https://ntrs.nasa.gov/search.jsp?R=20060020227 2018-07-25T05:58:56+00:00Z

Source of Acquisition
NASA Goddard Space Flight Center

Possible Effects of Climate Warming on Selected Populations of Polar Bears (*Ursus maritimus*) in the Canadian Arctic

Ian Stirling

Canadian Wildlife Service

5320 122 St

Edmonton, AB. T6H 3S5 Canada

(ian.stirling@ec.gc.ca)

Claire L. Parkinson

NASA Goddard Space Flight Center

Cryospheric Sciences Branch/Code 614.1

Greenbelt, MD 20771 USA

Key words: climate warming, polar bear, sea ice, Arctic

ABSTRACT. Polar bears are dependent on sea ice for survival. Climate warming in the Arctic has caused significant declines in coverage and thickness of sea ice in the polar basin and progressively earlier breakup in some areas. In four populations of polar bears in the eastern Canadian Arctic (including Western Hudson Bay), Inuit hunters report more bears near settlements during the open water period in recent years. These observations have been interpreted as evidence of increasing population size, resulting in increases in hunting quotas. However, long-term data on the population size and condition of polar bears in Western Hudson Bay, and population and harvest data from Baffin Bay, make it clear that those two populations at least are declining, not increasing. While the details vary in different arctic regions, analysis of passive-microwave satellite imagery, beginning in the late 1970s, indicates that the sea ice is breaking up at progressively earlier dates, so that bears must fast for longer periods during the open water season. Thus, at least part of the explanation for the appearance of more bears in coastal communities is likely that they are searching for alternative food sources because their stored body fat depots are being exhausted. We hypothesize that, if the climate continues to warm as projected by the IPCC, then polar bears in all five populations discussed in this paper will be stressed and are likely to decline in numbers, probably significantly so. As these populations decline, there will likely also be continuing, possibly increasing, numbers of problem interactions between bears and humans as the bears seek alternate food sources. Taken together, the data reported in this paper suggest that a precautionary approach be taken to the harvesting of polar bears and that the potential effects of climate warming be incorporated into planning for the management and conservation of this species throughout the Arctic.

INTRODUCTION

Polar bears (*Ursus maritimus*) are distributed throughout the ice-covered waters of the circumpolar Arctic in 20 relatively discrete subpopulations (Lunn et al. 2002). Initially, and until recently, scientists have considered harvesting to be the principal threat to polar bear populations because of their low reproductive rate. In response to unregulated harvesting throughout most of its circumpolar range in the 1960s, the five nations with polar bears in their jurisdictions negotiated the Agreement on the Conservation of Polar Bears, signed in Oslo, Norway in 1973 (Prestrud and Stirling, 1994; Appendix I in Stirling 1988). Article II of the Agreement states: "Each Contracting Party shall take appropriate action to protect the ecosystems of which polar bears are a part, with special attention to habitat components such as denning and feeding sites and migration patterns, and shall manage polar bear populations in accordance with sound conservation practices based on the best available scientific data." In Canada, "sound conservation practices" has been interpreted to include sustainable hunting by aboriginal people, regulated through an annual quota, usually estimated from the results of a scientifically conducted (mark-recapture) population assessment. In Nunavut, it is also government policy that Inuit hunters' "traditional knowledge" of wildlife should play a role equal to scientific knowledge in evaluation of wildlife management practices.

In February 2005, the Department of Environment of the Government of Nunavut, Canada, announced an overall increase in polar bear quotas in the Territory of 28.5%, varying between 0 and 64% in different subpopulations. For the majority of populations in which the quotas were increased, the estimates of population size, and the sustainable quotas from them, were determined on the basis of scientific studies (mark-recapture, survival rates, and reproductive

rates). However, in four populations -- Western Hudson Bay (WH), Foxe Basin (FB), Baffin Bay (BB), and Davis Strait (DS) (Fig. 1) -- Inuit traditional knowledge was the primary information source that influenced the increase in quotas. More specifically, Inuit hunters in these four populations have reported seeing more bears in recent years around settlements, hunting camps, and sometimes locations where they have not (or only rarely) been seen before, resulting in an increase in threats to human life and damage to property. Most of the bears seen were along or near the coast during the open water season in fall. In those regions, the increased number of bears seen has been interpreted as evidence that the populations were growing, and this led to an increase in the annual quotas (Table 1).

Unfortunately, there has been no documentation of the actual numbers of bears that hunters or other residents in Nunavut have seen over time, dates or locations of sightings, approximate age and sex composition of bears causing perceived problems, or other information such as the physical condition or fatness of problem bears killed which could be independently evaluated or the number of trips to areas during which no or few bears were seen. Regardless, Inuit observations of wildlife are generally regarded as accurate (e.g., Nakashima 1993), so the conclusion that hunters are seeing more bears in recent years, at times and places where they used to see them less frequently, can be considered reliable. However, to date, there has been no attempt to evaluate whether explanations other than an increase in population size, could account for the increase in polar bear sightings. For example, additional possible factors include changes in the distribution or abundance of prey species, or sea ice, both of which the bears depend on for their existence.

Although some quantitative data exist on distribution, abundance, and life history parameters of prey species in the areas occupied by these polar bear populations (e.g., Lunn et al. 1997; Ferguson et al. 2005; Stirling 2005), in general they are inadequate for doing more than speculating about their possible relevance to trends in polar bear populations. A possible exception is documentation of changes in numbers of harp (*Pagophilus groenlandicus*) and hooded seals (*Cystophora cristata*) and the species composition of polar bear diets in Davis Strait (Healey and Stenson 2000; Iverson et al. 2005).

In contrast, over the last 20 years or so, there has been considerable documentation of significant reductions in sea ice cover in several parts of the Arctic, thinning of multiyear ice in the polar basin and in Hudson Bay, and changes in the dates of breakup and freeze-up of the sea ice, likely as a consequence of climate warming (e.g., Parkinson and Cavalieri 1989; Parkinson et al. 1999; Rothrock et al. 1999; Comiso and Parkinson 2004; Gough et al. 2004a; Gough et al. 2004b; Gagnon and Gough 2005). Because polar bears are dependent on sea ice, changes in the distribution and abundance of sea ice have the potential to significantly impact the health of polar bear populations (Stirling and Derocher 1993; Derocher et al. 2004). Furthermore, in WH at least, recent studies have confirmed that, apparently in response to climate warming, the ice is melting earlier, and bears are declining in both condition and population size (Stirling et al. 1999; Gagnon and Gough 2005; Regehr et al. unpublished data).

Because of more sightings of polar bears on land near settlements and outpost camps in recent years, the Nunavut Department of Environment concluded that the populations have been increasing in WH, FB, BB and DS (Fig. 1). These regions have in common that the sea ice melts

completely, or very nearly so each summer, so that all bears in the population must spend several months on shore surviving on their stored fat reserves and whatever limited and unpredictable food sources they might find on land. In this paper, we evaluate patterns of sea ice breakup and freeze-up in each of these areas to test the hypothesis that at least part of the explanation for sightings of more polar bears in these populations might be related to changes in sea ice, possibly resulting from climate warming, and are not necessarily indicative of increases in population size. Although no increases in numbers of polar bears have been reported from Eastern Hudson Bay (EH) (including James Bay, Fig. 1), we have included it in our study because, like the other four populations, polar bears in that area also must fast on their stored fat reserves for several months during the open water period in summer and fall.

Materials and methods

Study Area

The five regions for which we analyze patterns of ice breakup are based on the accepted boundaries of the management zones used to manage polar bears by the respective government agencies in Canada and Greenland (Lunn et al. 2002; Fig. 1). These boundaries were delineated using studies of movements of tagged bears of all age and sex classes, adult females with satellite radio collars, and genetic studies (e.g., Paetkau et al. 1999; Taylor et al. 2001; Stirling et al. 2004). The boundaries we use for WH, EH, and BB are based on Lunn et al. (2002), whereas the boundaries we use for FB and DS are modified (Fig. 1). Although it is known from movements of tagged and radio-collared bears that some individuals move back and forth through Hudson Strait, the majority appear to remain either in FB or DS, so we do not include Hudson Strait in our analysis of ice in either zone. For DS, our eastern boundary extends only

as far as the approximate maximum limit of ice in winter (e.g., Gloersen et al. 1992), in order to exclude the large area that remains unfrozen in the zone defined by Lunn et al. (2002). Although occasional polar bears are recorded along the coast of Newfoundland, most of the radio-collared individuals did not go south of the southern tip of Labrador (Taylor et al. 2001; Stirling, unpublished data) so we used that as the limit for DS.

Satellite sea ice data

Satellites have collected multichannel passive-microwave data on the Arctic sea ice cover since late 1978. These data allow the frequent monitoring of the ice cover to a resolution of approximately 25 km. The data are collected day and night, in all seasons of the year, and under all weather conditions. They take advantage of the facts that the microwave emissions of ice and liquid water are quite different and that at many microwave wavelengths the radiation can readily pass through most clouds (e.g., Parkinson 2000b).

We use two satellite passive-microwave data sets, one from NASA's Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR) and the other from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSMI). The Nimbus 7 SMMR was launched in October 1978 and collected data through mid-August 1987, mostly on an every-other-day basis. The first SSMI was launched on the DMSP F8 satellite in June 1987 and subsequent SSMIs have been launched on later DMSP satellites, together providing a daily record of the sea ice cover for almost all of the period since June 1987. We use the SSMI record through the end of 2004, the last full year prior to this study.

The SMMR and SSMI radiative data are converted to sea ice concentrations (percent areal coverages of sea ice) through a multichannel algorithm based on polarization and gradient ratios. Details on the algorithm can be found in Gloersen et al. (1992), and details on matching the SMMR and SSMI records can be found in Cavalieri et al. (1999). The ice concentrations are used to determine ice extents and ice areas on a regional and hemispheric basis. Ice extents are calculated by summing the areas of all pixels (grid elements, approximately 25 km x 25 km) with at least 15% ice concentration in the region of interest; and ice areas are calculated by summing the products of the area and ice concentration of all pixels with at least 15% ice concentration. Results have shown considerable interannual variability in the arctic sea ice cover, especially when examined regionally, but have also shown a strong signal toward lessened sea ice extents and areas since late 1978 (Parkinson and Cavalieri 1989, Johannessen et al. 1995, Maslanik et al. 1996, Bjorgo et al. 1997, Parkinson et al. 1999, Johannessen et al. 2004).

For this paper, we calculated ice areas for the polar bear regions identified in Figure 1. We divided these ice areas by the area of the respective region, to obtain daily percent ice coverages. In the SMMR years, when data were generally collected only every other day, temporal interpolation was performed, linearly from the preceding and following dates, to provide values for the days without data. Similarly, missing data throughout the data set were filled in by interpolation, resulting in a complete daily data set. From the completed data set, we determined the date in each year when the ice cover fell to below 50%, then calculated the trend in that date over the course of the 1979-2003 record. We selected a 50% cutoff as reflective of ice breakup following Etkin (1991), Stirling et al. (1999), and Gagnon and Gough (2005).

Polar bears

In WH, measurements of the straight line body length and axillary girth were taken from about 100-300 immobilized polar bears each fall in order to estimate their weights and overall body condition (Stirling et al. 1989, 1999). To control for variation in the dates on which individual bears were captured between years, weights were scaled to a constant capture date of 21 September by adding or subtracting 0.85 kg to or from the weights of all bears for each day they were caught before or after that day (Derocher and Stirling, 1992). The results of analyses of condition data from adult males and adult females accompanied by dependent young were given elsewhere (Stirling et al. 1999; Regehr et al, unpublished data). In this paper, we present the mean estimated mass of lone (and thus possibly pregnant) adult female polar bears in Western Hudson Bay from 1980 through 2004.

Recording of observations of problem bears varies widely among areas. However, at Churchill, Manitoba (Fig. 1), Conservation Officers record all problem bears reported in the area throughout the year although most occur during the open water season. Similar records are not kept in Nunavut. Bears killed there because they threatened human life or property are usually recorded as "problem kills", but if a regular harvest quota tag is used for the hide, it may or may not be recorded as having been a problem bear.

RESULTS AND DISCUSSION

Western Hudson Bay

Figure 2a presents a time series of the daily percent ice coverages in Western Hudson Bay, from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR and SSMI data. Figure 2b presents a plot of the Julian dates by when the percent ice coverage decreased to 50% or less, following the winter maximum, for the years 1979-2004.

Although these data show some interannual variability, there is a clear overall trend toward progressively earlier sea ice breakup. A linear least squares fit through the data points of Figure 2b yields a slope of -0.75 ± 0.25 days/year, i.e., breakup is, on average, coming about 7-8 days earlier per decade. The earliest breakup came in the second to last year of our data record, 2003, although was followed by a late breakup in the last year of the record, 2004. The second earliest breakup came in the middle of the record, in 1990, and was followed two years later by the latest breakup, in 1992 (the cold year that followed the eruption of Mt Pinatubo in 1991; e.g., Soden et al. 2002).

Similar trends showing progressively earlier breakup of the sea ice in WH and EH were documented by Stirling et al. (1999, 2004), Gough et al. (2004a), and Gagnon and Gough (2005). Gagnon and Gough (2005) also reported significant autocorrelation in areas of Hudson Bay for freeze-up and break-up dates.

Skinner et al. (1998) reported that the temperature at Churchill and over the adjacent sea ice has warmed at 0.3-0.5° C/decade during April through June from 1950 to 1990, and Gagnon and Gough (2005) reported that the annual temperature at Churchill has increased 0.5° C/decade over the period 1971-2001. Gough et al. (2004b) further found sea ice thickness to be dependent

in some areas of Hudson Bay on pre-conditioning of the waters in the previous summer season. Thus, progressively earlier breakup in WH (Fig. 2b) is significantly correlated with, and most likely caused by, climate warming.

In WH (Fig. 1) all bears in the population must fast for at least four months during the ice-free season and pregnant females must do so for eight months because they are giving birth to cubs in maternity dens at about the time the rest of the population can return to the ice to hunt seals again (Ramsay and Stirling 1988). Gagnon and Gough (2005) and Stirling et al. (2004) reported that the sea ice is breaking up about 3 weeks earlier than it did 30 years ago, an estimate consistent with the trend line in Figure 2b. Consequently, over those decades, the entire polar bear population of WH has been forced to come ashore to begin fasting progressively earlier and for a longer duration (Stirling et al. 1999; Lunn and Stirling, unpublished data). There is a statistically significant relationship between the date of breakup and the condition of the bears when they come ashore: i.e., the earlier the breakup the poorer the condition of the bears and conversely (Stirling et al. 1999). Because of progressively losing condition, survival of cubs, subadults, and bears 20 years of age and older has declined, resulting in a reduction in the total size of the WH polar bear population from about 1200 in 1988 to about 950 in 2004, a decline of about 21% (Regehr et al., unpublished data). The reduction in total population size has probably also been accelerated by overharvesting since the annual quota has probably not been sustainable for at least 10 years.

Figure 3 shows the decline in mean estimated mass of lone (and thus possibly pregnant) adult female polar bears in WH from 1980 through 2004. Between 1980 and 2004, the average

weight has declined by about 65 kg (from 295 to about 230 kg), a change that is statistically significant ($F_{1,23} = 15.1$, $r^2 = .394$, $p < 0.001$). Atkinson and Ramsay (1995) and Derocher and Stirling (1996) demonstrated a strong relationship between the body weight of an adult female in the fall and the subsequent survival of her young, i.e., fatter females produced larger cubs which survived better. Further, Derocher et al. (1992) reported that no females weighing less than 189 kg in the fall were recorded with cubs the following spring, suggesting that value approximates a minimum weight, the limit below which they can no longer successfully reproduce. Given that the current average weight of lone adult females in the fall is about 230 kg, if their mean weight continues to decline at a similar rate, most will stop producing cubs within the next 20 to 30 years. Further, since the average weights of those that do produce cubs will also decline if the trends in temperature and ice breakup documented to date continue as predicted, the weights of cubs will also decline as will their survival.

Figure 4 shows that the number of problem bears being handled by the Conservation Officers in Churchill in Western Hudson Bay has increased dramatically over the past decade (Fig 4a) and that there is a statistically significant relationship between the date of breakup of the sea ice and the number of bears handled (i.e., the earlier the ice breaks up, the more problem bears there are and conversely) (Fig. 4b). Over a similar time period, residents of the Nunavut coast of western Hudson Bay, from Arviat to Rankin Inlet, have also reported seeing many more polar bears in the ice free period, especially in recent years, though there has been no systematic documentation of numbers. Since the progressively earlier breakup is also significantly correlated with a decline in the bears' physical condition (Stirling et al. 1999), it seems clear that many bears, especially subadults, are exhausting their stored body fat before freeze-up when

they can return to the ice and hunt seals. Thus, it seems likely that the reason for increasing numbers of polar bears coming into coastal settlements in WH is because they are hungry and not because their population is increasing. This conclusion is supported by an extensive analysis of the population data collected continuously since the 1980s that indicates unequivocally that the polar bear population declined from about 1200 in 1989 to 950 in 2004 (Regehr et al., unpublished data).

Although much of the reason for the decline in the bears' condition in recent decades is related to progressively earlier breakup (which shortens the time available to them to hunt and store fat to fast through the open water season), other factors may be involved as well. For example, Ferguson et al. (2005) and Stirling (2005) document a reduction in ringed seal recruitment, reduced survival of young, and a slight reduction in the pregnancy rates of adult females. The reasons for these changes are unclear, but it is possible that some factor related to the warming climate and loss of sea ice is having additional but unknown ecological effects on the marine ecosystem of Hudson Bay and hence on the distribution, survival, or availability of ringed seals. Gaston et al. (2003) documented a large-scale change in the diet of thick-billed murres (*Uria lomvia*) in northern Hudson Bay as the area of open water adjacent to the breeding colony increased greatly in size during the period that chicks were being fed. The loss of ice appeared to be caused by the warming climate, and the change in diet associated with increased open water suggests the possibility of a major shift in ecosystem dynamics. Lastly, warmer springs may cause ringed seal birth lairs to collapse prematurely or bring unseasonable rain that causes the birth lair roofs to collapse or wash away (e.g., Stirling and Smith 2004) leaving the young seals vulnerable to high levels of predation and exposure to the elements. Cumulatively, these

events may be having a negative effect on the ringed seal population on which polar bears principally depend in WH.

Foxe Basin

Figure 5a presents a time series of percent ice coverage in Foxe Basin from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR and SSMI data. Figure 5b presents a plot of the Julian dates by when the percent ice coverage decreased to 50% or less, following the winter maximum, for the years 1979-2004. As in Western Hudson Bay, there is a clear overall trend toward earlier ice breakup, this time with a linear least squares fit rate of -0.58 ± 0.19 days/year, i.e., ice coverage reducing to 50% of Foxe Basin earlier by about 6 days per decade. As was the case in Western Hudson Bay, the earliest ice breakup was in 2003.

Most previous examinations of trends in ice amounts or breakup times for Foxe Basin have considered that area together with Hudson Bay, and sometimes Hudson Strait, as a single unit (e.g., Parkinson et al. 1999). However, in examining the length of the sea ice season, much greater spatial detail is possible, and trends in the length of the sea ice season in Foxe Basin were determined to be slightly positive over the 1979-1986 period of the SMMR satellite record (Parkinson 1992) but slightly negative (a shorter ice season, longer open water season) when the record was extended, through the addition of SSMI data, to cover the period 1979-1996 (Parkinson 2000b). Heide-Jørgensen and Laidre (2004) examined several relatively small areas known to have open water in March and thus be of importance to marine mammals. They found that between 1979 and 2001, there was a steady trend toward the open water areas becoming larger, which is consistent with our results for the overall area.

The estimate of the size of the polar bear population of FB in 1996 was about 2100 (Table 1). On the basis of local reports of seeing more polar bears in recent years, it was assumed the population had increased so the "target" population was increased to 2300 and the quota was raised from 97 to 106. No other studies that might support or negate that conclusion have been conducted since 1996. Other factors, such as climate warming in particular, might also be contributing to the sighting of more bears around settlements and outpost camps, but these were not considered. It is unknown at this point whether or not the increased quotas are sustainable.

Baffin Bay

Figure 6a presents percent ice coverages in Baffin Bay from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR and SSMI data. Figure 6b presents a plot of the Julian dates by when the percent ice coverage decreased to 50% or less, following the winter maximum, for the years 1979-2004. As in the cases of Western Hudson Bay and Foxe Basin, there is a clear trend toward earlier ice breakup, this time with a linear least squares fit rate of -0.66 ± 0.20 days/year, i.e., ice coverage reducing to 50% of Baffin Bay earlier by 6-7 days per decade. The latest ice breakup (as determined by reduction to below 50% ice coverage) came in 1996, and the trend toward earlier ice coverage has been rapid since then, although the overall trend from 1985 to 1996 had been toward later breakup (Fig. 6b).

Most previous analyses of trends in sea ice have not treated Baffin Bay separately but as part of a continuum extending south through Davis Strait and the Labrador Sea (e.g., Gloersen et al. 1992; Parkinson et al. 1999). When taken together, past reports have indicated a trend toward

increasing total amounts of sea ice (Stern and Heide-Jørgensen 2003) or a fluctuating, perhaps cyclical behavior (Parkinson et al. 1999; Parkinson 2000a). Heide-Jørgensen and Laidre (2004) reported that, unlike Davis Strait or Foxe Basin, between 1979 and 2001 the small areas of open water being used by overwintering marine mammals were becoming smaller. Data on sea ice presented by Born (2005) indicated no detectable trend.

It is uncertain how to interpret the data on polar bear population studies in relation to local reports of increased numbers of bears seen around settlements and outpost camps. Taylor et al. (2005) estimated a population of 2,100 in 1997, capable of sustaining a total sustainable harvest of 88 (in which they assumed an annual harvest by Greenland of 18-25 bears). However, Born (2002) reported an average harvest of 83 ± 13 (SD) from 1993 to 1998 from Qaanaaq and Upernavik alone (Fig 1) Born and Sonne (in press) reported that from 1999 to 2003 the harvest for this region averaged 115 bears per year (SD=52.9; range: 68-206 bears). Thus, a conservative estimate of the cumulative total of the polar bear harvest in Baffin Bay, after incorporating the Nunavut increases, is likely to be in the vicinity of 150-200+. To be sustainable, the population of polar bears in Baffin Bay would have to be somewhere in excess of 4000 (based on estimates of sustainable harvests of females by Taylor et al. 1987), or about double the scientifically determined estimate of population size in 1997 (Taylor et al. 2005). While it is possible that the population has increased since the population study was completed, this seems unlikely considering the harvest it has sustained since then, while the possibility that it has doubled is remote. Consequently, it is unlikely the current annual harvest level for this population is sustainable. The trend toward progressively earlier breakup of the sea ice and increases in numbers of bears seen around settlements is similar to WH though there are no

recent data on either the condition of bears on land or survival of cubs and subadults. However, from the available data it is unlikely that more polar bears are being seen near settlements during the open water period because the population has increased. No data are available on trends in numbers, reproductive rates, or distribution of ringed seals or other prey species.

Davis Strait

Figure 7a presents percent ice coverages in Davis Strait from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR and SSMI data. Figure 7b presents a plot of the Julian dates by when the percent ice coverage decreased to 40% or less, following the winter maximum, for the years 1979-2004. We used 40% ice cover as the cutoff in DS, in contrast to 50% in the other regions, because in some years the percent ice coverage in DS never rose above 50% of the area we delineated based on historical information. The maximum percent ice coverage in DS varies considerably more between years than in WH, FB, or BB, being below 50% in 1981, 1986, and 2004, but above 85% in 1983, 1984, and 1993 (Fig. 7a). Correspondingly large interannual fluctuations are apparent in the timing of ice breakup (Fig. 7b), making a linear trend less meaningful, although the long-term slope of the trend line for Davis Strait is a non-statistically significant -0.64 ± 0.69 days/year. In contrast, the trend is decidedly negative from 1991 on (Figure 7b).

Similar to Baffin Bay, previous studies of sea ice in Davis Strait have tended to consider the area as part of a single unit extending from Baffin Bay in the north through the Labrador Sea to the south (e.g., Gloersen et al. 1992; Parkinson et al. 1999). Long-term cooling was reported up to 1990 (Skinner et al. 1998); a trend toward increasing total amounts of sea ice was reported by Stern and Heide-Jørgensen (2003); and a fluctuating, perhaps cyclical behavior, with sea ice

increases 1978-1983, decreases 1983-1988, increases 1988-1993, and decreases 1993-1999, were reported by Parkinson et al. (1999) and by Parkinson (2000a), and are clearly reflected in Figure 7a. In recent years, within Davis Strait and the Labrador Sea there are areas where the temperatures are increasing and the amount of sea ice is decreasing. In central Davis Strait, Comiso and Parkinson (2004) calculated that the surface warming between the August 1981-July1992 period and the August 1992-July 2003 period was about 2.6° C, one of the greatest changes documented in the entire circumpolar Arctic. Similarly, Born (2005) reported significant declines in the total annual ice cover in selected study areas in both the eastern and western portions of Davis Strait. Heide-Jørgensen and Laidre (2004) also examined several relatively small areas known to have open water in March and found that between 1979 and 2001 there was a trend toward those areas becoming larger.

The present status and trend of the polar bear population of DS, which is shared by Nunavut, Labrador, Québec, and Greenland, is unknown. Based on a mark-recapture population study conducted on the coastal sea ice in spring from 1976 to 1979, Stirling et al. (1980) estimated the total population in the area of southeastern Baffin Island at 700-900. That estimate was probably biased low because it was done in spring when there would have been an unknown number of bears much further offshore and inaccessible on the pack ice so they were not available for capture. In a subsequent study limited to the Labrador coast, from 1991 through 1994, no attempt was made to estimate population size but the number of bears captured per hour of helicopter search in those years was approximately double what it had been during previous studies in 1979 (Stirling and Kiliaan 1980; Stirling, unpublished data). Large adult males were abundant which, subjectively at least, is also a fairly reliable indicator that the

population was not being overharvested. For example, when the polar bear population in the Southern Beaufort Sea was being overharvested in the late 1960s and early 1970s, bears older than 10 years were almost nonexistent but became abundant as the population recovered (Stirling 2002).

Between when the first polar bear studies were done in DS and the Labrador coast in the 1970s and when the later more limited studies were done in northern Labrador in the 1990s, there were significant increases in the abundance of harp (*Pagophilus groenlandicus*) and hooded seals (*Cystophora cristata*) (Bowen et al. 1987; Stenson et al. 1997; Healey and Stenson 2000). This is particularly relevant to the likely increase in the size of the polar bear population between the late 1970s and early 1990s because both these seal species pup in large numbers near the outer edge of the pack ice in March (Fig. 1), and are much less wary of being approached to close distances by humans or polar bears (Stirling, unpublished observations). Furthermore, both harp and hooded seals are much larger than ringed seals so that, on average, there is much more fat available to a bear from each animal killed. Fat is the most favored part of a seal to a polar bear (Stirling and McEwan 1975) and is digested with a digestive efficiency of 98% (Best 1975) after which it can be stored on the body of the bear for use up to several months later when food may not be available (Nelson et al. 1983). Outside the pupping and breeding season, harp seals also haul out on the ice in variable sized groups and can often be approached closely enough by humans that they can be captured in a hand-thrown net for tagging. Similarly, periodic onshore winds along the northern Labrador coast during winter and spring sometimes compresses the ice sufficiently in some areas to cause harp seals to be temporarily stranded on the sea ice with limited access to water for escape from predators. Lastly, the harp seal population increased

from less than 2 million in the early 1970s to over 5 million by 2000. Taken together, the larger size, reduced wariness, and large numbers of accessible individuals has meant that polar bears in the Davis Strait population have had a very large accessible food base for two to three decades that other populations of polar bears have not. This is particularly relevant because, as demonstrated by Iverson et al. (in press) through examining fatty acids of DS polar bears, harp seals are by far the most important species in the diet of polar bears in that area, in contrast to the predominance of ringed seals in most other areas (Smith 1980; Stirling and Archibald 1977; Stirling and Øritsland 1995). Throughout Davis Strait, harp seals comprised 50% of bears' diets, which is consistent with the large increase in the harp seal population in this region. Off southern Labrador closer to the whelping patch (Fig. 1), harp seals accounted for 90% of diets. The highest proportion of hooded seals in polar bear diets were recorded in animals from northern Davis Strait, closest to the seals' northern whelping patch (Fig. 1).

In recent years, Inuit hunters in Nunavut have reported seeing many more bears around the coast of SE Baffin Island. Those observations, were interpreted as evidence of an increase in polar bear population size and consequently the Nunavut quota was increased by 12 (35%) from 34 to 46 (Table 1). From the limited available data, we suggest the DS population of polar bears increased to an unknown number between the late 1970s and the early 1990s, possibly in response to a greatly increased food supply and an increased amount of sea ice habitat through the 1980s (Fig 6b). However, the harp seal population stabilized in the early 1990s and between 1993 and 2002 there was a significant reduction in ice cover and a rapid reduction of sea ice in spring, conditions which have previously been correlated with increased mortality of pups (Sergeant 1991; Johnson et al. 2005) and generally support the hypothesis that juvenile mortality

in some recent years has been up to 5 times greater (Anonymous 2003). While the present population size and trend of the DS polar bear population are unknown, it seems likely that the population is no longer increasing and could, in time, be negatively affected by the trend toward less sea ice and earlier breakup if the climate continues to warm as is predicted.

Hudson Strait

Although Hudson Strait was not considered directly in this study, Heide-Jørgensen and Laidre (2004) examined several relatively small areas known to have open water there in March, as part of an assessment of the importance of polynya areas to wintering marine mammals in Baffin Bay and adjacent areas. They found that between 1979 and 2001, there was a steady trend toward the open water areas becoming larger, which is consistent with the trends noted above for the adjacent regions. Their observations are generally consistent with other studies that have shown increasing length of the ice-free period in Hudson Strait and later freeze-up in northeastern Hudson Bay (Houser and Gough 2002; Gagnon and Gough 2005).

Eastern Hudson Bay

Figure 8a presents percent ice coverages in EH from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR and SSMI data. Figure 8b presents a plot of the Julian dates by when the percent ice coverage decreased to 50% or less, following the winter maximum, for the years 1979-2004. As in WH (Fig. 2), percent ice coverage consistently rose above 90% in winter, and reduction to 50% ice cover consistently occurred between Julian day 140 and day 195. In both portions of the Bay, the latest breakup occurred in 1992. In WH the earliest breakup came in 2003 (Fig. 2b), whereas in EH the earliest breakup came in 2001 and

2003 had a considerably later breakup, at least as indicated by the 50% ice percent cutoff (Fig. 8b). Taken as a whole, the trend toward earlier breakup in EH is weaker, especially with the later breakups in 2002-2004 and the seemingly random fluctuations earlier (Fig. 8b). The trend value, at -0.14 ± 0.31 days/year, has the lowest magnitude of any of the regions and is less than 20% of the magnitude of the –0.75 days/year slope for WH. However, in other studies that considered smaller components of EH separately (i.e., the southern coast of Hudson Bay and James Bay) both statistically insignificant and significant trends toward earlier breakup were demonstrated (Stirling et al. 2004; Gagnon and Gough 2005).

We included EH in this study because the polar bears there, as in the four other regions discussed above, spend several months fasting on land during the open water season, in this case along the Ontario coast and on some of the small uninhabited islands in James Bay. In the mid-1990s, bears of each age and sex class in EH were in significantly better condition than their counterparts in WH during the open water season, probably because the ice breaks up later there so they have consistently had a longer time to feed before beginning their fast (Stirling et al. 1999). However, recent studies have confirmed a statistically significant trend toward progressively earlier breakup along the south coast of Hudson Bay (Gough et al. 2004a; Gagnon and Gough 2005), so that the duration of the open water season is increasing. Similar to the pattern already demonstrated in WH, the condition of polar bears in SH now also appears to have declined between 1984-86 and 2000-2004 (M. Obbard and M. Cattet, unpublished data, cited in Richardson et al. in press). Although these trends in bear condition and ice breakup were initially more difficult to detect in EH than in WH as explained above, we predict that if the climate continues to warm in that area, they will continue as presently projected.

The present status and trend of the polar bear population in EH are unknown. Despite the ecological similarities between EH and the other polar bear populations discussed above, there have not yet been reports of an increase in the number of sightings of EH bears that might lead to suggestions of population increase. However, it is possible this inconsistency may be explained by the distribution of Inuit settlements in the area. The only Inuit village in EH from which polar bears are hunted is Sanikiluaq in the Belcher Islands (Fig. 1). However, the first ice to break up in EH does so along the eastern coast of Hudson Bay (Gagnon and Gough 2005), with the result that polar bears rarely summer on land along the coast of either Québec or the Belcher Islands. Consequently, no conflicts with humans are reported from either area during the open water season. Instead, the polar bears remain on the ice until it finally breaks up along the Ontario coast (where the last ice remains each year) and finally go ashore there to fast until freeze-up in the fall (Prevett and Kolenosky 1982; Stirling et al. 2004). Unlike the coastal distribution of settlements in Nunavut, Indian settlements along the Ontario coast tend to be several kilometres inland, so that although people travelling on the coast see polar bears, there are few camps and no villages to attract hungry bears, apparently resulting in fewer reports of human-bear conflicts.

SUMMARY

There are five polar bear populations in the Canadian Arctic (including two shared with Greenland) in which the whole population must fast on shore for several months because all the sea ice melts completely. In four of these populations (WH, FB, BB, and DS) residents of coastal settlements have reported seeing more polar bears and having more problem bear encounters during the open water season, particularly in the fall. In those areas, the increased numbers of sightings have been interpreted as indicative of an increase in population size with the result that quotas for Inuit hunters were increased. In Western Hudson Bay, the decline in population size, condition, and survival of young as a consequence of earlier breakup of the sea ice brought about by climate warming have been well documented (Stirling et al. 1999; Regehr et al. unpublished data). In Baffin Bay, the available data suggest the population is being overharvested, so the reason for seeing more polar bears is unlikely to be an increase in population size. We suggest that the increase in numbers of sightings of polar bears in FB and DS may also be influenced by factors related to earlier breakup of the sea ice. In DS and WH, preliminary information suggest populations of seals being preyed upon by polar bears may also be affected by the effects of climate warming on the sea ice. We hypothesize that, if the climate continues to warm as projected by the IPCC, then polar bears in all five populations discussed in this paper will be stressed and are likely to decline in numbers, probably significantly so. As these populations decline, there will likely also be continuing, possibly increasing, numbers of problem interactions between bears and humans as the bears seek alternate food sources. Taken together, the data and concepts reported in this paper suggest that a precautionary approach be taken to the harvesting of polar bears and that the potential effects of climate warming be

incorporated into planning for the management and conservation of this species throughout the Arctic.

ACKNOWLEDGEMENTS

This study was supported for one of us (IS) by the Canadian Wildlife Service, the Department of Biological Sciences at the University of Alberta, the Natural Sciences and Engineering Research Council of Canada, the Nunavut Wildlife Management Board, the Polar Continental Shelf Project, and World Wildlife Fund (Canada and International) and for the other (CLP) by NASA's Cryospheric Sciences Program. We thank N.J. Lunn and E. Richardson for significant help with data extraction, creation of the polar-bear figures, and constructive criticism of the manuscript. We also thank Nick DiGirolamo of Science Systems and Applications, Inc. (SSAI) and NASA Goddard Space Flight Center, for excellent assistance with the sea ice calculations and the five sea ice figures.

REFERENCES

ANONYMOUS. 2003. Atlantic seal hunt 2003-2005 management plan. Fisheries Resource Management – Atlantic. Fisheries and Oceans Canada. p. A10

ATKINSON, S.N., and RAMSAY, M.A. 1995. The effects of prolonged fasting on the body composition and reproductive success of female polar bears. Functional Ecology 9:559-567.

BEST, R.C. 1975. Ecological aspects of polar bear nutrition. Pp. 203-211, *In* PHILLIPS, R.L., and JONKEL, C.J., (Eds.) Montana Forest and Conservation Experiment Station, University of Montana, Missoula 268 pp.

BJORGO, E., JOHANSESSEN, O.M. and MILES, M.W. 1997. Analysis of merged SMMR-SSMI time series of Arctic and Antarctic sea ice parameters 1978-1995. Geophysical Research Letters 24: 413-416.

BORN, E.W. 2002. Research on polar bears in Greenland. Pp. 67-74, In, LUNN, N.J., SCHLIEBE, S., and BORN, E.W., (Eds.) 2002. Polar Bears. Proceedings of the Thirteenth Working Meeting of the IUCN/SSC Polar Bear Specialist Group. Occasional Paper of the IUCN Species Survival Commission No. 26. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland. 155 pp.

BORN, E.W. 2005. An assessment of the effects of hunting and climate on walruses in Greenland. Dr. Philos. Thesis. Natural History Museum, University of Oslo. 356 pp.

BORN, E.W., and SONNE, C. 2006. Report on polar bears in Greenland, 2001 to 2005. *In*, Aars. J. Derocher, AE, and Lunn, NJ. (Eds), Proceedings of the 14th Working Meeting of the IUCN/SSC Polar Bear Specialist Group. Occasional Paper of the IUCN Species

Survival Commission No. 26. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland. (in press).

BOWEN, W.D., MYERS, R.A., and HAY, K. 1987. Abundance estimation of a dispersed, dynamic population: hooded seals (Cystophora cristata) in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences 44:282-295.

CAVALIERI, D.J., PARKINSON, C.L., GLOERSEN, P., COMISO, J.C. and ZWALLY, H.J. 1999. Deriving long-term time series of sea ice cover from satellite passive-microwave multisensor data sets. Journal of Geophysical Research 104 (C7): 15,803-15,814.

COMISO, J.C., and PARKINSON, C.L. 2004. Satellite-observed changes in the Arctic. Physics Today 57(8):38-44.

DEROCHER, A.E., and STIRLING, I. 1992. The population dynamics of polar bears in western Hudson Bay. In: McCullough, D.R., and Barrett, R.H., eds. Wildlife 2001: Populations. London: Elsevier Applied Science. 1150-1159.

DEROCHER, A.E., and STIRLING, I. 1996. Aspects of survival in juvenile bears. Canadian Journal of Zoology 74:1246-1252.

DEROCHER, A.E., STIRLING, I. and ANDRIASHEK, D. 1992. Pregnancy rates and serum progesterone levels of polar bears in western Hudson Bay. Canadian Journal of Zoology 70:561-566.

DEROCHER, A.E., LUNN, N.J., and STIRLING, I. 2004. Polar bears in a warming climate. Integrative and Comparative Biology 44:163-176.

ETKIN, D.A. 1991. Break-up in Hudson Bay: Its sensitivity to air temperatures and implications for climate warming. Climatological Bulletin 25:21-34.

FERGUSON, S.H., STIRLING, I., and McLOUGHLIN, P. 2005. Climate change and ringed

seal (*Phoca hispida*) recruitment in western Hudson Bay. Marine Mammal Science 21:121-135.

GAGNON, A.S., and GOUGH, W.A. 2005. Trends in the dates of ice freeze-up and break-up over Hudson Bay, Canada. Arctic 58:(in press)

GASTON, A.J., WOO, K. and HIPFNER, J.M. 2003. Trends in forage fish populations in northern Hudson Bay since 1981 as determined from the diet of nestling Thick-Billed Murres *Uria lomvia*. Arctic 56:227-233.

GLOERSEN, P., CAMPBELL, W.J., CAVALIERI, D.J., COMISO, J.C., PARKINSON, C.L., and ZWALLY, H.J. 1992. Arctic and Antarctic Sea Ice, 1978-1987: Satellite Passive-Microwave Observations and Analysis. National Aeronautics and Space Administration, Washington, DC, 290 pp.

GOUGH, W.A., CORNWELL, A.R., and TSUJI, J.S. 2004a. Trends in seasonal sea ice duration in southwestern Hudson Bay. Arctic 57:298-304.

GOUGH, W.A., GAGNON, A.S., and LAU, H.P. 2004b. Interannual variability of Hudson Bay ice thickness. Polar Geography, 28:222-238.

HEALEY, B. P., and STENSON, G.B. 2000. Estimating pup production and population size of the northwest Atlantic harp seal (*Phoca groenlandicus*). Can. Stock. Ass. Sec. Res. Doc. 2000/081. 27p.

HEIDE-JØRGENSEN, M.P., and LAIDRE, K.L. 2004. Declining extent of open-water refugia for top predators in Baffin Bay and adjacent waters. Ambio 33:488-495.

HOUSER, C., and GOUGH, W.A. 2002. Variations in sea ice in the Hudson Strait: 1971-1999. Polar Geography 26:11-24.

IVERSON, S.J., STIRLING, I., and LAND, S.L.C. 2005. Spatial, temporal, and individual variation in the diets of polar bears across the Canadian Arctic: Links with and indicators of changes in prey populations. Pp. 00-00 *In*, Boyd I. (Ed), Management of Marine Ecosystems: Monitoring change in upper trophic levels. Symposium of the Zoological Society of London.

JOHANNESSEN, O.M., MILES, M., and BJORGO, E. 1995. The Arctic's shrinking sea ice. Nature 376: 126-127.

JOHANNESSEN, O.M., BENGTSSON, L., MILES, W.M., KUZMINA, S.I., SEMENOV, V.A., ALEKSEEV, G.V., NAGURNYI, A.P., ZAKHAROV, V.F., BOBYLEV, L.P., PETTERSSON, L.H., HASSELMANN, K., and CATTLE, H.P.. 2004. Arctic climate change: Observed and modelled temperature and sea-ice variability. Tellus 56A (4): 328-341.

JOHNSON, D.W., FRIEDLAENDER, A.S., TORRES, L.G. and LAVIGNE, D.M. 2005. Variation in sea ice cover on the east coast of Canada from 1969 to 2002: climate variability and implications for harp and hooded seals. Climate Research 29:209-222.

LUNN, N.J, STIRLING, I., and NOWICKI, S.N. 1997. The distribution and abundance of seals in western Hudson Bay. Canadian Journal of Fisheries and Aquatic Sciences 54:914-921.

LUNN, N.J., SCHLIEBE, S., and BORN, E.W., Eds. 2002. Polar Bears. Proceedings of the Thirteenth Working Meeting of the IUCN/SSC Polar Bear Specialist Group. Occasional Paper of the IUCN Species Survival Commission No. 26. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland. 155 pp.

MASLANIK, J.A., SERREZE, M.C., and BARRY, R.G. 1996. Recent decreases in Arctic summer ice cover and linkages to atmospheric circulation anomalies. Geophysical Research Letters 23 (13): 1677-1680.

NAKASHIMA, D. J. 1993. Astute observers on the sea ice edge: Inuit knowledge as a basis for Arctic co-management. In: J.T. Inglis (Ed) *Traditional Ecological Knowledge: Concepts and Cases.* Canadian Museum of Nature and International Development Research Centre, Ottawa. pp. 99-110.

NELSON, R.A., FOLK, Jr., G.E., PFEIFFER, E.W., CRAIGHEAD, J.J., JONKEL, C.J., and STEIGER, D.L. 1983. Behavior, biochemistry, and hibernation in black, grizzly, and polar bears. International Conference on Bear Research and Management 5:284-290.

PAETKAU, D., AMSTRUP, S.C., BORN, E.W., CALVERT, W., DEROCHER, A.E., GARNER, G.W., MESSIER, F., STIRLING, I., TAYLOR, M., WIIG, Ø., and STROBECK, C. 1999. Genetic structure of the world's polar bear populations. Molecular Ecology 8:1571-1585.

PARKINSON, C.L. 1992. Spatial patterns of increases and decreases in the length of the sea ice season in the north polar region, 1979-1986. Journal of Geophysical Research 97 (C9): 14,377-14,388.

PARKINSON, C.L. 2000a. Recent trend reversals in Arctic sea ice extents: Possible connections to the North Atlantic Oscillation. Polar Geography 24(1): 1-12.

PARKINSON, C.L. 2000b. Variability of Arctic sea ice: The view from space, an 18-year record. Arctic 53(4):341-358.

PARKINSON, C.L., and CAVALIERI, D.J. 1989. Arctic sea ice 1973-1987: Seasonal, regional, and interannual variability. Journal of Geophysical Research, 94(C10):14,499-14,523.

PARKINSON, C.L., CAVALIERI, D.J., GLOERSEN, P., ZWALLY, H.J., and Comiso, J.C. 1999. Arctic sea ice extents, areas, and trends, 1978-1996. Journal of Geophysical Research 104(C9):20,837-20,856.

PRESTRUD, P., and STIRLING, I. 1994. The International Polar Bear Agreement and the current status of polar bear conservation. Aquatic Mammals, 20:1-12.

PREVETT, P., and KOLENOSKY, G.B. 1982. The status of polar bears in Ontario. Le Naturaliste Canadien (Revue d'Écologie et de Systématique) 109:933–939.

RAMSAY, M.A., and STIRLING, I. 1988. Reproductive biology and ecology of female polar bears (*Ursus maritimus*). Journal of Zoology (London) Series A 214:601-634.

RICHARDSON E., BRANIGAN M., CALVERT, W., CATTET, M., DEROCHER, A.E., DOIDGE, W., HEDMAN, D., LUNN, N.J., McLOUGHLIN, P., OBBARD, M.E., STIRLING, I., and TAYLOR, M. 2006. Research on Polar Bears in Canada 2001-2004. *In*, Aars. J. Derocher, AE, and Lunn, NJ. (Eds), Proceedings of the 14th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, 20-24 June 2005, Seattle, WA. USA. IUCN Publications, Cambridge, England (in press).

ROTHROCK, D.A., YU, Y., and MAYKUT, G.A. 1999. Thinning of the Arctic sea-ice cover. Geophysical Research Letters 26:3469-3472.

SERGEANT, D.E. 1991. Harp seals, man, and ice. Canadian Journal of Fisheries and Aquatic Sciences Special Publication 114. 153 pp.

SKINNER, W.R., JEFFERIES, R.L., CARLETON, T.J., ROCKWELL, R.F., and ABRAHAM, K.F. 1998. Prediction of reproductive success and failure in lesser snow geese based on early season climatic variables. Global Change Biology 4:3-16.

SMITH, T.G. 1980. Polar bear predation of ringed and bearded seals in the land-fast sea ice habitat. Canadian Journal of Zoology. 58:2201-2209.

SODEN, B.J., WETHERALD, R.T., STENCHIKOV, G.L., and ROBOCK, A. 2002. Global cooling after the eruption of Mount Pinatubo: A test of climate feedback by water vapor. Science 296:727.

STENSON, G.B., MYERS, R.A., NI, I-H., and WARREN, W.G. 1997. Pup production and population growth of hooded seals (*Cystophora cristata*) near Newfoundland, Canada. Canadian Journal of Fisheries and Aquatic Sciences 54:209-216.

STERN, H.L., and HEIDE-JØRGENSEN, M.P. 2003. Trends and variability of sea ice in Baffin Bay and Davis Strait. Polar Research 22:11-18.

STIRLING, I. 1988. *Polar Bears*. University of Michigan Press, Ann Arbor, Michigan. 232 pp.

STIRLING, I. 2002. Polar bears and seals in the Eastern Beaufort Sea and Amundsen Gulf: A synthesis of population trends and ecological relationships over three decades. Arctic 55, Supplement 1:59-76.

STIRLING, I. 2005. Reproductive rates of ringed seals and survival of pups in Northwestern Hudson Bay, Canada, 1991-2000. Polar Biology 28:381-387.

STIRLING, I., and ARCHIBALD, W.R. 1977. Aspects of predation of seals by polar bears in the eastern Beaufort Sea. Journal of the Fisheries Research Board of Canada, 34:1126-1129.

STIRLING, I., and DEROCHER, A.E. 1993. Possible impacts of climatic warming on polar bears. Arctic 46:240-245.

STIRLING, I. and McEWAN, E.H. 1975.caloric value of whole ringed seals (*Phoca hispida*) in relation to polar bear (*Ursus maritimus*) ecology and hunting behavior. Canadian Journal of Zoology 53:1021-1026.

STIRLING, I., and KILIAAN, H.P.L. 1980. Population ecology studies of the polar bear in northern Labrador. Canadian Wildlife Service Occasional Paper 42. 19 pp.

STIRLING, I., and ØRITSLAND, N.A. 1995. Relationships between estimates of ringed seal and polar bear populations in the Canadian Arctic. Canadian Journal of Fisheries and Aquatic Sciences 52:2594-2612.

STIRLING, I., and SMITH, T.G. 2004. Implications of warm temperatures and an unusual rain event on the survival of ringed seals on the coast of southeastern Baffin Island. Arctic 57:59-67.

STIRLING, I., LUNN, N.J., and IACOZZA, J. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic, 52:294-306.

STIRLING, I., CALVERT, W., and ANDRIASHEK, D. 1980. Population ecology studies of the polar bear in the area of southeastern Baffin Island. Canadian Wildlife Service Occasional Paper 44. 31 pp.

STIRLING, I., SPENCER, C., and ANDRIASHEK, D. 1989. Immobilization of polar bears (*Ursus maritimus*) with Telazol in the Canadian Arctic. Journal of Wildlife Disease 25:159-168.

STIRLING, I., LUNN, N.J., IACOZZA, J., ELLIOTT, C., and OBBARD, M. 2004. Distribution and abundance of polar bears along the western and southern coast of Hudson Bay during the open water season in relation to the breakup pattern of the annual ice and population trends. Arctic 57:15-26.

TAYLOR, M.K., DeMASTER, D.P., BUNNELL, F.L., and SCHWEINSBURG, R.E. 1987. Modelling the sustainable harvest of female polar bears. Journal of Wildlife Management. 51:811-820.

TAYLOR, M.K., LAAKE, J., McLOUGHLIN, PD., BORN, E.W., CLUFF, H.D., FERGUSON, S.H., ROSING-ASVID, A., SCHWEINSBURG, R., and MESSIER, F. 2005. Demography and viability of a hunted population of polar bears. Arctic 58:203-214.

TAYLOR, M.K., AKEEAGOK, S., ANDRIASHEK, D., BARBOUR, W., BORN, E.W., CALVERT, W., CLUFF, H.D., FERGUSON, S., LAAKE, J., ROSING-ASVID, A., STIRLING, I., and MESSIER, F. 2001. Delineation of Canadian and Greenland polar bear (*Ursus maritimus)* populations using cluster analysis of movements. Canadian Journal of Zoology 79:690-709.

Table 1. Changes proposed by the Nunavut Department of Environment to polar bear harvest quotas for five populations of polar bears harvested entirely or partially by Nunavut hunters. (For completeness, data on quotas for all populations and jurisdictions are provided.)

Population	Estimated population size on which quota is based	Quotas that applied through the 2004-2005 hunting season (Nunavut portion in brackets)	Proposed Increases in Nunavut quotas only (as of Feb 2004)	Proposed Increases to Nunavut portions of quotas (as of Jan 2005) (% increase in brackets)
Baffin Bay	2074	(64) no quota observed by Greenland	0	41 (64%)
Foxe Basin	2119	(97)	9	9 (9%)
Davis Strait	1400	40 (34) no quota observed by Greenland or Québec (quota of 6 in Labrador)	12	12 (35%)
Western Hudson Bay	1200	55 (47) maximum of 8 bear quota retained by Manitoba for control of problem bears	9	9 (19%)
Eastern Hudson Bay	1000	55 (25) quota of 30 in Ontario Indian villages	0	0

FIGURE CAPTIONS

Figure 1. Map of the study area showing delineations of areas of each polar bear population discussed (WH – Western Hudson Bay; EH – Eastern Hudson Bay; FB – Foxe Basin; BB – Baffin Bay; DS – Davis Strait).

Figure 2. (a) Time series of the daily percent ice coverages and ice areas in Western Hudson Bay, from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR and SSMI data, and (b) the Julian dates by when the percent ice coverage decreased to 50% or less, following the winter maximum, for the years 1979-2004.

Figure 3. Mean estimated mass of lone (and thus possibly pregnant) adult female polar bears in Western Hudson Bay from 1980 through 2004.

Figure 4. (a) The number of problem bears handled by the Conservation Officers in Churchill in Western Hudson Bay from 1984 through 2003, and (b) the relationship between the date of breakup of the sea ice and the number of problem bears handled.

Figure 5. (a) Time series of the daily percent ice coverages and ice areas in Foxe Basin, from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR and SSMI data, and (b) the Julian dates by when the percent ice coverage decreased to 50% or less, following the winter maximum, for the years 1979-2004.

Figure 6. (a) Time series of the daily percent ice coverages and ice areas in Baffin Bay, from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR

and SSMI data, and (b) the Julian dates by when the percent ice coverage decreased to 50% or less, following the winter maximum, for the years 1979-2004.

Figure 7. (a) Time series of the daily percent ice coverages and ice areas in Davis Strait, from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR and SSMI data, and (b) the Julian dates by when the percent ice coverage decreased to 40% or less, following the winter maximum, for the years 1979-2004.

Figure 8. (a) Time series of the daily percent ice coverages and ice areas in Eastern Hudson Bay, from November 1, 1978 through December 31, 2004, as determined from the satellite SMMR and SSMI data, and (b) the Julian dates by when the percent ice coverage decreased to 50% or less, following the winter maximum, for the years 1979-2004.

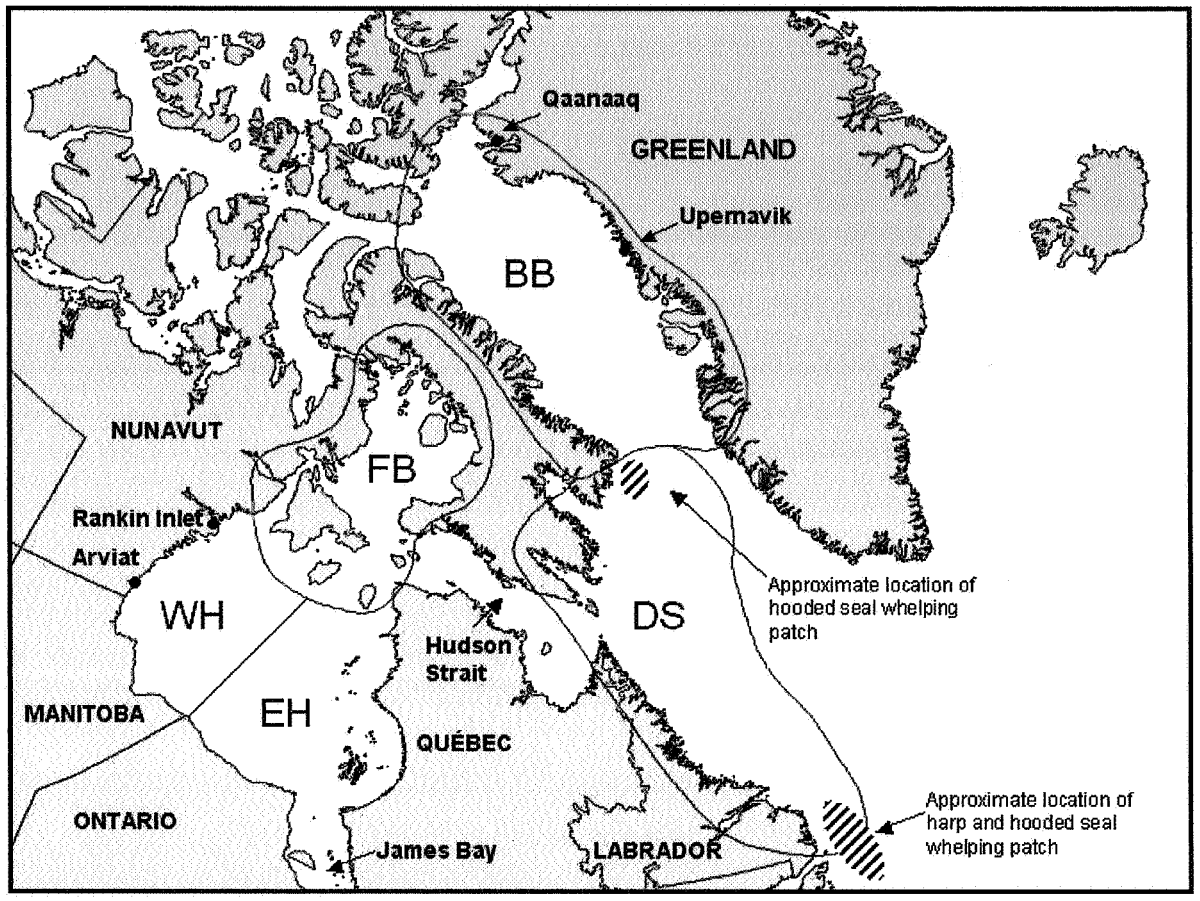

Qaanaaq
GREENLAND
Upernavik
BB
NUNAVUT
FB
Rankin Inlet
Arviat
WH
DS
Approximate location of hooded seal whelping patch
Hudson Strait
MANITOBA
EH
QUÉBEC
ONTARIO
James Bay
LABRADOR
Approximate location of harp and hooded seal whelping patch

Figure 1.

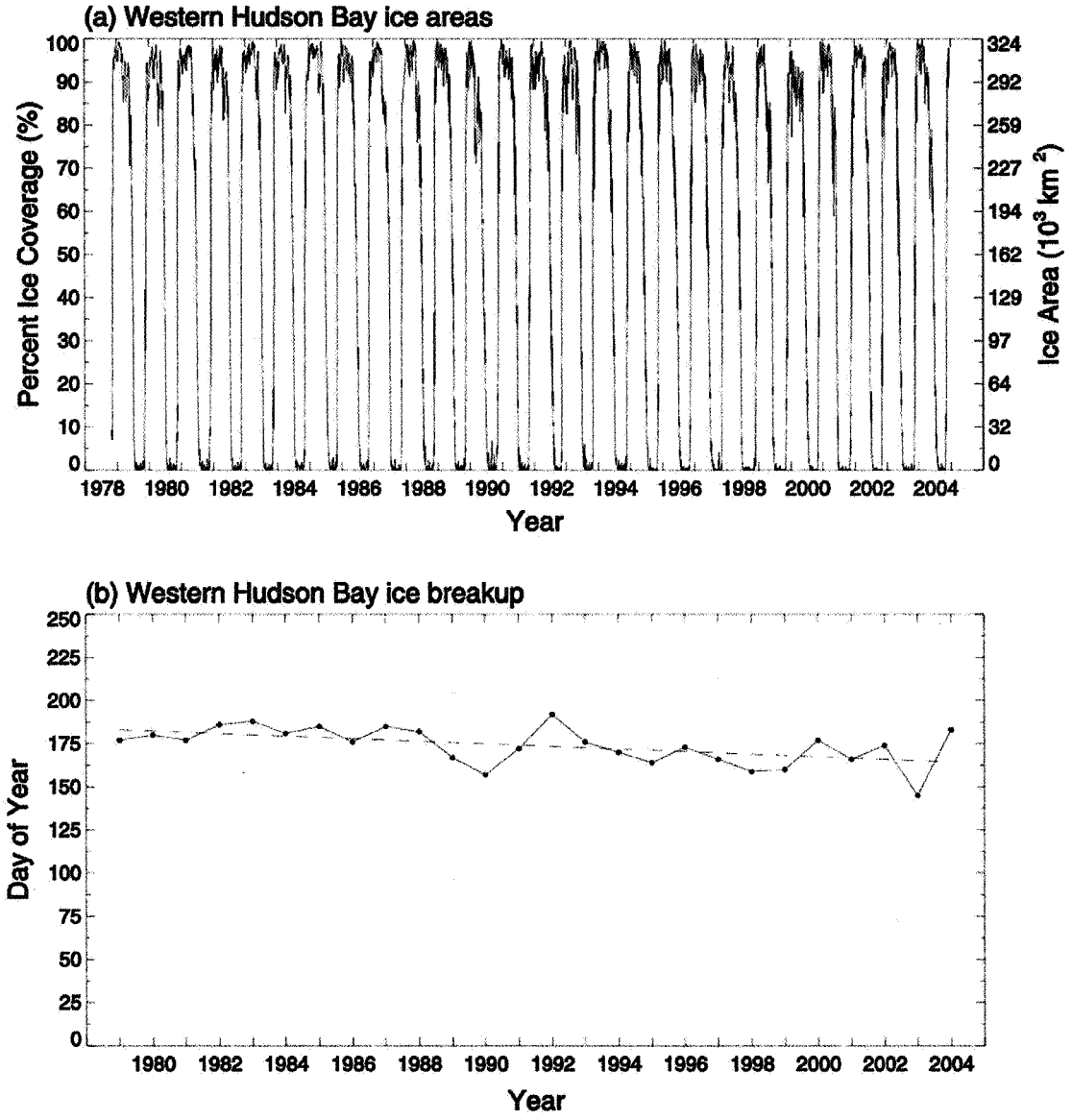

(a) Western Hudson Bay ice areas
Percent Ice Coverage (%)
Ice Area (10^3 km^2)
Year
(b) Western Hudson Bay ice breakup
Day of Year
Year

Figure 2.

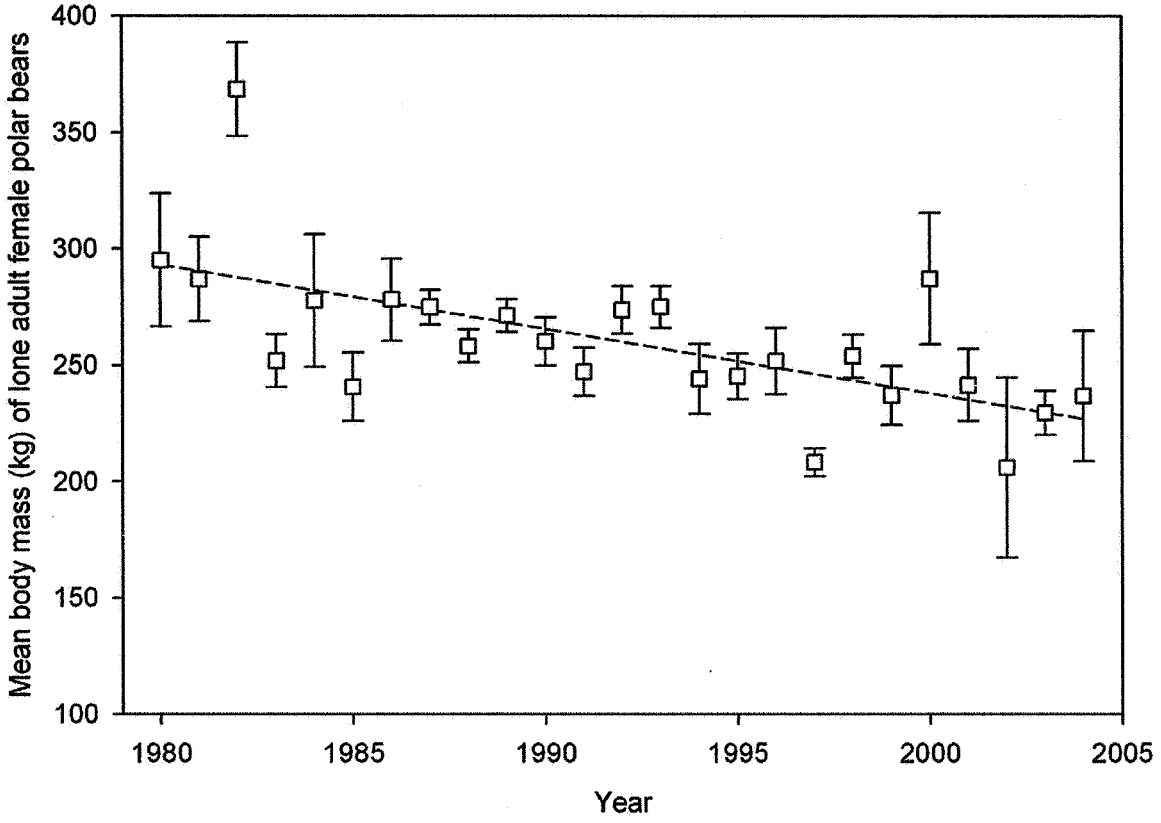
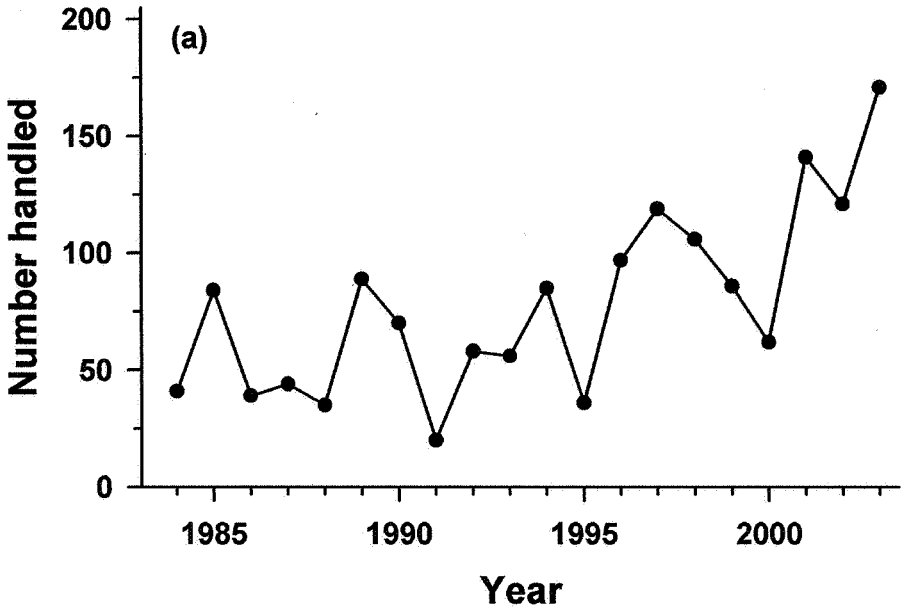

Mean body mass (kg) of lone adult female polar bears
400
350
300
250
200
150
100
1980
1985
1990
1995
2000
2005
Year

Figure 3.


(a)
Number handled
200
150
100
50
0
1985
1990
1995
2000
Year

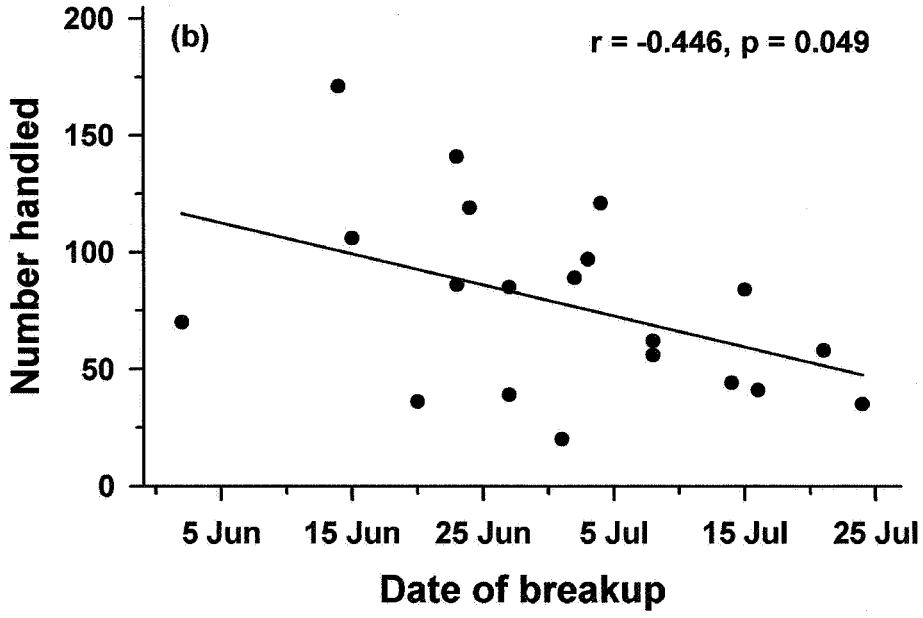

(b)
r = -0.446, p = 0.049
Number handled
200
150
100
50
0
5 Jun
15 Jun
25 Jun
5 Jul
15 Jul
25 Jul
Date of breakup

Figure 4.

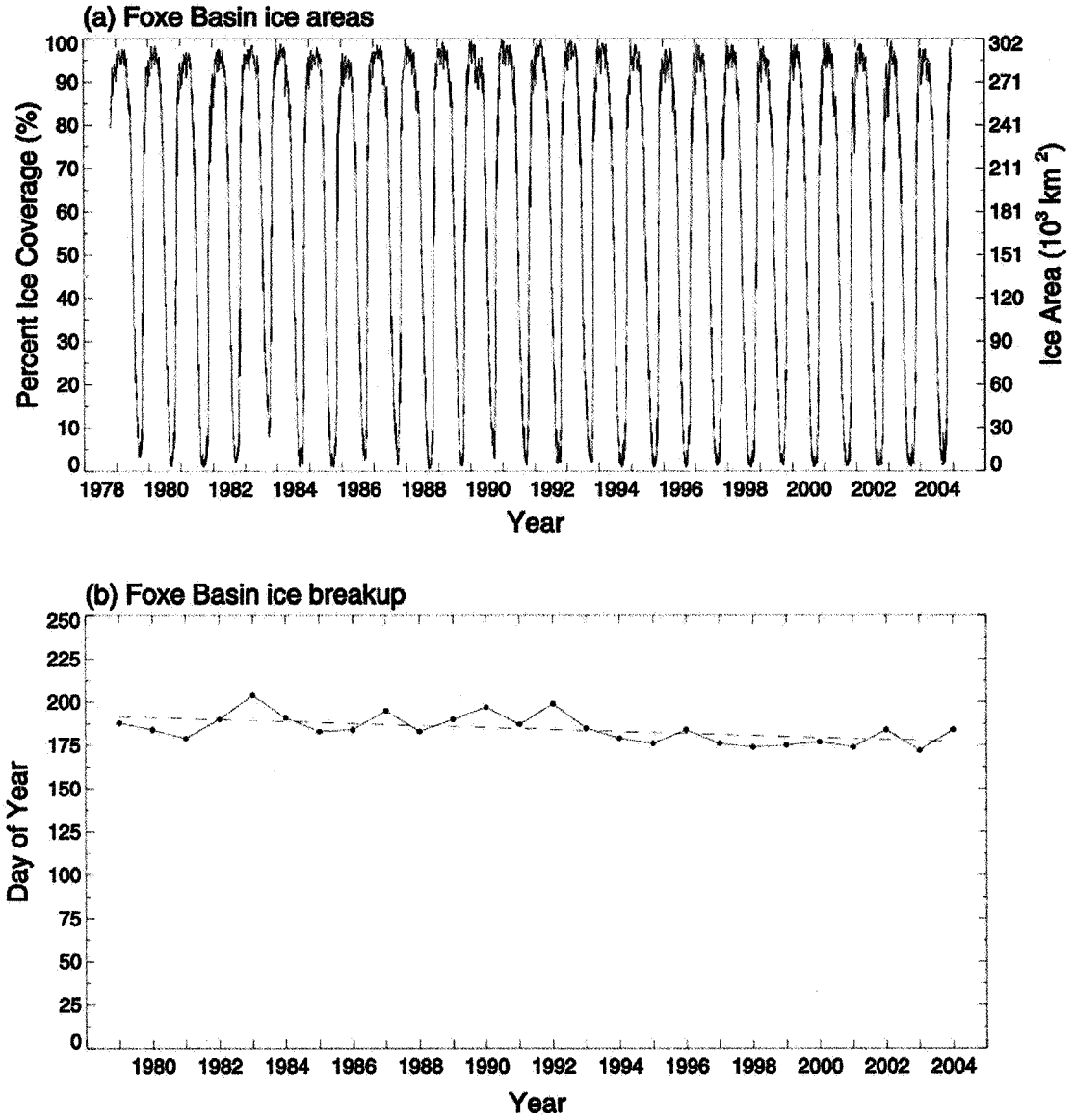

(a) Foxe Basin ice areas
Percent Ice Coverage (%)
Ice Area (10^3 km^2)
Year
(b) Foxe Basin ice breakup
Day of Year
Year

Figure 5.

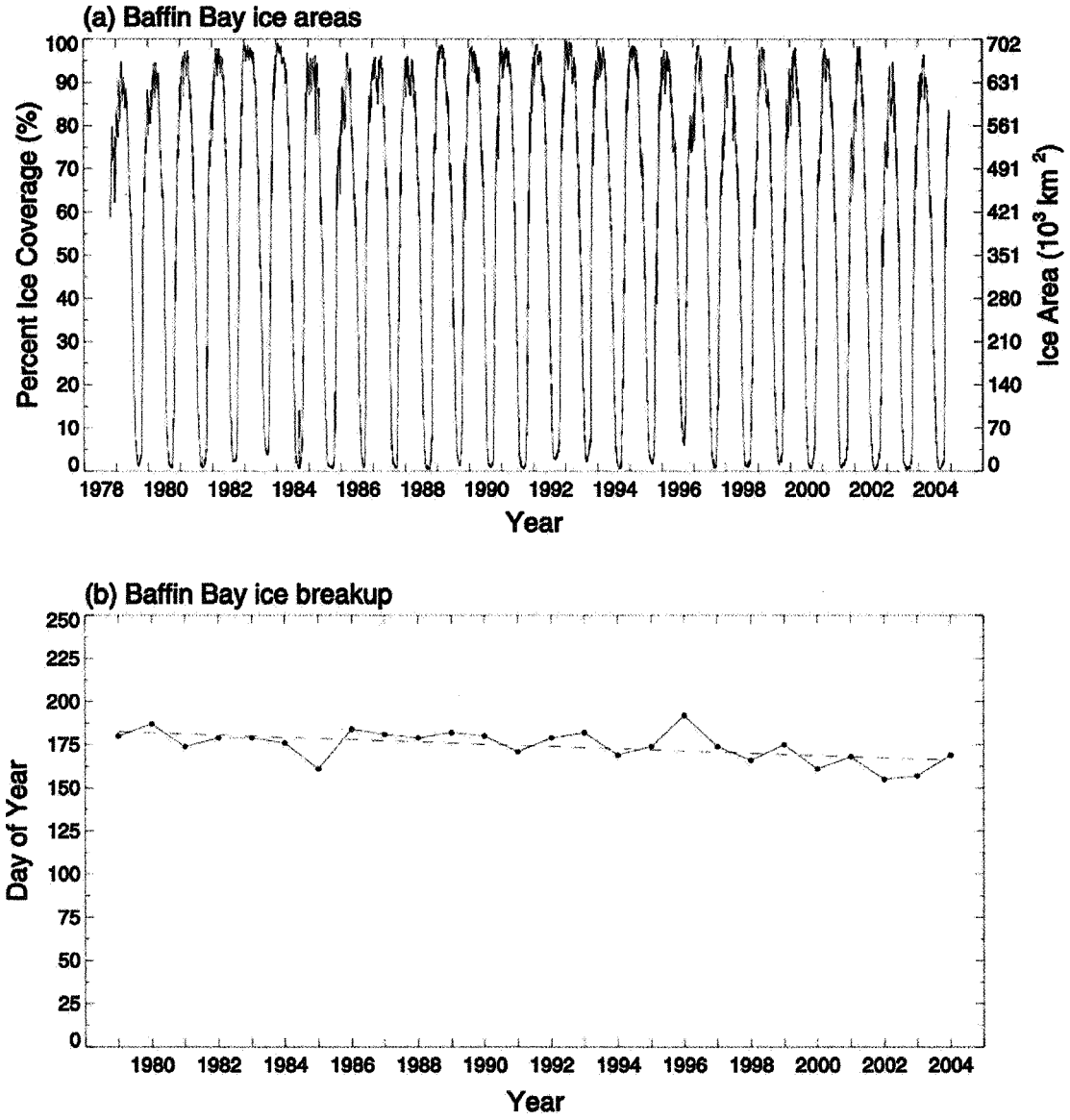

(a) Baffin Bay ice areas
Percent Ice Coverage (%)
Ice Area (10^3 km^2)
Year
(b) Baffin Bay ice breakup
Day of Year
Year

Figure 6.

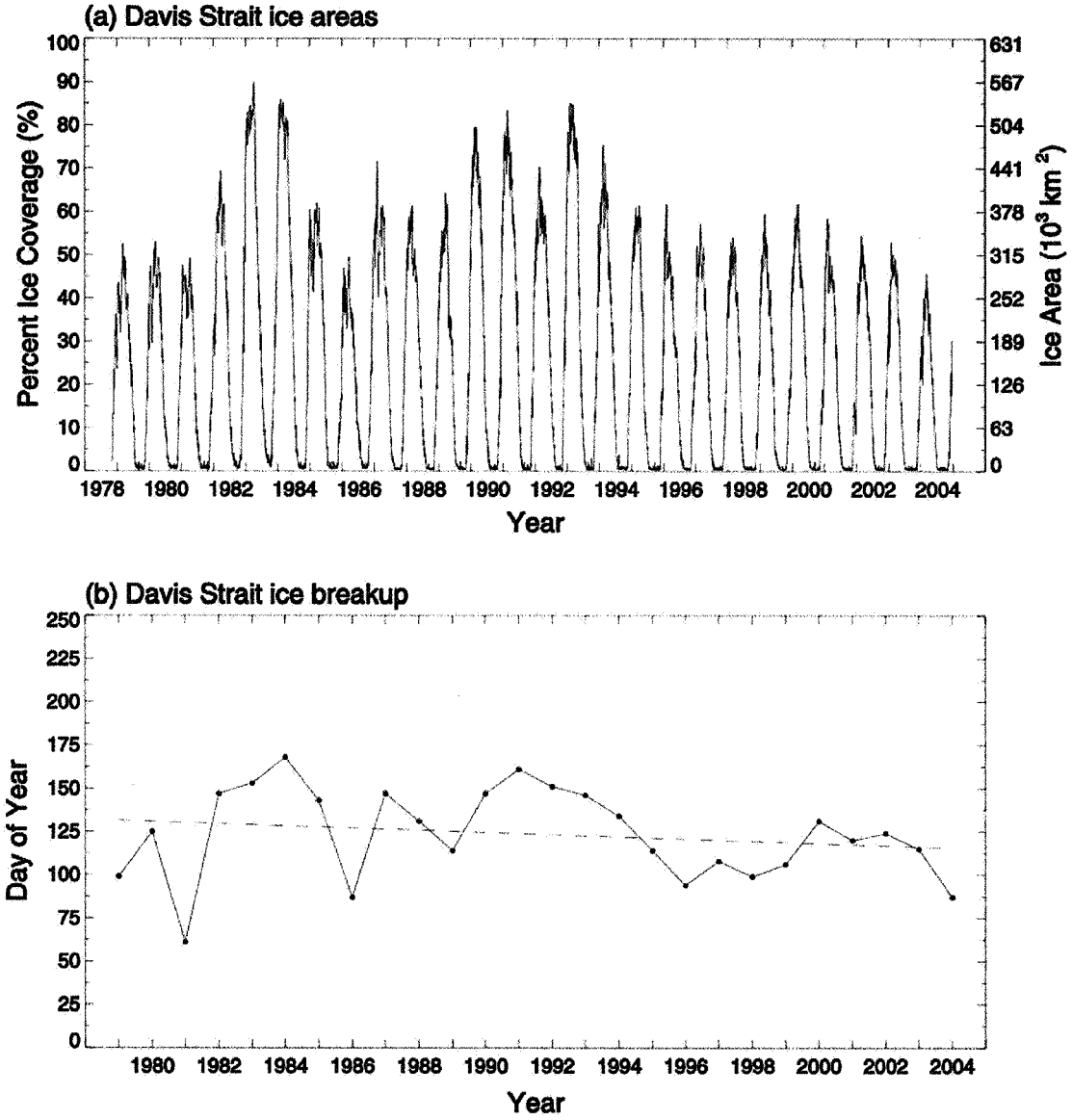

(a) Davis Strait ice areas
Percent Ice Coverage (%)
Ice Area (10^3 km^2)
Year
(b) Davis Strait ice breakup
Day of Year
Year

Figure 7.

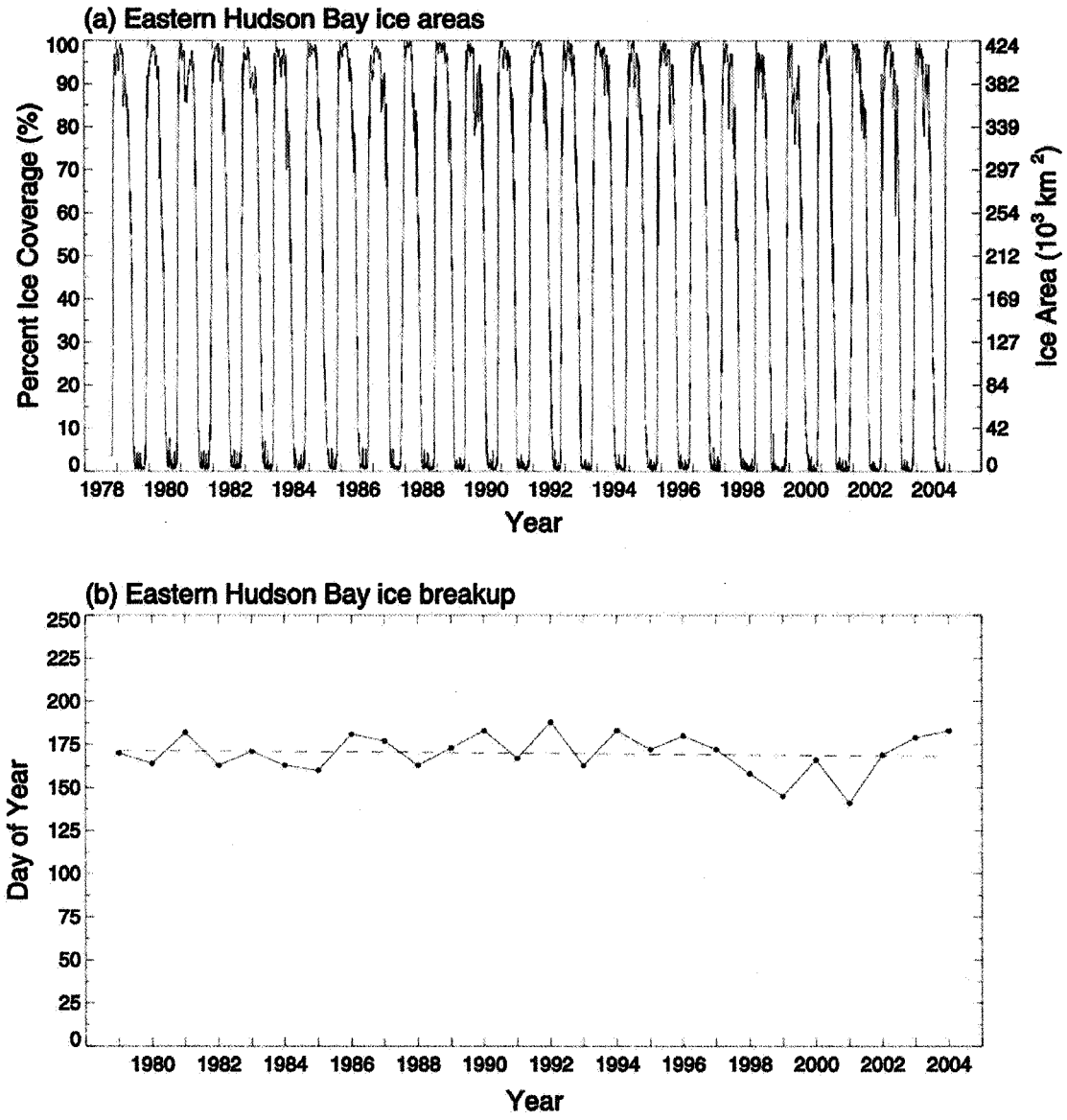

(a) Eastern Hudson Bay ice areas
Percent Ice Coverage (%)
Ice Area (10^3 km ^{2})
Year
(b) Eastern Hudson Bay ice breakup
Day of Year
Year

Figure 8.

Possible Effects of Climate Warming on Selected Populations of Polar Bears (*Ursus maritimus*) in the Canadian Arctic

Ian Stirling
Canadian Wildlife Service
Edmonton, AB T6H 3S5 Canada
ian.stirling@ec.gc.ca

and

Claire L. Parkinson
NASA Goddard Space Flight Center
Greenbelt, MD 20771 USA
claire.l.parkinson@nasa.gov

Popular summary

Polar bears are iconic figures in the polar north, majestically wandering the ice, swimming in the ice-cold waters, and seeking prey. Their traditional lifestyles, however, might be in jeopardy, as they are dependent on the Arctic sea ice cover and that cover has, overall, been reducing in recent years. Traditionally, polar bears feed from the ice in the cold season, then, when the ice retreats from the coast in spring, they move onto the land and fast until the return of the ice in autumn. As the ice cover reduces, the retreat from the coast comes earlier in the spring and the polar bears are forced to spend a longer time on the land, causing extended hunger and understandably leading to more instances of troublesome bear/human interactions, as the bears maraud for food. This paper uses satellite passive-microwave data on sea ice and *in situ* data on polar bears to examine the sea ice/polar bear connection in Western Hudson Bay, Eastern Hudson Bay, Foxe Basin, Baffin Bay, and Davis Strait, all regions with distinct polar bear populations where the sea ice cover disappears fully in summer, forcing the bears onto the land. The conclusion is that if the climate continues to warm and sea ice continues to retreat, as projected by the Intergovernmental Panel on Climate Change (IPCC) and other groups, the polar bears in all five of the examined populations will likely be further stressed and will likely decline in numbers. Governmental quotas for the killing of polar bears have increased in recent years based on the increased sightings of polar bears near human settlements. These quotas should be reconsidered given the likelihood that the increased sightings reflect the increased length of time the polar bears must spend on land rather than an increase in the polar bear populations.

paper to be submitted to *Arctic*, November 2005

Possible Effects of Climate Warming on Selected Populations of Polar Bears (*Ursus maritimus*) in the Canadian Arctic

Ian Stirling
Canadian Wildlife Service
Edmonton, AB T6H 3S5 Canada

and

Claire L. Parkinson
NASA Goddard Space Flight Center
Greenbelt, MD 20771 USA

Significant Findings

Decreases in sea ice coverage in the Canadian Arctic are likely affecting the regional polar bear populations, causing decreased body mass and increased troublesome human/bear interactions. Linear least squares fits through satellite-derived sea ice data for 1979-2004 indicate that spring/summer sea ice breakup is coming about 7-8 days earlier per decade in Western Hudson Bay, about 6 days earlier per decade in Foxe Basin, about 6-7 days earlier per decade in Baffin Bay, and about 6 days earlier per decade in Davis Strait. The earlier sea ice breakup forces the polar bears to retreat to the land earlier, taking them away from their traditional marine-based diet. The shortened sea ice season means a lengthened period away from traditional food, helping to explain data showing thinning bears and increased instances of bears marauding through human settlements for food.

paper to be submitted to *Arctic*, November 2005

Possible Effects of Climate Warming on Selected Populations of Polar Bears (*Ursus maritimus*) in the Canadian Arctic

Ian Stirling
Canadian Wildlife Service
Edmonton, AB T6H 3S5 Canada

and

Claire L. Parkinson
NASA Goddard Space Flight Center
Greenbelt, MD 20771 USA

Abstract

Polar bears are dependent on sea ice for survival. Climate warming in the Arctic has caused significant declines in coverage and thickness of sea ice in the polar basin and progressively earlier breakup in some areas. In four populations of polar bears in the eastern Canadian Arctic (including Western Hudson Bay), Inuit hunters report more bears near settlements during the open water period in recent years. These observations have been interpreted as evidence of increasing population size, resulting in increases in hunting quotas. However, long-term data on the population size and condition of polar bears in Western Hudson Bay, and population and harvest data from Baffin Bay, make it clear that those two populations at least are declining, not increasing. While the details vary in different Arctic regions, analysis of passive-microwave satellite imagery, beginning in the late 1970s, indicates that the sea ice is breaking up at progressively earlier dates, so that bears must fast for longer periods during the open water season. Thus, at least part of the explanation for the appearance of more bears in coastal communities is likely that they are searching for alternative food sources because their stored body fat depots are being exhausted. We hypothesize that, if the climate continues to warm as projected by the IPCC, then polar bears in all five populations discussed in this paper will be stressed and are likely to decline in numbers, probably significantly so. As these populations decline, there will likely also be continuing, possibly increasing, numbers of problem interactions between bears and humans as the bears seek alternate food sources. Taken together, the data reported in this paper suggest that a precautionary approach be taken to the harvesting of polar bears and that the potential effects of climate warming be incorporated into planning for the management and conservation of this species throughout the Arctic.

paper to be submitted to *Arctic*, November 2005