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Information in Support of Indicator Selection for Monitoring the Tarium Niryutait Marine Protected Area (TNMPA)

Information à l'appui du choix des indicateurs relatifs à la surveillance de la zone de protection marine de Tarium Niryutait

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TABLE OF CONTENTS

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ABSTRACT

The Tarium Niryutait Marine Protected Area (TNMPA) consists of three sub-areas at the edge of the Mackenzie River Delta, within the Beaufort Sea Large Ocean Management Area. The conservation objective of the TNMPA is to conserve and protect Beluga Whales (*Delphinapterus leucas*) 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 conservation objective for established Marine Protected Areas. In Central and Arctic Region, the DFO Science sector has been asked to provide advice on indicators and protocols for monitoring the TNMPA to determine if it is meeting the conservation objective. An analysis was conducted of candidate monitoring indicators. Given the broad scope of the TNMPA conservation objective, a hierarchal framework was developed according to six main categories: ecosystem structure, ecosystem function, population structure of key species, health of key species, physical and chemical environment and physical disturbance. Eighty-two indicators were identified within the framework. Some higher-trophic level species that use the TNMPA, especially belugas, have a wide 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 how, when and why key species use, and processes operate in, the TNMPA. Indicators related to threats that cannot be managed (e.g., climate change), as well as those that can (e.g., noise resulting from anthropogenic disturbance), are recommended to provide a more complete picture of how local and global stressors impact or drive ecosystem processes both in- and outside the TNMPA. Indicators considered the highest priority for the TNMPA are related to (1) the ongoing Hendrickson Island Beluga Study, (2) a proposed community-based fish sampling program, (3) the physical and chemical environment and (4) anthropogenic noise. Given the important influence of adjacent ecosystems, it is recommended that monitoring activities within the TNMPA be integrated with similar activities in the Beaufort Sea Large Ocean Management Area and the Mackenzie River. Indicators that would monitor conditions in the TNMPA during the ice-covered season were not fully considered. Monitoring protocols can be developed once a suite of indicators is finalized.

RÉSUMÉ

La zone de protection marine (ZPM) de Tarium Niryutait comprend trois sous-zones situées à la limite du delta du fleuve Mackenzie, au sein de la zone étendue de gestion des océans de la mer de Beaufort. L'objectif de conservation de la ZPM de Tarium Niryutait est de préserver et de protéger les bélugas (*Delphinapterus leucas*) et d'autres espèces marines (poissons anadromes, sauvagine et oiseaux de mer), leurs habitats ainsi que leur écosystème. Afin de soutenir l'Initiative pour améliorer la santé des océans, le secteur des Sciences de Pêches et Océans Canada (MPO) doit fournir des indicateurs, des protocoles et des stratégies valables du point de vue scientifique en matière de surveillance de l'objectif de conservation des ZPM établies. Dans la région du Centre et de l'Arctique, on a demandé au secteur des Sciences du MPO de donner des conseils sur les indicateurs et les protocoles relatifs à la surveillance de la ZPM de Tarium Niryutait, dans le but de déterminer s'ils remplissent l'objectif de conservation. Une analyse des indicateurs de surveillance possibles a été menée. Étant donné que la portée de l'objectif de conservation de la ZPM de Tarium Niryutait est vaste, un cadre hiérarchique a été élaboré. Il se divise en six grandes catégories : structure de l'écosystème, fonction de l'écosystème, structure de population des espèces-clés, santé des espèces-clés, environnement physique et chimique ainsi que perturbation physique. Le cadre a permis de déterminer quatre-vingt-deux indicateurs. Certaines espèces de niveau trophique plus élevé qui évoluent dans la ZPM de Tarium Niryutait, particulièrement les bélugas, sont réparties sur une vaste étendue et passent peu de temps dans la ZPM chaque année. C'est pourquoi on recommande certains indicateurs servant à surveiller une échelle spatiale pus grande que la ZPM de Tarium Niryutait. Une série d'indicateurs, plutôt qu'un ou deux, est également recommandée en matière de surveillance pour permettre de mieux comprendre comment, où et pourquoi les espèces importantes utilisent la ZPM de Tarium Niryutait – ainsi que la façon dont les processus y fonctionnent. On recommande des indicateurs connexes aux menaces qui ne peuvent être gérées (p. ex. changements climatiques) et à celles qui peuvent l'être (p. ex. bruit attribuable à la perturbation anthropique) afin de dresser un portrait plus complet de la façon dont les facteurs de stress locaux et mondiaux touchent ou marquent les processus de l'écosystème, tant à l'intérieur qu'à l'extérieur de la ZPM de Tarium Niryutait. Les indicateurs jugés prioritaires pour la ZPM de Tarium Niryutait sont liés à (1) l'étude sur les bélugas en cours à l'île Hendrickson, (2) soit un programme communautaire proposé d'échantillonnage des poissons, (3) l'environnement physique et chimique et (4) le bruit anthropique. Étant donné la grande influence des écosystèmes adjacents, on recommande que les activités de surveillance menées dans la ZPM de Tarium Niryutait soient intégrées aux activités semblables menées dans la zone étendue de gestion des océans de la mer de Beaufort et sur le fleuve Mackenzie. Aucun indicateur voué à la surveillance des conditions de la ZPM de Tarium Niryutait pendant la saison englacée n'a été examiné en profondeur. Les protocoles de surveillance pourront être élaborés une fois la série d'indicateurs terminée.

INTRODUCTION

Under the Health of the Oceans Initiative, Fisheries and Oceans Canada (DFO) Science sector has been asked to provide advice on indicators and protocols for monitoring whether the conservation objective (CO) for the Tarium Niryutait Marine Protected Area (TNMPA) is being met. This report provides a list of recommended indicators relating to Beluga Whales (*Delphinapterus leucas*), beluga habitat, other key marine species and ecosystem health. Included with the recommended indicators is an evaluation of their suitability to establish methods for using them to track status, condition and trends. Ultimately the indicators will be used to demonstrate how effective the TNMPA is in achieving its CO.

HISTORICAL DEVELOPMENT OF THE TNMPA AND THE CONSERVATION OBJECTIVE

In 1984, the Inuvialuit Final Agreement (IFA) mandated the formation of a Fisheries Joint Management Committee (FJMC) to assist in administering the rights and obligations related to fisheries in the Inuvialuit Settlement Region (ISR). The FJMC was established by the Minister of DFO in 1986. In 1991, the FJMC finalized the Beaufort Sea Beluga Management Plan (BSBMP; last amended in 2001) with the purpose of maintaining responsible and effective management of Beaufort Sea beluga (FJMC 2001). However, with the renewal of oil and gas exploration activity in 2006, the need for enhanced protection of beluga and their habitats led to the development of a Marine Protected Area (MPA) in the Mackenzie River Estuary. Work leading to this MPA began in 1998 when DFO Oceans Programs Division met with the Inuvialuit Game Council and FJMC to discuss options for a marine protected area in the Inuvialuit Settlement Region (Mathias and Fast 1998). The direction provided at that meeting was that a pilot MPA should be established, and a working group formed to consider in more detail the options presented for a potential MPA site in the ISR. This led to the formation of the Beaufort Sea Integrated Management Planning Initiative (BSIMPI) Working Group (WG). The WG was asked to evaluate the merits of establishing an MPA in portions of the Mackenzie River Estuary that were designated the highest priority for protection (Zone 1a) in the Beaufort Sea Beluga Management Plan (BSBMP) (FJMC 2001). Since that time there have been several alterations to the policy and legislative frameworks related to MPA creation and management. Work progressed towards a final agreement on the TNMPA in 2010 and development of its primary CO (Cobb *et al.* 2004, Ayles and Papst 2007, Cobb *et al.* 2008).

In 2004, the BSIMPI WG drafted four COs for the TNMPA which were later revised in 2010 to a primary objective:

> *to conserve and protect Beluga Whales and other marine species (anadromous fishes, waterfowl and seabirds), their habitats and their supporting ecosystem.*

The TNMPA will strengthen and complement the BSBMP objectives which are to ensure the long-term sustainable management of one of the world's largest summering stocks of Beluga Whales and their habitat.

THE TNMPA ECOSYSTEM

The TNMPA is nested within the Large Ocean Management Area (LOMA) that covers the ISR defined in the IFA (Figure 1). The TNMPA is made up of three separate and distinct sub-areas located in the Mackenzie River Estuary: Niaqunnaq (Shallow Bay), Okeevik (in Beluga Bay, east Mackenzie Bay near Kendall and Pelly Islands) and Kittigaryuit (Kugmallit Bay) (Figure 2), all areas where Beluga Whales aggregate each summer and subsistence harvesting occurs. The

TNMPA sub-areas correspond to Zone 1a of the BSBMP (FJMC 2001). There is a wealth of traditional knowledge about the TNMPA and ISR that can be found in socio-economic reports produced by DFO Oceans Programs Division. This report has a marine aquatic science-based advisory focus and, for that reason, traditional knowledge is not included here.

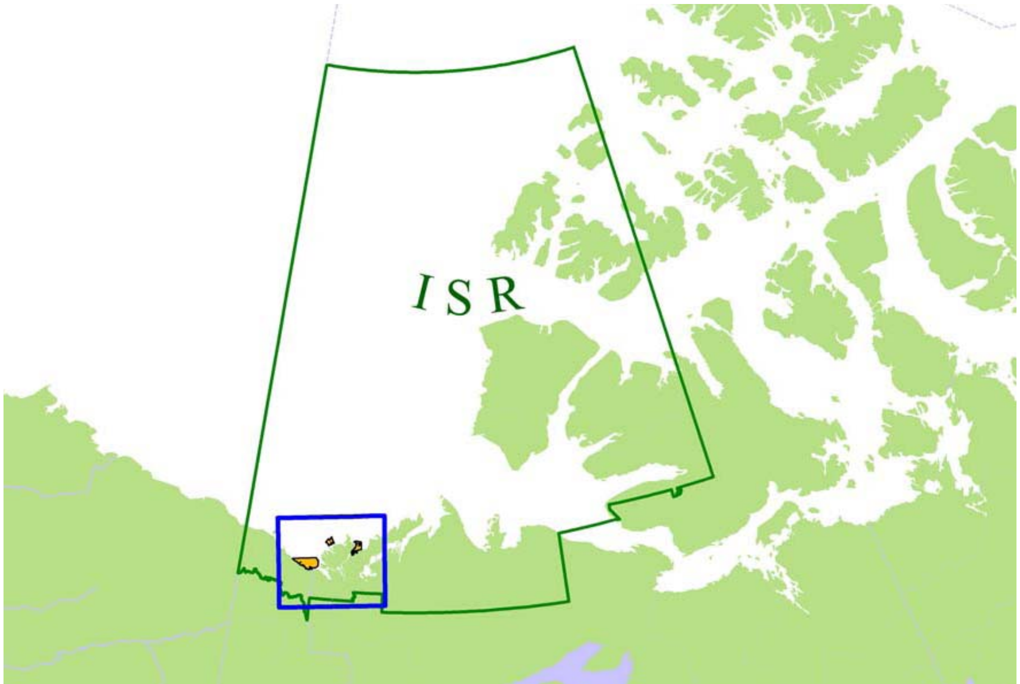

Figure 1. Inuvialuit Settlement Region (ISR) with Tarium Niryutait Marine Protected Area (Zone 1a beluga areas) shown inside box outline.

The dominant environmental factors that influence the chemical and physical conditions in the TNMPA are the Mackenzie River (Carmack *et al*. 2006), and the seasonal land-fast ice. The Mackenzie River Basin covers an area of 1.8 million km^2 and the river has an annual outflow of 330 km^3/yr. This accounts for 60% of the freshwater that flows into the Arctic Ocean from Canada. The Mackenzie River is the largest source of suspended sediments to the Arctic Ocean (Millot *et al*. 2003, Carrie *et al.* 2009). The discharge and resulting concentrations of nutrients, carbon, suspended mineral sediments, and contaminants, as well as water temperatures in the Mackenzie River, 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 by essentially making it inaccessible from above or below (in the case of grounded ice), and by trapping freshwater from the river creating a ‘freshwater lake’ under the ice in the late winter/spring (Carmack and Macdonald 2002). Limited light, due to overlying ice and snow, and the dominance of freshwater result in minimal productivity and species assemblages in the spring. Ice break-up begins in late April in the Mackenzie River headwaters and progresses north, with energy inputs from the river and solar radiation finally breaking up the landfast ice by late June (Carmack and Macdonald 2002). The sub-areas of the MPA are largely within the inner-shelf region of the larger Beaufort Sea Shelf. This inner-shelf is characterized by limited ocean water intrusions and highly turbid water, largely due to complete water column mixing via wind forcing sediment re-suspension (Carmack and Macdonald 2002). Due to the dominance of river-source

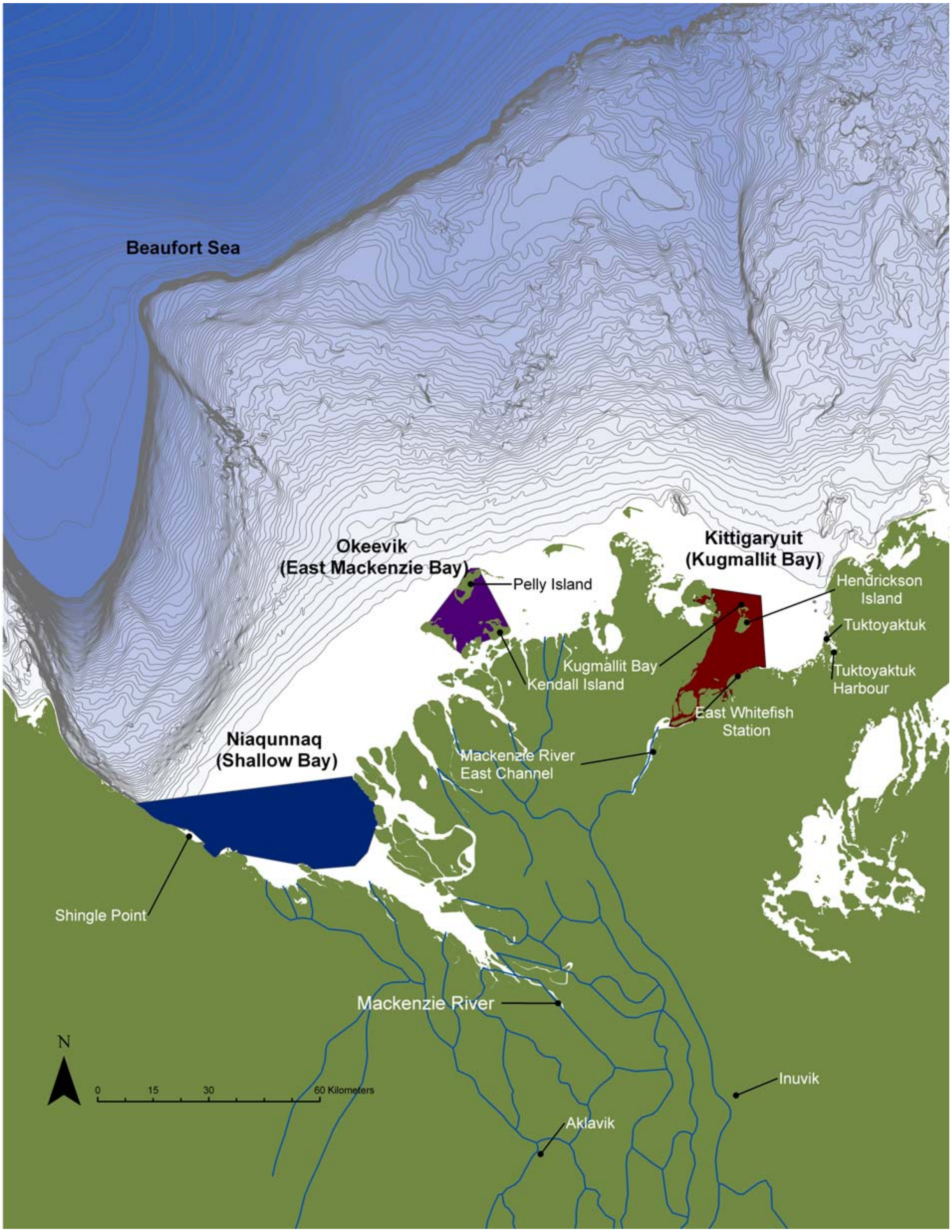

Figure 2. TNMPA sub-areas within the Mackenzie River Estuary in relation to the inner Beaufort Sea bathymetry. The depth contour interval is 5 m.

water and high turbidity, light and/or phosphorus limit primary production in this inner-shelf zone throughout the summer (Carmack and Macdonald 2002). This area is also characterized by 100% ice scouring and/or ice grounding (Lewis and Blasco 1990). Instability of benthic habitat due to ice effects, sediment deposition, re-suspension and movement makes this inner-shelf zone relatively uninhabitable for benthic organisms and communities. Zooplankton assemblages in the nearshore estuary, where *Podon leuckarti*, *Pseudocalanus* spp., *Copepoda nauplii* and *Limnocalanus macrurus* were most abundant (Walkusz *et al.* 2010), are characterized by significantly lower biomass concentrations relative to the mixed zone and offshore.

The presence of fishes in the TNMPA and other nearshore areas is characterized by the occurrence of an ‘anadromous highway’ (Carmack and Macdonald 2002 adapted from Gallaway *et al.* 1983) of upstream migrants (spawning and overwintering adults) during fall, and adult and larval fishes moving out from the Mackenzie River and following currents along the shore to feeding and rearing areas, respectively. The brackish waters that occur in summer, along the Yukon coast and in Kugmallit Bay, provide a relatively stable buoyancy-current that creates this important migration route for anadromous species (Carmack and Macdonald 2002). This habitat provides migration routes between the coastal lagoons and estuaries that many species use for foraging and as nursery areas (Cobb *et al.* 2008). Species composition in the estuaries shifts throughout the year with the changes in salinity and life history stages of the fishes. During the open water season, Least Cisco (*Coregonus sardinella*), Broad Whitefish (*Coregonus nasus*), Dolly Varden (*Salvelinus malma malma*), Inconnu (*Stenodus leucichthys*) and other anadromous species predominate. During periods of ice cover (October through June), waters are more saline, and the fish assemblage changes to predominately marine species including Fourhorn Sculpin (*Myoxocephalus quadricornis*), Saffron Cod (*Eleginus gracilis*) and Pacific Herring (*Clupea harengus pallasi*) (Karasiuk *et al.* 1993). There are about 20-25 different species of fishes.

For reasons which are not fully understood, thousands of Beluga Whales return to the shallow (< 5 m) and warm (up to 20°C) Mackenzie River Estuary each summer. The characteristic use of estuaries in summer is prevalent in many beluga populations (Richard 2009). Ecological perspective is often lacking in past studies of Beluga Whales in estuaries, in part due to the difficulty of studying Beluga Whales in their environment (Martin and Smith 1992, Martin *et al.* 1993, Martin *et al.* 1998, Heide-Jørgensen *et al.* 1998). Regardless, several hypotheses about why Beluga Whales come to estuaries in summer have been proposed including feeding (Kleinenberg *et al.* 1969, Seaman and Burns 1981, Seaman *et al.* 1982), calving (Sergeant and Brodie 1969, Sergeant 1973, Fraker *et al.* 1979), moulting (Finley 1982, St. Aubin *et al.* 1990), avoidance of killer whales (Brodie 1971) and humans (Caron and Smith 1990, Kilabuk 1998), thermal advantages (Sergeant and Brodie 1969, Fraker *et al.* 1979) and phylogenetic inertia (influence of an ancestor on its descendants) (Martins 2000, P. Richard, pers. comm.). The feeding hypothesis (Kleinenberg *et al.* 1969, Seaman and Burns 1981, Seaman *et al.* 1982) is not fully supported by stomach content analysis carried out during local harvest in the TNMPA (Harwood *et al.* 1996). Females are often seen with their calves in estuaries, thus calving was thought to be the primary behavioural motivation for estuary use (Sergeant and Brodie 1969, Sergeant 1973, Fraker *et al.* 1979). A more recent publication on blubber and skin growth (Doidge 1990a), along with some observations of females arriving in estuaries with their calves, provides evidence to the contrary. This, along with the characteristically warmer water in estuaries, led to the hypothesis of thermal advantage to all ages and sex classes of beluga (Fraker *et al.* 1979). However, this too was not widely accepted given the fact that Beluga Whales are well adapted to cold marine waters common in the pack ice where water temperatures can be as low as -4°C (Doidge 1990a). Further, Beluga Whales and Narwhals have the same insulation factor, yet only Beluga Whales seasonally occupy warm water estuaries. The moulting hypothesis has been strengthened by studies demonstrating elevated moulting hormone levels in Beluga Whales in some estuaries (Finley 1982, St. Aubin *et al.* 1990).

The annual use of the TNMPA by Beluga Whales is significant, and as such met the criteria for an ecologically and biologically significant area (EBSA) for the Eastern Beaufort Sea beluga population (Cobb *et al*. 2008, Paulic *et al*. 2009).

The Niaqunnaq sub-area (Shallow Bay) is the western most sub-area of the TNMPA in waters less than 5 m deep. It is used by Beluga Whales, Pacific Herring, anadromous fishes, Polar Bears (*Ursus maritimus*), Ringed Seals (*Phoca hispida*) and gulls. Beluga Bay is located east of the Mackenzie trough within the 10 m depth isobath and contains the Okeevik sub-area of the TNMPA. This area is used by Beluga Whales, Polar Bears, Tundra Swans (*Cygnus columbianus*), Snow Goose (*Chen caerulescens*), Ringed Seals and Pacific Herring. The Kittigaryuit sub-area of the TNMPA, in Kugmallit Bay, covers a shallow area that is used by Beluga Whales, Bowhead Whales (*Balaena mysticetus*), anadromous fishes, Pacific Herring, Ringed Seals, White-fronted Goose (*Anser albifrons*), Polar Bears and gulls.

Ultimately, ecosystem status and health indicators should reflect the biophysical nature of this inner-shelf environment. Therefore, monitoring the long-term patterns of, and changes to, physical ecosystem drivers such as river discharge, sediment dynamics and ice patterns are critical. In addition, the continued presence and movement of fishes and Beluga Whales are, in themselves, indicators of the continuing function and health of this ecosystem and therefore need to be monitored and better understood.

IDENTIFICATION OF THREATS AND POTENTIAL STRESSORS

The TNMPA and the surrounding area face a number of threats and potential stressors. While some of them are managed at the local level, others can only be addressed in international fora. 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. The following threats and potential stressors are presented in alphabetical order.

Climate Change

Climate-driven changes can directly or indirectly alter the structure and function of Arctic marine food webs and therefore is a potentially major ecosystem driver. Climate impacts that lead to sea ice loss may cause bottom-up impacts (change in productivity/energy flow) or top-down impacts (habitat loss, fragmentation). Bottom-up impacts associated with changes to the physical environment may alter the onset, duration, quantity and/or quality of primary productivity. As a result, the amount of energy or carbon available for food webs will change, thereby changing the structure and function of the biological community (e.g., predator-prey mismatching). Changes to the physical environment may alter habitats through a top-down cascade of trophic effects on food webs. The removal of sea ice habitat and its associated resources may lead to deterioration in health and survival of those species that depend on it. Changes in sea ice extent, properties and duration may affect the timing, location and quality of the Mackenzie River plume, leading to possible impacts on Beluga Whales. A changing climate may exacerbate contaminant-related health risks through changes to transport and fate mechanisms in a changing ice environment. A warming climate may allow for the introduction and establishment of new species, including parasites, bacteria and viruses against which local biota have no immunological defences. It may also increase stress in cold-adapted species. The impacts of climate change are hard to predict, making it difficult to understand the resulting effects on ecosystem dynamics, within and around the TNMPA, and on Beluga Whales.

Commercial Fishing

Large scale commercial fishing occurs in the Bering Sea, which is where the Eastern Beaufort Sea beluga population winters. Belugas may depend on the fishes of this productive area as a major food source. Over-fishing in the area could impact the health of the Beaufort Sea beluga population. There are no commercial fishing activities in the Canadian Beaufort Sea or Mackenzie River Estuary at this time, although such ventures may take place in the future.

Contaminants and diseases

The ability for many contaminants to undergo long-range transport has resulted in increased and measurable concentrations of contaminants in Beluga Whales and their prey. In addition, local sources of contaminants may become more critical with oil and gas exploration and development. Contaminants such as mercury (Hg) and persistent organic pollutants (POPs) are known to impact the neurological, reproductive, endocrine and immune systems in moderately-to highly-exposed humans and marine mammals (Loseto and Ross, in press). Thus changes in current levels brought on by local spills or changes in long range transport may result in impacts on beluga health. Disease impacts and parasite loads place an additional burden on beluga immune systems, ultimately impacting their overall health.

Hydrocarbon development and related activity

Three Significant Discovery Licences (SDLs) are present within the TNMPA sub-areas: one just outside the northwest corner of Kittigaryuit and two within Okeevik. Exploratory activities include seismic surveys that are supported by vessels and aircraft for supplies and crew change. Potential activities in support of development include barging, dredging, waste generation, seismic activity and pipeline burial (only during ice-covered period) that may impact Beluga Whales by disturbing their habitat. Even with proper regulations and mitigations in place, a catastrophic spill could occur impacting the coastal marine habitat including the MPA. Severity of the impacts would depend on factors such as timing of event, ocean currents, spill response, volume of spill, etc. The potential construction of the Mackenzie Gas Pipeline will require infrastructure transported via coastal regions, thus increasing shipping and barging activity. Such activities will impact the habitat through fragmentation and noise disturbance. Pipeline design that includes stream crossings in the Mackenzie River may alter the physical, chemical and biological characteristics of the Mackenzie River plume and potentially impact beluga use within the TNMPA.

Land-based activities

Land-based activities can introduce contaminants or noise to the aquatic environment of the TNMPA and could affect the health or well-being of Beluga Whales.

Noise and Disturbance

Barges, ships and boats, seismic activities and other commercial and industrial activities could produce noise at levels and frequencies that could disturb or disrupt beluga migratory movements, feeding and reproductive behaviours outside or within the TNMPA. Noise impacts range from temporary or permanent hearing loss to chronic impacts of masking that may interfere with feeding and social behaviour. It could also elevate cortisol levels and reduce immune function.

Recreation and tourism

Eco-tourism could affect the distribution of Beluga Whales in the TNMPA. While the exact reason(s) why Beluga Whales use the TNMPA is not known, their recurring presence there each summer suggests the MPA plays an important ecological role for this population. Repeated disturbance from unregulated eco-tourism activities may have biological consequences for Beluga Whales.

Shipping and Vessel Traffic

As part of exploratory and development activities, shipping and barge traffic is expected to increase near and in the TNMPA which may impact the beluga summer habitat use of the area. All activities by ships and boats are confined to community supply routes, which may be marked by Canadian Coast Guard navigational buoys. An exemption allows ships and boats to travel outside the community supply routes only to support existing leases and licences in the Special Management Zone (related to the SDLs). This travel can be conducted under existing authorization processes using best practices and technologies to minimize impacts, consistent with the CO of the MPA.

Subsistence Harvesting

Subsistence harvesting for fishes and belugas occurs within the TNMPA. The communities rely on this food source and have done so for hundreds of years. Currently, harvesting of Beluga Whales within the TNMPA is self-regulated, and is carried out at a sustainable level and monitored annually. The most recent population estimate for the Beaufort Sea beluga population, based on an aerial survey conducted in July 1992 is 39,258 (CV=0.229, minimum population estimate: 32,453) (Harwood *et al.* 1996, Hill and DeMaster 1999). The current population trend is unknown (Allen and Angliss 2010). The mean estimated subsistence take (i.e., number of whales landed) in Canadian and U.S. waters from the Beaufort Sea population during 2002-2006 was 139 (114 + 25, respectively) (Allen and Angliss 2010).

ASSESSMENT

INDICATORS FOR MONITORING

Current State of Monitoring and Research Activities

With the exception of the FJMC Beluga Harvest Monitoring Program (BHMP), research and monitoring activities in and around the TNMPA are not funded on a long-term basis, therefore funding must be sought and secured annually.

Beluga

The distribution of Beluga Whales within the Mackenzie River Estuary was monitored through systematic aerial surveys (50% coverage) each July from 1977 to 1985, and in 1992 (Norton and Harwood 1985, Harwood *et al*. 1996). The distribution of Beluga Whales seaward of the estuary was also monitored through a systematic aerial survey (10% coverage) during 1981-1986, 1992 and 2007-2009 (Norton and Harwood 1985, 1986, Harwood *et al.* 1996, Harwood *et al.* 2009). Beluga aggregation areas in the estuary and offshore are available, and provide a baseline for monitoring.

In addition, satellite tagging and tracking studies were conducted in 1993, 1995, 1997, 2004 and 2005 to examine beluga movements (Richard *et al*. 2001), habitat use (Loseto *et al*. 2006) and diving behaviour (Richard et al. 1997). One of the main objectives of Richard *et al.* (1997) was to correct for submerged Beluga Whales missed by aerial surveyors, and thus adjust relative abundance indices to more accurately estimate stock size. Finally, a new method to monitor and estimate the size of beluga aggregations using remote sensing is presently being developed and tested (P. Richard, pers. comm.).

Data and sample collections from belugas landed in the annual subsistence harvest in the Mackenzie River Estuary date back to 1973. The program was standardized in 1980 (Harwood *et al.* 2000, Harwood and Smith 2002), but was scaled back to three monitoring sites (from six sites) in 2008. Local hunters are employed as monitors at the seasonal whaling camps to collect hunt information and biological data and samples. Prior to 2008, all whales landed were included in the monitoring (e.g., not a sample, but a census). This is an important dataset as it provides an extensive long-term baseline (30 years) prior to establishment of the MPA, and the longest beluga harvest monitoring dataset in existence.

In the mid-1990s, genetic stock structure of Beaufort Sea belugas was examined using DNA collected from the BHMP (Brown Gladden *et al*. 1997, 1999). Currently, a new study is underway to analyse a larger number of genetic markers for the examination of micro-geographic stock structure and of kinship relationships within and among the beluga aggregations in the TNMPA (L. Postma, pers. comm.).

Additional research and monitoring has taken place annually at Hendrickson Island, one of the core whaling areas, from 2000 to the present. This initiative has been led by DFO, in partnership with the FJMC and the Northern Contaminants Programme (NCP). Monitoring focuses on beluga health and includes sampling of reproductive material and tissues to determine disease and contaminant loads (e.g., Hg, POPs). This study has been expanded in more recent years to measure diet biomarkers and indicators of health impacts (Table 1), and to involve local harvesters both in the collection of samples/data, and in the dissemination of results. The Hendrickson Island beluga program has attracted new research questions from within DFO and academia. Together, the DFO, FJMC BHMP and academia research and monitoring programs fit under an umbrella program known as the Hendrickson Island Beluga Study (HIBS).

Ecosystem Monitoring

Within or adjacent to the MPA sub-areas, several ecosystem research and community-based monitoring programs have taken place to evaluate components of the physical and biological ecosystem. Notable in the 1980s, the Northern Oil and Gas Action Program (NOGAP) carried out many preliminary baseline research studies in the Mackenzie Delta, Beaufort Sea Shelf and Beaufort Sea. 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 River plume. Coupled with these measurements were the collections of lower trophic level components of the food web including primary producers, consumers at the zooplankton and ichthyoplankton levels, up to marine demersal and anadromous fish species (e.g., Majewski *et al.* 2009). Also, coastal physical process studies are being conducted by Natural Resources Canada (NRCan) on the Beaufort Sea Shelf just outside the TNMPA. The DFO Oceans Tariuq community-based monitoring program was a pilot project for engaging communities in marine environmental quality monitoring. Samples of fishes and water were collected at Shingle Point (in Niaqunnaq sub-area), Tuktoyaktuk Harbour and East Whitefish station (in Kittigaryuit sub-area) between 2001 and 2003 (DFO, unpubl. data). An extensive fisheries assessment was conducted within Tuktoyaktuk Harbour in 1977-1999 (Harwood and Smith 2002).

<u>Selection of Appropriate and Meaningful Indicators</u>

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 CO. A body of literature exists on the selection of indicators for environmental monitoring (e.g., Rice and Rochet 2005, Tallis *et al*. 2010). They are normally selected using such criteria as relevance to people and the environment, availability of reliable and long-term measurements, and clear relationships between the indicator and the force of change in question. The most useful environmental indicators are relatively simple measurements that can be used to represent a more complex situation. Examples of a climate change indicator are ice freeze-up and break-up dates. As Beluga Whales are difficult to count in the turbid waters of the TNMPA, aggregations may be measured by some indicator of abundance.

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.

RATIONALE FOR INDICATORS

The structure and function of the ecosystem that encompasses the TNMPA and surrounding area are complicated and not fully understood. As well, conditions within the region can be highly variable within and among years. For these reasons, selecting monitoring indicators to support the broad CO is especially challenging. To aid in the process of selecting indicators, several guiding principles were established. 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 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 species[1], 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 impact or drive ecosystem processes both in- and outside the TNMPA.

[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.

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 within the TNMPA, impacts of human activities and effectiveness of management measures in achieving the CO (Table 2). This framework does not include species for which DFO has no jurisdictional responsibilities (e.g., waterfowl and seabirds).

DESCRIPTION OF INDICATORS

1.0 Ecosystem structure

This category refers to the individuals and communities of plants and animals which comprise an ecosystem and is described by biodiversity and trophic structure. Shifts in indicators within this category over time would signal changes in the ecosystem.

1.1 Biodiversity

1.1.1 Species lists

Description: Species lists are a basic indicator of biodiversity/species richness and provide some information about community structure.
Rationale: Species lists would show the current level of biodiversity in the TNMPA and changes over time would signal changes in the ecosystem. Some basic sampling would be required to produce and update the complete list by taxonomic group which could also provide samples for linked indicators (e.g., stable isotopes, fatty acids), making this a value-added indicator. Identifying the occurrence of colonizing species in response to climate change would result from regular monitoring of this indicator.
Historical information: A species list for the TNMPA was started in 2005 and is nearing completion (B. Stewart, unpubl. data). Taxonomic groups include birds, marine mammals, fishes, zooplankton, phytoplankton, benthos and pathogens. A database for fishes is also available for the region (Coad and Reist 2004). The current status of information for different taxonomic groups varies from complete lists for marine mammals and pathogens, seasonal lists for fishes, and incomplete lists for zooplankton, phytoplankton and benthos.
Work needed: Complete species lists for benthos, phytoplankton and zooplankton. Conduct desk analyses to determine extent of remaining work to develop lists for pathogens and fishes. Compare species lists spatially (in- versus outside the TNMPA) and, if the necessary information is available, temporally.

1.1.2 Biodiversity indices

Description: Biodiversity indices are measures of biodiversity/species richness by functional groups and/or ecosystem.

Rationale: Shifts in diversity parameters and relative abundance, presence of new species and so on would signal a significant change in the ecosystem.

Historical information: See Indicator 1.1.1.

Work needed: Perform computations to develop biodiversity indices by functional groups and/or ecosystem. Compare indices spatially (in- versus outside TNMPA) and, if the necessary information is available, temporally. Assess levels of information by taxonomic group.

1.1.3 Genomic and genetic analyses

Description: Genomic and genetic marker analyses can be used to measure biodiversity at different scales. Genetic resource profiling can characterize the population diversity and structure while genomics uses a quantitative approach regarding the regulation of genes specific to either species or functions.

Rationale: Shifts in biodiversity richness would signal changes in the ecosystem. For example, analyses of genetic markers can reveal changes in the level of heterozygosity of groups of animals and may be used to detect species hybridizations. Genomics is a relatively unexplored tool that can assess biodiversity and/or ecosystem functions in different ways. For example, diversity of microbial communities as a group can be effectively determined with genomics. Functions of microbes (e.g., bioremediation of toxic substances) can also be determined through genomic research. Genomics as an approach has not been widely applied within the region, with the exception of the microbial community. It would be necessary to assess the applicability of genomic analysis for measuring biodiversity within the TNMPA.

Historical information: Resource profiling of marine mammals and some fishes using genetic markers has been carried out in the Beaufort area for many years. Research using genomic tools has not been carried out in the TNMPA.

Work Needed: New initiative to gather samples and data.

1.1.4 Occurrence of unusual species

Description: The occurrence of unusual species, including the arrival of competitors, predators, parasites and others, would indicate a change in biodiversity.

Rationale: Monitoring the occurrence of unusual species would signal changes in biodiversity within the TNMPA. Importance of this indicator may rise as shipping activity increases in the region.

Historical information: Zooplankton species lists in the TNMPA vicinity are available and new publications are underway (Walkusz *et al.* 2010, K. Howland, pers. comm.) Species lists are available for fishes (Coad and Reist 2004) that can provide a baseline for identifying unusual species. Lists for the higher trophic levels could be completed using historical information from observers. Several unusual species have been reported in recent years such as Killer Whales (*Orcinus orca)*, Stellar Sea Lions (*Eumetopias jubatus*), Grey Whales (*Eschrichtius robustus*) and harmful algal blooms, while other species have been reported at greater frequencies such as Pacific sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*).

Work needed: Desk analysis to assess the potential for new programs to survey the data and/or collect new data. Good communication between DFO and community members would facilitate continued reporting of sightings of higher-trophic species.

1.1.5 Surveys

Description: Surveys can be used to map the distribution of species within an area and perhaps identify use of specific habitat(s).

Rationale: Mapping the distribution of species in the TNMPA, especially key species like Beluga

Whales, and monitoring for shifts in distribution, would indicate when changes in habitat have occurred and the need for investigation.
Historical information: Some baseline data exists for belugas within the TNMPA while very little, if any, data are available for other taxa.
Work needed: Desk analyses and spatial data collection.

1.2 Trophic structure

1.2.1 Stable isotopes

Description: General trophic structure of an ecosystem is indicated by fractionation of carbon, nitrogen and sulphur in a food web. Carbon stable isotopes are used to infer the dietary origins of carbon sources (i.e., nearshore versus offshore, benthic/littoral versus pelagic (France 1995)). Nitrogen stable isotopes can ascribe the trophic level of prey items as a result biochemical fractionation processes during excretion, whereby the lighter isotope is selectively utilized leaving behind the heavier isotope (DeNiro and Epstein 1978, 1981). Sulphur and carbon isotopes provide information on whether the source was marine or freshwater in origin.
Rationale: Due to the difficulties in observing marine predator feeding, marine mammal research has pursued a variety of approaches to characterize feeding ecology. Of most recent interest is the use of tissue biochemical markers such as stable isotopes (e.g., Hobson and Welch 1992, Kurle and Worthy 2002). Establishing stable isotopic signatures for fishes in each sub-ecosystem (i.e., benthic and water column, onshore (mixed water) and offshore (marine)) and the timeframe relevant to beluga feeding, and periodic monitoring of such (e.g., five-year time frame), provides information on stability of the actual food items that serve at the resource base. Linkages to similar work on lower trophic levels (i.e., production base), to other indicators (e.g., fatty acids), to contaminants, and to the belugas themselves would provide a powerful indicator for the overall ecosystem (Loseto *et al*. 2008a). Although the nearshore food web in the TNMPA may not comprise a significant portion of beluga diet it is important to have an understanding of the ecosystem structure and how Beluga Whales fit within it.
Historical information: Stable isotope data for belugas are available for muscle from 1980 onward, stable isotope analysis in liver was initiated in 2004 and some skin analysis was performed in 2005. Some food web papers were completed (e.g., Loseto *et al.* 2008a). There is a small quantity of phytoplankton, ice algae and zooplankton samples and data available. DFO currently has over 1,000 fish samples and over 100 marine mammal samples that have yet to be analyzed. Samples for benthos (limited numbers) and sediment were collected and are currently under analysis.
Work needed: Some lab and desk analyses of available samples and data. Collections of missing fish and lower trophic species needed as well as subsequent desk analyses.

1.2.2 Fatty acids

Description: Fatty acids are essential components of the energy transfer associated with trophic structure of ecosystems, and some may be essential for the well-being of particular organisms. Up to 65 long chain (> 12 carbon length) fatty acids are measurable in the marine food web that together provide a unique signature of fatty acid profiles among species and groups of similarly feeding organisms, thus serving as biomarkers that may be species- and/or ecosystem-specific (Budge *et al*. 2006).
Rationale: Assessment of benchmark fatty acid signatures when coupled with similar work on stable isotopes (indicator 1.2.1), both of which are derived from sampling for diversity (indicators 1.1.1), would provide a powerful tool for monitoring health and production in the TNMPA.
Historical information: Samples and data are available for marine mammals, fishes and invertebrates (Loseto *et al.* 2009). Samples for phytoplankton, benthos and sediment were collected for analyses. These samples are currently being analyzed based on priority needs.

Work needed: Lab and desk analyses of available samples and data.

1.2.3 Contaminant tracers

Description: Contaminants such as Hg and POPs (e.g., PCBs (Polychlorinated biphenyls) and PBDEs (Polybrominated diphenyl ethers)) accumulate in organisms over time and biomagnify up food webs. In doing so, they can be used as a tool to map food web and trophic structure.

Rationale: Concerns about contaminants in the Canadian Arctic emanate, in part, from studies which demonstrate possible health effects to humans, Polar Bears and Beluga Whales (White *et al*. 1994, Braathen *et al*. 2004). Monitoring beluga contaminants such as Hg and POPs has typically been related to human health concerns for consumption as well as an early warning tool for those contaminants with the ability to travel over long ranges (NCP, AMAP (Arctic Monitoring and Assessment Programme)). The focus on measuring contaminants (by DFO) has moved towards shifts in food web/ecosystem processes and health impacts of these contaminants on whales and other valued ecosystem components. Thus, levels of contaminants in belugas provide information pertaining to human health, beluga health, beluga diet and foraging ecology and the potential to measure shifts in ecosystem structure and function. In addition, a changing climate has the potential to alter contaminant pathways, something that might lead to higher contaminant levels in beluga.

Historical information: Analyses have been completed for Hg and POPs for much of the beluga food web so a relatively comprehensive contaminant database is available for Beluga Whales (Lockhart *et al.* 2005, Loseto *et al.* 2008b, Tomy *et al.* 2009). Contaminant measurements exist for belugas within TNMPA over time and for belugas from other sites in Canada. Contaminant data are available from 1981, but limited to certain tissues; consecutive annual sampling began in 2001.

Work needed: Desk analyses of specimen data.

2.0 Ecosystem function

This category refers to the energy flow in the food web and can be described by diet/trophism, biomass in relation to trophic level/group and age, size and sex structure within and among species. Indicators in this category would aid in determining the energetic consequences of climate change.

2.1 Diet

2.1.1 Stable isotopes

Description: See indicator 1.2.1.

Rationale: As described for indicator 1.2.1, stable isotopes are a parameter for measuring ecosystem/food web structure from a dietary focus. Organisms in pivotal positions in the food web would have highest priority for routine assays. Establishing stable isotopic signatures for lower trophic levels and fishes in each sub-ecosystem (i.e., benthic and water column, onshore (mixed water) and offshore (marine)) and Beluga Whales, and periodic monitoring of such (e.g., five-year time frame), would provide information about stability of the resource base.

Historical information: Considerable work has been done to understand beluga diet and the Beaufort Sea food web (e.g., Loseto *et al.* 2008a, 2008b, 2009). Data gaps remain for endangered marine fish species and other marine species. Recently, samples of zooplankton were collected in the coastal Beaufort Sea in the vicinity of the proposed TNMPA. Stable isotope samples were collected from particulate matter, phytoplankton, zooplankton, benthos and sediment from the Nahidik Program.

Work needed: Update and/or revise prey information. It would be helpful to collect information from which diet can be inferred for fishes, belugas and others. As stated above, DFO has more than 1,000 fish archived and available for analysis. Once a significant database is completed, a food web analysis could be carried out.

2.1.2 Fatty acids

Description: See indicator 1.2.2.

Rationale: Using fatty acid profiles of organisms provides information about feeding relationships as well as food composition (i.e., quantity and quality). This serves as an effective monitoring tool for ecosystem structure and function.

Historical information: Fatty acid analysis was carried out for Beluga Whales from 2004 to 2009. Fatty acids of potential prey items from the Beaufort Sea Shelf have been characterized in relation to belugas to describe their diet (Loseto *et al.* 2009). Zooplankton samples were recently collected in the coastal Beaufort Sea in the vicinity of the proposed TNMPA.

Work needed: Lab analyses of many prey items, ranging from lower trophic levels and invertebrates to fishes. Collections of missing species are needed as well as subsequent desk analyses. Some material from the open water season in 2008 and 2009 has been collected, including benthos, sediment, zooplankton and phytoplankton. These are currently being analyzed.

2.1.3 Stomach and intestine contents

Description: The stomach and intestinal contents of higher-level trophic species (e.g., whales, seals and fishes) reveal sources of food; however it is sometimes difficult to discriminate between prey of the target species and prey of the prey of the target species. Also, varying degrees of prey digestibility may over- or under-represent a prey species in the diet analysis. In the case of belugas, collected stomachs are often empty. Sampling beluga intestines may represent consumed prey over a longer residence time relative to the stomach, but few have been collected to date.

Rationale: The collection of contents from stomachs and intestines of belugas and fishes within the TNMPA offers another approach to understanding the diet of organisms in the three sub-areas. There are biases associated with this approach such as range of digestion rates for various species and the time frame (i.e., short term) it represents. However together with the biomarker approach, it may be possible to gain insight into diet in relation to estuarine use. Some genetic approaches for determining prey species are available, which have not been used to date.

Historical information: Stomach content data from Beluga Whales have been collected over many years in addition to anecdotal information. Diet based on historical literature for a number of key fish species, can be updated using new samples or new diet analyses started for these species in the TNMPA. Some analyses of larval fish stomachs have been completed (e.g., alligator fish; M. Papst, pers. comm.). Samples of Arctic Cod (*Boreogadus saida*) stomachs from the Beaufort Sea have been collected, analysed and a publication is in revision (Walkusz *et al*., in prep.). Many stomachs from Ringed Seals and Bearded Seals (*Erignathus barbatus*) have been collected and some analyzed (e.g., Harwood *et al.* 2007). Analysis of a Bowhead Whale stomach has been completed (Pomerleau *et al.*, in prep.).

Work needed: Lab and desk analyses of available samples and data. Collect beluga intestines to provide examination of consumed prey over longer residence time. A number of key fish species (historical literature) can be updated with the new samples or start new diet analyses for key species in the TNMPA.

2.1.4 Contaminant tracers

Description: See indicator 1.2.3.

Rationale: See indicator 1.2.3.

Historical information: Analyses have been completed for Hg and POPs for many species and a relatively comprehensive contaminant database is available for Beluga Whales (G. Stern, pers.

comm.).
Work needed: Field sampling to introduce temporal trends data, lab analyses to add to the database and desk analysis of current data. Hickie *et al.* (2000) completed an individual- and population-based model for the St. Lawrence Beluga Whale population that could be used for analysis of TNMPA data.

2.1.5 Calorimetry
Description: Calorimetry is a measure of energy in organisms and provides information on the quantity of energy in the ecosystem that, together with biomass and biodiversity, builds a complete picture of how the food chain is functioning.
Rationale: In the Arctic, lipids are the major currency in food webs.
Historical information: Little work on zooplankton in the area surrounding the TNMPA has been completed. Some calorimetry work has been done on fishes.
Work needed: Beluga based Dynamic Energy Model has been completed but needs to be updated. Expand work. Could likely conduct desk analysis for belugas.

2.2 Biomass in relation to trophic level/group

2.2.1 Contaminant tracers
Description: See indicator 1.2.3.
Rationale: See indicator 1.2.3.
Historical information: Analyses have been completed for Hg and POPs for most of the food web so a relatively comprehensive contaminant database is available for the beluga food webs. A major research effort would be needed to obtain biomass information for fishes, with the exception of some anadromous fish species.
Work needed: Field sampling of biomass data for fish species, lab analysis to add to the database and desk analysis of current data are needed. Much work would be needed to develop a model for energy flow/biomass using contaminants data for belugas.

2.2.2 Remote sensing of primary production
Description: Remote sensing applications provide measurements of physical and biological characteristics, including ocean primary productivity (algae and phytoplankton).
Rationale: Primary productivity hot spots indicate where energy for the food web is concentrated in space and time. It also provides information on the physical-chemical drivers that support the productive hot spots (i.e., nutrients, light, etc). Remote sensing can be used outside TNMPA but not within the MPA due to high sediment load (i.e., turbidity).
Historical information: Background information is available for outside TNMPA.
Work needed: Desk analysis of background information.

2.2.3 Zooplankton biomass
Description: Zooplankton feed on phytoplankton and serve as food for fish larvae and baleen whales such as Bowhead Whales. Zooplankton are passive swimming animals (usually smaller than 1 cm) that are transported with the water currents. Since zooplankton are incapable of swimming against water movement they are good biological indicators of water masses (Walkusz *et al*. 2010).
Rationale: Zooplankton biomass is an indicator of secondary and, indirectly, primary production as well as how much food is available for consumers like fishes and whales. Monitoring zooplankton allows ecosystem changes to be measured as well as indicating the place in the food chain where the change occurred.
Historical information: Some work has been conducted outside the TNMPA. A little work has been done within the TNMPA near Tuktoyaktuk; more is needed. It is likely that a reference

library/database of organisms and their associated fatty acids would need to be built for the Beaufort Sea in order to detect changes in zooplankton and their biomass at specific locations.
Work needed: Summarize all data collected from the Nahidik and similar programs in the near-shallow regions to better understand what type of biota may be found and what method of collection may be most appropriate. Conduct field studies and lab analyses to create reference library/database of organisms and their associated fatty acids.

2.3 Age, size and sex structure

2.3.1 Size spectrum within and among species

Description: This indicator can be used as a tool to map food web and trophic structure. Changes in sizes of individuals within a species (e.g., fishes) and changes in sizes of the species within assemblages (e.g., phytoplankton and zooplankton) may reflect changes in the ecosystem which could affect higher trophic levels.
Rationale: This indicator can be monitored via standardized capture methods, however it is likely difficult to establish baselines.
Historical information: Within the TNMPA, historical baseline information is rather poor.
Work needed: Explore potential for longer-term research and monitoring applications. Assess methods used to collect samples and then conduct substantial desk analyses of existing data.

2.3.2 Chlorophyll size fractions

Description: Certain light, temperature, nutrient and other environmental regimes may dictate which phytoplankton species dominate a region and thus their energy quality and quantity.
Rationale: This indicator can be easily measured. Chlorophyll filtrations can identify the size structure of phytoplankton communities. Also, in situ detectors may be able to identify algal groups, such as diatoms or green algae, based on their pigment signals.
Historical information: Samples have been collected outside the TNMPA, within the region.
Work needed: Field studies using chlorophyll detectors and lab analysis of results.

3.0 Population structure of key species

This category refers to the distribution, abundance, size and sex and age structure of key species identified within the TNMPA (Beluga Whales, Broad Whitefish, Arctic Cisco and Least Cisco[2]). Scientific understanding of the TNMPA ecosystem would be greatly enhanced if the same indicators were also measured and monitored for key species outside the TNMPA (Beluga Whales, Arctic Cod and Pacific Herring) because of their potential influence on species and processes within the MPA. For example, larger belugas in the Beaufort Sea appear to feed predominantly on offshore Arctic Cod (Loseto *et al.* 2009) so changes in the distribution and abundance of this prey species could affect belugas within the TNMPA. For this reason, it is recommended the same indicators measured for key species within the TNMPA also be measured and monitored for key species outside the MPA on the Beaufort Sea Shelf to understand what is occurring and place the findings from the MPA in proper context.

3.1 Beluga distribution

3.1.1 Sighting effort

Description: Beluga distribution can be monitored using aerial surveys (also included under indicator 1.1.5), or sightings either from a stationary sighting station or from boats based on a

[2] Success of the indicators related to Least Cisco and Arctic Cisco (especially those identified in categories 3 and 4) would depend upon identification of the ciscos to species.

catch (i.e., number of sightings)-per-unit-effort (CPUE).
Rationale: Aerial surveys currently offer the most reliable method to evaluate beluga distribution within the TNMPA. Standardized aerial surveys were conducted in the Mackenzie River Estuary for ten years. It may be possible to use satellite imagery but it is an unproven technique. Satellite imagery may work better offshore, but is potentially biased because of sexual segregation in the offshore. Hunter sightings from a stationary sighting station or conducted on a CPUE basis from boats would be challenging given the low vantage point, high turbidity, movements of belugas, variability in observation biases and lack of standardized methods at this time.
Historical information: Aerial surveys conducted in the Mackenzie River Estuary from 1977 to 1985 (L. Harwood, unpubl. data) as well as in 1992 (Harwood *et al.* 1996). No hunter sightings recorded within the TNMPA to date.
Work needed: Desk analysis needed to assess the feasibility and reliability of boat-based hunter sightings and, if promising, to develop a standardized method. Initiating a community-monitoring project would require training of observers/recorders. Evaluate satellite imagery as a tool.

3.2 Beluga abundance

3.2.1 Sighting effort

Description: Same as for beluga distribution (see indicator 3.1.1).
Rationale: Same as for beluga distribution (see indicator 3.1.1).
Historical information: Same as for beluga distribution (see indicator 3.1.1).
Work needed: Same as for beluga distribution (see indicator 3.1.1).

3.3 Beluga size structure

3.3.1 Morphometric data

Description: Morphometric size data obtained from hunter-collected beluga samples provides valuable information related to population structure. Observations from harvesters and whaling camps about belugas, including birthing activity, may also provide useful information about size (e.g., length and girth) and potential changes in this beluga population.
Rationale: Harvest samples within the TNMPA are limited in number and biased due to the targeted harvest. However, since the goal of the targeted harvest remains constant over time (i.e., to harvest the largest whales), temporal comparisons of the data would have the potential to show any changes in size that are occurring. Observational information from hunters regarding presence and size of newborns and shifts in timing of birthing provides information related to beluga population health and structure.
Historical information: Many samples and size structure data have been collected through the BHMP; some data have been worked up. Belugas harvested from the Eastern Beaufort Sea population are the oldest and attain the longest adult body lengths compared to lower-latitude populations in Hudson Bay (Doidge 1990b, Luque and Ferguson 2009). Elders have shared observations regarding timing, birthing dates, direction and absence of belugas at the Hendrickson Island monitoring camp. Such data are collected as part of the BHMP and are presently being written up (L. Harwood, pers. comm.).
Work needed: Desk analysis of current data and ongoing community-based field sampling. Update and refine the harvest collection.

3.4 Beluga sex structure

3.4.1 Gender data

Description: Gender data obtained from hunter-collected beluga samples provides valuable information about population structure.
Rationale: Monitoring the sex structure of belugas within the TNMPA would indicate when there is a shift in natural population and community structure despite selective hunting pressures. However, sex ratio is an inherently imprecise tool, especially if sampling is biased. Harvest samples for the TNMPA are limited and biased due to small numbers of females taken.
Historical information: Many samples and data were collected through the BHMP. The gender of almost all belugas landed in the harvest since 1980 is available in the FJMC database and is presently being written up (L. Harwood, in prep).
Work needed: Lab analysis of BHMP samples. Need to update and refine harvest collection.

3.4.2 Biopsies

Description: Beluga gender can be determined from biopsies, without having to handle or kill the animal. Biopsy samples are generally more representative of the larger stock or population than hunter-collected samples. Biopsies collected for gender analysis would have additional use for genetics, fatty acid and stable isotope studies.
Rationale: Taking biopsies is not a useful indicator within the TNMPA because Beluga Whales are difficult to approach close enough to obtain a biopsy and invasive techniques may be considered culturally inappropriate by Inuvialuit.
Historical information: None within the TNMPA.
Work needed: (see Rationale)

3.5 Beluga age structure

3.5.1 Aged teeth

Description: Teeth obtained from hunter-collected beluga samples provide valuable age information related to population structure.
Rationale: Monitoring the age structure of the belugas harvested from within the TNMPA may indicate changes if a shift in natural population and community structure occur.
Historical information: Many samples available from the BHMP; some data have been worked up. Although hunter biases are consistent, the data remains limited to larger males and a relatively small catch compared to the size of the population as a whole.
Work needed: Lab analysis of BHMP samples. Need to update and refine harvest collection.

3.6 Broad Whitefish distribution

3.6.1 Capture effort

Description: Presence-absence data of Broad Whitefish in the TNMPA could be monitored over time by recording CPUE for the subsistence fishery, using a program similar to the BHMP.
Rationale: This program would build on monitoring efforts already underway within the TNMPA for belugas and would permit monitoring of several indicators through a single program.
Historical information: Considerable inferred information available within the TNMPA and direct/inferred information from outside the MPA.
Work needed: A community-based program would need to be established to obtain local information about the regularity of encountering whitefish, locations of net sets, gear specifications and catch numbers. Local DFO fish research programs should be carried out to further monitoring using methods standardized spatially, temporally and by gear type to the community-based program. Desk analysis needed once the program is set up. Ground truth

program results against scientific data for Broad Whitefish from elsewhere.

3.6.2 Otolith microchemistry

Description: Otolith microchemistry has the potential to differentiate habitat use in wholly-marine areas versus partially-marine areas.
Rationale: This indicator tool would provide an alternate source of information about the distribution of Broad Whitefish within the TNMPA.
Historical information: Some baseline information available.
Work needed: Significant background research needed (e.g., baseline signatures for physical habitat and increased precision for otolith microchemistry) to become a workable monitoring indicator. Need increased number of samples for analyses.

3.6.3 Stable isotope analysis

Description: See indicator 1.2.1.
Rationale: See indicator 1.2.1.
Historical information: See indicator 1.2.1.
Work needed: Samples from previous programs have been analyzed that would require a desk analysis. Additionally samples of archived fish are available from past sampling efforts, an inventory would be needed and new samples collected for current representation.

3.6.4 Acoustic tagging

Description: The distribution of Broad Whitefish could be determined from acoustic tagging. Rationale: Though live capture and tagging of Broad Whitefish would not require killing fish, it would involve difficult and invasive techniques that may be considered culturally inappropriate by Inuvialuit.
Historical information: None
Work needed: (see Rationale)

3.6.5 Phenology of life history

Description: Timing the arrival of Broad Whitefish in the TNMPA each summer could be annually monitored through a local fishery monitoring program by recording when this species is first caught.
Rationale: Part of local monitoring program identified in indicator 3.6.1.
Historical information: See indicator 3.6.1.
Work needed: Collection of field data by community members. Program would have to be initiated each year before the arrival of Broad Whitefish. Desk analysis of data needed once the program is set up. Ground truth program results against scientific data from elsewhere.

3.7 Broad Whitefish abundance

3.7.1 Capture effort

Description: Abundance of Broad Whitefish in the TNMPA could be monitored based on CPUE data collected through a local fishery monitoring program.
Rationale: See indicator 3.6.1.
Historical information: See indicator 3.6.1.
Work needed: Ask local people if Broad Whitefish are regularly encountered and where they set nets to evaluate usefulness of this indicator within the TNMPA. If warranted, develop community-based program to collect data on net locations, size of nets, soak times, number of fish caught, etc. Once established, conduct desk analysis and ground truth results against scientific data from elsewhere.

3.8 Broad Whitefish size structure

3.8.1 Morphometric data

Description: Morphometric size data collected by local fishers and other research programs from Broad Whitefish in the TNMPA could provide valuable information related to population structure.
Rationale: This indicator would allow for comparison of size data over time to monitor for change and would be relatively easy to accomplish.
Historical information: Most historical data represent unbiased scientific sampling (versus harvest sampling which has known bias). Little information is available from within the TNMPA. Substantial information has been collected outside the MPA since the 1970s, particularly in freshwater upstream locations (delta fisheries). Likely the number of samples has been lower since 2000.
Work needed: Develop sampling regime for local fishers' harvest within TNMPA. Once established, conduct desk analysis and ground truth results against scientific data from elsewhere.

3.9 Broad Whitefish sex structure

3.9.1 Gender data

Description: Analysis of samples collected by local fishers and other research programs from Broad Whitefish in the TNMPA might provide valuable information related to population structure.
Rationale: Sex ratio is an inherently imprecise tool (e.g., immature fish can be difficult to sex and there may be a different capture rate for each sex), especially if sampling is biased.
Historical information: Most historical data represent unbiased scientific sampling (versus harvest sampling which has known bias). Little information is available from within the TNMPA. Substantial information has been collected outside the MPA since the 1970s, particularly in freshwater upstream locations (delta fisheries). Likely the number of samples has been lower since 2000.
Work needed: Develop sampling regime for local fishers' harvest within TNMPA. Once established, conduct desk analysis and ground truth results against scientific data from elsewhere.

3.10 Broad Whitefish age structure

3.10.1 Otolith aging

Description: Aging otoliths of Broad Whitefish caught by local fishers and other research programs could be used to determine the relationship between size and age of fish.
Rationale: This indicator would monitor trends in age structure.
Historical information: Otoliths are collected for research programs but not routinely aged.
Work needed: Field data collection, analysis of archived and new samples, and ground truthing.

3.11 Cisco distribution

3.11.1 Capture effort

Description: Presence-absence data for Least Cisco and Arctic Cisco in the TNMPA could be monitored over time by recording CPUE for the local subsistence fishery, using a program similar to the BHMP.
Rationale: A shift in prevalence from Least Cisco to Arctic Cisco would indicate a shift to more marine rather than freshwater influences. This program would build on monitoring efforts

already underway within the TNMPA for belugas and would permit monitoring of several indicators through a single program.
Historical information: Considerable inferred information available within the TNMPA and direct/inferred information from outside the MPA.
Work needed: A community-based program would need to be established to obtain local information about the regularity of encountering ciscos, locations of net sets and catch numbers. Harvesters would need to be trained to distinguish between the two cisco species. Local DFO fish research programs should be carried out to further monitoring using methods standardized spatially, temporally and by gear type to the community-based program. Desk analysis needed once the program is set up. Ground truth program results against scientific data for these cisco species from elsewhere.

3.11.2 Otolith microchemistry
Description: Otolith microchemistry has the possibility to differentiate habitat use in wholly marine versus partially marine areas.
Rationale: This indicator would provide an alternate source of information about the distribution of Least Cisco and Arctic Cisco within the TNMPA.
Historical information: Some baseline information available.
Work needed: Significant background research needed to become a workable monitoring indicator: baseline signatures for physical habitat and increased precision for otolith microchemistry. Need increased number of samples for analysis.

3.11.3 Stable isotope analysis
Description: See indicator 1.2.1.
Rationale: See indicator 1.2.1.
Historical information: See indicator 1.2.1.
Work needed: Samples from previous programs have been analyzed that would require a desk analysis. Additionally, samples of archived fish are available from past sampling efforts, an inventory would be needed and new samples collected for current representation.

3.11.4 Acoustic tagging
Description: The distribution of Least Cisco and Arctic Cisco could be determined from acoustic tagging.
Rationale: Though live capture and tagging of ciscos would not require killing fish, it would involve difficult and invasive techniques that may be considered inappropriate by Inuvialuit.
Historical information: None
Work needed: (see Rationale)

3.11.5 Phenology of life history
Description: Timing the arrival of Least Cisco and Arctic Cisco in the TNMPA each summer could be monitored annually through a local fishery monitoring program by recording when this species is first caught.
Rationale: Part of local monitoring program identified in indicator 3.11.1.
Historical information: See indicator 3.11.1.
Work needed: Collection of field data by community members. Feasibility of indicator would depend on ability to identify ciscoes to species. Program would have to be initiated each year before the arrival of ciscoes. Desk analysis of data needed once the program is set up. Ground truth program results against scientific data from elsewhere.

3.12 Cisco abundance

3.12.1 Capture effort

Description: Abundance of Least Cisco and Arctic Cisco in the TNMPA could be monitored based on CPUE data collected through a local fishery monitoring program.
Rationale: See indicator 3.11.1.
Historical information: See indicator 3.11.1.
Work needed: Ask local people if ciscoes are regularly encountered and where they set nets to evaluate usefulness of this indicator within the TNMPA. If warranted, develop community-based program to collect data on net locations, size of nets, soak times, number of fish caught, etc. Depends on identifying ciscoes to species. Once established, conduct desk analysis and ground truth results against scientific data from elsewhere.

3.13 Cisco size structure

3.13.1 Morphometric data

Description: Morphometric size data collected by local fishers and other research programs from Least Cisco and Arctic Cisco in the TNMPA could provide valuable information related to population structure.
Rationale: This indicator would allow for comparison of size data over time to monitor for change and would be relatively easy to accomplish.
Historical information: Most historical data represent unbiased scientific sampling (versus harvest sampling which has known bias). Virtually no information is available from within the TNMPA. Substantial information has been collected outside the MPA since the 1970s, particularly in freshwater upstream locations (delta fisheries). Likely the number of samples has been lower since 2000.
Work needed: Develop sampling regime for local fishers' harvest within TNMPA. Once established, conduct desk analysis and ground truth results against scientific data from elsewhere.

3.14 Cisco sex structure

3.14.1 Gender data

Description: Analysis of samples collected by local fishers and other research programs from Least Cisco and Arctic Cisco in the TNMPA might provide valuable information related to population structure.
Rationale: Sex ratio is an inherently imprecise tool (e.g., immature fish can be difficult to sex and there may be a different capture rate for each sex), especially if sampling is biased.
Historical information: Most historical data represent unbiased scientific sampling (versus harvest sampling which has known bias). Virtually no information is available from within the TNMPA. Substantial information has been collected outside the MPA since the 1970s, particularly in freshwater upstream locations (delta fisheries). Likely the number of samples has been lower since 2000.
Work needed: Develop sampling regime for local fishers' harvest within TNMPA. Once established, conduct desk analysis and ground truth results against scientific data from elsewhere.

3.15 Cisco age structure

3.15.1 Otolith aging

Description: Aging otoliths of Least Cisco and Arctic Cisco caught by local fishers and other research programs could help determine the relationship between size and age of fish.
Rationale: This indicator would monitor trends in age structure.
Historical information: Otoliths are collected for research programs but not routinely aged.
Work needed: Field data collection, analysis of archived and new samples, and ground truthing.

4.0 Health of key species

This category refers to "health" which does not have a singular meaning. To most Inuit, "health" means an adequate abundance of animals to meet their subsistence needs. This category includes the demographic rates, nutrition/condition, inter-annual stability of diet, body burden of contaminants and incidence of disease/parasites and appearance of key species identified within the TNMPA (Beluga Whales, Broad Whitefish, Arctic Cisco and Least Cisco). Together this information can be put into a health assessment model to describe population health in context with stressors. Scientific understanding of the TNMPA ecosystem would be greatly enhanced if the same indicators were also measured for key species outside the TNMPA (Beluga Whales, Arctic Cod and Pacific Herring) because of their potential influence on species and processes within the MPA. For example, larger belugas in the Beaufort Sea appear to feed predominantly on offshore Arctic Cod (Loseto *et al.* 2009) so changes in nutrition and condition of this prey species could affect belugas within the TNMPA. For this reason, it is recommended the same indicators measured within the MPA also be measured and monitored for key species on the Beaufort Sea Shelf outside of the TNMPA to understand what is occurring and place the findings from the MPA in proper context.

4.1 Beluga demographic rates

4.1.1 Sighting effort

Description: It may be possible to monitor demographic rates in belugas (e.g., birth rates) within the TNMPA through sightings (e.g., number of calves) made by local hunters from a stationary sighting location based on a catch (i.e., number of sightings)-per-unit-effort (CPUE).
Rationale: Estimating birth and death rates for belugas, and estimating short-term changes in age structure, is difficult using conventional studies. Photographic surveys can provide length-frequency information but are very expensive. Age structure based on harvested animals can be biased. Sighting effort by local hunters offers an alternate method for monitoring demographic information although beluga detection, especially calves, may be challenging due to high turbidity in the TNMPA. Also, sighting bias would have to remain constant from year to year to produce reliable/comparable results.
Historical information: No historical information known.
Work needed: Desk analysis needed to assess and develop this indicator. Initiating a community monitoring project would require training observers/recorders. Same indicator could be used offshore outside the TNMPA to detect number or cow/calf pairs.

4.1.2 Survivorship curves

Description: Survivorship curves, based on life table analysis, can show the strategy used by a population to maintain its numbers and age structure. This information can also provide insight into potential environmental constraints on life-history traits.
Rationale: This metric could provide information on population status. Survivorship curves are

expected to reveal changes over 5-10 year intervals, not necessarily annually.
Historical information: Published data (Luque and Ferguson 2009).
Work needed: Desk analysis needed to assess and develop this indicator.

4.1.3 Biopsy sampling

Description: Population health can be assessed through hormone analysis of biopsy material, without having to handle or kill the animals.
Rationale: This indicator/tool would allow collection of samples using a less biased method to better represent population health. However, belugas are difficult to approach close enough to obtain a biopsy and invasive techniques may be considered culturally inappropriate by Inuvialuit.
Historical information: Not previously attempted in the area.
Work needed: (see Rationale)

4.2 Levels of nutrition and condition in belugas

4.2.1 Blubber thickness

Description: Blubber represents a vital organ for marine mammals, providing buoyancy, mobility, thermal protection and energy reserves. At approximately 30-35% of their body weight, blubber quantity and quality are critical to the health of belugas.
Rationale: Blubber thickness is a measure of quantity of energy reserves that can provide insight into the health of the population. If sufficient calves/yearlings are taken during the harvest, comparison of blubber thickness at different spatial variability could infer health of the mother during lactation and gestation.
Historical information: Blubber thickness has been collected for the past 10 years by DFO and through the BHMP. Thus a baseline is available for blubber thickness quantity. Additionally, measurements of fatty acids were initiated in 2004, lipid classes in 2007 and genomic indicators of stress in 2008 which provide preliminary data about blubber quality.
Work needed: Desk analysis of historical data along with an updated plan for monitoring thickness at more than one geographical site for belugas.

4.2.2 Lipid classes

Description: Lipid content, lipid classes and fatty acids provide detailed information about the quality of blubber in belugas as a measure of preferred prey, and prey quality that can reflect ocean productivity (e.g., Loseto *et al*. 2009).
Rationale: There are many types of lipid classes and some are better stores of energy than others (e.g., triglycerides versus wax esters) (Koopman 2007). An increase in phospholipids or structural lipids would suggest a decrease in stores.
Historical information: Historical samples are available and analysis is underway.
Work needed: Analysis of previously collected samples to establish baseline.

4.2.3 Blood screening

Description: Beluga blood can be screened for various biochemical factors such as vitamin levels, cations/anions, hormones (e.g., estrogen, progesterone and thyroid hormones), proteins, fats (cholesterol), etc. As with human blood, levels of biochemical indicators typically reflect current (circulating) levels and are thus representative of short time frames.
Rationale: This indicator can provide substantial information about the current health status of belugas that use the TNMPA.
Historical information: Blood samples archived since the hunter sampling program began. Analyses of vitamins and hormones have been completed for the past three years.
Work needed: Laboratory and data analyses. Necessary understandings of acute and chronic

drivers are needed to interpret these data.

4.2.4 Fatty acids

Description: Fatty acid profiles in belugas can be used to infer diet (indicator 2.1.2) and to evaluate health. Relative proportions and concentrations of fatty acids, particularly essential fatty acids that cannot be synthesized in sufficient amounts to meet growth and development needs and are largely obtained from diet, may be used to assess the physiological condition of animals (Litzow *et al*. 2006).
Rationale: Lower levels of important essential fatty acids, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), may indicate a stress level that either reflects a change in prey availability or other physiological stress (e.g., temperature changes, contaminants).
Historical information: Fatty acid data available from 2004 to present.
Work needed: Analysis currently underway.

4.2.5 Chronic stress impacts

Description: Measuring stress is difficult yet several indicators have been suggested and include hormonal levels and oxidative by-products. New genomic techniques have been used to evaluate nutritional stress (i.e., peroxisome proliferator-activated receptor gamma (PPAR-g), adiponectin, leptin, insulin-like growth factor 1 (ILGF1)) and are currently being investigated in beluga blubber, liver and kidney tissues. This recently-developed method is meant to isolate the early onset of stress indicators. Additionally, lipid oxidative products such as isoprostanes are being investigated in blubber as an indicator of chronic stress. Hormones that include reproductive hormones, thyroid hormones and vitamin levels have also been used as indicators of stress. Measurements can be taken in blood and tissues (e.g., sloughed skin), and have been recently attempted in feces and whale blow hole gas exchange in other marine mammal species.
Rationale: This indicator would make it possible to determine whether stress levels in belugas within the TNMPA are changing over time and pose a significant threat.
Historical information: Some samples are currently being measured using new genomic techniques as part of the monitoring program since 2008.
Work needed: Method development and analyses using new genomic techniques (quantitative polymerase chain reaction (qPCR)) to determine the application and use of specific gene arrays. Method development needed to determine whether other types of samples (e.g., sloughed skin samples, feces and beluga blows) can be collected within the TNMPA to look for indicators of stress.

4.3 Inter-annual stability of diet in belugas

4.3.1 Fatty acids

Description: See indicator 1.2.2. Tracing fatty acids through the trophic system provides basic information on the nature of the food available and its composition (i.e., quantity and quality) for both belugas and their prey.
Rationale: Periodic monitoring of fatty acids in belugas and through the trophic system would provide information on the quality (and to some degree the composition) of the food base available to belugas. Assessment of benchmark fatty acid signatures when coupled with similar work on stable isotopes would provide a powerful tool for monitoring health and production in the TNMPA (e.g., Loseto *et al*. 2009).
Historical information: Some samples collected as part of harvest collections. Analysis of data completed since 2004 and published to a large extent.
Work needed: Lab and data analyses of older samples (e.g., try matching potential prey items with diet).

4.3.2 Stomach and intestine contents

Description: See indicator 2.1.3. Stomach contents can provide diet information and identify preferred prey.

Rationale: The collection of contents from stomachs and intestines is available through the BHMP and offers another approach to understanding the diet of belugas.

Historical information: Samples from belugas have been collected over many years in addition to anecdotal information.

Work needed: Desk analysis of historical data to establish baseline.

4.3.3 Stable isotopes

Description: See indicator 1.2.1.

Rationale: Measuring stable isotopes in belugas and their potential prey is valuable to understanding diet and food web processes. Feeding on higher- or lower-trophic level species can reflect processes in the food web. Shifts from nearshore to offshore feeding, or from pelagic to benthic feeding, can infer shifts in energy transfer in the food web.

Historical information: Samples have been collected since the 1980s and analysis completed every year and continues as a routine measurement. Some publications produced about beluga isotopes in reference to other biomarkers (Loseto *et al*. 2008b) and prey (Loseto *et al.* 2008a).

Work needed: Ongoing monitoring as funds are available. Important to match with food web analysis.

4.4 Body burden of contaminants in belugas

4.4.1 Persistent organic pollutants and Hg

Description: In recent years, DFO's focus on monitoring levels of contaminants in belugas such as Hg and POPs (e.g., PCBs, PBDEs) has shifted towards studying the health impacts of these contaminants on belugas and food web/ecosystem processes.

Rationale: Levels of contaminants in belugas provide information pertaining to human health, beluga health, beluga diet and foraging ecology and the potential to measure shifts in ecosystem structure and function.

Historical information: Contaminant measurements exist for belugas within the TNMPA from 1981, but are limited to certain tissues; consecutive annual sampling began in 2001. These data also exist for belugas from other sites in Canada. Some current research focuses on measuring new chemicals of concern (e.g., fluorinated compounds) and analyzing older samples to understand when they entered the food web.

Work needed: Ongoing monitoring as funds are available. Need toxicity endpoints linking back to environmental factors and an understanding of how to use contaminants as a tracer.

4.4.2 Toxic effects of contaminants

Description: Because of their higher trophic position, belugas may be more vulnerable to toxic injury than Bowhead Whales, Walrus (*Odobenus rosmarus*) and Ringed Seals (Loseto and Ross, in press). Previous research demonstrated that complex environmental mixtures of POPs are affecting the health of pinnipeds and presenting tangible risks to marine mammal populations in southern Canada (Mos *et al*. 2006, Tabuchi *et al*. 2006). Concerns about contaminants in the Canadian Arctic emanate, in part, from studies which demonstrate possible health effects in humans, Polar Bears and belugas (White *et al*. 1994, Braathen *et al*. 2004). Currently a new beluga health study is evaluating toxic injury associated with POP exposure in the Eastern Beaufort Sea beluga population. Toxic injury to belugas, in the form of endocrine, immune, reproductive and neurological effects, may also vary in a changing ice climate as a consequence of altered transport and fate of POPs in the Arctic environment. This highlights the

importance of monitoring endpoints that provide insight into broad measures of health. Toxic endpoints include, but are not limited to, thyroid hormones, reproductive hormones, vitamin levels, lipid oxidation, Aryl hydrocarbon receptor (AhR), and immune function. Currently, a suite of about ten hormone receptors are being used as indicators of toxic injury using genomics techniques (qPCR; e.g., AhR, metallothionein MT-1 expression) (also included under indicator 4.2.5).
Rationale: Evaluating toxic stress related to contaminant-exposure in belugas will provide a better link between burden of contaminants and changes in the surrounding environment.
Historical information: Work has been underway since 2007 and is in the early stages of measuring hormones and toxicological endpoints using genomic and traditional methods. Health-related data collections were initiated at Hendrickson Island (within the TNMPA) in 2008.
Work needed: Desk analyses, some lab analyses and some method development involving a cross-section of techniques to provide better linkage between burden of contaminants and changes in surrounding environment.

4.5 Incidence of diseases and parasites in belugas

4.5.1 Harvest collection

Description: Infectious diseases such as brucellosis and distemper are known to have severe impacts on animal health and abundance. There is no evidence that Arctic beluga populations have distemper at this time, therefore they have no herd immunity. It may arrive with infected cetaceans from the south via “global warming”. Mortalities of approximately 40-60% could be expected as the disease moves into Arctic beluga populations (Nielsen *et al.* 2000). Brucella is a bacterial disease that causes reproductive failure and death in infected animals. It also causes severe disease in humans. Brucellosis occurs in belugas throughout Arctic Canada including the ISR (Nielsen *et al.* 2001).
Rationale: Monitoring the incidence of emerging infectious diseases, in particular brucellosis, over time and relating its impact to overall beluga health (i.e., reproductive success), in conjunction with indices measuring extrinsic stressors (e.g., climate change, habitat alteration, oil development, and contaminant loading), would provide a measure of ecosystem health in the TNMPA.
Historical information: Data from samples, collected through the BHMP, dating back to the early 1990s are available for trend analyses. Brucellosis has been monitored for many years. Serology has still being done for both brucellosis and distemper on submitted blood samples. Archival tissue and blood is available for *Brucella* and distemper research.
Work needed: Develop operational plan for belugas harvested at Kendall and Hendrickson islands (in the TNMPA), by collecting samples through the HIBS, similar to the comprehensive Health Assessment model being developed in the U.S. and Europe for terrestrial and aquatic animals as part of individual Species Management Plans. Develop a health effects assessment, following new initiative by Americans whereby a veterinarian conducts an overall health assessment of individual animals, to help set a benchmark and streamline sampling, analysis and interpretation of results. Any monitoring program should include monitoring for distemper in harvested whales.

4.5.2 Biopsy sampling

Description: It may be possible to determine incidence of diseases and parasites in belugas through collection and analyses of biopsy material.
Rationale: This indicator/tool would allow collection of samples using a less biased method to better represent population health. However, belugas are difficult to approach close enough to obtain a biopsy and invasive techniques may be considered inappropriate by Inuvialuit.
Historical information: Not previously attempted in the area.

Work needed: (see Rationale)

4.5.3 Physical restraint

Description: It may be possible to take samples to investigate incidence of diseases and/or parasites while live-capturing and tagging belugas, depending on condition of the animal. Rationale: This is likely not a useful indicator/tool within the TNMPA because invasive techniques may be considered culturally inappropriate by Inuvialuit.

Historical information: No data available at present time.

Work needed: Could take samples while live-capturing and tagging belugas (an established technique) depending on condition of the animal, however see limitations identified under Rationale.

4.6 Reproductive success and natural mortality in Broad Whitefish

4.6.1 Life table analysis

Description: Life table analysis can provide useful information about vital rates.

Rationale: Reproductive success, natural mortality and age structure are important indicators of the health of a species.

Historical information: No information is available within the TNMPA.

Work needed: Extrapolation of comparable information available for Broad Whitefish outside the TNMPA. Assess the value of a dedicated Broad Whitefish sampling program (netting) within the TNMPA to gather a suite of indicators on health. Age structure analysis is likely not worth trying at the scale of the TNMPA.

4.7 Levels of nutrition and condition in Broad Whitefish

4.7.1 Length-weight relationships

Description: The relationship between length and weight in a fish provides information about its condition. At the population level, condition indices provide useful information about the health of a species.

Rationale: Using length-weight relationships to assess condition in Broad Whitefish within the TNMPA would integrate freshwater and mixed, and perhaps marine, inputs though it may be difficult to interpret the results.

Historical information: Much of the baseline information is for more interior freshwater locations, though some of the individuals sampled may have used the TNMPA.

Work needed: Assess the value of a dedicated Broad Whitefish sampling program (netting) to gather a suite of indicators on health.

4.8 Inter-annual stability of diet in Broad Whitefish

4.8.1 Stable isotopes

Description: See indicator 1.2.1.

Rationale: Diet is the best indicator of environmental change within the TNMPA and vicinity. Measuring stable isotopes would show diets within the past 3-6 months. Unusual variability over time would signal that something has changed.

Historical information: See indicators 1.2.1 and 2.1.1.

Work needed: Analysis of previously collected samples to track averages and variability, and analysis of temporal series of samples to provide baseline understanding of this indicator. Collect new samples for current representation if needed.

4.8.2 Fatty acids

Description: See indicator 1.2.2.
Rationale: Diet is the best indicator of environmental change within the TNMPA and vicinity. Measuring fatty acids, when coupled with similar work on stable isotopes, would provide a powerful tool for monitoring health and production in the TNMPA.
Historical information: See indicators 1.2.2 and 2.1.2.
Work needed: Analyses of previously collected samples to track averages and variability.

4.9 Incidence of diseases and contaminant loads in Broad Whitefish

4.9.1 Burden of diseases

Description: Infectious diseases are known to have severe impacts on animal health and abundance. Monitoring their levels provides useful information about the health of the target species and the food web and ecosystem processes in which it plays a role.
Rationale: Monitoring diseases in Broad Whitefish would indicate shifts in ecosystem structure and function which would be useful in a wider regional context.
Historical information: None.
Work needed: Collection of samples by community members or science programs.

4.9.2 Burden of contaminants

Description: See indicators 1.2.3 and 4.4.1. Monitoring levels of contaminants provides useful information about the health of the target species and the food web and ecosystem processes in which it plays a role.
Rationale: Monitoring this indicator in Broad Whitefish would indicate shifts in ecosystem structure and function which would be useful in a wider regional context.
Historical information: See indicator 1.2.3.
Work needed: Further analyses of archived samples and more collections if needed.

4.10 Reproductive success and natural mortality in ciscoes

4.10.1 Life table analysis

Description: See indicator 4.6.1.
Rationale: See indicator 4.6.1.
Historical information: See indicator 4.6.1.
Work needed: Extrapolation of comparable information available for ciscoes outside the TNMPA. Assess the value of a dedicated cisco sampling program (netting) within the TNMPA to gather a suite of indicators on health. Age structure analysis is likely not worth trying at the scale of the TNMPA.

4.11 Levels of nutrition and condition in ciscoes

4.11.1 Length-weight relationships

Description: See indicator 4.7.1.
Rationale: Using length-weight relationships to assess condition in Least Cisco and Arctic Cisco within the TNMPA would integrate freshwater and mixed, and perhaps marine, inputs though it may be difficult to interpret the results.
Historical information: See indicator 4.7.1.
Work needed: Assess the value of a dedicated cisco sampling program (netting) to gather a suite of indicators on health.

4.12 Inter-annual stability of diet in ciscoes

4.12.1 Stable isotopes

Description: See indicator 1.2.1.
Rationale: See indicator 4.8.1.
Historical information: See indicators 1.2.1 and 2.1.1.
Work needed: Analysis of previously collected samples to track averages and variability, and analysis of temporal series of samples to provide baseline understanding of this indicator. Collect new samples for current representation if needed.

4.12.2 Fatty acids

Description: See indicator 1.2.2.
Rationale: See indicator 4.8.2.
Historical information: See indicators 1.2.2 and 2.1.2.
Work needed: Analysis of previously collected samples to track averages and variability. Collect new samples for current representation if needed.

4.13 Incidence of diseases and contaminant loads in ciscoes

4.13.1 Burden of diseases

Description: Infectious diseases are known to have severe impacts on animal health and abundance. Monitoring their levels provides useful information about the health of the target species and the food web and ecosystem processes in which it plays a role.
Rationale: Monitoring diseases in ciscoes would indicate shifts in ecosystem structure and function which would be useful in a wider regional context.
Historical information: None.
Work needed: Collection of samples by community members or science programs.

4.13.2 Burden of contaminants

Description: See indicators 1.2.3 and 4.4.1.
Rationale: Monitoring this indicator in ciscoes would indicate shifts in ecosystem structure and function which would be useful in a wider regional context.
Historical information: See indicator 1.2.3.
Work needed: Further analyses of archived samples and more collections if needed.

5.0 Physical and chemical environment

This category refers to the physical and chemical properties and the characteristics and processes of the external surroundings that may influence the behaviour and development of an organism.

5.1 Timing of sea ice break-up

5.1.1 Distribution and properties of ice and snow, and effects of wind

Description: The timing of sea ice break-up in spring within the TNMPA is affected by a number of variables including ice thickness, snow thickness, distribution of bottom-fast ice and Stamukhi formations[3] prior to breakup, and wind speed, direction and duration passing over the ice. Sea ice break-up often varies among the three sub-areas. For example, in Kittigaryuit and Okeevik grounded ice causes overflow water from the Mackenzie River to deposit small amounts of

[3] Stamukhi is the accumulating rubble ice at the outer edge of landfast ice.

sediment on the ice surface that, combined with warm underflows, cause considerable ice melt in-situ. While in Niaqunnaq, there is typically little bottom ice but substantial moving ice that often results in a different pattern of break-up. The development of melt pools over bottomfast ice controls the break-up of landfast ice to a large extent although the exact mechanisms remain unclear. As no single process predicts sea ice break-up in the TNMPA, a suite of variables should be monitored.
Rationale: Belugas likely arrive in the TNMPA once the sea ice has disappeared or at least broken up. This indicator monitors a suite of variables related to the timing of sea ice break-up.
Historical information: Sea ice data obtained through remote sensing dates back to the 1970s, though temporal distribution was spotty; wider coverage started in 1993 and continuous ice data have been available since 1996.
Work needed: Continued annual monitoring of sea ice development and break-up within and adjacent to the TNMPA and desk analyses to establish baseline. Data collection of offshore wind fields through remote sensing. Better integration of these data with beluga behaviour and hunt information to better understand the critical controls between ice break-up and movement of beluga into the TNMPA in summer, and key variables that should be monitored. Advanced Very High Resolution Radiometers (AVHRR) sea surface temperature images at 1 km resolution are now available. The Canadian Ice Service collects ice data through the winter and spring, but limits monitoring to the landfast ice edge.

5.1.2 Timing and mode of Mackenzie River discharge and ice break-up

Description: While the link between ice break-up/discharge in the Mackenzie River and movement of landfast ice in the TNMPA is not fully understood, discharge, water levels and timing of flow volumes in the Mackenzie River are known to have a significant impact on ice break-up in the TNMPA.
Rationale: Belugas gather in the TNMPA once the sea ice has disappeared, or at least broken up. This indicator monitors a suite of processes related to the timing of sea ice break-up.
Historical information: Mackenzie River discharge curves have been measured throughout the year for a number of years. Real-time (Environment Canada) water surveys have been conducted throughout the Mackenzie River Delta.
Work needed: Ongoing measurement and analysis of discharge curves. Better integration of these data with TNMPA ice break-up data.

5.2 Physical and biochemical oceanographic parameters

5.2.1 Currents, temperatures, salinities, sediment loads, dissolved oxygen and chlorophyll a

Description: Currents, temperatures, salinity, suspended sediments, dissolved oxygen and chlorophyll *a* are fundamental indicators of the processes taking place within the TNMPA. The three sub-areas within the TNMPA are not typical estuaries. Considerable wind-driven mixing of fresh and marine waters occurs in as little as 2 m of water. Kittigaryuit has a small amount of salt water at the bottom. The Mackenzie River greatly affects turbidity in TNMPA. These oceanographic variables are highly changeable over time, on a daily or even an hourly basis. Regardless, monitoring them provides information to calibrate and validate numerical models that can be driven by more easily measurable phenomena (i.e., winds and tides) and allow examination of environmental conditions at critical times of the year and trends over time.
Rationale: Belugas may use the TNMPA for a variety of reasons including feeding, moulting and/or thermal advantage. This suite of indicators should be monitored in- and outside the TNMPA for changes that may impact belugas and/or other components of the food web.
Historical information: Almost no historical data are available to use as a baseline. There are moorings in place near Kendall Island. Some of these parameters have been measured outside

the TNMPA until present, but funding is expected to end. One mooring located at the mouth of Kugmallit Bay in 15 m and another in the Mackenzie Delta.
Work needed: Develop baseline by measuring currents, temperature, salinity, suspended sediments, dissolved oxygen and chlorophyll *a* during the open water season using one sensor mooring per TNMPA sub-area and a "deep water" mooring (e.g., 20 m depth) outside the TNMPA. Remote sensing could measure turbidity and mixing. The science community is currently experimenting with applying oceanographic models in the TNMPA with some success. Once operational, run the oceanographic model historically using hindcast wind data. Integrate results with biological/ecological information for TNMPA to better understand linkages between them. Calibrated coastal oceanographic models should be tied to oil spill trajectory models.

5.3 Sea bed morphology, sediment mobility and contaminant loadings

5.3.1 Bathymetry, substrate morphology and texture, coastline dynamics

Description: Each of the three sub-areas in the TNMPA cover a range of seabed environments ranging from shallow sand and mud banks to relatively deep holes and channels. Terrestrial portions adjacent to the TNMPA are changing as a result of erosion. Eroding material has a very different texture and make-up than material being discharged from the Mackenzie River. Changes in ice distribution may have affected patterns of erosion. Extension of shallow water in the TNMPA limits the size of the waves but changes the wave length/period.
Rationale: Two hypotheses that may explain why belugas use the TNMPA for part of the summer are for feeding and/or moulting. Seabed mapping within the TNMPA would aid in developing a better understanding of the relationship between beluga presence/absence and seabed environments. Bathymetry, substrate morphology and texture, erosion and sediment transport should be monitored for changes that may affect use of the area by belugas or their prey. These data are also critical for the development of numerical models of oceanographic behaviour.
Historical information: Bathymetric information now 40 years out of date.
Work needed: Develop baseline maps of seabed morphology (e.g., ice scourings, bedforms, ripple marks, hummocky beds), bathymetry, texture (grain size) and mobility to provide input into modelling. Compare seabed maps with beluga use of the area to investigate possible relationships. Develop protocols for community-based coastal erosion monitoring program within TNMPA through collaboration with the Northwest Territories Cumulative Impact Monitoring Program.

5.3.2 Burden of contaminants

Description: Future industrial development on the Beaufort Sea Shelf has the potential to contaminate sediments.
Rationale: As part of a program to monitor ecosystem health within the TNMPA, representative samples and cores should be obtained to estimate current contaminant loads, prior to significant development in the TNMPA and major changes in the Mackenzie River catchment resulting from development and/or climate change, and to monitor any future changes.
Historical information: Baseline attempted during Northern Oil and Gas Action Program (NOGAP). Sediment samples are available from the Nahidik program that could be used for analysis.
Work needed: Develop baseline prior to start of significant industrial development.

5.4 Sea level and tides

5.4.1 Sea level trends and tidal gauge measurements

Description: Sea level rise may occur in response to climate change. Sea level change and

storms affect coastal erosion which can influence carbon, nutrient and sediment loading in the coastal zone.
Rationale: Changes in carbon, nutrient and sediment loading, resulting from changes in sea level, may impact the ecosystem within the TNMPA.
Historical information: Tides have been measured at Tuktoyaktuk since the 1960s, except during the period between 1998 and 2003. Velocity could be determined from tidal measurements.
Work needed: Maintenance of tide gauge at Tuktoyaktuk. The magnitude of surges is likely quite different on the western side of the Mackenzie River Delta so data on short-term water level fluctuations should be collected in the two western sub-areas.

5.5 Meteorology

5.5.1 Wind, temperature, humidity and radiation

Description: Wind speed and direction, air temperature, humidity and short- and long-wave radiation drive oceanographic conditions and the associated seabed. In the TNMPA, wind is the most significant variable.
Rationale: Changes in oceanographic conditions and seabed morphology may affect the overall health of belugas and other biota in the ecosystem.
Historical information: Automated weather stations collected data at Shingle Point and Tuktoyaktuk since the 1950s (and stopped at Shingle Point in 1992) and at Pelly Island since 1994.
Work needed: Maintenance of the automated weather stations at Tuktoyaktuk and Shingle Point and data collection of offshore wind fields through remote sensing. Deployment of an Environment Canada system to map wind fields within the TNMPA using Radarsat data would also provide useful information for modelling and forecasting oceanographic conditions.

6.0 Noise and other physical stressors

This category focuses on noise and the response of belugas to it and other physical anthropogenic stressors (excluding direct harvest) that may cause disturbance, damage or death.

6.1 Noise

Spectral noise levels should be monitored throughout the TNMPA, as well as the surrounding area, for ambient noise, ship and aircraft traffic, oil and gas exploration (e.g., seismic) and development, and beluga vocalizations (including echolocation). This monitoring would likely be conducted through passive acoustic monitoring (PAM).

6.1.1 Anthropogenic noise

Description: Anthropogenic noise emitted in the vicinity of the TNMPA could disrupt the behaviour (e.g., movement and vocalizations) of belugas. Displacement and migratory diversion have been documented in some marine mammal species in response to seismic activity. However, whether the effects extend beyond the initial exposure depends on many factors (DFO 2004). Variables such as species, gender and age class, as well as the characteristics of the received noise, can all affect the whales' responses. To compare historical shipping records to present noise levels, it would be useful to be able to convert the amount of shipping activity to an estimate of attendant noise. Exposure to anthropogenic noise can result in masking and changes in marine mammal vocalizations. These changes could have negative consequences for belugas.

Rationale: By tracking anthropogenic noise (e.g., seismic surveys, ship and aircraft transits) and tagged belugas it may be possible to determine if displacement and/or diversion of migrating whales is occurring. This should be extended outside the TNMPA for a better understanding of the effects of anthropogenic noise on the welfare of belugas in the greater vicinity and over larger spatial scales. Using a hydrophone would provide the data to investigate whether there is a correlation between vocalizations and anthropogenic noise. If belugas significantly and consistently change their vocalizations in the presence of noise, this could be an indication of disturbance. If their echolocation sounds are heard less frequently, their feeding may be disrupted. If noise masks the beluga vocalizations heard at the hydrophones, their calls are likely masked from each other as well.
Historical information: Underwater industrial noise associated with dredging, artificial island construction and ship noise was recorded near the Kittigaryuit sub-area in summer 1976 (Ford 1977). Background noise levels of ship traffic recorded between 1980 and 1986 (data may be available in Mackenzie Gas Pipeline reports).
Work needed: Desk analysis of historical background noise data. Try to roughly calibrate the number and size of ships operating with associated noise levels. Develop ambient noise baseline. Investigate use of recording data obtained from the Canadian Arctic Shelf Exchange Study program. Investigate the potential of linking the Automatic Identification System (a short range tracking system used on ships) with noise produced by passing vessels and recorded by PAM bottom sensors. Investigate whether sound transmission in the TNMPA is attenuated by shallow water and muddy bottom. Research should be extended outside the TNMPA to look for cumulative effects.

6.1.2 Beluga vocalizations
Description: Beluga Whales are a highly vocal species. Anthropogenic noise has been known to disrupt their vocal behaviour (e.g., review by C. Perry, 1998).
Rationale: Investigating whether anthropogenic noise emitted in the vicinity of the TNMPA could disrupt their vocalizations (e.g., by masking) would require good baseline data on undisturbed vocal behaviour.
Historical information: Underwater beluga vocalizations were recorded near the Kittigaryuit sub-area in summer 1976 (Ford 1977).
Work needed: Desk analysis of available literature to determine if beluga vocalizations are correlated with anthropogenic noise and whether collection of field data is required. If so, deploy PAM bottom sensors. Investigate possibility of correlating beluga echolocation with changes in their behaviour or changes in the physical environment.

6.2 Response to Stressors

Measuring the impact of anthropogenic activities on belugas can be difficult. A few indicators are presented below.

6.2.1 Behaviour
Description: Marine mammals often exhibit behavioural responses to anthropogenic stressors. For example, belugas avoid moving barges and tugs once they came within the range of 2.4 km (Ford 1977). Belugas also avoid seismic activity by several kilometres based on comparison of ship-board and aerial surveys conducted offshore of the Mackenzie River Delta in the Beaufort Sea (Miller *et al.* 2005, L. Harwood, unpubl. data). A variety of tools are available to assess behavioural responses of marine mammals to stressors including observation, which can be conducted from a range of platforms including aircraft, boats and land. An alternate approach is the use of digital acoustic recording tags (known as D-tags) to record underwater sounds and movements of tagged animals. D-tags are non-invasive; they are commonly attached to whales

using suction cups.
Rationale: Assessing the behavioural response of belugas in the TNMPA to anthropogenic noise (e.g., seismic activities) and other activities would help to identify significant threats. Aerial observations and D-tags may offer the most effective tools.
Historical information: None in the TNMPA; previous studies (Ford 1977 and Miller *et al.* 2005) were conducted just outside the TNMPA.
Work needed: Assess the value of this indicator in the TNMPA and the logistical feasibility of available tools (e.g., aerial observations, D-tags, auditory brainstem response, hormone information from blow).

6.2.2 Stress levels
Description: See indicator 4.2.5.
Rationale: See indicator 4.2.5.
Historical information: See indicator 4.2.5.
Work needed: See indicator 4.2.5. Ongoing data collection may identify whether stress levels in belugas are increasing/changing over time within the TNMPA. It may be difficult to link stress levels with specific cause(s) of stress. It may be possible to correlate stress levels to presence or intensity of a stressor.

6.2.3 Injury or death
Description: Noise and other anthropogenic stressors can cause injury or death in marine mammals. A variety of tools are available for determining the extent of injury, and cause and manner of injury or death in wildlife. For example, necropsies are often performed on stranded animals in order to determine the underlying causes of death. Gas or fat emboli found during necropsies may be indicative of acoustically caused trauma, and ear membrane damage may indicate exposure to significant noise levels. Some methods are also available to assess the extent of injury in live-stranded marine mammals. For example, auditory brainstem response (ABR) is a screening test that has been performed on live-stranded animals to assess hearing response.
Rationale: Assessing the prevalence, cause and manner of injury or mortality in belugas within the TNMPA would help to identify significant threats. An effective tool would be an ongoing program to conduct post mortems of all harvested and found stranded belugas within the TNMPA. Performing tests on live stranded animals may be problematic at best.
Historical information: Post mortem examinations have been conducted, on an intermittent case-by-case basis, on abnormal, stranded and “sick” belugas identified by hunters.
Work needed: Baseline knowledge and long-term data sets of pathologies and new diseases that may be present in harvested belugas are required before a valid comparison can be made with conditions and pathologies found in stranded animals. Health assessment method development is needed to determine whether live stranded belugas can be assessed for injuries/pathologies without involving difficult and invasive techniques that may be considered culturally inappropriate by Inuvialuit.

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 MPA. 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 are those related to

(1) the HIBS (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, 3.6.3, 3.6.5, 3.7.1, 3.8.1, 3.9.1, 3.10.1, 3.11.1, 3.11.3, 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).

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 scientific value of species lists (1.1.1) and biodiversity indices (1.1.2) for providing baseline information on species richness was also recognized 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 may not be 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.

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Table 1. Generalized list of monitoring programs and the tissues taken from Beluga Whales harvested at Hendrickson Island since 2000. Long-term trend data are most readily available from the contaminant and disease programs.

Monitoring Programs	**Tissues Sampled**
Contaminants:	
mercury	skin, liver, muscle, kidney
organic contaminants	blubber
Toxicity indicators:	
hormones, vitamins	blubber, blood
hormone receptors	blubber, liver, kidney
neurological impacts	brain, blood
Diet and condition:	
stable isotopes	liver, muscle
fatty acids	blubber, liver
lipid classes	blubber, liver
Genetics	skin/blubber
Reproduction	ovaries, uterus
	lactation, foetuses, calves
Diseases:	
Brucella	blood, lymph nodes
Trichinella	tongue, muscle, diaphragm
Toxoplasma gondii	muscle, heart
general pathological screen	blood, up to 20 tissues

Table 2. 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. Descriptions of individual indicators are provided elsewhere in the document.

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
		3.15 Age structure	3.15.1	Otolith aging
4.0 HEALTH OF KEY SPECIES	Beluga	4.1 Demographic rates	4.1.1	Sighting effort
			4.1.2	Survivorship curves
			4.1.3	Biopsy sampling
		4.2 Levels of nutrition and condition	4.2.1	Blubber thickness
			4.2.2	Lipid classes
			4.2.3	Blood screening
			4.2.4	Fatty acids
			4.2.5	Chronic stress impacts
		4.3 Inter-annual stability of diet	4.3.1	Fatty acids
			4.3.2	Stomach and intestine contents
			4.3.3	Stable isotopes
		4.4 Body burden of contaminants	4.4.1	Persistent organic pollutants and mercury
			4.4.2	Toxic effects of contaminants
		4.5 Incidence of diseases and parasites	4.5.1	Harvest collection
			4.5.2	Biopsy sampling
			4.5.3	Physical restraint
	Broad whitefish	4.6 Reproductive success and natural mortality	4.6.1	Life table analysis
		4.7 Levels of nutrition and condition	4.7.1	Length-weight relationships
		4.8 Inter-annual stability of diet	4.8.1	Stable isotopes
			4.8.2	Fatty acids
		4.9 Incidence of diseases and contaminant loads	4.9.1	Burden of diseases
			4.9.2	Burden of contaminants

Category		Element	Indicator	
4.0 HEALTH OF KEY SPECIES (cont.)	Least & Arctic Cisco	4.10 Reproductive success and natural morality	4.10.1	Life table analysis
		4.11 Levels of nutrition and condition	4.11.1	Length-weight relationships
		4.12 Inter-annual stability of diet	4.12.1	Stable isotopes
			4.12.2	Fatty acids
		4.13 Incidence of diseases and contaminant loads	4.13.1	Burden of diseases
			4.13.2	Burden of contaminants
5.0 PHYSICAL AND CHEMICAL ENVIRONMENT	5.1 Timing of sea ice break-up		5.1.1	Distribution and properties of ice and snow, and effects of wind
			5.1.2	Timing and mode of Mackenzie River discharge and ice break-up
	5.2 Physical and biochemical oceanographic parameters		5.2.1	Currents, temperatures, salinities, sediment loads, dissolved oxygen and chlorophyll *a*
	5.3 Sea bed morphology, sediment mobility and contaminant loadings		5.3.1	Bathymetry, substrate morphology and texture, coastline dynamics
			5.3.2	Burden of contaminants
	5.4 Sea level and tides		5.4.1	Sea level trends and tidal gauge measurements
	5.5 Meteorology		5.5.1	Wind, temperature, humidity and radiation
6.0 NOISE AND OTHER PHYSICAL STRESSORS	6.1 Noise		6.1.1	Anthropogenic noise
			6.1.2	Beluga vocalizations
	6.2 Response to stressors		6.2.1	Behaviour
			6.2.2	Stress levels
			6.2.3	Injury or death