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

Central and Arctic Region

Canadian Science Advisory Secretariat
Science Advisory Report 2022/015

SCIENCE ADVICE TO ASSIST IN THE DEVELOPMENT OF AN ECOLOGICAL MONITORING PLAN FOR THE ANGUNIAQVIA NIQIQYUAM MARINE PROTECTED AREA

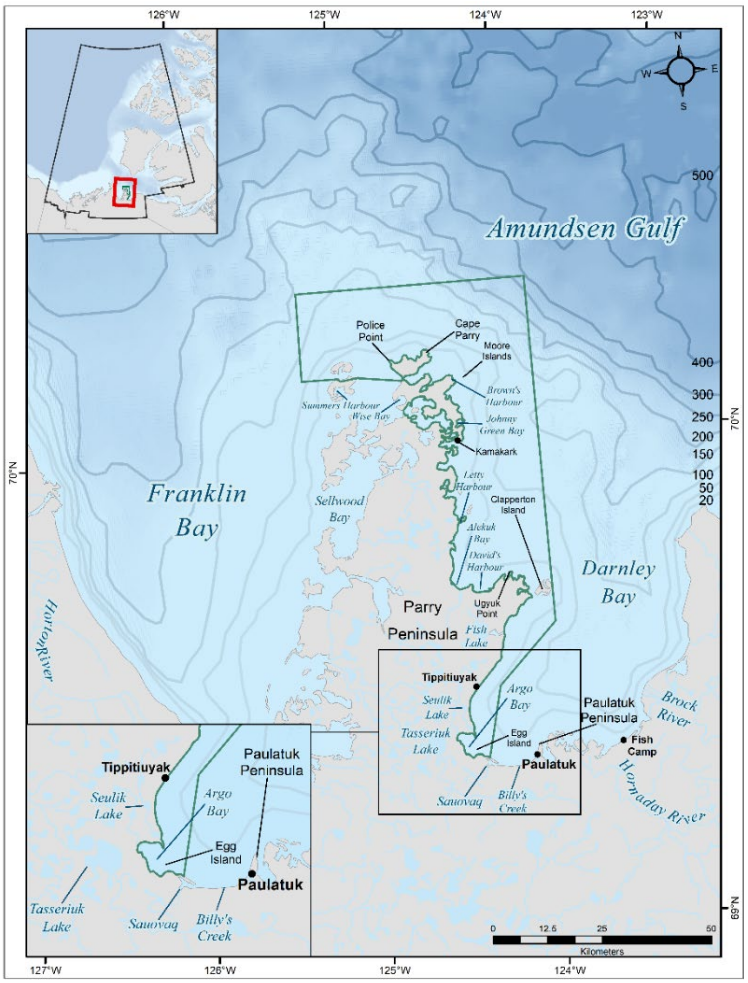

Figure 1. Map of traditional and local place names in the Anguniaqvia niqiqyuam Marine Protected Area. Map created by J. Friesen and local place names provided by the ANMPA Working Group. Bathymetry adapted from the IBCAO by M. Ouellette. Basemap and MPA boundaries available from the [Government of Canada Open Data Portal.]

Context:

Fisheries and Oceans Canada (DFO) Science sector provides advice in support of the management and monitoring of Marine Protected Areas (MPAs). A monitoring plan for Anguniaqvia niqiqyuam MPA (ANMPA) is currently being co-developed by DFO Marine Planning and Conservation and the ANMPA Working Group as a key component for ANMPA management. This monitoring plan will provide a *structured approach to gathering information to support the management and monitoring of the ANMPA, to meet its conservation objectives. The conservation objectives for 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 and to maintain the habitat to support populations of key species (such as Beluga whales [*Delphinapterus leucas*], Arctic Char [*Salvelinus alpinus*], and Ringed Seals [*Pusa hispida*] and Bearded Seals [*Erignathus barbatus*]).*

This Science Advisory Report is from the DFO Canadian Science Advisory Secretariat (CSAS) regional advisory meeting of February 18-20, 2020. It contains science advice requested by DFO Marine Planning and Conservation on the ecological themes identified in the draft monitoring plan developed by the ANMPA Working Group. Ecological monitoring advice extends and, where relevant, replaces previously identified indicators, protocols, and strategies (DFO 2015) in the context of recently published knowledge, as well as other information and data available for the ANMPA and the surrounding ecosystem. In addition, a generalized framework for the process of developing MPA monitoring plans that incorporates both scientific and Indigenous knowledge using the ANMPA as a case study was reviewed. The resulting advice will inform the development of the Ecological Monitoring Plan. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- The Anguniaqvia niqiqyuam Marine Protected Area (ANMPA) is Canada's first marine protected area (MPA) with conservation objectives based specifically on Indigenous knowledge and is the second MPA designated in the Canadian Arctic under the *Oceans Act*.
- A substantial amount of information about the ANMPA is held by Indigenous knowledge holders. This Indigenous knowledge was not accounted for at this meeting but community priorities derived by the ANMPA Working Group were provided to guide and inform discussion. Indigenous knowledge will continue to inform the finalized monitoring plan.
- In the last five years, increased scientific knowledge and data has been acquired in the MPA that has improved our understanding of ecosystem structure and function. This includes:
    - biodiversity and ecology of fishes (coastal and offshore),
    - winter ecology, including coastal ecosystem assessments, basic under-ice oceanographic parameters, as well as information on snow and ice thickness, completed as part of community-based projects,
    - structural and functional ecosystem relationships for both the inshore and offshore systems of the area (e.g., enhanced understanding of trophic (food web) pathways)
    - occurrence and timing of potentially colonizing species, and the first observation in the ANMPA of Pacific salmon in 2019,
    - continued long-term harvest data regarding Arctic Char (*Salvelinus alpinus*) in Darnley Bay; and,
    - presence/absence, timing, location, and group composition of Beluga whales (*Delphinapterus leucas*), Ringed Seals (*Pusa hispida*), and Bearded Seals (*Erignathus barbatus*).
- Two types of data collections are needed:
    1. **Foundational data**: A number of key foundational data gaps exist, which hamper monitoring ecosystem structure and function and limit our understanding of baseline conditions against which change can be assessed and in regard to essential indicators (e.g., benthic habitat distribution). These data gaps include bathymetry, ocean currents, linkages and influences between inshore and offshore processes, marine productivity

near Cape Parry, higher trophic level feeding, population dynamics of key species, and the roles these all play in supporting the conservation objectives.

2. **Baseline data:** Baseline data are essential to make educated assessments of the spatial (i.e., sample locations) and temporal (i.e., seasonal variations and timing) design, as well as frequency (i.e., replication, annual collection) of sampling to underpin effective monitoring. Longer-term data sets (i.e., obtained through monitoring) are also needed in order to identify change from underlying variability (baseline conditions).

- Indicators were organized into three categories: 1) indicators that provide background environmental context; 2) indicators on biological and food web integrity; and, 3) indicators for stressors and threats.
- In order to inform management and mitigation measures, monitoring needs to identify how an indicator has changed and why the change has occurred. This can be accomplished by identifying and monitoring a suite of linked indicators that relate to the structure and function of an ecosystem, and regularly testing and revising monitoring hypotheses.
- A validation and reporting process should be built into a monitoring plan to ensure that the selected indicators provide information relevant to the conservation objectives. Regular review and revision of these indicators is required as new knowledge is acquired in the system or in the event a new anthropogenic activity is introduced to the area (e.g., mining and associated infrastructure and shipping). Monitoring and ongoing assessment of the ecosystem in regards to the conservation objectives must therefore be adaptive to address emerging needs, and existing and new challenges.
- Important determinants of ecosystem integrity include the following list of indicator types based on the need to understand the structure of the ecosystem (i.e., set the stage), to differentiate natural variability in the system from change, and to develop effective parameters to detect change in the system and potential impacts from stressors (i.e., functional consequences):
  - oceanographic parameters (e.g., temperature and salinity profiles, currents);
  - primary producer abundance and composition;
  - bathymetry and benthic habitat mapping;
  - timing of sea-ice freeze-up and break-up and snow measurements;
  - tropic linkages (i.e., diet studies) and quality and quantity of energy transfer among trophic levels (e.g., food as energy pathways) (i.e., diet studies); and,
  - presence of species and linkages to habitat use (e.g., trophic roles and productivities of potential forage biota for valued species).
- Core oceanographic parameters and nutrient concentrations was recognized as being foundational to most other indicators. The most important oceanographic parameters to measure were temperature, salinity, fluorescence, and oxygen profiles, nutrients, carbonate chemistry, water clarity/turbidity/photosynthetically active radiation (PAR), oxygen isotope fractionation (to detect river input vs sea ice melt), currents and water movements (e.g., stratification, mixing), ancillary information (e.g., atmospheric drivers), background sounds (e.g., anthropogenic or natural such as during storms); and isoscapes (e.g., to assess movement of materials delivered by coastal erosion and freshwater inputs).
- Many of the parameters and indicators that were identified have strategies and protocols that can be undertaken from a community-based approach.
- A monitoring plan for the ANMPA that incorporates scientific and Indigenous knowledge needs to also consider prior and on-going monitoring in the area, be built on policies and guidance already in place, and focus on community priorities.

BACKGROUND

Canada's *Oceans Act* (1997) authorizes Fisheries and Oceans Canada (DFO) to provide enhanced protection to areas of the oceans and coasts which are ecologically or biologically significant by designating marine protected areas (MPAs). DFO Science sector provides advice in support of the management and monitoring of these MPAs. As part of the initial steps to establish MPAs in Canada, areas of interest are first identified and assessed. DFO Science has provided advice on potential conservation objectives (COs) for the Anguniaqvia niqiqyuam Area of Interest (ANAOI; DFO 2011), the identification of stressors, impacts, and pathways of effects (DFO 2014) and also on the identification of monitoring indicators, protocols, and strategies for COs (DFO 2015). The ANAOI was designated as an MPA in October 2016 with an expansion from the original AOI boundary to also include an area south of Ugyuk Point (Figure 1) and the addition of an Indigenous knowledge-based CO. A key component for management of the ANMPA is the co-development of a monitoring plan by DFO Marine Planning and Conservation (MPC) and the ANMPA Working Group. This co-developed monitoring plan will ultimately address multiple themes (e.g., social, economic, cultural, ecological) aligned with the MPA COs. The COs for the ANMPA are:

1. 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;
2. To maintain the habitat to support populations of key species (such as beluga whales, Arctic char, and ringed and bearded seals).

The ANMPA Working Group also provided monitoring priorities from a separate process as further supplemental information to inform the development of this science advice. The monitoring priorities were grouped by themes which included subsistence harvest, offshore, nearshore, unusual events, and pressures/threats. A complete list of the ANMPA working group priorities are available in Ehrman et al. (2022), Appendix A.

In addition to the identified monitoring priorities from the ANMPA Working Group, substantial research and baseline data collection has occurred in the region that would contribute to our understanding and assessment of identified indicators (see Ehrman et al. 2022). Based on this, DFO MPC has requested Science Advice on the ecological themes identified in the draft monitoring plan developed by the ANMPA Working Group to inform the development of the ANMPA Monitoring Plan.

ASSESSMENT

This CSAS review process is based on expert opinion and scientific knowledge available for the region. The report and advice focuses largely on available western science; however, it is recognized that this information is intended to support the co-development of the ANMPA monitoring plan and will be complemented with advice and information based on community values, goals, and Indigenous knowledge in a collaborative decision-making process. Contributions of knowledge along the entire spectrum from simple observations to holistic understanding are needed for a monitoring plan to be successfully delivered.

The scope of this review generally focused on the MPA (Figure 1) and both of its conservation objectives. It considered the biotic and environmental parameters that exist primarily within the MPA boundaries (e.g., kelp, coastal fish diversity) and those parameters that exist outside the MPA that affect valued species (e.g., Arctic Char [*Salvelinus alpinus*] source population from the Hornaday River). Building on past science advice provided for the ANAOI (DFO 2014, 2015), this review expanded in geographic scope to include southern portions of the ANMPA and offshore regions that are not within the ANMPA but may be key to consider for meeting the conservation objectives. As pressures and threats were identified as a monitoring priority by the ANMPA Working Group, this advice also encompasses indicators related to pressures and threats, and therefore builds on previous advice on stressors, impacts, and pathways of effects (DFO 2015). In addition to understanding what has changed in the MPA, it will be important to understand the cause-and-effect relationships in order to determine potential management strategies/mitigations. Therefore, the scope of this work expanded to identify indicators that either are causing change or that will help to explain cause and effect in the MPA, and the resulting impact(s) to the conservation priorities.

While 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, there are four geographic components to the overall system for monitoring the MPA:

1. the ANMPA itself (which includes at least three distinct areas and transitions from warmer, less saline waters, and sandy substrates in the south to colder, more saline waters, and rocky substrates in the north);
2. the coast line (which includes the southern and eastern margins and adjacent freshwater and/or terrestrial zones, including the Hornaday River);
3. the offshore area within Darnley Bay; and
4. the offshore area outside the ANMPA and outside of Darnley Bay (which includes Amundsen Gulf and Franklin Bay).

Due to the geographic differences within the MPA, and among the four geographic components of the overall system, there are different monitoring strategies that are more applicable to different locations and ecosystem types (e.g., nearshore marine, offshore marine, freshwater, or terrestrial). Despite these differences, however, the need for baseline data remains a common theme among all areas. The region has limited scientific data and yet baseline data are critical for all monitoring programs as they form the key datasets that are used to report on the status of the indicators and ultimately form the decisions associated with monitoring strategies. Baseline information also helps with choice of sampling location and frequency (including temporal and seasonal), and feeds into the development of the hypotheses that underlie monitoring questions.

There are two types of data collections that are needed:

1. **Foundational data** provides a solid basis for understanding the current status of the habitat/environment (e.g., bathymetry, benthic habitat mapping) and supports decisions on indicator monitoring design (e.g., transects, control locations). This data collection requires a large effort at first but with longer monitoring intervals (e.g., every 10 years); and,
2. **Baseline data** are used in monitoring to detect change and distinguish between natural variability and an actual trend. These data collections are required over a longer term and a more consistent frequency (e.g., every year, every 2 years).

Monitoring Framework

The Terms of Reference for this meeting included an objective to develop a monitoring framework that incorporates scientific and Indigenous knowledge using the ANMPA as a case study. A working paper was developed and discussed during this peer-review meeting, but ultimately was not adopted. The authors were encouraged to revise the working paper based comments received and the meeting discussions and to seek publication outside of this CSAS process (DFO 2021).

Advice, derived from these discussions, emphasized the importance of:

- providing equal representation of science and Indigenous knowledge;

- identifying a process for consultation with co-management partners, Indigenous groups, and community members that recognizes past contributions to monitoring programs as well as local perspectives regarding a monitoring framework;
- recognizing the movement toward Indigenous-led monitoring in the area;
- considering prior and on-going monitoring in the area; and,
- building upon policies and guidance already in place.

It is also important to recognize that a number of projects and programs have been applied in the Arctic, and these can be used to inform approaches to community-led, co-designed monitoring frameworks in the future. Movement toward Indigenous-led monitoring includes the equal representation of science and Indigenous knowledge; it is important to emphasize that equality of information sources is also required in a monitoring framework, especially within a co-management context.

Additionally, there was recognition of multiple approaches to develop and acquire data and information for the management and monitoring requirements (e.g., community-based, community-led, science-based), and the resulting need to define those terms in order to improve clarity and understanding among scientists, stakeholders, and rights-holders.

Updated Criteria for an Effective Monitoring Plan

The criteria used to evaluate an effective indicator and monitoring plan from the DFO (2015) meeting were further reviewed and updated. Those related to an effective indicator remain unchanged, whereas the criteria for an effective monitoring plan were updated to increase clarity.

To successfully evaluate whether the COs for the ANMPA are being met, the monitoring plan should be:

1. able to distinguish between anthropogenic-related change and environmental variation (i.e., 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), 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, to achieve meaningful outcomes from data collection;
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; and,
6. community-led and coordinated among co-management groups, government, and scientific partners.

In order to provide relevant and effective advice for future MPA management, key science needs include having monitoring protocols and a plan that can differentiate between a trend (directional change) and natural variations. Thus, the identification of key species, their role in the ecosystem, and processes that link stressors and their effects, are critical steps from which effective management strategies can be developed.

Ecological Monitoring Indicators

Ecological monitoring indicators were organized into three categories to capture the data required to link potential changes in valued upper-trophic animals and their ecosystem to the drivers of change. These categories are 1) Indicators that provide background environmental context; 2) Indicators of biological and food web integrity; and 3) indicators of pressures and threats. This “three-tiered indicator concept” is summarized in Figure 2, and more fully explained in Ehrman et al. (2022).

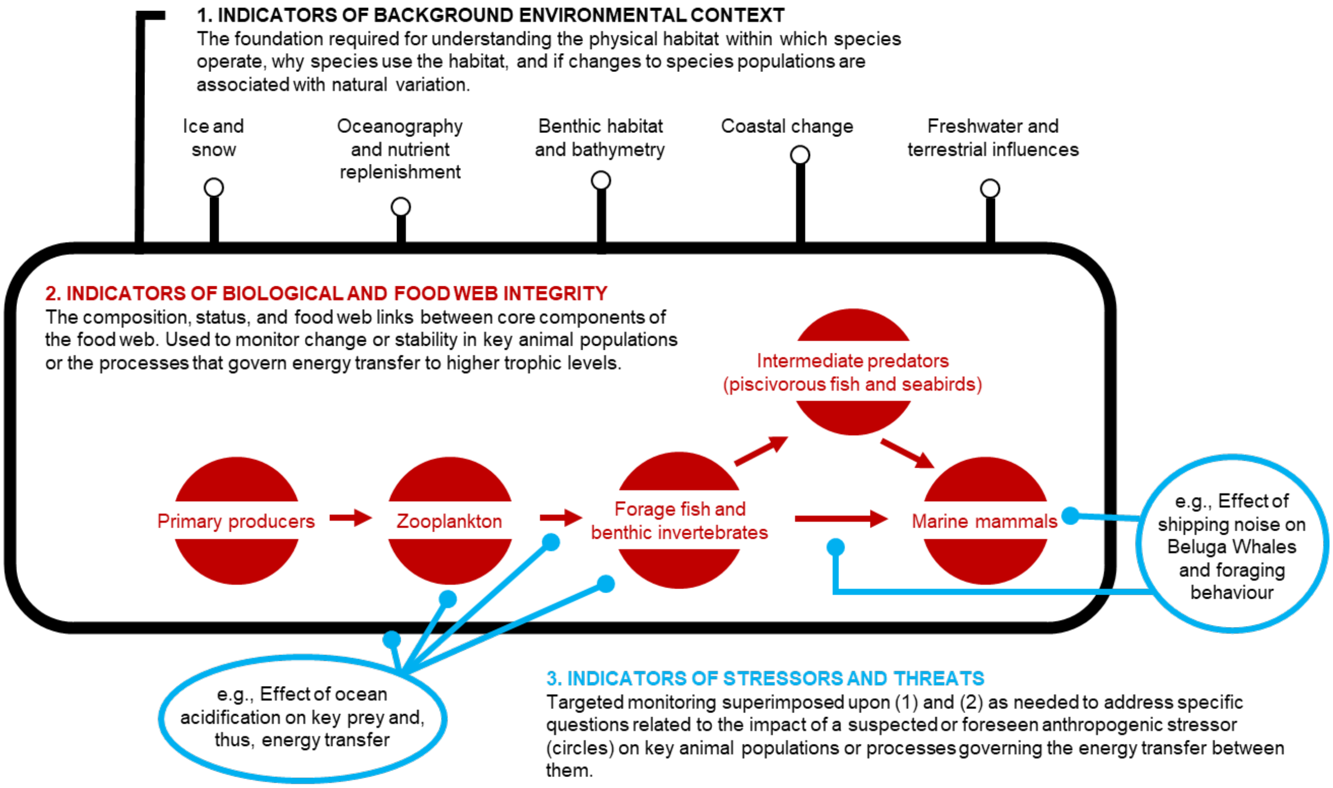

Figure 2. Schematic of the three-tiered indicator concept that guided indicator recommendations (from Ehrman et al. 2022). (1) Indicators that provide background environmental context lay the foundation for an ecosystem-based management approach to monitoring and are necessary to link observed species 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).

For each indicator, consideration was given to: 1) the identification of the hypothesized change(s) to the ecosystem that the indicator is meant to capture, 2) relevance to the ANMPA COs, 3) key recommended monitoring strategies; and, 4) the ANMPA Working Group priorities that the indicator addresses (see Appendix 1). For more information on the relevance of each parameter to monitoring the COs, the frequency of measurements and other considerations, see Appendix C in Ehrman et al. (2022).

Initial discussions during the meeting were started to develop tools and strategies for collecting monitoring data for each indicator at the community level; however, this should be more thoroughly explored and also build from successful community programs, monitoring frameworks, and policies already in place.

Indicators That Provide Environmental Context

Core Oceanographic Parameters and Nutrient Concentrations

Key measurement parameters for this indicator are:

1. temperature and salinity profiles (variation with depth);
2. dissolved oxygen profile;
3. nutrients: nitrate, phosphate, silicic acid;
4. dissolved inorganic carbon (DIC) and total alkalinity (indicator of acidification);
5. turbidity (water clarity);
6. oxygen stable isotope ratios ($\delta 18O$) (to detect river input vs sea ice melt);
7. currents velocities and sea ice drift (e.g., stratification, mixing, circulation patterns);
8. photosynthetically active radiation (PAR) profiles (amount of light available for primary production); and,
9. underwater sound profiles (e.g., anthropogenic or natural such as during storms).

This indicator underpins physical habitat, all biological processes, and the setting for all marine life; it is foundational to, and has strong linkages with, all other indicators. Information on this indicator is critical for interpreting biological changes in the system. Monitoring key parameters within physical oceanography and nutrient concentrations is strongly recommended as an integral part to any marine ecosystem monitoring program.

Several data gaps were identified for this indicator. There is a limited understanding of the interaction between Darnley Bay and the broader marine ecosystem. Similarly, data regarding oceanographic parameters within Darnley Bay are limited and the effects of the flow from the Hornaday River on key indicators (e.g., light and nutrient availability) are also unknown. It is also important to understand the source of nutrients, which may vary by season and/or location, as well as primary production, changes in the physical properties (e.g., temperature and salinity), or how events (e.g., storms, winds, upwelling) can impact the oceanography, as these are all linked to and will influence oceanographic habitats. Water circulation in Darnley Bay was identified as a large data gap, as 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 in the ANMPA. Bathymetry of Darnley Bay remains a data need (see Benthic Habitat Distributions below). It is also important to measure and include atmospheric drivers (e.g., precipitation, air temperature, wind speed), recognizing the influence of these parameters on oceanographic processes.

Oceanographic data can consist of sporadic measurements and long-term monitoring of parameters. A key consideration is the temporal and spatial resolution of sampling sites, as this pattern of sampling will be key to determining how, when, where, and at what frequency to monitor. There are several possible instruments that can be used to collect this data, including satellites, instruments attached to moorings as well as those deployed separately, and drones. These data collections can then be used to support models which allow interpolation between sparse data points. The strength and applicability of the model, however, is highly dependent on the quality and quantity of data available. Biophysical models could be developed for Darnley Bay with sparse data, and these models could estimate the chemical and physical habitat conditions that exist between the observations. The models could also be used to predict the effects of physical drivers (e.g., storm events, changing wind patterns, late or early ice retreat) on the system. This information could then be interpreted to predict the consequences for upper-trophic animals. Bathymetry was identified as an important component to developing accurate circulation models.

Moorings, community-based projects, and offshore programs can contribute to oceanographic data. Current velocities, which help to determine circulation patterns, can be measured with acoustic Doppler current profilers (ADCPs) installed on a mooring. Existing community-based programs could also be expanded to monitor key ocean properties and nutrient concentrations (e.g., SmartICE, Canadian Rangers Ocean Watch [CROW], Arctic Coast). Indeed, many of the oceanographic parameters recommended to be monitored can be measured using a conductivity-temperature-depth (CTD) probe equipped with the necessary sensors. Collecting water samples to measure nutrient concentrations and some oceanographic parameters is possible as part of a community-based program with appropriate training and equipment. Offshore research programs could be established, developed, or engaged to measure the large-scale physical processes that may be contributing to year-to-year variations and to changes observed in Darnley Bay. As these ship-based programs often operate collaboratively to address multiple objectives, they are equipped with scientific expertise and equipment necessary for oceanographic and nutrient sampling offshore.

Ice Structures, Snow and Ice Thickness, Ice Break up/Freeze Up Timing

Key measurement parameters for this indicator are:

1. timing of ice retreat (for fast ice), ice clearance (for pack ice), and ice formation; and,
2. snow thickness.

Snow and ice influence habitats for Arctic species and key processes in the Arctic (e.g., the timing, distribution, and magnitude of primary production, which has cascading effects to higher level trophic levels). Ice and ice structures provide habitat for key species, including polar bear, whereas ice leads are critical for marine mammals and birds. Snow is as important from an ecological perspective as is ice. Snow acts as an insulating blanket on the ice, moderating the exchange of heat between ice and atmosphere so that ice thickness is better maintained through the season and ice melt is delayed in spring under snow. Snow is also important to key species; for example, snow in combination with ridging provides habitat for Ringed Seals. Snow thickness is inversely related to the availability of light, which is critical for primary production. Thinning snow and ice in the spring can cue the onset of specific life history stages for zooplankton, fish, and marine mammals. The overall length of the ice-free season determines the availability of open-water foraging for upper trophic animals and the period of open-water primary production.

Several data gaps were identified. It was recognized that there is a paucity of information regarding ice in Darnley Bay, although more information is available for the northern part of the MPA (e.g., Cape Parry). Also, while panarctic ice information is available, it may be misleading for the MPA and the dynamics of sea ice and the patterns of ice movement are oversimplified. Therefore, both information on the effects of ice on the nearshore, including interaction between shore and sea ice, as well as ice data for coastal embayments in the MPA, were identified as data gaps. Assessing the effects of ice on the nearshore would be difficult and requires a dedicated study.

There is a need to study different locations to determine the timing and ecological importance of ice break up and freeze up, especially as there is different timing of freeze up and break up north to south in the MPA. A key first step, however, is to define break up and freeze up (e.g., 50% ice remaining for a minimum of 24 hours), which may differ depending on the species or process being monitored. Break up and freeze up may also be influenced by changing amounts of freshwater delivery, a suggested area for further study. As well, the impact on the sea floor from fresh water is unknown, as is the potential presence of bottom fast ice. Ice structures and thickness was identified as a data gap for Darnley Bay, especially as it influences winter travel. Radar imagery is needed to identify ridges, leads, rubble ice, and other structures, and there is no radar imagery currently available for the MPA.

There may be an opportunity to link existing community-based programs to monitor snow and ice parameters in the MPA. Ice charts can be used to calculate break up and freeze up, a method which can be developed into a community approach to build capacity. Using ice charts, a baseline of ice type and concentration could also be developed, with retrospective trends analyzed. Break up can also be easily identified from underwater noise recorders, in locations where those are deployed. Snow depth data could be collected using a ruler from a simple transect, as part of a community-led approach. Considerations of geographic and temporal scale, however, are important when sampling as it was recognized that there is value in taking a set of single data points across a larger space within a shorter time period and also in taking a series of repeated data points at fewer locations across a longer time period. The decision of which approach is most appropriate is dependent on the hypotheses to be tested.

Benthic Habitat Distributions

Key measurement parameters for this indicator are:

1. bathymetry;
2. sediment composition and benthic habitat mapping;
3. proxies for benthic food supply (e.g., organic matter content, benthic pigments, and stable isotope ratios ($\delta 15N$, $\delta 13C$), highly branched isoprenoids (HBI), fatty acid composition of the sediments); and
4. “extra” bulk sediment samples (for unforeseen future threats/contaminants).

Bathymetric information, which includes geomorphology and disturbances, is needed in order to interpret and understand oceanographic processes in the area. These data also link to benthic habitat types and distributions as they provide information on the parameters needed to support benthic communities. It was recognized that a full mapping exercise of benthic habitats across the MPA is not needed, and a transect-based approach may be sufficient. Linking the relevance of habitat mapping to the species included in the CO may help to identify critical areas. Monitoring the sediment composition for proxies of food supply relevant to benthic invertebrates provides linkage to benthic species distributions, biomass/diversity 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.

Several data gaps were identified. Key locations and habitats within the MPA need to be identified, researched in order to better understand their relevance to the CO’s, and then monitored to assess trends in change (or stability). While macroalgae was recognized as an important feature for benthic habitat mapping, it is not fully documented in the area. Nearshore bathymetry and structure were also identified as data gaps, and adjacent shore line characteristics were identified as a potential proxy for benthic habitat, although verification is needed. For instance, bedrock extending out provides habitat for kelp forest ecosystems and, since the bedrock habitat is relatively stable, implies that the ecosystem itself may be relatively stable (hence a longer periodicity for monitoring). Alternatively, extensive glacial tills held together by permafrost implies muddy unconsolidated adjacent coastal habitats with shorter periods over which changes might occur. A targeted approach focusing on areas experiencing extreme erosion may provide critical information about the sea floor amidst rapid change (see

Coastal Change section). Areas with extensive freshwater influence will have different communities.

Once foundational data gaps have been filled, that information can then be used to inform monitoring (e.g., choice of parameter, location, frequency, linkages with other indicators). Benthic habitat distributions can be mapped and monitored using remote operated vehicles (ROVs) in the nearshore, and this has been done as part of a community-led approach for the MPA, with equipment and training provided. Drones with echo sounders and GPS were identified as an option for recording bathymetry. Bathylidar may also provide information on benthic habitat to 10m depth; however, it is affected by sea state and turbidity. A satellite-based interferometry/altimeter system may also map bathymetry, and would need to be done only once, but is limited by ocean state changes. Data available from the Canadian Hydrographic Service (CHS) that were used to assess depth can also be used to begin to understand different benthic habitat types. Data on oceanographic parameters at the bottom (e.g., temperature, salinity) are also valuable and would contribute to understanding benthic habitats.

Coastal Changes

Key measurement parameters for this indicator are:

1. historic reference of coastal position;
2. aerial drone surveys of coastal position; and
3. installation of coastal observatory.

Coastal changes across the Canadian Arctic are contributing to an increase in sedimentation, change or destruction of nearshore habitat, and the potential for biogeochemical impacts related to changing ocean chemistry from terrestrial inputs. Increasing coastal erosion due to climate change, coupled with the currents in Darnley Bay, could be simultaneously impacting broad ecosystem function (e.g., primary productivity), and specific sensitive habitats (e.g., kelp forests). The surficial geology associated with the coastline and the nearshore link the terrestrial and nearshore ecosystems.

Several data gaps were identified. Coastal erosion is a data gap for the MPA, including the potential influence of sediments on primary production through changes to light availability and nutrients. While there are some data available to identify coastal sensitivity and type of substrate, there is a lack of baseline data available, and there are no data available to assess the rate of coastal change across the MPA. Satellite photos may also be available as a source of information; however, there was recognition that funding is needed in order to fill this data gap. Baseline information on elevation, the extent of isostatic rebound in the area, potential for flooding due to sinking land, and the effect on freshwater flows are all data gaps. Assessing biogeochemical impacts (e.g., carbon) has not been done in Darnley Bay but, more broadly, understanding terrestrial impacts to ocean chemistry is also a gap.

Installation of an automated coastal observatory to measure these parameters, and contribute to analyses regarding follow-on effects, would be useful in Paulatuk, NT, as there are currently none between Tuktoyaktuk, NT, and Cambridge Bay, NU, and would be relatively low cost.

Freshwater Inputs and Terrestrial Linkages

Key measurement parameters for this indicator are:

1. oxygen stable isotope ratios ($\delta 18O$) (to detect river input vs sea ice melt);
2. temperature and salinity profiles (depth and extent of warm, fresh water);
3. nutrients: nitrate, phosphate, silicic acid (terrestrially-derived nutrients);

4. turbidity (water clarity; suspended sediment in river discharge);
5. annual precipitation trends;
6. monthly discharge of Hornaday River; and
7. sediment δ15N, δ13C, and C:N ratios (terrestrially-derived, settled organic matter).

Ecological connections between the ocean and the land are most strongly maintained through the rivers that discharge into Darnley Bay. Factors to be considered include permafrost and transport of nutrients or contaminants into the system by means of fresh water. Land degradation, while also relevant here, is considered as part of the Coastal Change section.

Climate-driven changes to river flow (e.g., river discharge volume) and to the timing of spring freshet would have consequences to the amount and location of habitat available for anadromous, coastal, and offshore marine fishes in the ANMPA as well as brackish-tolerant zooplankton and benthic invertebrates. Extreme precipitation events may increase connectivity between marine and freshwater habitats due to higher water levels. It is important to understand the mechanisms through which freshwater and terrestrial inputs affect the marine ecosystem, as well as steps for potential mitigation and adaptation to these changes.

Several data gaps were identified. While freshwater flow data are available for the Hornaday River, no flow or water level data have been compiled for the Brock River. A broader understanding of the magnitude and variability in the extent of freshwater plumes from rivers draining into Darnley Bay is missing. Understanding the characteristics of these plumes would be relevant to identifying the distribution of euryhaline fishes (e.g., those that can tolerate a wide salinity range), zooplankton, and benthic invertebrates in southern the ANMPA. Also, a buoyant, brackish plume of water may accumulate under the ice during spring freshet across inner Darnley Bay south of Ugyuk Point, but the extent of the plume is unknown, as is how it is dissipated. The amount, importance, and spatial distribution of terrestrially-derived nutrients, organic matter, and sediment in Darnley Bay have also not been investigated. This, however, is of secondary importance to determining the movement of the fresh water itself.

Movement of fresh water can be tracked using water quality variables measured within a sampling program for key ocean properties and nutrient concentrations (e.g., temperature, salinity, oxygen stable isotope ratios ($\delta^{18}O$)). Measurement of $\delta^{18}O$ across a broad spatial area can be used to construct an “isoscape”, which can be viewed as a heat map to understand where the different concentrations of fresh water occur in Darnley Bay. Sea surface temperature and turbidity inferred from satellite images may also provide some insight into the distribution and movement of freshwater plumes. Terrestrially-derived organic matter that settles out of the river plume can be assessed by measuring sediment organic matter content, stable isotope ratios, and carbon-to-nitrogen ratios in sediment grabs collected by a benthic habitat sampling program. The spatial extent of terrestrially-derived organic matter and nutrients will generally follow water circulation patterns. The freshwater inputs and terrestrial linkages indicator, therefore, represents a “value-added” indicator that can be largely monitored by relying on the field programs and data collected for other background indicators (e.g., key ocean properties and nutrient concentrations, benthic habitat distributions).

Indicators of Biological and Food Web Integrity

While it may be impossible to monitor absolute abundances of trophic indicators, relative abundances of key organismal groups can provide the required information to indicate change (i.e., sampled communities in same way, using the same gear, over the same absolute or ecological time frames each year).

Trophic Links and Energetic Transfer

Key measurement parameters for this indicator are:

1. estimates of dietary links among key species in five primary trophic groups: primary producers, zooplankton, benthic invertebrates, fish, and marine mammals (using stomach contents and/or stable isotope ratios (δ15N, δ13C) and/or fatty acid compositions and/or highly branched isoprenoids (HBIs));
2. stable isotope ratios (δ15N, δ13C), HBI, and fatty acids of primary producers and sediment (to establish direction and magnitude of trophic transfer); and
3. caloric content of key zooplankton, forage fish, and benthic prey species (the energy density of prey).

Monitoring trophic links and energy transfer (defined in Ehrman et al. 2022) 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 feeding, by indicating whether key species are feeding on prey that occur within the ANMPA. Second, it may 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 this influences habitat usage within the ANMPA. Third, it may link trends in predator health or body condition to changes in prey composition, abundance, or energy density. Trophic links and energetic transfer are recommended to be monitored in four major web groups to "trace" effects from bottom-up or top-down: zooplankton, benthic invertebrates, fish, and marine mammals. Emphasis was placed on focusing on the structure of the food web pathways and on the energy flows between them as key indicators for monitoring the ecosystem.

Several data gaps were identified. Limited data exist regarding the specific composition or availability of Bowhead (*Balaena mysticetus*) prey near the ANMPA. The diets of the vast majority of nearshore and offshore fishes are uncertain, but observations of change in fish diets due to season, location, and time, would provide information about the natural variability in ecosystem components over time. Fish diet and stable isotope analyses may also help to understand habitat utilization or feeding areas due to direct observation or inferences regarding a nearshore or offshore source of prey. No data currently exist for benthic invertebrate energetics (calorie content) in the ANMPA. The caloric content of diet items is also relevant as changes in prey can be demographic (e.g., lowered relative/absolute abundances), habitat-related (e.g., displaced or moved elsewhere), or quality-related (e.g., lowered energetic value due to ecosystem alterations). Changes in prey types can also lead to shifts in handling times by predators whereby increased handling time reduces net energy gain to the predator from prey consumption.

Sampling can be easily incorporated into field programs designed for other indicators. Knowledge can be gained through direct observations of animal feeding behaviour or stomach contents analysis, or by analyzing one or a set of trophic biotracers in animal tissues (i.e., stable isotope ratios ($\delta^{15}N$, $\delta^{13}C$, $\delta^{34}S$), fatty acid composition, mercury concentrations, highly-branched isoprenoids (HBI), and lipid and calorie content). Trophic data derived from multiple methods can be layered on top of each other to build a more holistic understanding of trophic links if funding allows. Collection of stomach contents and/or tissues for biotracer analyses can be completed during 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. 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 is strongly recommended even if funding is not immediately available. Monitoring marine mammal condition may provide information about energy and resource availability/abundance or diet shifts; however, hunter biases may exist for marine mammal trophic data (e.g., harvested from select locations, size groups, healthier individuals, etc.).

Ice-associated, Under Ice, and Open-water Primary Producers

Key measurement parameters for this indicator are:

1. taxonomic composition of primary producers to assess community structure, function, and biodiversity;
2. chlorophyll a concentration (total and by size fraction) as a proxy of primary producer biomass (size classes represent functional and taxonomic composition of primary producers);
3. chlorophyll fluorescence profile as a proxy of the relative biomass of primary producers;
4. particulate organic carbon (POC) and particulate organic nitrogen (PON) as a measure of the organic material and its composition;
5. core oceanographic parameters (Core Oceanographic Parameters and Nutrient Concentrations); and,
6. nutrient concentrations (Core Oceanographic Parameters and Nutrient Concentrations).

Primary producer abundance and composition affects the entire ecosystem structure and functioning through a number of complex trophic relationships. Consequently, monitoring this key indicator is crucial for evaluating the status of the ANMPA COs (i.e., that the marine environment is productive and allows for higher-trophic feeding).

The major sources of primary production in Arctic marine ecosystems are pelagic and ice-associated (called sympagic) microalgae (i.e., phytoplankton and ice algae), which provide necessary food for higher trophic level organisms within the food web, and are vital to the survival and sustainability of the entire ecosystem. The timing, source, magnitude, and spatial extent of primary production can be indicative of broader shifts in atmospheric-ocean interactions and sea-ice regimes, linked to climate variability and change. Control mechanisms for the magnitude and timing of primary production in the Arctic are complex and interconnected but are primarily focused around light and nutrient availability.

Several data gaps were identified. Measurements of physical and chemical oceanographic parameters (e.g., temperature, salinity, $\delta^{18}O$, and dissolved nutrients) and sea ice conditions are necessary for providing background context on water mass distributions and the oceanographic habitat for primary producers. Continued monitoring may also highlight important changes that could indicate stratification in nutrient concentrations, and therefore productivity (e.g., a shift to a more flagellate-based system). Baseline information about primary production in or directly adjacent to the ANMPA is a data gap, however, as sampling has not occurred on a continuous basis at consistent locations. Assessment of ocean parameters (see Key Ocean Properties and Nutrient Concentrations Section) such as the presence of upwelling/downwelling events would be relevant to interpreting primary producer parameters and the importance of carbonate chemistry was stressed as a parameter to monitor acidification. Potentially toxic algal species are present in the MPA; however, their distribution, dynamics, actual toxigenicity and trophic transfer of toxins are data gaps. In addition to monitoring phytoplankton community composition for the presence of potentially toxic algal species, periodic monitoring of the benthos (e.g., benthic bivalves) is suggested to assess whether, and at which rate these toxins enter into the food web.

Several parameters (chlorophyll *a* concentration, flow cytometry analyses, taxonomic composition and abundance) were identified as relevant to assessing primary production as an indicator for the ANMPA. Generally, ideal sampling for this indicator would occur multiple times per year at a few key sites and once per year at a larger network of stations distributed across a wider geographic area. Chlorophyll *a* concentration (total and by size fraction) was identified as the parameter that could be feasible to measure as part of a community-based program. Implementing flow cytometry analyses would provide some information of primary producer community abundance, structure, and function at a reduced cost compared to taxonomic composition and abundance analyses. However, it cannot assess dominant species, or harmful algae presence. There are also field or lab instruments that can facilitate the monitoring of key indicators for primary producers. For example, fast repetition rate fluorometry (FRRF) can be used to provide estimates of primary production, and can be used in a field laboratory. Monitoring episodic or unusual events, for instance observations of algal blooms at the water surface or on shore, can also be completed at the community-level. Measurements of taxonomic composition and abundance for primary producer communities could be limited to specific locations or less frequent sampling but still relevant to ecological processes, and focus on key species.

Zooplankton Community Composition, Structure, and Function

Key measurement parameters for this indicator are:

1. taxonomic composition (to calculate indices of community composition); and,
2. relative biomass of key indicator species and/or size classes.

Changes in taxonomic or functional zooplankton composition can 1) impact the efficiency of energy transfer to highly valued marine mammals, seabirds, and predatory fish (e.g., through changes in zooplankton size), 2) signal the status of primary producers, 3) be indicative of changes to broader environmental drivers (e.g., via changes in ctenophores, pteropods, copepods), 4) identify the presence of new species, and 5) respond to anthropogenic disturbances. Two potential research questions were suggested:

1. Is the abundance/biomass of gelatinous zooplankton species changing, and is that change linked to temperature and water quality? Monitoring presence of sea jellies could be done by local observations.
2. Is a shift in size of copepods occurring, which would affect the transfer of energy to upper trophic levels?

Several data gaps were identified. Due to north-south and nearshore-offshore gradients in parameters within the ANMPA, there is a need to develop a monitoring program that can capture spatial and temporal heterogeneity in zooplankton and considers the timing of sampling due to seasonality, as well as climate and sea-ice dynamics. As year-to-year variation in oceanographic and climatic conditions may result in different zooplankton communities, indicators of background environmental conditions should be measured concurrently. It is recommended that taxonomic data be used to calculate the relative 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 of forage fish and upper-trophic level species is linked to zooplankton food availability. If funds are not available for full taxonomic analyses, estimating the biomasses of zooplankton size classes 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. Monitoring the community composition of zooplankton can be accomplished using straightforward procedures as part of a community-based monitoring program. Samples for zooplankton taxonomic analyses 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. Taxonomic analyses will require expert analyses in a laboratory setting, perhaps via 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.

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

Benthic Invertebrate Community Composition, Structure, and Function

Key measurement parameters for this indicator are:

1. taxonomic composition (to calculate indices of community composition);
2. relative biomass of key indicator species; and
3. benthic and oceanographic habitat information (see Key Ocean Properties and Nutrient Concentrations Section & Benthic Habitat Distributions Section).

The community structure and function of benthic invertebrates are relevant to the ANMPA COs because they can reflect changes in the lower levels of the food web that will likely have cascading effects on higher trophic animals. Benthic invertebrates may be particularly good candidates for indicators of natural and anthropogenic disturbance because many benthic invertebrates are long-lived, have relatively low mobility (high site fidelity), and respond differently to changing physical factors such as temperature, ocean acidification, sea ice, and sediment type according to their species' particular physiological thresholds. Shifts in benthic community composition may also indicate a change in marine water quality.

There are two types of benthic indicators: 1) descriptive indicators related to benthic community composition, including biomass, density, and biodiversity, and 2) functional indicators that measure ecosystem activities (e.g., changes to behaviour, metabolism, or stable isotopes). Key species of benthic communities, such as corals and sponges, could be important indicators to monitor long term; however, it first needs to be determined which species are present in the area. Over the long-term, and with a greater understanding of the benthic community, indicator species could be identified, which would provide some focus to monitoring the benthic environment.

There is a lack of scientific data regarding the benthic community composition in the ANMPA, and this was highlighted as a data gap, especially in the offshore area. 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. While intermittent benthic community composition and structure data were collected in offshore programs in the MPA, it was recognized that the challenge with offshore benthic sampling may be related to sampling methods and the heterogeneity of the benthic habitat (e.g., rocky areas disallow use of box core or net). The amount of available information may be increased by linking benthic habitat mapping with benthic biodiversity data.

Indeed, 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.

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 at the community level. Alternatively, less destructive methods for sampling in the region, such as ROVs or other, non-invasive camera technology, could provide more descriptive, although opportunistic, baseline information. 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). In addition, while environmental DNA was not a final recommendation from this process, it could be an important tool for monitoring key species and compositions of biotic communities, and this could be done by community members. 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.

Offshore Fish Community Composition, Structure, and Function

Key measurement parameters for this indicator are:

1. taxonomic composition of entire catch;
2. catch-per-unit-effort of key indicator species; and
3. benthic and oceanographic habitat information (see Key Ocean Properties and Nutrient Concentrations Section & Benthic Habitat Distributions Section).

Offshore fishes are considered all 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. Therefore, monitoring via this indicator in the ANMPA could identify events that trigger potential changes observed at higher trophic levels. Monitoring fish community composition as a whole provides important insight into how environmental variability and change are affecting the functioning of the ecosystem. Relative abundance was highlighted as the key monitoring parameter of interest for the offshore fish indicators.

Research is needed on the ecological resilience, sensitivities, temporal stability of ecosystem structure, and responses of key species to stressors. Aside from midwater trawling that was completed during the Canadian Beaufort Sea-Marine Ecosystem Assessment (CBS-MEA) to verify species compositions of hydroacoustic observations at Cape Parry, virtually no other fish sampling has been conducted in the pelagic realm of offshore areas in the ANMPA. 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) and relative abundance, perform robust analyses of spatial and temporal variability in community composition, and identify new species occurrences. Alternatively, identifying a representative set of key species at each trophic level 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 will help narrow the scope (e.g., Majewski et al. 2017). Tracking indices of fish community structure will help to establish baselines of biodiversity and distribution, which can be used as the basis for selecting the species key for monitoring. 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. As well, 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. This was identified as a sensitive life history stage for marine fishes.

Monitoring full offshore fish community composition and structure requires carefully planned and broadly distributed multi-species surveys that concurrently capture environmental habitat data. Offshore collections within Darnley Bay could potentially be conducted through a community-based program by using deep-set gillnets or a small benthic sled; however, most benthic offshore species are not amenable to capture by gillnets due to body shape and lower motility relative to pelagic species. Such deployments would require a winch-capable vessel and careful safety precautions, and may collect fewer and potentially different species than a typical larger-scale equipment typical to ship-based studies in the region. Potential alternatives to gillnets for capturing offshore fish include trammel nets, long lines, or crab pots, and can be set from smaller vessels. Such surveys may be challenging to execute through a community-based monitoring program, as sampling typically requires an offshore vessel to safely sample remote and/or exposed stations. Collaborating with ship-based research and monitoring programs may be a sound approach to collecting information on this indicator. Inshore and offshore fish surveys should be coordinated in time to study food web linkages, and for complementarity on presence/absence. If monitoring was focused specifically on the role of offshore fish as prey for higher trophic feeding, community-based programs could monitor the occurrence and relative abundances of different offshore fish in char and marine mammal stomachs, or bird forage.

Inshore Fish Community Composition, Structure, and Function

Key measurement parameters for this indicator are:

1. taxonomic composition of entire catch;
2. catch-per-unit-effort of key indicator species; and
3. benthic and oceanographic habitat information (see Key Ocean Properties and Nutrient Concentrations Section & Benthic Habitat Distributions Section).

Inshore fishes are considered all those that typically occupy waters from the shoreline to 20 m depth. Closely linking data from inshore and offshore programs is strongly advised; monitoring a few key species that are commonly caught in both areas would provide information on change at a larger spatial scale than possible through each individual program alone. Monitoring inshore fish community composition, structure, and function is relevant to the ANMPA COs because these represent some of the key prey items for marine mammals, seabirds, and Arctic Char and could identify the events that trigger potential changes observed at higher trophic levels. As well, inshore fish represent linkages to both freshwater and marine systems. Indeed, inshore fish communities can 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. Documentation of unusual inshore fish species and odd behaviours was advised for their potential association with environmental disturbances. Relative abundance was highlighted as the key monitoring parameter of interest for the inshore fish indicators.

Several data gaps were identified, including the stability of community structure and the temporal variance in relative abundance of important key species. Tracking indices of fish community structure is an approach that not only provides a means for detecting change in the fish community (e.g., invasive species, range expansions, rare but endemic species), but can additionally provide explanatory context for animal behaviour or changes in ecosystem function and structure. Integrating species inventories with relative abundances can then provide information relevant to a suite 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, maturity, 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. These indices may also help to establish a baseline in biodiversity and distribution, which can be used as the basis for selecting which species might be key for monitoring. Information about the ecology of ichthyoplankton, the eggs and larvae of fish, is a data gap for inshore and offshore fishes. Little is known about the ecology and habitat requirements of larval fish for most species, many of which are pelagic. This was identified as a sensitive life history stage for marine fishes.

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, relying 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). 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 and are subject to the limitations (outlined in Ehrman et al. 2022). 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.

Key Forage Fish Relative Abundance and Biomass

Key measurement parameters for this indicator are:

1. catch-per-unit-effort of adult fish (to calculate relative abundance and biomass);
2. relative abundance and/or biomass of juveniles; and
3. oceanographic habitat and sea ice/snow information (see Key Ocean Properties and Nutrient Concentrations Section & Ice Structures, Snow and Ice Thickness, Ice Break-up/Freeze-up Timing).

Forage fish are a key prey source for upper trophic predators that occupy the ANMPA. Tracking the relative abundance and biomass of forage fishes will provide two key pieces of information for reporting on the ANMPA COs: 1) it will indicate whether sufficient food is available for upper trophic predators in the ANMPA, and 2) changes in prey availability may provide an explanation for observed changes in predator behaviour, condition, or mortality rates. It was advised that the relative abundance of Capelin (*Mallotus villosus*), Arctic Cod, and Sand Lance (*Ammodytes hexapterus*) can be used as ecological indicators of change driven by climate variability.These three species have been documented as important prey for Beluga whales (*Delphinapterus leucas*), Ringed Seals, Arctic Char, seabirds, and to a lesser extent, Bearded Seals (*Erignathus barbatus;* see reviews in Ehrman et al. 2022). Sand Lance was also acknowledged as an important prey source for Beluga, especially if prey shifts from Arctic Cod occur.

Several knowledge gaps exist regarding Capelin. These include overwintering locations, larval Capelin dispersal sources, genetics of Capelin in the area, and location of aggregating shoals prior to summer spawning. Observations of spawning Capelin by community members, including timing of spawning, is valuable because Capelin is a prey source for key predators. Local observations indicate that Capelin spawn every summer on shorelines within the ANMPA between typically June and August. As Capelin are most commonly observed during their beach spawning, their presence does not truly represent the abundance and, conversely, their absence may mean they are present but not observed. Further, these episodic aggregations associated with observations of beach spawning events may suggest there are higher numbers of fish than are actually present. Further investigation into standardized survey methods for Capelin is required.

It is highly recommended that forage fish abundance and biomass be monitored concomittantly with inshore and offshore fish communities (more fully outlined in Ehrman et al. 2022). Moored hydroacoustic instruments may be particularly useful for monitoring pelagic forage fishes (and zooplankton) year-round in the northern ANMPA, where biomass is hypothesized to be related to the presence of marine mammals and seabirds. Monitoring predator diets concurrently with forage fish relative abundance and biomass, and possibly measuring trophic biotracers in both predator and prey, would allow investigation regarding potential shifts in prey species in the diets of upper-trophic predators. 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 digging in soft, pebbly sediments in the inter-tidal zone may be more effective at sampling than gill nets. By monitoring the diets of predators (see Trophic Links and Energetics) this could provide an indication of availability (i.e., presence/relative abundance) of forage species that would complement scientific surveys of relative abundance/biomass. Metrics for relative abundance/biomass of forage species could then be compared to what is being consumed by predators to assess food web variability and shifts. Moored Acoustic Zooplankton and Fish Profilers (AZFPs) provide an option to monitor the biomass of offshore forage species such as Arctic Cod at key locations (e.g., offshore of Cape Parry) both seasonally and inter-annually. AZFP’s would require periodic vessel-based surveys for echo validation and data extraction and servicing.

Anadromous Fish Relative Abundance, Habitat Use, and Population Structure

Key measurement parameters for this indicator are:

1. catch-per-unit-effort (to calculate relative abundance and biomass);
2. biological and population data from existing Hornaday and Brock river Arctic Char monitoring programs; and
3. timing of upstream/downstream migration.

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. Monitoring strategies designed for the marine nearshore fish community (e.g., Arctic Coast) are unlikely to provide sufficient information to evaluate if the habitat required to support populations of anadromous fishes is being maintained, which is an ANMPA CO. Monitoring within the ANMPA boundaries alone would also miss important information about habitat use, harvest pressure, and life history that are important to evaluate whether activities or disturbances in the MPA are impacting anadromous fish populations as a whole as the primary marine migration corridors, feeding grounds, and harvest locations for Arctic Char are outside of the MPA boundaries. Both Arctic Char and Broad Whitefish were listed as community priorities by the ANMPA Working Group (Ehrman et al. 2022, Appendix A).

Several knowledge gaps were identified. While there are long-term harvest-based monitoring programs, there is no stock assessment of char independent of the fishery. Therefore, using the harvest-based data for monitoring will require careful consideration on how to perform meaningful analyses for long-term trend analyses. Harvest-independent data may be more appropriate to address certain hypotheses or can provide information not currently captured using the fishery-dependent methods (e.g., index gillnetting, which may provide information about adult size, as well as different life-stages). Characterizing and understanding population structure of char in the area was identified as a data gap. This encompasses both genetic and morphological differences, and potentially also includes “blue char”, a morphotype reportedly different from those associated with the Hornaday River and of unknown origin, as is their relationship to other char in the southeastern area of Darnley Bay. An archive of samples is being collected to begin to address this using genetic analyses. Information regarding Broad Whitefish in the MPA is also a gap; however, there is also currently limited capacity to monitor them, limited concern over their abundance, and uncertainty regarding their habitat use within the ANMPA. If monitoring whitefish was desired, it was recommended that a program be designed specifically for them, rather than relying on by-catch data from other fish monitoring programs.

Arctic Char has a relatively long history and detailed baseline information compared to other biological indicators discussed in this report. Any new sampling programs devised to support monitoring of anadromous fishes should be closely coordinated with existing programs. Standardized char monitoring programs and community-led harvest surveys provide valuable information regarding char in the area, and are examples of efforts that contribute to monitoring that may not need to be done directly with funding from the MPA. Indeed, it may be possible to use the same monitors to extend the length and species focus of these existing monitoring programs, which could further contribute to MPA monitoring.

A simple and effective parameter to consider for monitoring change in fishes would be the timing of key life history events (e.g., timing of upstream/downstream migrations, spawning of Capelin, etc.). Age, size-at-age, condition, and catch-per-unit-effort were also identified as key parameters that should be monitored to look at changes in abundances and growth rates using data from existing harvest monitoring programs or stock assessments. The diet of char in this area, and their prey, could also be a potential indicator to monitor, and would contribute to the Trophic Links and Energy Transfer indicator. Assessing and monitoring habitat usage by key species, such as Arctic Char, is important both as baseline information and also as a potential indicator if habitat use changes (e.g., if the feeding zones of fish change over time that would indicate an underlying ecosystem change).

Occurrence and Timing of Potentially Colonizing Species

Key measurement parameters for this indicator are:

1. timing of arrival;
2. qualitative abundance or catch-per-unit-effort;
3. habitat associations; and
4. environmental DNA (eDNA).

Biodiversity change is a useful indicator of underlying ecological change and this indicator is intended to document changes in species biodiversity associated with new arrivals, migratory patterns, timing, and number of organisms. New arrivals should be categorized into a) natural range expansions (e.g., Pacific species moving east with changing ocean temperatures); b) invasive colonizing species (e.g., species whose movements are aided by human intervention and that actually become established), and c) vagrants (e.g., one-off occurrences of a few individuals that do not appear to have established a population as yet).

Key potentially colonizing fish species were identified, including Pacific salmon (*Oncorhynchus* spp) and potentially Greenland Halibut (*Reinhardtius hippoglossoides*) and Dolly Varden (*Salvelinus malma*). The tracking of habitat and environmental use by these key species provides important baseline information, as well as serves as a potential indicator of ecological change in response to environmental drivers. Monitoring the potential colonization of the ANMPA and nearby rivers by Pacific salmon was identified as a priority by the ANMPA Working Group (Ehrman et al. 2022, Appendix A).

The potential expansion of fish and invertebrate species into the ANMPA, either by naturally-occurring range expansions or human-facilitated means, has not been well-studied. Thorough species inventories for non-harvested fish and invertebrates (e.g., Northern Coastal Marine Studies [NCMS], CBS-MEA, and Arctic Coast) began only recently in Darnley Bay. Therefore, it may be difficult to determine whether a newly observed species represents a potentially colonizing species or simply the first detection of a species that has occupied the ANMPA for some time. Targeted habitat suitability modelling of Darnley Bay has not been conducted, and no known invasive vertebrate or invertebrate species have yet been recorded in the ANMPA. 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.

There were several options identified for monitoring this indicator. It is recommended that close collaboration continue with existing programs that document the annual number of Pacific salmon occurrences and their locations across the Canadian Arctic (i.e., Arctic Salmon, a community-based monitoring program). Data already being collected for other indicators could be re-purposed by evaluating the species lists accumulated by annual surveys, requiring detailed taxonomic data and information to support an assessment of relative abundance are collected in each survey. 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 critical habitat by species at risk (e.g., Bering Wolfish [*Anarhichas orientalis*]). Integrating species inventories with relative abundances can help track whether a potentially colonizing species is increasing in abundance or associated with a change in another ecosystem component (e.g., change in predator diets, decline in competitors).

A protocol should also be developed for reporting and preserving specimens that appear unusual to experienced technicians during field collections (e.g., voucher photos, formalin preservation) so that 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 and 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. Whenever possible, the habitat within which the potentially colonizing species was observed should be recorded, to infer the native species with which it may interact. Habitat requirements may also be used to develop control measures if those become necessary. Environmental DNA (eDNA) can also be used to detect the presence of potentially colonizing species, and field sampling aspects can be incorporated into a community-based monitoring program. 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.

Marine Bird Presence/Absence and Prey Items

This indicator highlights the importance of marine birds as an ecological component of the ANMPA, provides specific linkage to one of the ANMPA COs, which is 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, and calls attention to the many knowledge gaps that exist for marine birds in the area and the potential to leverage funding (e.g., for geolocators).

It is recommended, however, that this indicator be withheld from the ANMPA monitoring plan until the Joint Secretariat, Inuvialuit Game Council and Canadian Wildlife Service (CWS) have completed a co-management plan for the Cape Parry Migratory Bird Sanctuary, a process that is currently underway. While this process is on-going, CWS remains open to research on marine birds in the MPA, and recognizes that there are many knowledge gaps, including bird diet and range of the colony, as well as overwintering information and population metrics, which would be useful to inform the indicators. Marine bird prey items in the marine environment can also be inherently monitored through the indicators described for benthic invertebrate, offshore fish, and forage fish communities. Once the co-management plan has been developed for the Cape Parry Migratory Bird Sanctuary, the ANMPA Working Group could reconsider how an indicator for marine birds can be best incorporated into the ANMPA monitoring plan.

Marine Mammal Presence/Absence, Timing, Habitat Use, and Group Composition

Key measurement parameters for this indicator are:

1. movement;
2. timing of arrival/departure;
3. locations of aggregations; and
4. group composition.

The COs for the ANMPA focus on conserving the marine habitat and forage species that support key upper-trophic level species. There are three marine mammals of high cultural and subsistence value to the Inuvialuit: Beluga whale, *qilalugaq*, Ringed Seal, *natchiq,* and Bearded Seal, *ugyuk*. Monitoring marine mammal presence/absence, timing, habitat use, and group compositions will not provide a direct evaluation of whether the COs are being met; however, may uncover “red flags” that warrant further investigation.

Monitoring presence/absence, 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 and to track potential changes in habitat use over time. 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.

The ANMPA COs do not emphasize marine mammal health, however, health indices may provide additional context for understanding data collected through a monitoring program.

Several gaps in scientific knowledge were identified. It was also recognized that a substantial amount of information about marine mammals is held by Indigenous knowledge holders, which is not accounted for here but will further inform the final monitoring plan design. For Beluga, there is a large gap in data available as to why they are entering the Darnley Bay area, which the community is interested in determining and would require more research. There is also no consistent aerial survey, a complete absence of telemetry data, and the presence/absence of Beluga is difficult to estimate. The Beluga data that are available are mostly from harvest/Indigenous knowledge, which may support the second ANMPA CO. However, it was emphasized that harvest data has many human-related biases (e.g., data will only be available for good weather days when harvesters could safely hunt). Finally, additional research is needed to identify and understand the importance of observed rubbing and moulting behaviours, and whether those habitats should be of monitoring interest. For seals, there are limited aerial survey data (e.g., only June of 1974–1979 are available) and telemetry data are only available for Bearded Seal. Therefore, presence can be confirmed, but not absence, and there is no ground-truthing. To date, there is a large gap in data available for Bearded Seal, especially regarding diet. Information for Bearded Seal abundances, population structure, and movements are also limited for the ANMPA region. For Bowhead whales, foraging is mostly driven by upwelling events near Cape Parry, although there are no telemetry data available and data gaps include diet, population structure, and sex. An indicator for condition (e.g., body fat condition) may provide information regarding energy and resource availability/abundance or diet shifts.

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 non-harvesters to report observations of marine mammal species within the ANMPA and adjacent waters, which would strengthen the parallel use of Indigenous knowledge and scientific data (e.g., the "*Arctic Marine Observer App"*). Additionally, similar to the protocol for harvested fishes, a harvester-independent monitoring program could be developed. Standard protocols for recording different types of information, taking photographs, and geo-referencing would be beneficial to both these programs (e.g., an online application for phones or a standard form available from Hunters and Trappers Committees). Such programs would also improve the data available to monitor Bowhead whale habitat use near the ANMPA. Continued satellite tagging and intermittent 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. However, it should be recognized that satellite tagging and aerial surveys are expensive, difficult, and potentially not feasible to perform every year. Satellite tagging programs that specifically target Bearded Seals and Beluga whales known to utilize the ANMPA and adjacent waters would fill current knowledge gaps. Passive acoustic monitoring of vocalizations may also be used to monitor the presence/absence of marine mammals, and can provide information regarding habitat use when paired with passive sampling of oceanographic parameters. Note that acoustic monitoring, while potentially powerful, has some limitations. If marine mammal health is integrated into a monitoring plan, it is recommended to standardize with the existing Beluga Health Research and Monitoring program.

Indicators of Pressures and Threats

The terms driver, stressor, pressure and threat are all used to describe ecosystem change, but are ambiguous in many usages. Thus, it is important to define and distinguish among these terms (Figure 2). A *driver* is a natural factor that directly or indirectly results in stability or a change to the ecosystem. A *stressor* is an anthropogenic factor, meaning it is the result of human activities, that similarly changes the ecosystem. Natural drivers and anthropogenic stressors can be local or they can be pervasive, where local means they originate and act locally, usually over shorter timeframes, and pervasive means they originate and act over larger distances, over longer timeframes, and/or may act across many ecosystem processes or components (i.e., have multiple entry points into the ecosystem). A driver can result in a natural ecosystem response as it is a natural factor; a stressor cannot as it is an anthropogenic factor.

A stressor, however, can act on a driver (e.g., the presence of sea ice is a driver that is influenced by anthropogenic factors). A *pressure* is a directional driver (i.e., natural) or stressor (i.e., anthropogenic) that is causing the ecosystem to change but is prolonged and relatively mild in terms of consequences, thus the recipient ecosystem may tolerate or adapt to the change. A *threat* is a directional driver or stressor that is relatively severe or imminent, and results in a higher (and perhaps more immediate) risk to the ecosystem.

The categorization of a driver or stressor as a pressure or threat is derived from human interpretations. An indicator is essentially meant to capture the integration of complex ecosystem responses to drivers and stressors, based on the current human understanding (Figure 3). While an indicator does not need to be monitored to indicate the current state, it is defined here as such in order to be relevant in the context of a monitoring plan.

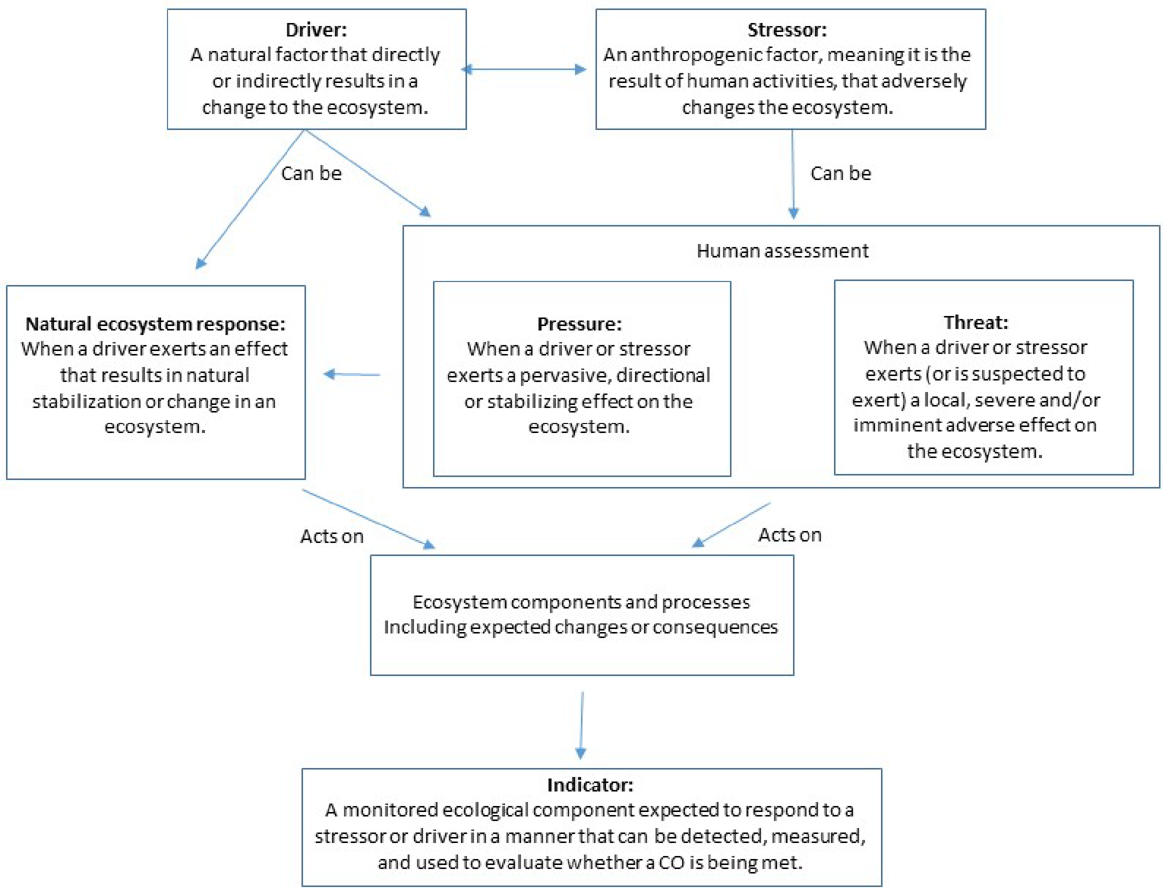

Figure 3. A representation of the relationships among indicator, driver, stressor, pressure, threat, and natural ecosystem response, as it relates to monitoring the ecosystem.

It is important to delineate among drivers (i.e., natural) and stressors (i.e., anthropogenic) as local (i.e., local origin and action, shorter timeframe) or pervasive (i.e., broad origin and action, longer timeframe), and identify them as pressures (i.e., mild, chronic) or threats (i.e., intense, imminent). This is because that categorization may influence prioritization among indicators for monitoring and the resulting management action if a change is noticed. For instance, climate change was discussed; it is a pervasive stressor that exerts various pressures on ecosystems, meaning that it is anthropogenic and causing directional change but originating and operating broadly, over a longer time. Pervasive stressors such as climate change may be monitored but local management action options to address them may be, in fact, limited. Monitoring for such pervasive stressors remains important, however, because they can change the ecosystem base parameters upon which other stressors are acting. These interactive effects will occur both from additive (e.g., multiple stressors affecting the same end point), and cumulative (e.g., internal feedbacks within and among complex stressors acting together) perspectives.

Previous science advice provided an assessment of stressors, impacts, and pathways of effects for the Darnley Bay ANAOI (DFO 2014). This advice identified key features or properties of the system, called Valued Ecosystem Components (VECs), and used pathways of effects models to evaluate how human activities could potentially affect VECs (DFO 2014). In order to relate the outcomes of that assessment to current advice, the terms used previously must be explained in the context of the definitions provided here:

- All of the four pervasive “drivers” identified in DFO (2014) are anthropogenic, so would be called *pervasive stressors* using the terms as defined here.
- The 11 “drivers” with potential to affect VECs identified in DFO (2014) are anthropogenic, so would be called *stressors* here, and are local.
- The “stressors” identified in DFO (2014) would be called *threats* using the definitions provided here.
- Effects would remain termed as in DFO (2014), which is the potential effect of the threat on the VEC.

It is important to note that this current advice does not replace previous advice regarding stressors, impacts, and pathways of effects, but provides clarification using updated definitions so the advice cumulates and is relatable.

Several indicators of pressures and threats were identified as potentially of interest for monitoring; however, only anthropogenic noise was explicitly discussed herein among these indicators. Therefore, advice on other indicators should be taken conservatively and expert consultation should be sought prior to developing a specific monitoring plan for other indicators in this section.

Anthropogenic Underwater Noise

Key measurement parameters for this indicator are:

1. vessel noise;
2. marine vessel tracking data;
3. marine mammal vocalizations;
4. ambient noise; and
5. local sound propagation characteristics.

Underwater noise was identified as a main potential stressor for the ANMPA ecosystem (DFO 2014) and the ANMPA Working Group identified it as a priority concern for monitoring. Shipping is a present concern for the ANMPA Working Group and for the community of Paulatuk. Vessel traffic in the Canadian Arctic is increasing as sea ice declines; however, anthropogenic underwater noise is also generated by local transportation in small, community-owned vessels, supply barges, and research vessels. Therefore, while not all noise is shipping noise, and noise is not the only impact of shipping, anthropogenic underwater noise was kept as a separate indicator because it is identified as an indicator in the original request by the community.

While baseline noise data are being gathered, the current lack of baselines is problematic for monitoring change caused by potential anthropogenic stressors. This was highlighted as a need to consider for the future. For most lower trophic-level indicators, the influence of sound is unknown. The effect of noise on marine birds is also an understudied area. The effect of noise on potentially colonizing species is also unknown, and dependent on the species.

Options for assessing anthropogenic underwater noise include monitoring for noise itself, understanding the effects of noise on marine mammals, and also exploring ocean properties that influence noise (e.g., temperature, salinity, bathymetry). Cortisol levels in Beluga could also indicate chronic stress. While a direct link between chronic stress and cortisol cannot be made with regards to shipping, it could be used as a potential baseline to monitor change (e.g., Watt et al. 2022).

Contaminant Concentration in the Environment and in Marine Mammals

Key measurement parameters for this indicator are:

1. mercury and organic contaminants in key prey species;
2. organic contaminants in marine mammal blubber and liver;
3. mercury concentrations in marine mammal muscle, liver, skin;
4. archived tissue samples from marine mammals, where possible;
5. trophic biotracer information and supporting size, sex, and age data;
6. microplastics in the digestive tracks of key marine mammals, fish species, and sediments; and,
7. bulk sediment samples for archiving.

There was limited discussion of this indicator. Only preliminary information is therefore 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. Legacy contaminant release from degrading permafrost areas may also be relevant, although was identified as a data gap. Similarly, the drainage of large areas by rivers to a semi-enclosed bay such as Darnley Bay, may also be relevant and also unknown. As there is potential for a nickel mine southeast of the ANMPA, it may be of value to establish baseline data on heavy metals in the area. However, establishing baselines outside the focal component of monitoring and available baseline information from areas outside the MPA could be used.

Assessing the potential threat posed by ocean plastics to marine species was listed as a priority by the ANMPA Working Group, although it should be noted that this remains a research question rather than a monitoring objective. This was identified as a data gap as little research has yet been published on the prevalence of microplastics in the marine environment of the western Arctic, especially for higher trophic animals.

Other Threat Considerations

Pathogens and parasites in marine mammals is considered as an additional threat; however, there was limited discussion of potential indicators related to this threat. Only preliminary information is therefore 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 pathogens may not originate within the ANMPA or may not be indicative of processes occurring within the boundaries. However, pathogens and parasites remain a concern for the community and inform on the health of important species. The ecological consequences of pathogens and parasites in marine mammals should be the focus for monitoring, as opposed to the potential effects on humans, for the ecological component of a monitoring plan.

Ocean acidification is also considered a threat. This was not discussed specifically but considerations for monitoring ocean acidification were identified as part of the discussions regarding relevant indicators: dissolved organic carbon and alkalinity within Key Ocean Properties and Nutrient Concentrations; carbonate chemistry within Pelagic and Ice-associated Primary Producers; pteropods, which have a calcium carbonate shell within Zooplankton Community Composition, Structure, and Function; benthic invertebrates within Benthic Invertebrate Community Composition, Structure, and Function; and the effects of ocean acidification on key prey and thus energy transfer is outlined in Figure 2.

Uncommon Ecological Occurrences

Uncommon ecological occurrences is unusual processes or timings of events associated with the ecosystem. The primary role of recording uncommon ecological occurrences within a monitoring program would be to flag potential concerns that require further investigation, or to provide context that may be important for understanding other data collected. A definition of what is, and is not considered an uncommon event will be important for determining the types of information recorded. Establishing baselines for the MPA is necessary in order to identify an episodic or uncommon ecological occurrence. Although the focus for recording such occurrence should be within the ANMPA, reports for the area generally, including the terrestrial system should be included as these may be indicative of more general drivers or stressors that are relevant to the MPA. Monitoring unusual events is relevant to both the ecological and Indigenous knowledge themes of a potential monitoring plan.

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 (e.g., population abundance estimates), none can provide enough information to test hypotheses about underlying drivers of change (e.g., rational for a population decline in a given year). 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 developed to explain or understand any changes.The goal of monitoring should not be just to show if something changed or not, but rather to explain how it changed, and to also inform the development of potential management actions (e.g., mitigation, remediation).

In order to facilitate the selection of indicators both for the monitoring plan, and also to test hypotheses regarding drivers of change, the connectivity among indicators was determined and the strength of those linkages were ranked (Table 1). While these linkages are summarized here, more information about each indicator is available in the relevant sections contained herein and also in the associated Research Document (Ehrman et al. 2022). 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.

Indicators that provide environmental context were generally strongly linked to indicators of biological and food web integrity, as could be inferred due to the coupling of species and habitats. Within this, however, there were some exceptions and the strength of the linkages varied among indicators. Oceanography was strongly linked to all other identified indicators and was recognized as being foundational to the ecosystem.

Advection between offshore and the coastal MPA links the offshore and nearshore ecosystems and species. Upwellings provide important mixing, and bring nutrient-rich water closer to the surface, which strongly affects the abundance and distribution of marine species. Core oceanography strongly influences offshore fish community structure and is of high importance to inshore fishes and forage fishes, as well as zooplankton and phytoplankton, and influences the prey base for both coastal and offshore fishes. Core oceanography also strongly influences the distribution of marine birds. Conversely, there are connections among trophic linkages and oceanography as well; pteropods can inform on oceanography and ocean properties, including ocean acidification, which is a threat.

Anadromous fishes are linked to core oceanography through species-specific temperature and salinity preferences. Oceanographic conditions can also provide a pathway for new or colonizing species. Although nutrient concentrations are coupled with oceanography as one indicator, nutrient concentrations were only strongly linked to core oceanography, were less strongly linked to lower trophic-level indicators, and were not linked to upper trophic-level indicators, recognizing that nutrient concentrations provided a source of energy from the bottom-up, toward fishes. The variability of nutrient concentrations may reduce its effectiveness as an indicator.

Indicators that provide environmental context related to ice (i.e., ice structures, snow and ice thickness, and ice break-up/freeze up timing) were strongly linked to indicators of biological and food web integrity that were also associated with ice (i.e., ice-associated primary producers and protists). In addition to ice parameters, snow depth and distribution are also important features to monitor. Light penetration is influenced by ice and snow thickness, which can affect Arctic Cod foraging behaviour. Ice thickness and snow may influence visual foraging and can affect diets. Ice thickness can also impact nearshore fishes and benthic invertebrates if ice touches bottom. The importance of ice structures to fishes, however, is assumed to be low, with the exception of Arctic Cod for habitat use and of nearshore fishes for habitat displacement and movement, as well as possibly salmonids using ice edges for foraging. Among fishes, ice is especially important for Arctic Cod and is connected to spawning and foraging and also as refuge from predators. Ice break-up influences habitat use for Arctic Cod and directly affects when fish can forage. Generally, for newly colonizing or invasive species, ice presence will influence survival, and ice thickness is less significant but can still influence establishment. Snow and ice presence influence marine bird movements and migration.

More broadly, it is unknown if ecosystem status is more affected by changes in the timing of ice break-up or ice freeze-up; however, the timing of break-up is predicted to have a larger effect. Earlier ice-off and later ice-on timing will affect productivities in various component ecosystems (coastal, nearshore/shelf, offshore) and will also affect transport mechanisms such as water mass movements (wind-driven vs inertially driven) and by extension passive transport of nutrients and biota. Ice break-up and freeze-up were strongly linked to all other biological indicators except benthic invertebrates and, to a lesser degree, offshore fish. Ice break-up was more strongly linked to under-ice and ice-associated primary producers and protists than was ice freeze-up. Ice break-up was also more strongly linked to fishes than was ice freeze-up because of the influence of break-up on sea surface temperature and fish movement, including migration, and also break-up directly affects where fish can forage. Ice break-up also strongly influences anadromous fish species movements, spawning, and general habitat use. In fresh water, however, ice freeze-up may be more important than ice break-up for anadromous fishes because migration upstream seems to be driven by light cues and active spawning is driven by freshwater temperatures. Partial ice concentration may also be important, in addition to ice break-up and freeze-up seasons. For instance, polynyas are relevant as essential habitat elements. Also, floating sea ice in summer is a relevant ephemeral but physical habitat that concentrates biota. In addition, categorizing ice seasons as break-up and freeze-up is an oversimplification as there are phases during both freeze-up and break-up. Finally, there is temporal and spatial variability in freeze-up and break-up within the MPA and also between the

MPA and the greater Darnley Bay area that should be recognized. Sea ice may also act as a barrier to visualizing the aquatic environment (e.g., may not see cod through ice). Data from indicators of core oceanography and sea ice/snow will be especially relevant to explaining patterns in forage fish relative abundance and biomass, and recruitment is linked to environment conditions for all three forage fish species.

Benthic habitat distributions were strongly linked to indicators of biological and food web integrity that rely on the benthos. The benthic habitat is strongly linked to inshore fishes due to habitat availability and foraging opportunity; for forage fish, sediment size limits spawning in Capelin and habitat availability and use for Sand Lance. Benthic habitat distributions were also linked to offshore fishes as many of the offshore fish species are present in the benthos. Benthic habitats were linked to potentially colonizing species because of the link between the potential for new species to colonize and benthic habitat requirements (e.g., Green Crab [*Carcinus maenas*]). Anadromous chars, however, are less strongly linked to benthic habitat because they are pelagic feeders, whereas Broad Whitefish feed benthically thus may be more tightly linked. There is a noted strong linkage between Bearded Seal and the benthos, including benthic habitats and benthic invertebrate composition, due to their reliance on the benthos as a food source and the related impacts of Bearded Seals on the benthic environment. The linkage among other seal species to the benthos was less strong. Benthic habitat distributions were strongly linked to anthropogenic underwater noise, an indicator related to a pressure or threat, due to the potential for ocean properties to influence noise transmission.

Coastal change was strongly linked to only inshore fish, forage fish, and anadromous fish indicators of biological and food web integrity, due to their proximity to, and reliance on, the coastal environment. For instance, coastal change would impact habitat quality (including spawning habitat), due to increased sediments for forage fishes. Coastal change would also affect benthic structure, and could influence the establishment of newly colonizing or invasive species. Erosion would also influence visual foraging, connecting erosion to trophic linkages (fish prey), as well as visual predators such as anadromous fishes. Coastal change may also affect the movement of fish prey. Coastal change was less strongly linked to open water producers and protists, and marine mammals (due to turbidity). Coastal change was weakly linked to zooplankton, benthic invertebrates, marine birds, and anthropogenic underwater noise. There was no link between coastal change and under-ice and ice-associated primary producers and protists and offshore fish.

There were also linkages identified among the indicators of biological and food web integrity. However, the large ecological diversity in Darnley Bay cannot be easily reduced to simple associations. Therefore, only superficial generalities are possible except where specific species are mentioned. Ice-associated, under-ice, and open-water primary producers, zooplankton, and benthic invertebrates are a food source for, and are therefore strongly linked to, fishes (inshore, offshore, and forage fish indicators), including larval life-stages. The benthic invertebrate community structure was also strongly linked to the fishes indicators due to connections with larval fish habitat, as specific habitat for different life-stages and species, and as a food source for fish. The connection among fishes and the benthic invertebrate community varies by species. Broad Whitefish (*Coregonus nasus*), for instance, are more strongly linked to the benthic community than are char or Capelin due to feeding preferences and habitat use. Similarly, there are differences in linkage among primary producers and forage fish as cod are strongly linked to ice-associated and open-water prey, as well as open-water habitat, whereas Sand Lance are more associated with the nearshore, and Capelin use both nearshore and offshore during different life-history stages. Anadromous fishes may be weakly linked to ice-associated biota by feeding at ice edges; however, there is a strong linkage between anadromous fishes and open-water primary producers, zooplankton, and forage fishes as a primary food base. Although anadromous fishes are linked to both nearshore and offshore environments for food availability and habitat use, some linkages may only be relevant for specific species (e.g., Broad Whitefish vs. char habitat use). Juvenile life-stages of anadromous fishes may also provide food to other predators. Forage fishes are an important source of prey for Arctic Char and other larger piscivorous fishes, marine birds, and marine mammals. Newly colonizing or invasive species are less strongly linked to ice-associated, under-ice, and open-water biota. Higher biodiversity among lower trophic species may lead to more resilience to colonizing species. The offshore environment is a critical vector for newly colonizing species, and the nearshore environment is important for establishment. Newly colonizing species may become prey for anadromous, nearshore, and offshore fishes, and diet shifts in northern species could indicate ecosystem change or presence of a new species.

Marine mammal indicators also had strong linkages to all indicators that provide environmental context, due to their association with habitat, as well as many indicators of biological and food web integrity due to the linkage to food availability. In fact, marine mammal presence/absence, timing, habitat use, and group composition is so tightly linked to marine mammal prey that they were ranked the same across all indicators. Marine mammals were only less strongly associated with zooplankton and potentially colonizing species, and were weakly associated with anadromous fishes and marine birds.

Marine birds were also linked to some indicators of environmental context and biological and food web integrity, although the associations were more variable and quite species-dependent. Marine birds were strongly linked to ice break-up and ice freeze-up as ice presence influences access to food. Similarly, marine birds were strongly connected to trophic linkages (fish prey), open-water primary producers, zooplankton, and benthic invertebrates as sources of food, although there are differences among species. Marine birds were strongly linked to offshore, nearshore, and key forage fishes as sources of food. Marine birds were only weakly linked to anadromous fishes and coastal erosion.

Anthropogenic underwater noise, an indicator of a potential pressure or threat, was strongly linked to almost all indicators of environmental context and upper trophic-level indicators of biological or food web integrity. Noise can also influence these indicators, and some of these indicators can influence the propagation of noise (e.g., benthic habitats).

Table 1. The indicators are listed and the information including hypothesized changes to the ecosystem that the indicator is meant to capture, relevance to the ANMPA COs, key recommended monitoring strategies, and the ANMPA Working Group priorities that the indicator addresses. Indicators are divided into three categories: indicators that provide background environmental context, indicators of biological and food web integrity, and indicators of stressors and threats. Key monitoring indices (i.e., the actual data to be collected) are outlined for each indicator in the accompanying Research Document (Ehrman et al. 2022).

	Core oceanography	Benthic habitat distributions	Ice structures	Snow and ice thickness	Ice break-up/freeze-up timing	Coastal Change	Nutrient concentrations	Trophic links (Fish prey items) (trophic links and energy transfer)	Trophic links (Marine mammal prey items) (trophic links and energy transfer)	Under-ice primary producers and protists	Ice-associated primary producers and protists	Open-water primary producers and protists	Zooplankton	Benthic Invertebrates	Offshore fish	Inshore fish	Key forage fish	Anadromous fish	Marine birds	Marine mammals	Anthropogenic underwater noise	Potentially colonizing species
Core oceanography	-	-	-	-	-	-	3	3	3	3	3	3	2	3	3	3	3	3	2	3	3	3
Benthic habitat distributions	-	-	-	-	-	-	1	3	3	1	1	1	3	3	2	3	3	1	1/3	3	3	3
Ice structures	-	-	-	-	-	-	X	3	3	3	3	X	2	1	2	3	3	2	1	3	3	3
Snow and ice thickness	-	-	-	-	-	-	X	2	3	3	3	X	2	X	1	3	3	0	1	3	3	2
Ice break-up/freeze-up timing	-	-	-	-	-	-	X	3	3	3/1	3/1	3/3	3/3	1	2	3	3	3	3	3	3	3
Coastal Change	-	-	-	-	-	-	X	2	2	0	0	2	1	1	0	3	3	3	1	2	1	2
Nutrient concentrations	-	-	-	-	-	-	-	3	2	3	3	3	3	1	3	3	3	3	2	2	1/?	2
Trophic links (Fish prey items)	-	-	-	-	-	-	X	-	3	3	3	1	?	?	X	X	3	3	3	3	3	2
Trophic links (Marine mammal prey items)	-	-	-	-	-	-	X	3	-	X	X	X	X	X	X	X	3	3	1	3	3	?
Under-ice primary producers and protists	-	-	-	-	-	-	2	3	3	-	3	1	2	1	3	3	3	2	1	3	1/?	1

	Core oceanography	Benthic habitat distributions	Ice structures	Snow and ice thickness	Ice break-up/freeze-up timing	Coastal Change	Nutrient concentrations	Trophic links (Fish prey items) (trophic links and energy transfer)	Trophic links (Marine mammal prey items) (trophic links and energy transfer)	Under-ice primary producers and protists	Ice-associated primary producers and protists	Open-water primary producers and protists	Zooplankton	Benthic Invertebrates	Offshore fish	Inshore fish	Key forage fish	Anadromous fish	Marine birds	Marine mammals	Anthropogenic underwater noise	Potentially colonizing species
Ice-associated primary producers and protists	-	-	-	-	-	-	2	3	3	3	-	1	2	2	3	3	3	2	1	3	1/?	1
Open-water primary producers and protists	-	-	-	-	-	-	2	3	3	2	1	-	3	3	3	3	3	2	2/3	3	1/?	2
Zooplankton community	-	-	-	-	-	-	2	3	2	2	2	3	-	2	3	3	3	3	3	2	1/?	2
Benthic community	-	-	-	-	-	-	2	3	3	1	1	1	X	-	3	3	2	3	1/3	3	1/?	2
Offshore fish community	-	-	-	-	-	-	X	3	3	1	1	1	X	1	-	3	3	3	3	3	3	2
Inshore fish community	-	-	-	-	-	-	X	3	3	1	1	1	X	1	X	-	3	3	3	3	3	2
Key forage fishes	-	-	-	-	-	-	X	3	3	1	X	X	X	X	X	X	-	?	3	3	3	2
Anadromous fishes	-	-	-	-	-	-	X	2	1	X	X	X	X	X	X	X	3	-	1	1	?	2
Marine birds	-	-	-	-	-	-	1	3	1	X	X	X	X	1	X	X	3	3	-	1	2	?
Marine mammals	-	-	-	-	-	-	X	3	3	X	X	X	X	2	X	X	3	3	1	-	3	?
Anthropogenic underwater noise	-	-	-	-	-	-	X	3	?	X	X	X	X	X/2	X	X	3	3	2	3	-	?
Potentially colonizing species	-	-	-	-	-	-	2	2	?	1	1	2	2	2	2	2	2	3	2	2	?	-

CONCLUSIONS

The Government of Canada's commitment to establish MPAs requires that data and information underpin assessments and any follow-on decision making. MPAs in the Arctic Region can be challenging to collect relevant data for because they typically cover more expansive areas, there are challenges in access during particular seasons (e.g., winter), and there are often limited baseline data available. There is some sense of urgency in the development of effective monitoring for this region due to the rapid environmental changes experienced in the recent past and ongoing present, the significant increase in extent of areas requiring protection and management, and the essential services provided by coastal ecosystems in the Arctic to Indigenous Peoples. It will be important to consider protocols and approaches for monitoring that may be transferrable from other programs and/or areas as well.

This science advice uses the ecological themes identified in the draft monitoring plan developed by the ANMPA Working Group to further inform the development of the Ecological Monitoring Plan for the ANMPA. Organization of the indicators into categories of indicators that provide environmental context, indicators of biological and food-web integrity, and indicators of pressures or threats provides important structure for identifying indicators for monitoring. This organization also helps to highlight linkages among indicators and the connectivity among ecosystem components. 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 and ramifications of change. The goal of monitoring should not be just to show if something changed or not, but rather to explain how it changed and what can be done about it.

Recognizing the co-management process, a separate and parallel workshop is anticipated to take place with the ANMPA Working Group in order to bring this Science Advice to Indigenous knowledge holders for their consideration during the development of the monitoring plan.

OTHER CONSIDERATIONS

- A network of monitoring will be important, especially as protected areas increase in the Arctic (e.g., Tarium Niryutait Marine Protected Area, Tuvaijuittuq, Tallurutiup Imanga National Marine Conservation Area).
- Indigenous knowledge will contribute to the documentation of knowledge to support management of the area. This knowledge will also be important to inform the co-design of research and monitoring programs.
- It would be helpful to review past and ongoing monitoring activities in and external to the ANMPA, to identify lessons learned, and to summarize monitoring policy and guidance to inform the development of a monitoring plan.
- The development of a list of indicator species was beyond the scope of this process. However, information relevant to the selection of indicator species is summarized in Appendix C of Ehrman et al. (2022), where information was available.
- A separate process with subject-area experts could build on this advice to describe how the resulting plan may be implemented 'on the ground,' including the mechanics of data collections, analyses (e.g., strategy, threshold, sensitivity analysis), data management, and reporting.
- Management and mitigation measures will need to be adaptable to changing intensity and frequency of stressors from anthropogenic and natural factors/pressures. In addition, these measures will need to evolve as our understanding of the area expands.

Monitoring for a Future Arctic

The Arctic is experiencing rapid climatic and environmental changes, which may affect the marine ecosystem, species, and ecological processes in the ANMPA. These environmental changes are also associated with new socio-economic opportunities and challenges for the Arctic region (ANMPA Regulations, GoC 2016). For example, warming may result in an extended shipping season or create new shipping routes, which in turn may facilitate access to mining, oil and gas exploration and development, and increased commercial fishing opportunities, research, and tourism across the Arctic, including small vessels. Increased accessibility for these types of activities poses a risk to the habitats, biodiversity and ecosystem functions within the Arctic and within the ANMPA, specifically. Ensuring that commercial shipping activity, small- and large-scale tourism activities, discharges from ships, and ocean plastics do not disturb or disrupt marine mammals in the ANMPA, or degrade ANMPA habitats or species, remain top monitoring priorities for the ANMPA Working Group (Ehrman et al. 2022, Appendix A).

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). The indicators recommended to provide background environmental context and those indicative of biological and food web integrity will remain applicable to evaluating the COs regardless of the specific threats that may impact the ecosystem (for detail, see Ehrman et al. 2022). However, it is recommended that indicators of stressors and threats 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 (for detail, see Ehrman et al. 2022). 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.

Area-based conservation is also 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 may become a moving target. In addition, the MPA will be influenced by stressors both within and outside its boundaries. Migratory species will be affected by stressors encountered throughout their ranges, whereas non-migratory species are more influenced by changes occurring within the MPA boundaries. Adaptability should be built into a monitoring plan as much as possible, with a focus on preserving key functions.

LIST OF MEETING PARTICIPANTS

All participants at this science peer review meeting are expected to participate as objective and knowledgeable individuals on the subject matter under review; not advocates or representatives of any interest group.

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SOURCES OF INFORMATION

This Science Advisory Report is from the February 18–20, 2020 Meeting on Science Advice to Assist in the Development of an Ecological Monitoring Plan for the Anguniaqvia niqiqyuam Marine Protected Area. Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDIX 1. SUMMARY OF RECOMMENDED INDICATORS FOR MONITORING THE ANMPA CONSERVATION OBJECTIVES

Table A1. The indicators are listed and the information including hypothesized changes to the ecosystem that the indicator is meant to capture, relevance to the ANMPA COs, key recommended monitoring strategies, and the ANMPA Working Group priorities that the indicator addresses. Indicators are divided into three categories: indicators that provide background environmental context, indicators of biological and food web integrity, and indicators of stressors and threats. Key monitoring indices (i.e., the actual data to be collected) are outlined for each indicator in the accompanying Research Document (Ehrman et al. 2022).

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
INDICATORS THAT PROVIDE BACKRGOUND ENVIRONMENTAL CONTEXT				
5.1 Core oceanographic parameters and nutrient concentrations	-	• Underpins physical habitat and the setting for all marine life. • Necessary for testing hypotheses regarding mechanisms of change for organisms at all trophic levels, including upper-trophic predators.	• Two-tiered sample design including frequent sampling at a few key local sites paired with less frequent sampling at a larger geographic scale. • Moored instruments for continuous, real-time measurements of habitat variables. • Moored ADCPs for measuring currents and determining water circulation patterns. • Biophysical modeling (added value from data collected through direct monitoring; model results can provide feedback to improve monitoring program).	• Almost all. Core oceanography is strongly recommended as an integral part of any marine ecosystem monitoring plan because it sets the stage for all biological processes and is necessary for hypothesis-driven monitoring. • Underpins interpretation of biological data for priorities under: 1. Subsistence harvests 2. Offshore and Nearshore environments 3. Unusual events • Indices link strongly to indicators for primary production and animal distributions. • Necessary to determine sound speed for interpreting data on underwater noise associated with shipping and tourism.

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
5.2 Ice structures, snow and thickness, and ice break-up/freeze-up timing	-	• Underpins annual cycles of biological productivity and life cycles for animals at all levels of the food web; influences primary production and nutrient replenishment at the base of the food web that have cascading effects on upper-trophic animals. • The timing and distribution of snow and ice reflects large-scale climatic and oceanographic conditions that impact habitat suitability, recruitment, food availability, and/or vertical migration timing for zooplankton, forage fish, Arctic Char, seabirds, and marine mammals. Snow and ice are key habitat parameters for Beluga, Ringed and Bearded seals, and Polar Bears.	• Historical trend analyses of ice break-up and freeze-up patterns across Darnley Bay using archived ice charts and satellite imagery from the Canadian Ice Service (CIS) (with consideration of differences between the southern, central and northern portions of the ANMPA) • Continued use of annual CIS data to monitor ice break-up and freeze-up patterns • Linking existing community-based programs to monitor snow and ice parameters in the MPA • When safe, snowmobile surveys of snow and ice thickness taken along regular transects that capture spatial heterogeneity • Measuring the thickness of coastal fast ice could be started as part of a weather observation program • Use of moored upward-facing ice profilers to capture seasonal ice movements in areas accessed less frequently (e.g., northern ANMPA).	• Almost all. Monitoring snow and ice timing and distributions are strongly recommended as an integral part of any Arctic marine ecosystem monitoring plan. Understanding sea ice timing and snow distributions will be necessary for hypothesis-driven monitoring of animal behaviours. • Specific priorities addressed include: 1. 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 2. 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.
5.3 Benthic habitat distributions	-	• Linked to benthic species distributions, biomass hotspots, and oceanographic processes, which influence food	• Initial surveys to map bathymetry, bottom features, and sediment types throughout Darnley Bay using a combination of non-invasive	• Important for understanding the habitats, occurrence, and distributions of key marine mammal benthic prey.

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
		availability derived from primary producers and foraging behaviours of upper-trophic marine mammals, fish, and seabirds (especially Bearded Seals and Eiders). May identify attractive habitats for Beluga whales (e.g., rubbing rocks). • Pre-requisite to determine the locations of sensitive benthic habitats prior to granting permissions for potentially damaging activities, such as dredging, anchorage, bottom-contact sampling for fish and benthic invertebrates, etc. • Bathymetry necessary for proper understanding of water circulation in Darnley Bay (see 5.1). • Archived sediment samples could provide time-series for potential unforeseen pollutants.	technologies such as camera-mounted benthic sleds and ROVs, LiDAR (collaboration with Canadian Hydrographic Service), ship-mounted multi-beam hydroacoustics, and/or satellite radar data. • Annual or bi-annual stratified random sampling design across habitat types to monitor habitat stability (via sediment sampling or camera-based technologies) and to collect sediment for analyses of benthic food sources and potential pollutants.	• Specific priorities addressed include: 1. Complete bathymetric chart of Darnley Bay and the ANMPA for navigation, interpretation of biological data, and to understand patterns of circulation 2. Monitoring the occurrence and diet of Ringed and Bearded seals, their prey and their habitats in the nearshore ANMPA 3. Establish patterns, timing, and location of areas in the ANMPA that attract Beluga whales, and the reasons why they are attracted 4. Ensure that discharges from ships do not degrade ANMPA habitats or species 5. Assess and monitor the extent of ocean plastics in the ANMPA habitats and species
5.4 Coastal change	-	• Large influxes of nutrients, carbon, and potentially contaminants may have strong impacts on Arctic embayment ecosystems where shallow nearshore zones represent a relatively large proportion of the total marine area. Material introduced into marine	• Establishing a coastal erosion vulnerability assessment for the ANMPA, to identify shoreline areas that may be particularly sensitive • Installation of a coastal observatory to monitor changes in coastline position and storm surges in areas	-

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
		coastal environments may alter biogeochemical cycling, enhance or dampen primary production, and/or degrade benthic habitat conditions required for macroalgae, benthic invertebrates, and coastal fish, all of which have effects on food availability for upper-trophic animals in nearshore zones.	deemed particularly sensitive to erosion • Annual aerial drone or ground-based photographic surveys to measure coastline position	
5.5 Freshwater inputs and terrestrial linkages	-	• Land-ocean ecological connections are most strongly maintained through the rivers that discharge into Darnley Bay. Rivers act as important migration corridors and over-wintering habitat for anadromous fish. They also deliver fresh water, sediment, and terrestrially-derived nutrients to the marine environment, creating unique coastal habitats for macro-algal beds, benthic invertebrates, nearshore fishes, Arctic Char, and Broad Whitefish. Climate-driven changes to precipitation, river discharge volumes, and the timing of the spring freshet will have uncertain consequences for nearshore marine environments, and	• Leverage data collected for certain key ocean properties and benthic habitat characteristics (indicators 5.1 and 5.3) to infer the extent and movement of freshwater and terrestrially-derived organic matter in the marine environment • Access existing precipitation and river discharge data collected by ECCC to track how changes to hydrology and climate impact anadromous fish movements and condition. • Movement of freshwater can be tracked using water quality variables via a sampling program for key ocean properties (e.g., temperature, salinity, oxygen stable isotope ratios ($\delta^{18}O$)). • Measurement of $\delta^{18}O$ across a broad spatial area to construct an “isoscape” to understand the	• Monitoring the health and viability of Arctic Char stocks, their prey and their habitats in the ANMPA • Ensuring the health and viability of whitefish stocks, their prey and their habitats in the ANMPA

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
		especially for anadromous fish.	different freshwater concentrations that occur in Darnley Bay. • Sea surface temperature and turbidity inferred from satellite images may provide insight into the distribution and movement of freshwater plumes. • Terrestrially-derived organic matter that settles out of the river plume can be assessed by measuring sediment organic matter content, stable isotope ratios, and carbon-to-nitrogen ratios in sediment grabs collected by a benthic habitat sampling program.	
INDICATORS OF BIOLOGICAL AND FOOD WEB INTEGRITY				
6.1 Trophic links and energetic transfer	• 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 and earlier onset of primary production, if they occur, will favour pelagic communities, limiting the amount of production exported to the benthic food web	• Ensuring the ANMPA supports upper-trophic feeding requires an understanding of food web structure, predator-prey dynamics, and foraging behaviour. Data on trophic linkages and energetics will 1) indicate whether upper-trophic level predators are feeding on prey that occur within the ANMPA, 2) provide insight on how the spatial and/or temporal variability of prey influences ANMPA habitat use by predators, and 3) indicate whether trends in predator health or body condition are related to changes in prey	• Trophic links should be determined for four primary trophic groups: zooplankton, benthic invertebrates, fish (especially forage fish), and marine mammals. • Collection of tissues for trophic biotracer analyses (stable isotopes, fatty acids, highly branched isoprenoids, and calorie content) across the four trophic groups. • Direct feeding observations through Indigenous knowledge, video, or stomach content analyses. • Ideally, sampling of tissues and/or stomachs would	• 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 • 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

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
	and reducing benthic-pelagic coupling. • The distributions, abundances, and energy content of forage species will influence the distribution, prey selection, and health of upper-trophic level predators.	composition, abundance, or energetic density.	coincide with sampling for major biological groups associated with other indicators (indicators 6.2 to 6.11). • Data pertinent to tracking trends in upper-trophic level predator diets includes contextual information on habitats, as well as trends in prey abundance, composition, and distributions (as collected through other indicators in Sections 5 and 6).	• 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 patterns, timing, and location of areas in the ANMPA that attract Beluga whales, and the reasons why they are attracted
6.2 Ice-associated, under-ice, and open-water primary producers and protists	• The timing, distribution, and magnitude of primary production is influenced by complex sea ice, climatic and oceanographic processes affecting the availability of light and nutrients. • Changes in the timing of phytoplankton blooms can result in a mismatch between the availability of algae and the arrival of zooplankton grazers to the surface in spring, impacting energy transfer to higher tropic levels. • Primary producer community structure and function is	• Primary production underpins the energetic transfer to higher trophic levels in the marine system. It fuels the pelagic and benthic marine food web and determines benthic food supply through the sinking of ice algae, phytoplankton (benthic-pelagic trophic coupling). Phytoplankton community size structure affects energy transfer up the food web. The timing, source, and magnitude of production can be indicative of broader shifts in sea ice-ocean-atmosphere interactions linked to climate variability and change.	• Ideally, sampling would coincide with sampling for key ocean properties and nutrient concentrations, and mirror the two-tiered sampling approach recommended for indicator 5.1, wherein frequent sampling at a few key local sites is paired with less frequent sampling at a larger geographic scale.	• Almost all. Monitoring primary production is strongly recommended as an integral part of any Arctic marine ecosystem monitoring plan. Understanding the timing, distribution, and magnitude of primary production will be necessary for hypothesis-driven monitoring of animal behaviours because it fuels the food web. • Underpins interpretation of biological data for priorities under: 1. Subsistence harvests 2. Offshore and Nearshore environments 3. Unusual events • The indices link strongly to indicators for core oceanographic

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
	influenced by conditions of light, nutrients, variability in sea ice, and oceanographic processes. • Changes in stratification with warming can influence the composition of phytoplankton communities with species that are adapted to higher temperatures; modifying food web transfers.			parameters, nutrient distributions, and animal distributions.
6.3 Zooplankton community composition, structure, and function	• 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 act as some of the most important, energy-dense prey species for the forage fish that sustain highly valued marine mammals, seabirds, and predatory fish. Zooplankton are the key link between primary production and higher trophic levels and have a direct impact on the efficiency of energy transfer up the food web. • The community composition, structure, and function of zooplankton respond to anthropogenic disturbances, and can be indicative of broader environmental changes because they are closely tied to oceanographic	• Coordinated sampling in nearshore and offshore areas from community-based and ship-based programs to collect samples for taxonomic analyses and biotracers. • Sampling program would preferably be conducted twice annually (spring and summer) and coincide with basic oceanographic measurements (temperature and salinity profiles, Chl a). • eDNA may be used to monitor for newly colonizing or invasive species. • Moored acoustic fish and zooplankton profilers for year-round monitoring and monitoring in offshore areas.	• 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 • Monitoring the health and viability of Arctic Char stocks, their prey and their habitats in the ANMPA • Ensuring the health and viability of whitefish stocks, their prey and their habitats in the ANMPA • Ensure that discharges from ships do not degrade ANMPA habitats or species

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
		conditions and primary production. • Important for detecting potential introductions of new species from shipping.		
6.4 Benthic invertebrate community composition, structure, and function	• 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).	• Important prey sources for marine fish, mammals, and seabirds, especially Bearded Seals and Thick-billed Murres. • Benthic invertebrates are tightly linked to their seafloor habitats, and will likely act as effective indicators for disturbances. They will also reflect changes to energy pathways at the base of the food web (e.g., climate-altered benthic-pelagic coupling, nutrient enrichment from ship effluent), which will eventually impact upper-trophic animals.	• Annual surveys of benthic community composition at a set of core monitoring sites using either bottom-contact sampling gear or non-invasive camera technologies • Inshore surveys may be conducted off small winch-capable vessels; offshore surveys will likely require collaboration with large vessels • Selection of a set of indicator species to monitor closely; Indicator species should represent important prey for upper trophic animals and/or species with particularly high sensitivities to an anticipated stressor	• Monitoring the occurrence and diet of Ringed and Bearded seals, their prey and their habitats in the nearshore ANMPA • Ensure and monitor continued use of the offshore ANMPA by subsistence species of marine mammals • Ensure that large and small scale tourism activity in the ANMPA does not disturb or disrupt marine mammal use of nearshore habitats (as linked to the locations of benthic prey hotspots, which may be disturbed by anchorage or ship effluent) • Ensure that discharges from ships do not degrade ANMPA habitats or species
6.5 Offshore fish community composition, structure, and function	• 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	• Important prey for marine mammals, birds, and predatory fish. • Offshore fish species distributions, community composition, and recruitment success reflect dominant environmental conditions. Community composition and structure	• Multi-species fish survey coupled with measurements of habitat information (temperature, salinity, and depth at minimum) to monitor community composition (richness, biodiversity, etc.) and the relative abundances and biomass of key species.	• Understand the occurrence and significance of invasive species in the ANMPA, and how and if they interact with, compete and/or displace CO2 species • Marine mammals: ensure and monitor continued use of the offshore ANMPA by subsistence species of marine mammals

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
	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.	may also be affected by newly colonizing species or anthropogenic stressors, with cascading effects for higher trophic levels.	• Would likely require collaboration with an offshore research vessel, especially for less-accessible northern areas of the ANMPA. • Community-based sampling of offshore environments within Darnley Bay could include deep gillnet sets or small benthic sled from a winch-capable vessel. • Moored acoustic zooplankton fish profilers could provide year-round data on fish biomass but would be limited in its ability to distinguish species composition.	• Monitoring the occurrence and diet of Ringed and Bearded seals, their prey and their habitats in the nearshore ANMPA • Ensure that discharges from ships do not degrade ANMPA habitats or species
6.6 Inshore fish community composition, structure, and function	• 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.	• Important prey for marine mammals, birds, and predatory fish. • Inshore fish species distributions, community composition, and recruitment success reflect dominant environmental conditions and underlying habitat availability (benthic habitat distributions). Community composition and structure may also be affected by newly colonizing species or anthropogenic stressors, with cascading effects for higher trophic levels.	• Community-based Darnley Bay coastal fishes survey (later referred to as Arctic Coast) • Carefully planned and broadly distributed multi-species surveys that concurrently capture environmental habitat data • Trawling and hydroacoustic surveys can provide some information about inshore fishes as part of offshore-focused assessments	• 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 the health and viability of Arctic Char stocks, their prey and their habitats in the ANMPA • Ensuring the health and viability of whitefish 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

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
				• Ensure that discharges from ships do not degrade ANMPA habitats or species
6.7 Forage fish relative abundance and biomass	• •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 abundance or distribution 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.	• Some of the most important prey sources for Beluga, Ringed Seals, Thick-billed Murres, and Arctic Char. • Offshore fish species distributions, community composition, and recruitment success reflect dominant environmental conditions and lower-trophic prey availability. In turn, upper trophic predators respond to changes in forage fish availability by shifting prey selection and foraging behaviours.	• Community-based Darnley Bay coastal fishes survey (later referred to as Arctic Coast) • Carefully planned and broadly distributed nearshore multi-species surveys that concurrently capture environmental habitat data • For Sand Lance: beach seine nets and intertidal digging in soft, pebbly sediments may be more effective than gill nets • Community-based efforts to observe and collect Capelin spawning on beaches • Trawling and hydroacoustic surveys as part of offshore-focused assessments • Diet assessments of marine mammals	• 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 • 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 • 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 • Establish patterns, timing, and location of areas in the ANMPA that attract Beluga whales, and the reasons why they are attracted • Ensure that discharges from ships do not degrade ANMPA habitats or species

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
6.8 Anadromous fish relative abundance, condition, and population structure	• 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, fresh water discharge and the availability of brackish coastal habitat, and the locations and frequency of upwelling/downwelling	• Arctic Char is a key species included in the second ANMPA CO	• Community-based monitoring program for Arctic Char and a community-based subsistence harvest survey • Community-based Darnley Bay coastal fishes survey (later referred to as Arctic Coast) if gear specifications and placement are designed to be effective for anadromous species • 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.	• Monitoring the health and viability of Arctic Char stocks, their prey and their habitats in the ANMPA
6.9 Occurrence of potentially colonizing species	• 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	• Interactions among new species and key species included in the COs	• Arctic Salmon, a community-based monitoring program to assess fish biodiversity change • 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 • Environmental DNA (eDNA) can be used to detect the presence of potentially colonizing species, and can be	• Understand the occurrence and significance of invasive species in the ANMPA, and how and if they interact with, compete and/or displace CO2 species • 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)

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
	invasive invertebrate species into the ANMPA. • The establishment of a newly colonizing species may have implications for upper-trophic predators by direct or indirect competition for prey and/or habitat (if the new colonizer is upper-trophic), by redirecting energy pathways or changing the relative availability of prey resources (if the colonizer is lower-trophic), or by habitat augmentation.		incorporated into a community-based monitoring program • Anecdotal observations of potentially colonizing species could be recorded. The habitat within which the potentially colonizing species was observed could be recorded, to infer the native species with which it may interact and potentially to develop control measures if such become necessary • 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	
6.10 Marine bird presence/absence and prey items	• For future consideration – not currently recommended	• 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 to the southern Beaufort region. Seabirds are integral members of the ANMPA food web.	• Specific strategies for monitoring marine bird presence/absence and prey items may be considered after the co-management plan for the Cape Parry Migratory Bird Sanctuary is completed, is applicable to the ANMPA monitoring plan.	-
6.11 Marine mammal presence/absence, timing, habitat use, and group composition	• Changes to ocean-sea ice-atmosphere interactions that influence the distributions and abundances of zooplankton and forage fish prey will	• Marine mammals (specifically Beluga as well as Ringed and Bearded seals) are key species included in the second ANMPA CO	• The Inuvialuit and their ancestors have sustainably harvested marine mammals for centuries, and have developed a deep understanding of their habitat	• Ensure and monitor continued use of the offshore ANMPA by subsistence species of marine mammals • Monitoring the occurrence and diet of Ringed and Bearded seals, their prey and their

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
	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.		use, behaviours, and migratory patterns. • Aerial population surveys • Satellite telemetry tagging studies • Sampling from harvested whales • Standardized, community-led FJMC Fish and Marine Mammal Community Monitoring Program, collecting information about the harvest timing and conditions, record observations on physical characteristics of the whales • The Beluga Health Research and Monitoring program, collecting data and biological samples to investigate the health and ecology of harvested whales • Arctic Marine Observer App • Acoustic monitoring data and harvest statistics	habitats in the nearshore ANMPA • Establish patterns, timing, and location of areas in the ANMPA that attract Beluga whales, and the reasons why they are attracted • 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
INDICATORS OF ACUTE STRESSORS/THREATS				
7.1 Anthropogenic underwater noise	• 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	• 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. Beluga appear to be	• Monitoring of ambient sound in the ocean will additionally enable characterisation of the natural soundscape of the area • An array of moored passive acoustic recorders (hydrophones) can be used to characterize the underwater	• 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

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
	prevalence of anthropogenic underwater noise	particularly sensitive to underwater noise pollution from vessel traffic.	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 • Spatial heterogeneity in the sources of vessel noise, and the range in which hydrophones can detect noise, should be considered when choosing locations for acoustic recorders	disrupt marine mammal use of nearshore habitats
7.2 Contaminant concentrations in the environment and in marine mammals	• Positive or negative trends in migratory marine mammal contaminant concentrations will reflect environmental exposures over the long-term 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. • Contaminant concentrations in marine mammals may be positively related to trophic level and influenced by feeding strategy (i.e., highly	• Monitoring contaminants is one approach to addressing impacts of human activities on the integrity of the ANMPA ecosystem. Measuring concentrations in a few key upper-trophic species can provide information on exposure levels, and some contaminants can provide insight into abiotic system processes or food web pathways.	• Sample harvested marine mammals in the ANMPA for a standard set of tissues: muscle, liver, and skin for mercury; blubber and liver for organic contaminant monitoring (e.g., PAHs) • Collection of supporting sex, age, size, and trophic biotracer data (e.g., stable isotopes and fatty acids) is important for determining exposure risk/potential through dietary means	• 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

Indicator	Change hypotheses	Relevance to ANMPA COs	Key strategies	ANMPA Working Group priorities addressed
	hydrophobic contaminants)			
7.3 Pathogens and parasites in marine mammals	• For future consideration – not currently recommended	-	-	-
7.4 Other threat considerations	-	The ANMPA COs specifically address the impact of anthropogenic activities on the marine ecosystem.	Additional stressors and/or threats should be considered for inclusion in a monitoring plan as they arise, or dropped as they become resolved.	Will depend on stressors/threats identified

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