MONITORING INDICATORS FOR THE TARIUM NIRYUTAIT MARINE PROTECTED AREA (TNMPA)

Beluga Whale calf and mother surfacing.

Photo credit: Frank Pokiak

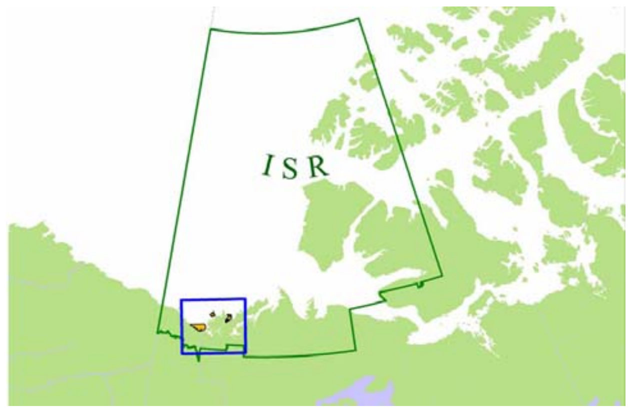

Figure 1. Inuvialuit Settlement Region (ISR) in the western Canadian Arctic showing the three sub-areas (within the box outline) that form the Tarium Niryutait Marine Protected Area.

Context :

Three areas in the Mackenzie River Estuary of the western Canadian Arctic are being considered for designation as a Marine Protected Area (MPA) under the Oceans Act*. The conservation objective (CO) of the Tarium Niryutait Marine Protected Area (TNMPA) will be to conserve and protect Beluga Whales and other marine species (anadromous fishes, waterfowl and seabirds), their habitats and their supporting ecosystem.*

In support of the Health of the Oceans Initiative, Fisheries and Oceans Canada (DFO) Science is required to deliver scientifically defensible indicators, protocols and strategies for monitoring the CO for established MPAs. This Science Advisory Report (SAR) contains advice requested by DFO Oceans Programs Division on biological and ecological indicators for monitoring the ecological health of the TNMPA and determining whether it is meeting the CO.

SUMMARY

- Selecting monitoring indicators for the TNMPA was challenging because ecosystem structure and function in the region are complicated and not fully understand, and environmental conditions can be highly variable within and among years.
- The broad scope of the TNMPA CO resulted in an ecosystem-based approach to the development of monitoring indicators, excluding species for which DFO does not have jurisdictional responsibilities (e.g., waterfowl and seabirds).
- Some higher-trophic level species that use the TNMPA, especially belugas, have a large distribution and spend limited time within the MPA each year, thus some indicators that can be used to monitor at a spatial scale larger than the TNMPA are recommended.
- A suite of indicators, rather than one or two, is recommended for monitoring, to provide a better understanding of ecological processes within the TNMPA and how, when and why key species, especially belugas, use the area.
- Indicators related to threats that cannot be controlled (e.g., climate change) are recommended, as well as those that can be controlled (e.g., noise resulting from anthropogenic disturbance), to provide a more complete picture of how local and global stressors impact or drive ecosystem processes both in- and outside the TNMPA.
- Eighty-two monitoring indicators were identified within six categories: ecosystem structure, ecosystem function, population structure of key species, heath of key species, physical and chemical environment, and noise and other physical stressors.
- Indicators considered to be highest priority for the TNMPA are those related to the ongoing Hendrickson Island Beluga Study, a proposed community-based fish sampling program, the physical and chemical environment and anthropogenic noise.
- High priority indicators for key species in the TNMPA should also be measured and monitored for key species on the Beaufort Sea Shelf outside of the TNMPA, and all monitoring activities within TNMPA must be integrated with similar activities in the Beaufort Sea Large Ocean Management Area (LOMA) and the Mackenzie River, in order to place findings from the TNMPA in proper context.
- Further consideration should be given to the identification of indicators that would monitor conditions in the TNMPA during the winter (ice-covered) season as those processes may feed into the summer (ice-free) ecosystem structure and health.

BACKGROUND

Rationale for Assessment

In support of the Health of the Oceans Initiative, DFO Science has been asked to deliver indicators, protocols and strategies for monitoring the COs for established MPAs.

Monitoring biological and ecological indicators (and their respective threats) is essential for the following:

- incorporation of an ecological component into broader MPA monitoring “plans” or “programs”,
- tracking status, condition and trends to determine if MPAs are effective in achieving their COs,
- aiding managers in the adjustment of MPA management plans to achieve COs, and
- reporting to Parliament and Canadians.

Therefore, the selection of indicators and protocols for collection and analysis of data must be scientifically defensible.

These indicators are not intended to address social or economic aspects of monitoring, with the exception of threats from anthropogenic activities. In addition, they are not intended to address other legislative protection tools such as those under the authority of Environment Canada.

Description of the MPA

The TNMPA consists of three separate and distinct sub-areas nested within the Beaufort Sea LOMA that covers the Inuvialuit Settlement Region (ISR) in the western Canadian Arctic (Figure 1). All three sub-areas lie at the edge of the Mackenzie River Delta, within the nearshore region of the Mackenzie River estuary, and together encompass approximately 1,800 km^2 (Figure 2). Niaqunnaq (Shallow Bay) is the western-most sub-area of the TNMPA in waters less than 5 m deep. Okeevik is located east of the Mackenzie Trough near Kendall and Pelly Islands, in east Mackenzie Bay, within the 10 m depth isobath. Kittigaryuit is the eastern most sub-area, extending from the mouth of the East Channel of the Mackenzie River into the western portion of Kugmallit Bay in waters less than 5 m deep.

The dominant environmental factors that influence the chemical and physical conditions in the TNMPA are the Mackenzie River and seasonal land-fast ice (Loseto *et al.* 2010). Discharge from the Mackenzie River and resulting concentrations of nutrients, carbon, suspended mineral sediments and contaminants, as well as water temperatures, play vital roles in defining physical and biological conditions within the TNMPA. The presence of ice, largely consisting of grounded or land-fast ice, during the period from freeze-up to break-up, shapes the nature and function of this estuarine ecosystem. This area is also characterized by 100% ice scouring and/or ice grounding.

Zooplankton assemblages in the nearshore estuary (including the TNMPA) are more abundant compared to benthic organisms and communities, due to instability of the benthic habitat, although at significantly lower biomass concentrations than farther offshore (Loseto *et al.* 2010). In summer and fall, anadromous fishes (i.e., those that migrate from the ocean to freshwater to spawn) move out from the Mackenzie River and follow currents along the shore to feeding and rearing areas in the TNMPA and other nearshore areas (Loseto *et al.* 2010). Anadromous species, including Least Cisco (*Coregonus sardinella*) and Broad Whitefish (*Coregonus nasus*), predominate during the open water season (July through September) while mostly marine species including Pacific Herring (*Clupea harengus pallasi*) are present during the period of ice cover when waters are more saline (Loseto *et al.* 2010).

For reasons that are not fully understood, each summer thousands of Beluga Whales (*Delphinapterus leucas*) that belong to the Eastern Beaufort Sea population return to the shallow (<5 m) and warm (up to 20°C) Mackenzie River Estuary, including the TNMPA. Summer habitat use of estuaries is prevalent in many beluga populations and several hypotheses have been proposed including feeding, calving, moulting, predator avoidance including Killer Whales and humans, thermal advantage and phylogenetic inertia (i.e., the influence of an ancestor on its descendants) (Loseto *et al.* 2010). Other aquatic mammals including Polar Bears (*Ursus maritimus*), Ringed Seals (*Phoca hispida*) and, in the Kittigaryuit sub-area, Bowhead Whales (*Balaena mysticetus*) are also known to use the TNMPA (Loseto *et al.* 2010).

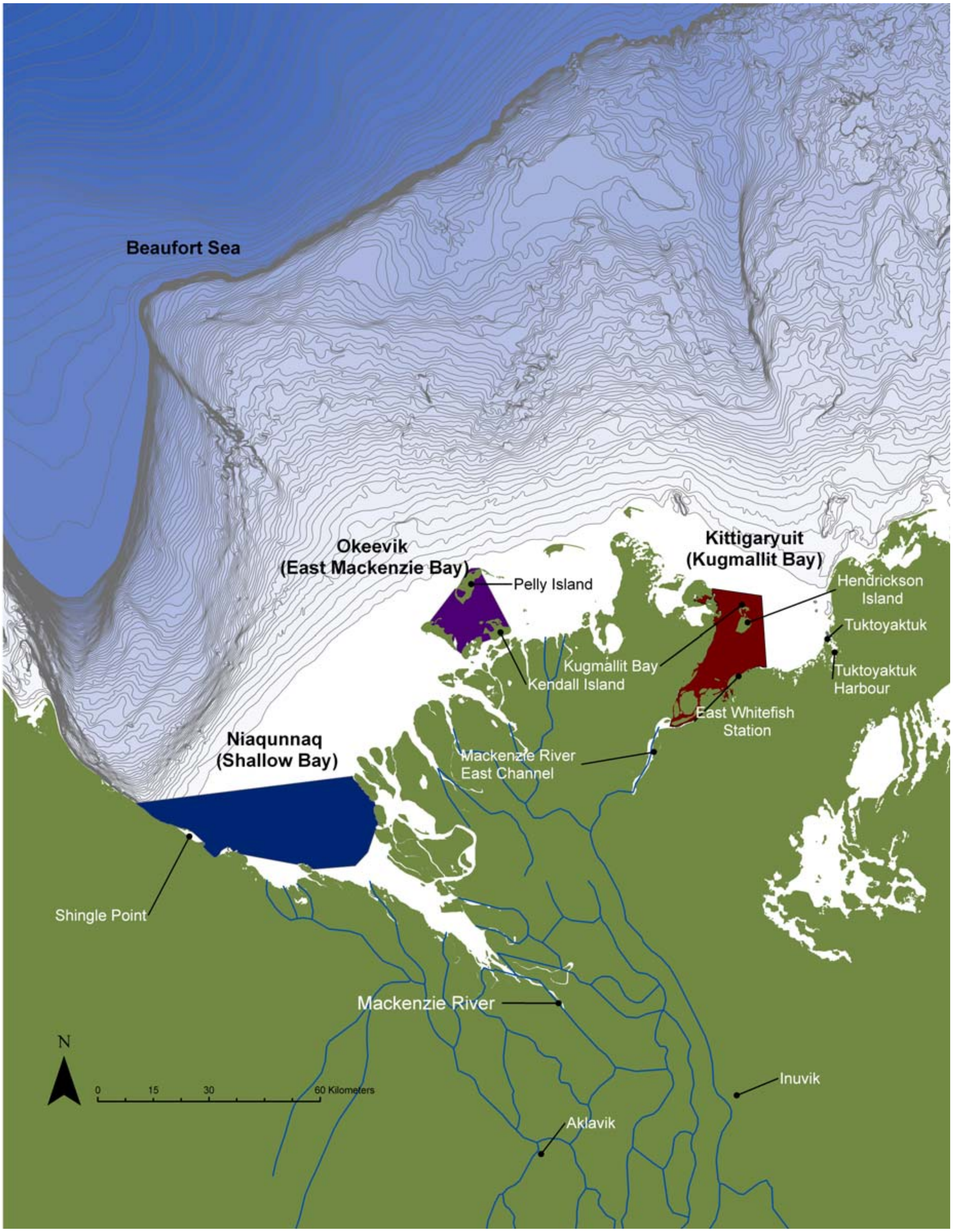

Figure 2. The TNMPA sub-areas within the Mackenzie River Estuary in relation to the inner Beaufort Sea bathymetry. The depth contour interval is 5 m.

Conservation Objective

The CO of the TNMPA is to conserve and protect beluga whales and other marine species (anadromous fishes, waterfowl and seabirds), their habitats and their supporting ecosystem.

Key Threats

The TNMPA and the surrounding area face a number of threats and potential stressors from (in alphabetical order) climate change, commercial fishing, contaminants and diseases, hydrocarbon development and related activity, land-based activities, noise and disturbance, recreation and tourism, shipping and vessel traffic and subsistence harvesting. While some are manageable at the local level, others can only be addressed in international fora. These threats and potential stressors have different degrees of urgency, importance and time-scales over which they occur. Regardless, defensible scientific indicators are needed so that monitoring can assess whether these activities are negatively impacting the TNMPA now and/or in the future.

ASSESSMENT

Current State of Monitoring and Research Activities

Studies have been conducted since the late 1970s to understand the distribution, abundance and movements of Beluga Whales in the Mackenzie River Estuary and offshore (Loseto *et al.* 2010). A new method for monitoring and estimating the size of beluga aggregations using remote sensing is being developed and tested. Data and samples from beluga harvests have been collected from Hendrickson Island, in the Kittigaryuit sub-area, since 2000 to measure variables potentially affecting beluga health such as diseases and contaminant levels (Loseto *et al.* 2010). This work has been expanded in recent years to measure diet biomarkers and indicators of health.

Within, or adjacent to, the TNMPA several ecosystem research and community-based monitoring programs have taken place to evaluate areas of the physical and biological ecosystem. Preliminary baseline research studies were carried out in and near the Mackenzie Delta, Beaufort Sea Shelf and Beaufort Sea under the Northern Oil and Gas Action Program (NOGAP) in the 1980s. More recently, between 2003 and 2009, studies were conducted under the Northern Marine Coastal Studies program, based from the CCGS *Nahidik*, in support of proposed hydrocarbon development. Research programs included the collection of information on the physical-chemical features of the Mackenzie plume, physical processes of the coastal zone and lower trophic level components of the food web including primary producers, zooplankton, ichthyoplankton and fishes (Loseto *et al.* 2010). Between 2001 and 2003, fish and water samples were collected at Shingle Point in the Niaqunnaq sub-area and East Whitefish station in the Kittigaryuit sub-area through the Tariuq community-based monitoring program.

Indicators for Monitoring

Selection of Appropriate and Meaningful Indicators

Environmental monitoring indicators are used to provide an overview of a situation and a focal point for explaining trends and consequences of environmental change and examining the efficacy of a conservation objective. They are normally selected based on criteria including their relevance to people and the environment, ability to provide reliable and long-term measurements, and clear relationship to the force of change(s) in question. The most useful environmental indicators are relatively simple measurements that can be used to represent a more complex situation. For example, sea ice freeze-up and break-up dates could be used as indicators of climate change.

The process of selecting environmental indicators for the TNMPA, for the purpose of developing science advice, was based primarily on scientific knowledge and validity. Management-related (e.g., financial, legal and socio-economic) values, requirements or constraints were given little or no consideration though it is recognized they may influence the final choice of indicators.

Several guiding principles were used to select monitoring indicators for the TNMPA. Consideration was given to only those indicators that are, or at least are thought to be, scientifically valid and would provide useful information/measures about the ecological health of the TNMPA. An ecosystem-based approach was used to develop indicators because the CO is broadly based and some higher-trophic level species that use TNMPA, especially belugas, have a wide distribution and movements and spend limited time within the MPA each year. Thus, indicators that can be used to monitor at a spatial scale larger than the TNMPA were included. A suite of indicators, rather than one or two, were selected to provide a better understanding of how, when and why key[1] species, in particular belugas, use the TNMPA. This understanding would permit future development of indicator thresholds and appropriate management actions. Finally, indicators related to threats that cannot be controlled (e.g., climate change) were considered, as well as those that can be controlled (e.g., noise resulting from anthropogenic disturbance), to provide a more complete picture of how local and global stressors and drivers impact or drive ecosystem processes both in- and out-side the TNMPA.

General Description of the Indicators Framework

Six categories of monitoring indicators were identified that would, when combined, make it possible to assess whether the CO for the TNMPA is being met.

1. Ecosystem structure
2. Ecosystem function
3. Population structure of key species
4. Health of key species
5. Physical and chemical environment
6. Noise and other physical stressors

Within each category, elements were identified and within each element, indicators (or tools to measure indicators in some cases) were identified at an appropriate methodological scale. Together, the categories, elements and indicators form a hierarchical framework that provides a meaningful approach for monitoring, assessing and understanding ecosystem health in the TNMPA, impacts of human activities and the effectiveness of management measures in achieving the CO (Table 1). A total of 82 indicators were identified. A description of each is provided in Loseto *et al.* (2010).

Ecosystem structure refers to the individuals and communities of plants and animals which comprise an ecosystem. This category consists of two elements: biodiversity and trophic structure. Species lists, biodiversity indices, genomic and genetic analyses, occurrence of

[1] Key species were identified on the following basis: specifically identified in the CO, or supporting species identified in the CO, and/or known or suspected of being ecologically important within the TNMPA.

unusual species and/or distribution surveys could be used to measure and monitor species richness (biodiversity) in the TNMPA. Stable isotopes, fatty acids and/or contaminant tracers could be used to measure and monitor trophic structure and connectivity. Shifts in indicators within this category over time would signal changes in the ecosystem.

Ecosystem function refers to energy flow in the food web and can be described by three elements: diet/trophism (i.e., what an organism eats and what eats the organism), biomass in relation to trophic level/group and age, size and sex structure within and among species. Stable isotopes, fatty acids, contaminant tracers and/or calorimetry (i.e., a measure of energy in organisms) could be used to measure and monitor diet, energy flow and productivity. Contaminant tracers, remote sensing of primary production and/or zooplankton biomass could measure and monitor biomass in relation to trophic level. Size spectrum within and among species and/or chlorophyll size fractions in phytoplankton communities could measure age, size and sex structure within and among species. Indicators in this category would aid in determining the energetic consequences of climate change.

Population structure of key species refers to the distribution, abundance, size, sex and age structure of ecologically important species within the TNMPA. These biological characteristics comprise the five elements of this category. Beluga Whale, Broad Whitefish (*Coregonus nasus*), Least Cisco (*Coregonus sardinella*) and Arctic Cisco (*Coregonus autumnalis*) were identified as key species inside the TNMPA. It is recognized these key species may depend on species that inhabit areas outside the TNMPA, such as Arctic Cod which are an important prey species for belugas but found outside the MPA. Changes in distribution, abundance, size, sex and age structure of key species over time would signal broader changes in the ecosystem. In belugas, they could be measured and monitored using sighting effort, morphometric and gender data, biopsy sampling and aged teeth. In Broad Whitefish and the two species of cisco, they could be measured and monitored using capture effort, otolith microchemistry, stable isotope analysis, acoustic tagging, phenology of life history, morphometric and gender data and otolith aging.

Health of key species refers to demographic rates, levels of nutrition/condition, inter-annual stability of diet, body burden of contaminants and incidence of diseases in ecologically important species within the TNMPA. These biological characteristics comprise the elements of this category and temporal changes in them would signal broader changes in the ecosystem. Sixteen indicators/tools could be used to measure and monitor belugas for these biological characteristics: sighting effort, survivorship curves, biopsy sampling, blubber thickness, lipid classes, blood screening, fatty acids, stomach and intestine contents, stable isotopes, halogenated organic compounds and mercury, toxicity effects, harvest collection, biopsy sampling and physical restraint. Six indicators could be used to measure and monitor Broad Whitefish and the two species of cisco: life table analysis, length-weight relationships, stable isotopes, fatty acids, burden of diseases and contaminants. Together this information can be put into a health assessment model to describe population health in context with stressors. Scientific understanding would be greatly enhanced if the same indicators were also measured for key species outside the TNMPA (Beluga Whales, Arctic Cod and Pacific Herring), so that findings from the MPA could be placed in proper context.

Physical and chemical environment refers to the properties, characteristics and processes of the external surroundings in which an organism exists and that can influence its behaviour and development. This category consists of six broad elements: timing of sea ice break-up, physical and biochemical oceanographic parameters, sea bed morphology, sediment mobility and contaminant loadings, sea level and tides and meteorology. Improving knowledge of current conditions and processes of, and temporal changes in, these elements would provide a better understanding of the ecology of the TNMPA, including why belugas use the area and how changes in the physical and chemical environment may impact the ecosystem. The distribution and properties of sea ice and snow and effects of wind in the TNMPA, and the timing and mode of Mackenzie River discharge and ice break-up could be used to measure and monitor the timing of sea ice break-up in the MPA. Measuring and monitoring currents, temperatures, salinities, sediments loads, dissolved oxygen and chlorophyll *a* in the TNMPA could provide a fundamental understanding of the physical and biochemical oceanographic processes taking place. Bathymetry, substrate morphology and texture and coastline dynamics (i.e., erosion and sediment transport) could track changes in the TNMPA that may affect use of the area by belugas or their prey. Measuring and monitoring the burden of contaminants in TNMPA sediments could track changes resulting from future industrial development on the Beaufort Sea Shelf. Sea level trends and tidal gauge measurements could track changes in carbon, nutrient and sediment loading and their impacts on the ecosystem. Wind speed and direction, air temperature, humidity and short- and long-wave radiation could track oceanographic processes and seabed morphology which may affect the overall health of belugas and other biota in the ecosystem.

Noise and other physical stressors refers to noise and the response of belugas to it and other physical anthropogenic stressors (excluding direct harvest) that may cause disturbance, damage or death. This category consists of two elements: noise and response to stressors. Anthropogenic noise and beluga vocalizations could be measured and monitored in the TNMPA to determine the effects of noise on beluga welfare, including whether it causes them to be displaced or diverted from the MPA or disrupts their vocal behaviour. Beluga behaviour, stress levels, injury or death could be measured and monitored to assess their response to stressors and, thus, identify significant threats.

Prioritization of Indicators

The 82 indicators were prioritized. They were rated according to their scientific value for monitoring, assessing and understanding ecosystem status within the TNMPA, the impacts of human activities and the effectiveness of management measures in achieving the CO. Secondary considerations were also taken into account. For example, it is recognized that working in the Arctic poses a number of challenges including high costs, often harsh conditions and logistical difficulties that constrain research and monitoring practices. Some indicators have already been used successfully in the TNMPA while others still require method development, testing and/or ground truthing before they may be useful in the TNMPA. The importance of northern context and relevance of indicators to co-management organizations, in order to gain buy-in for monitoring and community support, is also understood. With these additional considerations also in mind, the indicators were prioritized on the basis of positive attributes whereby the indicator would

(1) relate directly to beluga abundance and well-being,
(2) build on research and monitoring efforts already underway,
(3) monitor several indicators through a single program,
(4) be relatively easy to measure,
(5) be non-invasive to the target species and/or
(6) involve local communities.

Indicators considered to have highest priority for the TNMPA (see Table 1) are those related to

(1) the Hendrickson Island Beluga Study (indicators 1.2.1-1.2.3, 2.1.1-2.1.5, 2.2.1, 3.3.1, 3.4.1, 3.5.1, 4.2.1- 4.2.5, 4.3.1-4.3.3, 4.4.1, 4.4.2 and 4.5.1), including the proposed hunter sighting effort program (indicators 3.1.1 and 3.2.1),

(2) a proposed community-based fish sampling program (indicators 1.2.1-1.2.3, 2.1.1-2.1.5, 2.2.1, 3.6.1, 3.6.5, 3.7.1, 3.8.1, 3.9.1, 3.10.1, 3.11.1, 3.11.5, 3.12.1, 3.13.1, 3.14.1, 3.15.1, 4.7.1, 4.8.1, 4.8.2, 4.9.1, 4.9.2, 4.11.1, 4.12.1,4.12.2, 4.13.1 and 4.13.2),
(3) the physical and chemical environment (indicators 5.1.1, 5.1.2, 5.2.1 and 5.3.1) and
(4) anthropogenic noise (indicator 6.1.1).

(For more details about individual indicators see Loseto *et al.* 2010.)

In the ecosystem structure category, indicators that measure and monitor trophic structure (1.2.1-1.2.3) were given higher priority than the biodiversity indicators in part because of the availability of historical information and samples for analyses and/or the potential to obtain more samples through a community-based sampling program. The value of species lists (1.1.1) and biodiversity indices (1.1.2) for providing baseline information on species richness was also recognized for their scientific value though deemed a lower priority because it may be more difficult to fully characterize biodiversity than to observe changes in ecosystem structure using stable isotopes, fatty acids or contaminant tracers. In the ecosystem function category, indicators that measure and monitor diet (2.1.1-2.1.5) were given higher priority than the indicators related to biomass (element 2.2), with the exception of contaminant tracers, and age/size and sex structure (element 2.3). Considerable research on diet indicators, some in the vicinity of the TNMPA, has already been undertaken whereas the other indicators in this category would, in general, require significantly more effort or may not work in the MPA. Contaminant tracers (2.2.1) were also rated high priority though much field and lab work may be needed to make this indicator useful for the TNMPA. In the population structure of key species and the health of key species categories, indicators that involve biopsy sampling (3.4.2, 4.1.3 and 4.5.2), acoustic tagging (3.6.4 and 3.11.4) or physical restraint (4.5.3) were given lower priority because they would involve live handling of animals which is often difficult and not acceptable to Inuvialuit. Indicators that would involve sighting effort for beluga demographic rates (4.1.1), otolith microchemistry (3.6.2 and 3.11.2), survivorship curves (4.1.2) and life table analysis (4.6.1 and 4.10.1) were also given lower priority because they would likely require more time to develop and assess and/or effort to use. In the physical and chemical environment category, highest priority was given to the annual monitoring of sea ice break-up (5.1.1 and 5.1.2) because of its importance to the movements of belugas in relation to the TNMPA. Physical and biochemical oceanographic parameters (5.2.1) and sea bed morphology and sediment mobility (5.3.1) were also rated high because of their potential influence on belugas and/or other components of the food web and usefulness in developing a better understanding of how and why belugas use the TNMPA. In the noise and other physical stressors category, highest priority was given to measuring and monitoring anthropogenic noise (6.1.1) because of the potential of this stressor to displace and/or divert migrating belugas in and near the TNMPA.

Other Considerations

Monitoring activities within the TNMPA should be integrated with similar activities in the Beaufort Sea LOMA and the Mackenzie River. It is recommended the same indicators measured for population structure and health of key species within the MPA also be measured and monitored for key species on the Beaufort Sea Shelf outside of the TNMPA. These efforts would allow the comparison of results, proper interpretation of the significance of any observed changes and a better overall understanding of the structure, function and processes at work within the TNMPA.

Further consideration should be given to the identification of indicators that would monitor conditions in the TNMPA during the winter (ice-covered) season as those processes may feed into the summer (ice-free) ecosystem structure and health.

Data and Knowledge Gaps

Much is still not known, or fully understood, about the TNMPA. One of the most important knowledge gaps is to understand why Beluga Whales use the area and what, if any, biological processes and/or habitat characteristics within the MPA are important or critical for them. Further research is also needed on many attributes and processes of the physical, chemical components and how they drive the biological components of the environment, especially during the ice-covered period, to develop better baseline datasets for temporal and spatial comparisons. A better understanding of the potential impacts of threats, and how best to monitor them, would be useful.

Sources of Uncertainty

Some indicators (3.6.2, 3.11.2, 4.1.1, 4.1.2, 4.2.5, 4.6.1, 4.7.1, 4.10.1, 4.11.1, 6.2.1, 6.2.2, 6.2.3) require background research and/or analyses (e.g., develop baseline knowledge and/or methods, assess logistical feasibility, ground truthing) to be completed before their potential for monitoring and assessing whether the TNMPA is meeting its CO can be fully determined. Indicators requiring further method development are identified in Loseto *et al.* (2010).

CONCLUSIONS

The broad scope of the CO requires an ecosystem-based approach to the development of monitoring indicators. Some higher-trophic level species that use the TNMPA, especially belugas, have a large distribution and spend limited time within the MPA each year, thus some indicators that can be used to monitor at a spatial scale larger than the TNMPA are recommended. A suite of indicators, rather than one or two, is also recommended for monitoring, to provide a better understanding of ecological processes within the TNMPA and how, when and why key species, in particular belugas, use the area. Indicators related to threats that cannot be controlled (e.g., climate change) are recommended, as well as those that can (e.g., noise resulting from anthropogenic disturbance), to provide a more complete picture of how local and global stressors impact or drive ecosystem processes both in- and out-side the TNMPA. Improved comprehension would permit future development of indicator thresholds and appropriate management actions in response to environmental change.

Eighty-two indicators were identified on the basis of their scientific value for monitoring and assessing the ecological health of the TNMPA and determining whether it is meeting the CO of the MPA. They were selected according to six categories that relate to the CO: ecosystem structure, ecosystem function, population structure of key species, heath of key species, physical and chemical environment and noise and other physical stressors. Beluga Whale, Broad Whitefish, Least Cisco and Arctic Cisco were identified as key species inside the TNMPA.

Indicators thought to be highest priority for the TNMPA are those that relate directly to beluga abundance and well-being, build on research and monitoring efforts already underway, monitor several indicators through a single program, are relatively easy to measure, are non-invasive to the target species and involve local communities. Almost all the indicators in categories 1-4 considered highest priority were related to the Hendrickson Island Beluga Study, including the proposed hunter sighting effort (Catch per Unit Effort) program (indicators 3.1.1 and 3.2.1), or a proposed community-based fish sampling program. Indicators related to sea ice break-up, physical and biochemical oceanographic parameters, sea bed morphology and sediment mobility and anthropogenic noise also warrant high priority.

Belugas are identified as a key species in the TNMPA CO. Several hypotheses have been posed but not yet confirmed to explain why they gather in the Mackenzie River Estuary, including the TNMPA, each summer. A number of the identified indicators would help to confirm what biological processes and/or habitat characteristics of the TNMPA are important for belugas.

Monitoring activities within the TNMPA should be integrated with similar activities in the Beaufort Sea LOMA and the Mackenzie River. It is recommended the same indicators measured for population structure and health of key species within the MPA also be measured and monitored for key species on the Beaufort Sea Shelf outside of the TNMPA. These efforts would allow the comparison of results, proper interpretation of the significance of any observed changes and a better overall understanding of the structure, function and processes at work within the TNMPA.

By and large, the recommended indicators are related to the spring and/or summer period. Further consideration should be given to the identification of indicators that would monitor conditions in the TNMPA during the winter (ice-covered) season as those processes may feed into the summer (ice-free) ecosystem structure and health.

OTHER CONSIDERATIONS

While the TNMPA will be established under Canada's *Oceans Act*, it is located in the ISR which is governed in accordance with the Inuvialuit Final Agreement. DFO and the Fisheries Joint Management Committee (FJMC) will define roles and responsibilities for managing the TNMPA.

Monitoring protocols can be developed once DFO Oceans has decided which indicators will be monitored.

SOURCES OF INFORMATION

Loseto, L., T. Wazny, H. Cleator, B. Ayles, D. Cobb, L. Harwood, C. Michel, O. Nielsen, J. Paulic, L. Postma, P. Ramlal, J. Reist, P. Richard, P.S. Ross, S. Solomon, W. Walkusz, L. Weilgart and B. Williams. 2010. Information in support of indicator selection for monitoring the Tarium Niryutait Marine Protected Area (TNMPA). DFO Can. Sci. Advis. Sec. Res. Doc. 2010/094. vi + 45 p.

Table 1. Categories, elements and indicators that form a hierarchical framework for monitoring, assessing and understanding ecosystem health in the TNMPA, impacts of human activities and effectiveness of management measures in achieving the CO. Highest priority indicators are highlighted in yellow. For detailed descriptions of indicators see Loseto et al. (2010).

Category		Element	Indicator	
1.0 ECOSYSTEM STRUCTURE		1.1 Biodiversity	1.1.1	Species lists
			1.1.2	Biodiversity indices
			1.1.3	Genomic and genetic analyses
			1.1.4	Occurrence of unusual species
			1.1.5	Surveys
		1.2 Trophic structure	1.2.1	Stable isotopes
			1.2.2	Fatty acids
			1.2.3	Contaminant tracers
2.0 ECOSYSTEM FUNCTION		2.1 Diet	2.1.1	Stable isotopes
			2.1.2	Fatty acids
			2.1.3	Stomach and intestine contents
			2.1.4	Contaminant tracers
			2.1.5	Calorimetry
		2.2 Biomass in relation to trophic level/group	2.2.1	Contaminant tracers
			2.2.2	Remote sensing of primary production
			2.2.3	Zooplankton biomass
		2.3 Age/size and sex structure	2.3.1	Size spectrum within and among species
			2.3.2	Chlorophyll size fractions
3.0 POPULATION STRUCTURE OF KEY SPECIES	Beluga	3.1 Distribution	3.1.1	Sighting effort
		3.2 Abundance	3.2.1	Sighting effort
		3.3 Size structure	3.3.1	Morphometric data
		3.4 Sex structure	3.4.1	Gender data
			3.4.2	Biopsy sampling
		3.5 Age structure	3.5.1	Aged teeth
	Broad whitefish	3.6 Distribution	3.6.1	Capture effort
			3.6.2	Otolith microchemistry
			3.6.3	Stable isotope analysis
			3.6.4	Acoustic tagging
			3.6.5	Phenology of life history
		3.7 Abundance	3.7.1	Capture effort
		3.8 Size structure	3.8.1	Morphometric data
		3.9 Sex structure	3.9.1	Gender data
		3.10 Age structure	3.10.1	Otolith aging

Category		Element	Indicator	
3.0 POPULATION STRUCTURE OF KEY SPECIES (cont.)	Least & Arctic Cisco	3.11 Distribution	3.11.1	Capture effort
			3.11.2	Otolith microchemistry
			3.11.3	Stable isotope analysis
			3.11.4	Acoustic tagging
			3.11.5	Phenology of life history
		3.12 Abundance	3.12.1	Capture effort
		3.13 Size structure	3.13.1	Morphometric data
		3.14 Sex structure	3.14.1	Gender data
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FOR MORE INFORMATION

Contact: Lisa Loseto
Arctic Aquatic Research Division
Central and Arctic Region
Fisheries and Oceans Canada
501 University Crescent, Winnipeg, Manitoba, R3T 2N6
Government of Canada
Tel: 204-983-7219
Fax: 204-984-2403
E-Mail: lisa.loseto@dfo-mpo.gc.ca

This report is available from the:

Center for Science Advice (CSA)
Central and Arctic Region
Fisheries and Oceans Canada
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

Telephone:(204) 983-5131
Fax: (204) 984-2403
E-Mail: xcna-csa-cas@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas

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