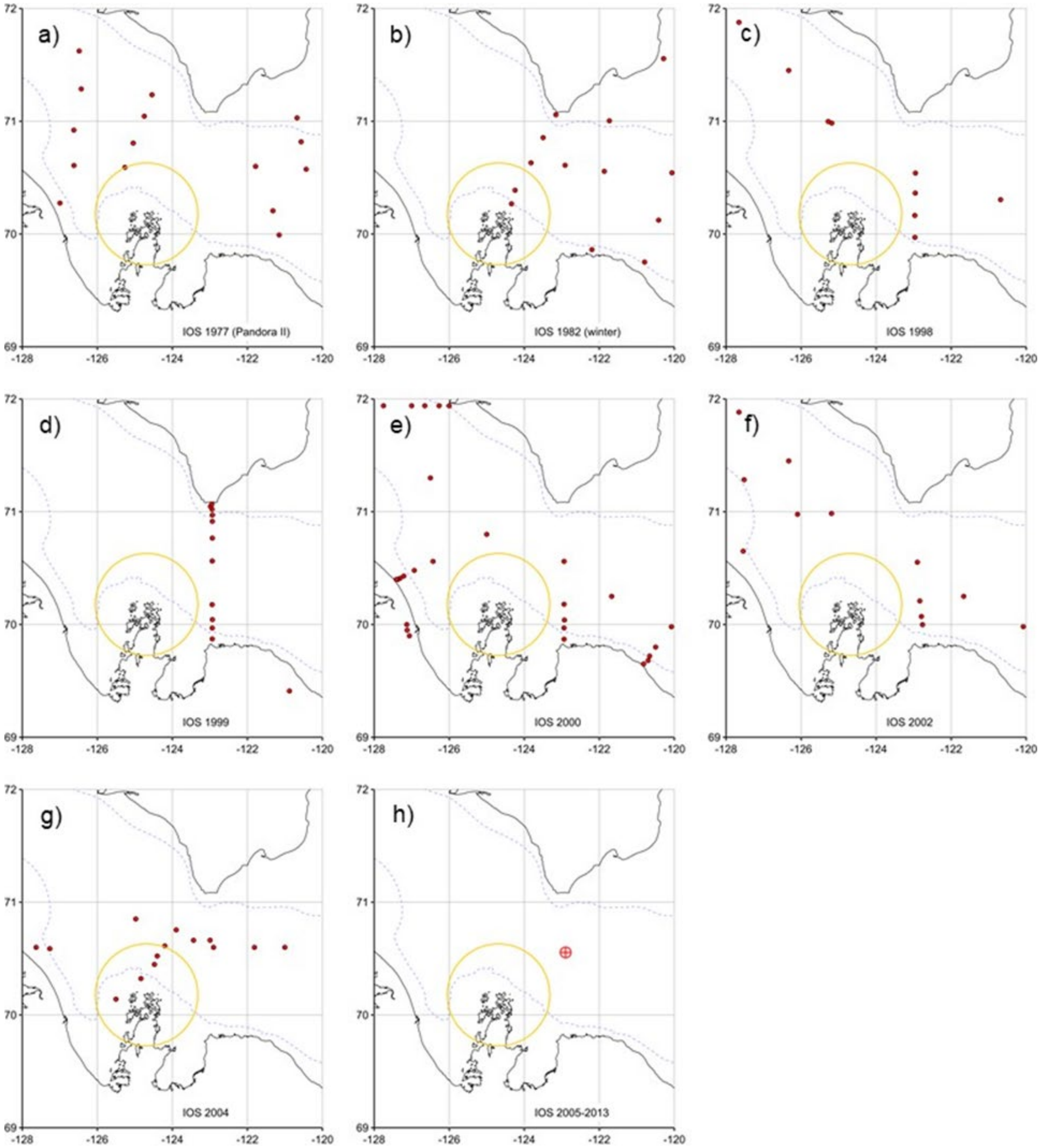


Figure 5. The locations of (a – g) of water profile surveys of temperature, salinity, chlorophyll a fluorescence, water transparency, dissolved nutrients, and dissolved oxygen conducted by the Institute of Ocean Sciences (Fisheries and Oceans Canada) within 100 km of the ANMPA between 1977 and 2004, and (h) the location of reference station A1 at the deepest point in the Amundsen Gulf where full-depth oceanographic profiles have been measured annually since 1997 (H. Melling, DFO, unpublished data). Maps provided by H. Melling.

Continuous sea surface temperature and salinity measurements were collected along the ship tracks of the CCGS *Sir Wilfred Laurier* during its transit north of Darnley Bay in late September of 2006 to present (H. Melling, DFO, unpublished data), and by the CCGS *Nahidik* during the Northern Coastal Marine Studies (NCMS) program in 2008 (B. Williams, DFO, unpublished data). Surface current trajectories were measured using satellite-tagged buoys ("drifters") released in the region in the late summer of 1987 and 1988 (H. Melling, DFO, unpublished data, Williams and Carmack 2008), and by the CBS MEA from 2017 and 2019 (B. Williams, DFO, unpublished data). Surface drifter data demonstrated that coastal currents developed during strong westerly winds transported surface water from the Beaufort Shelf and Cape Bathurst into Franklin Bay, Darnley Bay, and eastward into Dolphin and Union Strait in a matter of days (Niemi et al. 2020). The observations indicate that frequent wind- and bathymetry-driven upwelling/downwelling along the Beaufort shelf-break and at Cape Bathurst (e.g., Williams and Carmack 2008) are important regionally. The same processes may be active along the southern shore of Amundsen Gulf, across the mouth of Darnley Bay and at Cape Parry, but this has yet to be established via observations. If frequent upwelling is so demonstrated it will be critical for the ANMPA ecosystem, replenishing nutrients in surface waters that eventually enter Darnley Bay (Niemi et al. 2020).

Very limited oceanographic data exist for the nearshore areas of the ANMPA. Temperature and salinity data were collected in association with fish surveys conducted in nearshore waters of the ANMPA in 2012, and 2014–2019 by the Arctic Coast summertime coastal monitoring program (McNicholl et al. 2017, D. McNicholl, pers. comm.). Unpublished summer turbidity data also exist from Arctic Coast for 2017.

Further offshore, full oceanographic profiles of temperature, salinity, dissolved oxygen, fluorescence, light transmission, and turbidity were collected in the southern Amundsen Gulf region in support of several fisheries and environmental surveys operating at larger scales, including the Canadian Arctic Shelf Exchange Study (CASES; 2002–2004), ArcticNet (2004–2009), the Circumpolar Flaw Lead (CFL) System Study (2007–2008), the NCMS (2008), and during the consecutive programs carried out aboard the F/V *Frosti*: the Beaufort Regional Environmental Assessment Marine Fishes Project (BREA MFP, 2012–2013), the Beaufort Sea Marine Fishes Project (BSMFP, 2014), and the CBS MEA (2017–2019; Eert et al. 2015, Niemi et al. 2015, 2020). The CASES program sampled stations north and west of Cape Parry and in Franklin Bay from September to October of 2003, then during an over-wintering study in Franklin Bay from 2003–2004 (Fortier et al. 2008, Simard et al. 2010a). The CFL System Study occurred between the fall of 2007 and summer of 2008, sampling over the course of the open-water and winter seasons. Winter sampling mostly occurred within the polynya and flaw lead systems in northern Amundsen Gulf while the ship was attached to ice floes, and along the landfast ice edge across the mouth of Franklin Bay (Barber et al. 2010, Tremblay et al. 2012). Point sampling of open water and landfast ice stations in Darnley Bay was limited during CFL (Barber et al. 2010). Data from the CASES and CFL programs represent some of the only continuous oceanographic measurements made during winter for the region (although see below for recent wintertime sampling events, and year-round moorings). Similarly, oceanographic data collected during the ArcticNet expeditions focused on the offshore Amundsen Gulf and Franklin Bay (Simard et al. 2010b,c, Rail and Gratton 2011, Rail et al. 2011). The NCMS collected data at stations north of Cape Parry and throughout the southern reaches of Darnley Bay in 2008 (Figure 6; Lowdon et al. 2011, Williams 2008, W. Williams, DFO, unpublished data). Data from the NCMS indicated warmer water temperatures and lower salinities, in summer, in coastal habitats at the southern, inshore end of Darnley Bay relative to northern areas near the tip of Cape Parry, and relative to greater depths at the time of sampling (W. Williams, DFO, unpublished data cited in McNicholl et al. 2017). Similar gradients from south to north were observed from temperature and salinity data collected in association with

Arctic Coast summertime fish surveys conducted in 2012, and 2014–2019 (see above; McNicholl et al. 2017, D. McNicholl, DFO, pers. comm.). During field programs conducted from the F/V *Frosti*, stations were sampled between August and early September along a transect running north of Cape Parry in 2013, 2014, and 2019, along a transect running east from Bennett Point in 2013, 2014, and 2017–2019, and at various transects in Franklin Bay in 2014, and 2017–2019 (Figure 7). Integrated temperature-salinity profiles of transect cross-sections are presented in Niemi et al. (2020). The data collected through the BREA MFP and CBS MEA revealed high variability in surface currents, temperatures, salinities, and the vertical density structure of the water column over short time scales. The time series is still too short to discern inter-annual variability from that induced by the wind-driven events that occurred over much shorter timeframes during sampling (Niemi et al. 2020).

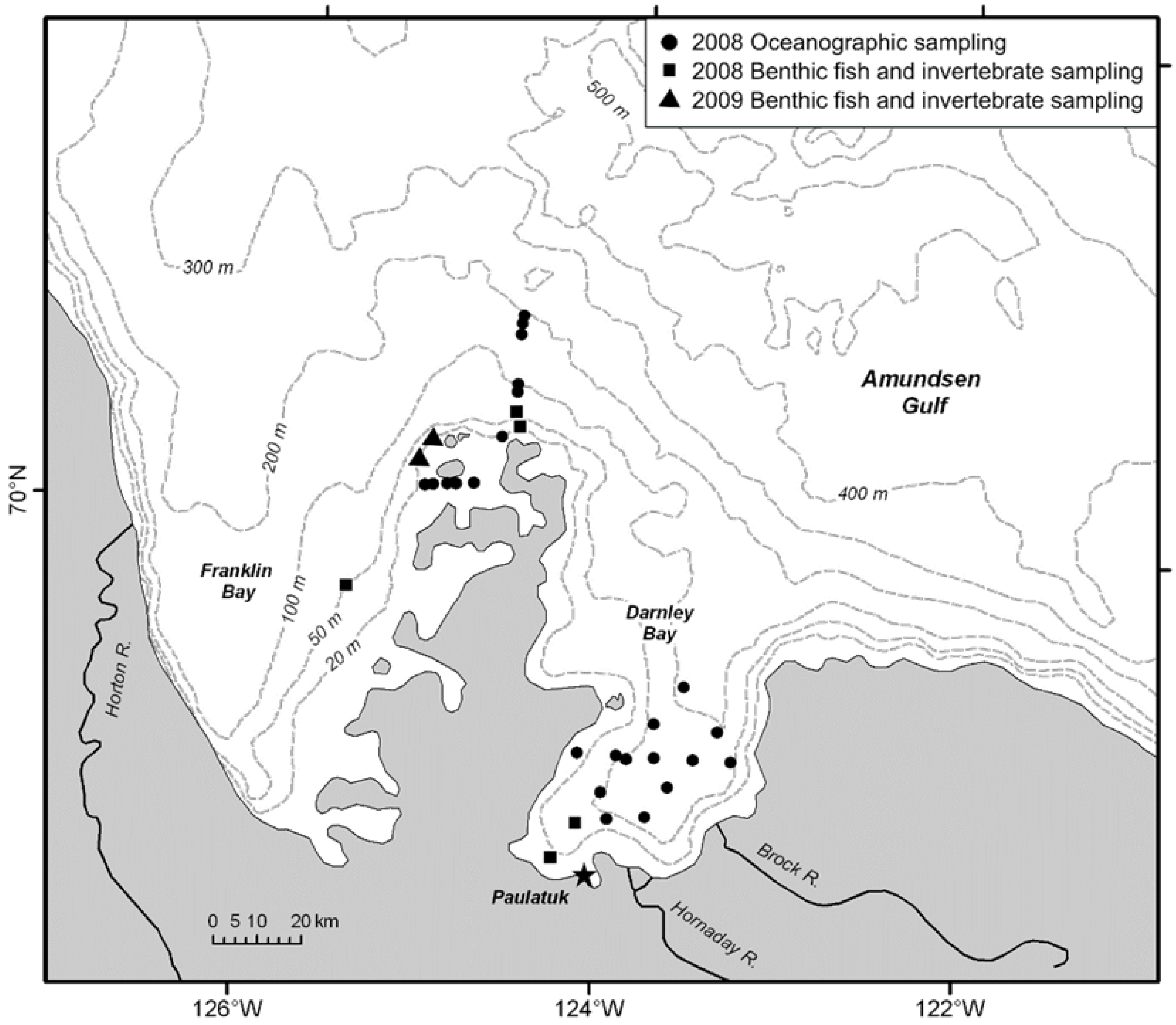


Figure 6. Stations sampled in the vicinity of the ANMPA during the Northern Costal Marine Study in 2008 and 2009 from the CCGS Nahidik. Oceanographic sampling typically included full profiles for physical and chemical oceanography, and occurred at both fish and invertebrate sampling stations (squares and triangles) as well as at dedicated oceanographic stations (circles). Map modified from Paulic et al. 2012 and Lowdon et al. 2011).

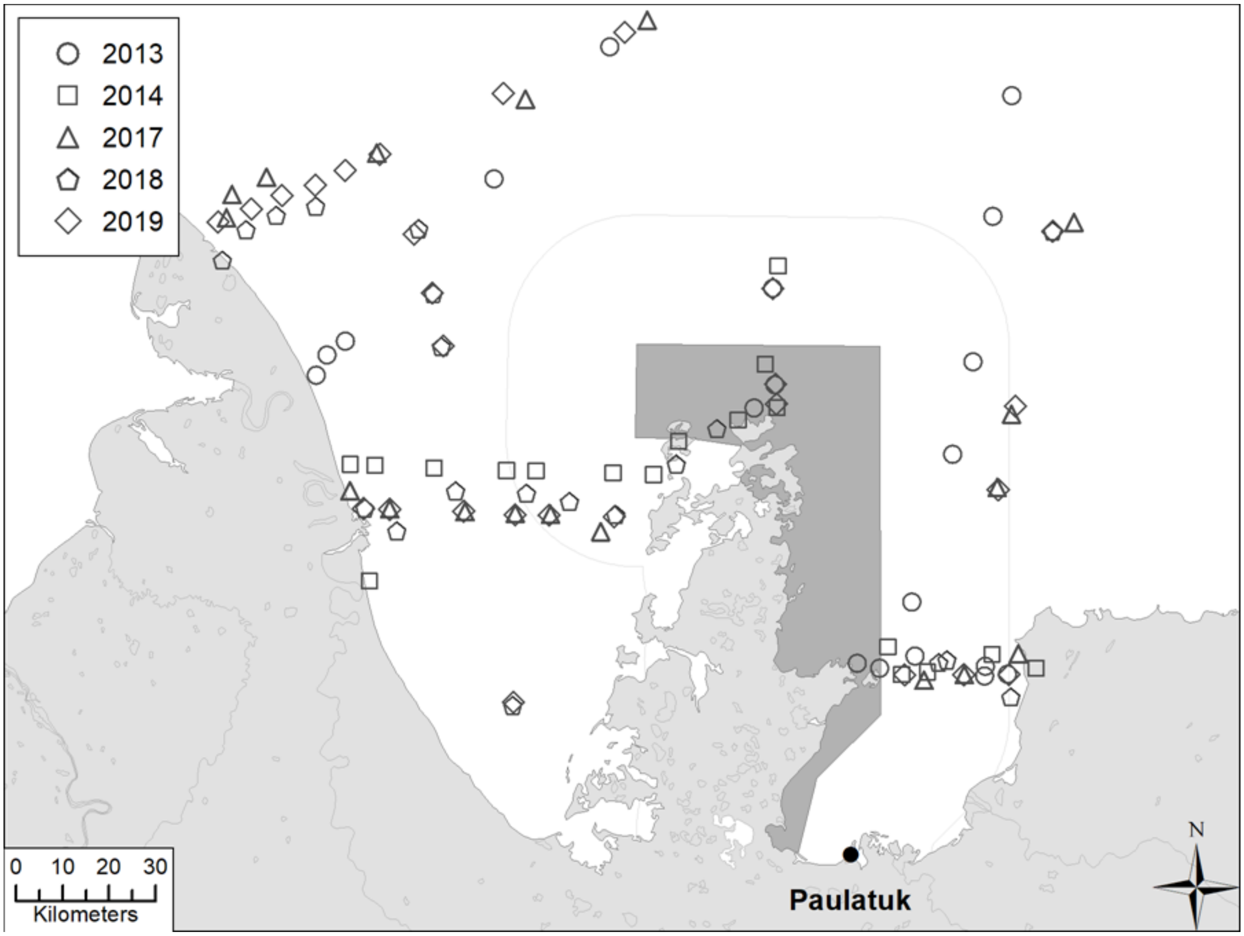


Figure 7. Stations sampled within the vicinity of the ANMPA during the consecutive ecosystem assessment programs conducted from the F/V Frosti: BREA MFP (2013), BSMFP (2014), and CBS MEA (2018–2019). Station sampling typically included full profiles for physical and chemical oceanography, water sampling for nutrient concentrations and primary production, zooplankton biodiversity, bottom sediment characterization, and bottom trawling for fish and benthic invertebrate biodiversity. Continuous hydroacoustic observations of fish and zooplankton aggregations in the water column were recorded along the ship track (not shown). A 15 nm radius around the ANMPA is shown in light grey. Map created by M. Ouellette.

Winter oceanographic measurements have only recently been collected in Darnley Bay. The Canadian Rangers Ocean Watch (CROW) expanded to Paulatuk in 2018 and 2019. CROW collected temperature, salinity, dissolved oxygen, and fluorescence data within the ANMPA at Argo Bay, and at coastal stations south and east of Bennett Point in April of 2018 and 2019. Two of the stations east of Bennett Point were consistent with locations sampled for oceanography during the CBS MEA program in the preceding summer. Water samples were collected in 2019 to measure dissolved inorganic carbon, alkalinity, salinity, nutrients, and δO^{18}. Winter sampling of temperature and salinity were collected in Argo Bay at a second date in April 2019 by the Arctic Coast program, using methods consistent with CROW (D. McNicholl, DFO, pers. comm.). The data collectively suggest that Argo Bay is hydrographically cut-off from mixing with Darnley Bay during winter, and does not received substantial input of fresh water from nearby lakes and streams (Dempsey et al. 2018, 2019). The SmartIce Program partnered with the Munaqsiyit Monitors to launch their ISR pilot in Paulatuk in January 2020, with plans to continue sampling on an annual basis. Many of the parameters collected by Arctic Coast winter monitoring, CROW, and SmartIce are similar.

Environment and Climate Change Canada has collected weather data at Cape Parry since 1956 (temperature, wind speed, wind direction) that can be used in conjunction with available oceanographic data to assess atmospheric-ocean coupling.

Oceanographic and biological (AZFP) data are available from a number of year-round moorings deployed over the last two decades in offshore regions of the Amundsen Gulf by the Institute of Ocean Sciences, CASES, CFL, ArcticNet, and CBS MEA. None were positioned close to the ANMPA, but accumulated data that may provide insight into year-round physical processes occurring in response to wind, weather, and ice conditions at a larger geographic scale.

No data on water current patterns or bathymetry are readily available for Darnley Bay, representing a significant deficit in the ability to understand or model the water circulation that governs nutrient, freshwater, and sediment delivery and distribution.

Spatial, seasonal, and inter-annual variability in the concentration of nutrients within the ANMPA and adjacent waters remain poorly characterised. Nutrients were often measured concurrently with physical oceanographic parameter profiles and indices of primary production during the CASES, CFL, NCMS, BREA MFP, BSMFP, and CBS MEA programs described above. The most consistent baseline data on nutrient concentrations within the ANMPA and adjacent waters exist for the three transects to the west, north, and east of Cape Parry sampled during August 2014, and 2017–2019 as part of the offshore programs conducted from the F/V *Frosti* (Figure 7). Albeit, the data are only for a short span of summers.

An understanding of nutrient standing stocks available for the spring bloom during late winter is lacking for the ANMPA, although limited data from distributed sampling exist. Nutrient concentrations were measured at fast-ice stations along the mouth of Darnley Bay during the CFL System Study in spring of 2008 (C. Michel, DFO, pers. comm.). Nutrient concentrations, fluorescence, and dissolved inorganic carbon were included in the suite of measurements taken by the CROW program in 2018 and 2019 (described above).

The contribution of terrestrially-derived nutrients from river discharge and/or coastal erosion remains uncharacterised in the ANMPA region (see *Section 5.5*).

5.1.2. Strategies and application

Atmospheric forcing on large geographical scales (thousands of kilometers) sets the stage for the ocean and sea-ice events and conditions encountered in Darnley Bay. Inflows to the Arctic from major rivers, from the Pacific Ocean via Bering Strait, and from the Atlantic Ocean determine the chemical properties of Arctic Ocean waters just outside the bay. Currently available data indicate that Darnley Bay is affected by physical processes occurring far beyond the ANMPA borders. However, the response of the local system to large-scale forcings can be modulated by local conditions (e.g., bathymetry, coastal geography, sea-ice extent, freshwater inputs) if they are known. Nutrient concentrations in the upper water column, and the system's ability to replenish nutrients in the euphotic zone, are important factors for primary productivity in the region. However, nutrient measurements alone will not provide readily-interpretable data on the system's productive capacity. These measurements need to be paired with biological measurements for primary producers (e.g., chlorophyll *a,* primary production; *Section 6.2*). It is recommended that field sampling programs for core oceanographic parameters and nutrient concentrations be integrated with field sampling for ice-associated, under-ice, and open-water primary producers (*Section 6.2*) and zooplankton (*Section 6.3*).

A two-tiered design for data collection at local and regional scales is recommended, consistent with standard practice for oceanographic and nutrient sampling: 1) frequent sampling (several times annually) at a small subset of localized sites within the ANMPA to capture seasonal variation and episodic events such as upwelling, and 2) less frequent sampling (once or twice annually) at a larger set of sites spread across a wide geographic area to capture broader atmospheric, sea ice, and oceanographic forcings acting at a regional scale.

For the frequent component of a sampling program, ANMPA-specific sampling would provide localized information on variability in water mass distributions and properties across the varied habitats encompassed by the ANMPA (estuarine, nearshore, offshore), and across relevant seasonal and inter-annual time scales. Careful consideration should be given to the temporal and spatial resolution provided by the sampling sites selected, as core oceanographic parameters and nutrient concentrations will exhibit spatial and temporal variability across the region. Nutrient concentrations in the southern embayment are likely to be influenced by mixing and circulation dynamics at shallow depths, draw-down from ice-associated production in fast ice, stratification from riverine freshwater inputs, and terrestrially derived nutrients. In the north near the oceanic interface with the Amundsen Gulf, nutrient concentrations are likely to be influenced by greater exposure to wind mixing and possible upwelling processes that may occur along the slopes of the central basin of Amundsen Gulf and near the recurring polynya (Barber et al. 2010). Contextual information regarding ocean-sea-ice-atmosphere interactions, sea-ice characteristics and movements, water mass structure and water movements will be important for understanding the drivers of nutrient availability across the ANMPA, which are the building blocks for ecosystem productivity.

Core oceanographic parameters and nutrient concentrations could be monitored within ANMPA boundaries by strengthening and expanding existing community-led programs (e.g., CROW, Arctic Coast) to gain information across larger seasonal and spatial scales. Many of the core oceanographic parameters recommended (Table C1) can be measured easily with a single conductivity-temperature-depth (CTD) probe equipped with the necessary sensors. Collecting water samples to measure nutrient concentrations and verify oceanographic parameters is relatively straightforward using standard practices, but requires clean methods and access to a deep freezer (-80 to -20 °C) for immediate freezing. In addition to sampling at monitoring sites, basic oceanographic measurement protocols could be introduced to community-based programs operating for other indicators to collect information in habitats directly relevant to the COs and key species (e.g., community Beluga monitors could take CTD casts at harvest locations).

For the less frequent component of a sampling program, offshore research programs should either be established or engaged to inform on large-scale physical processes that may be contributing to year-to-year variations and to changes observed in Darnley Bay. The ship-based programs that are capable of sampling in the offshore are usually equipped with the expertise and equipment needed for standardization, and operate collaboratively to serve various scientific purposes. Collaboration may be the most feasible strategy for oceanographic and nutrient sampling in the offshore. The large majority of oceanographic and nutrient data available for the ANMPA region were collected outside of ANMPA boundaries, mostly north of Bennett Point and Cape Parry at offshore locations.

Sampling locations for which intermittent oceanographic time-series already exist would be good candidates for long-term monitoring sites. Information from long-term sites would be improved with more frequent sampling across seasons, using sensors on satellites, year-round autonomous measuring instruments on submerged oceanographic moorings and possibly through comparable protocols incorporated into a community-based monitoring program (e.g., one of the offshore sampling stations from CBS MEA was sampled by the CROW program during the winter of 2019).

The strategic placement of a mooring equipped with a suite of oceanographic instruments would lengthen the seasonal record of physical and chemical observations through passive monitoring. Instruments are available to measure a suite of parameters over an annual cycle, including temperature, salinity, dissolved oxygen, fluorescence, pressure, current velocities, ice thickness, natural levels of background noise (as measured previously; Waddell and Farmer 1988, Xie and Farmer 1991, 1992), and a range of biological parameters (*Section 6*). Oceanographic moorings may be especially useful in the northern reaches of the ANMPA that are not accessed as often, where sea-state and sea-ice conditions are more challenging and where few data exist to characterise the oceanographic processes supporting the Cape Parry marine feeding area. Although passive technology on moorings is expensive, it is the cost of positioning and maintenance using an offshore vessel that dominates the expense. Moorings positioned by local community vessels would lower the cost substantially, although may be limited to shallower waters. Moorings would need to be removed from areas < 20 m deep prior to landfast ice formation in the fall.

There is a large knowledge gap concerning water circulation in Darnley Bay. An understanding of water circulation patterns that deliver and distribute nutrients, fresh water, and sediments is necessary to understand the physical processes that sustain the ecological production and capacity of the ANMPA. Current velocities, which help determine circulation patterns, are thus recommended as one of the core oceanographic variables to include in a monitoring plan. Current velocities can be measured using acoustic Doppler current profilers (ADCPs) installed on a mooring. There is growing capacity and skill to develop Darnley Bay-specific biophysical models that use oceanographic data collected through a monitoring program to estimate the chemical and physical habitat conditions that exist between sparse observations. They may also predict the effects of physical drivers (e.g., storm events, changing wind patterns, late or early ice retreat) on the system, with follow-on interpretations of the consequences for upper-trophic level animals. Modelling and monitoring together could be an iterative process, whereby the model outputs are used to inform and improve the selection of monitoring parameters and sampling locations. However, modelling efforts alone will suffer from the lack of information on currents and bathymetry. The need for bathymetry is discussed in *Section 5.3*.

5.2. ICE STRUCTURES, SNOW AND ICE THICKNESS, AND ICE BREAK-UP/FREEZE-UP TIMING

The formation, prolonged presence, and melting of sea ice and snow are defining features of Arctic marine ecosystems. The distribution, concentration, and timing of sea-ice formation and snow accumulation impart strong bottom-up influences on marine life. Ice can be either a barrier or platform for foraging (e.g., Smith 1981, Loseto et al. 2006, Asselin et al. 2011), and provide safe denning habitat for seals and polar bears (e.g., Smith and Stirling 1975, Amstrup and Gardner 1994). Similarly, sea ice during all seasons can be used as relevant habitat by marine fishes such as Arctic Cod, particularly for avoiding predators (LeBlanc et al. 2020). Thinning snow and ice in the spring can cue the onset of specific life history stages for zooplankton, fish, and marine mammals (Wold et al. 2011, Harwood et al. 2012a, Yurkowski et al. 2016b, Darnis et al. 2019). The overall length of the ice-free season determines the availability of open-water foraging for upper-trophic level animals and may constrain the period of open-water primary production. Longer ice-free seasons may benefit some species, such as marine birds, Arctic Cod, and Arctic char by allowing longer access to important seasonal foods, whereas there may be detrimental trade-offs with earlier ice break-up for ice-reliant species such as Ringed Seals. Similarly, shorter durations of spring ice presence may result in declines of under-ice primary and secondary production (see *Section 6.2*). Snow distributions and thicknesses significantly influence both physical and ecological components of the winter and spring marine environment. Snow acts as an insulating blanket on the ice, moderating the exchange of heat between the ice and atmosphere so that ice thickness is better maintained through the season and spring ice melt is delayed. Snow is typically distributed relatively evenly over smooth, first-year ice (Iacozza and Barber 1999) which dominates in Darnley Bay. However, thick drifts can build up near ice ridges and pressure cracks, providing critical denning and pup-rearing habitat for Ringed Seals, and hunting habitat for Polar Bears (e.g., Smith and Stirling 1975, Ferguson et al. 2005, Iacozza and Ferguson 2014).

At a more fundamental level in the environment, ice, snow, and ocean processes at the ice-ocean interface act as controls on the timing, distribution, and magnitude of primary production with cascading effects to higher trophic levels (e.g., Post 2017, Stige et al. 2019). Snow thickness imparts a strong control on the amount of photosynthetically active radiation that reaches sympagic primary producers within and below the ice (Welch and Bergmann 1989, Mundy et al. 2005, Campbell et al. 2015). Sea ice plays a key role in ecosystem processes. For instance, as sea ice freezes it releases dense, cold brine into the water column in a phenomenon known as brine rejection (Polyakov et al. 2013). In shallow waters, brine rejection can greatly increase salinity of underlying waters. In deeper waters, brine rejection induces density-driven convective mixing processes that thicken the top-most water layer (the Polar Mixed Layer) and replenish dissolved nutrients in the photic zone (Peralta-Ferriz and Woodgate 2015). As a result, the upper water column is primed for the next productive season. Freezing sea ice has been shown to entrap diverse protist assemblages within its structure, which survive the winter and initiate the ice algal bloom upon return of the sun in the spring (Niemi et al. 2011). The freezing sea ice has been demonstrated to selectively incorporate larger cells (> 4μm) resulting in significant differences in the taxonomic composition of protists between sea ice and surface waters as the fall season progresses (Rózańska et al. 2008). Changes in the onset of freeze-up timing in the region have been hypothesized to potentially affect protist abundance in sea ice in the spring, but not necessarily their diversity (Niemi et al. 2011). Variability and trends in sea-ice and snow phenology, extent, and thickness are thus expected to induce cascading responses across the food web. There are direct consequences for some of the valued ecosystem components and key species identified for the ANMPA that utilize sea-ice and snow drift habitats (e.g., see *Sections 6.8* and*6.11*; e.g., Laidre et al. 2008, DFO 2014, Meier et al. 2014, Hollowed et al. 2018, Steiner et al. 2019). Variability and change in the extent and duration of ice cover may have major effects on the biogeochemical cycles that fuel the marine food web. Trends towards declining summer sea-ice extent and thickness observed across the Arctic in general and particularly in the Canada Basin of the Beaufort Sea (e.g., Markus et al. 2009, Stroeve et al. 2012, Steiner et al. 2015, Galley et al. 2016, Stroeve and Notz 2018) cannot be directly applied to Darnley Bay, as it is ice-free in the summer and is dominated by first-year rather than multi-year ice in other seasons. Comparable data from the few monitoring stations that exist across Canada and the Russian Arctic indicate that coastal fast-ice thickness can be tightly linked to snow thickness, and there is evidence of only slight decline in fast-ice thickness (Dumas et al. 2005, Yu et al. 2014, Howell et al. 2016, Niemi et al. 2019, Li et al. 2020). Dedicated, local studies on Darnley Bay snow and ice trends are lacking. Monitoring snow depth and distribution, as well as sea-ice structures, thickness, and break-up/freeze-up timing in the ANMPA is recommended to provide fundamental information on potential ice trends and their potential connection to trends in biological data.

5.2.1. Available information

Indigenous Knowledge documented at a community workshop in Paulatuk in 2011 outlined the general timing, extent, and structural formation of sea ice in Darnley Bay, including the formation of rubble ice fields and leads (Kavik-AXYS Inc. 2012). Indigenous Knowledge and satellite imagery provide the most complete information available for sea-ice structures, thickness, and break-up timing in the vicinity of the ANMPA. Most other observations were intermittent or occurred in areas not directly within Darnley Bay.

Historical data on snow and landfast ice thickness were collected by the Meteorological Survey of Canada from 1959–1992 from a North Warning System station located at Cape Parry. The original data are now housed with the Canadian Ice Service (see below). During this time period, landfast ice formation typically began around late September to early October, and break-up occurred in late June to early July, with maximum thicknesses of about 1.5–2.3 m in late May (Figure 8a). Snow thickness during this time exhibited a similar trend, accumulating from about early October to early July, with maximum thicknesses typically occurring between April and May (Figure 8b). Maximum snow thickness had high interannual variability, from < 10 to > 50 cm (Figure 8b). Ice and snow thicknesses have not been measured consistently at any given location within the vicinity of the ANMPA, or across time, since 1992.

There are two primary sources of satellite-derived sea-ice data that can be accessed online or by request. The Canadian Ice Service, a division of the Meteorological Service of Canada, houses archived and recent data on sea-ice extent, concentration, and thickness in the western Canadian Arctic dating back to 1968 (available at Canadian Ice Service: Latest Ice Conditions). Ice charts that summarize the extent and concentration of sea ice in the western Canadian Arctic are available during the navigational season on a weekly basis from 1968 to present, and locally on a daily basis when ships were in the area; during the remainder of the year charts were only prepared on a monthly basis prior to 2005. Additional information regarding ice thickness and floe size was included with ice charts from as early as 1980 (through the “egg code”). Ice charts were derived from analyses of satellite imagery in conjunction with other supporting data, and were primarily produced to aid navigation for Canadian Coast Guard operations and so may not be available for all time periods, especially in the early part of the record. Daily and weekly composites of satellite images that document general ice coverage and thickness are available, as are raw ice thickness data. Detailed open-access datasets on sea-ice characteristics are additionally available from the National Snow and Ice Data Centre housed at the University of Colorado, Boulder, including information on sea-ice extent, concentration, thickness, surface temperature, and freeboard. Other data derived from models that infer ice characteristics from satellite data (passive microwave sensors) can also be obtained. Unfortunately, limitations on geographic coverage and resolution (25 km at best) of satellite-borne microwave sensors likely render these of limited value within the ANMPA. Data on sea-ice types and structures are available from optical imagery and active radar satellites (RadarSAT) at a finer spatial and temporal resolution since 1994; however, the data are opportunistic and limited to the spring through autumn period.

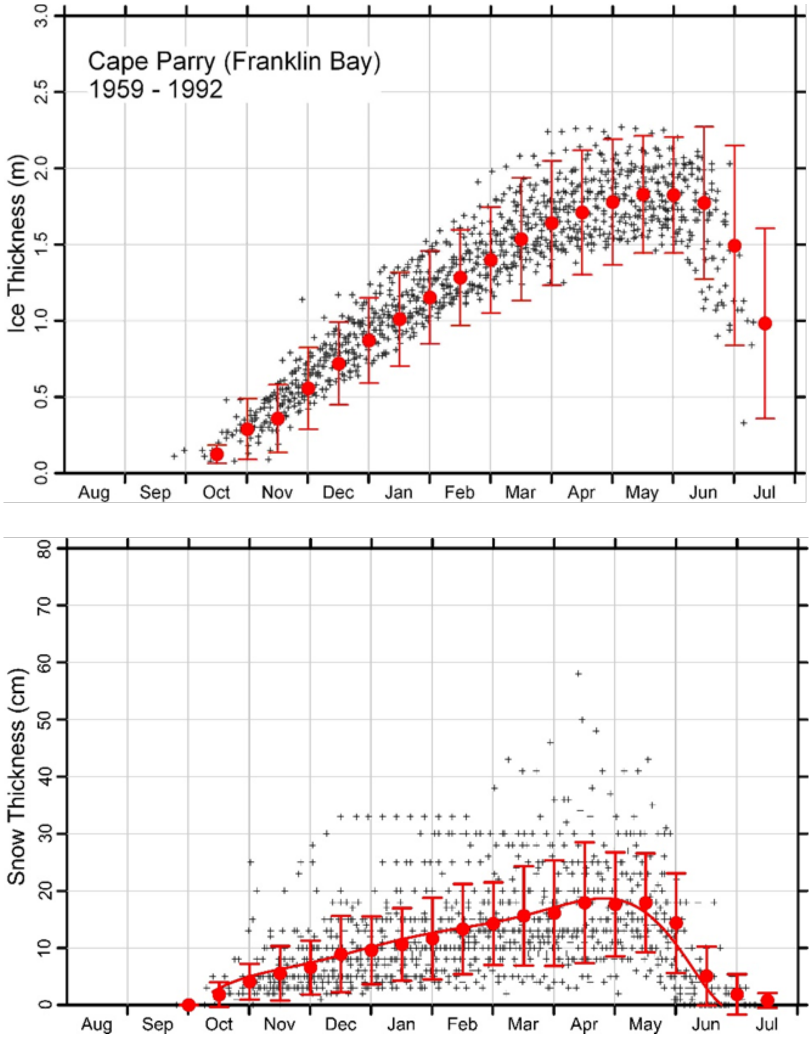


Figure 8. Time series of (a) fact-ice thickness (m) and (b) snow thickness (cm) collected from 1959–1992 by the Meteorological Survey of Canada at a North Warning System station located at Cape Parry. Figure provided by H. Melling.

Field observations of snow thickness, ice thickness, and surface roughness were made using a helicopter-borne electromagnetic sonar sensor in May 2004 during the CASES overwintering study to verify inferences made from satellite imagery by the Canadian Ice Service (Prinsenberg et al. 2008). Transects extended from the south-central Franklin Bay to north of Cape Parry. The CFL study measured ice and snow characteristics at stations along the landfast ice edges across the mouth of Franklin Bay, and to a much lesser degree, at the mouth of Darnley Bay from May-June of 2008 (Barber et al. 2010). Sampling regimes during the CFL study included measurements of sea-ice thickness, temperature and salinity profiles, and microstructure (Barber et al. 2010).

Spring sampling of ice thickness, ice freeboard, snow depth, air temperature, and the temperature at the snow-ice interface were collected within the ANMPA by the CROW program at Argo Bay, and at coastal stations south and east of Bennett Point in April of 2018 and 2019 (M. Dempsey, DFO, pers. comm.). A second location in Argo Bay was sampled in winter 2019 by the Arctic Coast program, using methods consistent with the CROW program (D. McNicholl, DFO, pers. comm.). Matching oceanographic measurements were taken at the winter sampling stations (*Section 5.1*).

Recent summaries of historical trends and model projections for the Canada Basin of the Beaufort Sea have documented a decrease in multiyear ice extent, age, and thickness over the past 20 years, and an increase in the length of the ice-free season (Steiner et al. 2015, Galley et al. 2016, Niemi et al. 2019). Mean sea-ice thickness within the central Arctic as a whole is expected to decline by a further 0.3–2.0 m, while a concomitant decrease in summer ice extent by 10–80 % could lead to ice-free summers in the coming decades. Little change in winter conditions is anticipated (Steiner et al. 2015). These projections, however, are not directly applicable to the ANMPA because of its small size, coastal location, and physical separation from the Canada Basin. Current evidence using data from the Canadian Ice Service suggests that the mean open-water season in Amundsen Gulf may have increased by about one week since 1983 as a result of later freeze-up (Galley et al. 2016). Weekly ice charts from the Canadian Ice Service indicate the timing of ice break-up in southern Darnley Bay may have become earlier by about 2.2 days per decade since 1990 (Figure 9), and freeze up may have occurred later by about 2.5 days per decade (Figure 10; H. Melling, DFO, unpublished data). Near the mouth of the Hornaday River, new ice may have formed later by about 3.4 days per decade since 1990 (Figure 10), and open water may have appeared earlier by about 0.6 days per decade, although this last value is likely not reliable (Figure 9).

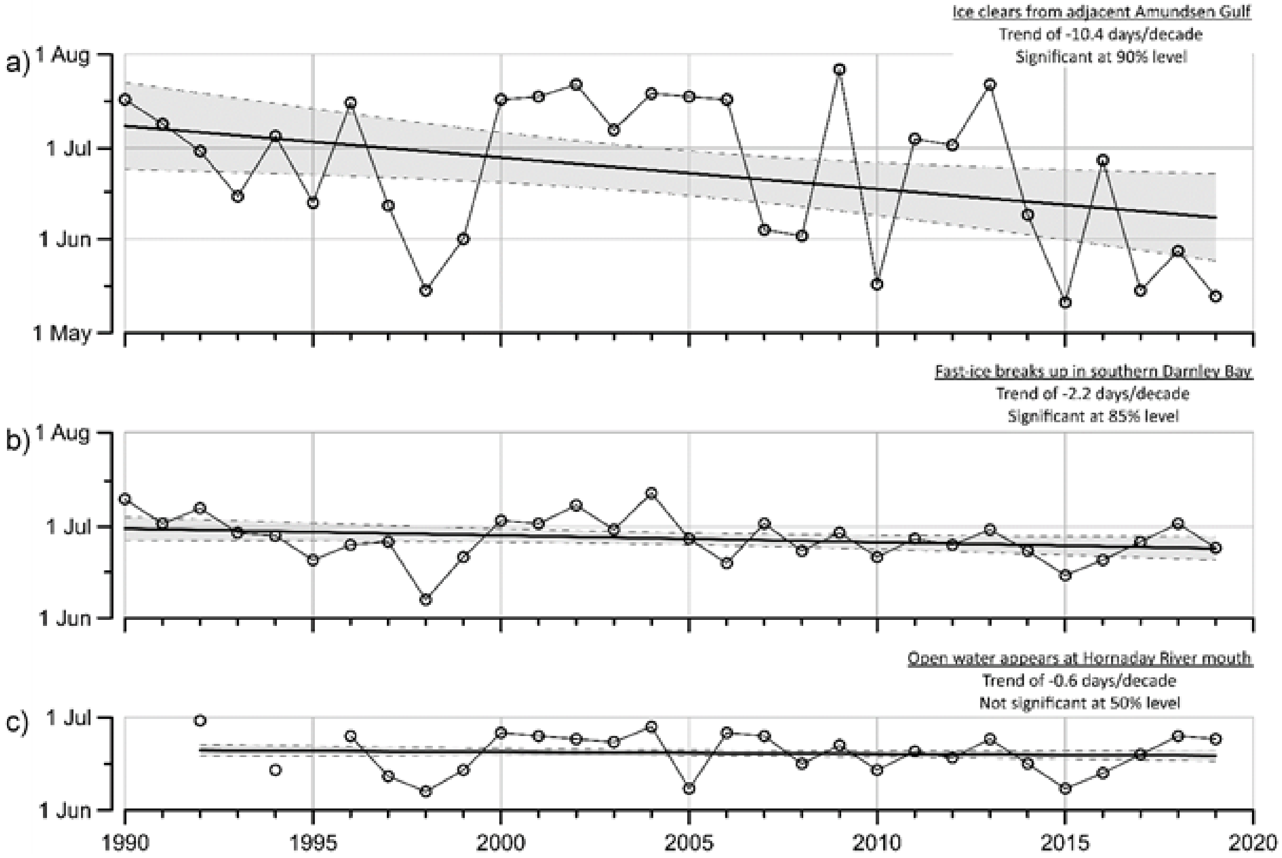


Figure 9. Timing of ice break-up from 1990 to 2019 in a) Amundsen Gulf, b) southern Darnley Bay, and c) mouth of the Hornaday River. Figure provided by H. Melling.

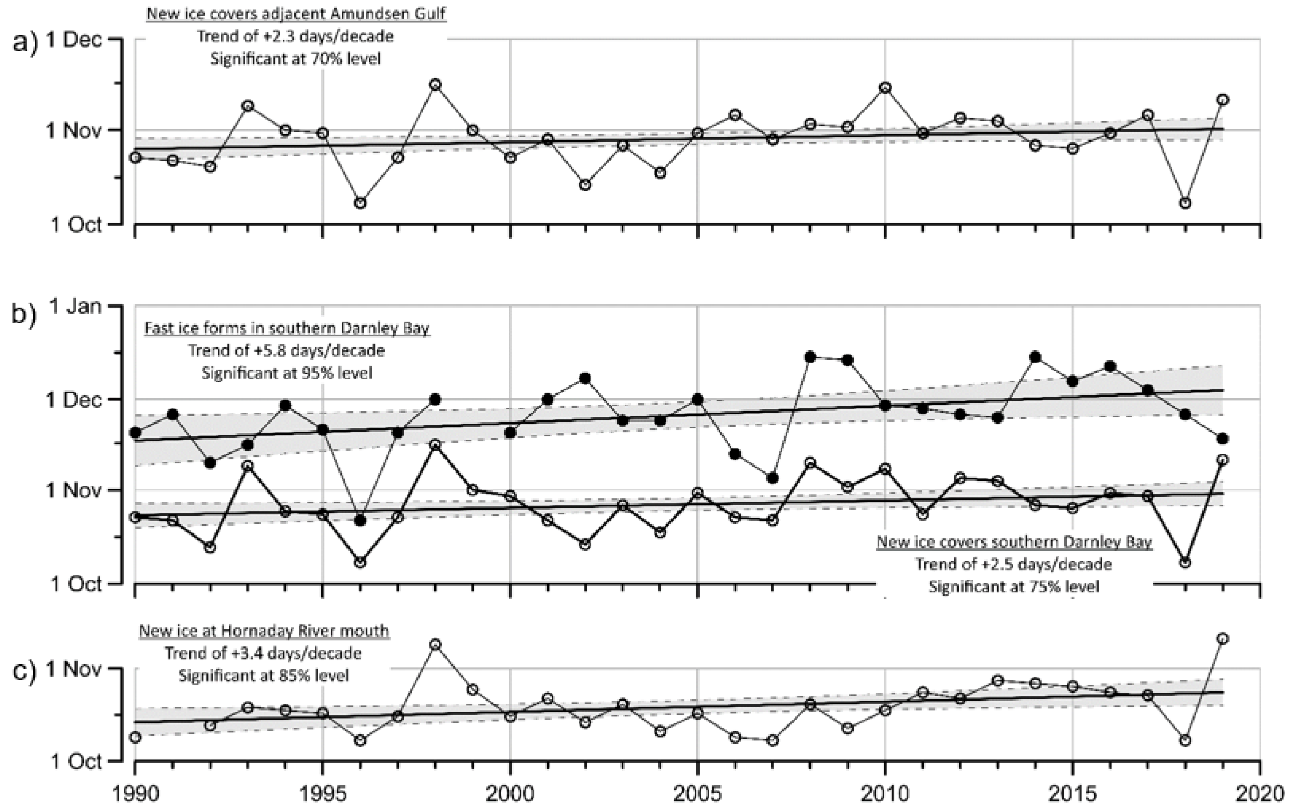


Figure 10. Timing of ice freeze-up from 1990 to 2019 in a) Amundsen Gulf, b) southern Darnley Bay, and c) mouth of the Hornaday River. Figure provided by H. Melling.

5.2.2. Strategies and application

Data on regional-scale sea-ice type, extent, concentration, and timing in Darnley Bay may be easiest to access through the Canadian Ice Service or satellite imagery. Interference from cloud cover and light availability are drawbacks for optical satellite imagery, but are not a problem for satellite imagery derived from passive or active microwave sensors (e.g., RadarSAT). RadarSat imagery can be requested for the ANMPA once per year from the National Snow and Ice Data Centre. The Canadian Ice Service archive is valuable for providing a long record of ice conditions, but has temporal gaps for the ANMPA and is coarse in its interpretation. Nonetheless, if the data are sufficient, historical break-up and freeze-up dates for the ANMPA could easily be estimated from the Canadian Ice Service archive as a baseline (e.g., Figures 9 and 10), and is strongly recommended (see below). The length of the ice-free seasons could then be calculated. Historical trend analyses of ice concentration, types, and structures could also be achieved using these existing data but are somewhat more complicated to perform. The most important structures to monitor are likely the locations and availability of snow drifts along ice ridges, which are imperative for Ringed Seal pupping.

Localized information on snow depth and distribution, and on ice thickness, structures, and thermal properties in the land-fast ice may be collected by strengthening and expanding existing community-based monitoring programs during months when surface travel is safe (e.g., CROW and Arctic Coast). Measuring snow depth along set transects is straightforward with snowmobiles and basic equipment, and provides substantial information on the biological setting in the winter and spring (snow drift habitat for marine mammals, thermal and light properties that influence ice thickness, melt timing, and ice algae production). Careful consideration must be given to the length and locations of snow measurement transects to ensure they capture the high spatial variability in snow thickness (see Appendix C). Snow and ice thickness data collected to monitor safe travel conditions (e.g., SmartICE) could be doubly used for environmental monitoring if available, but it should be noted that the towed electromagnetic sensor used by SmartICE is not accurate for measuring the thickness of ice ridges and snow drifted against them. The Munaqsiyit Monitoring Program is currently in the process of establishing SmartICE programs in each of the six communities in the ISR, creating opportunity for monitoring in both the ANMPA and TNMPA and to increase connectivity across Western Arctic MPAs. It is important that consistent or comparable methods be used if snow and ice sampling is conducted by multiple programs. Supplementary information on snow and ice structures and phenology near Paulatuk could be collected at the community level by implementing standard protocols for taking pictures and recording associated observations and metadata (e.g., descriptions of ice and snow types, observed use by animals, ice and snow characteristics and qualities as informed by Indigenous Knowledge, break-up and freeze-up timing). Pairing ice and snow measurements with oceanographic and biological measurements would optimize their potential power to explain trends in animal- and production-related indicators.

Two steps are advised for monitoring snow depth and distribution, and ice structures, break-up, and freeze-up dates in the ANMPA: 1) use historical satellite imagery and Canadian Ice Service data to analyse historical changes in ice phenology and structures as a baseline (which can be calculated by a trained community member), and 2) combine in-situ measurements from community-based monitoring with contemporary satellite imagery (RadarSAT and/or Canadian Ice Service data) to produce more accurate, region-specific data. In situ measurements are especially important for snow, as satellite data are not currently available at a useful resolution for monitoring.

Upward-facing ice profiling sonar attached to a moored oceanographic observatory can provide measurements on ice thickness and structures throughout the ice season, and on storm waves during the open water season. Similarly, moored acoustic receivers could be used to detect break-up occurrence by sound. As described in *Section 5.1*, year-round monitoring in the open ocean using moored instruments poses some challenges, including that the logistics and instruments required are expensive, positioning in offshore regions may require the use of a large vessel, and data collected from such installations are recorded internally and can only be retrieved annually. Installations in shallow waters (< 20 m) must be removed before freeze-up to prevent destruction by grounding ice. However, moored ice profilers may be especially useful for the northern reaches of the ANMPA that are accessed infrequently.

Regardless of how snow and ice conditions are measured, there are a few key considerations that will impact sampling program design and how the data are analysed. First, there are many ways to define ice break-up and freeze-up from in-situ and satellite data. An expert should be consulted to select the definitions/calculations most appropriate for the type of information desired (e.g., one definition may focus on implications for Ringed Seals, another for spring bloom progression). Moreover, there are likely to be considerable differences in break-up and freeze-up dates between the southern ANMPA (a protected embayment dominated by relatively stable, first-year ice and influenced by inputs of warm, fresh river water) and the northern region around Cape Parry (a peninsula influenced by relatively active multi- and first-year ice dynamics in the open Amundsen Gulf; e.g., see Figures 9 and 10). It may be most appropriate to determine break-up and freeze-up dates separately for sections along the north-south transition of the ANMPA, or to monitor the stability of how break-up and freeze-up patterns progress across the ANMPA. Lastly, it is important that data on ice break-up and freeze-up progression across the Beaufort Sea and Amundsen Gulf are consulted during the interpretation of data on localized ice conditions, as regional-scale ice activity will influence that which occurs in the ANMPA.

5.3. BENTHIC HABITAT DISTRIBUTIONS

Bathymetry and benthic habitat mapping are considered large knowledge gaps for the ANMPA and Darnley Bay. Depth, bottom-type, sedimentary grain size composition, and physical seafloor features influence the distributions of bottom-dwelling animals via their specific habitat preferences and requirements related to physiology, living habit, and/or life history stages. From the perspective of protection, monitoring benthic habitat distributions can provide an indication of impact from natural or anthropogenic disturbances, such as coastal erosion/slumps, dredging, grounding, anchorage, or the settling of potential contaminant spills. Knowledge of where sensitive benthic habitats are located can also inform decisions regarding where bottom-disruptive activities, such as dredging, anchorage, or scientific sampling may be permitted.

Benthic habitat assessments are, therefore, recommended as a priority prerequisite for several reasons relevant to the COs and ANMPA Working Group priorities: 1) identifying habitats that may be sensitive to specific kinds of disturbance (e.g., shipping, coastal erosion), including bottom-sampling for a monitoring program; 2) providing safe navigation and risk reduction, and improving modelling of water circulation by establishing bathymetry in Darnley Bay (see *Section 5.1*); 3) linking benthic habitat variables to benthic community compositions and distributions to understand where and why benthic food sources are concentrated for upper-trophic level marine mammals and seabirds; and 4) identifying the locations of rare habitat types that may serve specialized functions (e.g., kelp, rearing habitat for fish, rubbing rocks for Beluga).

Of secondary importance to a monitoring plan is to regularly measure benthic habitat characteristics that are directly linked to benthic food supply. Sediment composition parameters can provide insight on how and why benthic species and biomass “hotspots” and “coldspots” are distributed across the ANMPA (Grebmeier et al. 1989, Magen et al. 2010, Link et al. 2013, Roy et al. 2014, 2015, Majewski et al. 2017, Stasko et al. 2018). Areas of concentrated benthic food attract upper-trophic level predators that rely on them, especially Bearded Seals and some seabirds. In addition, measuring sedimentary proxies for benthic food supply can provide information on particle fluxes linked to the physical oceanography, primary production, and benthic-pelagic coupling that fuel the local marine food web, and which are predicted to exhibit significant shifts in response to climate variability and change (e.g., Carmack et al. 2006, Moore and Stabeno 2015). If collected, data for benthic food supply can be used in conjunction with information on water circulation and nutrient concentrations (*Section 5.1*), primary producers (*Section 6.2*), and zooplankton communities (*Section 6.3*) to develop a more holistic understanding of how the food and nutrients that fuel the base of the food web are delivered into Darnley Bay.

5.3.1. Available information

Data on benthic habitat distributions are limited for Darnley Bay, and are not sufficient to provide a credible baseline for the entire extent of the ANMPA. Outside of some local observations reported for bottom substrate types (Kavik-AXYS Inc. 2012), little to no sedimentary habitat data have been produced for the inshore ANMPA.

Surface sediment samples were collected intermittently in Darnley Bay from several offshore research programs, concurrent with trawling for benthic macrofaunal diversity. Surface sediments were collected from two stations within Darnley Bay during ArcticNet’s CFL study in the fall of 2007 and summer of 2008 (Barber et al. 2010, Roy et al. 2014); from several stations within Darnley Bay and north of Cape Parry at depths between 20 and 50 m during the NCMS in

2008 (Figure 6; Conlan et al. 2013); and from transects to the west, east, and north of Cape Parry at depths between 20 and 350 m during the BREA MFP (2013), BSMFP (2014), and CBS MEA (2019–2019; Figure 7, raw data available in Niemi et al. 2020). At a larger regional scale, surface sediment samples were collected in Franklin Bay and in the offshore Amundsen Gulf by the aforementioned programs, as well as during the CASES overwintering expedition from 2003–2004 (e.g., Renaud et al. 2007a, 2007b, Conlan et al. 2008). All offshore programs produced data on sediment grain size, organic matter content, and sedimentary elemental compositions (% C, % N, $\delta^{13}C$, $\delta^{15}N$). Extra frozen sediments are available from the latter two programs for potential future analyses. Photosynthetic pigment concentrations and fatty acid compositions were additionally measured during F/V *Frosti* and NCMS programs, respectively. Although limited, sampling indicated a predominance of silt in bottom sediments throughout Darnley Bay, and no clear spatial trends in sedimentary proxies for benthic food supply (Conlan et al. 2013, Niemi et al. 2020).

Footage of benthic habitat was taken in nearshore areas of the ANMPA using remotely operated vehicles (ROV) in Argo Bay (summer 2017, winter 2020), Brown's Harbour (2014, 2015), and Bennett Point (2014, 2019) by the Arctic Coast coastal monitoring program. Some footage documents extensive macroalgae beds present at Bennett Point and Brown's Harbour (described in McNicholl et al. 2017a). ROV observations agreed with Indigenous Knowledge habitat descriptions outlined in the Paulatuk Community Conservation Plan and with observations reported by Paulatuk residents during a traditional and local knowledge workshop held in 2012 (Kavik-AXYS Inc. 2012, Paulatuk Hunters and Trappers Committee et al. 2016). Reported Indigenous Knowledge additionally indicated marine vegetation is present in Wise Bay, is most prevalent between Paulatuk and Bennett Point, and generally grows in sandy substrate (Figure 11). Determining the extent and significance of under-sampled macrophyte habitat, and associated fishes and invertebrates, is relevant to establishing comprehensive baselines of biodiversity for the ANMPA.

Offshore sedimentary and benthic diversity data collected in the vicinity of the ANMPA have been incorporated into larger studies of how habitat drives benthic macrofaunal distributions at a regional scale (Conlan et al. 2013, Roy et al. 2014, Stasko 2017). Benthic habitat variables were significant predictors of benthic biomass, but spatial correlations were weak because localized habitat heterogeneity interrupted large-scale environmental gradients (Conlan et al. 2013, Roy et al. 2014, Stasko 2017). The results demonstrate the importance of measuring benthic habitat variables at the local scale and at a spatial extent that captures heterogeneity across the ANMPA.

The ANMPA Working Group identified bathymetric mapping of Darnley Bay as a priority for navigation, understanding circulation patterns, and interpreting biological data. No full bathymetric surveys have yet been conducted in Darnley Bay, although depth measurements and observations of bathymetric features were continuously taken with onboard hydroacoustics during the NCMS and F/V *Frosti* programs. In 2003 and 2009, the CCGS *Amundsen* produced a number of multi-beam images for detailed bathymetry at depths around 50 - 100 m in Darnley Bay, which can be accessed through the ArcticNet Ocean Mapping Group (Paulic et al. 2012). The images revealed some ice scours and relict glacial features (Paulic et al. 2012).

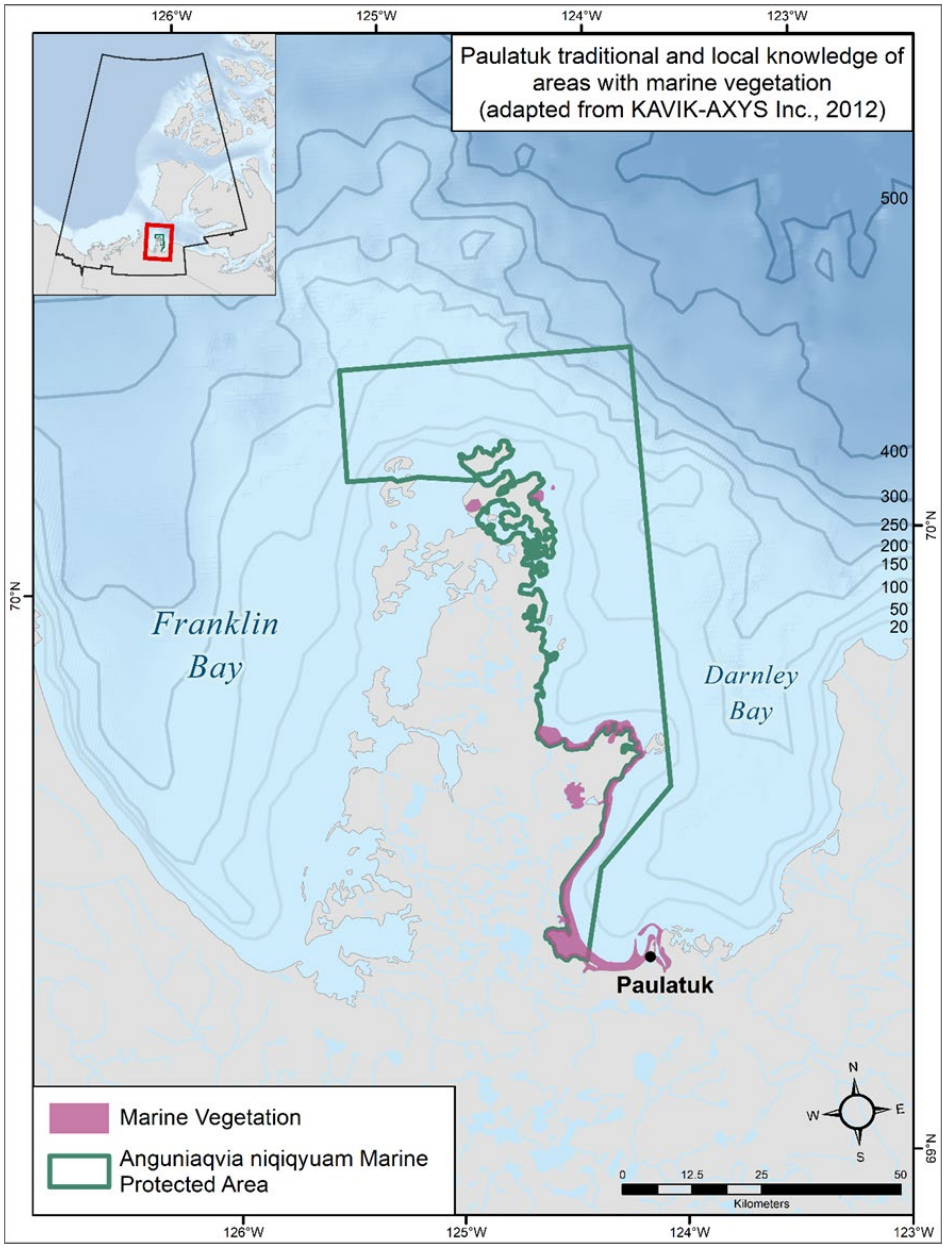


Figure 11. Locations of marine vegetation in the vicinity of the ANMPA from traditional and local knowledge gathered during a workshop in Paulatuk in 2011. Map adapted from KAVIK-AXYS Inc. (2012) by J. Friesen and provided by the ANMPA Working Group.

5.3.2. Strategies and application

Benthic habitat mapping represents a significant knowledge gap for Darnley Bay, and is recommended as a high priority under this indicator. The benthic habitat survey data that exist for Franklin Bay and the Amundsen Gulf are likely limited in their applicability to benthos in the ANMPA aside from generalizations regarding species-specific habitat associations. An initial survey to map bathymetry, bottom features, and sediment types in Darnley Bay would establish the baseline necessary to better understand the availability of different habitat types, spatial trends in benthic species distributions, water mass circulation, and, possibly, sediment movement. These types of information are foundational to designing sampling programs to monitor fish and benthic invertebrates, and for understanding the behaviours and foraging locations of upper-trophic level marine mammals and birds that prey on them.

Once established, baseline information on benthic habitat distributions could be used to design future benthic monitoring activities in two regards. First, ongoing surveys of benthic habitat and benthic invertebrate species composition (linked to *Section 6.4*) are most effective when sampling is randomly stratified across habitat types. But such a design is not possible until those habitat types and their locations have been identified. If baseline surveys find that coastal habitat characteristics are related to those offshore, it may be possible to use shoreline habitat type as a proxy for the benthic habitat type that exists directly offshore when designing a stratified, random survey. Second, baseline habitat characterisation will inform the frequency of future surveys. For example, offshore areas may be relatively stable and only require repeat habitat surveys every 5 to 10 years, whereas some coastal habitats may be deemed sensitive to dynamic processes or anthropogenic risks that require more frequent monitoring (e.g., kelp beds, areas expected to erode, high-traffic areas). In all cases, the locations of habitat mapping transects should be carefully considered so that they capture the substantial spatial heterogeneity across the ANMPA. It is recommended that the locations of significant macroalgal beds be identified as part of a baseline benthic habitat assessment.

The Canadian Hydrographic Service (CHS) may be engaged to support bathymetric surveys using LiDAR in nearshore areas (new programs required) and offshore areas (potential collaboration with CBS MEA). Bathymetric data may also be obtainable from satellite radar from the Canadian Space Agency. Physical bottom habitat features can be assessed with other non-invasive technologies such as acoustic surveys or cameras mounted to ROVs, raised benthic sleds, and/or drop-camera frames (e.g., Rooper 2008). Sediment composition and bathymetry can be non-invasively determined with multi-beam hydroacoustic surveys. Non-invasive methods for benthic habitat assessments may be best, especially for the initial baseline survey when the specific locations of sensitive habitats are still unknown. However, ground-truthing conclusions from non-invasive seafloor surveys, and measuring proxies for benthic food supply, would require collecting sediments using corers or grabs.

Benthic habitat distributions could be surveyed and/or monitored by local community members within shallower nearshore areas via benthic grabs or remotely operated cameras deployed from small vessels, and by shoreline habitat assessments. Sediment sampling in deeper habitats would likely require a larger vessel platform with winch capabilities. Specialized ROVs or sled-mounted camera systems often require specialized expertise both for deployment and for data processing to produce quantitative data from images, although they can be ultimately cost-effective and versatile if the relevant agencies/experts are engaged. Substrate mapping using remotely operated technology would thus likely be most successful in a collaborative framework.

5.4. COASTAL CHANGE

Ice-bounded sediments that form much of the Beaufort Sea coastline are experiencing accelerated rates of coastal erosion as a result of climate variability and change from two primary mechanisms (Steiner et al. 2015, AMAP 2017, Fritz et al. 2017). First, melting permafrost from warming air temperatures has decreased the stability of Arctic coasts, and made them more vulnerable to wave action. Second, the northward retreat of the summer ice pack has increased fetch, which has allowed the build-up of larger storm waves and enabled higher sea-surface temperature (Steiner et al. 2015, AMAP 2017). Increased wave action and storm surges can lead to greater coastal erosion and, consequently, substantial sediment mobilization. However, changes in the open Beaufort Sea that promote greater coastal erosion west of Darnley Bay may not have the same coastal impact in the ANMPA, much of which is protected by the Parry Peninsula from stronger west winds and consequent wave action. Both fetch and wind strength from the east have not changed substantially, since ice typically clears from Amundsen Gulf anyway. Knowledge gained from the Beaufort Sea thus cannot be directly applied to predict or understand coastal change in the ANMPA. In addition, there is substantial spatial heterogeneity in the vulnerability of the ANMPA coastline to climate-related coastal change. Most of the coastline along the exposed northern Parry Peninsula is low risk because it is dominated by bedrock and rock cliffs that are not vulnerable to thermokarst erosion by waves. The central ANMPA coastline is comprised of a mix of bedrock and permafrost (ice-bound sediments) that are at intermediate risk. The southern ANMPA shoreline is dominated by sandy beaches and low-lying tundra that may be at relatively high risk to storm surges and erosion, if storms become more frequent and wave action becomes stronger within Darnley Bay.

Coastal erosion can cause significant socio-economic concerns which are outside the jurisdiction of DFO Science, and outside the scope of this review. Here, emphasis is placed on the ecological consequences of coastal erosion in the vicinity of the ANMPA and its applicability to the COs. Large influxes of nutrients and carbon may have particularly strong impacts on Arctic embayment ecosystems where shallow nearshore zones represent a relatively large proportion of the total marine area. However, the fate of released material and its corresponding role in nearshore biogeochemical cycling remain uncertain (reviewed in Fritz et al. 2017). Released material could either fuel or dampen primary production by pelagic phytoplankton and benthic macroalgae by introducing nutrients or decreasing light transmission, respectively, with consequences for the distributions, biodiversity, and abundance of lower-trophic level biota (*Sections 6.2 and 6.3*). Deposited sediment could become buried locally rather than transported out of the bay, changing sedimentary habitat characteristics, bottom turbidity, and rates of sediment resuspension and remineralization that influence benthic community compositions and species distributions (*Sections 5.3* and *6.4*). Changes to water column and sediment properties would also have consequences for the availability of foraging and spawning habitat to coastal fishes (*Sections 6.6*, *6.7,* and *6.8*). Sediment-bound contaminants could be released into the marine environment by coastal erosion, but no data currently exist to investigate contaminant loads in terrestrial inputs to Darnley Bay or whether they pose a threat to upper-trophic level animals (*Section 7.2*).

Coastal change may thus have consequences for several of the biological indicators that can inform on the ANMPA COs. Previous science advice for ANMPA monitoring indicators did not consider coastal change (DFO 2015, Schimnowski et al. 2017), but it is recommended here for its potential to provide background environmental context that may be important for interpreting biological trends in the ANMPA.

5.4.1. Available information

Very few data exist concerning coastal stability or erosion in Darnley Bay to provide a baseline for shoreline positions, or an understanding of the potential for carbon/sediment release. Some information may be drawn from air photo mapping that occurred since the 1940’s, but such information has not yet been summarized. The published sources of Indigenous Knowledge drawn upon for this review (Appendix B) did not provide historical context for coastal erosion, which may or may not be due to their focus on ecological rather than environmental information. Historical tide and sea level data, which are relevant to storm surges, were collected at Cape Parry by the Canadian Hydrographic Service between 1966–1982 (DFO 2019).

The shorelines of the ANMPA and much of Darnley Bay were described and classified in the Beaufort Regional Coastal Sensitivity Atlas (ECCC 2015). Coastline sections were classified according to their sensitivity to oil spills using an Environmental Sensitivity Index that accounts for shoreline type, exposure to wave and tidal energy, and biological production and sensitivity

(ECCC 2015). However, the atlas did not provide a specific assessment of coastal vulnerability to erosion. CanCoast, a collection of datasets used to characterise the vulnerability of Canada's marine coastlines to climate change, did provide broad categorizations for the sensitivity of Darnley Bay to coastal change, but the data were not at a fine enough resolution to provide detailed rates of change or predictions. CanCoast classified the ANMPA shoreline as highly sensitive to permafrost thaw and erosion, whereas sensitivity along the eastern shore of Darnley Bay was moderate to high compared to other coastal areas across Canada (Manson et al. 2019). Similarly, the general Coastal Sensitivity Index indicated the coasts in the region had high to very high sensitivity to physical change from climate change and climate variability compared to other regions (Manson et al. 2019). More detailed site-specific data collections are planned as part of the State of the Beaufort Sea Assessment coastal monitoring plan, being led by Natural Resources Canada's Coastal Dynamics Activity in the Climate Change Geoscience Program.

Sankar et al. (2019) recently used aerial photography and satellite imagery to evaluate rates of change in shoreline position in Paulatuk. The study observed shoreline degradation over a long-term period from 1984–2016, and over two short-term periods that reflect changes in sea-ice and climatological patterns from 1995–2005, and from 2006–2016. The long-term rate of change for Paulatuk's coastline was relatively low compared to other Arctic shorelines, but results suggested high-intensity winds and storm events significantly altered the coastline (Sankar et al. 2019). The spatial scale of the study was restricted to Paulatuk, but may provide some insight into potential storm impacts on coastal erosion in the southern ANMPA.

Natural Resources Canada completed the first surveys of shoreline positions and erosion near Paulatuk and Argo Bay in 2019 using drones, and continued work on this project is planned in coming years in collaboration with the ANMPA Working Group, Paulatuk HTC, and Natural Resources Canada (D. Whalen, Geological Survey of Canada, pers. comm.). Data acquired from drone surveys will be used to validate satellite imagery of the region. Sampling of permafrost is planned at key sites of coastal instability in the near future to determine the geochemical signature of material that is eroded into the marine environment (D. Whalen, Geological Survey of Canada, pers. comm.). The over-arching goals of Natural Resource Canada's coastal dynamics research in the ANMPA region is to assess localized coastal change, determine erosion rates and volumes, create flood and erosion maps for the community of Paulatuk, and provide the foundational research necessary to understand carbon and contaminant flux into the coastal marine ecosystem.

5.4.2. Strategies and application

A coastal erosion vulnerability assessment in the ANMPA is still needed, as is the establishment of a baseline of "normal" rates of shoreline movement and/or degradation. There are very few recent coastal survey data available. However, a long-term assessment of the coastline at Paulatuk demonstrated that archived aerial photography and satellite imagery may be a viable option for reconstructing historic conditions (Sankar et al. 2019). Current and ongoing efforts by Natural Resources Canada to survey the ANMPA coastline and ground-truth satellite-based analyses will provide a baseline understanding of coastal degradation, but a strategy for ongoing monitoring should be developed as a follow-on product of the knowledge gained. If validation of satellite-derived coastal data is successful, access to coastal retreat data may be requested to support a monitoring plan for the ANMPA. Natural Resources Canada also plans to install a coastal observatory that could provide access to information in real-time that may be incorporated into a monitoring plan. Community-based monitoring strategies include drone surveys, visual/photographic surveys from the ground level, or measuring coastal retreat relative to markers installed inland.

As described above, the coastline of the ANMPA exhibits substantial spatial heterogeneity, transitioning from predominantly sandy beaches in the south to rocky bluffs in the north. The vulnerability of the coastline to erosion, flooding, and storm surges will be heterogeneous as well, and may require spatially distinct approaches to monitoring. It should be noted that the land is currently sinking as a result of isostatic rebound, but the rate of change locally has not been quantified. Isostatic rebound may be a consideration when interpreting change in coastal position.

Monitoring for coastal erosion should be linked spatially and temporally to monitoring benthic habitat distributions, primary production, and the community composition and abundance of inshore fishes and benthic invertebrates. The deposition of a large amount of material into the coastal domain is likely to change the physical composition of the seafloor and introduce terrestrially-derived nutrients but also decrease light transmission through the water column. These effects, in turn, would change the productivity of nearshore waters, the habitat suitability for local kelp and macroalgae, and the suitability of benthic substrates for specific benthic organisms or spawning fish.

5.5. FRESHWATER INPUTS AND TERRESTRIAL LINKAGES

The ocean and land are ecologically connected. For the ANMPA, this connection is most strongly maintained through the rivers that discharge into Darnley Bay. The rivers not only provide access to important overwintering habitat for anadromous fishes, but also deliver fresh water, sediment, and terrestrially-derived nutrients into the marine environment. Such inputs from the Hornaday, Brock, and other rivers create distinct water property gradients from the inner to outer areas of Darnley Bay (see below), establishing unique coastal habitats that benefit organisms at several levels of the food web. These freshened coastal waters in Darnley Bay function as seasonal migration corridors and foraging grounds for anadromous fishes (e.g., Kavik-AXYS Inc. 2012, Harwood and Babaluk 2014), as potential spawning and rearing habitat for some marine fishes (McNicholl et al. 2017b, 2017a), and as suitable habitat for kelp beds that are otherwise rare in the western Canadian Arctic and may support unique biotic communities (Paulic et al. 2012, Filbee-Dexter et al. 2019).

Climate-driven changes to the hydrology in adjacent terrestrial ecosystems will have direct and indirect impacts on marine ecosystems (e.g., Chavarie et al. 2019). Increases in river discharge volume, earlier freshets, and higher inter-annual variability in freshwater inputs are predicted across much of the Arctic under a warming climate (reviewed in AMAP 2017), although the extent to which the Hornaday and Brock rivers will experience changing hydrology have yet to be studied. Climate-related shifts in the timing and amount of freshwater runoff would have consequences for spatial and temporal habitat availability to anadromous, coastal, and offshore marine fishes in ANMPA waters as well as to brackish-tolerant zooplankton and benthic invertebrates (see overviews in *Sections 6.3*, *to 6.8*). For example, high growth rates in Hornaday River Arctic Char have been linked to extreme spring precipitation events, presumably because higher precipitation increased habitat connectivity between freshwater and marine habitats, and nearshore ecosystem productivity was enhanced by increased nutrient delivery (Harwood and Babaluk 2014, Chavarie et al. 2019). At a fundamental level in the food web, stronger stratification from climate-driven increases in freshwater content can push the nitracline deeper and reduce surface water nitrate concentrations (Coupel et al. 2015). The resultant nutrient limitation could affect overall primary productivity and potentially favour small-sized phytoplankton and heterotrophic bacterioplankton that are less efficient at transferring energy up the food web (Li et al. 2009, Blais et al. 2017).

Freshwater inputs and terrestrial linkages are recommended for monitoring to 1) contribute to establishing water circulation patterns within Darnley Bay (*Section 5.1*); 2) provide background context on the habitat availability and suitability for coastal and anadromous fishes, benthic invertebrates, zooplankton, and primary producers that benefit from lower salinity, higher temperatures, and/or terrestrially-derived nutrients; and 3) provide the data necessary to understand whether changing terrestrial hydrology and/or precipitation can explain changes observed in biological communities.

5.5.1. Available information

Environment and Climate Change Canada operates a water gauge installed in the Hornaday River (station 10OB001). This gauge provides monthly and annual rate of discharge for 1999–2001 and river flow rates and water levels from 2002–2009 and 2010–2021 (data available from ECCC: Hydrometric Data Search). A preliminary analysis for data available up until 2011 reported by Paulic et al. (2012) indicated the Hornaday River discharges 2.0 - 2.5 km^3 of fresh water annually, which is significant for a small embayment. Near zero flow occurs in the winter on the Hornaday River. The large majority of freshwater discharge occurs in June, during which the spring freshet begins, peaks, and declines (Paulic et al. 2012). Landfast ice is commonly still present during the spring freshet, likely causing a buoyant, brackish plume of up to 1 m deep to accumulate at the surface, under the ice, across inner Darnley Bay south of Bennett Point (Paulic et al. 2012). However, the occurrence and extent of this under-ice plume have not yet been confirmed by in situ sampling. It remains unknown how and where the brackish river plume is dissipated by wind mixing, water circulation, the Coriolis effect, and tides once the landfast ice has receded in mid-July. No flow or water level data have been compiled for the Brock River or other smaller systems in the area.

Temperature and salinity data collected by the NCMS and Arctic Coast summer programs indicated north-south and inshore-offshore gradients that are likely linked to freshwater inputs from the rivers in the south, with warmer water temperatures and lower salinities in coastal habitats at the southern, inshore end of Darnley Bay relative to northern areas and greater depths (W. Williams, DFO, unpublished data, McNicholl et al. 2017, D. McNicholl, DFO, pers. comm.).

The amount, importance, and spatial distribution of terrestrially-derived nutrients, organic matter, and sediment in Darnley Bay have not been investigated.

Precipitation data are available from Environment and Climate Change Canada from a climate station at the Paulatuk climate station (ID 2203058). Depth of snow on ground, when present, and total precipitation are measured, although the total precipitation value does not allow discrimination of snowfall from rain. The majority of precipitation occurs in the summer, with rainfall peaking in August and snowfall peaking in October (Paulic et al. 2012).

5.5.2. Strategies and application

This indicator represents an “added value” component of a monitoring plan, as it simply requires re-purposing data that are collected to inform the core oceanographic parameters and nutrient concentrations indicator (temperature, salinity, δ^{18}O, turbidity, nutrient concentrations; *Section 5.1*) and the benthic habitat distributions indicator (sediment δ^{15}N and δ^{13}C; *Section 5.3*). Contextual data for monitoring precipitation and river discharge are already collected by, and available from, Environmental and Climate Change Canada.

Characterising the magnitude and variability in the extent of freshwater plumes from discharging rivers would have particular relevance for the distributions of euryhaline fishes, zooplankton, and benthic invertebrates in the southern portions of the ANMPA. Regular sampling of core oceanographic parameters near and offshore of river mouths would help delineate general patterns in freshwater movement and mixing. Movement of fresh water can be tracked using water quality variables measured within a sampling program for core oceanographic parameters (see *Section 5.1*). In particular, temperature, salinity, and oxygen stable isotope ratios ($\delta^{18}O$) together can indicate the extent and direction of freshwater movement. Turbidity and nutrient concentrations can be used to infer how decreased light transmission and the availability of terrestrially-derived nutrients may affect spatial and temporal patterns in primary production Measurements of $\delta^{18}O$ across a broad spatial scale can be used to construct an "iscoscape," which can be viewed like a heat map to understand where the highest concentrations of fresh water occur in Darnley Bay. Sea surface temperatures and turbidity inferred from satellite images may also provide some insight into the distribution and movement of freshwater plumes.

The relative importance, spatial extent, and movement of terrestrially-derived organic matter that settles out of the river plume can be determined by measuring sediment organic matter content, stable isotope ratios ($\delta^{15}N$, $\delta^{13}C$), and carbon-to-nitrogen ratios in sediment grabs collected by a benthic habitat sampling program (*Section 5.3*). It should be noted that determining the extent and importance of terrestrially-derived nutrients and sediment are of secondary importance to determining the movement of the fresh water itself. The spatial extent of terrestrially-derived organic matter and nutrients will generally follow water circulation patterns, and while this does not provide information on how important those nutrients and organic matter are for the ecosystem, it is still somewhat informative if sampling programs are limited by logistical of financial constraints.

6. INDICATORS OF BIOLOGICAL AND FOOD WEB INTEGRITY

6.1. TROPHIC LINKS AND ENERGETIC TRANSFER

Hypotheses and/or predictions of change:

- Key upper-trophic level species will continue to be attracted to the ANMPA as long as there are prey in sufficient quantities and of sufficient energetic quality.
- Longer open-water seasons, if they occur, will change the balance of coupling between primary producers, pelagic communities, and benthic communities.
- The distributions, abundances, and energy content of forage species will change the distribution, prey selection, and health of upper-trophic level predators.

Trophic links were identified as valued ecosystem components in the ANMPA (DFO 2011, 2014), and are underscored by the ANMPA COs' focus on maintaining ecosystem productivity for upper-trophic level feeding. To monitor whether or not this objective is being met, the underlying focus across indicators must be on energy transfer and delivery. *Trophic links* are the feeding relationships that exist in the food web, which establish the pathways through which energy is transferred from primary production to top predators. *Energetic transfer* is the amount of energy that passes through a given trophic link. Many different factors can affect the efficiency of the food chain by altering trophic links and/or energetic transfers, including the raw materials available to primary producers, the specific species that are a part of the food web, their relative abundances, the palatability and ease of capturing/handling available prey species, the food quality (e.g., lipid or calorie content), and how species impact each other's populations via predator-prey interactions or competition.

As indicated in previous science advice (DFO 2015, Schimnowski et al. 2017), understanding how the ANMPA ecosystem supports key species and upper-trophic level feeding requires an examination of the consequences that food web structure, predator-prey dynamics, and foraging behaviour have on the growth, survival, and reproduction of those species. In that regard, monitoring trophic links and energy transfer can provide information relevant to several aspects of the COs. First, it can directly address the question of whether the ANMPA habitat is being maintained to provide upper-trophic level feeding, by indicating whether key species are feeding on prey that occur within the ANMPA. Second, substantial evidence suggests that the movements, distribution patterns, and group compositions of Beluga Whales, Bowhead Whales, Ringed Seals, Bearded Seals, and Arctic Char are driven, at least in part, by foraging opportunities (see overviews below and in *Section 6.11*). Monitoring trophic links and energy transfer may therefore indicate how the spatial and/or temporal availability of prey contributes to attracting different species, sexes, or age groups of upper-trophic level animals to the ANMPA, and how it influences habitat use within the ANMPA. Third, it will permit the investigation of whether trends in predator health or body condition are related to changes in prey composition, abundance, or energy density (Harwood et al. 2012b, Choy et al. 2020). Conversely, monitoring the species compositions, relative abundances, distributions, and energetic densities of prey could provide forewarning of potential consequences to key predators in the ANMPA.

It is important that trophic dynamics are not studied for upper-trophic level species only. Although studying predator diets is a starting point, the diets alone will not be able to identify *why* predator diets or the energy content of their prey change. That requires a broader look at the food web. For example, variability and change in the relative proportions of sympagic versus pelagic primary production associated with sea-ice decline will shift food web pathways for primary consumers. Negative outcomes are expected for some mid- and upper-trophic level animals, and positive outcomes are expected for others (e.g., Meier et al. 2014, Hollowed et al. 2018, Steiner et al. 2019), but predicting the outcomes requires an understanding of how the effects will cascade through the food web. For bottom-up environmental change, there is a “lag” in response time for top predators as the effects trickle up from lower trophic levels (e.g., Post 2017). This can be a particular challenge for migratory marine mammals that may have left the ANMPA before any effect is observed or which obtain the majority of their energy from outside the ANMPA. Monitoring lower trophic-level species will provide a better chance for early warnings of change.

Consequently, trophic links and energetic content are recommended to be monitored in four major food web groups to “track” effects from bottom-up or top-down: zooplankton, benthic invertebrates, fish, and marine mammals, each of which is likely to respond somewhat differently to environmental drivers at different time scales.

Knowledge on trophic links and energetic transfer can be gained through direct observations of animal feeding behaviour or stomach contents analysis, or by analysing one or a set of trophic biotracers in animal tissues. Trophic biotracers are naturally-occurring chemicals that can be used to infer the sources and/or quality of an organism’s food, and include stable isotope ratios (δ15N, δ13C, δ34S), fatty acid compositions, mercury concentrations, highly-branched isoprenoids (HBI), and lipid and calorie contents.

6.1.1. Available information

Zooplankton fatty acid signatures were measured from samples collected in the vicinity of the ANMPA during the CASES (2003–2004) and the CFL System Study (Wold et al. 2011, Connelly et al. 2012, 2014, Darnis et al. 2019). Together with recent biotracer studies of relevant fishes in the neighbouring Beaufort Sea, data confirm that zooplankton are important conduits of energy to benthic and pelagic fishes across the region (Connelly et al. 2012, 2014, Giraldo et al. 2016, 2018, Stasko et al. 2016). Zooplankton are also known prey for many benthic and pelagic invertebrates, as well as Bowhead Whales (Walkusz et al. 2012). In the ANMPA specifically, energetic densities (calorie content) were quantified for various important zooplankton prey species, including *Calanus* copepods, *Paraeuchaeta glacialis*, *Themisto* amphipods, and *Thysanoessa* krill (Lynn 2016). These species, along with *Metridia longa* have been identified as some of the most important prey for Arctic Cod and Capelin (*Mallotus villosus*) captured within and adjacent to the ANMPA (Lynn 2016, Majewski et al. 2016a, McNicholl et al. 2016).

Stable isotope ($\delta^{15}N$, $\delta^{13}C$) data are available for fishes and a broad suite of their potential zooplankton and benthic prey collected across the Amundsen Gulf during the BREA MFP program in 2012 and 2013 (Stasko et al. 2017), including those sampled within 15 nm of the ANMPA in 2014 (Niemi et al. 2020). The existing trophic biotracer data represent a wide range of feeding guilds and were used to construct the basic trophic hierarchy and relative importance of benthic versus pelagic organic matter for lower- to mid-trophic organisms sampled near the northern ANMPA (Figure 12). Mobile benthic and benthopelagic carnivores such as Eelpouts (*Lycodes* spp.) and large prawns typically occupied the highest trophic positions, whereas the lowest trophic positions were typically occupied by herbivorous zooplankton and suspension- and surface deposit-feeding infaunal bivalves (Figure 12; Niemi et al. 2020). Additional stable isotope data for fishes, zooplankton, and benthic invertebrates associated with the sampling program are forthcoming from the BSMFP in 2014 and the CBS MEA in 2017–2019 (A. Ehrman, A. Niemi, and A. Majewski, DFO, unpublished data). Fatty acid and HBI data will be available for a more limited subset of these samples. The samples, and a large archival collection, are available to anlayse additional trophic biotracers if desired, but analyses have not yet been conducted.

Although other benthic fish species represent a small proportion of the total fish abundance compared to Arctic Cod, they represent most of the remaining fish diversity (Majewski et al. 2017). Published data on the trophic structure and function of fishes in the ANMPA are still lacking for most species, although stomach contents and stable isotope data are available for some fish species from Arctic Coast summer sampling (D. McNicholl, DFO, unpublished data), BREA MFP, BSMFP, and CBS MEA as outlined above. Information on trophic and functional roles for fishes that inhabit the ANMPA can be inferred from studies recently completed in the Mackenzie River Estuary (Brewster et al. 2016) and Beaufort Shelf (Majewski et al. 2013, Giraldo et al. 2016, Stasko et al. 2016, 2017). Stable isotope and fatty acid trophic biomarkers revealed high within-species variability in the diets of several relatively abundant demersal fishes (aside from Arctic Cod), resulting in high overlap among species (Giraldo et al. 2016). Recent analyses of biotracer data from coastal fishes in the Tarium Niryutait Marine Protected Area, including several species that also occur in the ANMPA, indicated generalist and/or opportunistic feeding strategies were common, but species could be categorized into broad feeding groups that partitioned resources along the freshwater-marine and benthic-pelagic gradients (Brewster et al. 2016). These studies provide a baseline understanding of the diets of a few of the most common nearshore and offshore fishes, but the diets of the vast majority remain uncertain.

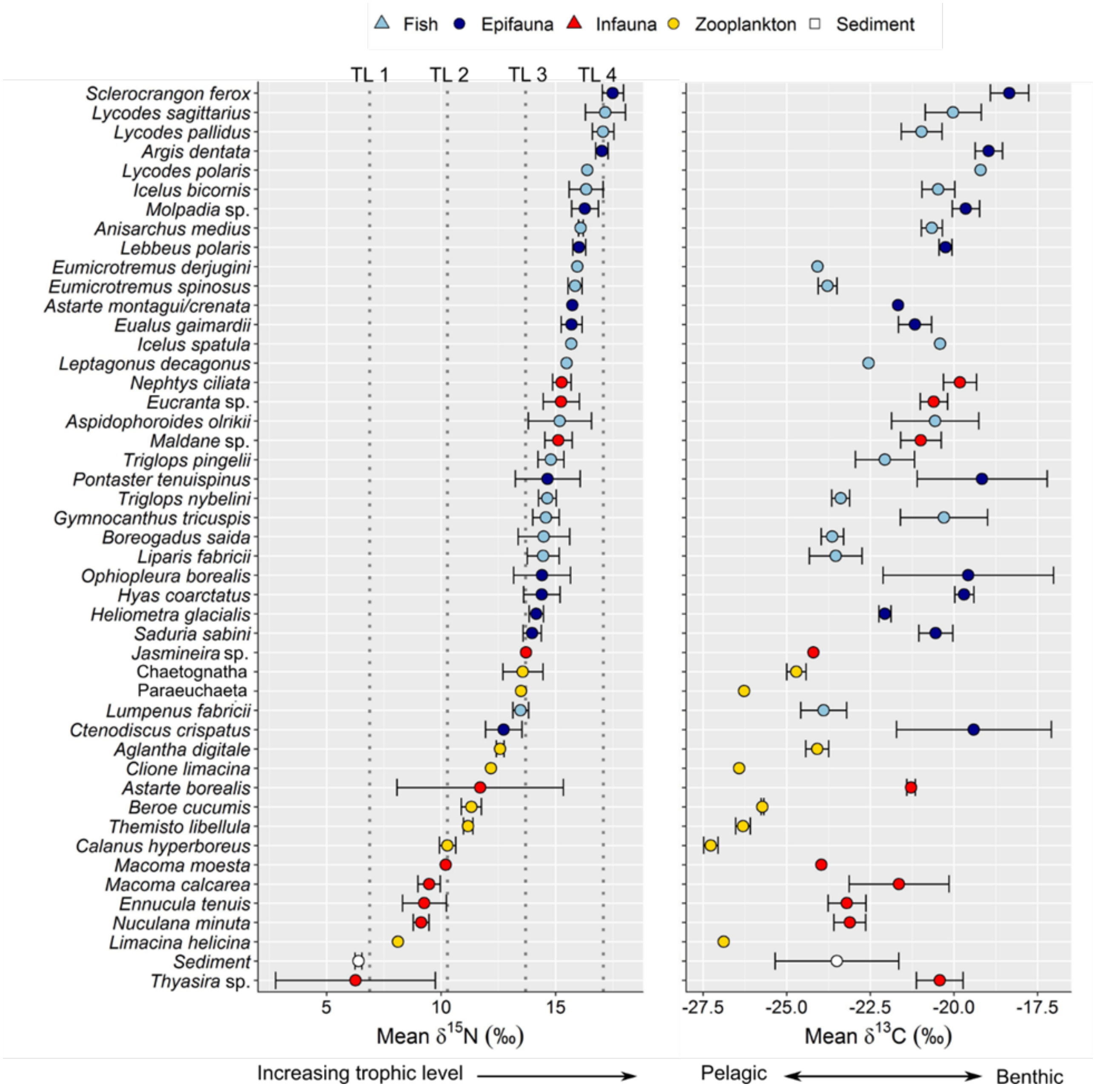


Figure 12. The mean a) δ^{15}N and b) δ^{13}C values measured in fish, epifauna, infauna, zooplankton, and sediments sampled during the 2013 BREA MFP at stations along the DAR transect that fall within 15 nm of the ANMPA. Error bars represent the mean ± standard deviation. Vertical dotted lines indicate the δ^{15}N values that correspond to estimated discrete trophic levels (TL), using C. hyprboreus as a representative baseline for TL = 2 and a trophic enrichment factor of 3.4 ‰, following Post (2002). Biota with higher δ^{15}N at a given station occupy relatively higher trophic positions. Lower δ^{13}C values suggest that the taxon relies on a relatively greater proportion of pelagic carbon sources, whereas lower δ^{13}C suggests greater reliance on benthic carbon sources. Figure courtesy of A. Ehrman, taken from Niemi et al. 2020.

Additional biological samples collected during the offshore programs conducted on the F/V *Frosti* were preserved and are available to increase sample sizes for biotracer data, or to potentially perform matching analyses of energetic densities (calorie content), mercury concentrations, microplastics, or stomach contents analyses (A. Ehrman, A. Majewski, A. Niemi,

W. Walkusz, and S. MacPhee, DFO, pers. comm.). Similarly, tissue samples are available for potential analyses from Arctic Coast for inshore fishes.

An inventory of functional feeding traits is currently being compiled for benthic fish and invertebrates that comprised the majority of cumulative community biomass observed during the BREA MFP and BSMFP (2012–2014), including stations within and adjacent to the ANMPA (Stasko 2017). Feeding traits may aid in the interpretation of biotracer data and/or with the selection of a subset of monitoring species. No data currently exist for benthic invertebrate energetics (calorie content) in the ANMPA,

Beluga Whales harvested in Darnley Bay often have empty stomachs (Loseto et al. 2009, Kavik-AXYS Inc. 2012, Harwood et al. 2015a). Observations regarding the stomach contents of harvested Beluga are available through the FJMC Fish and Marine Mammal Community Monitoring Program (see Appendix D). Indigenous Knowledge shared by Paulatuk residents via voluntary interviews and workshops indicated that Beluga in Darnley Bay are often observed in areas where there are large schools of fish between 5 to 10 cm long (Kavik-AXYS Inc. 2012, McNicholl et al. 2017b), corresponding with sizes typical of the common pelagic, schooling forage fish Arctic Cod (*Boreogadus saida*), Capelin, and Sand Lance (*Ammodytes hexapterus*). Data on mercury concentrations and dietary tracers (stable isotope ratios and fatty acid composition) are available through the Paulatuk Health and Knowledge Project for Beluga that is linked to the regional Beluga Health Research and Monitoring program. Beluga Whales harvested throughout Darnley Bay were analysed for mercury and trophic biotracers in 1993 (mercury only), 2005, 2011–2016, and 2018–2020 (L. Loseto, DFO, unpublished data, mercury pending for 2018–2020). The data have been included in assessments of spatial and temporal variation in diet, condition, habitat use, and mercury concentrations (Loseto et al. 2008b, 2009, Choy et al. 2017, 2020, MacMillan et al. 2019). Trophic biotracers are especially useful for estimating diet because empty stomachs are prevalent in harvested whales. Fatty acid analyses of whale tissues suggested that Arctic Cod from both nearshore and offshore habitats were the predominant summer prey items for EBS Beluga, followed by Capelin and Canadian Eelpout (*Lycodes polaris*; Loseto et al. 2009, Choy et al. 2020). Fatty acid analyses suggested Greenland Halibut (*Reinhardtius greenlandicus),* snailfishes (Liparidae), decapods, and other benthic prey were generally of low dietary importance, although the largest males consumed the highest proportions of both Arctic Cod and Greenland Halibut relative to all other sex and size classes (Loseto et al. 2009, Choy et al. 2020). The conclusions were consistent with the selection of deep, offshore habitat by large male Beluga Whales (Barber et al. 2001, Loseto et al. 2006) where deep-dwelling Greenland Halibut and large aggregations of adult Arctic Cod occur (Geoffroy et al. 2011, Majewski et al. 2017). Females, which typically select coastal habitat, consumed higher proportions of Capelin and lower proportions of Arctic Cod than did small- and medium-sized males (Choy et al. 2020). These observations support the hypothesis that sex- and size-driven habitat segregation during summer may be driven by energetic, physiological, and reproductive requirements (Loseto et al. 2006, 2009, Hauser et al. 2014, Choy et al. 2019). Most Beluga harvested near Ulukhaktok during the unusual occurrence of Beluga in 2014 had full or partially full stomachs, dominated by Sand Lance (found in 92% of stomachs), with much lower occurrences of Arctic Cod, Arctic Char, and other fishes (Loseto et al. 2018a). Body condition observed for EBS Beluga whales was lowest in 2014 relative to 2011, 2012, and 2013 (Choy et al. 2020). The biomass of their preferred prey, Arctic Cod, was lower in 2014 across the Amundsen Gulf and Canadian Beaufort Sea than observed in other years of the BREA MFP and CBS MEA programs, presumably as a result of low recruitment linked to late ice-off in 2013 (A. Majewski, DFO, pers. comm., Niemi et al. 2020). Although the observations did not occur directly in the ANMPA, knowledge of EBS Beluga movement responses to food availability is applicable to monitoring considerations.

The Amundsen Gulf region is considered an important summer feeding ground for Bowhead Whales, with several areas identified to support annually recurring feeding aggregations including Darnley Bay (e.g., Harwood et al. 2010, 2017b, Quakenbush et al. 2012, Walkusz et al. 2012). Bowhead Whales are thought to be attracted to Darnley Bay by feeding opportunities, based on Indigenous Knowledge shared by Paulatuk residents (Kavik-AXYS Inc. 2012) and behaviours inferred from aerial surveys (Harwood et al. 2017b). Limited data exist regarding the specific composition or availability of Bowhead prey near the ANMPA. However, data are available from nearby Franklin Bay and Cape Bathurst. Zooplankton sampling was conducted in close proximity to Bowhead feeding aggregations observed in the southeastern Beaufort Sea in 1985 and 1986, and near the Tuktoyaktuk Peninsula and Cape Bathurst in 2008 (LGL 1988 cited in Harwood et al. 2010, Harwood et al. 2010, Walkusz et al. 2012). Sampling near Bowheads in 2008 revealed dense zooplankton aggregations on shelf areas of the eastern Tuktoyaktuk Peninsula and offshore of Cape Bathurst, which were comprised primarily of resting phases of *Calanus* spp. thought to be delivered by upwelling events (Walkusz et al. 2012). Caloric analyses indicated that such a high abundance of lipid-dense copepods represented six times the energetic content of contemporaneous zooplankton samples from shelf areas further to the west (Walkusz et al. 2012). Together with subsequent evaluations of aerial and tagging data (Harwood et al. 2017b), results support the conclusion that Bowhead Whale habitat use in the Canadian Beaufort Sea and Amundsen Gulf is tightly linked to oceanographic conditions that promote the production and aggregation of their prey. Zooplankton samples were also taken in the vicinity of feeding Bowhead Whales in Franklin Bay during the BREA MFP and CBS MEA field programs in 2014, 2017, and 2019, and are available for analyses of biodiversity and, to a lesser extent, trophic biotracer analyses (A. Niemi, DFO, pers. comm.). Some of these samples have already been analysed.

Stomach contents data are available for Ringed Seals harvested for subsistence near Paulatuk, Ulukhaktok, and Sachs Harbour in the 1980’s. Data on Ringed and Bearded seal condition and stomach contents have been additionally collected from subsistence harvesters since 2015 through a collaboration with the Wildlife Conservation Society (Insley et al. 2021). Samples were collected from harvesters in Paulatuk (spring, summer, and fall), Sachs Harbour (summer), and Ulukhaktok (winter). Stable isotope data are available for Ringed Seal liver tissue harvested near Ulukhaktok between 1990–1996 (n = 18) and between 1999–2011 (n = 120; Yurkowski et al. 2016a). Results indicate that foraging was most intense/successful in the autumn and winter relative to the summer, that ontogenetic shifts to higher trophic level prey occur from sub-adults to adults, and that some regional diet specificity exists (Yurkowski et al. 2016a, Insley et al. 2021). Arctic Cod were a primary prey species, and commonly occurred in stomachs concurrently with Sand Lance, Capelin, and *Themisto* spp. (Insley et al. 2021), whereas stable isotope analyses suggested shrimp and sculpins were also important (Yurkowski et al. 2016a). Ringed Seal diets have become more diverse since the 1980’s, possibly as a consequence of the relatively recent arrival and proliferation of sub-Arctic fishes (Yurkowski et al. 2016a). Similar to Bowhead Whales, Harwood et al. (1989, cited in Paulic et al. 2012) demonstrated that summer aggregations of Ringed Seal can also be associated with oceanographic processes that promote high primary production and consequent retention of zooplankton prey. Ringed Seals may be attracted to such locations either for the zooplankton prey itself (e.g., krill), or, perhaps more likely, for the predatory pelagic fish and shrimp that may be attracted to those locations by the zooplankton.

Bearded Seals are widely considered benthic feeders, which is thought to be partially responsible for their distributions near open water (e.g., Smith 1981, Stirling et al. 1982). Limited stomach contents data are available from Bearded Seals captured in Darnley Bay in 1972 (n = 3) and 1977 (n = 3), in Sachs Harbour in 1972 (n = 25), in Ulukhaktok between 1971–1977 (n = 19, Smith 1981), and from recent community-based monitoring in Darnley Bay from 2015 to present (S. Insley, Wildlife Conservation Society Canada, pers. comm.). Stomach contents from collections in the 1970's were dominated by benthic animals, including polychaetes, snails, bivalves, squid, octopus, amphipods, shrimp, and several species of fish including Arctic Cod and sculpins (Smith 1981). Harvesters from Paulatuk reported finding squid and shrimp in the stomachs of Bearded Seals (Kavik-AXYS Inc. 2012).

Region-specific data on marine mammal diets may also potentially be available from observations recorded through the Inuvialuit Harvest Study, which was a community-based monitoring program that collected harvest information and traditional knowledge voluntarily from Inuvialuit harvesters above the age of 16 that were registered with their local hunters and trapper committees.

6.1.2. Strategies and application

Monitoring trophic links and energetic transfer is strongly connected to other indicators of biological and food web integrity outlined in this report, such that sampling can be easily incorporated into the field programs designed for other indicators. The two most straightforward strategies are to collect stomach contents and/or tissues for biotracer analyses during harvesting or sampling. Tissue collection for trophic analyses is already common practice for many existing research and harvest monitoring programs. The key considerations are to examine whether the existing sampling programs 1) collect data for the predator and prey species of interest, 2) have sufficient temporal and/or spatial coverage to test hypotheses, and 3) have sufficient matching data for prey groups to test hypotheses. As outlined in the indicators listed below (*Sections 6.2 to 6.11*), sampling programs may need to be tailored to specific areas of the ANMPA, as the spatial habitat heterogeneity across the ANMPA is likely to result in gradients in prey availability, biotracer baseline values, and prey/predator community compositions.

Determining trophic links is most effectively accomplished by direct feeding observations, stomach content analyses, and/or trophic biotracers. Direct feeding observations (video footage or reports from community members) and stomach contents analyses have the advantage of determining exactly what an organism ate, but they only reflect the last meal. Trophic biotracers measured in consumer tissues, such as lipid content, energy density (calories), fatty acid compositions, and stable isotope ratios reflect diets integrated over longer time scales and may be used to determine broader dietary patterns, trophic levels, or the use of basal carbon sources from specific food web compartments. This is especially true for species that are frequently sampled with empty stomachs (e.g., Beluga Whales, species sampled during migration and spawning activities). The utility of trophic biotracers is strengthened when measured concurrently with those in potential prey items, information on prey availability/biodiversity, and environmental parameters.

Dietary biomarkers are the easiest and most cost-effective tool for estimating diets (fatty acids, highly branched isoprenoids), relative trophic positions (stable isotopes, mercury) over a longer time period. However, like all dietary and trophic biotracers, they have substantial limitations when used alone (e.g., the inability to identify specific prey items, distinguish inter-individual variability in diet, and natural spatial and temporal variation in ecosystem baseline values). Trophic data derived from multiple methods can be layered on top of each other to build a more holistic understanding of trophic links if resources allow. Fortunately, the samples required for trophic biotracer analyses can be easily archived for later use, and the same sample can often be used for multiple analyses if there is sufficient tissue. Collecting samples for trophic biotracer and/or contaminant analyses (see *Section 7.2*) is strongly recommended even if funding is not immediately available.

Estimating energetic transfer requires estimating the relative amount of energy that a consumer derives from different prey sources. Relative abundance of prey items observed in stomach contents can provide a coarse measurement of energy transfer from different prey sources or pathways (e.g., pelagic versus benthic). Stable isotope and fatty acid data can also be used to estimate the relative diet contributions from slightly more specific sources (zooplankton, bivalves, bacteria, carnivory, etc.). Highly branched isoprenoid analyses can help determine how much energy an animal received directly or indirectly from ice algae, and may be an especially important parameter to monitor if trends are observed in sea ice. If the relative importance of different prey items is determined from any one of the methods listed above, caloric densities can be measured in prey and used to estimate the actual amount of energy they transferred to the consumer. Caloric densities can be used as one indication of prey quality, and if combined with relative biomass for prey, can be used to estimate the amount of energy available to a predator,

Monitoring trophic links and energy transfer should involve data collection at multiple trophic levels. Five primary trophic groups are recommended for a monitoring plan, which align with indicators for community composition and structure: primary producers, zooplankton, benthic invertebrates, fish, and marine mammals. Primary producers set the stage for the amount of energy available to higher trophic levels and the efficiency of energy transfer, notwithstanding the delivery of subsidies from outside the local system (e.g., organic matter delivered by ocean currents or freshwater discharges). Primary producers are intimately tied to the physical and chemical environmental conditions. The role of ice algae and phytoplankton in marine food webs can be evaluated through fatty acid biomarkers, some specific to ice algae (e.g., Kohlbach et al. 2019). For this reason, these biomarkers are important parameters for ecosystem monitoring and to assess potential changes that would impact higher trophic levels. Zooplankton are primary derived from consumers and have the shortest lifespans. They will likely respond most quickly to changes in pelagic primary production or community composition of pelagic primary producers, representing an indicator for short-term fluctuations. Benthic invertebrates are representative of benthic energy pathways, but additionally rely on the export of pelagic organic matter to contribute to sedimentary detritus. Unlike zooplankton and phytoplankton, biotracers measured in the tissues of many benthic invertebrate species do not typically fluctuate strongly with seasonal fluxes in primary production and food availability (Legeżyńska et al. 2012, North et al. 2014). Long-term datasets of trophic biotracers from benthic invertebrates, especially when coupled with community composition, will likely reflect long-term directional trends in trophic structure better than those in zooplankton. Fish are a key link between the energy produced and concentrated in lower-trophic level animals to upper-trophic animals, and can be integrators of benthic and pelagic energy sources. In each major group, a set of sentinel species should be selected for long-term trophic monitoring based on careful considerations of how the species will respond to drivers and stressors relevant to the COs, on knowledge of functional roles, and on known trophic links. When selecting a set of key species for long-term monitoring of diet composition, it is important to consider the spatial scale at which the species feeds, and how that may affect its representation of the local ecosystem. Further discussion on the selection of key species is provided in the individual sections below.

Stomach and tissue samples for dietary analyses can be collected from community-based programs developed for monitoring inshore zooplankton, benthic invertebrates, and marine and anadromous fishes. Additional offshore samples for zooplankton, benthic invertebrates, and offshore fish can be requested from offshore vessel-based research/monitoring programs. Community-based monitoring of the stomach contents of harvested Beluga Whales, Ringed Seals, and Bearded Seals would provide a basis for understanding the particular prey items consumed by marine mammals in the ANMPA. Coarse stomach contents analyses for marine mammals and fish can be conducted in the field, but detailed taxonomic analyses will require expert analyses in a laboratory setting via collaboration with researchers or hiring specialized consultants.

It is important to note that collecting data pertinent to understanding marine mammal diets reaches beyond the diet composition itself. Contextual information from other indicators, both environmental and biological, will be especially important for understanding any potential trends or unusual observations in marine mammal diets, condition, or health. Monitoring the community composition, relative abundances, and energetic content of zooplankton, fish, and benthic invertebrates will inform how the availability of different prey species influences marine mammal prey selection and, possibly, the consequences for marine mammal distributions, foraging behaviours, and health (Walkusz et al. 2012, Yurkowski et al. 2016a, Harwood et al. 2017b, Loseto et al. 2018, Insley et al. 2021).

Environmental parameters are key complementary data. For example, oceanographic and benthic habitat characteristics affect the distributions of key zooplankton, macroinvertebrate, and fish prey based on their species-specific preferences, tolerances, or life history. Advective currents and upwelling can concentrate zooplankton prey via physical displacement or by triggering algal bloom events that enhance secondary production. Sea-ice characteristics and phenology are similarly linked to nearly every aspect of the lower-trophic food web that supports marine mammal prey, including prey life history and reproductive strategies, feeding opportunities, predator-prey dynamics, and the transfer of energy between sympagic, pelagic, and benthic compartments of the ecosystem. Ideally, a monitoring program would collect sufficient information to be able to track cascading relationships through the food web and connect them to prevailing, potentially causative environmental conditions.

6.2. ICE-ASSOCIATED, UNDER-ICE, AND OPEN-WATER PRIMARY PRODUCERS

Hypotheses and/or predictions of change:

- The timing, distribution, and magnitude of primary production (and primary producer composition) will be influenced by a complex interplay of light and nutrients which, in turn, will be influenced by variability and change in snow, ice, coastal, and oceanographic processes.
- Changes in the timing of ice algae and phytoplankton blooms are likely to result in a mismatch between the availability of algae and zooplankton grazers with potentially significant effects on the energy transfer to higher tropic levels.
- Harmful algal blooms are likely to become more frequent with warmer ocean temperatures.

The Arctic provides a unique habitat for phytoplankton communities due to the pronounced seasonality in environmental conditions including light and nutrient availability, and the presence of sea ice (Sakshaug 2004, Ardyna et al. 2011, Tremblay et al. 2015, see also *Section 5.2*). These unique conditions lead to the presence of two types of primary producer communities, those that thrive in the ocean (phytoplankton) and those that thrive in the sea ice (ice algae). They both play an essential role in the transfer of energy and materials (including contaminants and toxic algal blooms) to the food webs and determine the productive capacity of the overall ecosystem.

Primary producers use light and energy (from nutrients, see *Section 5.1*) to build organic matter. Therefore, these two simple parameters are fundamental to primary production and marine food webs. However, these simple parameters and the response of primary producers to their behaviour, vary in complex manners. Nutrient supply, in particular nitrate (NO_3^-), but also other nutrients remineralized by bacterial action on the shallow shelves, constrains overall primary production, whereas light availability modulates the productive period and can also impact seasonal production (Tremblay et al. 2015). Factors that influence light availability go well beyond the presence of the snow-covered sea ice and include, for example, suspended sediments and other particles, and stratification which constrain (or not) phytoplankton cells in the surface layer. Monitoring ice-associated, under-ice, and open-water primary producers is fundamental to understanding the structure and functioning of the ecosystem, its productive capacity and energetic transfer to higher trophic levels. Consequently, key indicators of primary production are necessary for evaluating the status of the ANMPA COs (i.e., that the marine environment is *productive* and allows for higher-trophic feeding).

The return of daylight to the Arctic in the spring, together with thinning ice and snow cover, trigger the growth of ice algae within sea ice, fueling a lower-trophic community of ice-associated micro- and meio-fauna, and under-ice copepods and amphipods (Michel et al. 1996, 2002). A large amount of ice algal biomass accumulates over the growing season and most of this biomass is released into the water column at the time of ice melt, where it fuels zooplankton communities (Michel et al. 1996) or sinks to the seafloor where it fuels benthic communities (Renaud et al. 2008, Kohlbach et al. 2019). The balance between these two pathways is influenced by oceanographic processes and climatic events that influence sea ice melt in spring (Michel et al. 2006), affecting energy transfers to higher trophic levels. As the sea ice retreats, ice-edge and open water phytoplankton blooms develop in the surface lit ocean layer. Phytoplankton blooms also develop under the ice when conditions allow, for example with early snow melt (Fortier et al., 2002). The declining sea-ice cover in the Arctic further indicates that underice phytoplankton blooms may become more frequent which would change the seasonal dynamics and availability of nutrients for the subsequent open-water bloom (Horvat et al. 2017). The subsurface chlorophyll maximum (i.e., the depth at which maximum chlorophyll *a* biomass is found) becomes progressively deeper over the season as nitrate is depleted in the upper water column, which is characteristic of the southeastern Beaufort Sea and the Amundsen Gulf region (Martin et al. 2010). Polynyas, such as that near the northern ANMPA, provide sites where wind-driven upwelling can occur and trigger massive pelagic phytoplankton blooms near the ice edge (Mundy et al. 2009).

Aside from fuelling the pelagic food web, primary production by phytoplankton and ice algae has a strong influence on benthic food supply through benthic-pelagic trophic coupling (Grebmeier and Barry 1991, Cochrane et al. 2009, Link et al. 2013). The export of organic material from the euphotic zone to the seafloor, including fresh ice algae, phytoplankton, and fecal pellets is an important source of organic material for benthic communities from spring to fall in the coastal and offshore Beaufort Sea (e.g., Renaud et al. 2007, Juul-Pedersen et al. 2008a,b, 2010, Forest et al. 2001, Sallon et al. 2011). Benthic algae also contribute substantially to local production in nearshore areas where light reaches the seafloor, despite being minor sources relative to phytoplankton and ice algae at the regional scale (Oxtoby et al. 2016). The contribution of benthic algae to primary production in the ANMPA is unknown.

The timing, source, magnitude, and spatial extent of production can be indicative of broader shifts in atmosphere-ocean interactions and sea-ice regimes, linked to climate variability and change (*Sections 5.1* and *5.2*). In shallow coastal areas such as in the ANMPA, the influence of coastal erosion and resuspension can be important. As in many other regions of the Arctic, recent increases in primary production have been observed in the Beaufort Sea associated with declining sea ice, longer open water period, and more favorable conditions for wind-driven upwelling (Mundy et al. 2009, Tremblay et al. 2011, Steiner et al. 2015, reviewed in AMAP 2017). Recent global model simulations for the Arctic indicate high variability in the response of ice algal production to anticipated changes in sea ice (Tedesco et al. 2019). However, it remains unclear whether similar increases in primary production are occurring in Darnley Bay as no studies on this topic have been conducted in the area.

Moreover, changes in phytoplankton and ice algae community structure alter energy transfer efficiency up the food web (reviewed in Tremblay et al. 2011). Large-sized diatoms tend to dominate phytoplankton communities in highly productive regions and are directly consumed by herbivorous fish and zooplankton, fostering efficient transfer of primary production to secondary production (Sampei et al. 2011, Forest et al. 2011). Stronger stratification driven by increases in freshwater content can isolate the productive surface layer from deeper nutrient inventories, pushing the chlorophyll a maxima downward and favouring small-sized phytoplankton cells that are better adapted than larger cells to low nutrient conditions (Li et al. 2009, Coupel et al. 2015, Blais et al. 2017). The degree to which primary production in the ANMPA and adjacent waters responds to physical and climatic forcings will vary spatially across the transition from fresher, shallower, and more sheltered waters in the south, to deeper, more saline waters in the north that are exposed to the open Amundsen Gulf and presumed upwelling/downwelling at the shelf-break. Year-to-year variability in primary production will remain linked to variability in ocean-sea ice-atmosphere interactions (see above).

6.2.1. Available information

Substantial information on primary production and primary producer community composition in the offshore areas of Amundsen Gulf, Franklin Bay, and Darnley Bay has been collected in the past two decades and provides some insight on general levels of primary production in the region. Data collection within or directly adjacent to the ANMPA, however, has not occurred on a continuous basis at locations consistent enough to characterise a reliable baseline for the region and thus represents a distinct knowledge gap.

The Marine Productivity Laboratory at the Freshwater Institute (DFO) has collected data on lower-trophic level ice-associated, under-ice and open-water biota within a 100 km radius of the ANMPA since 2002, including: indices of biomass/standing stocks for ice-associated and open-water lower-trophic level biota and primary production (total and size-fractioned chlorophyll *a*, dissolved organic carbon, dissolved nitrogen, particulate organic carbon, and particulate organic nitrogen); indices of food web function and biodiversity (abundance, functional group composition, and biodiversity of bacteria, phytoplankton, and heterotrophic protists); indices of toxin-producing algal species and their toxins (phycotoxin concentrations and toxic algae species in bivalves; Pućko et al. 2019); indices of food web linkages (fatty acid and stable isotope analyses of suspended matter); and estimates of benthic-pelagic coupling (sinking export of organic material below the euphotic zone from sediment traps). Samples were consistently collected in conjunction with oceanographic measurements to provide contextual information on physical forcings that determine the distribution and composition of lower-trophic level biota. Various combinations of the data types listed above were collected as part of the CASES (fall of 2002 and overwintering from 2003–2004), the CFL System Study (fall 2007, and overwintering into 2008), the NCMS (2008; Figure 6), and during the BREA MFP, BSMFP, and CBS MEA (2013, 2014, 2017–2019; Figure 7). Samples collected during the CASES and the CFL System Study included some of the only winter time observations of phytoplankton and microbial biodiversity and community composition available within the vicinity of the ANMPA. Data collected through these programs shed light on the spatial and temporal variability in biological standing stocks, community composition, and biogeochemical properties that contribute to sympagic and open-water production at a regional scale (e.g., Riedel et al. 2007b, Rózańska et al. 2009, Shadwick et al. 2011, Tremblay et al. 2011, Niemi and Michel 2015, Niemi et al. 2015), trophic structure and dynamics at the base of the sympagic and pelagic food webs (e.g., Riedel et al. 2007a, Forest et al. 2011), regional processes that control benthic-pelagic coupling through the retention and downward export of organic matter produced in the upper water column (e.g., Juul-Pedersen et al. 2008a,b, 2010, Kellogg et al. 2011, Sallon et al. 2011), and the contribution of ice-edge upwelling to under-ice phytoplankton blooms (Mundy et al. 2009). Further analyses of spatial and temporal variability in primary producer functional and species diversity using offshore datasets collected near the ANMPA are forthcoming.

CROW collected temperature, salinity, dissolved oxygen, and fluorescence data within the ANMPA at Argo Bay, and at coastal stations south and east of Bennett Point in April of 2018 and 2019. Two of the stations east of Bennett Point were consistent with locations sampled for oceanography during the CBS MEA program in the preceding summer. Water samples were collected in 2019 to measure dissolved inorganic carbon, alkalinity, salinity, nutrients, and $\delta^{18}O$ (an indicator of freshwater inputs).

Detailed open-access datasets on ocean colour are available for research purposes from NASA (NASA Earth Data: Ocean Color Data), from which surface chlorophyll *a* concentrations can be estimated.

6.2.2. Strategies and application

Incorporating ice-associated, under-ice, and open-water primary producers into a monitoring plan is essential to support the ecosystem-based approach to monitor the ANMPA COs. Biomass/standing stocks of primary producers provide important information on the productive capacity of the ecosystem, and can be informed by measuring chlorophyll *a* concentrations (total and/or by phytoplankton size fractions) and/or by using fluorescence measured from a CTD as a proxy for chlorophyll *a*. Fluorescence measurements provide relative values that can be compared over a season to provide important real-time information such as the timing of algal blooms. Shifts in the timing of the spring bloom, for example, have important consequences for energy transfer through the food web. Secondarily, particulate organic carbon and nitrogen are important parameters for understanding the food web consequences of the primary producer community. Particulate organic carbon indicates the amount of carbon transformed into a more bioavailable form of food that can potentially be used by upper trophic levels. Particulate organic carbon can also be used for modelling carbon cycles and movement through and ecosystem. The C:N ratio, calculated from both particulate organic carbon and nitrogen, can indicate a shift in species composition or in the quality of food available to grazers. Third, measuring the taxonomic composition of primary producers is essential to assess lower-trophic level food web structure and function (determinants of energy transfers to higher trophic levels), species range expansions, or the detection of key indicator species. Detecting shifts in the species assemblages may serve as early indicators for concern, such as increasing abundance of species that can, under specific conditions, produce harmful marine toxins (Pućko et al. 2019), with important consequences for upper trophic level animals and food security for communities. Video-based flow cytometry technologies (e.g., FlowCam®) could be investigated, as they may provide some information on primary producer community abundance and structure at a reduced cost compared to taxonomic composition analyses. However, they should not be considered a replacement for conventional taxonomy.

It is important to note that annual rates of primary production are difficult to estimate due to high inter-annual and spatial variability. Monitoring indicators of primary production would provide the most complete information when monitored across the productive season, and using a suite of standard available methods. Concomitant measurements of physical and chemical oceanographic parameters such as temperature, salinity, $\delta^{18}O$, and dissolved nutrients are necessary for providing background context on water mass distributions and the oceanographic habitat for primary producers. Ideally, sampling for this indicator would coincide with sampling for core oceanographic parameters and nutrient concentrations, and mirror the two-tiered sampling approach recommended in *Section 5.1* wherein sampling occurs multiple times per year at a few key sites, and once per year at a larger network of stations distributed across a wide geographic area.

In parallel with traditional scientific programs, community-based programs could be developed to monitor indicators of primary production in areas that are accessible at regular time intervals throughout the productive period (spring to fall). For example, ice-associated biota can be sampled by collecting ice cores. Such methods could be incorporated into existing programs, such as CROW or Arctic Coast. Under-ice and open-water primary producers could be collected using water samplers deployed through the ice or from small vessels in shallower waters, ideally coupled with real-time fluorescence measurements. Fairly straightforward procedures for collecting and preserving samples for chlorophyll *a* and taxonomy, or for using fluorometer sensors, may be incorporated into community-based monitoring programs for nearshore areas. Collecting water from offshore areas in the open-water season may require collaboration with vessel-based programs, and should be coordinated with coastal sampling programs. Sediment traps could be used to collect important information on the vertical export of particulate organic matter from the upper layers of the water column, and provide estimates of benthic-pelagic coupling.

In addition to distributed sampling conducted at the community-level and from larger vessels, remote sensing data from satellite imagery could be used to derive estimates of surface chlorophyll *a* concentrations from ocean colour in ice-free areas. However, phytoplankton occupying deeper sub-surface chlorophyll maximum layers can account for up to 50 % of annual new production and may be difficult to detect by remote sensing (Tremblay et al. 2008, Martin et al. 2010), and suspended sediments in nearshore areas can make remote sensing estimates unreliable. Therefore remote-sensing data need to be paired with in situ measurements. Appropriate algorithms, such as those specifically developed for suspended matter in the coastal Beaufort Sea, should be considered (Tang et al. 2013). Data analyses and modelling procedures required to use remote sensing are time intensive and require specialized expertise, but are also cost-effective. Moored oceanographic instruments equipped with biologically relevant sensors could be employed in areas that are deeper and/or more difficult to access, and provide observations across a longer and more continuous time period than distributed sampling. Moored profilers, as opposed to fixed-depth moorings, are preferable to obtain essential biological data in the upper water column throughout the year because primary production takes place in the surface water layers where light penetrates.

Monitoring ice-associated, under-ice, and open-water primary producers is tightly linked to monitoring core oceanographic parameters and nutrient concentrations (*Section 5.1*), sea ice and snow (*Section 5.2*), and zooplankton community composition, structure, and function (*Section 6.3*). Readers are encouraged to consult the other relevant sections for a broader view of how these inter-linked indicators provide complementary information and can/should be collected together.

6.3. ZOOPLANKTON COMMUNITY COMPOSITION, STRUCTURE, AND FUNCTION

Hypotheses and/or predictions of change:

- With warming conditions, there will be an increase in gelatinous zooplankton species.
- Changes to sea-ice duration and extent, and to core oceanographic parameters, could result in a shift to smaller species with potentially negative effects on the energy transfer to higher trophic levels.

Zooplankton represent the most important primary and secondary consumers in the Arctic marine ecosystem. Zooplankton consume and concentrate organic matter and primary production at the base of the food web into forms that are easily transferred to higher trophic levels, and are a dominant food source for Arctic Char, Ringed Seals, Bowhead Whales, some seabirds, and for the forage fish that sustain many marine mammals. Consequently, changes to zooplankton community composition, structure, and function can exert a bottom-up influence on higher-trophic animals.

Zooplankton community composition, structure, and function can be indicative of changes to broader environmental drivers because of their close link to habitat conditions. Zooplankton can also signal the status of primary producers because of their direct reliance on algal food sources. Large, herbivorous copepods comprise the majority of zooplankton biomass and are some of the most important zooplankton prey due to their high lipid content, including *Calanus glacialis*, *Calanus hyperboreus*, and *Metridia longa,* whereas amphipods and krill are important prey because their larger size provides greater calories per meal (Lynn 2016). Some zooplankton remain active throughout the winter, feeding opportunistically on sympagic algae and other zooplankton. Others, such as *Calanus* species, undergo seasonal vertical migrations that are triggered by light and food availability. *Calanus* species are able to amass lipid reserves exceeding 60 % of their dry mass by grazing on diatom-dominated sympagic and pelagic algae during spring and summer, necessary to survive up to 10 months of fasting during overwintering (Falk-Petersen et al. 2009). Zooplankton thus tend to proliferate in areas where environmental conditions are most suitable to their species-specific depth and temperature preferences, and where algal food is abundant, and in turn, attract predators. As a result, zooplankton community composition and trophic structure can reflect algal bloom progression and primary producer community composition (e.g., Basedow et al. 2010, Darnis et al. 2019), as well as the environmental conditions driving primary production (Darnis et al. 2008, Walkusz et al. 2012, Post 2017, Smoot and Hopcroft 2017).

Monitoring zooplankton community composition could identify new species introduced by climate-induced range expansions and/or vessel traffic (see *Section 6.9*). Zooplankton community composition can also be used to monitor the relative abundance of native species, either those that are expected to increase due to climate change (e.g., gelatinous zooplankton Brodeur et al. 1999), or those sensitive to threats such as ocean acidification (e.g., pteropods).

The community composition, structure, and function of zooplankton communities are relevant to evaluating the status of the ANMPA COs because changes in taxonomic or functional composition can 1) affect the efficiency of energy transfer to highly valued marine mammals, seabirds, and predatory fish because zooplankton are the most important source of food for their forage fish prey, 2) be indicative of changes to broader environmental drivers, and 3) respond to anthropogenic disturbances.

6.3.1. Available information

Data availability for zooplankton community composition in the ANMPA and adjacent waters is similar to that described for parameters of primary production and nutrient concentrations in *Sections 5.1* and *6.2*. Relevant data were collected during the CASES, CFL, NCMS, BREA MFP, BSMFP, and CBS MEA programs in conjunction with measurements of oceanographic properties and nutrient concentrations.

Samples collected during the CASES (fall of 2002 and overwintering from 2003–2004; Figures 6 and 13), the CFL System Study (fall 2007, and overwintering into 2008; Figures 7 and 13) included some of the only winter time observations of zooplankton biodiversity available within the vicinity of the ANMPA. Together, community composition data from these programs shed light on regional species inventories, distributions, processes contributing to the seasonal succession of zooplankton species, and responses of zooplankton to shifts in the timing and composition of primary producers (e.g., Darnis et al. 2008, 2012, 2019, Rózańska et al. 2009, Tremblay et al. 2011, 2012, Forest et al. 2011, Darnis and Fortier 2014, Leu et al. 2015). Although most conclusions from the CFL System Study and CASES were not drawn specifically for the ANMPA, the knowledge gained for zooplankton biodiversity in the southern Beaufort Sea and Amundsen Gulf may place data from the ANMPA in context. For example, analyses of zooplankton community composition collected during the CASES in the fall of 2002 indicated that mesozooplankton biomass was higher in Franklin Bay and along the west side of the Parry Peninsula relative to the offshore Amundsen Gulf and Beaufort slope (Darnis et al. 2008). Species composition in Franklin Bay was similar to that on the Beaufort Shelf, and similar onshore-offshore gradients in species composition were observed in both areas, coincident with depth and reduced ice cover towards the Cape Bathurst polynya (Darnis et al. 2008). Similar onshore-offshore gradients in species composition may exist in Darnley Bay. Moreover, there is potential for zooplankton to be advected into Darnley Bay from adjacent area by strong currents or wind-generated energetic events (upwelling/downwelling, strong surface currents; see *Section 5.1*).

Measurements of zooplankton community composition, structure, and function specific to the ANMPA and immediately adjacent waters are limited mostly to northern, offshore regions in the ANMPA sampled within a relatively narrow summer time frame. Datasets/samples of zooplankton community composition and, to a lesser extent, stable isotope values ($\delta^{15}N$, $\delta^{13}C$) are available from the NCMS, BREA MFP, BSMFP, and CBS MEA programs for northern Darnley Bay, Franklin Bay, and north of Cape Parry (Figures 9 and 10; Niemi et al. 2020, W. Walkusz and C. Michel, DFO, unpublished data). Auxiliary data associated with the samples include oceanographic profiles of temperature, salinity, dissolved oxygen, flurorescence, oxygen isotopic composition ($\delta^{18}O$) and nutrients as well as onboard hydroacoustic observations of zooplankton biomass in the water column. Analyses of spatial and temporal variability in zooplankton biodiversity using the offshore datasets are forthcoming. Sampling at stations within 15 nm of the ANMPA in 2013 and 2014 identified 65 mesozooplankton taxa, including 42 copepod taxa. Species occurrences, as well as the biomass and abundances for the top 10 contributing species to zooplankton biomass are reported in Niemi et al. (2020). Mesozooplankton abundance, biomass, and species compositions were variable between years, but generally indicated a numerical dominance of copepod species, an abundance of gelatinous species (*Fritillaria* sp. and *Oikopleura* sp.) within the ANMPA, higher mesozooplankton biomass in Franklin and Darnley bays compared to within ANMPA boundaries, and increasing biomass from nearshore to offshore (Niemi et al. 2020). Zooplankton compositions measured during the BREA MFP and BSMFP within the vicinity of the ANMPA are similar to shelf assemblages observed on the Mackenzie Shelf and in Franklin Bay during sampling for the CASES in 2002 (Darnis et al. 2008).

Pteropod shell dissolution, as a result of ocean acidification, was assessed on samples collected near Cape Parry during the BSMFP in 2014 (Niemi et al. 2021). A range of shell damage was observed, from minimal to severe, indicating that species in the area experience some level of corrosive waters during their life cycle, particularly at larval stages. The full consequences of ocean acidification in the Arctic are not yet understood, but may affect energetic transfers if zooplankton populations are not able to adapt.

Data on zooplankton species composition, structure, and function are lacking for nearshore and southern areas of the ANMPA. Coastal zooplankton samples were collected with qualitative horizontal tows during the Arctic Coast program in summer 2018 and 2019, but have not yet been analysed for taxonomic composition (D. McNicholl, DFO, pers. comm.).

6.3.2. Strategies and application

As outlined previously, the habitat heterogeneity that exists along a southern-to-northern gradient in Darnley Bay underscores the need to develop a monitoring program that can capture spatial heterogeneity in zooplankton biodiversity. Because zooplankton community composition follows seasonal phenologies linked to climate and sea-ice dynamics, the timing of sampling will be an important consideration for determining the types of information provided by the data. Monitoring zooplankton community composition and relative biomass may be applicable in both spring (to capture ice-associated biota and upward migration of key copepod species) and summer (coincident with the summer occurrences of upper-trophic level marine mammal and fish species in the ANMPA). Climate variability will be an important factor to consider when evaluating trends in zooplankton community composition and relative biomass as very different oceanographic and climatic conditions may prevail during different sample years, even if the sampling dates remain consistent. For this reason, indicators of background environmental conditions should be measured concurrently with zooplankton community composition and relative biomass.

Samples for zooplankton taxonomic analyses (providing biodiversity, abundance, and biomass data), which are used to determine species compositions, relative abundance, and biomass, can be collected from small vessels using standard zooplankton nets, although sampling in deeper waters may require the use of a winch mechanism or larger vessel. Net mesh sizes and the speed at which nets are pulled through the water will affect which species are captured. Larger, faster swimming zooplankton such as amphipods and krill can avoid small-mesh nets that are pulled slowly through the water, whereas a net that is pulled too quickly will “push” water rather than filter it. Depending on the target species chosen, multiple nets of different size fractions may be deployed to capture various size fractions. In addition, zooplankton specimens collected for biotracer analyses (*Section 6.1*) should ideally be taken from a net haul dedicated to that purpose, as removing them from taxonomic samples will mean they are not considered in taxonomic results. Taxonomic analyses will require expert analyses in a laboratory setting, which may be accomplished by contracting specialized consulting services or through collaboration among co-management and research partners (e.g., some DFO labs may be capable of performing basic taxonomy). The level of taxonomic detail required will affect the time and cost of processing samples. An expert should be consulted to determine the level of taxonomic detail required to answer monitoring questions. Collecting zooplankton community composition samples is highly recommended even if funds are not available for full taxonomic analyses. They are relatively easy to collect, and can be preserved in ethanol or formaldehyde for long-term storage, permitting retrospective time-series analyses when funds become available or a potential issue arises. Archived taxonomic samples should never be frozen.

It is recommended that taxonomic data be used to calculate the relative abundances/biomasses of key zooplankton prey species, so that their relative availability to forage fish and upper-trophic level predators can be compared across locations and years. Such information can be used to understand whether trends in the relative biomass, behaviours, or habitat use by forage fish and upper-trophic level species is linked to zooplankton food availability. Some of the key open-water zooplankton groups for energy transfer to higher trophic levels (i.e., key prey species) include lipid-rich copepods such as *Calanus* sp. and *Metridia longa*, pelagic amphipods such as *Themisto* spp., and euphausiid krill such as *Thyanoessa* spp. Full taxonomic data, if available, can be used to estimate relative abundance and biomass at the community level, and to potentially identify any newly colonizing species (see *Section 6.9*). If resources are not available for full taxonomic analyses, estimating the biomasses of zooplankton size classes (i.e., bulk weights) can still provide useful information for monitoring broad changes in community structure without the need to identify species. In such a case, it is still recommended that a representative split of each size class be preserved for potential future identifications. An expert should be consulted to decide on the size classes that will provide the best information for the monitoring question.

New technology can also be considered for taxonomic data collection for key species. At discrete locations, an underwater imaging system can collect video of zooplankton throughout the water column. A computer identification model developed for the Canadian Arctic could then be used to identify key species and life stages (Schmid et al. 2016, 2018). Such analyses provide point data sources, as do net tows, and would require specialized training and computing capacity for the analyses.

Collecting under-ice zooplankton and amphipods, may require deploying gliders, specialized nets designed to scrape the bottom of the sea ice, baited traps, or simplified vertical zooplankton net tows. Deploying cameras could provide qualitative information about the under-ice community composition (e.g., Arctic Cod, amphipods) if biological samples were not required for detailed taxonomy or trophic biotracer analyses.

Zooplankton biomass may alternatively be monitored using a moored acoustic fish and zooplankton profiler, which would link zooplankton occurrence and biomass directly to offshore and/or nearshore forage fish (see *Sections 6.5* and *6.6*). Given that zooplankton respond quickly to environmental conditions, ice dynamics, and food availability, intermittent net sampling will inevitably miss key seasonal events that alter the structure of zooplankton communities and its subsequent quality for predators. Moored equipment that provide a complete seasonal perspective are thus invaluable for understanding forage species status and dynamics within the ecosystem. Such annual datasets provide key insights into how the conditions of the current year affect the next. Moored active acoustics, including Acoustic Zooplankton Fish Profilers (AZFP), can be used to assess zooplankton presence throughout the water column for the entire year, and follow-on analyses can provide estimates of abundance and biomass for key groups such as copepods, euphausiids and fish (see *Section 6.5*; Berge et al. 2020, Hauri et al. 2018, Kitamura et al. 2017).

Monitoring zooplankton community composition, structure, and function is tightly linked to monitoring core oceanographic parameters and nutrient concentrations (*Section 5.1*), sea ice (*Section 5.3*), primary production (*Section 6.2*), inshore and offshore fish community composition (*Sections 6.5 and 6.6*), and forage fish relative biomass (*Section 6.7*). Readers are encouraged to consult the other relevant sections for a broader view of how these inter-linked indicators provide complementary and cumulative information, and rationales as to why these can/should be collected together. The selection of a subset of long-term monitoring sites and coordination among monitoring/research programs will be key to maximizing the utility of the data for detecting trends (or stability), and for hypothesis-testing.

6.4. BENTHIC INVERTEBRATE COMMUNITY COMPOSITION, STRUCTURE, AND FUNCTION

Hypotheses and/or predictions of change:

- Changes/disturbances to seafloor habitat will have a direct impact on benthic invertebrate community composition.
- Changes to pelagic primary production will indirectly alter benthic community composition, structure, and function by altering benthic-pelagic coupling.
- Benthic community composition and distributions influence the distributions and condition of marine mammals and seabirds that rely on benthic prey (e.g., Bearded Seals, Eiders).

Benthic communities can significantly affect carbon storage (e.g., Trueman et al. 2014), organic matter remineralisation, the cycling of nutrients back into the water column (e.g., Bourgeois et al. 2017), community resilience (e.g., Blanchard et al. 2011), and the locations of important feeding grounds for migratory marine mammals (Bluhm and Gradinger 2008). Although polar benthic communities respond quickly and opportunistically to freshly delivered organic matter from pulses in primary production, they derive the majority of their nutrition from sedimentary sources accumulated over longer time scales (Mincks et al. 2005, Renaud et al. 2008, Legeżyńska et al. 2012, North et al. 2014). Consequently, spatial patterns in benthic biomass and community composition in polar seas tend to reflect long-term indicators of benthic food supply rather than seasonal or episodic food inputs (Renaud et al. 2008, Kędra et al. 2012, Legeżyńska et al. 2012, Link et al. 2013a). Moreover, many benthic invertebrates are long-lived, have relatively low mobility (high site fidelity), and respond differently than do pelagic biota to changing physical factors such as temperature, ocean acidification, sea ice, and sediment type according to their species' particular physiological thresholds (e.g., Morley et al. 2019). Benthic invertebrates are thus particularly good candidates for indicators of natural and anthropogenic disturbance. From a monitoring perspective, pairing indices of biodiversity and function for benthos with those for lower trophic pelagic species provides information on bottom-up processes that shape food web dynamics.

Benthic community structure and function are relevant to the COs because they can reflect changes in the lower levels of the food web that will likely have cascading effects on higher trophic animals. Climate change is altering the organic matter pathways that fuel benthic marine food webs both in the Arctic, and worldwide (Hoegh-Guldberg and Bruno 2010, Kortsch et al. 2015). Enhanced primary production from rising sea temperatures and longer ice-free periods on Arctic shelves is expected to be largely retained by pelagic communities, decreasing the export of labile organic matter to benthos (Sampei et al. 2011, Forest et al. 2011, Tremblay et al. 2012) and raising concerns over climate-change impacts on food web functioning (Wassmann and Reigstad 2011).

Previous science advice (DFO 2015, Schimnowski et al. 2017) suggested monitoring benthic community composition structure, function, and energetics as an indicator of both environmental drivers (e.g., changes to benthic food supply mechanisms, habitat distributions) and the potential consequences of anthropogenic disturbances (e.g., shoreline development, inputs of deleterious substances). Data on benthic community composition could also provide information on prey availability for key marine mammal and fish species that consume benthic invertebrates, including Arctic Char, Beluga Whales, Ringed Seal, and Bearded Seal (*Section 6.1*), and be used to detect potential occurrences of non-indigenous species either from range expansions or anthropogenic introductions from vessel traffic (*Section 6.9*).

6.4.1. Available information

Benthic invertebrate community compositions and distributions in the nearshore domain of the ANMPA are a substantive knowledge gap, although Paulatuk residents that participated in a workshop to compile and document ecological Indigenous Knowledge in 2011 reported that crabs, sea urchins, clams, mussels, amphipods, decapods, krill, sea anemones, and isopods were found commonly in nearshore areas, whereas shrimps were common in deeper waters and large jellyfish are occasionally observed offshore (Kavik-AXYS Inc. 2012, Figure 13). The observations were reiterated in the Paulatuk Community Conservation Plan, supported by identifications through DFO (Paulatuk Hunters and Trappers Committee et al. 2016). To address the knowledge gap, the Paulatuk Invertebrate Survey was initiated by the Paulatuk HTC to characterise the invertebrate community in Darnley Bay, and has been in development since 2017. Within the program, local technicians are hired by the Paulatuk HTC to set crab and shrimp traps in areas identified by the Paulatuk HTC. Data collected include trap set location, weather, time and depth, catch abundances, carapace width measurements, and observations of females with eggs, and egg counts if possible.

Nearshore benthic epifauna species composition data are available from coastal areas of Argo Bay sampled by Arctic Coast in summer 2017 (D. McNicholl, DFO, unpublished data). The survey confirmed the presence of coralline algae, which build unique encrusted structures that act as habitat and are thought to be sensitive to ocean acidification.

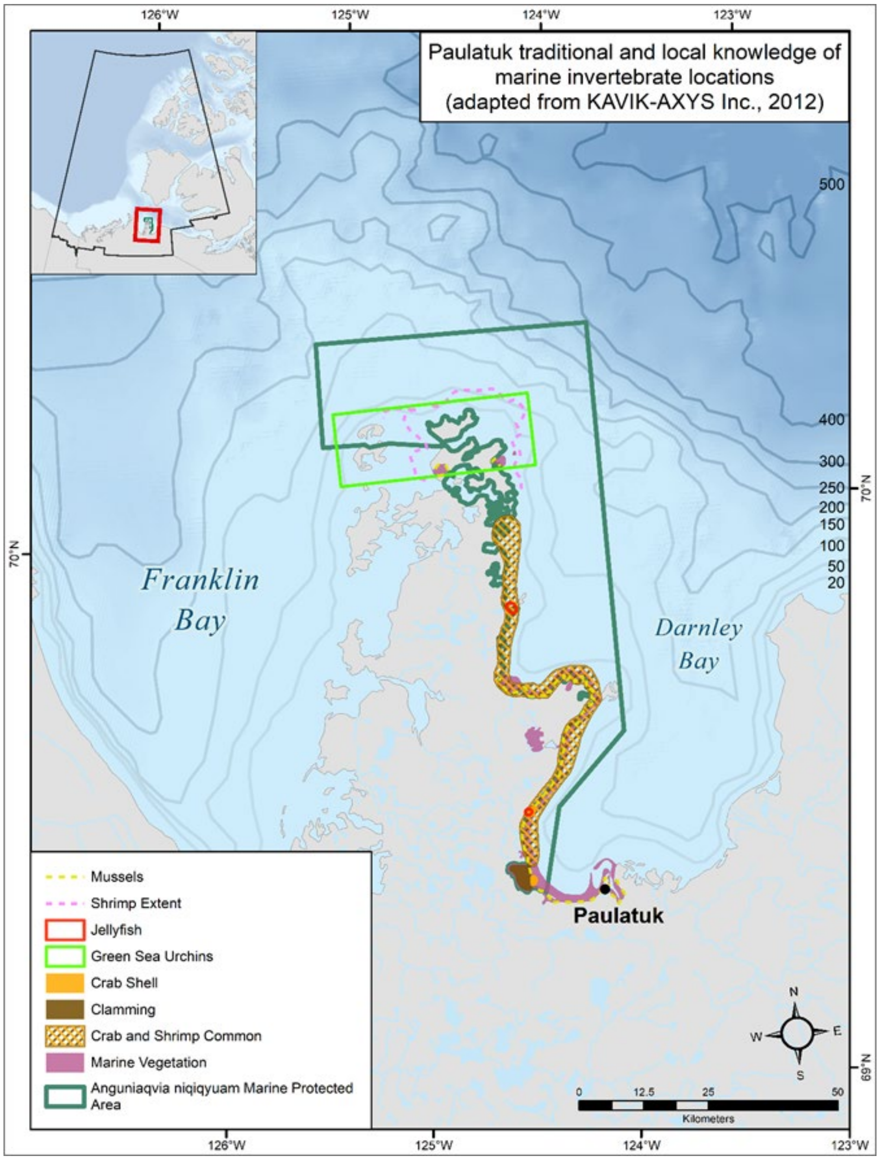


Figure 13. Locations of key marine invertebrate habitats and invertebrate harvesting areas in the vicinity of the ANMPA from traditional and local knowledge gathered during a workshop in Paulatuk in 2011. Map adapted from KAVIK-AXYS Inc. (2012) by J. Friesen and provided by the ANMPA Working Group.

Data relevant to this indicator in the offshore domain were collected intermittently between 2003 and 2017 from the same offshore programs that collected data on benthic habitat distributions described in *Section 5.3*, including the CFL, CASES, NCMS, BREA MFP, BSMFP, and CBS MEA programs. Quantitative survey data on benthic community composition and structure have primarily been collected from the northern portion of Darnley Bay, offshore of Cape Parry, and in Franklin Bay, although two stations were sampled in the southern ANMPA by the NCMS program in 2008 (Figure 6). Typically, biomass, abundance, and community composition of benthic invertebrates were measured from samples collected with sediment box corers (0.5 m^2 area), non-quantitative sediment grabs, or a small Agassiz trawl (1.5 m net opening).

The most extensive benthic invertebrate surveys conducted within the ANMPA and adjacent waters were those conducted offshore by the successive environmental assessments conducted from the F/V *Frosti* between 2013 and 2017 (Figure 7; BREA MFP, BSMFP, and CBS MEA). Infaunal invertebrates (those that live within the sediment) were quantitatively sampled with a sediment box corer. Epifaunal invertebrates (those that live on the sediment surface) were collected using a combination of a small 3 m benthic beam trawl and a large, commercial-scale otter trawl. Trawling decreased biases associated with sampling small surface areas, but trawling survey results are not directly comparable with those conducted with smaller gear during prior programs. Infaunal biomass densities observed along stations north of Cape Parry in 2008 were comparable to those observed during the F/V *Frosti* programs in 2013–2018 (both sampled by a box corer; Conlan et al. 2013, Niemi et al. 2020). Benthic invertebrate biodiversity observed during the F/V *Frosti* programs was higher than any observed during the CFL System Study (Roy et al. 2014, Niemi et al. 2020), which is likely linked to the greater surface area sampled during the former. During the F/V *Frosti* programs*,* 400 epifaunal and 352 infaunal taxa were recorded, representing 12 and 14 Phyla, respectively. Taxonomic richness at stations sampled within 15 nm of the ANMPA between 2013–2018 ranged from five to 114 for epifauna, and from 14 to 72 taxa for infauna (Niemi et al. 2020). Epifaunal diversity generally increased from inshore to offshore, whereas infaunal diversity displayed the opposite pattern (Niemi et al. 2020).

Data from the offshore sampling programs described above were used to describe regional distributions of benthic invertebrate communities in the Beaufort Sea and Amundsen Gulf, and to investigate large-scale environmental drivers of spatial variability in community composition. Benthic taxonomic composition in the region did not appear strongly related to indices of benthic food supply (Conlan et al. 2008, Roy et al. 2014). However, a lower sinking flux of pelagic organic matter in the Amundsen Gulf relative to the Beaufort Sea (Sallon et al. 2011, Sampei et al. 2011) was linked to weaker benthic-pelagic coupling and the use of a wider diversity of carbon sources among benthic consumers (Stasko et al. 2018). The trophic functional diversity of benthic communities was greatest at shelf-break habitats, which are subject to dynamic oceanographic processes that promote episodic pulses of benthic food supply (A. Ehrman, DFO unpublished data).

6.4.2. Strategies and application

There is a substantial knowledge gap regarding benthic invertebrate communities and their habitat associations in the ANMPA, especially for southern and coastal regions. Because there is a lack of strong linear correlations between large-scale environmental gradients and benthic community structure in the southern Beaufort Sea and Amundsen Gulf (Conlan et al. 2008, Roy et al. 2014), benthic community composition, structure, and function cannot be reliably predicted from other data and need to be measured locally within the ANMPA. Benthic community composition and structure will likely vary with depth, and between the northern and southern domains of the ANMPA due to gradients in benthic habitat characteristics (e.g., temperature, salinity, substrate type, physical oceanography). As with other indicators, a benthic sampling program would be most effective if incorporated into a larger sampling regime conducted at a set of key long-term monitoring sites that are randomly distributed across habitat types. Benthic habitat mapping will be a pre-requisite for effectively selecting sample locations that capture spatial variability in benthic habitat characteristics, and avoid sensitive areas. Moreover, because benthic invertebrate community composition, structure, and function are strongly tied to habitat conditions, hypothesis-testing will require associated information on benthic habitat distributions (*Section 5.3*), and core oceanographic parameters and nutrient supply (*Section 5.1*). Location-relevant information on the timing of sea-ice break-up (*Section 5.2*), pelagic primary production (*Section 6.2*), and zooplankton community composition (*Section 6.3*) would permit hypotheses to be tested regarding the role of benthic-pelagic coupling in structuring lower-trophic level food webs.

Sampling for quantitative estimates of benthic community biomass, abundance, and composition could be performed in nearshore areas within a community-based monitoring program by towing a small benthic sled from a small- to mid-size vessel with winch capabilities. Quantitative surveys would require careful consideration of gear specifications, how to standardize deployment effort, and catch subsampling protocols. Coarse sorting into broad feeding or functional groups could be completed by community field technicians. Alternatively, visual surveys of benthic community composition and abundance can be conducted with the non-invasive camera technologies such as a raised benthic sled equipped with specialized camera equipment, drop-cameras, or an ROV. Piloting ROVs and interpreting camera footage will require collaboration with experts that have knowledge and access to specialized software, but would be especially useful in sensitive habitats or those that cannot be easily sampled with bottom-contact gear (e.g., kelp beds, rocky areas). Sampling for benthic invertebrates in deep, offshore areas, especially in northern reaches of the ANMPA and adjacent waters, will likely require use of a large vessel. Most strategies for collecting data on benthic invertebrate community composition (bottom-contact or non-invasive) also capture information on benthic fish, contributing to data collection for the indicator on inshore and offshore fish community composition, structure, and function (*Section 6.5*). Camera-based strategies have the added bonus of collecting benthic habitat data (*Section 5.3*).

Out of all major species groups considered in this report, benthic invertebrates may be the most likely to act as good indicator species for the effects of local disturbance because they are so tightly linked to their habitats. Many are relatively long-lived and have high site fidelity, thus reflecting long-term processes, and have species-specific tolerances to potential disturbances, pressures, and threats. Previous science advice on potential monitoring indicators for the ANAOI concluded that additional research was necessary to determine a set of indicator species on which to focus monitoring efforts (e.g., detailed numerical counts, biomass, and biotracers on a subset of target species). This is still true. It remains uncertain which species in the ANMPA are sensitive enough to environmental drivers and anthropogenic stressors to be useful indicators. However, some generalizations can be made. For example, sessile and low-mobility organisms such as sponges, soft corals, and bivalves can be highly sensitive to activities that disturb the seabed (e.g., Clark et al. 2016) and may indicate the effects of potential dredging, harvesting with bottom-contact gear, coastal infrastructure development (DFO 2014), or natural disturbances such as gouging by sea-ice keels. Coralline algae and shell-building organisms will be more sensitive to ocean acidification than soft-bodied organisms. Because information on species-specific sensitivities is currently lacking, if target species are selected for monitoring they should represent a range of functional groups and habitat preferences to capture potential changes occurring through different mechanisms (e.g., filter-feeding bivalves, mud-burrowing polychaetes, mobile carnivorous decapods). The data on relative abundance, biotracers, and functional feeding groups that have recently been acquired for benthic communities near the ANMPA (Stasko et al. 2017, Niemi et al. 2020) may be able to guide a such a generic selection process.

Until species-specific sensitivities are better understood in the ANMPA, perhaps a better approach would be to use benthic community composition data to calculate aggregate metrics. For example, simple parameters can be calculated to detect and/or quantify the effects of disturbance on benthic communities based on known sensitivities of general taxon groups (e.g., the AZTI Marine Biotic Index, Borja et al. 2000, Culhane et al. 2019). Standard biodiversity metrics (e.g., species richness, diversity, evenness, and density) can be also used to detect changes in the distribution, structure and function of benthic communities that may be triggered by pressures such as coastal erosion (Brown et al. 2011), nutrient enrichment from tourism- or community-generated wastewater effluent (Krumhansl et al. 2015, Culhane et al. 2019), reduced or expanded kelp beds (Włodarska-Kowalczuk et al. 2009, Kortsch et al. 2012), and climate change (e.g., Kortsch et al. 2012, Renaud et al. 2015, Beaugrand et al. 2019). Habitat suitability modelling may help determine which benthic species are most at risk to climate change in the ANMPA (Degraer et al. 2008, Goldsmit et al. 2018), but the modelling procedures can be complex and require high quality habitat data as a pre-requisite. Habitat suitability modelling may thus become a useful tool in the future, once monitoring has established baseline benthic and oceanographic habitat data.

6.5. OFFSHORE FISH COMMUNITY COMPOSITION, STRUCTURE, AND FUNCTION

Hypotheses and/or predictions of change:

- Inter-annual variation in ice phenology, ocean temperatures, and primary production will alter energy pathways, favouring increased abundance and diversity of pelagic fishes relative to benthic fishes. Similarly, variability and change to ice phenology will affect pelagic larval fish growth and development, acting as an indicator of recruitment success.
- Significant changes to zooplankton community composition and/or abundance will affect inshore and offshore marine fish habitat use, condition, and relative abundance.
- Significant changes to fish species relative abundances or biomasses will have cascading effects on food web structure.

For the purposes of this review, offshore fishes are considered those that typically occupy waters deeper than 20 m. Monitoring offshore fish community composition, structure, and function is relevant to the ANMPA COs because offshore fishes represent some of the key prey items for marine mammals, seabirds, and Arctic char. Accordingly, offshore fishes can transmit the bottom-up influences of environmental variability and change to upper trophic levels.

Although forage fish are likely the most important community subset to monitor for direct trophic consequences to marine mammals (*Section 6.7*), monitoring fish community composition as a whole provides important insights into how environmental variability and change are affecting the functioning of the ecosystem. For example, long-term monitoring of offshore fish community structure in the Barents Sea has documented the expansion of Boreal species into Arctic waters as a result of changing oceanographic conditions (e.g., Frainer et al. 2017). The data have been used to demonstrate that new species alter food web structure by creating new feeding relationships and competition, with cascading effects across the food web (e.g., Pecuchet et al. 2020). Moreover, little is currently known about how feeding interactions among non-forage fish, benthos, and zooplankton contribute to overall ecosystem resilience and stability. Monitoring offshore fish community composition, structure, and function in the ANMPA, and adjacent areas in Darnley Bay and Amundsen Gulf, would provide a dataset capable of identifying the events that trigger potential changes observed at higher trophic levels.

In general, offshore fish community composition and structure appear to be most closely associated with the gradients of temperature, depth, and salinity associated with the circulation of water masses (Logerwell et al. 2011, Majewski et al. 2013, 2017, Norcross et al. 2013). Sea-ice extent and timing are suspected controls on the recruitment of Arctic Cod (Bouchard et al. 2017, LeBlanc et al. 2020), but little is known about the ecology and habitat requirements of larval fish for other species, many of which are pelagic. Larval fish ecology is a significant knowledge gap for the western Canadian Arctic in general.

Substantial research on offshore fish community composition, structure, and function has been conducted since the previous Science Advisory peer review. Research has yielded baseline data on fish biodiversity, relative abundances, and habitat distributions as well as a deeper understanding of the functional and trophic roles of many species (see below). However, the need remains for research on the ecological resilience, sensitivities, temporal stability of ecosystem structure, and responses of key species to stressors (Schimnowski et al. 2017).

6.5.1. Available information

Previously documented and compiled Indigenous Knowledge is limited for offshore fish species that occur near the ANMPA aside from Arctic Cod (Kavik-AXYS Inc. 2012, Paulatuk Hunters and Trappers Committee et al. 2016).

Within 15 nm of the ANMPA, benthic fishing surveys occurred at six stations during the 2008 NCMS expedition conducted from the CCGS *Nahidik* (Figure 6; Lowdon et al. 2011), and at 50 stations during the 2013, 2014 and 2017–2019 expeditions of the BREA MFP, BSMFP, and CBS MEA programs conducted from the F/V *Frosti* (Figure 7; A. Majewski, DFO, unpublished data, Niemi et al. 2020). Trawling was conducted using a 3 m benthic beam trawl, and with a combination of a 3 m beam trawl and a larger Atlantic Western IIA otter trawl during the NCMS and F/V *Frosti* programs, respectively. Supporting data on oceanography, primary production, nutrient concentrations, zooplankton biodiversity, sedimentary habitat distributions, and benthic invertebrate community composition were collected concurrently during both programs.

The NCMS was the first scientific assessment of fish distributions and occurrences in waters deeper than 20 m in Darnley Bay. A minimum of 25 fish species were recorded (Lowdon et al. 2011). Fish community composition varied by location. Arctic Cod was dominant in trawl catches north of Cape Parry, whereas sculpins (Cottidae), eelpouts (Zoarcidae), and sticklebacks (Stichaeidae) were variably dominant at stations sampled in more southern reaches of Franklin and Darnley bays (Lowdon et al. 2011).

During the 2013, 2014, and 2017 environmental assessments conducted from the F/V *Frosti*, a minimum of 21 marine fish species were captured within 15 nm of the ANMPA, representing 18 genera and 11 families (potentially more, pending genetic confirmations of species identities; Niemi et al. 2020; A. Majewski, DFO, pers. comm.). Arctic Cod was the most abundant species across all transects and years, except north of Cape Parry in 2014 when Arctic Alligatorfish (*Aspidophoroides olrikii*) dominated numerical abundances. Capelin co-occurred with Arctic Cod at sampling stations in Franklin Bay and east of Bennett Point, but with relatively low abundances (A. Niemi et al. 2020). Similar to the results of the NCMS in 2008 (Lowdon et al. 2011), sculpins, eelpouts, and sticklebacks were common in offshore areas in the vicinity of the ANMPA (see details in Niemi et al. 2020). Continuous hydroacoustic surveys conducted along the ship track of the F/V *Frosti* suggested similar overall densities of pelagic fish and large zooplankton between 2013 and 2014, with a slight increase northwest of Cape Parry (Niemi et al. 2020).

The functional roles of many offshore fishes that occur within the ANMPA and adjacent waters remain poorly understood. Information on trophic and functional roles for some offshore fishes that inhabit the ANMPA can be inferred from recent studies of fish distributions, habitat associations, and food web structure on the Beaufort Sea and Amundsen Gulf (Majewski et al. 2013, 2016, 2017, Giraldo et al. 2016, 2018, Stasko et al. 2016, 2017). Offshore fishes were included in the inventory of species functional feeding traits described in *Section 6.4* (Stasko 2017).

McNicholl et al. (2020) recently compiled all available information on anadromous and marine fish occurrences and distributions in Darnley Bay and waters associated with the ANMPA. To date, 28 offshore shelf-basin species have been observed. This document also includes information on basic functional attributes of each species that may help explain the causes or effects of any observed changes in community composition.

Aside from midwater trawling that was completed during the CBS MEA to verify hydroacoustics observations, virtually no sampling has been conducted in the pelagic realm of offshore areas in the ANMPA. Model projections for changes in offshore fish distributions in response to shifting spatial patterns of oceanographic parameters and primary production are not yet available for the ANMPA region, aside from general predictions regarding Arctic Cod.

6.5.2. Strategies and application

As previously advised (DFO 2015), monitoring full offshore fish community composition and structure requires carefully planned and broadly distributed multi-species surveys that concurrently capture environmental habitat data. Such surveys may be difficult to execute through a community-based monitoring program, as sampling typically requires a large vessel with offshore capability. Collaborating with vessel-based research and monitoring programs may be a sound approach to collecting information on this indicator. Offshore collections within Darnley Bay could be conducted through a community-based program by using deep-set gillnets or a small benthic sled; however, such deployments would require a winch-capable vessel and careful safety precautions, and would likely collect fewer and potentially different species than a typical large-scale trawl. Most benthic, offshore species are not amenable to capture by gillnets, and depths for winch-deployed nets would be restricted. Potential alternatives to gillnets for capturing offshore fish include trammel nets, long lines, or crab pots, being aware that catchability and target species vary among gear types. Inshore and offshore fish surveys should be coordinated in time for the study of food web linkages, and for complementarity on presence/absence. Direct comparisons of relative abundance and biomass are likely not possible between inshore and offshore surveys as differences in methods and gear types will result in differences in the relative catch efficiencies of each program.

Acquiring full taxonomic identifications for large survey catches can be time consuming and expensive, but does yield rich data that can be used to calculate composite metrics of biodiversity (e.g., Shannon’s diversity Index, Pielou’s evenness), relative abundance, perform robust analyses of spatial and temporal variability in community composition, and identify new species occurrences. Alternatively, it may be strategic to select a set of representative key species for monitoring that are expected to respond to an array of ecosystem alterations relevant to the COs, and/or which represent different key functional groups. A major consideration for selecting species for targeted monitoring is their importance as prey for upper-trophic level predators, especially predators important to the residents of Paulatuk, which is why forage fishes such as Arctic Cod are considered as an independent indicator (*Section 6.7*). However, monitoring forage fish alone will provide a limited understanding of how fish contribute to ANMPA ecosystem and food web functions because 1) they are selected based on limited knowledge of predator diets and may not represent the breadth of species consumed, 2) information on the entire fish community is necessary for making meaningful comparisons of forage fish relative abundances (e.g., if a decline is observed in the relative abundance of a specific forage fish, is it being replaced by another species, or are all species trends behaving similarly?), and 3) excluding non-forage species may result in a lack of baseline information if an unforeseen ecosystem change raises new concerns regarding other species (e.g., potentially colonizing species, lower overall biodiversity from environmental change, etc.). With that in mind, other potential species selected for targeted monitoring should be representative of different functional groups and habitat associations in the offshore. For example, eelpouts, Greenland Halibut, and sculpins are all benthic species that represent potentially important prey for Beluga Whales and Ringed Seal (see *Section 6.*1), but represent different trophic roles (e.g., Giraldo et al. 2016, Stasko et al. 2016) and occupy different habitat ranges based on depth, temperature, and salinity (Majewski et al. 2017).

Potential parameters for monitoring a subset of species would include catch-per-unit-effort of each species (a measure of relative abundance), distributions, and follow-on energetic/biotracer analyses (*Section 6.1*). Pairing relative abundance data with size, age and/or sex will enable the calculation of demographic indices that relate to condition or trophic status (e.g., Jennings et al. 2002, Shin et al. 2005, Harwood et al. 2013, Stasko et al. 2016) if needed.

Moored active acoustic profiling (similar to ship-based hydroacoustics) allows for inter-seasonal and inter-annual comparisons of overall fish distribution, biomass and movement at the mooring location. They also provide opportunities to integrate among disciplines (e.g., oceanography, primary production), trophic levels (zooplankton, krill, and fish are measured at once), and offshore programs in the Beaufort Sea and Amundsen Gulf area that use similar technology. Active acoustics detect fish targets throughout much of the water column at the mooring location, for the entire deployment period. Fishes at the sea surface or near the sea floor cannot be detected due to acoustic interference at these surfaces. Therefore, moored or ship-based hydroacoustic instruments are more applicable to monitoring pelagic species and pelagic larvae (see *Section 6.7*), rather than adult benthic species. Given the prevalence of Arctic Cod in the Beaufort Sea, these acoustic tools are particularly useful for monitoring this key forage species. Net sampling can validate species identifications made by acoustic software.

6.6. INSHORE FISH COMMUNITY COMPOSITION, STRUCTURE, AND FUNCTION

Hypotheses and/or predictions of change:

- Changes to inshore fish community composition, structure, and function will reflect broad environmental changes to temperature, salinity, river discharge, and ocean circulation.
- Significant changes to species relative abundances or biomasses will have cascading impacts on food web structure.

For the purposes of this review, the inshore fishes of Darnley Bay and the ANMPA are considered those occupying waters from the shoreline up to a depth of 20 m. The inshore habitat is distinguished from that of the offshore by freshwater discharges from coastal rivers that typically lower salinity, and increase temperature and turbidity (D. McNicholl, DFO, unpublished data). Inshore fish represent linkages to both freshwater and marine systems and are therefore an important indicator of shifts in multiple environments. Anadromous and forage fishes are considered inshore fishes of special monitoring interest, and are discussed independently (see *Sections 6.7* and *6.8*). Inshore fishes are relevant to the conservation objectives of the ANMPA because they comprise an important prey base for higher-trophic marine birds, fish, and mammals, particularly Beluga, seals, and Arctic Char that were identified as key species for their cultural and subsistence value (e.g., Quakenbush et al. 2012, Harwood and Babaluk 2014, Paulatuk Hunters and Trappers Committee et al. 2016, Gallagher et al. 2017). Inshore fish communities can additionally act as sentinels for cascading effects of habitat or climatic changes because the community composition, structure, and functional attributes of inshore fishes are often linked to habitat characteristics. For this reason, previous science advice for the ANAOI underscored the importance of integrating data on inshore fish communities with oceanographic data (DFO 2015, Schimnowski et al. 2017). Documentation of unusual inshore fish species and odd behaviours was advised for their potential association with environmental disturbances (see also *Section 8*). Some baseline data for inshore fish community composition and diversity were identified prior to the designation of the ANMPA from Indigenous Knowledge gathered via voluntary participation in interviews (McNicholl et al. 2017b) and a workshop (Kavik-AXYS Inc. 2012), and from baseline community-led fish surveys (McNicholl et al. 2017a, 2020). However, additional research on trophic interactions, energetics, community structure, and resilience to stressors was needed before target species for monitoring could be identified (Schimnowski et al. 2017).

Tracking parameters of fish community structure not only provides a means for detecting change in the fish community, but can additionally provide explanatory context for animal behaviour or changes in ecosystem function and structure. Species inventories are particularly important for tracking the introduction of invasive species (e.g., via vessel traffic), the extent of ongoing range expansions (e.g., Pacific salmon), or the potential utilization of protected habitat by species at risk (e.g., Bering Wolfish). Integrating species inventories with relative abundances can then provide information relevant to a whole host of potential monitoring interests relevant to the COs, such as: understanding species responses to environmental variability (e.g., ice off-dates, river discharge volumes), tracking the establishment rates of invasive species, or measuring the relative availability of different prey to marine mammals and birds. Pairing relative abundance data with data on size, age, sex and/or functional and feeding attributes will enable more detailed tracking of fish community structure, and could potentially assist with identifying causes or effects of any observed shifts in community composition. As with all parameters, those discussed here can only be used to draw cause-and-effect relationships once natural variability in the parameter is understood.

6.6.1. Available information

Some historical baseline data for inshore fish community composition in Darnley Bay are available from by-catch data from the Hornaday River Arctic Char monitoring program beginning in 1990 (*Section 6.8*), and from the Inuvialuit Harvest Study. Indigenous Knowledge shared at a workshop in 2011 by Paulatuk residents selected by the Paulatuk HTC outlined key areas of occurrence for locally-important inshore fishes (Flounder, Pacific Herring, Rock Cod, Tom Cod, and Char) as well as key fish harvesting areas (Kavik-AXYS Inc. 2012; Figure 14). The Paulatuk Community Conservation Plan provides a more comprehensive list of inshore fish species known to occur in Darnley Bay (Paulatuk Hunters and Trappers Committee et al. 2016).

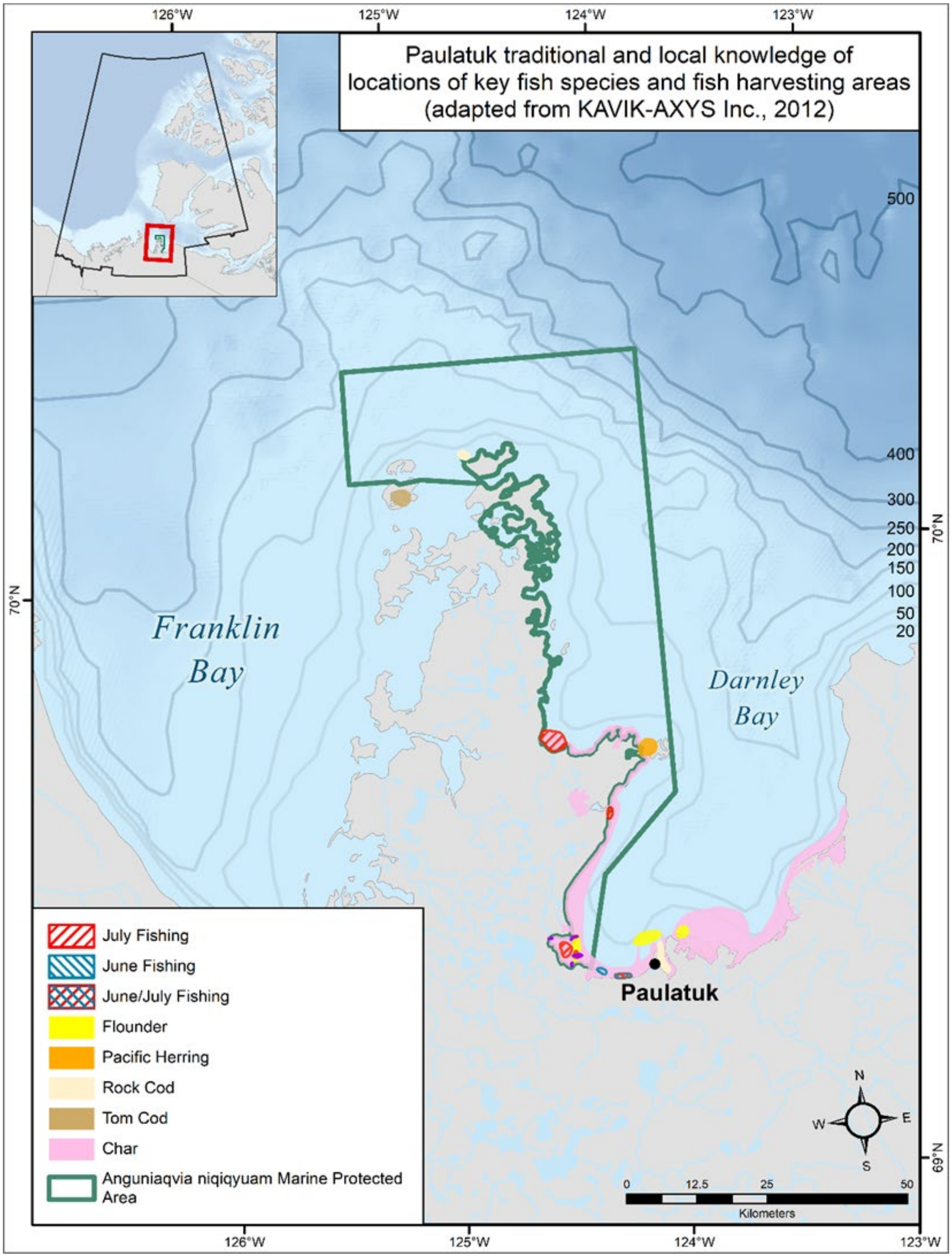


Figure 14. Locations of key fish species and fish harvesting areas in the vicinity of the ANMPA from traditional and local knowledge gathered during a workshop in Paulatuk in 2011. Map adapted from KAVIK-AXYS Inc. (2012) by J. Friesen and provided by the ANMPA Working Group.

Substantial data on inshore fish community composition and structure have been collected in recent years for the ANMPA and adjacent areas, partially in response to data deficiencies identified for the ANMPA. The community-based Darnley Bay coastal fishes survey (later referred to as Arctic Coast) was initiated to collect baseline information on the abundances, species composition, trophic interactions, and habitat associations of coastal fishes to support community-based monitoring, MPA management, and linkages with offshore marine sampling programs (McNicholl et al. 2017a). Sampling was conducted during July and August at Bennett Point (2012, 2014, 2015, 2019), Brown's Harbour at the northern end of Cape Parry (2014, 2015), and Argo Bay (2016 – 2019; Figure 15). Arctic Coast was expanded to include winter sampling of fish, ice thickness, ice freeboard, snow depth, temperature, and salinity at Argo Bay in winter 2019 (D. McNicholl, DFO, pers. comm.). Detailed biological data (size, sex, maturity) were measured from a subset of fish collected through the program, and tissues were subsampled for determination of age, genetics, and feeding information (stomach contents and stable isotope analyses). Sediments, zooplankton, and benthic invertebrates were collected in conjunction with fish from 2017 to 2019. Depth, temperature, and salinity were additionally measured at netting sites to provide insight into fish habitat associations. Similar to offshore surveys, nearshore fish abundances and species composition were temporally and spatially variable. Species richness and diversity were higher in Argo Bay relative to Bennett Point and Brown's Harbour, due to the presence of anadromous and euryhaline species (McNicholl et al. 2017a, D. McNicholl, DFO, unpublished data). Inshore fishes that characterised the coastal habitat, but were typically absent from offshore surveys (NCMS, BREA MFP, and CBS MEA) included: anadromous fishes (Arctic Char, Broad Whitefish Anaaktiq / *Coregonus nasus*, Arctic Cisco *Coregonus autumnalis*), Arctic Flounder (*Pleuronectes glacialis*), Arctic Shanny (*Stichaeus punctatus*), spawning Capelin, Greenland Cod (*Gadus ogac*), Ninespine Stickleback (*Pungitius pungitius*; usually in fresh or brackish waters only), Pacific Herring (Piqquaqtitaq / *Clupea pallasii*), Rainbow Smelt (*Osmerus mordax*), Saffron Cod (*Eleginus gracilis*), and Starry Flounder (*Platichthys stellatus*). Sculpins were previously thought to be rare in the coastal waters of Darnley Bay (Chambers and MacDonell 2012, Paulic et al. 2012). The presence of five sculpin species has since been confirmed through Arctic Coast summertime coastal fish surveys; Shorthorn Sculpin (*Myoxocephalus scorpius)*, Fourhorn Sculpin (Kanayuq / *Myoxocephalus quadricornis*), and Arctic Staghorn Sculpin (*Gymnocanthus tricuspis*) were commonly observed during sampling years, whereas Ribbed Sculpin (*Triglops pingelii)* and Twohorn Sculpin (*Icelus* bicornis) were present but relatively rare. Evidence of spawning activity was observed for Shorthorn, Fourhorn, and Arctic Staghorn sculpins. Larval fishes were observed utilizing lagoon habitats in the southern ANMPA (McNicholl et al. 2017). The first regional records of Bering Wolfish (*Anarhichas orientalis*), a species at risk in the Canadian Beaufort Sea, and Banded Gunnel (*Pholis fasciata*) were observed in July 2019. It is unclear if these rare species were new to the area, or whether they were typically present despite not being observed previously. It is important to note that fish species inventories to date may not be complete, as species that live in specialized habitats such as kelp were not effectively targeted.

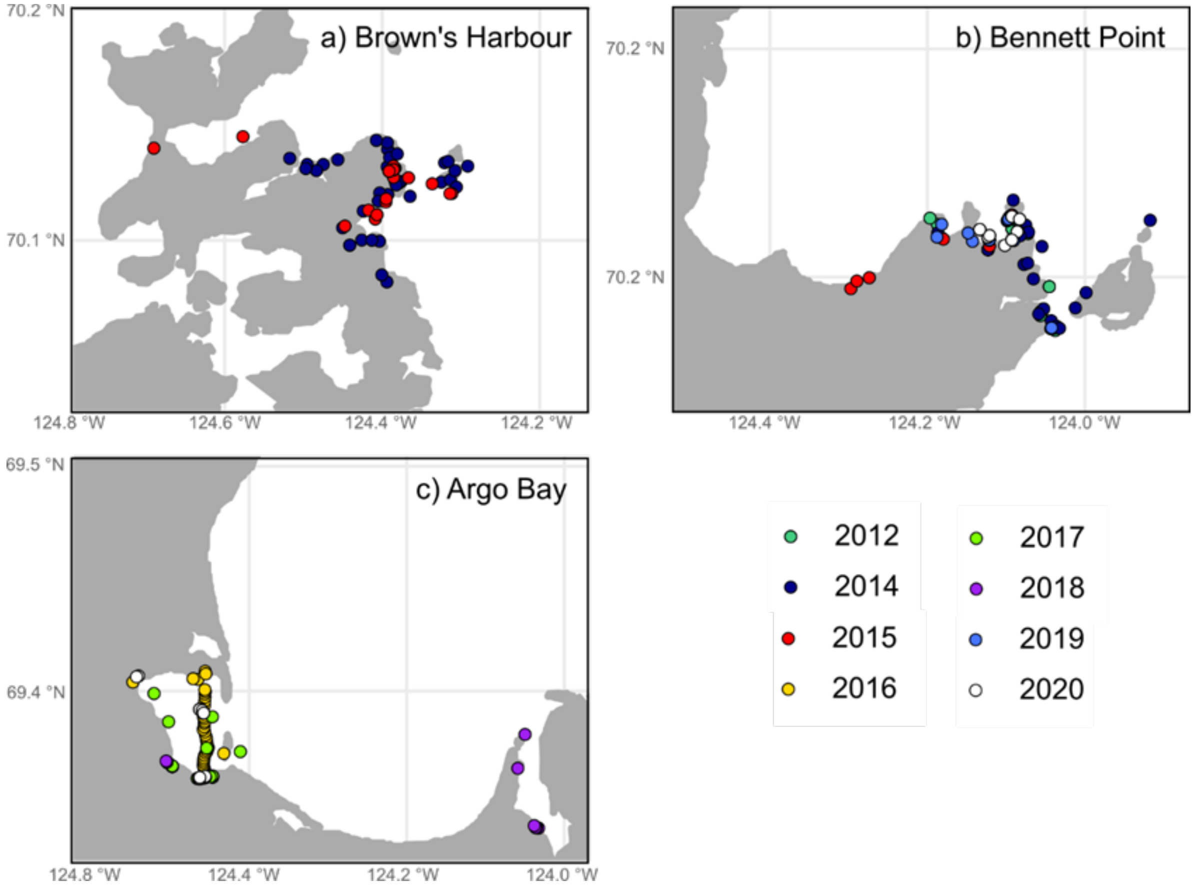


Figure 15. Stations sampled for fish community composition within the vicinity of the ANMPA during the Arctic Coast summer fish surveys from 2012 to 2020. Sampling gears included trap nets, gillnets, and seine nets.

Limited data on inshore fish abundance and species composition are available through the NCMS, BREA MFP, BSMFP, and CBS MEA offshore surveys (see *Section 6.5* for fish program overviews). Trawling was conducted at 20 m depth stations in Argo Bay in 2008 and directly off Bennett Point in 2013 during the NCMS and the BREA MFP programs, respectively (Lowdon et al. 2011, Niemi et al. 2020). Abundance estimates are additionally available from backscatter data collected with continuous onboard hydroacoustics surveys as the F/V *Frosti* transited through northern reaches of the ANMPA in 2013, 2014, and 2017–2019 (Niemi et al. 2020).

To date, 25 coastal marine and anadromous species and 12 freshwater species have been documented in waters associated with the ANMPA (Paulatuk Hunters and Trappers Committee et al. 2016, McNicholl et al. 2020).

6.6.2. Strategies and application

Much of the information that has been gained in recent years is relevant to southern portions of the ANMPA that were not previously subject to review during scientific advisory processes. Data collected across both northern and southern reaches of the ANMPA through the Arctic Coast coastal monitoring program may serve as a baseline for monitoring moving forward.

Relatively low numbers of fish that are more typically considered offshore species were captured at northern coastal sites in the ANMPA, where temperatures and salinities in the nearshore environment are more similar to those in the offshore. These observations suggest that the region around Cape Parry may represent a transitional zone between the coastal habitat and offshore shelf habitat of the Amundsen Gulf (McNicholl et al. 2017a). However, the contribution of coastal-derived energy to offshore food webs, or the contribution of marine-derived energy to coastal food webs, is still poorly understood. In some years, coastal fish surveys were concurrent with offshore fish surveys conducted through the BREA MFP and CBS MEA programs (2014, 2017–2019). There is potential to link or compare data on inshore and offshore fishes, but no direct studies on this topic have been conducted to date. Distinct differences in survey scale and methods may make catch-per-unit-effort data difficult to compare between the programs, but relative indices such as species richness, relative abundance, biodiversity (e.g., Shannon's diversity, Pielou's distinctness), and inventories of species and functional types could provide fruitful nearshore-offshore comparisons. Regardless, each program can inform on changes within their specific study areas. It is important to note that decreasing species abundances within ANMPA boundaries will not necessarily indicate lower fitness or survival. Species may relocate if conditions within the ANMPA are no longer suitable to their specific thermal and salinity tolerances, prey preferences, or competitive abilities (e.g., Dulvy et al. 2008, Milazzo et al. 2013, Frainer et al. 2017). In such cases, connecting inshore and offshore data will become particularly helpful in teasing apart population declines from relocation. Closely linking data from inshore and offshore programs is strongly advised. For example, detailed monitoring of a few key species that are commonly caught in both programs would provide information on change at a larger spatial scale than the individual programs can provide.

As previously advised (DFO 2015), monitoring inshore fish community composition, structure, and function requires carefully planned and broadly distributed multi-species surveys that concurrently capture environmental habitat data. Arctic Coast summer fish surveys have laid the methodological groundwork for monitoring this indicator. Arctic Coast has demonstrated the successful implementation of a community-based program that relies on small shore-based vessels and a suite of standardized protocols for collecting fish, with concurrent data on oceanography and other ecosystem components (zooplankton, benthic invertebrates, and sediments). Building on such existing datasets will be beneficial to long-term monitoring, paired with the selection of target species for focused monitoring efforts of important ecosystem functions (e.g., key prey species for marine mammals and birds, those with specific physiological constraints, those that represent a range of trophic/functional roles; see discussion on target species selection in *Section 6.5*). Passive monitoring using moored cameras or acoustic profilers could lengthen the seasonal record of fish habitat use relative to netting programs, but provide less detail than net sampling (see discussion in *Section 6.5*). Passive technology would need to be removed from areas < 20 m deep prior to landfast ice formation in the fall. Expansion of monitoring programs into the winter, if desired, may thus need to rely on ice-based net sampling, which would provide information on seasonal shifts in species composition, abundance, and habitat use that are currently lacking, albeit with decreased capture efficiencies relative to open-water sampling.

6.7. KEY FORAGE FISH RELATIVE ABUNDANCE AND BIOMASS

Hypotheses and/or predictions of change:

- Forage fish recruitment/survival success is tightly linked to sea-ice conditions and water temperatures. In particular, Arctic Cod recruitment is predicted to be higher during years of early ice-off dates, and lower during years with late ice-off dates.
- Following the above, potential changes in forage fish abundances or distributions will affect the behaviour, movements, and condition of upper-trophic level predators that feed on them.

- The presence of seabirds and whales offshore of Cape Parry is related to forage fish biomass.
- Significant changes to zooplankton community composition and/or abundance will affect forage fish habitat use, condition, and relative abundance.

Forage fish are a key prey source for upper-trophic level predators that occupy the ANMPA. Tracking the relative abundances and biomasses of forage fishes will provide two key pieces of information for reporting on the ANMPA COs: 1) it will indicate whether sufficient high-quality food is available for upper-trophic level predators in the ANMPA, and 2) changes in prey availability may provide an explanation for observed changes in predator behaviour, condition, or mortality rates. Previous science advice suggested that local observations of the timing, location, and semi-quantitative abundance of Capelin spawning on beaches could be a practical indicator for monitoring Capelin presence/absence in the ANMPA region (DFO 2015, Schimnowski et al. 2017). Here, advice is updated. It is recommended that directly monitoring the relative abundances and biomasses of three key forage species in the ANMPA is more relevant to the COs: Arctic Cod, Capelin, and Pacific Sand Lance. These three species have been documented as important prey for Beluga Whales, Ringed Seals, Arctic Char, seabirds, and to a lesser extent, Bearded Seals (see reviews in *Section 6.1* and *6.10*).

Arctic Cod are arguably the most important forage fish in the ANMPA as they represent an energetically dense food source with high lipid content (e.g., Harter et al. 2013, Hop and Gjøsæter 2013) and are by far the most abundant fish in the region (Lowdon et al. 2011, Majewski et al. 2017, Niemi et al. 2020). Capelin occupy a similar role to Arctic Cod in the food web as mid-trophic consumers and as important conduits of planktivorous energy to higher trophic biota (McNicholl et al. 2016, 2018), but are more restricted to nearshore areas and not as abundant as are cod (Lowdon et al. 2011, McNicholl et al. 2017a, Niemi et al. 2020). Sand Lance are pelagic schooling fish as well, but spend a significant amount of time buried in fine gravel or sandy substrates when not foraging, presumably to avoid predation. Thus, Sand Lance typically occur in nearshore areas up to and including the intertidal zone.

Capelin, Sand Lance, and other pelagic forage fish could possibly represent important alternative prey sources for some predators, such as Beluga Whales, when/if Arctic Cod biomass is low (Choy et al. 2017, 2020, Loseto et al. 2018a). However, no other forage fish in the region presently occurs in the same high abundances as Arctic Cod (Majewski et al. 2017), and it remains uncertain whether other species will be sufficient to meet the energetic requirements of upper-trophic level species if Arctic Cod abundance declined. For example, increased consumption of Capelin relative to Arctic Cod was thought to be partially responsible for lower nestling growth rates in Hudson Bay Thick-Billed Murres because Capelin represent lower mass per foraging trip (Gaston et al. 2005) despite having similar energetic densities to cod (Hop and Gjøsæter 2013). The energetic cost of foraging may be significantly less for marine mammals, who do not need to transport prey back to a nest for their young, but research is lacking on the topic for populations that use the ANMPA.

6.7.1. Available information

The Arctic Coast summer sampling program collected information on relative abundance (catch-per-unit-effort), size, and age for Capelin in the ANMPA. Capelin abundance was variable among sampling locations and years. Capelin were the most abundant species captured at Bennett Point in 2012 and 2014, Brown's Harbour in 2014 and 2015, and Argo Bay in 2016, 2018, and 2019 (McNicholl et al. 2017a, D. McNicholl, DFO, unpublished data). Capelin captured in July of 2012, 2014, and 2015 displayed characteristics of spawning, and eggs were observed adhered to sediments in 2014 (McNicholl et al. 2017a). Capelin were additionally observed spawning on beaches in 2019. It should be noted that Capelin do spawn every year, but may only be observed on beaches when air temperatures are above normal, weather is calm, and/or the beaches are free of ice (McNicholl et al. 2017b). Arctic Cod and Sand Lance have not been captured in the Arctic Coast program.

Relative abundance, relative biomass, and size data are available for Arctic Cod, Capelin, and Sand Lance captured within the vicinity of the northern ANMPA, Franklin Bay, and Amundsen Gulf by the F/V *Frosti* programs from 2013, 2014, and 2017–2019 (A. Majewski, DFO, unpublished data). Arctic Cod was the most abundant fish captured across all stations and transects within the vicinity of the ANMPA, except for north of Cape Parry in 2014 when Arctic Alligatorfish was most abundant instead (A. Niemi et al. 2020). Capelin co-occurred with Arctic Cod along all sampling transects, except for within Wise Bay, but had lower relative abundances. Capelin was most abundant off of Bennett Point in 2013. The full extent of Capelin and Sand Lance distributions in Darnley Bay remain uncertain (McNicholl et al. 2020).

Hydroacoustic observations collected during the CASES and CFL System Study overwintering expeditions revealed large wintertime aggregations of adult Arctic Cod in the deep waters of Franklin Bay, presumably as a strategy for escaping predation by diving seals (Benoit et al. 2008, 2010, Geoffroy et al. 2011). These observations suggest that coastal embayments may be important overwintering, and possibly spawning, habitat for Arctic Cod, serving to concentrate an energy-dense food source for marine mammal predators during winter. Similarly, net-validated hydroacoustics observations along the track of the F/V *Frosti* during the BREA MFP (2013) and BSMFP (2014) confirmed that large schools of pelagic fish were common in the vicinity of the ANMPA during summer, primarily comprised of age-0 Arctic Cod (A. Niemi et al. 2020). These summer abundances were greatest in the northwestern ANMPA near Cape Parry (A. Niemi et al. 2020).

Recent evidence from dietary markers collected from 2011 to 2014 suggested that Eastern Beaufort Sea (EBS) Beluga Whales consumed the lowest proportion of Arctic Cod and the highest proportion of Capelin in 2014, when Arctic Cod biomass was low in the region (Choy et al. 2020). In some areas of the eastern Canadian Arctic, Capelin consumption by upper-trophic level predators has increased over the past several decades, partly in association with their increasing availability through range expansion and/or local increases in abundance, and partially in association with declining sea-ice extent and Arctic Cod availability (Thick-billed Murres; Gaston et al. 2003, Provencher et al. 2012, Beluga Whales; Marcoux et al. 2012, Yurkowski et al. 2018a, Arctic Char, Ringed Seals, and Greenland Halibut; Ulrich 2013, Yurkowski et al. 2018a). These same predator species inhabit areas within or near the ANMPA. However, it is important to note that, unlike the eastern Arctic, Capelin have been observed in Darnley Bay for at least 60 years (McNicholl et al. 2017b), genetic and morphological evidence suggests they are a distinct western Arctic population rather than a newcomer, and are not known to be undergoing current range expansion. Capelin, therefore, do not represent a new prey source, although it is uncertain at present if their relative abundance has changed recently.

Sand Lance relative abundance and biomass is a knowledge gap for the ANMPA. Sand Lance have not been captured in the vicinity of the ANMPA by recent inshore and offshore fish surveys (NCMS, Arctic Coast, BREA MFP, BSMFP, CBS MEA). Their occurrence is likely under-reported because standardized sampling methods are not effective at capturing Sand Lance, which live in sediments as adults. Reports of Sand Lance in predator stomachs abound for the ANMPA, indicating their presence and importance for the food web. Larval Sand Lance have been observed in pelagic zooplankton tows in Franklin Bay during the CBS MEA (A. Niemi and A. Majewski, DFO, unpublished data).

Limited data exist for the ANMPA on the abundance and biomass of larval stages of Arctic Cod, Capelin, and Sand Lance.

6.7.2. Strategies and application

Temporal trends in the relative abundance and/or biomass of key forage fishes can be monitored by comparing catch-per-unit-effort over time if surveys utilize standard methods across years and sites. However, monitoring only the key species is unlikely to provide sufficient data to predict the *consequences* of changes to their abundance and/or biomass (see discussion in *Section 6.5*). For example, the impact of Capelin stock collapses on various marine mammal, seabird, and fish predators in the Barents Sea, where Capelin represent one of the most important forage species, depended on the availability of alternative prey (Gjøsæter et al. 2009). If fish survey programs are in place to monitor key forage species, recording the relative abundances of other fishes captured in the survey will be beneficial to the monitoring program as a whole. Consequently, it is highly recommended that forage fish abundance and biomass be monitored concomittantly with inshore and offshore fish communities, through survey programs already described in *Sections 6.5* and *6.6.* Moored hydroacoustic instruments may be particularly useful for monitoring pelagic forage fishes (and zooplankton) year-round in the northern ANMPA, where the presence of marine mammals and seabirds is hypothesized to be related to forage fish biomass (see *Section 6.5*).

Surveys of the relative abundance of Sand Lance may require a dedicated technique, since they are evasive to standardized netting procedures used for other fish. Beach seine nets and intertidal digging in soft, pebbly sediments will be more effective than gill nets (e.g., Robards et al. 1999).

Data from indicators of core oceanography and sea ice/snow will be especially relevant for explaining patterns in forage fish relative abundance and biomass, and recruitment is linked to environment conditions for all three forage species. Sea-ice extent and timing are suspected controls on the recruitment of Arctic Cod (*Boreogadus saida*; Bouchard et al. 2017, LeBlanc et al. 2020). The timing and location (beach versus demersal) of spawning for Capelin is dictated by water temperature (e.g., Nakashima and Wheeler 2002, Davoren 2013). In Darnley Bay, Capelin tend to spawn in deeper water when air temperatures are relatively warm, or on beaches when temperatures are relatively cooler, according to Paulatuk residents interviewed in a recent traditional ecological knowledge study (McNicholl et al. 2017b). Community observations of Capelin spawning on beaches, which had been previously advised, may thus be monitored to link recruitment strategies to prevailing temperatures in a given year. Sand Lance spawning typically occurs in the intertidal zone and is influenced by water temperatures (Robards et al. 1999), but little is known about the environmental triggers for Pacific Sand Lance in the Arctic.

Understanding whether a particular forage fish is becoming a more important component of upper-trophic level predator diets is perhaps, at this point, a research question rather than a monitoring objective. However, monitoring predator diets concurrently with forage fish relative abundance and biomass, and similarly measuring trophic biotracers in both predator and prey (*Section 6.1*), would provide information required to answer this question over the long term. Monitoring the occurrence and relative abundances of forage fish in marine mammal stomachs or bird forage without monitoring relative abundance of the inshore, offshore, and forage fish populations themselves is not recommended. Marine mammals can be highly selective and efficient predators, such that stomach contents may be stable even if prey abundance is declining, at least until there is a problem. Stomach contents will not act as an early warning indicator. Further, without fish community data it will be impossible to determine if changes in marine mammal diets are due to predator preference or prey availability.

6.8. ANADROMOUS FISH RELATIVE ABUNDANCE, HABITAT USE, AND POPULATION STRUCTURE

Hypotheses and/or predictions of change:

- Variability and change in sea-ice break-up/freeze-up timing and coastal habitat disturbance will impact habitat use within the ANMPA by anadromous fishes.
- Anadromous fish habitat use within the ANMPA will be affected by prey availability, linked to nutrient concentrations, freshwater discharge and the availability of brackish coastal habitat, and the locations and frequency of upwelling/downwelling

Anadromous Arctic Char and Broad Whitefish are of high cultural and subsistence value for the residents of Paulatuk. Nearshore marine waters throughout Darnley Bay, including some southern portions of the ANMPA, provide summer feeding habitat for anadromous Arctic Char and Broad Whitefish (e.g., Kavik-AXYS Inc. 2012, Harwood and Babaluk 2014). Previous science advice on monitoring indicators for the ANAOI did not review those specifically related to anadromous fishes (DFO 2015) because they are not typically harvested offshore of Cape Parry, and because the proposed CO for the ANAOI at the time did not place any emphasis on these species. Since then, Arctic Char have been identified as a key species of interest in the COs for the ANMPA. Both Arctic Char and Broad Whitefish were listed as community priorities by the ANMPA Working Group (Appendix A).

Monitoring anadromous fish relative abundance, habitat use, and population structure are relevant to the ANMPA because some key summer feeding and subsistence harvest sites are located within the ANMPA boundaries, including Argo Bay and Tippitiuyak. However, the ANMPA represents a small proportion of the overall summer marine habitat and harvest areas for Arctic Char (Figure 14; Kavik-AXYS Inc. 2012, Harwood and Babaluk 2014, Gallagher et al. 2017, E. Lea, DFO, pers. comm.). The Arctic Char that utilize summer feeding habitat within the ANMPA boundaries are likely part of larger stocks that originate in the Hornaday and Brock rivers (Roux et al. 2011, Boguski et al. 2016, Harris et al. 2016) and depend, as a population, on summer feeding grounds in nearshore regions throughout Darnley Bay. The primary marine corridor for local char is along the eastern shore of Darnley Bay north to Pearce Point, where frequent upwelling triggers enhanced marine productivity that creates a particularly important feeding ground (Harwood and Babaluk 2014). The majority of the Arctic Char subsistence harvest currently occurs along the eastern shore of Darnley Bay in summer, at the mouth of the Hornaday River during the upstream migration in late summer, and in freshwater habitats during winter (Kavik-AXYS Inc. 2012, Gallagher et al. 2017). Assessing the sustainability of harvesting anadromous fish populations requires detailed species-specific information (e.g., harvest data, catch-per-unit-effort, age, size, growth, condition), which is already collected for Arctic Char through an existing stock assessment program and Char Management Plan. These programs can provide information on habitat use, harvest pressure, and life history that are important to evaluate whether activities or disturbances in the ANMPA are impacting Arctic Char populations as a whole, and possibly provide some information on Broad Whitefish through accidental captures. However, relying on harvest and population assessment data alone would not capture how anadromous fish utilize the ANMPA, and would not provide detailed information for species aside from Arctic Char. For this reason, additional monitoring of anadromous fish relative abundance and habitat use within the ANMPA is recommended in addition to data collected in association with the fishery, whereas population structure information acquired by existing stock assessment program be used to inform trends observed within the ANMPA.

6.8.1. Available information

The Hornaday River and Brock River Arctic Char stocks are co-managed by the Paulatuk Hunters and Trappers Committee, Fisheries Joint Management Committee, DFO, and Parks Canada through the Paulatuk Char Working Group. Data pertinent to Arctic Char stock assessment for Darnley Bay populations are currently collected annually through two community-based programs: 1) a standardized monitoring program that has been in place since 1990, led by the FJMC and DFO and administered by locally-hired monitors that work within a defined time frame and sample size target, and 2) a subsistence harvest survey that has been administered by the Paulatuk HTC since 1998. Arctic Char data collected through the programs are compiled and summarized annually by DFO, then shared with the PHTC and Paulatuk Char Working Group to support the Paulatuk Char Management Plan (E. Lea, DFO, pers. comm.), which was implemented in 1998 (Paulatuk Hunters and Trappers Committee et al. 2016). The PHTC-administered harvest survey is tied to the char monitoring program, but both are independent from the Inuvialuit Harvest Study which collected subsistence harvest information year-round from across the ISR (see Appendix D). Presence/absence, abundance, and biological data are also available for several anadromous fishes (Arctic Char, Broad Whitefish, Arctic Cisco) through the Arctic Coast summertime fish surveys, which operated standardized netting programs at Bennet Point, Brown’s Harbour, and Argo Bay in 2012 and 2014–2019 (see *Section 6.6*; McNicholl et al. 2017a). Stomach contents data from Arctic Coast indicate Broad Whitefish tend to rely more heavily on coastal food sources and consume more terrestrial invertebrates than do Arctic Char and Arctic Cisco. Some monitoring data specific to Broad Whitefish are available from standardized netting programs that took place from 2016 to 2018 as a collaboration between the Paulatuk HTC and the World Wildlife Federation. Monitoring data for Broad Whitefish have not been synthesized to date, but the current Paulatuk Community Conservation Plan lists them as locally abundant (Paulatuk Hunters and Trappers Committee et al. 2016).

Historical data pertinent to Arctic Char stock assessment are available from a commercial Arctic Char fishery that operated out of Paulatuk from 1968 to 1986. The fishery was closed in 1987 due to concerns over declining subsistence harvests, commercial catches, and fish body size. In response, test fisheries using multi-mesh gillnets were conducted at the Brock River (1987), Horton River (1988), Balaena Bay (1989), and Tom Cod Bay (1989) to search for alternative sources of char for the community (reviewed in Gallagher et al. 2017). The Hornaday River Char Monitoring Program was then established in 1990 and has continued to collect subsistence harvest, biological, and catch-per-unit-effort (beginning in 1997) data from the mouth of the Hornaday River during the upstream migration in late summer (Gallagher et al. 2017). In 2011, monitoring was expanded to include harvests at Lasard Creek near the mouth of the Brock River because of increased fishing efforts in this area by residents of Paulatuk. Data from a tagging study had also suggested greater char movement and mixing of stocks between the Hornaday and Brock rivers than previously suspected (Roux et al. 2011, Harwood and Babaluk 2014), which has since been confirmed (Boguski et al. 2016, Harris et al. 2016). Monitoring of harvests at Tippitiuyak was added to the program in 2012. The standardized Arctic Char monitoring programs have thus collected data from subsistence harvests at the mouth of the Hornaday River (1990–2019), Lasard Creek (2011–2019), and Tippitiuyak (2012–2019), including harvest numbers, catch-per-unit-effort, biological data, occurrences of ‘blue char’ (a morphotype reportedly different from those associated with the Hornaday River and of unknown origin), and tissue samples (note that not all data types have been collected in all locations and/or years). Data available from combined historical sources and Arctic Char monitoring programs are summarized in Gallagher et al. (2017). Population assessments derived from age, size, and catch-per-unit effort data available from the combined sources, up to 2013, did not indicate signs of overharvest in recent years (Gallagher et al. 2017, Zhu et al. 2017). Further assessment of data collected from the monitoring program at Tippitiuyak within the ANMPA from 2012 to 2019 suggested biological indicators and catch-per-unit-effort have continued to remain relatively stable (C. Gallagher, DFO, pers. comm.).

In addition to the standardized char monitoring program, community-led surveys administered by the PHTC collect harvest information for anadromous fish reported by active subsistence harvesters, typically on a monthly basis from April to December. Surveys document the species, number of individuals harvested, harvest location, harvest date, and other observations deemed relevant by the harvester. Lea et al. (2020) present the most recent summary of Arctic Char harvest information derived from the community-led surveys, from 2003–2013. Survey data for summer char harvests are assessed by region, including the Hornaday River, West Darnley Bay, and East Darnley Bay. The West Darnley Bay region includes harvest locations that fall within the borders of the ANMPA.

Catch-per-unit-effort and size data for Arctic Char and Arctic Cisco captured in the ANMPA are available from the Arctic Coast summer sampling program from 2014–2019.

6.8.2. Strategies and application

Cause-and-effect relationships between activities or disturbances within the ANMPA and anadromous fish populations cannot be drawn without examining the population, and its habitat, as a whole. Arctic Char in Darnley Bay currently benefit from the protection of the Paulatuk Char Management Plan, associated monitoring programs, and periodic stock assessment. Similarly, Broad Whitefish and other anadromous fishes in the ANMPA are currently monitored through Arctic Coast (see *Section 6.6*). Successful monitoring of anadromous fish relative abundance, habitat use, and population structure will be best supported by collaborating closely with the community-based monitoring and survey programs that collect information from throughout Darnley Bay. Continuing existing monitoring programs, or contributing similar data to existing data series, paired with community observations, is likely the best strategy for monitoring population structure of key anadromous fish species in the ANMPA.

Two primary knowledge gaps exist for anadromous fishes in the ANMPA that could be addressed by additional monitoring efforts in the ANMPA: diets and habitat use. Both are likely to be influenced by environmental conditions, especially upwelling events that influence prey distributions and the timing of sea-ice break/up and freeze up that influence migration timing. Habitat use data could be derived from the field program designed for monitoring inshore fish communities (*Section 6.6*), if gear specifications and placement are designed to be effective for anadromous species. An expanded list of biological metrics could be collected for anadromous fishes captured in ANMPA-specific field programs to contribute to potential population structure analyses, if desired, including catch-per-unit-effort, age (otoliths), size-at-age, and condition. Stomach contents and tissues for trophic biotracers should be collected during such programs to delineate trophic links between Arctic Char and their prey (*Section 6.1*). Community observations of the timing of upstream and downstream migration could also act as a gauge of environmental influences on marine habitat use and life history. Anadromous fish habitat use will be tightly linked to indicators of background environmental context, especially core oceanography and nutrient concentrations (*Section 5.1*) and the timing of sea-ice break-up and freeze-up (*Section 5.2*). This indicator has a relatively long history and detailed baseline information compared to other biological indicators discussed in this report, and any new sampling programs devised to support monitoring of anadromous fishes should be intimately coordinated with existing programs.

6.9. OCCURRENCE AND TIMING OF POTENTIALLY COLONIZING SPECIES

Hypotheses and/or predictions of change:

- Natural range expansions of new fish and invertebrate species into Darnley Bay will be associated with change and variability in oceanographic conditions (temperature, salinity, circulation) and sea-ice cover, and the associated consequences to the distribution of primary production and prey species.
- Increased shipping will bring a greater risk for the introduction of invasive invertebrate species into the ANMPA.
- The establishment of a newly colonizing species may have implications for upper-trophic level predators by direct or indirect competition for prey and/or habitat (if the new colonizer is upper-trophic level), by redirecting energy pathways or changing the relative availability of prey resources (if the colonizer is lower-trophic), or by habitat augmentation.

The increasing occurrence of a novel species in a geographic area outside current distributions, called a naturally occurring range expansion, serves as a useful indicator for ecological change. Shifting environmental conditions can influence the range expansion of a species into a new geographic region (e.g., Pacific salmon) and the timing of life history events, both of which can result in interactions among species that may not have occurred previously. These changes therefore reflect the larger effects of ecological change in response to environmental drivers. For example, modelling has suggested that *Calanus* zooplankton species that are typically boreal (*C. finmarchicus* and *C. marshallae*) cannot presently complete their life cycles in Arctic waters. Changed thermal regimes projected for the future may, however, provide sufficient growing season conditions for future colonization (Ji et al. 2012). Naturally occurring range expansions are the result of a species' response to follow specific habitat requirements (e.g., water temperature) or prey or both. Range expansions are different from artificial or invasive expansions, because they result from the species following its habitat needs rather than human intervention.

Invasive expansions typically involve non-indigenous species that arrived with human intervention. The introduction of invasive species is a growing concern in Arctic waters where increases in water temperature and shipping activity, and decreases in ice coverage, can favour the establishment of non-indigenous species transported in ship ballast waters or by organisms attached to ship hulls (Goldsmit et al. 2014, Chan et al. 2015).

For the purpose of this report, both range-expanding and invasive species are considered together as potentially colonizing species for two reasons: 1) the monitoring efforts required to detect them and their effects are similar, and 2) concerns around the ecological consequences of the arrival and establishment of a new species are similar regardless of whether they are invasive or natural colonizers. Understanding the occurrence and significance of invasive species, and of potentially colonizing salmon, in the ANMPA was identified as a monitoring priority by the ANMPA Working Group (Appendix A). This priority is relevant to the ANMPA COs specifically with regard to how potentially colonizing species may interact with resident species, and if those interactions will be detrimental to resident species, ANMPA ecosystem integrity, or feeding for key upper-trophic level predators.

6.9.1. Available information

Pacific salmon have been more abundant in Darnley Bay, and the western Canadian Arctic in general, in recent years (Dunmall et al. 2018). While the direct cause of their presence is unclear, their range expansion eastward in the Canadian Arctic is likely linked to a combination of searching for preferred habitat and/or prey. Four of the five species of Pacific salmon have been documented in Darnley Bay (Chum Salmon *Oncorhynchus keta*, Sockeye Salmon *Oncorhynchus nerka*, Pink Salmon *Oncorhynchus gorbuscha,* and Chinook Salmon *Oncorhynchus tshawytscha*), with Chum Salmon being the most common (McNicholl et al. 2020). Pacific salmon rear in freshwater habitats and migrate to the marine environment where they spend the majority of their life (5–7 years) until they reach sexual maturity. When they are ready to spawn they migrate into rivers in the late summer and fall, and die after they reproduce.

According to local observations, the first Pacific salmon in Darnley Bay was caught in the Hornaday River in 2008 (L. Ruben, Paulatuk, pers. obs.), and for the next 10 years, salmon were occasionally harvested in subsistence fisheries targeting other species in late summer and fall. In 2019, many salmon were harvested in the Darnley Bay area, following a similar trend of exceptionally high harvests of salmon across the Northwest Territories that year, and the first salmon were reported from ANMPA waters (K. Dunmall and D. McNicholl, DFO, unpublished data). Many knowledge gaps exist concerning their habitat use and spawning success, as well as potential for interactions with other fishes in Darnley Bay. Unlike Arctic Char and Broad Whitefish, salmon are generally not targeted for subsistence by the fishers from Paulatuk.

The potential expansion of other fish and invertebrate species into the ANMPA has not yet been investigated. Because thorough species inventories for non-harvested fish and invertebrates began only recently in Darnley Bay, it may be difficult to ascertain whether a newly observed lower-trophic level species represents a potentially colonizing species, or simply the first detection of a species that had occupied the ANMPA for some time. For example, the first records of Banded Gunnel and Bering Wolfish in Darnley Bay occurred in July 2019, but are suspected to be first observations rather than evidence of potentially colonizing species (McNicholl et al. 2020). Habitat suitability modelling for the entire Canadian Arctic suggested coastal habitats in the southern Amundsen Gulf may be suitable for the establishment of some invasive invertebrates that are considered high risk for introduction via shipping (Goldsmit et al. 2018). However, targeted modelling of Darnley Bay has not been conducted, and no known invasive invertebrate species have yet been recorded in the ANMPA.

6.9.2. Strategies and application

Monitoring the occurrence and timing of potentially colonizing species can be accomplished by evaluating the species lists accumulated by annual surveys designed to monitor zooplankton, benthic invertebrates, inshore fish, and offshore fish community composition and structure (*Sections 6.3* to *6.5*), if detailed taxonomic data are collected in each survey. Detailed taxonomic data would provide presence/absence as well as relative abundance estimates for any potentially colonizing species identified. In this case, monitoring potentially colonizing species would represent an added-value indicator, as it simply requires re-purposing data already collected for other indicators. Relative abundance data, collected either qualitatively or quantitatively, could be used to track trends in abundance and identify whether the potentially colonizing species is becoming more prevalent. Relative abundance may be important to predict whether the species is likely to have a significant impact on the ANMPA ecosystem. A protocol should be developed for reporting and preserving specimens that appear unusual to experienced technicians during field collections (e.g., voucher photos, formalin preservation) so potentially colonizing species can be verified by experts, even if detailed taxonomic analyses are not planned. Anecdotal observations of potentially colonizing species should be recorded for potential future investigation. Whenever possible, the habitat within which the potentially colonizing species was observed should be recorded, to allow for inferences regarding the native species with which it may interact and potentially to develop response measures if such become necessary.

Outside of detailed taxonomic surveys, environmental DNA (eDNA) can be used to detect the presence of potentially colonizing species, and can be incorporated into a community-based monitoring program (Larson et al. 2020). The use of eDNA for estimating biodiversity and detecting invasive species has already been tested in Arctic waters and could improve the efficiency of Arctic biomonitoring, although it may still need standardization (Lacoursière-Roussel et al. 2018) and will require follow-on ground-truthing.

Monitoring the potential colonization of the ANMPA and nearby rivers by Pacific salmon was identified as a priority by the ANMPA Working Group. It is recommended that close collaboration continue with existing programs that document the annual number of Pacific salmon occurrences and their locations. Understanding Pacific salmon habitat use and interactions with Arctic Char is a topic of targeted research rather than of monitoring, but monitoring data will be useful in that endeavor. For potentially colonizing species that utilize the ANMPA for only part of the year, such as salmon, documenting the timing of arrival and/or departure as observed by community members or monitoring programs could provide clues about the causes of migration to the area.

Habitat suitability and risk assessment modelling can help determine the likelihood that a potentially colonizing species will be able to establish and thrive in the ANMPA (e.g., Goldsmit et al. 2018, 2019). As discussed in *Section 5.3*, high quality information on local habitat conditions is a pre-requisite for habitat suitability modelling, making it a potential tool for the future once monitoring has established baseline habitat conditions.

The effects of a newly colonizing species cannot be determined without documenting trends in the species with which they potentially interact (e.g., switch in predator diet compositions, changes in the abundances of potentially competing native species). This indicator will thus be tightly linked to other indicators of biological and food web integrity, but the exact ones will depend on the potentially colonizing species identified.

6.10. MARINE BIRD PRESENCE/ABSENCE AND PREY ITEMS

The Cape Parry Migratory Bird Sanctuary is home to nesting colonies of Thick-billed Murres and, to a lesser extent, Black Guillemots that are unique within the southern Beaufort region (Johnson and Ward 1985). The area offshore of Cape Parry is considered important marine feeding habitat that supports the nesting colonies during summer, as well as several species of staging migratory waterfowl during spring and fall. Seabird conservation and management fall within the jurisdiction of Environment and Climate Change Canada through the Canadian Wildlife Service (CWS), and do not technically fall within the management jurisdiction of marine protected areas through DFO.

Ecologically, however, seabirds are integral members of the marine food web as mobile, upper-trophic level predators that rely on forage fish and benthic invertebrates (e.g., Hobson and Welch 1992, Gaston et al. 2003). Protection for seabirds is most effective when it involves both terrestrial breeding grounds as well as their adjacent marine feeding habitats (Mallory et al. 2019). The protection of marine foraging habitat for seabirds and marine mammals was part of the rationale behind recommending the Cape Parry offshore area for inclusion in the ANMPA (DFO 2011). The availability of productive waters and abundant pelagic forage fish appear to underpin the success of seabird colonies in the Arctic (e.g., Provencher et al. 2012, Divoky et al. 2015, Harwood et al. 2015c, Mallory et al. 2019). Dickson and Gilchrist (2002) speculated that foraging opportunities may be the reason that nesting colonies of Thick-Billed Murres only occur at Cape Parry in the western Arctic despite the suitable cliff habitats available at Nelson Head on Banks Island. Marine bird prey items can also indicate change in the marine ecosystem, as nest provisions can reflect the relative availability of food sources in response to large-scale environmental drivers (Gaston et al. 2003, Provencher et al. 2012, Divoky et al. 2015, Mallory et al. 2019). Monitoring seabird presence/absence and prey items is thus recognized as relevant to evaluating whether the northern ANMPA remains productive for higher trophic feeding, but it is recommended to defer monitoring for reasons outlined below.

6.10.1. Available information

Presence/absence and diet information is available for the ANMPA from Indigenous Knowledge. At a workshop held in Paulatuk in 2011, knowledgeable community members selected by the HTC noted the locations of nesting areas for several marine birds, and the remains of benthic invertebrates (crabs and shrimp) observed around some nesting sites (Kavik-AXYS Inc. 2012).

In addition to Indigenous Knowledge, presence/absence and abundance data are available for the Cape Parry Migratory Bird Sanctuary from intermittent censuses conducted every one to five years by the CWS (D. Hogan, Canadian Wildlife Service, pers. comm.).

Virtually no detailed data on migratory marine bird forage are currently available for the Cape Parry area or the ANMPA in general. In the western Beaufort Sea, long-term monitoring programs at two Black Guillemot colonies documented that a dietary switch from predominantly Arctic Cod to predominantly sculpins was associated with declines in chick growth, condition, and survival (Divoky et al. 2015, Harwood et al. 2015c). In both cases, nest provisioning with sculpins was coincident with low Arctic Cod availability due to shifting Arctic Cod distributions (Cooper Island, Alaska) and relatively low abundances (Herschel Island, Yukon) (Divoky et al. 2015, Harwood et al. 2015). Similar shifts from Arctic Cod to Capelin were observed in nest provisions of Thick-billed Murre colonies in the eastern Canadian Arctic in response to changing relative abundances in pelagic forage fish, but the energetic consequences remain uncertain (Gaston et al. 2003, 2005, Provencher et al. 2012).

6.10.2. Strategies and application

It is recommended that specific strategies for monitoring marine bird presence/absence and prey items be considered after the co-management plan for the Cape Parry Migratory Bird Sanctuary (currently underway) has been developed. At that time, the ANMPA Working Group may reconsider how an indicator for marine birds can be best incorporated into the ANMPA monitoring plan. Until then, marine bird prey items in the marine environment can be inherently monitored through the indicators described for benthic invertebrates, offshore fish, and forage fish communities (*Sections 6.4, 6.5, and 6.7*). Data on the relative abundance of prey offshore of Cape Parry can later be used to test the hypothesis that prey availability is related to seabird nest provisions, condition, or presence (see *Section 6.5*). Access to data from intermittent CWS population surveys at Cape Parry may be requested at any time.

6.11. MARINE MAMMAL PRESENCE/ABSENCE, TIMING, HABITAT USE, AND GROUP COMPOSITION

Hypotheses and/or predictions of change:

- Changes to ocean-sea ice-atmosphere interactions that influence the distributions and abundances of zooplankton and forage fish prey will concomitantly influence the presence/absence, habitat use, and group composition of marine mammals within the ANMPA.
- Changes to sea-ice extent and break-up/freeze-up timing will influence the timing of arrival and departure for migratory marine mammals in the ANMPA, as well as the distribution and habitat use of Ringed and Bearded seals.

- Increased human activities in the area (vessel traffic, anthropogenic underwater noise, industrial activities) will affect marine mammal movements and habitat use.

The COs for the ANMPA focus on conserving the marine habitat and forage species that support key upper-trophic level species. The habitat of Arctic marine mammals is threatened by climate-induced variability and changes in sea-ice characteristics, ocean acidification, species distributions, prey availability, and trophic structure (Laidre et al. 2008, Huntington 2009, Choy et al. 2017), as well as by increasing anthropogenic activity such as hydrocarbon development, infrastructure/port development and operation, and vessel traffic (e.g., Richardson et al. 1987, Harwood et al. 2012, Quakenbush et al. 2012, DFO 2014, Reeves et al. 2014) . Beyond recording presence/absence of marine mammals in the ANMPA, monitoring the timing of arrival and departure, habitat use, and group composition is the first, and most practical, step in evaluating whether the marine habitat in the ANMPA region is supporting the requirements of each species. These data will provide the contextual information needed to track potential changes in habitat use over time by different segments of the population, and to investigate potential avoidance of anthropogenic activities (e.g., Richardson et al. 1987, Halliday et al. 2019). In turn, data on environmental conditions, sea-ice characteristics, prey composition, and other habitat variables will be especially important to infer underlying reasons for potential changes in habitat use.

Six Valued Ecosystem Components were identified within the ANMPA by scientific review and by the ANAOI Steering Committee based on Indigenous Knowledge compiled for Darnley Bay by Paulatuk knowledge holders (DFO 2014). Valued Ecosystem Components included three marine mammals of high cultural and subsistence value to the Inuvialuit: Beluga Whale (Qilalugaq / *Delphinapterus leucas*), Ringed Seal (Natchiq / *Phoca hispida*) and Bearded Seal (Ugyuk / *Erignathus barbatus*) (DFO 2011, 2014, Paulatuk Hunters and Trappers Committee et al. 2016). Bowhead Whale (Arviq / *Balaena mysticetus*) was not identified as a Valued Ecosystem Component in any formal review process, but is included in the current review because it is of interest to the residents of Paulatuk (see Appendix A for community priorities identified by the ANMPA Working Group), there are substantial baseline data available, and Bowhead habitat use is often associated with other indicators of ecosystem productivity (see review below). A sensitivity analysis performed by Laidre et al. (2008) suggested that Beluga and Bowhead whales were considered “moderately sensitive” to climate change due to high site fidelity, migratory behaviour, and low potential growth rates. Ringed and Bearded seals were considered highly sensitive to loss of sea-ice habitat, but were otherwise ranked as less sensitive due to their large circumpolar population sizes, flexible habitat and feeding requirements, and high potential population growth rates (Laidre et al. 2008).

Brief descriptions of species ecologies for marine mammal populations that utilize the ANMPA and nearby waters are provided here for context. For detailed summaries, which are beyond the scope of this review, see Chambers and MacDonell (2012), Paulic et al. (2012), and Paulatuk Hunters and Trappers Committee et al. (2016).

Beluga from the EBS population are traditionally harvested for subsistence by Inuvialuit as the whales migrate from the Bering Sea to their summering grounds in the western Canadian Arctic. Beluga Whales usually enter Darnley Bay from about mid-July to late August or early September. Harvesters from Paulatuk will hunt them from a number of locations around the bay including Brown’s Harbour, Johnny Green Bay, Fish Lake, Argo Bay, Egg Island, and Tippitiuyak . The EBS Beluga population was last estimated at approximately 39,000 whales (DFO 2000). Harvest levels are currently considered sustainable (Harwood et al. 2015a).

Bowhead Whales are considered a Species of Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2009). Whales from the Bering-Chukchi-Beaufort stock migrate annually from their overwintering grounds in the Bering Sea to feed in the Canadian Beaufort Sea and Amundsen Gulf during summer (e.g., Quakenbush et al. 2012). At a workshop held in 2011 to document and compile Indigenous Knowledge, knowledgeable community members selected by the Paulatuk HTC reported seeing Bowhead feeding in Darnley Bay every year in July or August, sometimes in groups of up to 12 individuals (Kavik-AXYS Inc. 2012). Bowhead were reported to sometimes be observed offshore the mouth of the Hornaday River and close to shore, but were not known to enter Argo Bay (Kavik-AXYS Inc. 2012).

Ringed Seals are the most abundant and widespread pinniped in the ANMPA and adjacent waters, and are valued by Inuvialuit as a source of food and fur (Kavik-AXYS Inc. 2012, Paulatuk Hunters and Trappers Committee et al. 2016). Unlike Beluga and Bowhead whales, Ringed Seals occur in the Canadian Beaufort Sea year-round. Ringed Seals use sea ice to construct protective subnivean birthing lairs in late March to early April (preferably on landfast ice), followed by a nursing period (average 6 weeks) and mating period prior to the June moulting period (e.g., Smith 1987, Smith 1991). Ringed Seals also use sea ice as a platform for pelagic foraging during summer and fall (e.g., Smith 1987, Smith 1991, Kavik-AXYS Inc. 2012). Consequently, Ringed Seals are expected to be particularly sensitive to the continued loss of sea-ice habitat as the climate warms (Laidre et al. 2008). Although it is rare for Ringed Seals to pup or haul-out on land, some populations outside of the western Arctic have been known to do so and may indicate a potential for adaptation to reduced spring sea ice (reviewed in Laidre et al. 2008, Lydersen et al. 2017). However, hauling out on land is likely not a feasible solution for rearing pups due to increased predation and thermoregulation stress (Lydersen et al. 2017).

Bearded Seals are less common and less well-studied than the other three key marine mammal species. Inuvialuit value Bearded Seals for their fur and leather, and for food and dog food (Paulatuk Hunters and Trappers Committee et al. 2016). Bearded Seals occur in the Canadian Beaufort Sea and Amundsen Gulf year-round, with no published evidence for regular migratory patterns. Bearded Seals in the Canadian Beaufort Sea and Amundsen Gulf tend to occur near moving ice, shore leads, and polynyas in shallower waters of the continental shelf (e.g., Stirling et al. 1977, 1993). Ice is important habitat for pupping and hauling out (Smith 1991, Stirling et al. 1993), although Bearded Seals may occasionally haul-out on land as well (reviewed in Laidre et al. 2008).

6.11.1. Available information

The Inuvialuit and their ancestors have sustainably harvested marine mammals for centuries, and have developed a deep understanding of their habitat use, behaviours, and migratory patterns (Kavik-AXYS Inc. 2012, Ostertag et al. 2018). The review of baseline data provided below draws upon available scientific data, and Indigenous Knowledge specific to Darnley Bay shared by and documented from knowledgeable community members selected by the Paulatuk HTC during a workshop in 2011 (Kavik-AXYS Inc. 2012), and by Indigenous Knowledge published in the Paulatuk Community Conservation Plan (Paulatuk Hunters and Trappers Committee et al. 2016). The review below does not cover the substantial amount of unpublished information held by traditional and local knowledge holders, which will further inform the final monitoring plan design during the co-development process.

Aerial population surveys for marine mammals have been intermittently conducted in the Canadian Beaufort Sea since the 1970’s. Although surveys generally targeted a specific species, non-target marine mammals were also opportunistically counted. Data are available from aerial population surveys conducted between 1971–1975 between the Alaskan border and Darnley Bay (e.g., Fraker 1979, 1981, Stirling et al. 1993, Hoover et al. 2016), and represent some of the only aerial survey data collected in the springtime (March to May) for this region.

Later aerial surveys only covered the Canadian Beaufort Sea as far east as Cape Bathurst, including those conducted in July to September of 1980 (Norton and Harwood 1985, Richardson et al. 1987, see list of studies in Harwood et al. 2010), in late July of 1992 (e.g., Harwood and Norton 1996), in late July of 2007–2009 (e.g., Harwood et al. 2010, 2015a), in June of 2011–2013 (e.g., Hoover et al. 2016), and most recently in late July of 2019 (M. Marcoux, DFO unpublished data). Detailed information for most aerial surveys flown in the Canadian Beaufort Sea up to 2012, covering areas as far east as Cape Bathurst, are summarized in Hoover et al. (2016).

Given the importance of Beluga to traditional diets, substantial data have been collected over the past few decades on the presence/absence, timing, habitat use, and group composition of Beluga in Darnley Bay, and the ISR in general. A description of Indigenous Knowledge on the typical Beluga migration patterns and group compositions in the ANMPA vicinity is provided in Kavik-AXYS Inc. (2012), shared by knowledgeable community members during a workshop in 2011. Aerial survey data from the 1970's suggested that Beluga tended to utilize areas of heavy pack ice near the shelf-break during the spring, while avoiding open water and heavy land-fast ice (Asselin et al. 2011). Use of shelf-break habitat was hypothesized to be associated with foraging (Asselin et al. 2011, Hornby et al. 2017), as this corresponds with aggregations of bottom-dwelling Arctic Cod (Geoffroy et al. 2011, Majewski et al. 2016), an important forage species for Beluga (e.g., Loseto et al. 2009, Choy et al. 2017, 2020). Analyses of summer distributions from later aerial surveys (2007–2009) and of distribution and diving behaviour from telemetry studies (1993, 1995, 1997, 2004–2005, 2018–2019), supported the hypothesis that Beluga distributions in both offshore and nearshore waters were related to factors indicative of favourable foraging conditions (Hauser et al. 2014, Hornby et al. 2017, L. Loseto, DFO, unpublished data). Satellite telemetry tagging studies of Beluga Whales were carried out in 1993 (n = 4 whales), 1995 (n = 16), 1997 (n = 7), 2004 (n = 9), 2005 (n = 4), 2018 (n = 14), and 2019 (n = 40) on whales tagged in the Mackenzie River Estuary. Results of Beluga telemetry studies from the 1990's are published in Richard et al. (1997, 2001); those from 2004–2005 are published in Hauser et al. (2014). Results of tagging conducted from 2018–2019 are ongoing and not yet published (L. Loseto, pers. comm.). Tagging data revealed substantial inter-individual variation in movement patterns. Some individuals travelled northward into Prince of Wales Strait, M'Clure Strait, and/or Viscount Melville Sound, while others circulated between the Mackenzie Estuary and the offshore Beaufort Sea or Amundsen Gulf for several weeks (Richard et al.1997, 2001, Hauser et al. 2014, L. Loseto, DFO, unpublished data). All EBS Beluga in the studies were instrumented in the Mackenzie Estuary and none of the tagged whales entered Darnley Bay, possibly as an artefact of biases in the capture location and timing, raising new questions about population structure of EBS Beluga. Whales are not observed to enter Darnley Bay every year. Whales sampled from harvests in Darnley Bay had lower mercury concentrations and stable isotope values than those harvested on Hendrickson Island, and whales tagged near Hendrickson Island did not enter Darnley Bay, prompting questions about whether the whales using Darnley Bay are a separate cohort from the whales for which tagging data exist (Paulic et al. 2012, Ruben et al. 2013). Nonetheless, tagging data identified broad habitat divisions related to size and sex that are applicable to whales utilizing the ANMPA: females with calves and small males selected coastal open water habitat, whereas larger males selected habitat in deeper waters near the ice edge or under heavy sea-ice (Barber et al. 2001, Loseto et al. 2006). The size- and sex-based segregations in habitat use are in agreement with observations by Paulatuk residents, who reported that whales entering the ANMPA in late July are comprised mainly of females with calves and some small males, whereas a group of larger adults remain in deeper waters offshore the Parry Peninsula (Kavik-AXYS Inc. 2012). A group of mostly large males may enter Darnley Bay later in the summer (termed "stragglers"; Kavik-AXYS Inc. 2012). The mouths of the Hornaday and Brock rivers are thought by residents of

Paulatuk to be important feeding grounds for Beluga, whereas Argo Bay may also be used for rubbing on rocks to aid in moulting (Kavik-AXYS Inc. 2012, Paulic et al. 2012). Additional research is needed to identify why Beluga Whales enter Darnley Bay, understand the importance of observed rubbing and moulting behaviours, and determine whether those rubbing habitats should be of monitoring interest. An unprecedented number of Beluga Whales were observed and harvested near Ulukhaktuk in 2014, where Beluga were previously known to occur only sporadically (Loseto et al. 2018). Although the occurrence was not directly related to the ANMPA, the unusual Beluga movements were thought to be driven by prey availability linked to environmental conditions at a large geographic scale (Loseto et al. 2018a), which would likely affect movements within the ANMPA.

Annual harvest-based monitoring of the EBS Beluga in the ISR is conducted through the standardized, community-led FJMC Fish and Marine Mammal Community Monitoring Program (formerly the “Beluga Monitoring Program”; Harwood et al. 2002, FJMC 2013, Paulatuk Hunters and Trappers Committee et al. 2016) linked to the Beluga Health Research and monitoring Program. The Beluga Monitoring Program was jointly established in 1980 by DFO and the Hunters and Trappers Committees of the six communities in the ISR to record harvest information, and to collect biological data and samples on landed whales. The program has been led by the FJMC since 1987. It is one of the longest standing monitoring programs in the Canadian Arctic. Prior data on Beluga harvests are also available from harvest monitoring programs conducted in the Mackenzie Estuary by the Fisheries and Marine Service of the Government of Canada (1973–1975) and the oil and gas industry (1977–1982; summarized in Harwood et al. 2002). Currently, Beluga Monitors hired by the local HTCs in partnership with the FJMC (Harwood et al. 2002) travel each summer to traditional whaling camps where they work with harvesters to collect information about the harvest timing and conditions, record observations on physical characteristics of the whales, and take tissue samples for later analysis by DFO Science and their colleagues (e.g., Harwood et al. 2015a, Loseto et al. 2018). As a result, data on location and date of harvest, sex, length, girth, fluke width, blubber thickness, colour, and harvester observations are available for Beluga Whales harvested in Darnley Bay since 1989 (Harwood et al. 2020) (although note the data do not necessarily represent all landed whales as the program is voluntary) in addition to health metrics (e.g., Ostertag et al. 2019, Choy et al. 2022). Data reports detailing methodology and summarizing data collected through harvest monitoring programs are available for 1970–2015 in (Harwood et al. 2020).

A Bowhead Whale tagging study has been led by the Alaska Department of Fish and Game since 2006, in collaboration with the Alaska Eskimo Whaling Commission, Whaling Captain’s Associations of Barrow, Kaktovik, Gambell, and Savoonga, the Aklavik and Tuktoyaktuk Hunters and Trappers Committees, the North Slope Borough, the Barrow Arctic Science Consortium, the DFO, and the Greenland Institute of Natural Resources. Maps of Bowhead movements are available from the Alaska Department of Fish and Game website. Between 2006–2017, there have been 52 observations of tagged Bowhead in the offshore Amundsen Gulf and Darnley Bay area from May to September, with 16 observations of tagged whales (all juvenile males) entering the ANMPA boundaries (Alaska Department of Fish and Game unpublished data). Analyses of tagging and aerial survey data from Canadian waters revealed that Bowhead form large, loose summer feeding aggregations between early August and early October, moving, to some extent, between shallow areas where their zooplankton prey are concentrated by oceanographic conditions (Harwood et al. 2010, 2017b, Walkusz et al. 2012). The most important feeding grounds in the southern Canadian Beaufort Sea appeared to be in shallow waters (20–50 m) off the Tuktoyaktuk Peninsula, and near Cape Bathurst (Harwood et al. 2010, Walkusz et al. 2012). Annually recurring feeding aggregations were also observed in shallow waters near the Mackenzie and Kugmallit canyons, in coastal waters off the Yukon

North Slope, across the Beaufort Shelf, in Viscount Melville Sound, in Franklin Bay, and occasionally, in Darnley Bay, Alaska Department of Fish and Game unpublished data, BREA MFP/CBS MEA unpublished observation). Group composition differed among feeding grounds, with juvenile whales rarely venturing eastward of Cape Bathurst (Harwood et al. 2017b). Between 1987–2016, four stranded adult and sub-adult Bowhead Whales have been found in Darnley Bay by hunters from Paulatuk and Sachs Harbour, one being within ANMPA boundaries (Harwood et al. 2017a).

Aerial survey data for Ringed and Bearded seals are only available from June of 1974–1979 (L. Harwood, DFO, pers. comm.). Surveys indicated a relatively ubiquitous distribution of Ringed Seals within the ANMPA, with slightly higher densities in offshore regions (Stirling et al. 1982, L. Harwood, DFO, pers. comm.). Bearded Seals were observed in lower densities, mainly in areas north of Bennett Point (Stirling et al. 1982). These findings agree with regular observations by the residents of Paulatuk (Kavik-AXYS Inc. 2012). The Paulatuk Community Conservation Plan indicates that additional monitoring of seal reproduction and condition was conducted in Paulatuk between 1992–1994, Sachs Harbour between 1987–1989, in 1992, and between 2003–2007, and in Ulukhaktok between 1992–2014 (Paulatuk Hunters and Trappers Committee et al. 2016, Smith 1987). The body condition of Ringed Seals harvested near Ulukhaktok declined significantly between 1992–2011, and was correlated with later ice break up (Harwood et al. 2012b). Information collected near Sachs Harbour and Ulukhaktok may be useful to provide context if changes to Ringed Seal presence/absence, timing, or group composition are observed within the ANMPA (Insley et al. 2021).

Several telemetry tagging studies have been conducted to provide further insight on the movements and habitat use of Ringed Seals that utilize the ANMPA and the Amundsen Gulf. Ringed Seal adults and sub-adults were tagged at Cape Parry in 2001 and 2002 (n = 8), and near Ulukhaktok in 1999, 2000, and 2010 (n = 17; described in Harwood et al. 2012a, 2015b). Aerial survey and tagging data reiterated movement patterns reported by Indigenous Knowledge (Kavik-AXYS Inc. 2012), and revealed they were related to sex, age-class, season, and ice phenology (Smith et al. 1982, Harwood et al. 2012a, 2015b, Yurkowski et al. 2016). During the open-water season, Ringed Seals occupied large home ranges for foraging, including the Amundsen Gulf, Prince of Wales Strait, and Viscount Melville Sound (e.g., Harwood et al. 2015b, Yurkowski et al. 2016b). In late fall, adult seals moved into coastal areas with stable landfast ice to establish more restricted breeding territories, while sub-adults typically migrated westward as far as the Chukchi Sea (Harwood et al. 2012a, 2015b, Yurkowski et al. 2016b). The fall migration of sub-adults was thought to be driven by foraging opportunities (e.g., Smith 1987, reviewed in Harwood et al. 2012a, Yurkowski et al. 2016). Aerial surveys reported a decline in Ringed and Bearded Seal abundances in the mid 1970’s (Stirling et al. 1982) that was corroborated by residents of Paulatuk (Kavik-AXYS Inc. 2012).

Aside from the aerial surveys conducted in the 1970’s, information for Bearded Seal abundances, population structure, and movements are limited for the ANMPA region (Paulic et al. 2012). Residents of Paulatuk identify the western Amundsen Gulf, Franklin Bay, and nearshore regions of Pearce Point and Brown’s Harbour as important habitat for Bearded Seals (Kavik-AXYS Inc. 2012). Bearded Seals commonly haul out near Bennett Point (Kavik-AXYS Inc. 2012).

Information on marine mammal presence/absence, timing, location, and group composition may also be extracted from acoustic monitoring data (see *Section 7*) and harvest statistics. Marine mammal harvest numbers, locations, and associated observations for the Darnley Bay area were collected through the Inuvialuit Harvest Study (1988–1997 and 2016–2019), and are available from the Joint Secretariat (Inuvialuit Harvest Study — Joint Secretariat). Harvest numbers collected through the Inuvialuit Harvest Study from 1988–1997 for Paulatuk are published in The Joint Secretariat (2003). GIS shapefiles of abundance densities, diversity, and hotspots calculated from all satellite tracking data available up until 2018 are available by species group and season from Yurkowski et al. 2018b).

6.11.2. Strategies and application

Ongoing community-based monitoring programs can adequately provide information on the presence/absence, timing, locations, and group composition of Beluga Whales, Ringed Seals, and Bearded Seals. However, these operations are biased towards hunter preferences (e.g., sex, body size, health indicators) and the locations of traditional hunting grounds. Monitoring efforts would be bolstered by implementing a standardized method for reporting non-harvest observations of marine mammal species within the ANMPA and adjacent waters, which would strengthen the parallel use of Indigenous Knowledge and scientific data. A promising option is the "*Arctic Marine Observer App,"* which was co-developed with DFO Science and beluga harvesters from Paulatuk, Tuktoyaktuk and Inuvik with the purpose of collecting standardized, although opportunistic, observations on marine mammal occurrence, group composition, behaviour and habitat, with associated photographs and GPS locations (S. Ostertag, DFO, unpublished data). Administration of the app, including all associated data, has since been transferred to the Inuvialuit Joint Secretariat. The program has had limited uptake in the delta communities, but has been widely used by residents of Paulatuk (K. Hansen-Craik, Joint Secretariat, unpublished data). Such a program would especially improve the data available to monitor Bowhead Whale habitat use near the ANMPA, since Bowhead Whales are not typically harvested by Paulatuk residents. Continued intermittent satellite tagging programs and aerial surveys that include the ANMPA are likely to provide key information on larger-scale movements and, paired with data on environmental conditions and prey species distributions, could help tease apart the factors that attract marine mammals to the region. Short duration (~ 3 week), remotely-deployed tagging methods recently piloted in Kugmallit Bay (L. Loseto, DFO, unpublished data, 2018, 2019) can fill knowledge gaps related to movement and fine-scale habitat use and behaviour of beluga whales within Darnley Bay, and potentially response to vessel traffic. However, it should be recognized that satellite tagging and aerial surveys are expensive, difficult, and potentially not feasible to perform every year. Passive acoustic monitoring of vocalizations may also be used to monitor the presence of marine mammals, and can provide information regarding habitat use when paired with passive sampling of oceanographic parameters (e.g., as demonstrated for Beluga in the Mackenzie estuary by Scharffenberg et al. (2019). Note that acoustic monitoring, while potentially powerful, has some limitations (*see Section 7.1*).

The ANMPA COs do not emphasize marine mammal health, however, health parameters may provide additional context for understanding data collected through a monitoring program. If marine mammal health is integrated into a monitoring plan, it is recommended to standardize with the existing Beluga Health Research and Monitoring program. Health parameters co-developed using Indigenous Knowledge and scientific knowledge have been collected as part of the Beluga Health Research and Monitoring program in the Tarium Niryutait Marine Protected Area since 2015 (Ostertag et al. 2018), and at all Beluga monitoring locations across the ISR including Darnley Bay, since 2017 (FJMC unpublished data).

It should be noted that monitoring marine mammal presence/absence, timing, habitat use, and group compositions will not provide a direct evaluation of whether the COs are being met, as suggested in previous science advice (DFO 2015, Schimnowski et al. 2017). The health, demographics, or movements of populations may change under the influence of pressures outside of the ANMPA, especially for marine mammal species that migrate or have large home ranges (e.g., Loseto et al. 2018b). Nonetheless, monitoring within the ANMPA may uncover "red flags" that warrant further investigation. Accessing information from population studies or surveys conducted at broader regional scales will be important for providing the context necessary to evaluate whether action within the ANMPA will aid in conservation measures. As underscored in previous science advice (Schimnowski et al. 2017), the four key marine mammal species discussed here differ in their trophic status and role in the ecosystem, as well as their sensitivity to habitat change/disturbance (Laidre et al. 2008). When using monitoring data to evaluate potential reasons for change, consideration must be given to differences in life history, migration, habitat use, foraging, physiology, and other factors that may attract each species to the region.

7. INDICATORS OF PRESSURES AND THREATS

7.1. ANTHROPOGENIC UNDERWATER NOISE

Hypothesis and/or predictions of change:

- Marine mammals, especially Beluga Whales, will be affected by vessel-generated underwater noise such that their movements and habitat use in the ANMPA will be influenced by the prevalence of anthropogenic underwater noise.

Anthropogenic underwater noise has the potential to interfere with communication between marine mammals (Protection of the Arctic Marine Environment 2019), the detection of prey and predators and, in the case of whales, echolocation. Beluga appear to be particularly sensitive to underwater noise pollution from vessel traffic. Beluga adjust their communication behaviours in response to vessel noise, and avoidance responses appear to be different between large and small vessels (Halliday et al. 2017a, 2019). Vessel traffic in the Canadian Arctic is increasing as sea-ice declines, and one of the major Northwest Passage shipping corridors crosses the mouth of Darnley Bay just north of the ANMPA (Dawson et al. 2018). Wise Bay, on the western side of Cape Parry, is used as a safe harbour and staging area for large vessels throughout the summer. Anthropogenic underwater noise is also generated by supply barges, research vessels, and local transportation in small, community-owned vessels. Previous science advice listed underwater noise as a main potential pressure for the ANMPA ecosystem (DFO 2014), and the ANMPA Working Group identified it as a priority concern for monitoring (Appendix A). Consequently, monitoring the potential impacts of anthropogenic underwater noise on marine mammal behaviours and vocalizations is directly applicable to ensuring that the integrity of the ANMPA as a marine feeding habitat is not disrupted by human activities. The resulting information is directly applicable to developing management strategies to protect marine mammals from the impacts of anthropogenic underwater noise, such as establishing shipping and vessel routes that avoid sensitive areas or introducing regulations for vessel slowing or onboard marine mammal observers (McWhinnie et al. 2018, Pine et al. 2018).

As an added benefit, acoustic observations may contribute to monitoring the presence/absence, timing, and locations of marine mammals that vocalize (*Section 6.11*; Halliday et al. 2017b, Scharffenberg et al. 2019). Monitoring of ambient sound in the ocean will additionally enable characterisation of the natural soundscape of the area, with noise generated over a wide range of frequencies by ice movement, wind blowing snow on ice, thermal tension cracking, ridge building, ice break-up, and air bubbles generated by breaking waves or coastal surf. Such sounds may, at times, mask biological and anthropogenic sources of sound.

7.1.1. Available information

The first passive acoustic monitoring in Amundsen Gulf was conducted in the 1980s, with a specific focus on ice-associated noise in the ocean (Waddell and Farmer 1988, Xie and Farmer 1991, 1992).

Passive acoustic monitoring with a biological focus began only recently near the ANMPA under an initiative led by the Wildlife Conservation Society (WCS) Canada. Underwater noise was recorded year-round by a hydrophone moored near the northern ANMPA boundary in 2018–2019, and 2019-present. Three seasonal acoustic recordings were also made from July to September, 2019 in the southern ANMPA. Recordings are being used to quantify ambient background noise, monitor marine mammals and fish, and understand the impact of vessel-generated noise on marine life (WCS Canada: Arctic Noise). From a regional context, year-round passive acoustic monitoring has occurred near Sachs Harbour since 2014, and the summer soundscape was recently characterised in the vicinity of Ulukhaktok (Halliday et al. 2020a) and in Kugmallit Bay in the Tarium Niryutait Marine Protected Area (Halliday et al. 2020b).

7.1.2. Strategies and application

An array of moored passive acoustic recorders (hydrophones) can be used to characterise the underwater soundscape, and when integrated with marine vessel tracking data, can be used to track the responses of marine mammal communications to vessel-generated underwater noise, as has been done successfully in the Tarium Niryutait Marine Protected Area (Halliday et al. 2017a, 2019, 2020b). Vessel traffic data for the area can be purchased from AIS tracking services. It may be most strategic to support the acoustic monitoring program currently initiated in Darnley Bay.

Spatial heterogeneity in the sources of vessel noise, and the range at which hydrophones can detect noise, should be considered when choosing locations for acoustic recorders. Anthropogenic underwater noise will be dominated by sounds from small community-owned vessels in the southern reaches of the ANMPA, whereas large offshore vessels will be a more prominent source of noise in the northern reaches. If possible, attaching acoustic recorders onto mooring observatories deployed to gather data on oceanography, carbon fluxes, ice profiles, and/or fish and zooplankton aggregations would minimize costs and effort associated with deployment and retrieval while maximizing data output per effort (see *Sections 5.1, 5.3, 6.3 and 6.5*). The length of time the acoustic moorings are deployed should cover the length of the open-water season at a minimum, but would ideally be year-round to capture ice-breaking vessels and wintertime marine mammal activity (seals and potentially Bowhead Whales).

7.2. CONTAMINANT CONCENTRATIONS IN THE ENVIRONMENT AND IN MARINE MAMMALS

Hypotheses and/or predictions of change:

- Positive or negative trends in migratory marine mammal contaminant concentrations will reflect environmental and/or dietary exposures at the scale of their migrations, whereas those in resident marine mammals will be more closely linked to contaminant concentrations in the ANMPA environment and in locally available prey species.
- Concentrations of persistent contaminants (i.e., mercury) in marine mammals will be driven by trophic level and influenced by feeding strategy (where concentrations in Beluga Whales > Ringed Seals > Bearded Seals > Bowhead Whales), that can be compounded by climate

change influences on contaminant transport within the system and on the food web and food availability.

Contaminants or pollutants are terms used to refer to a suite of compounds or chemicals that are foreign to a local environment and cause harm. As such, monitoring contaminants is one approach to addressing impacts of human activities to the integrity of the marine environment. Often, contaminants of concern that are monitored are categorized as “PBT contaminants” because they a) *Persist* in the environment, are not easily broken down, and, in the case of the Arctic, are often transported to northern cold regions from southern locations, b) *Bioaccumulate* in organisms over time, resulting in food web biomagnification, and c) are *Toxic* and cause injury or harm. These three properties are often used to identify chemicals whose production should be eliminated or restricted under conventions such as the Stockholm Convention. PBT contaminants include organo- halogenated, brominated, and fluorinated compounds and the organic form of mercury (methyl mercury). However, there are contaminants that do not exhibit all of these properties yet are of concern due to the harm they may impose, such as radionuclides, polycyclic aromatic hydrocarbons (PAHs), metals, and microplastics.

Marine mammals, often due to their long lives, higher trophic levels, and large fat stores, are susceptible to PBT contaminants such as polychlorinated biphenyls (PCBs) and mercury (note mercury binds to proteins, whereas PCBs bind to lipids). PBT contaminants travel to the Arctic by air and water (both freshwater and marine) where they enter the base of food webs, bioaccumulate in individual organisms, and biomagnify up food webs to levels of concern (AMAP 2011, Loseto and Ross 2011). As a result, marine mammals are ideal indicators of contaminant trends, and depending on the type of contaminant provide context on the fate and transport pathways that can inform mitigation strategies. The predominant exposure route of PBT contaminants and microplastics to marine mammals is via diet (Bradney et al. 2019). Contaminant levels in marine mammals thus have added value as a food-web biotracer, and are especially powerful with combined with other food-web biotracers (see *Section 6.1*). Other compounds such as PAHs and radionuclides can cause harm via direct contact (e.g., acute injury with contact to skin, eyes, or inhalation) in addition to potentially being ingested, although they are metabolized quickly relative to PBT contaminants. Due to differing physio-chemical properties, such as the solubility in lipids and water, each contaminant is partitioned differently among air, water and sediment environments. Similarly, “microplastics” is a catch-all term that includes particles diverse in size, shape, chemical composition, and polymer class. These properties influence the prevalence of different microplastic compounds across different habitats (e.g., surface water, sediments, Rochman et al. 2019), which influences the exposure risk of each marine mammal species.

Consequently, understanding marine mammal feeding strategy and feeding habitat is critical to characterising risk from the dietary exposure of contaminants. Both trophic links and contaminants are important to consider together in monitoring plan design (see *Section 6.1*, Loseto and Ross 2011). Among the four marine mammals in the ANMPA, Beluga Whale and Ringed Seals feed at a similar trophic level (Yurkowski et al. 2016a, Choy et al. 2020). However, concentrations of mercury and organohalogens are typically three times higher in Beluga Whales than Ringed Seals (Gaden et al. 2009, Loseto et al. 2008a, Nöel et al. 2018, Houde et al. 2019) because a diet of invertebrates and smaller-sized fish places Ringed Seals at a lower exposure risk than Beluga. Bowhead Whales have lower exposure levels relative to Beluga Whales and Ringed Seals because they feed on small invertebrates and zooplankton at low trophic levels. The Bearded Seals benthic foraging strategy and diet results in a different exposure route that amplifies risk from sediment-bound or associated contaminants, which may range in concentration based on the prey species.

Monitoring the fate and transport of a select group of compounds to the ANMPA is relevant to the COs because it addresses disruption by human activities, and may provide a baseline against which future, unforeseen impacts may be measured (e.g., localized events, release of legacy contaminants from melting permafrost). However, it should be recognized that contaminants may not originate within the ANMPA or are not necessarily indicative of processes occurring within the MPA boundaries. Marine mammals are recommended for monitoring contaminant concentrations because they provide the best representation of exposure risk due to their long lives and position as top predators. In addition, monitoring contaminant concentrations in their primary prey is recommended to provide information on dietary pathways for contaminants. Because migratory marine mammal contaminant concentrations may reflect exposure outside of the ANMPA, understanding prey and supporting food web processes are important in light of climate change impacts on both the food web and contaminant transport.

7.2.1. Available information

Contaminant data for marine mammals in the ISR, specifically for OC's and mercury, spans back to the 1980s (Lockhart et al. 2005, Stern et al. 2005, Addison et al. 2005, 2009, 2014, Loseto et al. 2015, Nöel et al. 2018, Smythe et al. 2018, Houde et al. 2019). Contaminant monitoring has been ongoing since the 1970's for Ringed Seals based out of Sachs Harbour and Ulukhaktok, and out of Paulatuk in 1993, and since the 1980s for Beluga throughout the ISR, as a result of multiple initiatives and partnerships between communities, FJMC, DFO, Environment and Climate Change Canada, and support through Canada's Northern Contaminant Program (Crown-Indigenous and Northern Affairs Canada). The Fish and Marine mammal Community Monitoring Program (formerly known as the Beluga Monitoring Program) has collected tissues since 1980 and represents one of the longest standing monitoring programs in the ISR. Trends in mercury and persistent organic pollutants have been summarized for marine species of interest across the Canadian Arctic (Braune et al. 2005, 2015, Brown et al. 2018). Beluga Whales, Ringed Seals, and Polar Bears from the Beaufort Sea have higher mercury concentrations than those from other regions in the Canadian Arctic (Braune et al. 2015, Brown et al. 2019).

For Beluga Whales, the last 20 years of contaminant monitoring and toxicity effects research has been based out of Hendrickson Island, a core butchering location for Tuktoyaktuk hunters who land whales nearby and flense the whale at the island prior to returning to Tuktoyaktuk (Waugh et al. 2018). Trends in Beluga mercury concentrations have shown considerable fluctuations, with levels peaking in the late 1990s and early 2000s when they were higher than those measured in other Canadian Beluga populations (Lockhart et al. 2005). In recent years, Beluga mercury concentrations have declined (Loseto et al. 2015) and remained steady (Stern et al. 2017). Trends in legacy contaminants such as PCBs have not shown a decline over time (Nöel et al. 2018), despite a ban on the use of 12 well-known PBT contaminants by the Stockholm Convention. Some brominated and fluorinated compounds have shown mixed trends associated with congeners, but levels remain extremely low (Smythe et al. 2018). The lack of a declining trend in legacy compounds was also observed in Ringed Seals in Sachs Harbour and Ulukhaktok, where concentrations in the region are generally higher than other Canadian communities (Houde et al. 2019). Though not significant, there has been a 0.7% increase per year in Hg in ringed seal liver and a 2.3% decrease in Hg in ringed seal muscle over time (1972 to 2017, Houde et al. 2020). Mercury concentrations in Ringed Seal harvested in Ulukhaktok were higher following both short and long ice free seasons (Gaden et al. 2009). Recent work has shown ringed seal relationships with climate drivers such as the Arctic Oscillation (Houde et al. 2020).

Close examination of feeding ecology, habitat use and mercury concentrations in the EBS Beluga Whales revealed important relationships driven by size, sex and age associations (Loseto et al. 2006, 2008a, 2009). For example, larger-sized male Belugas that used ‘risky’ offshore habitats in heavy sea-ice concentrations had a diet high in Arctic cod and had higher mercury levels than smaller-sized Belugas that used coastal areas (Loseto et al. 2008a, 2009, Choy et al. 2020). These observations of size-, sex- and age-influenced movement and foraging strategies need consideration when monitoring contaminant trends (Loseto et al. 2008a, Douglas et al. 2012).

In the early 2000’s the community of Paulatuk harvested Beluga Whales more frequently and at higher numbers likely due to increased accessibility related to changing sea-ice trends and lengthening open water seasons (Harwood et al. 2015a, Loseto et al. 2018b). Although Beluga Whales landed in Darnley Bay are from the same EBS Beluga population as those harvested at Hendrickson Island, research from 2005 showed differences in mercury concentrations, diet markers and other biological measurements (Loseto et al. 2008a). This raised new questions about population variability and habitat use. As a result of new questions raised by Paulatuk, a focused contaminant tissue collection program began in 2011. In 2012, the PHTC and DFO secured funds to begin monitoring concentrations of mercury in harvested Beluga Whales along with diet biomarkers (i.e., stable isotopes and fatty acids) through the Paulatuk Beluga Health and Knowledge Project. Although the Northern Contaminants Program stopped funding the program in 2015, the contaminant monitoring has continued with support from DFO and FJMC. There have been a total of 11 years of Beluga tissues (liver, skin, muscle) analysed for mercury concentrations (1993, 2005, 2011–2016, 2018, 2019, 2020), with no whales landed in 2017 to collect samples and additional data pending for 2018 to 2020. Concentrations of mercury in Belugas collected from Paulatuk have typically been similar to concentrations measured at Hendrickson, unlike the observation in 2005 (Ruben et al. 2015). No trend was observed in mercury concentrations measured from 2005 to 2015 (n = 6 years), however, the recent additions of data for 2018 to 2020 will enable a decadal analysis.

Because vertebrates can metabolize PAHs, the concentrations in higher trophic species, such as Beluga, are extremely low (Muir et al. 1992). Beluga samples from 2005 at Hendrickson and Kendal islands in the Tarium Niryutait Marine Protected Area were analysed for 37 PAH compounds, all of which were not detectable (Wetzel et al. 2007). Beluga samples were also assessed for prevalence of metabolic endpoints associated with exposure (PAH-DNA Adducts), and indicated low to no exposure and effects (Poirier et al. 2018). However, trace levels of PAHs were detected in several Ringed Seal samples analysed from Tuktoyaktuk Harbour (Wetzel et al. 2007).

The Fukushima nuclear accident in 2011 prompted the analysis of EBS Beluga Whale samples from Hendrickson Island to assess exposure levels to the radiation before (2010) and after (2011) the accident. The main radionuclide of concern was cesium-137 (^{137}Cs), which has a half-life of 30 years and is a surrogate for potassium in biological systems, easily accumulating in plants and animals. Results revealed the Fukushima accident did not result in an increase in radioactivity from the atmospheric plume from the Fukushima accident (Stocki et al. 2016). It is important to note that while the Fukushima atmospheric plume has spread toward the western Arctic, with no measured effects on Beluga Whales, there is also an aquatic plume that has not been assessed.

Gastrointestinal tracts and feces were collected from seven Beluga Whales harvested at Hendrickson Island near Tuktoyaktuk to investigate potential microplastics ingestion by the EBS Beluga population (Moore et al. 2019). Microplastics were detected in the gastrointestinal tracts of every whale sampled, but were not of a size to cause intestinal obstructions and were thought to originate from trophic transfer through prey rather than from deliberate consumption (Moore et al. 2019). Five species of fish collected during the summer of 2017 and 2018 from Shingle Point in the Tarium Niryutait Marine Protected Area and from the offshore Beaufort Sea were analysed for the presence of microplastics, including Arctic Cod (*Boreogadus saida*), Saffron Cod (*Eleginus gracilis*), Arctic Cisco *(Coregonus autumnalis),* Four-horn Sculpin (*Myoxocephalus quadricornis),* and Capelin (*Mallotus villosus*) (Moore 2020). Microplastics were detected in all five fish species; an average 21 % of all samples investigated had plastic polymers, with a mean abundance of 1.42 ± 0.44 particles per individual. No particles > 5 mm were found, and 78 % of particles observed were fibers (Moore 2020). Samples of benthic invertebrates, fish, and zooplankton have been collected near/within the ANMPA by the Arctic Coast and the CBS MEA programs using methods conducive to potential future studies of microplastics (D. McNicholl, A. Majewski, A. Ehrman, and A. Niemi ,DFO, pers. comm.). Further research is required to determine the prevalence of microplastics in marine mammal prey items and the potential for trophic transfer.

7.2.2. Strategies and application

Sampling tissues for mercury and organic contaminants should be integrated into existing field collections, such as harvest monitoring programs, or else with sampling programs designed for indicators of biological and food web integrity within the monitoring program (e.g., *Sections 6.1, 6.7*, and *6.8*). This indicator thus represents “value-added” from sampling programs.

Many standardized approaches to measuring contaminants exist and have been adopted in existing sampling programs. It is recommended to sample harvested marine mammals in the ANMPA for the key tissues: muscle, liver and skin for mercury monitoring (liver reflects a lifetime burden and skin and muscle reflects more recent dietary exposures) and blubber and liver for organic contaminant monitoring. Note that contaminant loads measured in marine mammals may reflect processes occurring outside of the ANMPA, but will still provide context for understanding marine mammal health and vulnerability, and for contaminant transport to the ANMPA. Thus, measuring the same suite of contaminants in a few key prey species is recommended to understand the dietary exposure risk within the ANMPA, which may be particularly important for resident marine mammals (e.g., Bearded Seals) and for discerning relative exposure within and outside of the ANMPA for migratory marine mammals. Given known variability feeding behaviour, and thus exposure to contaminants, it is important to collect supporting size, sex, age data together with trophic biotracer information (stable isotopes, fatty acids) for both marine mammals and prey species. Specialized sampling gear are not required for sample collection and preservation in common chest freezers is sufficient.

Contaminants in tissues samples have low degradation rates in storage, and thus can be collected, inventoried, and analysed in the future if funds are not immediately available. It is impossible to predict the timing and occurrence of a future threat. Archiving tissues for potential future analyses is in line with a future-oriented approach to monitoring, allowing retrospective studies that can reconstruct contaminant levels before a threat occurred (see also *Section 5.3* on archiving sediments for potential future contaminant exposure in the environment).

Assessing the potential threat posed by ocean plastics to marine species was listed as a priority by the ANMPA Working Group. It should be noted that this remains a research question and it is uncertain whether it should be included as a monitoring objective. Little research has yet been published on the prevalence of microplastics in the marine environment of the western Arctic, especially for higher trophic animals. The health implications of microplastic ingestion at concentrations found in natural ecosystems remain uncertain for higher trophic animals (e.g., Carbery et al. 2018, reviewed in Moore et al. 2019). Methods for the standardized collection of microplastic samples from marine mammals, which are easily contaminated, are being developed by expert working groups (e.g., Arctic Monitoring and Assessment Programme). Due to the size of marine mammals, various approaches have been used including taking portions of intestines, examining stomachs and using feces. Recently the Beluga monitoring program based out of Hendrickson Island in the Tarium Niryutait Marine Protected Area has focused collections on feces when they are available, and has begun offering this option in all Beluga monitor kits. These methods may be modified to reflect updated approaches and may include sampling the end of the colon with feces (Moore et al. 2019). It is important to note little is known about the bioaccumulation or excretion rates of these compounds, or whether they present a problem. It is recommended that tissues or feces sampled to measure microplastic concentrations be archived for future analysis when funds are available and more is understood about their impacts.

When choosing the suite of organic contaminants to monitor, consideration should be given to those currently being monitored in the Tarium Niryutait Marine Protected Area. The ability to draw comparisons of mercury, organic contaminants, and microplastics across two marine protected areas that represent two very different environments may prove valuable when addressing sources and fates of contaminants.

7.3. OTHER THREAT CONSIDERATIONS

A future-oriented monitoring plan should remain flexible to incorporate new indicators of foreseeable anthropogenic threats. Otherwise, data are likely to be lacking to produce a credible baseline against which the effects of a threat can be measured (e.g., offshore drilling, nearshore mining, port construction or dredging). For example, although it was beyond the scope of this report, assessing pathogens and parasites in marine mammals was identified during the 2020 Science Advisory meeting as a potentially important indicator to incorporate into a future monitoring plan, as marine mammal health will have important top-down implications for the ANMPA food web. If selected in the future, standardization with health indicators that have been assessed and approved for monitoring in the Tarium Niryutait Marine Protected Area should be a key consideration.

The indicators recommended to provide background environmental context (*Section 5*) and those indicative of biological and food web integrity (*Section 6*) will remain applicable to evaluating the COs regardless of the specific threats that may impact the ecosystem. However, it is recommended that indicators of pressures and threats (*Section 7*) be treated as modular; their applicability should be re-evaluated on a regular basis, and indicators should be added or removed as threats become imminent or resolved. Some may be semi-permanent, such as monitoring pathogens in harvested marine mammals. Others may only be applicable for a few years to monitor a short-term activity.

8. UNCOMMON ECOLOGICAL AND ENVIRONMENTAL OCCURRENCES

There should be a means by which community members can report and provide documentation (photographs, etc.) of observations that appear to be ecologically important, or indicative of ecosystem change, but which are uncommon and do not fall within another indicator category. There is also value in logging uncommon environmental conditions, since such might provide insight into ecological events. These data would generally be considered non-quantitative and are not an indicator per se, but would be used to flag potential concerns that require further investigation, to provide context that may be important for understanding other data collected, or for stimulating research into a topic area. A definition of what is, and is not, considered an uncommon event will be important for determining the types of information recorded.

Unusual ecological and environmental events that occur outside of the ANMPA may also be relevant for planning or to provide context for observations within the ANMPA, such as unusual marine mammal behaviours or mortalities, or unusually high abundances of a specific species. Having a community-based outlet for reporting and recording such observations alongside other indicators in a monitoring plan will ensure the information is available to provide context when the data are analysed.

9. CONNECTIVITY AMONG INDICATORS AND PROGRAMS

No monitoring indicator discussed here is intended to stand alone. As the different components of the ecosystem are connected, so too are the indicators intended to monitor them. While individual indicators may be sufficient to test hypotheses regarding temporal or spatial trends for a single ecosystem component, none can provide enough information to test hypotheses about underlying drivers of change nor wider contexts of consequences of the changes. Consequently, the selection of which indicators are ultimately included in a monitoring plan for the ANMPA should consider how the individual indicators can support one another in a hypothesis-testing framework. The data available should be able to not only identify potential correlations, but also to test and reject competing hypotheses. For example, if Arctic Char abundance declined, the data available should be able to distinguish between several potential explanations such as prey availability (monitored through inshore fish community composition), potential competition with newly-arrived species (monitored through potentially colonizing species), harvest levels (monitored through community-based harvest monitoring programs), unsuitable environmental conditions in a given year (monitored through a suite of background environmental indicators), or a natural cycle in population demographics (monitored through intermittent stock assessments over the longer term).

Constraints on capacity in terms of time, resources, funding, workforce, and expertise underscore the need for the monitoring plan to be efficient in its implementation. A common pitfall of long-term monitoring programs is over-extension. The current review demonstrates that substantial data with the potential to support an ANMPA monitoring plan have been, and will continue to be, collected in the area. However, there are clear data gaps, and data collection has been disjointed. Greater cross-connection is needed between perceived ecosystem boundaries (e.g., coastal versus offshore), ecosystem components, research and monitoring programs, and organizations. Accessing and collating information across boundaries will be both a challenge and an opportunity. Capitalizing on research and monitoring programs that are implemented outside the direct control of ANMPA management bodies will be a key strategy for some indicators. In some cases, accessing data/information that are collected at a spatial scale larger than the ANMPA will be vital to increase the reach and contextual value of monitoring data (e.g., for migratory Beluga and Bowhead whales). In other cases, partnering with established data collection programs will optimize efficiency with respect to expertise, time, and funding (e.g., Arctic Coast, the Hornaday River and Brock River Arctic Char monitoring programs). Continuing and/or initiating relevant follow-on analyses from existing samples (e.g., archived fish) and data (e.g., ice charts, harvest information) can be a key strategy to establish baseline conditions, accumulate monitoring data, and develop research to better understand the system and provide fundamental ecological context for the monitoring.

10. KEY SYNERGIES AND EFFICIENCIES FOR SAMPLING PROGRAMS

- The transition from the freshened inner reaches of Darnley Bay to the more oceanic waters surrounding Cape Parry governs the availability of habitat for specific marine communities. Not all indicators will be applicable across the entire ANMPA, and in many cases the strategies and indices best suited to monitor an indicator may differ between northern and southern ecosystem regimes. It may be strategic to develop northern and southern, and/or offshore and inshore, sub-components of a monitoring plan, taking care to use comparable methods so connectivity between the various sub-regions can be investigated.

- Sampling for the following indicators can and should be integrated into a single field sampling program:
    - Core oceanographic parameters and nutrient concentrations (*Section 5.1*)
    - Under-ice, ice-associated, and open-water primary producers (*Section 6.2*)
    - Freshwater inputs and terrestrial linkages (*Section 5.5*)
    - Zooplankton community composition, structure, and function (*Section 6.3*) at core sites
- Sampling for community composition, structure, and function of benthic invertebrates (*Section 6.4*) and benthic inshore and offshore fishes (*Section 6.5*) may be completed with a single sampling program depending on the gear types chosen (e.g., a small benthic sled with a cod end will capture both if net specifications are adjusted to do so). Even if different sampling gears are chosen for fish and benthic invertebrates, sampling at the same locations will maximize linkages between communities. Ideally, basic oceanographic parameters (CTD casts) would be measured at biological sampling locations. If possible, sediment habitat characteristics (*Section 5.3*) should also be sampled at benthic fish and invertebrate sampling locations.
- Sediment composition data collected to inform the indicator for benthic habitat distributions (sediment grain size, organic matter content, benthic pigments, sediment δ^{15}N and δ^{13}C, C:N) can additionally be used to inform on benthic-pelagic coupling (*Section 6.2*), water circulation and current velocities (*Section 5.1*), coastal change (*Section 5.6*), and the extent and dominance of terrestrially-derived nutrients in nearshore areas (*Section 5.5*).
- Sampling for trophic biomarkers (*Section 6.1*) can occur concomitantly when sampling for community structure, function, and structure for primary producers (*Section 6.2*), zooplankton (*Section 6.3*), benthic invertebrates (*Section 6.4*), inshore and offshore fish (*Section 6.5*), forage fish (*Section 6.6*), and anadromous fish (*Section 6.7*). Sampling for trophic biomarkers in marine mammals can occur during harvest events if hunters are willing to provide samples (*Section 6.11*).
- Moored observatories can house instrumentation that will provide information on multiple indicators simultaneously, including all or a subset of: core oceanographic parameters; hydroacoustic observations of pelagic fish, zooplankton, and drifting ice; acoustic monitoring of background noise, fish and marine mammal vocalizations, and anthropogenic underwater noise.
- There are opportunities to maximize sampling efficiency and data utility by collaborating among programs to sample consistent locations across seasons or years for multiple indicators. A tiered approach could be taken, where a set of key long-term monitoring sites is established for sampling at the most frequent time scale, and a set(s) of supplementary sites are monitored on a less frequent basis. Sample archiving and preservation (e.g., dried, frozen, or chemical preservation) is an option for most indicators in years when funds for follow-on analyses are not immediately available. Moreover, archiving a select few “extra” samples would allow for future retroactive analyses that address newly emerging monitoring questions or utilize new technologies. However, sample archiving can be space consuming. Archival choices, both in terms of “what” and “from where,” should be carefully chosen to maximize impact while minimizing space needs. Archived animal tissues, sediment, and eDNA are likely to hold the most promise.

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APPENDIX A. MONITORING PRIORITIES PROVIDED BY THE ANMPA WORKING GROUP

Table A1. Monitoring priorities provided by the ANMPA Working Group to inform discussions of ecological monitoring indicators.

Theme	ANMPA Working Group Priority
Subsistence harvest	Collect, synthesize, and summarize existing subsistence harvest data for the ANMPA
	Provide for the ongoing, long-term collection and verification of subsistence harvest data for the ANMPA
Offshore	Summarize and examine trends in sea-ice concentration, timing of freeze up and clearance, movements, distribution and type of ice in the offshore ANMPA and adjacent waters past, present, and future
	Complete bathymetric chart of Darnley Bay and ANMPA for navigation, interpretation of biological data, and to understand patterns of circulation
	Identify and track forage fish communities offshore of Cape Parry, such as Arctic Cod, that sustain and attract marine mammals for foraging, particularly ringed seals year round and beluga whales seasonally
	Marine mammals: ensure and monitor continued use of the offshore ANMPA by subsistence species of marine mammals
Nearshore (< 20 m)	Understand the occurrence and significance of invasive species in the ANMPA, and how and if they interact with, compete and/or displace CO2 species
	Monitoring health and viability of forage fish stocks in the nearshore including capelin and Arctic Cod, their prey and their habitats in the nearshore ANMPA

Theme	ANMPA Working Group Priority
	Monitoring the health and viability of Arctic char stocks, their prey and their habitats in the ANMPA
	Monitoring the occurrence and diet of ringed and bearded seals, their prey and their habitats in the nearshore ANMPA
	Ensuring the health and viability of whitefish stocks, their prey and their habitats in the ANMPA
	Establish baseline of extent, concentration, type, timing of sea-ice in nearshore ANMPA, as substrate for travel, as seal and bear habitat, as ecosystem component.
	Complete a current bathymetric map for the ANMPA and Darnley Bay
	Establish patterns, timing, and location of areas in the ANMPA that attract beluga whales, and the reasons why they are attracted
Unusual Events	Collect, compile and centralize existing and new records/observations of unusual ecological events so that changes and shifts in ANMPA species, habitats and/or ecosystem can be identified (canaries in the coalmine approach)
Pressures/ Threats	Ensure that commercial shipping activity does not disturb or displace marine mammals, particularly beluga
	Ensure that large and small scale tourism activity in the ANMPA does not disturb or disrupt marine mammal use of nearshore habitats
	Ensure that discharges from ships do not degrade ANMPA habitats or species
	Assess and monitor the extent of ocean plastics in the ANMPA habitats and species

APPENDIX B. ANNOTATED BIBLIOGRAPHY OF PUBLISHED INDIGENOUS KNOWLEDGE SOURCES DRAWN UPON FOR THIS REVIEW

KAVIK-AXYS Inc. 2012. Traditional and Local Knowledge Workshop for the Paulatuk Area of Interest. KAVIK-AXYS Inc., Inuvik, NT and Calgary, AB. 46 p.

This report documents Traditional and Local Knowledge gathered during a 1.5 day workshop held in Paulatuk in March, 2011 on biota and plants within the vicinity of the Parry Peninsula and Darnley Bay, with a particular focus on the coastline between Cape Parry and Paulatuk. Twelve Inuvialuit residents of Paulatuk were selected by the Paulatuk Hunters and Trappers Committee (HTC) to participate, including a cross-section of age groups from youth to elders. A questionnaire co-developed by DFO and KAVIK-AXYS Inc. and a set of maps were used to guide discussions, and additional resources were available to assist participants (e.g., Paulatuk Community Conservation Plan, Inuvialuit Harvest Study Atlas, species pictures and reference books). The workshop included large open group discussions, break-out sessions in focus groups, and question-guided discussions, and ended with a session to clarify and validate information gathered. Information was recorded in written and video formats and summarized in the report produced by KAVIK-AXYS Inc.

McNicholl, D.G., Wolki, B., and Ostertag, S. 2017b. Traditional Ecological Knowledge and Local Observations of Capelin (*Mallotus villosus*) in Darnley Bay, NT. Can. Manuscr. Rep. Fish. Aquat. Sci. 3144: vi + 20 p.

In July 2015, DFO led a study to document historic observations made by Paulatuk community members regarding how long Capelin had been observed in Darnley Bay, where they were observed, if they were prey for important subsistence species, and if they had ever been harvsted for human consumption in Paulatuk. Indigenous Knowledge on Capelin was collected through interviews and a structured questionnaire delievered by an Inuvialuit youth selected by the Paulatuk HTC. Five knowledge holders were chosen to participate in interviews by the Paulatuk HTC based on their long-term experience at Cape Parry and along the Darnley Bay coast. Five additional Inuvialuit observers from Paulatuk volunteered to participate and share more recent knowledge of Capelin in the area. The questionnaires were reviewed and approved by various ethics committees and the Paulatuk HTC.

Paulatuk Hunters and Trappers Committee, Paulatuk Community Corporation, Northwest Territories Wildlife Management Advisory Council, Fisheries Joint Management Committee, and Joint Secretariat. 2016. Paulatuk Community Conservation Plan. Joint Secretariat, Inuvik, NT. 188 p.

The Paulatuk Community Conservation Plan is a community-based planning document originally prepared in 1990 by the Paualtuk HTC, Paulatuk Community Corporation, and Paulatuk Elders Committee to satisfy the first objective of the Inuvialuit Renewable Resource Conservation and Management Plan (1998). Updates to the Paulatuk Community Conservation Plan were undertaken in 2000, 2008, and 2016 by re-establishing working groups that included a cross-section of age groups from both Inuvialuit and non-Inuvialuit organizations, with considerable effort to include opinions and advice from Inuvialuit community members and government organizations. The plan describes the current conservation and resource management system in the ISR, a strategy to address conservation goals, processes for avoiding land use conflicts and cumulative impacts, and provides a brief overview of the ecology, habitat use, and cultural and economic significance of species of interest within the planning area. The plan is intended to express the goals of the Inuvialuit community with respect to the conservation of lands, water, and living resources.

APPENDIX C. KEY MONITORING PARAMETERS FOR EACH RECOMMENDED INDICATOR

Table C1. Key measurement parameters for monitoring core oceanographic parameters and nutrient concentrations (Section 5.1).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Temperature and salinity profiles (variation with depth)	Measurements of temperature and salinity at discrete depths, or continuously through the water column depending on technology/sampling technique. Allows basic classification of marine habitat, water mass distributions, circulation patterns, and upwelling/downwelling events that distribute the nutrients which support ecosystem productivity, especially when measured alongside nutrient concentrations. Can be used to track fresh water discharged from rivers and sea ice melt, especially when used with $\delta^{18}O$.	Identification of where preferred temperature and salinity conditions exist for primary producers, fish, and marine mammals Influences the formation and melting of sea ice, a key habitat of Arctic marine systems. Controls the stratification/mixing of the water column, which in turn is linked to nutrient availability in the upper water column and affects the location and timing of algal blooms, the composition of primary producer communities, and energetic transfer up the food web. Enables identification of upwelling and downwelling events, ocean circulation patterns, and determination of the depth of wind mixing, which are important for replenishing nutrients that support ecosystem productivity in the photic zone (see *Section* 6.2).	Most of the indices advised can be measured at one time with a single instrument equipped with multiple sensors. Physical water samples must be collected to measure nutrient concentrations (nitrate, phosphate, silicic acid), oxygen stable isotope ratios, and dissolved inorganic carbon (DIC). If measured using periodic sampling programs (i.e., technicians taking physical measurements at prescribed locations/times), careful consideration should be given to temporal and spatial resolution. The pattern of sampling builds the picture. Standard practice typically takes a two-tiered approach involving (1) relatively frequent sampling (every few weeks) at a few selected sites to observe seasonal variation, and to capture episodic events and their biological implications, and (2) less frequent sampling (one to three times annually) at a larger set of widely distributed sites to capture regional patterns and unusual events at a larger spatial scale, both within and outside of the ANMPA. It may be beneficial to use real-time continuous monitoring for some of these parameters at a select number of locations using moored instruments to get detailed data for part (1) of the sampling program. Moored acoustic Doppler current profilers (ADCPs) would be required for measuring current velocities.
Dissolved oxygen profile	Amount of dissolved oxygen available at all depths.	Links oceanography to habitat for upper trophic animals. Dissolved oxygen is required for most non-mammal marine life (e.g., zooplankton, fish, benthos). Anoxic conditions can indicate habitats unsuitable for many animals, and link the development of anoxia to oceanographic or biological conditions. Also used to indicate water mass distributions.	
Nitrate	Concentration of nitrate available throughout the water column.	In physical oceanography, inorganic nutrients contribute to determining water mass	

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Phosphate	Concentration of phosphate available throughout the water column.	distributions, the detection of upwelling/downwelling events and the determination of the depth of wind mixing. For primary production, nitrate and phosphate are limiting nutrients for growth of all autotrophic organisms. Silicic acid can be a limiting nutrient for diatoms, which can dominate phytoplankton communities in the Arctic. The nutrient supply available to primary producers in the photic zone not only influences the total potential primary production of the system, but also the types of primary producers that can thrive under those conditions. Large-sized diatoms that are palatable to larval fish and zooplankton grazers tend to dominate when nutrients are abundant, and thus promote efficient energy transfer to higher trophic levels. Small-sized phytoplankton that are better adapted to low nutrient concentrations do not transfer energy as efficiently to upper trophic levels.	Ideally, indices for primary production (see *Section 6.2*) would be measured concomitantly with core oceanographic parameters and nutrient concentrations. Micro-nutrients such as iron also influence primary production and food web processes.
Silicic acid	Concentration of silicic acid available throughout the water column.		
Dissolved inorganic carbon (DIC) and total alkalinity	Indicator of ocean acidification.	Cold water absorbs more CO_2 from the atmosphere than does warmer water, making Arctic waters especially vulnerable to ocean acidification. Acidic waters can disrupt a host of functions for zooplankton and benthic invertebrates that are sensitive to shell dissolution, such as pteropods, crabs, bivalves, and starfish. Consequences for many key prey species (e.g., *Calanus* spp., *Themisto* spp.) and fish larvae remain uncertain.	
Turbidity	Water clarity and amount of suspended particles in the water.	Determinant of habitat conditions for zooplankton, fish, and marine mammals. May limit light availability for visually detecting prey for some upper-trophic predators, and may limit light available for primary production. Can indicate energetic oceanographic events that re-suspend sediment from the seabed.	

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Oxygen stable isotope ratios (δ^{18}O)	Distribution of freshwater inputs.	Freshwater distributions influence the movements of some valued top predators, including Arctic Char and Beluga Whales. Enables the tracking of contaminants carried to the Arctic Ocean by inflows from rivers and the North Pacific Ocean. Influences the distribution of some prey species, such as zooplankton and forage fish, that prefer fresher waters. Influences the distribution of some benthic habitats and detrital food sources, as suspended terrestrial organic matter settles out of the freshwater plume. Influences primary production and primary producer species composition. Production may increase due to additional nutrients from freshwater sources locally, or decrease if suspended sediment load decreases light availability in the water column	
Current velocities and sea-ice drift	Water circulation patterns.	Currents (and sea-ice drift) are the means by which sea ice, river water, Pacific Water, Atlantic Water, their nutrients, dissolved oxygen, suspended sediment, contaminants, and plankton are delivered to the ANMPA from outside of the local ecosystem. Determines the way in which energetic oceanographic events (wind-driven water movements, upwelling, downwelling) occurring both within and outside of the ANMPA influence local habitat conditions, primary production, and habitat availability for animals at all levels of the food web. Without a better understanding of water circulation, it will be difficult to understand how the marine environment in Darnley Bay interacts with, and is influenced by, physical and biological oceanography in the larger Amundsen Gulf	

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
		system, which ultimately influence whether the ANMPA habitat will remain suitable for valued upper-trophic animals. Enables better biophysical modelling of habitats and prediction of the consequences of environmental change (e.g., storm events, changing wind patterns, etc.)	
Photosynthetically active radiation (PAR)	The amount of light available for primary production and the depth to which it penetrates.	Determines the depths at which primary production can occur and determines the period when photosynthesis (based on solar radiation) can take place. Important for modelling primary production of food webs; linked to primary production and other ocean parameters (e.g., suspended sediments).	
Underwater sound profiles (if also monitoring anthropogenic underwater noise)	The speed at which sound travels through the water, which depends on a number of the above-listed parameters of the water column, which vary with depth.	Sound speed is required to accurately interpret underwater noise data (See *Section 7.1*). If underwater noise is being measured, ambient underwater noise should also be monitored to tease apart natural from anthropogenic sources of noise.	

Table C2. Key measurement parameters for monitoring ice structures, snow and ice thickness, and ice break-up/freeze-up timing (Section 5.2).

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Timing of ice retreat (for fast ice), ice clearance (for pack ice), and ice formation	Key dates for the clearance and formation of sea ice, and the overall length of open-water season	Probably the most relevant index to overall ecosystem function in this category. The timing of sea ice clearance and formation affects the length of season for seal pupping; determines timing of arrival and departure migrations for Beluga Whales, Bowhead Whales, and young adult Ringed Seals at a regional scale, and seaward migrations of Hornaday and Brock River Arctic Char at the local scale; affects success of recruitment for Arctic Cod and	Annually; Can be obtained from satellite data, and back-calculations can be performed for previous years to create a baseline.

		Calanus zooplankton; and affects food and open-water availability for staging seabirds. Springtime ice-ocean-atmospheric interactions set the stage for primary production and nutrient replenishment Longer ice-free seasons can benefit some marine mammals, seabird, and Arctic Char by providing longer access to open-water foraging for important food resources, but is detrimental to ice-dependent species such as Ringed Seals and Polar Bears. Arctic Cod recruitment benefits from somewhat longer open-water growing seasons, but is also considered ice-dependent. Duration of open-water seasons for adjacent freshwater systems also affect nearshore habitats (e.g., amount of freshwater delivery and its coastal extent) which, in turn, may affect nearshore production and/or migratory and feeding patterns of nearshore biota including key species.	
Snow thickness	Availability of under-snow habitat for seals; proxy for how much photosynthetically active radiation is reaching algae below the ice (likely more important than ice thickness itself).	Imperative for Ringed Seal pupping in spring, which predominantly occurs on fast ice that formed the previous autumn. It may be especially important to monitor snow drift thickness where it accumulates against ice ridges. Together with sea-ice thickness, it affects the development of ice algal production in spring and early summer, which has cascading effects on all upper trophic levels.	At regular intervals while travel on ice is safe; at least once per month or more frequently (e.g., weekly). Snow depth measurements should be taken along transects so spatial variability can be examined. Transects should be longer than 25 m, with sampling at 1 m intervals. Transects should be completed both parallel and perpendicular to the snow drift direction.

Table C3. Key measurement parameters for monitoring benthic habitat distributions (Section 5.3).

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Bathymetry	Bathymetry for all of Darnley Bay.	From a biological perspective, bathymetry is required primarily to understand and build computer models of ocean circulation (prediction), which affects all marine life. Also identifies important habitat features (e.g., ridges, habitat depths, seafloor features, etc.).	One-time survey to set a baseline is highly recommended. Sounding lines spaced 1 to 2 km apart would meet the initial need.
Sediment composition/ benthic habitat mapping	The distribution of different sediment types (e.g., grain size) and habitat features.	Determines habitat types available to benthic fish and invertebrates, which contribute to the distribution of key benthic food sources for upper trophic animals. May identify attractive habitats for Beluga Whales (e.g., rubbing rocks), identify bottom-scour effects of ice-keeling (a natural disturbance), and identify unique or rare habitats (e.g., kelp). Linked to oceanography and ocean circulation (e.g., fast currents scour silt from the bottom and promote large sediment grain size) and to tracking the marine implications of coastal change (e.g., the effects of deposition of eroded material and terrestrial nutrients into nearshore areas). Pre-requisite for determining the locations of sensitive benthic habitats prior to any bottom-contact sampling for fish and benthic invertebrates, and to inform permissions for potentially damaging activities such as dredging and anchorage.	One-time survey to set a baseline is highly recommended; repeated on relevant timescales if related to a specific hypothesis, risk, or sensitivity (e.g., to monitor stability of shoreline habitats exposed to potential erosion). Modern multi-beam sonar for depth mapping also provides echo strength which can guide classification of benthic habitat.
Proxies for benthic food supply (e.g., organic matter content, benthic pigments, and stable isotope ratios ($\delta^{15}N$, $\delta^{13}C$), HBI, fatty acid composition of the sediments)	How much detrital food is available for the benthic food web, how it is distributed across space, and where it came from (e.g., freshly settled ice algae, phytoplankton, decaying marine matter, or terrestrial).	Linked to benthic species distributions, biomass hotspots, amount and type of primary production, and oceanographic processes, all of which influence food availability and foraging behaviours of upper-trophic marine mammals, fish, and seabirds.	Annually at a set of core sites that are distributed across different habitat types (locations determined by sediment composition). Stable isotopes provide the most information for the lowest effort and cost. HBI provides information on the relative availability of carbon produced by ice algae versus phytoplankton. Organic matter and pigment

“Extra” bulk sediment samples	Time series for unforeseen future threats/contaminants.	Contaminants and pollutants often settle and accumulate in sediments. It would be prudent to collect extra bulk sediment samples in conjunction with those collected for benthic food supply. The “extra” samples would remain archived in a freezer until potentially needed in the future. Archived samples could provide a time series to track the introduction of some future contamination threat (retrospective analyses, before-after statistical design).	concentrations provide important data on food availability in sediments if quantitative core samples can be collected.

Table C4. Key measurement parameters for monitoring coastal change (Section 5.4).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Historic reference of coastal position	Long term erosion rates from air photo and satellite coastal position leading to a 50 year assessment for the entire region	The deposition of large amounts of terrestrial material has consequences for coastal fish, invertebrates, and primary producers, although they are not yet well understood. For example, newly deposited terrestrial matter could create or destroy habitat required by specific coastal species, deposit contaminants in the marine environment, and either enhance primary production by introducing nutrients, or decrease primary production by limiting light availability.	Measurements should be repeated on a 2–5 year cycle in key identified areas. Focused studies should be performed at sites identified by Indigenous Knowledge on a yearly or bi-yearly basis to better understand the immediate response of coastlines to severe events (storms) and their impacts to the region.
Aerial drone surveys of coastal position	Detailed data on average coastal position to detect coastal erosion or coastal sediment deposition.		
Installation of a coastal observatory	Real-time data on environmental factors that lead to coastal change (wind, waves, sea-level and air temperature)		Observations should occur from ice break-up to after ice freeze-up, as the worst storms occur in the autumn. Real-time data available.

Table C5. Key measurement parameters for monitoring freshwater inputs and terrestrial linkages (Section 5.5).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Oxygen stable isotope ratios ($\delta^{18}O$) (Table C1)	Distribution of freshwater inputs.	Influences the movements of some valued top predators, including Arctic Char and Beluga Whales. Influences the distribution of some prey species, such as zooplankton and forage fish, that prefer fresher waters. Influences the distribution of some benthic habitats and detrital food sources, as suspended terrestrial organic matter settles out of the freshwater plume.	Sampling should be concomitant with sampling for core oceanographic parameters and primary production, and follow the two-tiered sampling approach described in *Section 5.1.* The locations of sampling sites should include areas near and offshore of river mouths to capture freshwater inputs.
Temperature and salinity profiles of the water column (Table C1)	Depth and spatial extent of warm, fresh water that is likely derived from river discharge.		
Nitrate, phosphate, and silicic acid (Table C1)	Distribution and concentration of terrestrially-derived nutrients.	Nutrient ratios influence the type and magnitude of primary production. Additional freshwater input can alter nutrient ratios, which in turn can modify primary production, change primary producer species composition, and promote the dominance of smaller cells do not transfer energy efficiently to higher trophic levels. May also potentially influence toxin-producing algae that can accumulate in the food web.	
Turbidity (Table C1)	Effect of suspended sediment in river discharge on light transmission through the water column.	The availability of light may be decreased within the freshwater plume due to suspended sediment and increased turbidity, potentially decreasing primary production.	
Annual precipitation trends	Link between precipitation trends, water levels in rivers, and river discharge rates.	The timing, type, and amount of precipitation directly affect the seasonal patterns of water levels and discharge rates in the rivers that drain the catchment. For Darnley Bay, increased precipitation can increase habitat connectivity between river and marine environments for anadromous fish, increase the availability of terrestrially-derived nutrients for coastal environments, and thus	Year-round. A truncated set of precipitation data collected at the Paulatuk climate station are available from Environment and Climate Change Canada. No data are currently available from the watershed of the Brock and Hornaday rivers. Currently the only freshwater flow data available for the MPA is from an Environment and Climate Change Canada water gauge installed in the Hornaday River. This gauge provides monthly and annual flow data for 1999–2001 and river flow rates and water
Monthly discharge of Hornaday River	The amount of fresh water discharged into the marine system from the main		

(total volume and rates)	freshwater source in Darnley Bay, and seasonal trends in discharge rate (e.g., when peak flows occur).	contribute to increased growth rates in anadromous (and potential coast marine) fish. Changes to the timing or magnitude of the spring freshet can impact ice break-up dates in the southern ANMPA with potential follow-on effects for the timing of anadromous migrations, ice habitat use by upper-trophic level animals, and the timing and magnitude of primary production in the coastal areas.	levels from 2002–2009 and 2010–2021 (data are available from ECCC: Hydrometric Data Search)
Sediment $\delta^{15}N$, $\delta^{13}C$, and C:N ratios (Table C3)	The extent and distribution of terrestrially-derived organic matter that settled out of the freshwater plume.	Provides information regarding the amount of terrestrially-derived organic matter that has settled out of the water column into the sediment (and may act as a proxy for other materials delivered from permafrost degradation). From a biological perspective, this provides information on the availability of terrestrial food supplements to benthic organisms. There is evidence that terrestrially-derived organic matter can act as an efficient food source for benthic marine bacterial communities, which in turn can fuel productive benthic invertebrate communities that act as prey for upper-trophic animals. From a physical oceanography perspective, this information can help infer the water circulation patterns that govern the movement of terrestrial inputs and/or promote the settling of organic matter.	Sampling should be concomitant with sampling for benthic habitat distributions, and follow approaches described in *Section 5.3*. The locations of sampling sites should include areas near and offshore of river mouths to capture terrestrial inputs.

Table C6.1. Key measurement parameters for monitoring trophic links and energetic transfer (Section 6.1).

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Estimates of dietary links among key species in five primary trophic groups: **primary producers**, **zooplankton**, **fish**, **benthic invertebrates**, and **marine mammal**. Dietary links can be estimated using one or a combination of:		Trophic links were identified as valued ecosystem components in the ANMPA, and are underscored by the ANMPA COs' focus on maintaining ecosystem productivity for upper-trophic feeding. To monitor whether or not this objective is being met, the underlying focus across indicators must be on energy transfer and delivery.	Annually, unless there are specific monitoring interests in diets at different times of year, or in understanding seasonal changes Note that contaminants also bioaccumulate and biomagnify, and can be used as proxies to elucidate trophic pathways and energy transfers over varying timescales. Data collected to monitor contaminants (Table C7.2) may have value-added as a parameter for trophic links and energetic transfer.
Stomach content analyses AND/OR	The prey species consumed and their relative proportions in the consumer's diet of the immediate past.	Benefits include determining the exact species and proportions of prey consumed. However stomach contents only represent the last meal consumed and are biased against easily-digested prey such that diet diversity may be under-represented. Stomachs are often empty upon capture. They may be expensive, depending on the level of detail desired.	
Stable isotope ratios ($\delta^{15}N$, $\delta^{13}C$) AND/OR	Trophic level ($\delta^{15}N$) and carbon sources ($\delta^{13}C$; e.g., benthic versus pelagic carbon) integrated over weeks to months.	Benefits include low cost and diet integrated over longer time scales. Drawbacks include a lack of determination for exact prey species, and potential confounding abiotic/biotic factors influencing stable isotope ratios (e.g., starvation, microbial enrichment of heavy isotopes, hydrocarbons).	
Fatty acid compositions AND/OR	General sources of energy and feeding habits integrated over days to weeks.	Benefits include a more specific determination of potential food sources compared to stable isotopes, since some fatty acids cannot be synthesized in the consumer and are assimilated directly from prey. However, unlike stomach contents, they cannot be used to determine exact food sources since most fatty acids indicate broad prey categories (e.g.,	

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
		bacteria, *Calanus* sp., bivalves) and may be passed on by an intermediary prey (e.g.,. a predator can acquire *Calanus* fatty acids from Arctic Cod that have fed on *Calanus* sp.). Drawbacks include sensitive storage requirements and relatively high costs.	
Highly branched isoprenoids	Reliance on energy derived from ice algae relative to phytoplankton.	Benefits include tracing the relative contributions from the two primary energy sources at the base of the food web, sympagic algae and phytoplankton, to a consumer. Ice algae provide essential fatty acids for the growth and reproduction of key zooplankton species that can not synthesize them. Drawbacks are the same as those for fatty acid compositions.	
Stable isotope ratios ($\delta^{15}N$, $\delta^{13}C$), HBI, and fatty acids of sediment	Baseline values for biotracers at the bottom of the food web are necessary to establish the direction and magnitude of trophic transfers.	Allows for the identification of the energy sources fueling the benthic food web (e.g., ice algae, phytoplankton) as well as the materials through which energy is transferred (fresh marine-derived organic matter, recycled marine-derived organic matter, and/or terrestrial organic matter). Identifies major food web pathways that can be traced through upper trophic levels. In addition for stable isotopes, can be used to provide a measure of isotopic baseline, which is necessary to calculate trophic levels, estimate food web pathways, and compare stable isotope ratios for upper-trophic animals between years and sites.	
Caloric content of key zooplankton, forage fish, and benthic prey species	The energy density of prey sources, in calories.	When measured in prey, estimates prey quality in terms of energy density. When combined with biomass estimates for prey, can be used to estimate the energy available to consumers in a given location. Accordingly, contributes to understanding connections between prey quality and the nutrition of key predators.	

Table C6.2 Key measurement parameters for monitoring ice-associated, under-ice, and open-water primary producers (Section 6.2).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Chlorophyll *a* concentrations (total and/or by size class)	Used to estimate total primary producer biomass (standing stocks), and to make spatial and temporal comparisons of ocean primary production. When analysed by size classes, also reflects functional and taxonomic composition of primary producers	An indicator for primary producer standing stocks, which determine the amount of organic matter (and energy) available for the food web, up to and including upper-trophic level marine mammals, seabirds, and predatory fish. The timing and magnitude of ice algae and phytoplankton blooms (events of high biomass) are important for understanding how much of that energy may be transferred to upper trophic levels. Spatially-distributed sampling also identifies productive hot spots and, when paired with physical and chemical oceanography and sea ice conditions (Tables C1. and C2), provides an understanding of conditions that support those hot spots (e.g., whether the spring bloom coincides with the time at which key zooplankton prey for fish return to the surface and require abundant algal food; whether blooms occur at times and locations that support mid-trophic grazing communities sufficient to attract and support Bowhead Whales and Arctic Char). When analysed by size class, Chl *a* is an indicator for the biomass produced by specific size groups of primary producers. The size class and taxonomic type of primary producer impacts the efficiency of energy transfers to upper trophic levels. In simplified terms, for example, large-sized diatoms are directly consumed by herbivorous zooplankton and larval fish, fostering efficient transfer of primary to secondary production. Small-sized phytoplankton are transferred less efficiently to higher trophic levels. These broad groups of primary producers thrive under different conditions.	At least annually, but preferably several times per year at a set of key sites to capture seasonal variation. If resources are limited, measuring species composition may be limited to a few core sites. Measuring throughout the year will capture trends in the timing and magnitude of primary production (e.g., algae blooms) whereas spatially-distributed sampling also identifies productive hot spots and, when paired with physical and chemical oceanography and sea ice conditions, provides an understanding of conditions that support those hot spots. An effective sampling protocol would match primary production sampling events to oceanographic sampling events, using the two-tiered sampling design described in *Section 5.1*. The development of a list of indicator species was beyond the scope of this review. A list of toxin-producing algal species observed in the western Arctic is provided in Pućko et al. (2019), which can inform interpretation of taxonomic analyses or selection of potential indicator species. Note that presence of the species does not confirm that harmful algal blooms have or will occur, as many toxin-producing species only produce toxins under specific environmental conditions.

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Chlorophyll fluorescence profile	Chlorophyll fluorescence is an indicator of the relative biomass (amount) of primary producers.	A key indicator for primary producers. Fluorescence profiles help determine the depth at which maximum primary producer biomass occurs and are often used to select depths for water sampling for primary production parameters. The relative fluorescence and depth of maximum fluorescence provide information regarding the seasonal progression of primary producer biomass and the location of hotspots. Phytoplankton fluorescence varies widely depending on physiology, in particular as a response to light conditions. Therefore, fluorescence does not directly represent chlorophyll *a* biomass, nor phytoplankton biomass. The ecological value of fluorescence profiles is greatly improved when it is ground-truthed by phytoplankton biomass measured from water samples.	
Particulate organic carbon (POC), particulate organic nitrogen (PON)	POC reflects the amount of carbon available from primary producers. Together, POC and PON are used to calculate the C:N ratio, an indicator of the health and condition of the system. Both are measured from the same sample.	POC measures the amount of organic carbon available to upper trophic levels. POC and PON are important parameters for biophysical models (e.g., to evaluate impacts of climate change) and for food web models that evaluate energy transfers and trophic links. The C:N ratio can indicate a shift in the quality of food available to grazers.	
Taxonomic composition	Structure and function of primary producer community; biodiversity and functional diversity; species range expansions; occurrence of species that can produce harmful marine toxins under specific conditions; identification of key indicator species	Changes in community composition may be associated with environmental changes. The species composition of primary producers is important for understanding the structure and functioning of the ecosystem, and under which conditions different species are likely to thrive with climate change. This is important because different species play different roles in the food webs and cycle energy and materials differently. Shifts in the species assemblages may be early indicators for concern, such as the presence or	

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
		increase in abundance of toxin-producing species, with important consequences for upper trophic level animals and food security for communities. Key dominant species of ice algae and phytoplankton can act as indicator species, including potentially toxic algae, which can identify changes in the primary producer community and provide early warning of potential changes that may affect the food webs and higher trophic levels.	
Core oceanographic parameters (Table C1)	Primary producer parameters provide ecological and food web information that should be paired with core physical and chemical oceanographic parameters.	Habitat available to primary producers, which influences the total productive capacity of the system and the types of primary producers that can thrive under those conditions/areas	
Nutrient concentrations (Table C1)	Primary producer parameters should be paired with those listed for nutrient concentrations; At minimum, macro-nutrients: nitrate (+ nitrite), silicic acid and phosphate.	Nutrient supply available to primary producers, which influences the total potential production of the system and the types of primary producers that can thrive under those conditions/areas. Micro-nutrients such as iron also influence primary production and food web processes.	

Table C6.3. Key measurement parameters for monitoring zooplankton community composition, structure, and function (Section 6.3).

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Taxonomic composition	Structure of full zooplankton community, including inventories of species present.	Full taxonomic data can be used to calculate indices of community structure such as species richness, diversity, and evenness (e.g., Shannon's diversity index, Pielou's eveness). Taxonomic information can be used to estimate functional diversity in the community, which is important for how efficiently energy is transferred from primary producers to higher trophic levels through zooplankton prey; Can	At least annually, but preferably multiple times per year to capture seasonal variation from summer to winter. Would be best if sampling co-occurred with measurements of core oceanographic parameters, nutrient concentrations, and primary production at least once annually. Temperature and salinity profiles

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
		also be used to track the introduction of new species from range expansions or invasions. Relative abundance and biomass calculated from species composition data are important for understanding how the community is structured, and how it may change in response to anthropogenic disturbance or climate variabilities and change. Can be used to track changes in the relative dominance of species and thus act as an early warning sign for change near the bottom of the food web (e.g., declines in the relative abundance of key prey species, declines of species considered sensitive to a specific threat such as ocean acidification, increases in the relative abundance of unpalatable gelatinous zooplankton).	should be taken concomitantly with zooplankton samples whenever possible.
Relative biomass of key indicator species and/or size classes	The biomass of key zooplankton indicator species (or size classes) relative to each other or standardized to sampling effort (e.g., biomass density per volume of water sampled).	Provides an indication of the relative availability of key prey to marine fish and mammal predators. Important to track changes in species that represent key functions in the ecosystem. An indicator species set should include species that are important to fish and marine mammal diets, species that are sensitive to specific stressors/threats (e.g., ocean acidification, ship-related contaminants), and/or species that span a wide range of functional groups. Relative abundance/biomass can be calculated from full species composition data (see above) assuming sampling methodology is standardized and compared between sites, years, or seasons to track changes. Alternatively, the relative biomass of key zooplankton size classes can be used to monitor broad changes in community composition, with representative splits of each size classes preserved for potential future taxonomic analyses.	Same as above. Year-round biomass data can be collected using a moored acoustic fish and zooplankton profiler (AZFP), which may be useful in northern and offshore areas of the ANMPA that are accessed less frequently. Development of a list of indicator species was beyond the scope of this review. However, important prey species for a wide variety of mid-trophic consumers (Arctic Cod, benthic fishes, and Bowhead Whales) include: *Calanus hyperboreus, Calanus glacialis, Metridia longa, Themisto libellula, Thysanoessa inermis*.. The pteropod *Limacina helicina* is sensitive to shell dissolution from ocean acidification.

Table C6.4. Key measurement parameters for monitoring benthic invertebrate community composition, structure, and function (Section 6.4).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Taxonomic composition	Structure of benthic community, including inventories of species present and their relative densities. Taxonomic composition would preferably be collected at the species-level, but may be sorted to coarser taxonomic groups (e.g., bivalves, decapods, amphipods, etc.).	Full taxonomic data can be used to calculate indices of community composition such as species richness, diversity, and evenness (e.g., Shannon's diversity index, Pielou's eveness), or indices of community response to disturbance (e.g., AZTI Marine Biotic Index) that can be used to track how benthic food quality changes in response to anthropogenic and climate forcings. Taxonomic information can be used to estimate functional diversity in the community, which is important for how efficiently energy is transferred from lower to higher trophic levels, and for nutrient cycling. Taxonomic data at the species level can be used to track the introduction of new species from range expansions or invasions.	Annually during the open-water season at a set of key monitoring sites that capture spatial heterogeneity in habitat types. Additional winter sampling would provide insight into seasonal community or trophic dynamics, if of interest. Sampling design would be best informed by mapping benthic habitat distributions (see *Section 5.3*) to ensure sampling captures spatial variation in habitat characteristics, and to ensure non-invasive sampling strategies are employed where sensitive habitats are identified.
Relative biomass of key indicator species	The biomass of key benthic indicator species relative to each other or standardized to sampling effort (e.g., biomass density per meter of seafloor surveyed).	Important to track changes in species that perform key functions in the ecosystem, possibly as early warning indicators for alterations to the the food web. An indicator species set should include species that are important to fish and marine mammal diets and/or species that are sensitive to specific stressors/threats. Relative biomass can be compared between sites, years, or seasons to track changes in the relative availability of key food sources, identify potential declines in sensitive species, and/or track benthic responses to environmental drivers (especially if paired with habitat data, see below). Relative biomass can be calculated from full species composition data (see above) assuming sampling methodology is standardized. May also identify feeding hotspots for upper-trophic predators.	Development of a list of indicator species was beyond the scope of this review. Many benthic invertebrates are considered good indicator species for specific types of local disturbances because they are so tightly linked to their habitats. Substantial research on this topic exists, but the specific goals of monitoring need to be defined in order to select indicator species (e.g., are indicators species needed to reflect the impact of warming, sewage effluent, sedimentation, coastal infrastructure development, contaminants, etc.). In the absence of data on species-specific sensitivities, indicator species should span a wide range of functional groups. Aggregate indicators, like the AZTI Marine Biotic Index, might be a better approach in the interim. See Table C6.9 for potentially colonizing invertebrates.

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Benthic and oceanographic habitat information	Depth, bottom temperature, and bottom salinity at a minimum. See additional habitat variables described in Tables C1 and C3.	Taxonomic data can be used in conjunction with oceanographic and benthic habitat distributions to determine species habitat associations that could help identify the locations of food hotspots for marine mammals and predict the reactions of fish to potential environmental changes.	

Table C6.5. Key measurement parameters for monitoring offshore fish community composition, structure, and function (Section 6.5).

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Taxonomic composition of entire catch	Structure of fish community, including inventories of species present and their relative abundances.	Full taxonomic data can be used to calculate indices of community composition such as species richness, diversity, and evenness. These metrics provide important information on the relative availability of different prey species to marine mammals, and act as an indicator of overall ecosystem function. Taxonomic data at the species level can be used to track the introduction of new species from range expansions or invasions, and contribute to monitoring the occurrence of potentially colonizing fishes (*Section 6.8*).	Annually during the open-water season at a set of key monitoring sites that capture spatial heterogeneity in habitat types. Would be best if sampling co-occurred with temperature and salinity profiles whenever possible. Additional winter sampling would provide insight into seasonal community or trophic dynamics, if of interest. Taxonomic overlap among offshore, inshore and forage fishes may allow for comparative insights to stability or changes in the different eco-types present in the ANMPA and the greater Darnley Bay area. Similarly, taxonomic overlap among these three groups of fishes can aid in establishing trophic and energetic linkages among them, and better understanding of their relevance to higher trophic organisms.
Catch-per-unit-effort of key indicator species	Used to calculate relative abundances and biomass of key indicator species.	Important to track changes in species that occupy key functional roles in the ecosystem, possibly as early warning indicators for alterations to the food web. An indicator species set should include species that are important to fish and marine mammal diets, species for which the ANMPA represents critical habitat, and/or species that are sensitive to specific	Development of a list of indicator species was beyond the scope of this review, aside from species that are already highlighted in other sections for their specific ecosystem functions (see Tables C6.7 to C6.9). Indicator species selection is currently hindered by a lack of understanding of how important Darnley Bay may be for regional populations (e.g., does it represent key rearing or feeding habitat for

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
		stressors/threats (e.g., ocean acidification, ship-related contaminants). Relative biomass can be compared between sites, years, or seasons to track changes in the relative availability of key food sources, identify potential declines in sensitive species, and track fish responses to environmental drivers (especially if paired with habitat data, see below). Relative abundances and biomass can be calculated from full species composition data (see above) assuming sampling methodology is standardized. May also identify food hotspots for upper-trophic predators.	some species?) and of sensitivities to specific anthropogenic stressors across life stages. In the absence of such data, indicator species should span a wide range of functional groups.
Benthic and oceanographic habitat information	Depth, bottom temperature, and bottom salinity at a minimum. See additional habitat variables described in Tables C1 and C3.	Taxonomic data can be used in conjunction with oceanographic and benthic habitat distributions to determine species habitat associations, which could help identify the locations of feeding hotspots for marine mammals and predict the responses of fish to potential environmental changes.	

Table C6.6. Key measurement parameters for monitoring inshore fish community composition, structure, and function (Section 6.6).

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Taxonomic composition of entire catch	Structure of fish community, including inventories of species present and their relative abundances.	Full taxonomic data can be used to calculate indices of community composition such as species richness, diversity, and evenness. These metrics provide important information on the relative availability of different prey species to marine mammals, and act as an indicator of overall ecosystem function. Taxonomic data at the species level can be used to track the introduction of new species from range expansions or invasions, and	Annually during the open-water season at a set of key monitoring sites that capture spatial heterogeneity in habitat types. Would be best if sampling co-occurred with temperature and salinity profiles whenever possible. Additional winter sampling would provide insight into seasonal community or trophic dynamics, if of interest. Taxonomic overlap among offshore, inshore and forage fishes may allow for comparative insights

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
		contribute to monitoring the occurrence of potentially colonizing fishes (*Section 6.8*).	to stability or changes in the different eco-types present in the ANMPA and the greater Darnley Bay area. Similarly, taxonomic overlap among these three groups of fishes can aid in establishing trophic and energetic linkages among them, and better understanding of their relevance to higher trophic organisms.
Catch-per-unit-effort of key indicator species	Used to calculate relative abundances and biomass of key indicator species.	Important to track changes in species that occupy key functional roles in the ecosystem, possibly as early warning indicators for alterations to the food web. An indicator species set should include species that are important to fish and marine mammal diets, species for which the ANMPA represents critical habitat, and/or species that are sensitive to specific stressors/threats (e.g., ocean acidification, ship-related contaminants). Relative biomass can be compared between sites, years, or seasons to track changes in the relative availability of key food sources, identify potential declines in sensitive species, and track fish responses to environmental drivers (especially if paired with habitat data, see below). Relative abundances and biomass can be calculated from full species composition data (see above) assuming sampling methodology is standardized. May also identify food hotspots for upper-trophic predators.	Development of a list of indicator species was beyond the scope of this review, aside from species that are already highlighted in other sections for their specific ecosystem functions (see Tables C6.7 to C6.9). Indicator species selection is currently hindered by a lack of understanding of how important Darnley Bay may be for regional populations (e.g., does it represent key rearing or feeding habitat for some species?) and of sensitivities to specific anthropogenic stressors across life stages. In the absence of such data, indicator species should span a wide range of functional groups.
Benthic and oceanographic habitat information	Depth, bottom temperature, and bottom salinity at a minimum. See additional habitat variables described in Tables C1 and C3.	Taxonomic data can be used in conjunction with oceanographic and benthic habitat distributions to determine species habitat associations, which could help identify the locations of feeding hotspots for marine mammals and predict the responses of fish to potential environmental changes.	

Table C6.7. Key measurement parameters for monitoring forage fish relative abundance and biomass (Section 6.7).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Catch-per-unit-effort of adult fish	Used to calculate relative abundances and biomass of key forage species.	Provides information on the relative availability of key prey sources for marine mammals and identification of locations of food hotpots. Necessary to investigate whether changes in marine mammal behaviour or health are connected to changes in food availability. Can also be used to establish forage fish habitat associations when used in conjunction with core oceanography and benthic habitat distributions. Together, data can be used to predict the effects of environmental change on key marine mammal prey species.	Annually during the open-water season at a set of key monitoring sites that capture spatial heterogeneity in habitat types. Would be best if sampling co-occurred with temperature and salinity profiles whenever possible. Additional winter sampling would provide insight into seasonal community or trophic dynamics, if of interest. Year-round biomass data can be collected using a moored acoustic fish and zooplankton profiler (AZFP), which may be especially useful in northern and offshore areas of the ANMPA that are accessed less frequently. Taxonomic overlap among offshore, inshore, and forage fishes may allow for comparative insights to stability or changes in the different eco-types present in the ANMPA and the greater Darnley Bay area. Similarly, taxonomic overlap among these three groups of fishes can aid in establishing trophic and energetic linkages among them, and better understanding of their relevance to higher trophic organisms. Key forage fishes include Arctic Cod (*Boreogadus saida*), Capelin (*Mallotus villotus*), and Sand Lance (*Ammodytes hexapterus*).
Relative abundance and/or biomass of juveniles	Used to understand recruitment success and inter-annual fluctuations in adult cohort abundance.	Data are used to determine recruitment success for key prey species. Can also be used to establish the habitat associations of forage fish larvae when considered in conjunction with core oceanography and benthic habitat distributions. Such information can in turn be used to predict the effects of environmental change on the recruitment success and survivorship of key prey populations.	
Oceanographic habitat and sea ice/snow information	Depth, temperature and salinity profiles at a minimum, with regional contextual information on sea ice/snow thickness and sea ice break-up timing. See additional habitat variables described in Tables C1 and C3.	See above. Habitat information is key to identifying/predicting the locations of feeding hotspots for marine mammals and predicting the responses of forage fish to potential environmental changes.	

Table C6.8. Key measurement parameters for monitoring anadromous fish relative abundance, habitat use, and population structure (Section 6.8).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Biological and population data from existing Hornaday and Brock river Arctic Char monitoring programs	Assessments of population structure, size, and/or catch-effort related directly to harvest	It is currently unclear how the ANMPA is used by important anadromous fish (e.g., Arctic Char, Broad Whitefish). Data associated with the Arctic Char fishery are available through existing programs, but additional data from randomized netting programs independent of the fishery will be useful to determine marine habitat use outside of key harvest areas, and for species other than Arctic Char. Relative abundances can be compared among locations and years to monitor how anadromous fish are using the ANMPA habitat. When used in conjunction with core oceanography and benthic habitat distributions (Tables C1 and C3), relative abundances can help understand/predict the effects of environmental change on anadromous fishes. Data would also provide information on relative abundance of prey sources for marine mammals.	Annually when Arctic Char are feeding in the marine environment; Sampling program may be integrated with annual nearshore fish surveys (*Section 6.6*) to determine habitat use, and relative abundance within ANMPA specifically. Can additionally integrate data provided by the existing Arctic Char stock assessment and harvest monitoring programs for areas within the ANMPA (Tippitiuyak, Argo Bay). When available, use stock assessment data to place data from harvested fish in context.
Catch-per-unit-effort	Used to calculate relative abundances.		
Timing of upstream/downstream migration	Time window within which anadromous fishes utilize the marine habitat	Simple index of the seasonal window within which anadromous fish use the marine habitat, which may be linked to changes in ocean and sea ice conditions or other environmental factors.	Annually; may be determined from community observations or existing harvest monitoring programs and possibly linked with duration of open-water season.

Table C6.9. Key measurement parameters for monitoring the occurrence and timing of potentially colonizing species (Section 6.9).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Timing of arrival	Year and time of year when first encountered	Provides potential clues regarding the cause of migration into the area, especially when used in conjunction with indicators of background environmental context (Tables C1 to C5).	Reported on the same time scale as surveys for zooplankton, benthic invertebrates, and fish species compositions. Observations and specimen collections made independent of monitoring surveys or through other programs should be collected on a continuous basis (i.e., whenever the observation is made). Salmon have been identified as potentially colonizing species in Darnley Bay, although their ability to establish reproducing populations in unclear. Invertebrates identified as aquatic invasive species with a relatively high risk of establishment in the Canadian Arctic (due to combined effects of climate change and increased shipping traffic) include: *Littorina littorea, Mya arenaria, Paralithoides camtschaticus*. For more information, see Goldsmit et al. (2018).
Qualitative abundance or catch-per-unit-effort	Qualitative abundance estimate if observations are made outside of a monitoring survey, or catch-per-unit-effort and relative abundance/biomass if observed by a standardized monitoring survey.	Used to track trends in abundance and identify whether a potentially colonizing species is becoming more prevalent. Relative abundance is important to predict whether the species is likely to have a significant impact on the ANMPA ecosystem.	
Habitat associations	The habitat within which the new species was observed	Provides an indication of habitat requirements, which are important for developing potential control measures; can be used to infer the native species that may interact with, compete with, or benefit from the potentially colonizing species.	
eDNA	Presence of a new species	Identification of potentially colonizing species that may interact with, compete with, or benefit from the potentially colonizing species; allows for initial signal of underlying community or ecosystem change and for inferences regarding possible consequences (which may then be used to inform sampling and monitoring).	Annually during the open-water season at several key areas/sites within the ANMPA and in the greater area of Darnley Bay.

Table C6.10. Key measurement parameters for monitoring marine mammal presence/absence, timing, habitat use, and group composition (Section 6.11).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Movement	How marine mammals move within the vicinity of the ANMPA, including offshore areas and the rest of Darnley Bay.	The COs for the ANMPA focus on conserving the marine habitat and forage species that support key upper-trophic species. Monitoring the movement patterns, timing of arrival and departure, locations of aggregations, and group composition of marine mammals is the first step in evaluating whether the marine habitat in the ANMPA region is supporting the requirements of each species. These data will provide the contextual information needed to track potential changes in habitat use over time by different segments of the population, to investigate potential avoidance of anthropogenic activities, and to investigate how habitat use may be linked to environmental conditions, sea ice characteristics, and prey composition. Inferences from such data allow for assessment of relative importance (e.g., frequency and duration of use) of areas or habitats. Similar information for movements and habitat usage outside the ANMPA will provide insight to the relative importance of the ANMPA to marine mammals.	Continuously based on opportunistic community and hunter observations (e.g., through the *Arctic Marine Observer App* and information gained from harvest surveys). Tagging and aerial survey data should be used as available from ongoing/future surveys, and from historical tagging studies; provide financial and logistical support to aerial and tagging studies that may be planned for future years so that the surveys include Darnley Bay. Note that accessing information from population studies or surveys conducted at broader regional scales will be important for providing the context necessary to evaluate whether action within the ANMPA will aid in conservation measures. Such information will also contribute to MPA Network monitoring at the regional scale, especially if methodology/indices are standardized with those developed for other MPAs. When using monitoring data to evaluate potential reasons for change, consideration must be given to differences in life history, migration, habitat use, foraging, physiology, and other factors that may attract each of the four key marine mammal species to the region.
Timing of arrival/departure	Community/hunter observations of when migratory marine mammals arrive and depart the ANMPA		
Locations of aggregations	Observations of where marine mammals aggregate within the ANMPA and their behaviours (e.g., feeding, rubbing, rearing young)		
Group composition	Observations of the sex, size, and ages of mammal aggregations using the ANMPA		

Table C7.1. Key measurement parameters for monitoring anthropogenic underwater noise (Section 7.1).

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Vessel noise	The influence of boasts and large ships on the underwater soundscape	Anthropogenic underwater noise has the potential to interfere with communication between marine mammals, the detection of prey and predators and, in the case of whales, echolocation. Anthropogenic noise derived from ships has been documented to also affect habitat usage by key forage fish species elsewhere (e.g., Arctic Cod) which, in turn, may affect foraging opportunities for higher trophic predators. Vessel traffic in the Canadian Arctic is increasing as sea ice declines, and one of the major Northwest Passage shipping corridors crosses the mouth of Darnley Bay just north of the ANMPA. Consequently, monitoring the potential impacts of anthropogenic underwater noise on marine mammal behaviours and vocalizations is directly applicable to ensuring that the integrity of the ANMPA as a marine feeding habitat is not disrupted by human activities, and to developing appropriate noise management strategies.	At a minimum during the open-water period, when the majority of marine mammals and vessel traffic are present. However, Bowhead Whales may reach the area in April and stay until November, or sometimes year-round. Ice-breaking vessels may also be present year-round. Observations should ideally capture the early spring and late autumn, if not year-round.
Marine vessel tracking data	The presence of vessels near the ANMPA	Can be integrated with acoustic observations of vessel noise, and with observations of marine mammal movements (based on a collection of community observations, acoustic observations, and/or tagging data) to determine whether vessel noise influences marine mammal behaviour or movements within the ANMPA	During the same period for which hydrophones are deployed for recording vessel traffic and marine mammal vocalizations. In addition to using passive acoustic monitoring to confirm the presence of ships, data on large vessels can be purchased from AIS tracking services. There are limitations with tracking small vessels.
Marine mammal vocalizations	Presence of marine mammals and calling behaviours	Can be used to confirm the presence of marine mammals in the ANMPA, but not absence. Can also be used to study behaviours associated with vocalizations (e.g., calls between individuals, echolocation for hunting, frequencies and call-types used to communicate)	Depending on location of acoustic recorders and specific question of interest, acoustic monitoring may occur year-round or during a specific season when marine mammals are known to inhabit the area.

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Ambient noise	Natural background underwater noise that occurs throughout the year	Ambient noise and sound speed in the water are important for understanding the underwater soundscape, and interpreting sound from vessels and marine mammals. Ambient noise may also capture natural events relevant to other indicators, such as the timing of ice break up, wave and tide action, etc.	Year-round through passive acoustic monitoring.
Local sound propagation characteristics	How quickly sound travels through the water and other important variables		Measured when temperature and salinity data are collected as part of sampling programs for core oceanography and nutrient concentrations (*Section 5.1*).

Table C7.2. Key measurement parameters for monitoring contaminant concentrations in the environment and marine mammals (Section 7.2). Note that only preliminary information is provided and additional expert advice is necessary prior to inclusion of this indicator in a monitoring plan. In addition, it may be difficult to link this indicator to the COs as contaminants may not originate within the ANMPA or are not indicative of processes occurring within the boundaries.

Parameter	**Information provided**	**Relevance to monitoring COs**	**Frequency of measurements / Other considerations**
Mercury and organic contaminants in key prey species	Risk posed to upper-trophic animals by dietary exposure to mercury and organic contaminants within the ANMPA	Monitoring the fate and transport of a select group of compounds to the ANMPA is relevant to the COs because it addresses disruption by human activities. Measuring concentrations in key prey species will provide context on the dietary exposure risk posed by prey that inhabit the ANMPA and surrounding region. This may be particularly important for understanding food web pathways of contaminants to resident marine mammals (e.g., Bearded Seals). In contrast, concentrations in migratory marine mammals may reflect dietary exposure from areas outside of the ANMPA.	Integrated with sampling programs designed for indicators of prey populations (*Sections 6.1–6.8*).
Organic contaminants in marine mammal blubber and liver	Dietary exposure to organic contaminants (for migratory marine mammals, exposure will not be restricted to the ANMPA)	Monitoring the fate and transport of a select group of compounds to the ANMPA is relevant to the COs because it addresses disruption by human activities. Measuring concentrations in key upper-trophic species can provide information on toxicity effects at the individual and population levels, and provide context on their health and vulnerability. In addition, monitoring contaminants can provide insight into abiotic system processes, biotic processes, or food web pathways by acting as natural tracers because contaminants bioaccumulate in individual organisms, and biomagnify up food webs to levels of concern. Mercury and many organic contaminants are toxic, bioaccumulate, and biomagnify, with a primary exposure route via the food web. Note that contaminant loads measured in marine mammals may reflect processes occurring outside of the ANMPA, but will still provide context for understanding marine mammal health and vulnerability, and for contaminant transport to the ANMPA.	Integrated with sampling programs for trophic links and energy transfer (*Section 6.1*), or whenever biological sampling is taking place in marine mammals within the ANMPA, such as during harvests.
Mercury concentrations in marine mammal muscle, liver, skin	Muscle and skin reflect recent dietary exposure to mercury; Liver reflects an animal’s lifetime burden of mercury (for migratory marine mammals, exposure will not be restricted to the ANMPA)		

Parameter	Information provided	Relevance to monitoring COs	Frequency of measurements / Other considerations
Archived tissue samples from marine mammals, where possible	Will provide time series of contaminant delivery from localized sources (e.g., those from mining, shipping, oil spill) and long-range atmospheric and marine transport	It is impossible to predict the timing and occurrence of a future threat. Archiving tissues for potential future analyses is in line with a future-oriented approach to monitoring, allowing retrospective studies that can reconstruct contaminant levels before a threat occurred. This is a “value-added” parameter, as most tissues already being sampled can be sub-sampled for archival purposes.	
Trophic biotracer information and supporting size, sex, and age data	Allows inferences on feeding strategy (see *Section 6.1*)	Dietary exposure is the leading route for contaminant accumulation in upper-trophic animals. When paired with an understanding of feeding strategy, contaminants can be used to characterise the risk to upper-trophic animals from dietary contaminants exposure. Size, sex, and age data should be collected concomitantly with samples for contaminants and trophic biotracer analyses due to known variability in feeding behaviour.	
Microplastics in the digestive tracks of key marine mammals and sediments (archived)	Preserves samples for later determination of ambient levels of microplastics in the ANMPA (sediment), and for levels detected in migratory marine mammals once health implications, bioaccumulation, and excretion rates are better understood.	Microplastics are listed as a priority concern by the ANMPA Working Group. However, little research has yet been published on the prevalence of microplastics in the marine environment of the western Arctic, especially for higher trophic animals, and the health implications of microplastic ingestion remain uncertain. This topic remains a research question. It is recommended that tissues or feces sampled to measure microplastic concentrations be archived for future analysis when funds are available and more is understood about their impacts.	Since relatively little is understood about the risk posed by microplastics, samples should be collected regularly (e.g., at least once per year) and archived for future analysis until funds are available or the risk is better understood.
Bulk sediment samples for archiving	Time series for unforeseen future threats/contaminants.	See *Section 5.3*. Contaminants and pollutants often settle and accumulate in sediments. Archiving sediment samples in a freezer could provide a time series to track the introduction of some future contamination threat (retrospective analyses).	Annually

APPENDIX D. RESEARCH, HARVEST, AND MONITORING PROGRAMS REFERRED TO IN TEXT

Table D1. Brief synopses of the scope, timing, and objectives of the major monitoring and research programs (in alphabetical order) that are mentioned frequently in this document because they collected data in the vicinity of the ANMPA pertinent to several monitoring indicators. The following is not an exhaustive list of all data collection programs mentioned in this report.

Program	Synopsis
Arctic Coast	A community-based coastal monitoring program that has operated out of Paulatuk since 2012. The program was initially implemented by DFO to assess coastal fish community structure. Leadership has been transferred to the community of Paulatuk, and the sampling program has expanded to include sampling for zooplankton, benthic invertebrates, and water quality parameters in coastal waters (< 40 m). The original program was referred to colloquially as the Darnley Bay fish monitoring program, but was later named Arctic Coast when the sampling design was implemented in additional Arctic communities in the Northwest Territories and Nunavut.
Beluga Health Research and Monitoring Program	The Beluga Health Research and monitoring program leverages and connects to the FJMC Fish and Marine Mammal Community Monitoring Program. It is enhances sample collections to investigate health and ecology of harvested of beluga at a select number of whaling camps since 2011. DFO Science teams together with veterinarians work with Beluga Monitors to collect additional data and specialized samples. Some of this work occurs to address a question that may be short term (i.e., one year sample collection) other components take an iterative approach where information is gathered, analysed and developed to build into the monitoring program (based on needs questions) that then become monitored over time. Data reports detailing methodology and summarizing data collected through harvest monitoring programs are available for 1970–2015 in (Harwood et al. 2020).
BREA MFP	Beaufort Regional Environmental Assessment Marine Fishes Program. An offshore, multidisciplinary, vessel-based marine research program that operated off the *F/V Frosti* in 2012 and 2013, and sampled across the Canadian Beaufort Sea and Amundsen Gulf, including within Darnley Bay and the ANMPA. The program was led by DFO, in partnership with several universities and with the support of the IGC. Sampling programs included core oceanography, water quality, primary production, sediments, zooplankton, benthic invertebrates, and offshore fishes. The primary goal of the program was to collect baseline environmental and species distribution information for previously under-studied offshore regions, to inform management decisions. Data collected are pertinent to the ANMPA and surrounding region, as well as to understanding the larger Amundsen Gulf ecosystem.

Program	Synopsis
BSMFP	Beaufort Sea Marine Fishes Project. An extension of the BREA MFP that operated in the Canadian Beaufort Sea and Amundsen Gulf in 2014. Program design remained virtually the same.
CBS MEA	Canadian Beaufort Sea Marine Ecosystem Assessment. An extension of the BREA MFP and BSMFP that operated from 2017 to 2019. Baseline data collection continued but research objectives focussed on functional physical-biological relationships. In addition to ship-based sampling, moored observatories were installed offshore of Cape Bathurst, in Franklin Bay, and in Minto Inlet through to collect year-round data on physical oceanography and hydroacoustic observations of fish and zooplankton aggregations. Data collected are pertinent to the ANMPA and surrounding region, as well as to understanding the larger Amundsen Gulf ecosystem.
CASES	Canadian Arctic Shelf Exchange Study. An international, multidisciplinary research effort under Canadian leadership that aimed to understand the biogeochemical and ecological consequences of sea ice variability and change on the Mackenzie Shelf. The field program operated off the *CCGS Amundsen*. The expedition began in September 2003 and ended in August 2004, completing an over-wintering expedition in Franklin Bay. Data were not collected within Darnley Bay or the ANMPA, but are pertinent to baseline understanding of primary production, lower-trophic level food web structure, carbon export, sea ice biogeochemistry, benthic invertebrate community structure, and sediment characteristics in the larger Amundsen Gulf ecosystem.
CFL	Circumpolar Flaw Lead study. An international research effort under Canadian leadership to investigate the importance of the circumpolar flaw lead system on physical, chemical, and biological aspects of the Arctic marine ecosystem. The field program operated off the *CCGS Amundsen* in the Amundsen Gulf and southern Beaufort Sea from October 2007 until July 2008. The expedition remained mobile within the polynya south of Banks Island over winter, with ice-based sampling at the mouths of Franklin and Darnley bays. Data were not collected within Darnley Bay or the ANMPA, but are pertinent to baseline understanding of primary production, carbon export, sea ice biogeochemistry, sympagic algal communities, and zooplankton community composition in the larger Amundsen Gulf ecosystem.
CROW	Canadian Rangers Ocean Watch. A collaboration between the Department of National Defence, DFO, and northern communities through which Canadian Rangers living in northern communities collect oceanographic data opportunistically during patrols. The program expanded to Paulatuk in 2018 and 2019 and collected temperature, salinity, dissolved oxygen, and fluorescence data within the ANMPA at Argo Bay, and at coastal stations south and east of Bennett Point.

Program	Synopsis
Fish and Marine Mammal Community Monitoring Program (formerly known as the Beluga Monitoring Program)	The Beluga Monitoring Program was jointly established in 1980 by DFO and the Hunters and Trappers Committees of the six communities in the ISR to record harvest information, and to collect biological data and samples on landed whales. The program has been led by the FJMC since 1987. It is one of the longest standing monitoring programs in the Canadian Arctic. The program was renamed the Fish and Marine Mammal Community Monitoring Program in 2010. Currently, Beluga Monitors hired by the local HTCs travel each summer to traditional whaling camps where they work with harvesters to collect information about the harvest timing and conditions, record observations on physical characteristics of the whales, and take tissue samples for later analysis by DFO Science and their colleagues. Harvesters may also submit information and samples directly to DFO. The program is separate from the Inuvialuit Harvest Study.
Inuvialuit Harvest Study	The Inuvialuit Harvest Study is a community-based monitoring program that collects monthly harvest information from Inuvialuit subsistence harvesters, 16 years or older, who are registered with their local Hunters and Trappers Committee. Harvest data are collected year-round for seabirds, fish, and marine mammals. Data collected through the program are used to assist with resource management decisions. The program was historically managed by a steering committee composed of members from the Inuvialuit Game Council and various partners including the FJMC, the Joint Secretariat, and several territorial and federal government organizations. The Inuvialuit Harvest Study represents the most complete long-term dataset on biological and harvest information available for Darnley Bay. The program initially ran from 1988–1997, and again from 2016–2019. In the interim, a harvest study for Arctic Char was administered by DFO (1999–2003) and the PHTC (2004–2016). The Inuvialuit Harvest Study is currently paused and undergoing a review.
Munaqsiyit Monitoring Program	A community-based monitoring program run by all six HTCs in the ISR with guidance from the Joint Secretariat Community-Based Monitoring Coordinator. Every HTC in the ISR has a full-time Munaqsiyit monitor position, with a current focus on establishing SmartIce monitoring programs. SmartIce uses Smart Qumatiq technology to gather data on ice conditions along coastal and offshore travel routes.
NCMS	Northern Coastal Marine Study. A multidisciplinary study led by DFO aimed at characterising the biological and physical habitat of the Canadian Beaufort Shelf, as well as species distributions. Sampling was conducted from the CCGS *Nahidik* between 2004–2008 across the Beaufort Shelf, including within Darnley Bay in 2008. Sampling programs included core oceanography, water quality, primary production, sediments, zooplankton, benthic invertebrates, and offshore fishes. Data collected are pertinent to the ANMPA and surrounding

Program	Synopsis
	region, as well as to understanding the larger Amundsen Gulf ecosystem.
Paulatuk Arctic Char monitoring program	A locally-implemented monitoring program led by the FJMC and DFO and administered by locally-hired monitors during a pre-defined timeframe and with pre-defined sample size targets. Data from the Paulatuk subsistence harvest survey and Arctic Char monitoring program are retained by DFO, with analyses and summaries provided to the Paulatuk HTC and Char Working Group.
Paulatuk Arctic Char subsistence harvest survey	A locally-implemented harvest survey specific to Darnley Bay Arctic Char that is separate from the Inuvialuit Harvest Study, and has been in place since 1998 when the Inuvialuit Harvest Study was paused. The survey is completed by community members hired by the Paulatuk HTC through a contract with DFO. Data from the Paulatuk subsistence harvest survey and Arctic Char monitoring program are retained by DFO, with analyses and summaries provided to the Paulatuk HTC and Char Working Group.
Paulatuk Beluga Health & Knowledge project	Initiated in 2012 through a science proposal submitted to NCP by the Paulatuk HTC and DFO in response to increased beluga subsistence harvest numbers in the community, and concerns regarding contaminants levels in marine mammal food sources. The program collects the same biological samples as other beluga harvest monitoring programs in the ISR and sends samples to partners at DFO science for analysis. It is linked to the Beluga Health Research and Monitoring program by feeding into a regional scale (all collections and analyses standardized and completed together to enable regional comparison).
Paulatuk Invertebrate Survey	A study initiated and run by the Paulatuk HTC to characterise the invertebrate community in Darnley Bay that has been in place since at least 2017. Local technicians are hired by the Paulatuk HTC to set crab and shrimp traps in areas identified by the Paulatuk HTC. Data collected include trap set location, weather, time and depth, catch abundances, carapace width measurements, and observations of females with eggs, and is possible egg counts.