4.0 MARINE ENVIRONMENT

4.1 INTRODUCTION TO THE MARINE ECOLOGY

Marine research in the southeastern Beaufort Sea-Amundsen Gulf area began in earnest in 1896 with an expedition from Stanford University to Herschel Island, and continued with an expedition from the American Museum of Natural History (1908) and the Canadian Arctic Expedition (1913-1918). However, regular studies in the Canadian Beaufort Sea-Amundsen Gulf area did not begin until the mid-1950s, when the Arctic Biological Unit of the Fisheries Research Board began a long series of marine biology and ecology studies. This work consisted largely of baseline and distributional studies and continued for over two decades.

Since the early 1970's, marine research efforts in the region have been closely tied to the level of interest in hydrocarbon development. Sampling efforts increased ca. 1972, in response to oil exploration and associated activities, such as seafloor dredging and artificial island construction. Most of this work consisted of environmental impact studies with a large, baseline/distribution or life history component. Both Government and Industry conducted these studies, some of which provide baseline data suitable for monitoring comparisons, but few lasted over 4 years. Hydrocarbon exploration activity in the region decreased in the mid-1980s, and with it the associated environmental research. Interest increased again in the mid-1990s and various environmental impact assessment studies are ongoing (e.g., Devon Canada Corp. 2004; http://www.mackenziegasproject.com).

Extensive, multi-disciplinary, marine research programs were carried out by scientists from the Department of Fisheries and Oceans (DFO) from 1984 through 1990, with funding from the Northern Oil and Gas Action Program (NOGAP) (e.g., Bond and Erickson 1989; Hopky *et al*. 1994; Chiperzak *et al*. 2003). This and other work formed the basis for the Beaufort Environmental Monitoring Project (BEMP), which began in 1983 and considered hypotheses related to the potential impacts of hydrocarbon development in the Beaufort Sea (ESL and Seakem 1989). A similar project, the Mackenzie Environmental Monitoring Project (MEMP) was initiated in 1985 for the Mackenzie Delta, including coastal areas of the Beaufort Sea (LGL *et al*. 1988).

The NCP is also conducting long term monitoring of contaminants in beluga, ringed seal, polar bear and anadromous char in and around the Beaufort Sea. Details of the plan can be found in the NCP Blueprint for research under the Environmental Trends subprogram.

While there have been many studies of the marine environment of the Beaufort Sea – Amundsen Gulf Area, remarkably few have provided trend-over-time data useful for monitoring environmental health. Key reasons for this deficiency include: 1) the high cost and difficulty of working in the region; 2) the short duration (<4 y) of the studies, most of which were designed to collect basic information on the environment or for environmental impact assessment; 3) the incomparability of data among studies, due to differences in the location, design, and/or methodology; and 4) the incomparability of data within longer-term studies due to changes over time in response to changing information requirements, improved understanding (e.g., the existence of separate populations), or technological advances (e.g., satellite technology). The comparability and repeatability of much of the research work conducted in the Canadian Beaufort Sea prior to ca. 1985-1993 was assessed by the Arctic Data Compilation Program (ADCAP) (oceanography: Cornford *et al*. 1982; Thomas *et al.* 1982, 1990; plankton: Woods and Smiley 1987; zoobenthos: Wainwright *et al*. 1987; fish: Ratynski *et al*. 1988; Stewart and Ratynski 1995; seals: Harwood *et al.* 1986; whales: Norton *et al*. 1987). This program also described marine industrial activity in the region (Taylor *et al*. 1985; Brouwer *et al*. 1988; ESL 1991).

Most of the sampling effort has been expended in the Mackenzie Estuary and on the Beaufort Sea shelf, typically within the 10 m isobath. This is primarily a function of the small boats used for sampling and because deep water is far offshore in most areas. Seal and polar bear surveys excepted, most sampling has been conducted during the open water period from July to October. Offshore research conducted in 1997-98 on the Surface Heat Budget of the Arctic Ocean (SHEBA) is an exception (e.g., Macdonald *et al.* 2002).

Two new research initiatives should provide valuable information on the oceanography of the Beaufort Sea-Amundsen Gulf area. In 2002, the Canadian Arctic Shelf Exchange Study (CASES) began a multi-year research program on the functioning of the Mackenzie Shelf ecosystem (http://www.cases.quebec-ocean.ulaval.ca/science.asp). The central hypothesis of this Canadian-led international program is: "The atmospheric, oceanic and hydrologic forcing of sea ice variability dictates the nature and magnitude of biogeochemical carbon fluxes on and at the edge of the Mackenzie Shelf." The CCGS Amundsen, formerly the icebreaker CCGS Sir John Franklin, has been refitted to provide a research platform capable year-round operation in the Arctic. The scientific studies will examine:

1. Atmospheric and Sea Ice Forcing of Coastal Circulation;
2. Ice-Atmosphere Interactions and Biological Linkages;
3. Light, Nutrients, Primary and Export Production in Ice-Free Waters;
4. Microbial Communities and Heterotrophy;
5. Pelagic Food Web: Structure, Function and Contaminants;
6. Organic and Inorganic Fluxes;
7. Benthic Processes and Carbon Cycling;
8. Millenial-Decadal Variability in Sea Ice and Carbon Fluxes; and
9. Coupled Bio-physical Models of Carbon Flows on the Canadian Arctic Shelf.

Another co-operative, multidisciplinary, multi-year research program in the Beaufort Sea is Theme 1 of ArcticNet. It began in 2004 and will document the links between environmental change, health and economy along the contrasted East-West gradient of the Canadian High Arctic (http://www.arcticnet-ulaval.ca/index.php?fa=ArcticNet.showArcticNet). Key indicators of change in the coastal environment and its inhabitants will be measured annually to gather the time-series data required to separate irreversible change from natural variability. Theme 1 results will contribute to the formulation of policies and adaptation strategies to help answer the specific needs of stakeholders in the fields of health, economy, geopolitics and industry. ArcticNet research programs will be supported by CCGS Amundsen, but will include a larger coastal component than the CASES research. Studies will be undertaken to assess:

1.1 Warming Coastal Seas & Shrinking Sea Ice;
1.2 Coast Vulnerability in a Warming Arctic;
1.3 Contaminant Cycling in the Coastal Environment; and
1.4 Marine Productivity & Sustained Exploitation of Emerging Fisheries.

Carmack and Macdonald (2002) provide a clear, readable overview of oceanographic processes on the Canadian shelf of the Beaufort Sea. The following report describes the Marine Environment adjacent to the Northwest Territories (NWT), with particular emphasis on:

- current monitoring/research programs and data;
- trends in the data and the significance of these trends; and
- information gaps and recommendations for additional monitoring/research.

4.2 MARINE STRESSORS

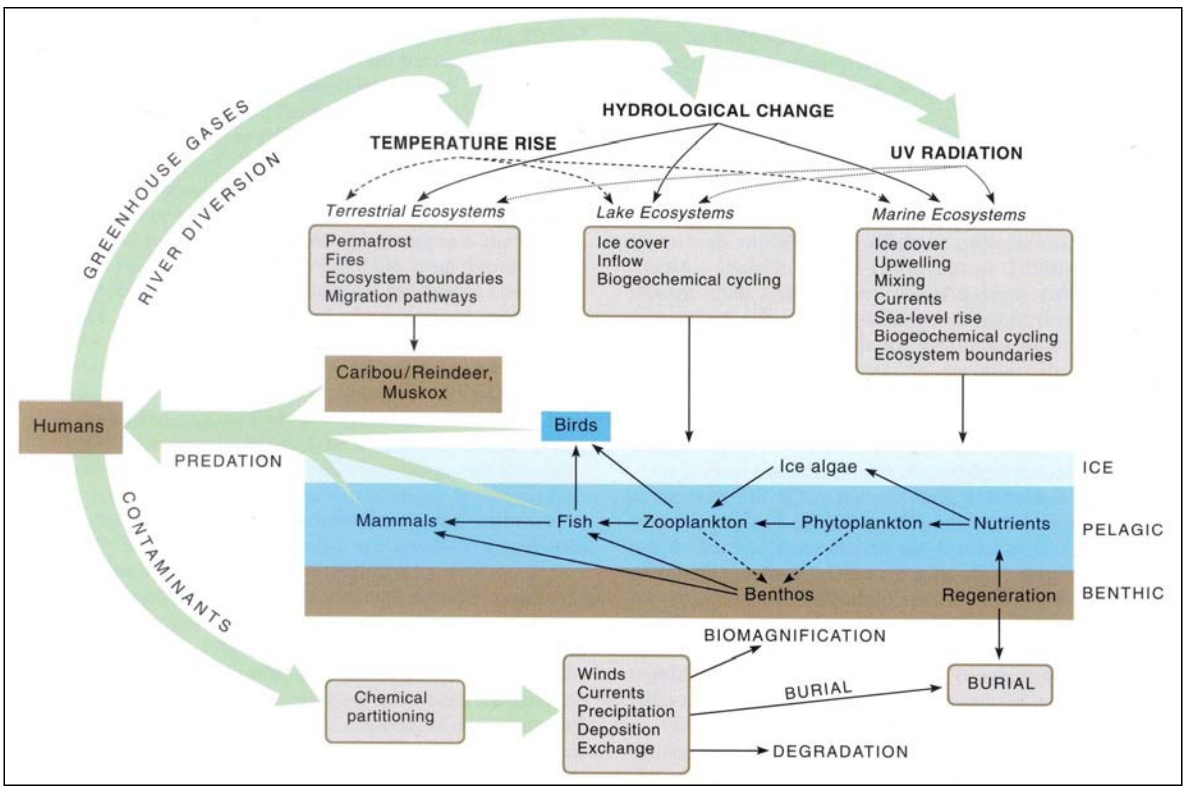
Marine ecosystems offshore of the Northwest Territories are vulnerable to a wide range of anthropogenic and natural stressors, each with the potential to affect the ecology in different ways. Chief among these stressors, but listed in no particular order, are:

- contaminants,
- harvesting,
- habitat disruption,
- disturbance,
- species invasions, and
- climate change.

4.2.1 Contaminants

Contaminants are transported to the region over long distances by marine currents, air currents, freshwater runoff from the land, and migratory biota (Figure 4.2-1) (Macdonald 2000, CACAR II 2003; Macdonald *et al.* 2003a,b; AMAP 2002, 2004). These long-range transport mechanisms carry a wide range of pollutants over the pole in seawater, ice, or air; from the Mackenzie Basin and other smaller Arctic watersheds upstream; and from habitats throughout North and South America, and disperse them throughout the region. Toxic, persistent substances that tend to accumulate in biota are of particular concern, including heavy metals such as mercury and cadmium, and organochlorine compounds such as PCBs, chlordane, and toxaphene. The risk they pose to Arctic marine systems is predicated on a conspiracy between physical, chemical, and biological processes that produces relatively high concentrations in apex feeders far from known sources. Radionuclides are not generally considered a threat in this region but Cesium-137, which was produced primarily by nuclear tests in the 1960's, does provide an excellent tracer of ocean pathways.

FIGURE 4.2-1
CONTAMINANTS PATHWAYS TO AND FROM THE ARCTIC MARINE ECOSYSTEM



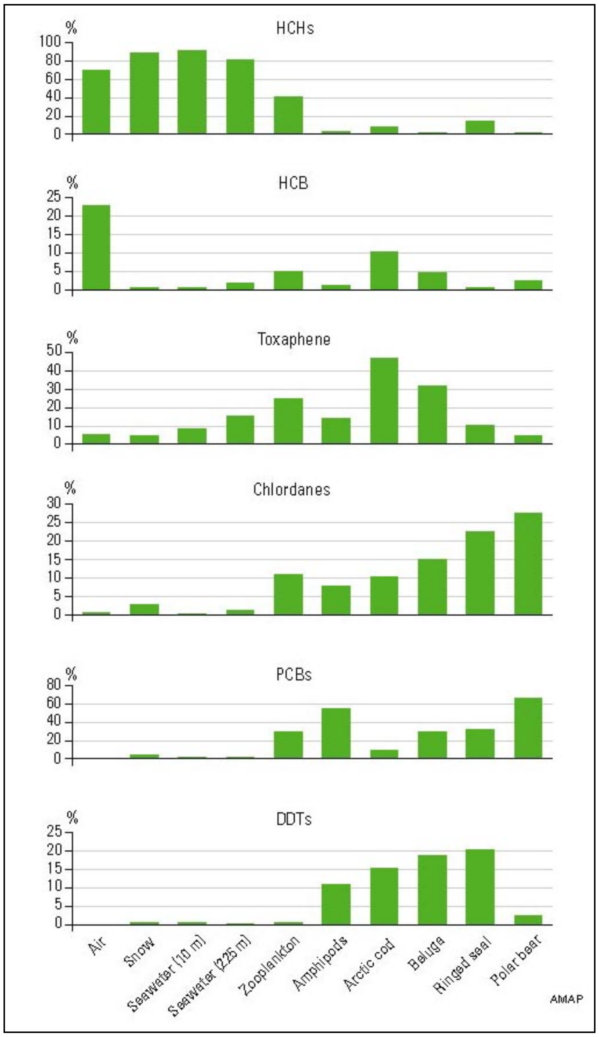
Source: Macdonald et al. 2003b, p. 48).

Contaminants are also transported directly to, or mobilized from, the local environment by human activities. While they may eventually disperse widely, these substances emanate from point sources that can be identified. PCB contamination at DEW Line Sites (CACAR II 2003), and nutrients and contaminants from sewage disposal and landfill sites at the communities, are examples of existing point sources. The potential for oil spills or natural gas leaks from hydrocarbon developments is significant in the region, and is likely to increase if hydrocarbon developments proceed. Shipping tracks are one of the few line-sources of contaminants entering the Arctic marine environment, and may increase in importance over time, with predicted longer ice-free shipping seasons resulting from climate warming.

Marine organisms accumulate contaminants from their environment and their diet. The types and body burdens of contaminants they accumulate reflect their habitat use, movements, diet, age, and metabolism (Figures 4.2-2, and 4.2-3) (AMAP 2002, 2004; CACAR II 2003; Macdonald *et al.* 2003a,b; Hoekstra *et al*. 2003). Some contaminants are metabolized, while others such as chlordanes and mercury accumulate over the life of the organism and can be present in increasingly high concentrations moving up the food web. As technology changes, new types of synthetic contaminants are constantly being made. Brominated flame-retardants, like polybrominated diphenyl ethers (PBDE), are one class of these compounds that has been identified in the past decade and is accumulating in Arctic marine biota (Ikonomou *et al*. 2002). Their biological effects on marine biota are largely unknown.

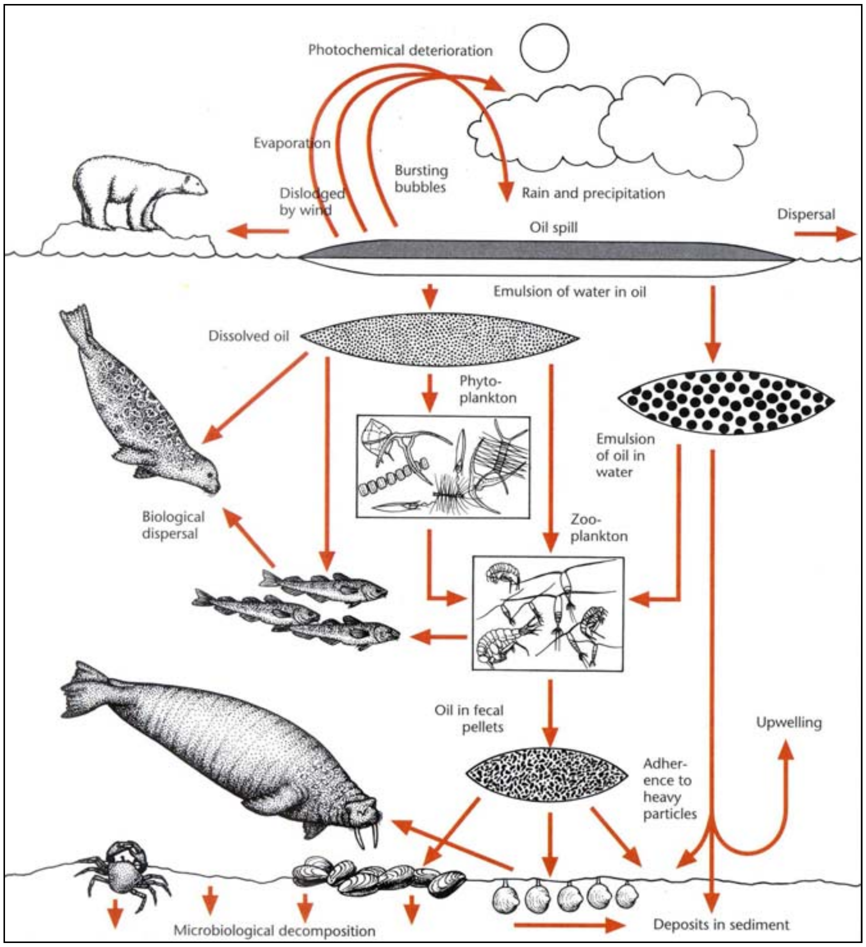
It is important in any monitoring program to differentiate between concentrations of contaminants in biota, which may be of direct concern to humans that eat these animals, and the health effects of contaminants on the biota themselves. Contaminants that are metabolized quickly may only be present at low levels, whereas their effects on the animal's health may be significant and lasting. These health effects can be a better indicator of the importance of the contamination than the contaminants levels themselves.

FIGURE 4.2-2
DISTRIBUTION OF ORGANOCHLORINE CONTAMINANTS IN ARCTIC AIR, SNOW, SEAWATER, AND THE MARINE MAMMALS FOOD CHAIN



Source: de March et al. 1998, after Norstrom and Muir 1994.

FIGURE 4.2-3
OIL DISPERSAL PATHWAYS IN THE ARCTIC MARINE ENVIRONMENT



Source: Born and Bocher 2001, p. 391.

Climate change could significantly alter the availability of contaminants to Arctic biota. Changes associated with ice and precipitation, and with the trophic structure of ecosystems have the greatest potential to alter contaminant pathways and exposure (Macdonald *et al*. 2003b).

4.2.2 Harvesting

The Inuvialuit have a long tradition of harvesting animals from the Mackenzie Delta/Beaufort Sea/Amundsen Gulf area for food and materials (Farquharson 1976; Usher 1976; Smith 1987; Byers and Roberts 1995; Inuvialuit Harvest Study 2003). These harvests have provided many of the necessities of life and continue to be economically and socially important.

Most marine fishing efforts have been concentrated on obtaining anadromous fishes, particularly: Dolly Varden (*Salvelinus malma*), Arctic char (*Salvelinus alpinus*), lake whitefish (*Coregonus clupeaformis*), broad whitefish (*Coregonus nasus*), inconnu (*Stenodus leucichthys*), and ciscoes (*Coregonus* spp.). These species typically spawn and winter in fresh water and feed at sea in the summer. Where salinity and temperature conditions are favourable, some species may remain in the river plumes over winter.

Anadromous species are attractive to harvesters because they are predictably available during migration in the coastal rivers, and in summer along the coasts. They are tasty, tend to grow faster than their non-anadromous counterparts due to the relatively rich feeding opportunities in the coastal waters, and they shed most of their parasites on entering the marine environment or re-entering freshwater. Depending upon their seasonal movements, some of these fish stocks may be vulnerable to capture at various locations along seacoast and in fresh water. Some inconnu, for example, migrate over 1000 km inland in the Mackenzie River watershed (DFO 1998). There are quotas on the commercial harvests and catch and possession limits on the sport fisheries, but none on the subsistence harvests.

While the anadromous fishes are harvested for subsistence, commercial sale, and sport, relatively few truly marine species of fish or invertebrates are harvested (Stewart *et al*. 1993; Inuvialuit Harvest Study 2003). Pacific herring (*Clupea harengus*), Arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*), and sculpins (*Myoxocephalus* spp.) are caught in small numbers, primarily for use as dog food. To date none of the marine fish or invertebrate species identified from the region has demonstrated the potential to support an economically viable marine commercial fishery, including species that are commercially harvested elsewhere such as Pacific herring and Greenland halibut (*Reinhardtius hippoglossoides*). Difficult working conditions, high costs, and a limited resource base hamper these fisheries.

The harvest of marine mammals is also socially and economically important for the Inuvialuit. Ringed seals (*Phoca hispida*), bearded seals (*Erignathus barbatus*), beluga whales (*Delphinapterus leucas*), bowhead whales (*Balaena mysticetus*), and polar bears (*Ursus maritimus*) are the main species targeted (Inuvialuit Harvest Study 2003). Southern Beaufort Sea populations of these species, with the possible exception of bearded seals, undertake extensive seasonal westward movements that can make them vulnerable to harvest along the Alaskan or Siberian coasts (Richard *et al*. 2001; Harwood *et al*. 2002; Stirling 2002). There are no quotas on harvests of seals or belugas by Inuvialuit or Alaskan Inupiat for subsistence, but there are quotas on the harvest of polar bears. Inuvialuit require a special licence from the Minister of Fisheries and Oceans to harvest bowhead from the Western Arctic Population, which COSEWIC designated as endangered in 1986 and is listed in Schedule 2 of the Species at Risk Act. The species' status is currently being reassessed. Single animals were harvested in 1991 and 1996

(P. Hall, DFO Winnipeg, pers. comm. 2005). Walruses (*Odobenus rosmarus*) and other seals or whales are seldom harvested.

A variety of waterfowl that use coastal marine environments are harvested for subsistence. Those that make the greatest use of marine resources are the king and common eider ducks (*Somateria spectabilis* and *S. mollisima*), longtailed duck (i.e., oldsquaw; *Calangula hyemalis*), surf and white-winged scoters (*Melanitta perspicillata* and *M. fusca*), brant geese (*Branta bernicula*), and red-throated loons (*Gavia stellata*). There are no limits on the subsistence harvests of these birds by Inuvialuit.

4.2.3 Habitat Disruption

Bottom disturbance and sediment release from removal and placement activities have the potential to disrupt local habitat (Taylor *et al.* 1985; ESL and Seakem 1989). These activities can be related to the maintenance or construction of shoreline facilities such as harbours, or to offshore oil development. Transportation over the sea ice, and ice breaking in support of shipping activities, can also disrupt habitats by altering the ice surface or creating temporary leads. Ringed seal habitat in the landfast ice is that most likely to be affected.

4.2.4 Disturbance

Visual and noise disturbances related to coastal and offshore development activities can disturb animals in the region (Brouwer *et al.* 1988; ESL and Seakem 1989). Many species will acclimate to these disturbances, provided they are not associated with harvesting or injury. Walrus, however, may stampede at haulouts if they are disturbed, and sometimes trample smaller animals to death. They tend to leave areas disturbed by humans. Walruses are not common in the Canadian Beaufort Sea. Disturbances that cause animals and birds to enter the water when they are moulting and less well insulated may have a greater effect than during other seasons. The effects of seismic testing are intensified under the ice due to reflectance of pressure waves off its bottom surface (Wright 1982; Wright and Hopky 1998; Cott *et al.* 2003). This can physically harm marine biota or cause them to avoid areas near seismic tests.

4.2.5 Species Introductions

Species introductions can occur naturally in response to environmental changes that create favourable conditions in new areas, or with human assistance. Invasive species transported to the Great Lakes in ship bilges are one example of the latter; another is the downstream movement of an anadromous species such as rainbow smelt when it is introduced to a new watershed (e.g., the Nelson River) (Stewart and Lockhart 2005). Recent observations of an increasing variety of salmon species that in the past have seldom been reported from the Beaufort Sea, suggest that they may be moving north more often to feed (Babaluk *et al.* 2000). Introduced species need not become established to cause harm if they successfully vector a new disease or parasite that affects the indigenous species.

4.2.6 Climate Change

Climate change has the potential to profoundly alter the marine ecology by changing the volume and seasonality of freshwater runoff from the land, reducing or eliminating seasonal ice cover, and altering ocean currents and weather patterns (Mysak 2001; Carmack and Macdonald 2002; Macdonald 2003b; Loeng 2004). Predictions vary widely on how quickly and to what extent climate may change, and on the extent to which observed warming trends are driven by human activities (e.g., Mysak 2001; Parkinson 2000a,b; IPCC 2001; Curry *et al*. 2003; Curry 2004; Johannessen *et al.* 2004). A significant warming trend that reduces sea ice cover has the potential to alter the biological communities in and around the Beaufort Sea, from the bottom up by affecting nutrient availability and light conditions (Carmack and Macdonald 2002).

While biological productivity may increase over the long term, the direction and degree of change at any time during the transition is impossible to predict (Carmack and Macdonald 2002; Macdonald 2003b). Shifts may occur within and among communities and species, and the overall marine production will rise and fall until stability is regained. Species that cannot adapt to changes in habitat or food resources will be selectively eliminated. The effects on each species may depend in large part on how they use and interact with the ice environment, and on how plastic that use is. Ice-adapted species such as ice algae, sympagic amphipods, polar bears, and ringed and bearded seals, would likely be most affected by climatic warming. Indigenous, Arctic adapted species would probably face increasing competition from Pacific species that invade as conditions ameliorate.

Climate change also has the potential to fundamentally alter the local marine environment and resource base of communities such that traditional knowledge is no longer applicable, and to change patterns of northern development and marine transportation (Maxwell 1997; Duerden 2004).

4.3 MARINE ENVIRONMENTAL QUALITY (MEQ) INDICATORS

Indicators of marine environmental health can be drawn from the physical, chemical, and biological oceanography. The list of potentially useful indicators is very long but at present few offer data sets that are comparable for a period of over 3 years, and fewer still are repeatable for future comparison (see ADCAP reports).

A "top-down" approach, whereby large predatory species such as the polar bear, beluga whale, ringed seal, and anadromous char (i.e., Arctic char and Dolly varden) are examined offers perhaps the best potential for monitoring cumulative impacts on the marine environment at present. As high-level consumers, these species are integrators of change in the food web which itself responds to a myriad of stressors. This makes them particularly vulnerable to environmental perturbations, and to the accumulation of persistent contaminants. As large, predictably available species they are also very important to the Inuvialuit, who harvest them in quantity for food and materials. Consequently, government and other agencies have studied these animals over a longer period and in greater detail than most other species.

Changes in the composition of marine communities, in the seasonal abundance or availability of species, and in their quality and/or health can be useful indicators of changes in marine environmental health. Because the Arctic food web is relatively simple, the loss of a species or introduction of another may have important consequences, particularly for higher-level consumers, such as bears and people (Welch *et al.* 1992). However, natural variability among geographical locations, habitat types, seasons and years reduces the sensitivity of community monitoring as a tool for assessing environmental change.

Species with hard parts that grow throughout their lives (e.g., teeth, otoliths, or shells) are particularly useful for monitoring purposes as these parts can be examined to estimate the individual's age. The results of these estimates are however sensitive to the structure and methods used for age determination, which can yield very different estimates. Among invertebrate species, clams such as *Mya truncata* and *Serripes groenlandicus* offer the best opportunities for monitoring as they are long lived and can be aged using shell growth. However, research in the eastern Canadian Arctic suggests that populations may follow an 8-10 year cycle of abundance (T. Siferd, DFO Winnipeg, pers. comm. 2005).

Subsistence harvesters rely on the predictable abundance of a small number of species for food and materials, and their harvests per unit of effort can provide a useful indicator of changing availability. Depending upon the year-to-year continuity of harvesting efforts, and on how the data are collected, harvest data can serve as an indicator of abundance. Abundant, widely distributed species, such as the ringed seal may be more useful indicators than species like the polar bear, which are harvested under quotas. Hunter experience and observations can also provide an important long-term indicator of abundance. However, this information may be confounded over time if climate change alters environmental conditions such that animals change their seasonal movements and traditional knowledge is no longer valid.

The quality and health of animals, prior to their harvest, is an important consideration for the people who eat them. Qualitative observations of whether animals are fat or skinny, whether they taste different, and are energetic or lethargic can be useful indicators of larger problems. Because harvesters handle many more animals than scientists each year, from a much wider area, they are also more likely to encounter diseased or parasitized animals, which can be reported and examined. They can also provide insight into why these changes may be occurring. Harvesters are also more likely to capture uncommon species, such as salmon, that may provide an early indication of changes in community structure.

Contaminant levels are an important aspect of the marine environmental health that affects humans directly through their diet. Trends in accumulation can be followed over time, provided variations related to geography and age and sex of the animal are understood. The value of marine bottom sediment as a record of contaminant deposition over time is limited by the reworking of these sediments by benthic infauna.

Understanding of key atmospheric and oceanographic processes and their linkages to the biological indicators is critical for accurate interpretation of trends in these indicators. Trends in sea ice and water column stratification are particularly useful. Changes in sea ice cover are climate driven and have major oceanographic and ecological implications. All but the ice thickness can now be measured remotely by satellite over the entire region and compared digitally to identify trends over time. Inuvialuit knowledge of sea ice conditions has an important contribution to make in the interpretation of ice data, particularly in the ground-truthing of remote sensing images for subtle changes in ice formation over time. Changes in the seasonal profiles of light penetration, temperature, salinity, nutrients, and chlorophyll ***a*** in the water column are also useful indicators of change. They can provide important information on freshwater inputs, mixing, and biomass.

To date, the only marine valued ecosystem components identified by CIMP (2005) are marine mammals. The key monitoring indicators identified were: body condition and reproductive status of seals and whales; disease and contaminants loads in individuals; age of first maturity and reproductive rate; and stock size and range. Some of these indicators work better for one species than another.

To correctly interpret trends in these indicators, data must also be collected on other aspects of their environment. Consequently, the quality, extent, and duration of sea ice cover; prey quantity and quality; and ambient and anthropogenic noise levels were also identified as key indicators (CIMP 2005).

The indicators identified by CIMP (2005) are appropriate for the marine mammals but leave gaps with respect to monitoring the cumulative effects of stressors on the marine environment as a whole. They do not, for example, consider the effects on the polar bear, which as the apex predator may be more sensitive to stressors such as climate change and persistent contaminants, nor do they consider the effects on marine birds, fishes, invertebrates, or plants except as food for whales and seals. Because of differences in their diet, habitat use, physiology, and life history the stressors acting on the region's marine environment may affect these species differently (Figures 4.2-2 and 4.2-3).

As consumers, the species listed below integrate the effects of environmental changes (Table 4.2-1). Each species is vitally important to the traditional economy, has been studied in the region, and may provide a useful indicator of the state of the environment through time. At present, few if any other species or parameters, with the exception of sea-ice cover, offer useful trend-through time data. Among the potentially useful indicators, only those with the most useful data records will be discussed further.

TABLE 4.2-1
RATIONAL FOR SELECTION OF SPECIES AND PARAMETERS AS POTENTIAL MARINE ENVIRONMENTAL QUALITY INDICATORS

VEC	Parameter*	Rationale
Mammals		
Polar bear	• **natality** • **sex and age composition of the harvest** • body condition • contaminants • population abundance	• High level consumer, eats primarily ringed seals • Widely distributed in winter; more concentrated distribution in summer; den mostly along the western and southern coasts of Banks Island and on multi-year pack ice • Bears from the three management populations (Southern Beaufort/Northern Beaufort/Viscount Melville Sound) remain within the Beaufort Sea/Amundsen Gulf/western M'Clure Strait area year round • Extensive database of monitoring and research • Sensitive to changes in the quality, distribution, and duration of ice cover • Particularly vulnerable to the accumulation of persistent contaminants that bioaccumulate in the food web • Important resource and source of income for residents
Beluga	• **composition of the landed harvest** • **contaminants**	• Mid-level consumer that eats fish and invertebrates and is eaten by polar bears • Widely distributed in summer • Important traditional food source for communities • Composition of the landed harvest and contaminants monitored; growth parameters difficult to obtain in sample sizes sufficient for comparison; migrate east to Lancaster Sound and west to the Bering Sea, making it harder to understand the factors underlying any trends • Returns to the same estuaries each year, making it vulnerable to over-exploitation, might be a useful integrator of the downstream effects of changes occurring in freshwater systems

TABLE 4.2-1 (Cont'd)
RATIONAL FOR SELECTION OF SPECIES AND PARAMETERS AS POTENTIAL MARINE ENVIRONMENTAL QUALITY INDICATORS

VEC	Parameter*	Rationale
Ringed seal	• **harvesting removals** • **body condition** • **ovulation rate** • **contaminants** • recent pups in the harvest • population density	• Mid-level consumer between fish and invertebrates and foxes, polar bears, and people • Widely distributed, year-round resident • Major traditional source of food and materials for Inuvialuit • Sensitive to changes in the ice environment • Reproduction, condition, and contaminants can be monitored cost effectively each year by community-based sampling of the harvest • Contaminants monitored in seals from Holman since 1971
Birds		
red-throated loon	• surveys of nesting success • contaminants in chicks and eggs	• Mid-level consumer, eat small fish • Arrive in offshore leads in late May or early June and remain until nesting ponds have open water; these ponds winterkill so the loons must travel to the coast or a large lake to forage for fish to feed their young • Widely distributed and conspicuous nesting species in coastal areas in summer; typically nest within 8 km of the coast or a large lake • Young can be followed from egg to fledging unlike many other species with more mobile young and because they are fed local marine fish from an early age can be used to monitor local contaminants • Very vulnerable to oil pollution • Baseline data available on reproductive success; contaminants samples archived

TABLE 4.2-1 (Cont'd)
RATIONAL FOR SELECTION OF SPECIES AND PARAMETERS AS POTENTIAL MARINE ENVIRONMENTAL QUALITY INDICATORS

VEC	Parameter*	Rationale
		Fish
anadromous Dolly varden & Arctic char	• **population size** • **catch-per-unit effort** • **age at harvest** • **fish condition** • **harvest** • contaminants	• Low to Mid-level consumer, eats invertebrates and smaller fish and is eaten by ringed seals and belugas • Widely distributed in coastal areas in summer, winters in fresh water • Important traditional food source for residents and supports economically important commercial and sport fisheries • Individuals return to the same estuaries, rivers, and lakes each year, making populations vulnerable to over-exploitation • Population dynamics and fish condition monitored • May be vulnerable to environmental changes and fish species invasions
		Environment
sea ice	• **duration of ice cover** • **aerial extend to ice cover** • **ice thickness**	• Key determinant of Arctic marine processes at all levels of the ecosystem • Sensitive to climate change • Duration and extent of cover can be measured over the entire region by satellite; thickness and draft cannot • Important determinant of harvesting, transportation, and development activities

*key indicators are in bold type.

4.3.1 MEQ Indicator – Polar Bears

Polar bears (*Ursus maritimus*) are an apex consumer in the Arctic marine food web. They eat primarily ringed and bearded seals, and are eaten by humans. The species was chosen as a VEC because of its high trophic level, and its cultural and economic importance to the Inuvialuit.

Bears from three management populations (SB = Southern Beaufort, NB = Northern Beaufort, VM = Viscount Melville Sound) inhabit the Beaufort Sea/Amundsen Gulf/western M'Clure Strait area year round (Taylor *et al.* 2001). They are widely distributed on the sea ice in winter, with a more concentrated distribution in summer when sea-ice dissipates and they follow the receding ice edge to the permanent pack, or move ashore (Stirling 2002). The Southern Beaufort Population is shared with Alaska, and the others with Nunavut. Birthing dens have been found mostly along the western and southern coasts of Banks Island and on multi-year pack ice, although there are some on the northern coast of Yukon and Alaska.

Bears from these populations travel extensively but, with a few notable exceptions (Durner and Amstrup 1995), remain within their management areas (Amstrup *et al*. 2000; Taylor *et al*. 2001; Stirling 2002). Consequently, they are useful for monitoring environmental change and contaminants in these areas. Polar bears are very sensitive to changes in sea ice, which they use as a platform for travel and hunting seals (Stirling 2002; Derocher *et al.* 2004). The quality, extent, and duration of ice cover determine how successfully, where, and how long they can hunt seals in a particular area. It also determines where maternity dens can be constructed. As apex consumers, polar bears accumulate contaminants from both the benthic and pelagic food chains. They are particularly susceptible to the bioaccumulation of some persistent contaminants that are biomagnified by the food chain, including mercury and chlordane (CACAR I 1997; Norstrom *et al*. 1986, 1998), and may be useful for the early identification of new persistent contaminants.

i) What is being measured?

- **natality (birthrate)**
- **sex and age composition of the harvest**
- **body condition**
- **contaminants**
- **population abundance**

In the Canadian Beaufort Sea and Amundsen Gulf, research on polar bear populations and their ecological interrelationships with seals and sea ice conditions began in the fall of 1970 (Stirling 2002). Its purpose was to address worldwide concern about the conservation of polar bear populations, which had been severely over-harvested throughout the Beaufort Sea and

Amundsen Gulf area before quotas were established in Canada in 1968, and Alaska ceased all but subsistence hunting in 1972.

This research has involved the delineation of populations, population assessments, baseline studies of demographic and reproductive parameters, identification of maternity denning areas, studies of the ecological relationships between seals and polar bears, and the examination of data and specimens from the polar bear harvest (Stirling 2002). The Canadian Wildlife Service and NWT Department of Resources, Wildlife and Economic Development (RWED) have conducted much of this work, in cooperation with local hunters and researchers from Alaska and various universities.

Among the parameters measured, natality and the sex specific age structure of the harvest are perhaps the most immediately useful long-term indicators for monitoring purposes (Stirling 2002). Data on natality (the ratio of live births in an area to the population of that area) provides a measure of the reproductive rate and have been collected during mark-recapture surveys. Data on the age structure of harvested polar bears can reflect both short-term fluctuations in the ecosystem and the overall long-term status of the population in relation to harvesting (Stirling 2002; Derocher *et al*. 2004). Successful hunters must provide information about the hunt and submit proof of sex, the lower jaw or a premolar for aging purposes, and tags/tattoos of any marked bears. At the end of the year data from each population are compiled and reviewed by the Wildlife Management Advisory Committee (WMAC) to ensure that the annual harvest is sustainable. Body condition, contaminants, cub survival, and movement patterns may also provide useful indicators of environmental change (Derocher *et al*. 2004).

Fat samples have been collected from captured bears for contaminant analysis (Norstrom and Schweinsburg 1985; Norstrom *et al.* 1986, 1998). While higher levels of polychlorinated biphenyls (PCBs) have been found in the fat of bears from the Northern Beaufort Population than from populations elsewhere in Arctic Canada (Norstrom *et al*. 1986, 1998), too few of these samples have been analysed to assess trends in contaminant levels (Norstrom *et al.* 1998; CACAR II 2003). However, samples of bear fat have been archived for possible future examination (N. Lunn, EC, Yellowknife, pers. comm. 2005). At high levels, organochlorine contaminants can impair immune function (Lie *et al.* 2004, 2005) and may impair reproduction and cub survival (Skaare *et al*. 2002; AMAP 2002). Higher levels of mercury have been measured in the liver tissue of bears from the NWT than elsewhere in Arctic Canada (CACAR I 1997).

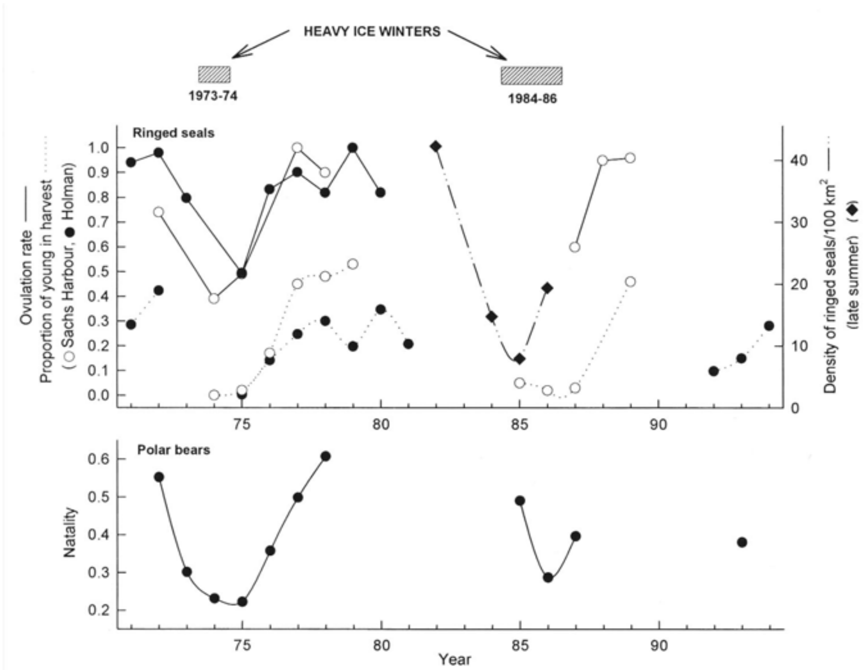
Population abundance estimates do not provide useful trend over time data at present. Initially, they were constrained by the inability to delineate populations. Studies in Canada and Alaska were conducted independently, until mark-recapture and satellite tracking studies demonstrated that the Southern Beaufort Sea population was shared. These estimates continue to be constrained by high costs and logistical difficulties, sampling biases (SB; Stirling 2002), the low density of bears (Lunn *et al*. 1995), and poor tag recoveries (Urquhart and Schweinsburg 1984). Harvest managers now rely on dated estimates from mark-recapture studies conducted in the late 1980s and early 1990s. During these studies, data are typically collected on the size, age (tooth), sex, reproductive state, and fatness of captured bears. Blood, fat and hair samples may also be collected for genetic and contaminants analyses.

Annual maternity denning surveys to estimate cub production are not feasible in the NWT as snow conditions make it difficult to find tracks and locate dens, and the distribution of dens is scattered (Urquhart and Schweinsburg 1984). Mean ashore dates, which are used in Hudson Bay, have less significance in the Beaufort where most bears summer in the permanent pack ice rather than onshore.

ii) What is happening?

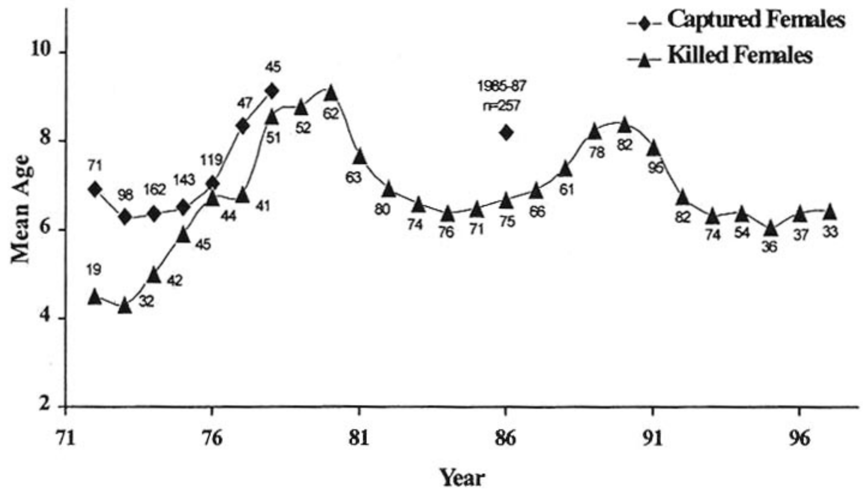
In the mid 1970s and again in the mid 1980s, significant declines were observed in the natality of polar bears and survival of subadults, after which both increased (Stirling 2002) (Figure 4.3-1). This pattern of fluctuations is also apparent in the mean sex-specific age of bears harvested by Inuit hunters over the same period (Figure 4.3-2). A substantial increase in the mean sex specific age of these bears was observed in the decade following the establishment of harvest quotas. The collection of these data has continued, but post-1996 data are not yet available.

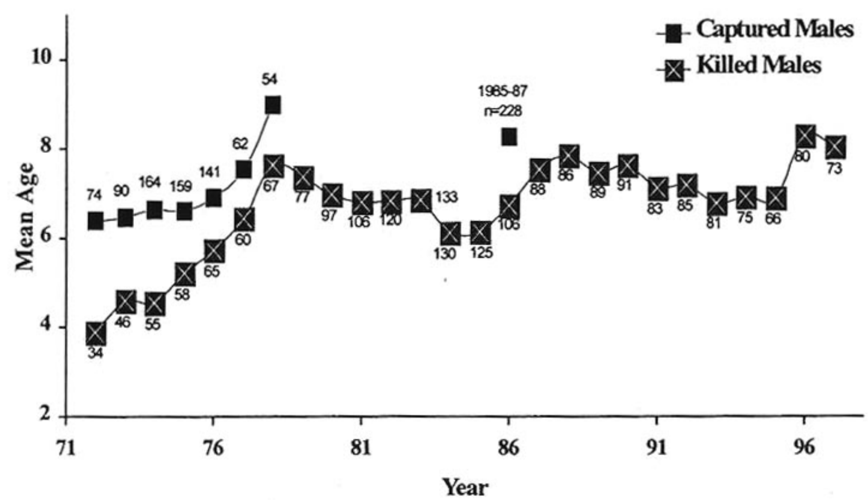
FIGURE 4.3-1
CHANGES IN INDICES OF PRODUCTIVITY OF RINGED SEALS AND POLAR BEARS



Source: Stirling 2002.

FIGURE 4.3-2
AVERAGE AGES OF FEMALE AND MALE POLAR BEARS ONE YEAR OF AGE AND OLDER CAPTURED





Source: Stirling 2002.

iii) Why is it happening?

The factors underlying fluctuations in polar bear natality are uncertain, but they follow a pattern similar to that of ringed seal productivity (Stirling 2002). The declines in seal productivity that were observed in the mid 1970s and again in the mid 1980s appear to be related to heavy ice conditions (Figure 4.3-2). Polar bear populations are closely dependant upon ringed seal productivity because the bears eat mostly ringed seals (Stirling and Øritsland 1995).

Quota implementation enabled bear populations to recover from over-harvesting. The average age of harvested bears increased in the decade following these harvest reductions as more bears lived longer before being harvested (Stirling 2002). Subsequent declines in the average age were due to an influx of young bears, rather than an absence of older animals. These influxes occurred in response to increases in ringed seal productivity that followed the heavy ice years and supported higher bear natality and the increased survival of younger bears. The drop in the average age of bears taken did not approach the low levels of the early 1970s when the population was being over-harvested. The pattern was more pronounced in female than male bears because older males tend to stay further offshore and are less vulnerable to harvest.

iv) What does it mean?

The polar bear populations in the NWT are believed to be stable, and hunting rates are believed to be sustainable. The apparent sensitivity to changes in the ice environment makes it important, with the threat of global warming, to re-establish baseline parameters for polar bears and their prey that will permit scientists to evaluate change and develop appropriate responses for conservation and management of marine mammals in the Beaufort Sea (Sterling 2002).

v) What is being done about it?

Ongoing studies that began in Alaska in 2001, were expanded to Canada in 2003, and may continue into 2006, should improve understanding of bear movements in the region and generate much better estimates of the Southern and Northern Beaufort Sea populations.

Harvests of bears from the NWT populations are now being jointly managed with Alaska or Nuanvut to avoid over-harvesting of bears that are vulnerable to harvest in several jurisdictions. In 1988, the Inuvialuit Game Council and North Slope Borough of Alaska implemented the Polar Bear Management Agreement for the Southern Beaufort Sea (Brower *et al*. 2002). It established a total annual harvest quota that, in March 2000, was revised to 80 bears, shared equally between the two jurisdictions. Kills of problem bears and research handling deaths are included in the harvest, of which no more than 27 animals can be female. A review of this agreement in 1998 concluded that it has been successful in limiting the total harvest and proportion of females in the harvest within sustainable limits. It highlighted the need to improve awareness of the need to prevent over-harvesting of females, and the need for better harvest monitoring in Alaska.

vi) What are the information gaps?

Temporal trends in the abundance of bear populations are uncertain. New population estimates should be generated based on ongoing research to facilitate harvest management. These estimates should be updated using comparable research at intervals of 15 years to facilitate population management and trend assessment, sooner if other indicators suggest the need.

The underlying causes of short-term fluctuations in natality and condition remain uncertain. This limits the ability of scientist to accurately predict how bear populations may be affected by long-term trends in sea ice cover. Linkages to other monitoring research on seals and sea ice should be continued and augmented to improve understanding of the how changes in these parameters affect bear populations.

Little is known of trends in contaminant accumulation by bears in the NWT, or of how different levels of these substances affect these animals. The analysis of archived samples might establish trends in contaminant accumulation over time that could be followed on an ongoing basis. The effects of high contaminants levels on the health and reproductive success of polar bears are not well understood.

4.3.2 MEQ Indicator – Beluga

The beluga whale is a mid-level consumer that eats fish and invertebrates and is eaten by polar bears and people. Whales from the Eastern Beaufort Sea stock undertake very extensive seasonal movements that can take them from wintering areas in the Bering Sea to eastern Viscount Melville Sound (Richard *et al.* 2001; Harwood *et al*. 2002). They follow ice leads eastward into the Amundsen Gulf area in May and June from wintering areas in the Bering Sea. As soon as ice conditions permit they move into the Mackenzie Estuary, where they remain until mid-July or early August. Females with calves then make a circuit or two around Amundsen Gulf before returning to their Bering Sea wintering areas. Males and resting females move offshore to the north of Banks Island and into Viscount Melville Sound, before returning west in September and then through Bering Strait in November and December to their wintering areas. The beluga's use of the Mackenzie Estuary makes them vulnerable to harvesters and perhaps to other stressors.

Belugas are an important traditional food source for Inuvialuit living in communities on the NWT mainland (Byers and Roberts 1995; Harwood and Smith 2002; Inuvialuit Harvest Study

2003). Each summer hunters and their families from Inuvik, Aklavik, and Tuktoyaktuk travel to traditional hunting camps along the eastern Beaufort Sea coast (Harwood *et al*. 2002). Most hunting takes place in July in the Kugmallit Bay, Beluga Bay, and Shallow Bay areas of the Mackenzie Delta (Norton and Harwood 1986). Inuvialuit at Paulatuk and Holman also have a tradition of harvesting belugas, usually in late July or August as they pass near the community, although few belugas are harvested in the Holman area (Farquharson 1976; Inuvialuit Harvest Study 2003). Harvested animals likely all belong to same stock, but are taken after the animals leave the estuary and move offshore to feed (Richard *et al*. 2001).

While the beluga stock is believed to be large, population estimates are difficult to obtain due the large geographical extent of their summer range. Monitoring contaminant accumulation by belugas is important, as the Inuvialuit eat these whales in quantity. However, extensive movements by the belugas make it difficult to relate contaminant levels in belugas to contaminants in the Beaufort Sea.

vii) What is being measured?

- **composition of the landed harvest**
- **contaminants**

Hunter-based monitoring programs have collected data on the number of belugas harvested and the efficiency of hunts in the Mackenzie Delta and Paulatuk areas since 1973 and 1989, respectively (Harwood *et al*. 2002). Since 1980, data on the standard length, fluke width, sex, and age of the landed whales have also been collected. These "on-the-beach" observations produced somewhat higher counts of landed whales than the recall surveys used for the Inuvialuit Harvesting Study (2003). Since 1972, tissue samples have been obtained from harvested belugas for contaminant analyses (de March *et al.* 1998).

Studies of trends in the prevalence of disease among belugas have been ongoing since 1999 (Nielsen *et al.* 2004; Philippa *et al*. 2004; O. Nielsen, DFO, Winnipeg, pers. com.). Preliminary results suggest that there has been an increase of 4-5 times in the prevalence of the Brucella virus since 2000, for unknown reasons. This virus causes Brucellosis, which can affect humans. The morbillivirus (distemper), which affects ringed seals and foxes, has not been found in belugas. This suggests that they either are not susceptible to infection or have not been exposed to the virus, which is a concern as this family of viruses can cause high mortality among whales (Nielsen *et al*. 2000). These disease studies rely on year-to year funding from the FJMC for continued operation.

viii) What is happening?

The number of belugas landed each year appears to be declining, despite increases in the human population (Harwood *et al*. 2002). The removal of belugas from the Eastern Beaufort Sea stock, including those landed by Alaskan harvests, is estimated at 189 per year. Harvest efforts are directed mostly at adult male animals (92% >10 years old; 2.3 males/female)

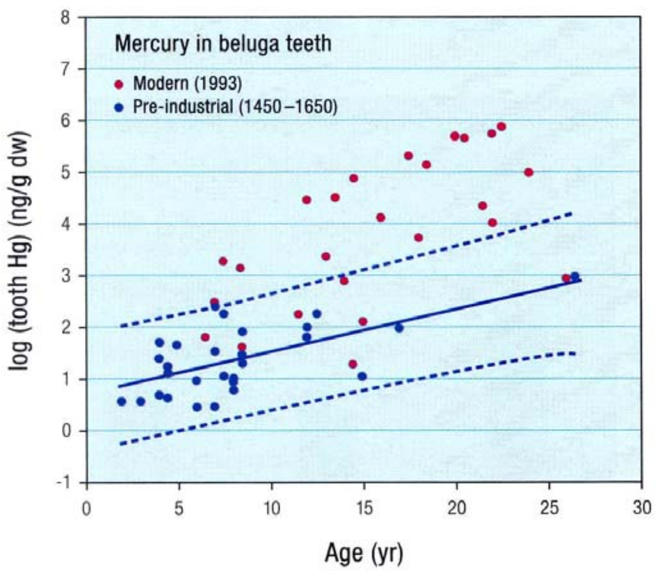
TABLE 4.3-1
BELUGA HARVEST DATA

Period	Average number of belugas harvested annually	Standard Deviation (SD)	Total landed harvest over 10 year period
1970-79	131.8	26.5	1337
1980-89	124.0	23.2	1240
1990-99	110.0	19.0	1110

Source: ***Harwood et al. 2002.***

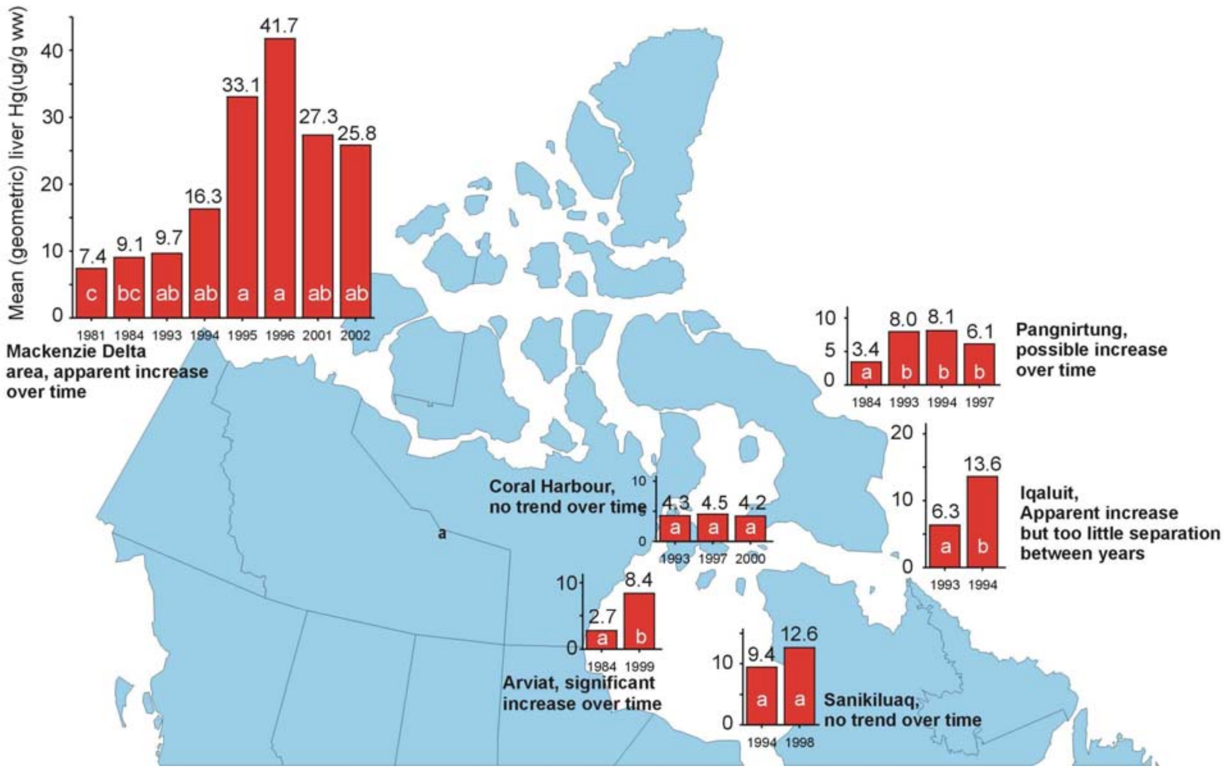
Studies of beluga teeth suggest that industrialization has led to a substantial increase in mercury accumulation by beluga whales that summer in the estuary of the Mackenzie River (Figure 4.3-3). Levels of mercury in the liver of belugas in this area are higher than those found elsewhere in the Canadian Arctic, and appear to have increased since 1981 (Figure 4.3-4).

FIGURE 4.3-3
MERCURY IN MODERN AND PRE-INDUSTRIAL TEETH OF BEAUFORT SEA BELUGA WHALES
(Outridge *et al*. 2002)



Source: CACAR II 2003, p. 80.

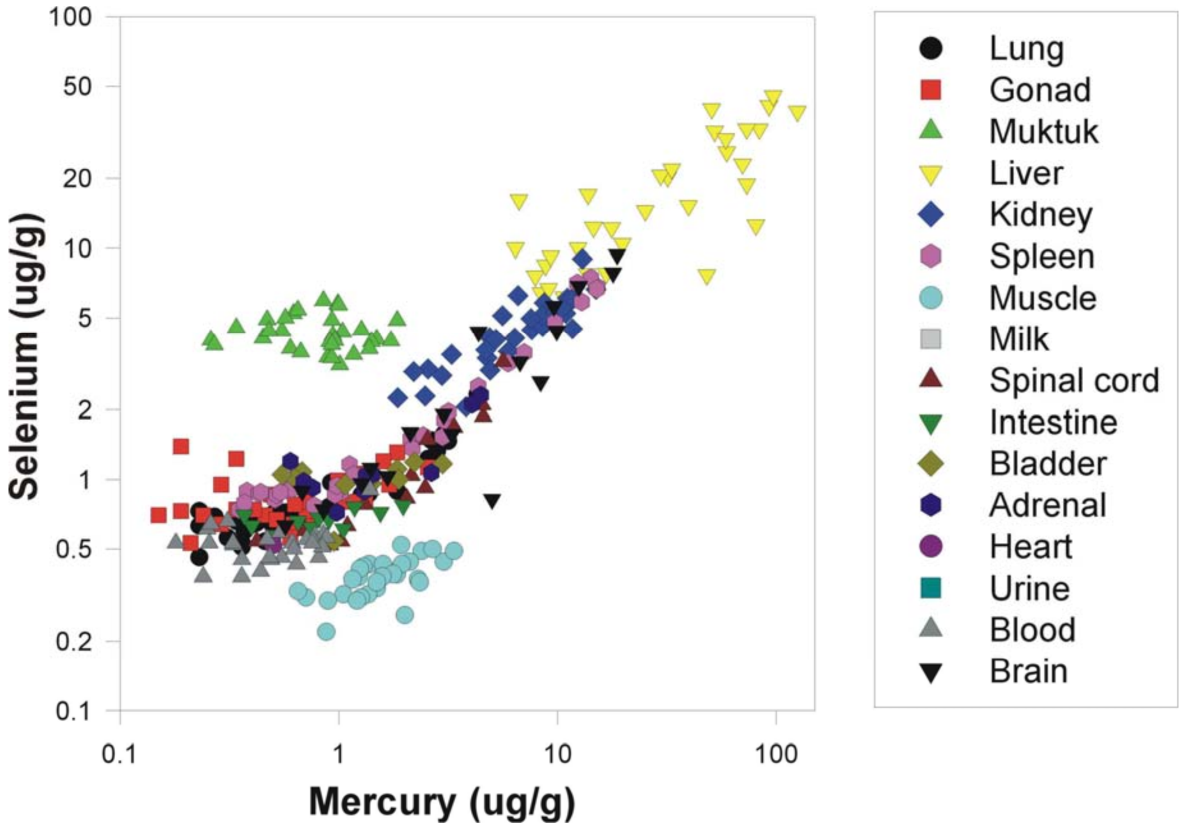
FIGURE 4.3-4
MEAN TOTAL MERCURY CONCENTRATIONS IN BELUGA LIVER



Source: Stewart and Lockhart 2005).

The levels of mercury and selenium vary greatly among different organs of belugas from the Mackenzie Delta (Figure 4.3-5). Mercury concentrations were considerably higher in liver than in other organs, and the level of selenium relative to mercury was relatively low in muscle and high in muktuk. The relationship between mercury and selenium may be important because the presence of selenium can ameliorate the toxicity of mercury (Eaton *et al.* 1981). Only about 6% of the total mercury in liver tissue is present as neurotoxic methylmercury (Lockhart *et al.* 1999). However, other tissues, such as muscle, can have a much higher proportion of methylmercury (Wagemann *et al.* 1998). Some belugas may contain sufficient mercury in their tissues that is could pose a toxicity risk to them (CACAR II 2003).

FIGURE 4.3-5
TOTAL MERCURY AND SELENIUM (µg/g WET WEIGHT)
IN ORGANS OF BELUGA WHALES



Source: Hyatt et al. 1999.

While belugas accumulate high levels of persistent organic pollutants in their blubber (e.g., PCBs from 3500 to 6000 ng/g), typically intermediate between those found in polar bears and ringed seals, temporal trends have not been found (de March *et al.* 1998; Macdonald 2000). Much lower levels are found in the muktuk.

ix) Why is it happening?

The rate of removal of belugas from the Eastern Beaufort Sea stock is small in relation to the expected maximum net productivity rate of this stock, which has an index of abundance of 19,629 belugas (Harwood *et al.* 1996). It is also smaller than historical harvests (Nuligak 1966). However, the annual harvest rate can vary by a factor of two from year to year (Harwood *et al*. 2002). There are no trends in the size of males or females in the harvest over the 30-year period of monitoring.

The accumulation of mercury by belugas is likely related to industrial development (Outridge *et al*. 2002). Pathways by which mercury and manmade organic pollutants enters the Arctic marine food chain are complex and likely to change with shifts in industrial activities and environmental conditions (Macdonald *et al*. 2003b).

x) What does it mean?

Current beluga harvests are believed to be sustainable (DFO 2000; Harwood *et al*. 2002). The low rate of removal, continued availability of large and old individuals after centuries of harvesting, and the apparent stability of the size and age structure of the catch in recent years, support this conclusion. Annual fluctuations in the harvest are likely related to a variety of factors, including changes in the need for beluga products and weather, but these have not been quantified.

Mercury concentrations observed in the meat and muktuk of belugas exceed the Health Canada human consumption guideline of 0.5 µg/g (ww) for commercial fish and 0.2 µg/g (ww) for subsistence fisheries (Macdonald 2000). There is also potential for the dietary intake of muktuk to exceed recommended daily intake levels of various organic contaminants, including PCBs.

xi) What is being done about it?

The Inuvialuit hunters and Canada Department of Fisheries and Oceans prepared the Beaufort Sea Beluga Management Plan (FJMC 1998) to address the management and conservation of belugas in the Canadian Beaufort Sea. Under the Inuvialuit-Inupiat Beaufort Sea Beluga Whale Agreement (2000), Canadian and Alaskan hunters have agreed to share information and co-manage the harvest to conserve the Eastern Beaufort Sea stock.

Work is ongoing internationally to reduce the use of persistent organic pollutants and to identify and reduce levels of new contaminants (AMAP 2004). There are a number of initiatives under the Northern Contaminants Program to inform consumers about the results of contaminants studies and to gather further samples (http://www.ainc-inac.gc.ca/ncp/).

xii) What are the information gaps?

The size of the Eastern Beaufort Sea beluga stock is unknown, so the rate of removal must be estimated. However, stock size is probably much larger than the index of abundance, which is currently used to assess rate of removal. Data are needed on the range, movements, site fidelity, stock structure, and reproductive potential of these belugas (DFO 2000; Harwood *et al.* 2002; CIMP 2005). These data are necessary for developing population models and assessing sustainable harvest potential. Harvest monitors could gather data on the reproductive status and history of harvested belugas that would be useful for assessing the reproductive potential of the population. Little is known of the biological effects of contaminants on belugas, or about temporal trends in their accumulation of persistent organic contaminants in the Beaufort Sea region.

4.3.3 MEQ Indicator – Ringed Seal

The ringed seal (*Phoca hispida*) is smaller and more common and numerous in coastal waters of the Beaufort Sea and Amundsen Gulf than the bearded seal (*Erignathus barbatus*), which is the only other seal species common in the Beaufort Sea (Stirling *et al.* 1977; Smith 1987). As a mid-level consumer, it is a keystone species in the Arctic food web between fish and invertebrates, and foxes, polar bears, and people. Inuvialuit harvested an average of 1085 ringed seals annually over the period 1988 to 1997 (Inuvialuit Harvest Study 2003).

Ringed seals can maintain breathing holes through the landfast ice (Smith 1987; Reeves 2001). This enables them to inhabit nearshore habitats year-round, and to use the more stable ice as a birthing platform. Birth lairs are built in snowdrifts on the ice. Melting conditions that cause the lair to collapse or ice to dissipate before the pups are ready to leave the lair and feed on their own may increase mortality from predation, thermal stress, and starvation (Harwood *et al*. 2000; Stirling and Smith 2004).

Because individuals are present year-round in the coastal waters the ringed seal has been considered a sedentary species, well suited for local contaminants monitoring. In reality, individual seals are very mobile. Animals tagged near Holman Island range northeast to M'Clintock Channel, southeast to Bathurst Inlet, and southwest to Cape Bathurst; those tagged at Paulatuk range west into the Bering and Chukchi seas, some 2625 km (http://www.beaufortseals.com/telemetry.htm). These movements may confound the interpretation of population surveys and contaminants data.

Its widespread occurrence, importance to humans, availability from the harvest, and sensitivity to change in the ice environment makes the ringed seal a useful and cost-effective species for monitoring environmental productivity and the effects of climate change (Stirling and Oritsland 1995). These animals are also useful for monitoring contaminant bioaccumulation, although the sources of these contaminants may be obscured somewhat by their movements.

xiii) What is being measured?

- **body condition**
- **ovulation rate**
- **contaminants**
- **recent pups in the harvest**
- **population density**
- **harvesting**

The annual seal harvest has been estimated from commercial sales records and harvest studies (Stewart *et al.* 1986; Reeves *et al*. 2001; Inuvialuit Harvest Study 2003; Stephenson 2004). While not always directly comparable, these data do provide a rough estimate of the trend over time in harvest removals over the past 50 years. The seal harvest was not monitored in 1998-2001, but since 2002 has been monitored by DFO (Stephenson 2004).

Ringed seals taken in the subsistence harvest at Holman have been sampled annually since 1992 (Harwood *et al.* 2000; L. Harwood, DFO Yellowknife, pers. com. 2005). About 100 animals are examined each year to assess their body condition (fatness) and two parameters of seal reproduction, ovulation rate and recent pups in the harvest. These parameters were selected because they varied with changes in the seal population during work in the same area in 1971-78 (Smith 1987), and because it was possible and practical to monitor these aspects over the long-term through a harvest-based study in the community of Holman (Harwood *et al.* 2000; (http://www.beaufortseals.com/monitoring.htm). Teeth are collected from the seals for aging, and tissue samples have been collected periodically since 1972 for contaminant analyses (e.g., Smith and Armstrong 1975, 1978; Addison and Smith 1998; Stern and Addison 1999; CACAR II 2003). The Holman samples represent the most complete temporal data set for contaminants in seals in the Canadian Arctic (CACAR II 2003), and a valuable source of data for monitoring ocean health (Strain and Macdonald 2002). Studies to collect similar data have been undertaken at the other NWT coastal communities, but do not as yet provide a time series sufficient for useful trend analysis.

Systematic aerial surveys of the distribution and abundance of ringed seals hauled out on the ice of the Beaufort Sea and western Amundsen Gulf were conducted in 1974 through 1979 (Stirling *et al.* 1977, 1982). They are being repeated in the area of the Devon Nearshore Lease, using the same flight paths, each June from 2003 through 2007 (Smith and Harwood 2004). The value of these surveys for long-term monitoring is limited by the wide variability introduced by differences in the ambient weather conditions, timing of breakup, and other factors (Moulton *et al.* 2002). They do provide useful seasonal information on seal densities among areas and habitats, but further work is required before temporal trends can be assessed.

xiv) What is happening?

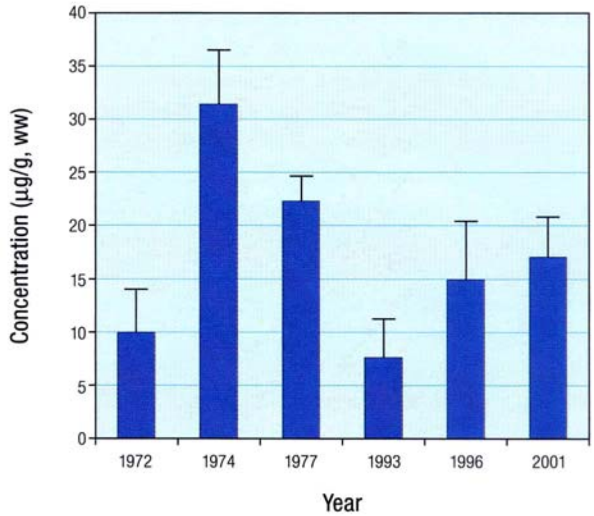
Despite an increase in the human population, the harvest has declined over the past 50 years. Annual removals were probably highest in the 1960s and 1970s, a period when sealskin prices were high (Stewart *et al.* 1986; Reeves *et al.* 2001). At Holman, for example, an average of 2,324 (STD 1312; n = 8 years) sealskins were traded annually to the Hudson Bay Company over the period 1961-74, with an unknown number of animals harvested for subsistence (Reeves *et al.* 2001). Harvests declined substantially in the 1980s following a collapse in sealskin prices related to the 1982 European ban on the import of skins from newborn harp and hooded seal pups. A strong subsistence harvest has continued, but there is no longer a substantial harvest of seals for the commercial sale of pelts. Over the period 1988-97, Holman hunters harvested 839 animals on average annually for subsistence (Inuvialuit Harvest Study 2003).

In the mid 1970s significant declines were observed in seal ovulation rate and proportion of young seals in the harvest at Holman and Sachs Harbour, after which they increased at both areas (Stirling 2002) (Figure 4.3-4). The body condition of adult female seals ($\geq$ 7 years of age) at Holman was poorest in 1974, which was a particularly heavy ice year (Harwood *et. al*. 2000; Stirling 2002). Fewer than half of the adult females examined that year were reproducing, compared to normal years when most reproduce. A widespread decline in the seal population of the Beaufort Sea-Amundsen Gulf area was also observed between 1974 and 1975 (Stirling *et al.* 1977), and again in the mid 1980s concurrent with heavy ice conditions (Stirling 2002). A similar decline may have occurred in the mid-1960s (Stirling *et al.* 1977). In contrast, 1998 was a year with a particularly early breakup and long period of open water (Harwood *et al*. 2000; http://www.beaufortseals.com/monitoring.htm). Many starveling pups were found while the older animals were in good condition. Apparently the early breakup provided favourable energetic conditions for the older animals but caused some pups to be weaned before they were ready, particularly those at the periphery of the seal breeding habitat.

The proportion of pups in the harvest fluctuated markedly and was not closely matched to ovulation rate the previous year (Harwood *et al.* 2000). The harvest is sensitive to weather and ice conditions that influence the availability of pups to hunters at breakup. Consequently, the proportion of pups in the harvest may not be a particularly good measure with which to assess population status or recruitment.

Average mercury concentrations in Holman ringed seals varied significantly over the 30-year period 1972-2001 (CACAR II 2003) (Figure 4.3-6). Higher concentrations were found in 1974 and 1977 (Smith and Armstrong 1978) compared to 1993 and 1996 (Wagemann *et al*. 1996). Results from 2001 were also significantly higher than in 1993 (Muir *et al*. 2002).

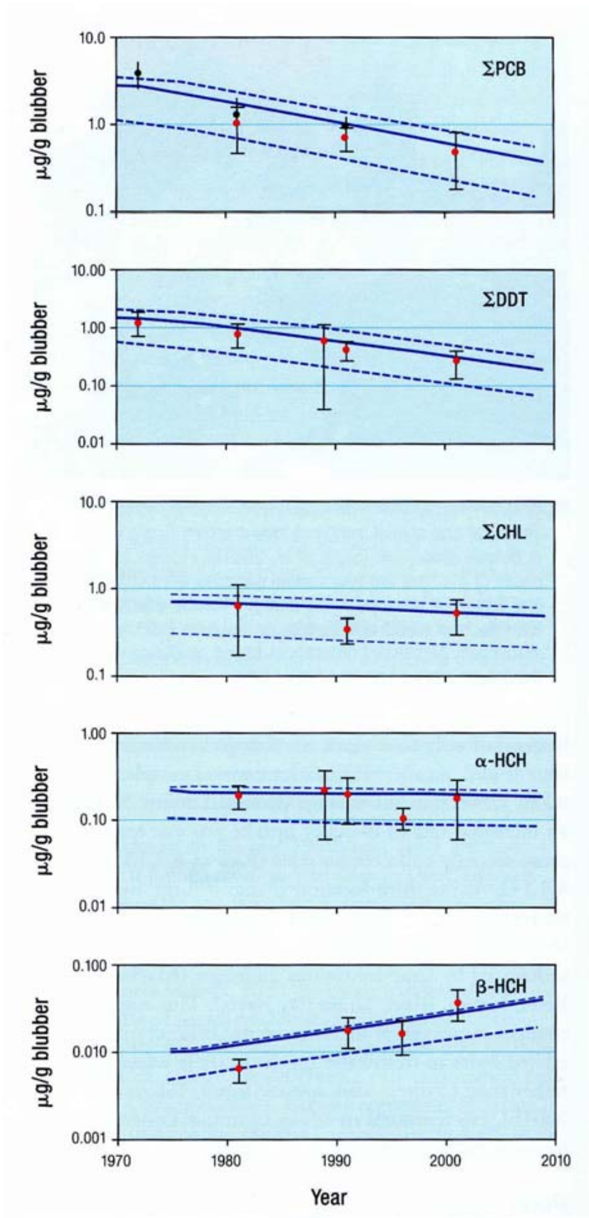
FIGURE 4.3-6
TEMPORAL TRENDS IN TOTAL MERCURY IN THE LIVER OF RINGED SEALS AGED 5 – 15 YEARS FROM HOLMAN, NWT (1972-2001)



Source: CACAR II 2003, P. 79.

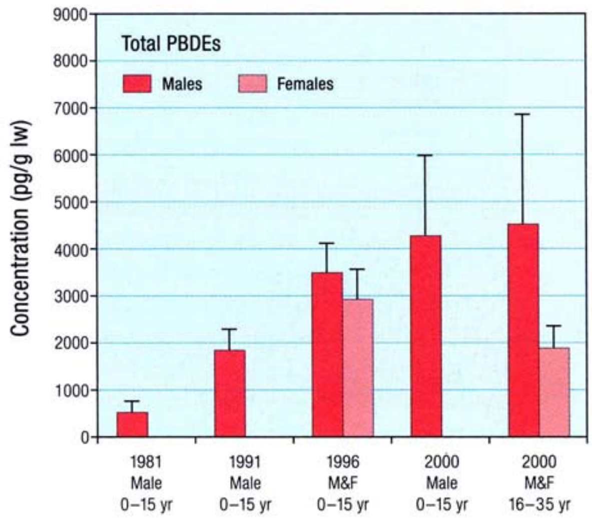
The levels of persistent organochlorine contaminants in the blubber of ringed seals from Holman are changing over time (Figure 4.3-7). The direction of change varies with the class of contaminant. Significant declines in the concentrations of polychlorinated biphenyls (∑PCB) and dichloro-diphenyl-trichloromethane (∑DDT) have been observed; chlordanes (∑CHL) and hexachlorocyclohexanes (∑HCH) have not changed significantly, but the α-HCH : β-HCH ratio has decreased since the early 1980s (CACAR II 2003; AMAP 2004). The change in ratio is a direct result of cessation of technical HCH use and the relative persistence and lag in delivery of β-HCH compared to α-HCH. Sample archiving has enabled researchers to revisit samples taken from ringed seals in the 1980s and 1990s, to establish that there has been a dramatic increase in the concentrations of polybrominated diphenyl ethers (PBDEs) in ringed seal blubber over the past two decades (Figure 4.3-8).

FIGURE 4.3-7
OBSERVED AND PREDICTED TRENDS OF POPS CONCENTRATIONS FOR RINGED SEALS FROM HOLMAN ISLAND



Source: CACAR II 2003, PG. 82 After Hickie 2002.

FIGURE 4.3-8
INCREASING CONCENTRATIONS OF TOTAL BR2-BR7 PBDE CONGENERS IN RINGED SEAL



Source: Macdonald et al. 2003a, p. 77, after Ikonomou et al. 2002)

xv) Why is it happening?

Changes in the ice environment have been linked to drastic changes in seal populations and reproduction over periods of several years at intervals of about 10 years. These population changes are likely related directly or indirectly to short-term changes in the ice environment, but disease and migration may also be contributing factors (Stirling *et al*. 1977).

Higher mercury levels in the western Arctic than in the eastern Arctic have been attributed to differences in the natural background concentrations (Wagemann *et al*. 1995, 1996), but factors underlying temporal differences in mercury concentrations are not well understood.

Body burdens of persistent organic pollutants reflect changes in the global use patterns of these chemicals--albeit with some time lag, and differences in their availability to the food web (Addison and Smith 1998; CACAR II 2003; AMAP 2004). The relatively recent development and use of fire retardant compounds in manufacturing has led to a global increase in the emissions of PBDEs. These persistent organic contaminants reach the Arctic by long-range transport mechanisms, and have increased sharply in Arctic biota over the past several decades.

xvi) What does it mean?

Ringed seals appear to be very sensitive to changes in their ice environment, which is a key determinant of their energetics and reproductive success. This makes them a very useful indicator of climate change. Their contaminants levels provide a good indication of trends in the bioaccumulation of some toxic substances by the pelagic food web, and in the exposure of polar bears and people to these persistent contaminants.

xvii) What is being done about it?

Studies are underway under CACAR (CACAR II 2003), AMAP (AMAP 2004), and the Northern Contaminants Program (http://www.ainc-inac.gc.ca/ncp/summ0405/nt_e.html) to identify emerging contaminants and to assess their impacts on marine biota. The main objective of the Northern Contaminants Program is to reduce and, wherever possible, eliminate contaminants in traditionally harvested foods, while providing information that assists informed decision making by individuals and communities in their food use (http://www.ainc-inac.gc.ca/ncp/index_e.html).

Continued community-based monitoring through harvest-based projects has been recommended as a good method for gathering data on trends in seals (CIMP 2005). These studies collect biological data that are otherwise difficult and expensive to gather, and provide more useful information than studies that simply enumerate the harvests.

xviii) What are the information gaps?

DFO has identified the need for data and information on the range, movements, site fidelity and stock structure of ringed seals, and on the impacts of climate change related to reduced ice cover (CIMP 2005). Better understanding of seal movements is needed to determine whether animals in the Beaufort Sea belong to a single population or several populations, and the extent to which seals in the Holman area represent those elsewhere in the NWT. The biological implications to ringed seals of the contaminants they accumulated are not well understood. The species' ability to adapt to changes in the ice environment is unknown, and a very important information gap.

Seals collected at Holman have been aged by counting growth rings in the dentine (Smith 1987; L. Harwood, DFO Yellowknife, pers. comm. 2005). This method tends to underestimate seal ages, particularly those of older animals with worn teeth (Stewart *et al.* 1996). It limits the comparability of data with that from elsewhere, and its use for age-specific determinations. Aging seals using growth rings in the tooth cementum provides a better record of age (Stewart *et al*. 1996). Consideration should be given to aging seals in future using both dentine and cementum to facilitate comparison and age-specific analyses.

4.3.4 MEQ Indicator – Red-throated Loon

Red-throated loons (*Gavia stellata*) arrive at offshore leads in the Beaufort Sea - Amundsen Gulf area in late May or early June (Dickson 1992, 1993, 1994; Dickson and Gilchrist 2002). They remain there until the shallow tundra ponds they nest beside have open water. These birds are a widely distributed, conspicuous nesting species near the coasts in summer. They typically nest within 8 km of the coast or a large lake and, because the shallow nesting ponds winterkill, those near the coast travel there to forage for fish to feed their young. The young remain at the nest until they are fledged, longer than most other marine bird species in the region. Because they migrate, the value of adult loons for local contaminant monitoring is limited. However, because of their coastal diving habit they are very vulnerable to local oil pollution.

The Canadian Wildlife Service studied the abundance, breeding effort, and breeding success of the red-throated loon along the mainland NWT coast between 1985 and 1989 (Dickson 1992). The species was identified as suitable for monitoring environmental changes caused by offshore oil and gas development in the Beaufort Sea. Little inter-annual variation was observed in the number of loons with breeding territories or in breeding effort, but there was wide variation in breeding success. Breeding success was recommended as the key indicator for monitoring purposes. However, due to wide natural inter-annual variability, only large changes in productivity (31-43%) will be detectable with statistical certainty (95%). This may make human-induced change difficult to identify, and necessitates long-term study to identify natural trends. The 1980s surveys have not been repeated, so trend over time in this indicator cannot be established.

Females pass very little in the way of contaminants on to their eggs, but feed the chicks almost entirely on small coastal marine fish (L. Dickson, CWS, Edmonton, pers. com. 2005). Consequently, contaminants accumulated by the young before they leave the nest originate from the local marine environment, making them a useful indicator of the local availability of contaminants to fish-eating marine birds. However, the available data are insufficient to assess trends over time.

4.3.5 MEQ Indicator – Anadromous Dolly Varden and Arctic Char

Anadromous Dolly Varden (*Salvelinus malma*) and Arctic char (*Salvelinus alpinus*) spawn and winter in fresh water but feed at sea during the summer. The two species are often confused with one another. Dolly Varden typically occurs west of the Mackenzie, while fish to the east and on the Arctic islands are typically Arctic char (Reist *et al*. 1997). These fish are low to mid-level consumers that eat freshwater and marine invertebrates and smaller fish, and are eaten by ringed seals, belugas, and people.

Both species show a high degree of fidelity to their natal spawning and over wintering areas, and because of their extensive seasonal movements a particular wintering stock may be vulnerable to harvest at numerous locations. Dolly Varden from the Rat and Big Fish rivers, for example, are vulnerable to capture along the Yukon coast, near Shingle Point, in the Mackenzie mainstem, and in their individual river systems (DFO 2001). This predictability makes them attractive to harvesters and vulnerable to over-harvesting. These fish are harvested in quantity for subsistence, sport and commercial sale, and are important to the culture and economy of the Inuvialuit (Stewart *et al*. 1993; Inuvialuit Harvest Study 2003; Stephenson 2004) and Gwich'in (Stewart 1996; MacDonald 1998a,b; http://www.grrb.nt.ca/Harvest_Study.html). Arctic char tagged at the Hornaday River system show very strong fidelity to that system (DFO 1999). They feed along the nearby coast and winter in the river system, and tagging studies have not found strays entering other systems. They appear to be vulnerable to harvest only by the Inuvialuit from Paulatuk.

Arctic char have been recommended as an ideal species for assessing the impacts of climate change on Arctic fishery resources (Reist *et al*. 2004). Char populations may become more productive over the short term in response to increased nearshore production, but over the long term may be replaced by other salmonid species that move northward to take advantage of increasingly favourable habitats.

xix) What is being measured?

- **population size**
- **catch per unit effort**
- **age at harvest**
- **fish condition**
- **harvest**
- **contaminants**

Most studies to assess the health of these fish populations have subsampled commercial, subsistence, or sport harvests for data on growth, reproduction, population structure, and condition (Ratynski *et al*. 1988; Stewart and Ratynski 1995; Stewart 1996). Some of these studies have provided tissue samples for contaminant analysis; others have estimated population size based on mark-recapture studies or counts at weirs. Typically, the annual harvest of fish from a particular population is uncertain and difficult to establish, due in part to the species' extensive movements. The sampling programs often have been undertaken in response to community concerns over resource depletion or fish quality. Studies conducted at the Rat (DFO 2001), Big Fish (DFO 2003), and Hornaday (DFO 1999) rivers are examples of this, but are unusual in their longevity and continuity. Populations in other rivers such as the Kagloryuak, Kuujjua, Kuuk, and Nalaogyok have also been studied. While some data are available on contaminants of the fish in these systems, they are too few to provide a useful assessment of the trend of accumulation over time (Macdonald 2000).

At the Rat River, annual harvest estimates are available beginning in 1986, with some earlier data back to 1972 (DFO 2001). Timing of the peak of the fishery at various locations has been recorded since 1996. Sex, maturity and catch-per-unit-effort (CPUE) data are available from the subsistence fishery since 1989. Mark-recapture estimates are available for the population in 1989, 1996, and 1998.

Population estimates based on mark and recapture studies (Peterson method) and weir counts are available for Dolly Varden in the Big Fish River in 1972, 1984, 1987, 1988, 1991, 1993, and 1998 (DFO 2003). Not all of these studies are directly comparable.

Data are available on the annual harvest of Arctic char from the Hornaday River since 1968 (DFO 1999; Stephenson 2004). Data on the catch-per-unit-effort by the fishery, mean age of male and female fish, and the condition of fish in the harvest were also collected between 1990 and 1998.

xx) What is happening?

At the Rat River, harvest levels appear to have been reduced since the 1970's (DFO 2001). This decline may be related to closure of the commercial fishery in 1985. The CPUE has fluctuated about an average of 38 fish/100 net m/24 h since 1986; the use of smaller gillnets (89 mm stretched measure) was discontinued by 1998. There were no trends in mean age over time, and the absence of smolts in the harvest after 1998 is likely related to the change in mesh size of the gillnets used in the fishery.

At the Big Fish River, abundance estimates suggest that the population was reduced substantially between 1972 and 1988, and has not recovered (DFO 2003). Over the five-year period ending in 1998 with the most recent population estimate, the number of adult fish in the population appears to have remained relatively stable at about 4000 fish.

The Paulatuk fishery removes the larger char from the Hornaday River stock (DFO 1999). While fish are now harvested only for subsistence, there was a substantial commercial harvest until 1986, when commercial fishing was suspended in response to concern that the stock was being over-harvested. Harvests peaked over the period 1976 to 1984, and since then have declined slowly, except in 1995 when there was a particularly large harvest (DFO 1999; PCWG 2002; Stephenson 2004). Both the CPUE and mean age of harvested fish were low from 1995 through 1997, but have recovered somewhat since then (DFO 1999; PCWG 2002). The condition of fish has varied among years, but was particularly good in 1993 and 1998, which were both years of light regional sea-ice conditions and early breakup.

xxi) Why is it happening?

In the Rat River stock, fluctuations in CPUE may be correlated with timing of the run, with unusually high CPUE in 1998 when the run was three weeks earlier than usual and unusually low in 2000, when the run was three weeks later than usual (DFO 2001).

The apparent lack of recovery of the Big Fish River stock, despite closure of the fishery in 1987, may reflect habitat changes rather than harvesting pressures (DFO 2003). The water level of the fish hole is much lower than in the 1960s and 1970s; salinity of this spring-fed pool has declined; and the mean annual air temperature in the area has been increasing. Seismic events in the region may have reduced the rate of groundwater flow into the site.

The Hornaday River stock does not appear to be capable of sustaining harvests of the magnitude taken in 1995 (DFO 1999). Changes in the data suggest that the subsistence harvest in 1995 removed a substantial proportion of the older fish in the population, and that it took several years for the stock to recover. Light ice conditions may result in better coastal feeding conditions.

xxii) What does it mean?

Results from the harvest monitoring suggest that the Rat River Dolly Varden stock is stable and sustaining the present harvest level (ca. 2000 AD) (DFO 2001). The timing of the run varies considerably in response to environmental conditions.

While empirical evidence is lacking, both fishers and scientist agree that habitat changes may be limiting the recovery of the Big Fish River Dolly Varden stock (DFO 2003). These changes must be taken into account in management of this fishery, which is further complicated by the vulnerability of this stock to harvest by mixed-stock fisheries along the coast and in the Mackenzie River system.

While the sustainable harvest level for the Hornaday char stock cannot yet be determined, care must be taken to avoid over-harvesting. There may be important linkages between sea ice cover and the condition of anadromous fishes.

xxiii) What is being done about it?

Working groups have been established to coordinate fishing pressure on these shared populations and prevent over-harvesting. A community based fishery plan has been in place at Aklavik and Fort McPherson for the Rat River since 1995, and community-based sampling program has monitored the fishery since 1989 (DFO 2001; http://www.fjmc.ca/rat_river_charr.htm). The fishery plan recommends that the annual harvest of Dolly Varden by the food fishery not exceed 2000 fish and specifies the number of nets, their size, and depth restrictions.

The West Side Working Group (WSWG) made up of fishers from Aklavik, community elders, biologists, and managers is working to develop a long-term, objectives-based Fisheries Management Plan for the Big Fish River and other rivers between the Mackenzie River and the Canada/Alaska border (DFO 2003). In addition, the Aklavik Inuvialuit Community Conservation Plan has designated the Fish Hole and riparian areas of the Big Fish River as Management Category E to protect them from development.

Char in the Hornaday River are now managed under the Paulatuk Char Management Plan, which was developed by the Paulatuk Char Working Group (PCWG) (DFO 1999; PCWG 2002). This plan has recommended the closure of Fish Holes between Coalmine and Aklak Creek to fall and winter fishing and a limit of 2000 on the total annual harvest of char from the river (PCWG 2002). The community does not have an alternative source of anadromous Arctic char nearby (MacDonell 1989), and wishes to conserve the stock and ensure its long-term well being (DFO 1999). Consequently, fishing for alternate species has been encouraged and fishers will be supported if they fish at alternate locations.

Completion of the Inuvialuit Harvesting Study in 1997 left a void in harvest monitoring that has been partially filled for fish and seals by DFO (Stephenson 2004). The department has made a number of recommendations for future harvest monitoring programs, including:

- their incorporation in any future fishing management plans; and that they
- document the harvest of specific stocks at specific locations or times;
- inquire about the capture of rare or unusual species;
- use door-to door rather than written surveys;
- be conducted co-operatively by several government departments;
- focus on the period(s) of highest harvesting activity in their area; and
- target sensitive species or areas, particularly those at the greatest risk of impact from increasing oil and gas activity.

xxiv) What are the information gaps?

Information is not currently collected on smolts from the Rat River population. Their collection would provide more information on recruitment, but would also increase mortality. Linkages between habitat changes and the failure of the Big Fish River population to recover are uncertain. If habitat changes are limiting the fishery, knowledge of the mechanisms by which they act could improve the ability to manage regional fisheries in response to changing climatic conditions.

Sustainable harvest levels, the vulnerability of stocks at various locations, and the reasons for declining harvests are uncertain for most stocks. Linkages between sea ice cover and the condition of anadromous fishes have not been examined, but may be important determinants of the sustainable harvest level.

4.3.6 MEQ Indicator--Sea Ice

Changes in the ice cover have major implications for the Beaufort Sea/Amundsen Gulf area. The reduction or loss of seasonal ice cover would reduce or eliminate an important component of the freshwater budget (i.e., sea ice melt) and threaten existing ecosystems (Carmack and Macdonald 2002; Macdonald *et al*. 2003b). How changes in the ice environment affect each species will depend very much on the exact way in which the animal or plant uses ice, and on the plasticity of that use.

A reduction or elimination of seasonal ice cover would:

- initially increase and eventually reduce or eliminate polynya and ice edge habitats that are important areas for the exchange of energy between ecosystems;
- alter seasonal tidal spectrums by reducing or eliminating the damping effects of ice cover;
- reduce or eliminate coastal ice scour and the redistribution of sediment and other material trapped within the ice or carried on its upper or lower surface;
- increase surface salinity by reducing or eliminating the release of fresh water at the surface by melting sea ice. With a thinner layer of low salinity water at the surface, and longer open water period, wind mixing should make more nutrients available to primary producers in the upper water column (Dunbar 1993).
- make more light available to primary producers;
- increase surface water temperature and reduce or eliminate freezing of macrophytes;
- reduce or eliminate ice habitats, their associated biota and seasonal biological production; and
- trigger trophic changes, from the bottom up and top down (Macdonald *et al*. 2003b).

A shorter duration of ice cover when coupled with stronger winds may:

- increase re-working of coastal habitats by wave action, leading to increases in longshore sediment transport and changes in spit and delta formation;
- increase winter mixing and upwelling, and thereby the nutrients available to phytoplankton (Carmack and Macdonald 2002);
- favour more severe wave development and more frequent storm surges; and
- lead to warmer temperatures and earlier melt in coastal areas. The rate of evapotranspiration would increase and could lead to drying of wetlands and lengthening of the growing season.

These changes are not necessarily linear and there may be a few threshold responses and non-linear surprises. There may also be unexpected cumulative effects when impacts of climate change interact with those from other environmental stressors.

xxv) What is being measured?

- **duration of ice cover**
- **areal extent of seasonal ice cover**
- **ice draft**

Satellite passive-microwave observations have proven tremendously valuable for monitoring the duration and extent of sea ice coverage. Observations of Arctic ice began in December 1972, following the launch of the Electronic Scanning Microwave Radiometer (ESMR) on board NASA's Nimbus 5 satellite (Parkinson 2000b). The ESMR provided good-quality data for most of the period from January 1973 through October 1976, but had only one channel so the accuracy of derived ice concentrations was ±15% and ice types could not be distinguished from one another. Since October 1978, more advanced passive-microwave instruments aboard subsequent U.S., Canadian, and European satellites have provided a record of ice concentrations that is more accurate and distinguishes between different types of ice (Parkinson 2000b; Parkinson and Cavalieri 2002; http://ice-glaces.ec.gc.ca).

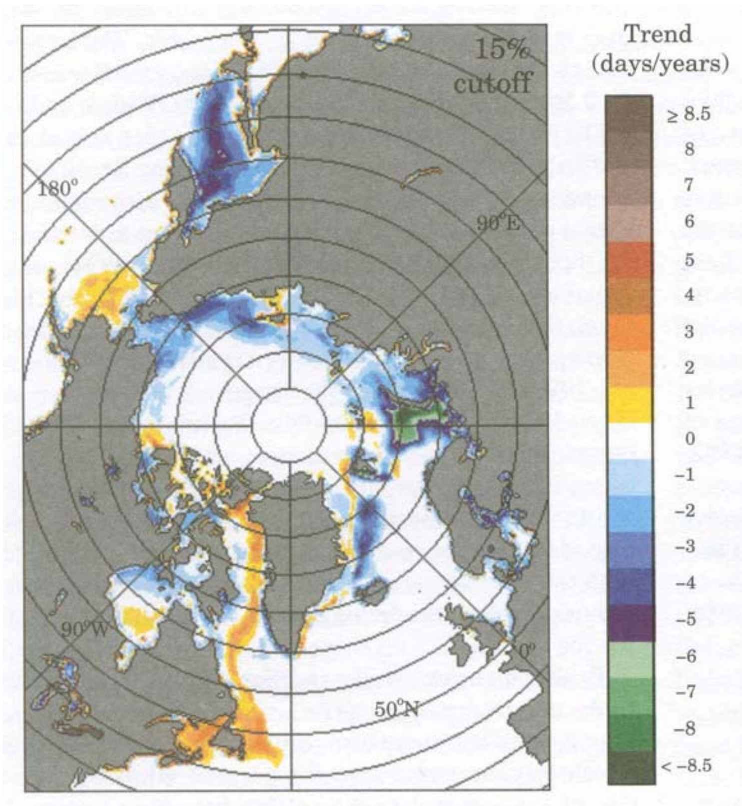
Ice draft has been measured since the late 1980s in the Beaufort Sea area using upward-looking sonar moored to the bottom of the ocean (Melling and Riedel 2004; http://www.aslenv.com/iceprofiler.htm), and using submarine-based upward looking sonars (Winsor 2001). Sea ice draft is a measure of the subsurface ice thickness, whereas the total thickness also includes the above-surface freeboard which accounts for about 10% of the ice thickness. In the past, the Canadian Ice Service also collected ice thickness data manually at stations along the NWT coast (http://ice-glaces.ec.gc.ca/). The length of the data record varies with station: Sachs Harbour (1956-86), Mould Bay (1949-97), Holman (1960-69), Cape Parry (1959-92), and Tuktoyaktuk (1971-77).

xxvi) What is happening?

The results of ice cover studies vary somewhat depending upon the area, parameters, and length of the observation record examined. Satellite observations suggest that there has been a general decrease in the duration and areal extent of the Arctic sea ice cover since the mid-1970s (Parkinson *et al*. 1999; Serreze *et al*. 2003; Johannessen *et al*. 2004). This is consistent with observations in Amundsen Gulf and the western Beaufort Sea, whereas the duration of sea ice cover increased slightly in the eastern Beaufort Sea (1979-96; Figure 4.3-9), as did the average sea ice concentration (1979-2000; Barber and Hanesiak 2004). Over the period 1978-2003, there was a slight decrease in the mean winter (March) ice concentration in the southeastern Beaufort Sea, but a slight increase in summer (September) (Johannessen *et al*. 2004). The increasing trend in ice concentration was greater over the period 1979-1996 than it was from 1979-2002 (Figure 4.3-10) (Rigor and Wallace 2004). This was due, at least in part, to record minima in the extent of the sea ice cover in September of 1998 and 2002 (Serreze *et al.* 2003). Since that analysis was completed, low sea ice cover was also reported in September of 2003 and 2004 (Stroeve *et al*. 2005).

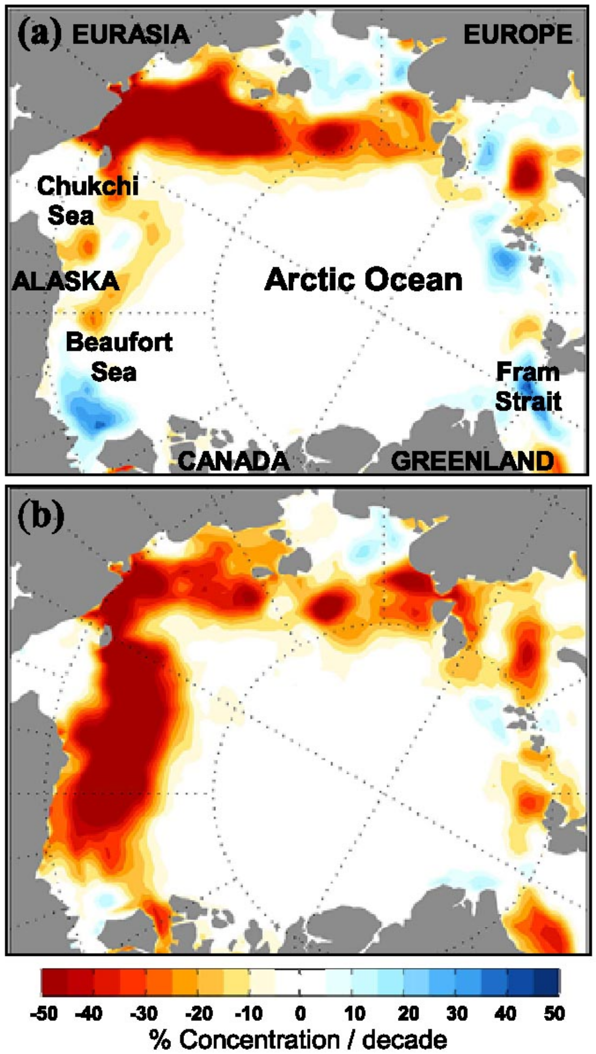
Between September 1991 and March 2003, a small thinning trend (0.07 m/decade) was found in ice draft at a site over the Mackenzie Shelf of the Beaufort Sea (Figure 14) (Melling et al. in press). The net change did not exceed the accuracy of measurement (±0.1 m), and was not statistically significant since seasonal and inter-annual variability are large. Ice was unusually thin during 1997-98. The trend toward greater ice concentration (0.12 m/decade), meaning more ice in summer, was significant at the 93% level. Data from conventional ice reconnaissance suggest that there has been little net change in ice conditions over the Beaufort shelves during the past 36 years, despite dramatic a decrease in summertime ice over the south-western Canada Basin to the northwest and a significant (1.6±0.4°C at 95% confidence) increase in air at Tuktoyaktuk, 100 km to the south (Melling et al. in press) (Figure 15).

FIGURE 4.3-9
TRENDS IN THE LENGTH OF THE SEA ICE SEASON FROM 1979 THROUGH 1996



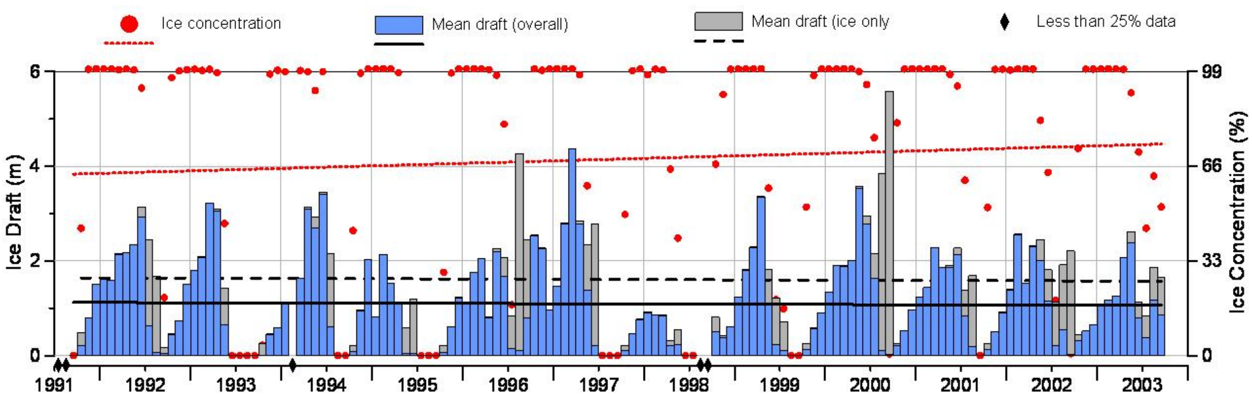
Source: ***From CACAR II 2003, (P. 79)***.

FIGURE 4.3-10
TRENDS IN SEPTEMBER SEA-ICE CONCENTRATION FROM MICROWAVE SATELLITE DATA FROM 1979-1996 (A) AND 1979-2002(B)



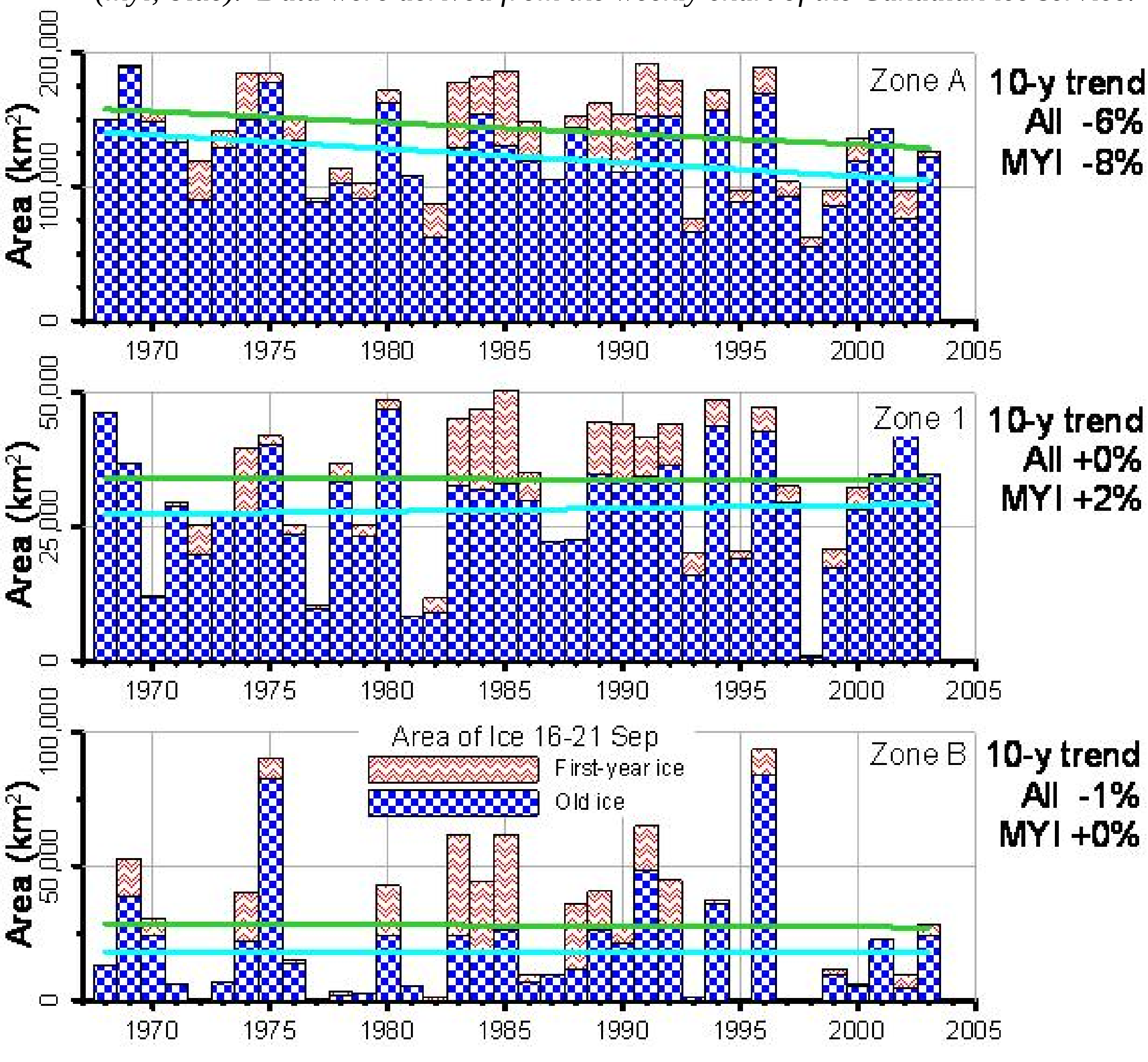
Source:Rrigor and Wallace 2004,(p. 2).

FIGURE 4.3-11
MONTHLY AVERAGE CONCENTRATION AND DRAFT OF PACK ICE ON THE MACKENZIE SHELF OF THE BEAUFORT SEA, 1991-2003.



Source: Figure courtesy of H. Melling, DFO Sidney, pers. com. 2005.

FIGURE 4.3-12
AREA COVERED BY SEASONAL AND MULTI-YEAR PACK ICE IN THE BEAUFORT SEA IN MID-SEPTEMBER, 1968-2003.
Zone a (top) is the domain of perennial pack ice in the Canada basin, zone 1 (middle) is the eastern continental shelf west of banks island, and zone b (bottom) is the southern continental shelf west of Cape Bathurst. Trend lines are shown for all ice (green) and for multi-year ice (myi; blue). Data were derived from the weekly chart of the Canadian ice service.



Source: Figure courtesy of H. Melling, DFO Sidney, pers. com. 2005.

xxvii) Why is it happening?

While the satellite sea ice data show changes in the sea ice, they do not explain their causes or predict future changes (Parkinson and Cavalieri 2002). If the recent observed changes are tied most closely to Arctic warming (Martin *et al*. 1997; Serreze et al. 2000; Johannessen *et al.* 2004) that continues, then the ice cover should continue to decrease; but, if the sea-ice changes are tied more closely to oscillatory changes in the climate system, such as the North Atlantic Oscillation and the Arctic Oscillation (Deser *et al.* 2000; Morison *et al*. 2000; Parkinson 2000a), then sea ice cover will likely fluctuate (Parkinson and Cavalieri 2002). Local, regional, and internal processes may play a more significant role in shaping the persistence of Arctic change than has previously been recognized (Barber and Hanesiak 2004; Overland and Wang 2005). Changing snow cover, ice circulation and ice deformation may obscure the direct effects of warming on seasonal pack ice (Melling et al. in press).

xxviii) What does it mean?

Uncertainty in the underlying causes of changes in sea ice cover means that extrapolations of recent sea ice conditions into the future should be done with caution (Parkinson 2000a).

xxix) What is being done about it?

There is intense concern over the potential impacts of significant changes in the ice cover on the Arctic ecosystem and on human activities. Large-scale research programs such as CASES and Arctic Net, which were described above, are underway to improve monitoring capabilities and assess changes in the sea ice. The results of these and other studies feed into programs such as the International Program for Climate Change (IPCC) and Arctic Monitoring and Assessment Program (AMAP), which consider their implications.

xxx) What are the information gaps?

While synoptic data are available for the duration and extent of ice cover, they are not available for ice thickness. This is a very important gap in the information necessary to understand changes in ice cover and develop predictive climate models (Laxon *et al.* 2003). The factors underlying natural variability of the sea ice cover, atmospheric couplings, and linkages between changes in sea ice and other aspects of the marine ecosystem are also uncertain. These information gaps limit the ability to predict how ice cover may change over time, and how species and biological communities may respond over the short or long term, and from one area to another. Longer time series are needed to detect and understand changes in the sea ice (Melling et al. in press). The role of sea ice in moving contaminants from one part of the environment to another also needs to be better understood.

4.4 RECOMMENDATIONS

Effective monitoring for changes in the health of the marine environment caused by human activities will not be possible until the natural variability of the indicators used for environmental

monitoring has been established. Many natural cycles in the Arctic are affected by the dramatic climatic shifts associated with the Arctic Oscillation, which follows a 5 to 7 year cycle. Only once the effects of these cycles, and of other environmental linkages, are understood will it be possible to differentiate changes that occur naturally in a healthy marine environment from those that are caused by human activities.
Lack of information on natural variability affects all types of monitoring, even that of contaminants and sea ice. The contaminants, because variability related to age of capture and diet is not well understood; the sea ice, because it may follow a cycle of natural variability that exceeds the length of our comparable records. Short-term (<5 y) research programs of the sort used to gather baseline environmental data for impact studies cannot properly assess natural variability, nor can collecting samples every 5 years circumvent the problem.

The solution to this problem lies in the design and completion of elegant long-term (>10 y) research designed to develop appropriate monitoring strategies, and the implementation of these strategies over the long term. Effective monitoring requires the proper choice of monitoring parameters; well-designed studies that are repeatable reliably over time; long-term support and continuity; the cooperation and participation of local communities, to ensure the integrity and success of sampling programs; and competent personnel.

Government scientists are often best equipped to conduct this research, and to provide the resources, expertise and long-term stability required for this work. However, fiscal planning must extend past the next fiscal year or next election. Otherwise the existing, short-sighted planning horizon that has failed to provide adequate resources for environmental monitoring will continue. This short-term approach simply does not support the type of science required for environmental monitoring, particularly cumulative impact assessment, and the problem is too important to ignore. New, ongoing research by the CASES and Arctic Net projects may provide the data necessary to establish natural variability, but only if their support base is maintained over the long term.

At present, community-based harvest sampling programs are the cornerstones of work to assess temporal trends in the marine environment of the NWT. This top-down approach may be a cost effective method of identifying that change is occurring, but it does not provide the information necessary to understand why change is occurring. Linkages between trends in these harvested species and their environment, and between contaminant burdens and species' health must be established. The applicability of these relatively local studies to other geographical areas, populations, or biota in the region must also be established. Establishing linkages between the quality, extent and duration of sea ice cover and biological indicators may be particularly important for understanding natural trends and assessing the effects of any climate change. The archiving of aging structures and banking of tissue specimens will be critical to future retrospective work on temporal trends in contaminants.

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