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Viewpoint

Polar bears of western Hudson Bay and climate change: Are warming spring air temperatures the "ultimate" survival control factor?

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ABSTRACT

Long-term warming of late spring (April–June) air temperatures has been proposed by Stirling et al. [Stirling, I., Lunn, N.J., 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] as the "ultimate" factor causing earlier sea-ice break-up around western Hudson Bay (WH) that has, in turn, led to the poorer physical and reproductive characteristics of polar bears occupying this region. Derocher et al. [Derocher, A.E., Lunn, N.J., Stirling, I., 2004. Polar bears in a warming climate. Integr. Comp. Biol. 44, 163–176] expanded the discussion to the whole circumpolar Arctic and concluded that polar bears will unlikely survive as a species should the computer-predicted scenarios for total disappearance of sea-ice in the Arctic come true. We found that spring air temperatures around the Hudson Bay basin for the past 70 years (1932–2002) show no significant warming trend and are more likely identified with the large-amplitude, natural climatic variability that is characteristic of the Arctic. Any role of external forcing by anthropogenic greenhouse gases remains difficult to identify. We argue, therefore, that the extrapolation of polar bear disappearance is highly premature. Climate models are simply not skilful for the projection of regional sea-ice changes in Hudson Bay or the whole Arctic. Alternative factors, such as increased human–bear interaction, must be taken into account in a more realistic study and explanation of the population ecology of WH polar bears. Both scientific papers and public discussion that continue to fail to recognize the inherent complexity in the adaptive interaction of polar bears with both human and nature will not likely offer any useful, science-based, preservation and management strategies for the species.

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1. Introduction

Polar bears (*Ursus maritimus*) are charismatic megafauna that symbolize the Arctic. They play an important cultural, spiritual, mystical, and traditional role in the lives of Canadian Inuit through hunting and subsequent sharing of meat and fur. Additionally, Inuit-guided sport hunts provide important revenue for the economically challenged communities (Lee and Taylor, 1994). The latest research findings suggest, however, that this multi-purpose natural resource faces threats from climatic change and environmental stress (Stirling and Derocher, 1993; Stirling et al., 1999; World Wide Fund for Nature, 2002; Derocher et al., 2004) or from simply unsustainable harvests by human hunters (see recent discussion in Taylor et al., 2005).

Unfortunately, polar bears and their shrinking ice habitat are commonly used rhetoric to argue for the possible severity of climate change and global warming to the general public (cf., Washington Post, 2005). The polar bears that are most often cited are a specific population that inhabits the southwestern Hudson Bay coast—1 of 14 polar bear populations found in Canada (Derocher et al., 1998; Taylor et al., 2001). The area they occupy encompasses almost the southernmost extent of the species (only the southern Hudson Bay polar bear population reaches farther south; Derocher et al., 1998). Population stresses have been observed, which has led to the proposition that an earlier break-up of Hudson Bay ice (and an associated increase in spring air temperatures) is the cause of decreases in reproduction, subadult survival, and body mass of some of these bears (Stirling and Derocher, 1993; Stirling et al., 1999). A long-term warming trend of spring atmospheric temperatures was proposed, though not shown directly,[1] to be "the ultimate factor" (Stirling et al., 1999, p. 294). As a result, it is commonly believed that climatic changes (or "global warming") are the predominant factors leading to adverse conditions for the polar bear populations, although other factors have been acknowledged (e.g., density-dependent population responses; Derocher and Stirling, 1992).

We argue that there are several related stress factors that can explain the observed patterns in polar bear population ecology. Global warming may indeed have an effect on the polar bears of western Hudson Bay (WH) but it must be assessed in a more realistic framework that considers all the likely stress factors and their cumulative impacts. In such a context, it is difficult to isolate one factor of predominant severity and, consequently, it is simply not prudent to overstate the certainty of any single factor. As emphasized in Li (2004) and Loehle (2004), a full scientific understanding of an issue as complex as the population ecology of polar bears must necessarily requires the combined assessment of both the natural and social systems rooted in the problem rather than consideration of either component in isolation (i.e., warmer spring air temperatures and related sea-ice conditions in WH).

In the next two sections, we examine some of the potential nonclimatic causes of decreased reproduction, offspring survival, and body masses, including repeated bear–human interactions, food availability and competition. We then consider climatic factors by examining available surface air temperature records and ice dynamics in the Hudson Bay basin. Finally we synthesize these findings to critically evaluate the forecasts of polar bear extinction in relation to model projected scenarios of global warming by Derocher et al. (2004).

2. Human–polar bear interactions in western Hudson Bay

Western Hudson Bay polar bears have a long history of interactions and confrontations with humans. Stirling et al. (1977) discusses interactions between humans and WH polar bears from Churchill at dump sites, in town, and adjacent town areas. Over the years, the three main sources of bear–human interactions for the WH bears are activities related to (a) scientific research, (b) tourism, and (c) the Polar Bear Alert Program.

Research activities for the WH area began in 1966, and continue today as a long-term ecological monitoring project in which over 80% of the bear population is marked (Stirling et al., 1977; Lunn et al., 2002). The majority of this field work has been carried out by the Canadian Wildlife Service (CWS), although universities also conduct research on polar bears in the area. Many bears are captured, marked, and eventually recaptured, sometimes within the same year, over a number of years (e.g., Calvert et al., 1991a,b, 1995a,b, 1998). For example, from 1977 to 1995, an estimated total of 2772 bears were captured (Derocher and Stirling, 1995, their Tables 2 and 3; Lunn et al., 1997a, their Tables 2 and 3), with a minimum (i.e., since not all captures are clearly reported in publications and conflicting information exists) of about 1100 recaptures (recapture rates of between 52 and 90%; mean number of bears captured/year between 1977 and 1995 is about 145 bears; see summary total of columns 2 and 3 in Table 1). If one considers that the WH population estimate then was between 700 and 1200 bears (Amstrup and Wiig, 1991; Wiig et al., 1995), and about 15–30% of the population was captured and recaptured due to high fidelity to locations along the coast (Derocher and Stirling, 1990a,b), it is very likely that many bears were/are exposed to capture activities on a repeated basis.

An assumption most frequently made by researchers is that their work (i.e., capturing and handling wildlife repeatedly) has no significant effect on fitness, behaviour or survival of the wildlife species in question (Seber, 1973; Lehner, 1979). Long-term trends of handling polar bears were suggested by Ramsay and Stirling (1986) and included the possible effects on females with cubs. Although their study did not find any statistically significant results, the trends they presented indicated that females may suffer from handling by being displaced from feeding sites, possibly resulting in lowered body mass. Note that female polar bear body mass is positively related to cub survival (Derocher and Stirling, 1996, 1998a). If females lose body mass due to handling, cubs will be adversely affected in their survival rates. Also, most polar bear capture work occurs either on family groups in spring as they emerge from their dens, or during the ice-free period while bears are distributed along the southwestern shore of Hudson Bay—times when the bears are either stressed due to lactation (Arnould, 1990) or undergo a fasting period while living off their stored fat reserves (Watts

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[1] Stirling et al. (1999) relied on the mean air temperature results of Skinner et al. (1998).

Table 1 – Captures of polar bears for research (males and females), for the Polar Bear Alert Program (PBAP), and total polar bear captures per year from 1977 to 1995

Year	Males[a]	Females[a]	PBAP[b]	Total captures/ year
1977	53	34	32	119
1978	29	26	16	71
1979	15	10	27	52
1980	20	29	18	67
1981	32	36	27	95
1982	68	42	32	142
1983	95	95	92	282
1984	96	63	18	177
1985	95	59	76	230
1986	84	53	26	163
1987	115	149	30	294
1988	140	152	35	327
1989	168	163	51	382
1990	107	92	64	263
1991	86	68	18	172
1992	57	74	54	185
1993	42	54	58	154
1994	63	64	79	206
1995	86	58	33	177
Total	1451	1321	786	3558
Mean	76	69	41	187

[a] Derocher and Stirling (1995); Tables 2 and 3, and Lunn et al. (1997a); Tables 2 and 3; whenever data were conflicting in their tables, we used the greater number for each gender/year.

[b] Kearney (1989), Calvert et al. (1991b, 1995b) and Lunn et al. (1998).

and Hansen, 1987). While the handling effect study of Ramsay and Stirling (1986) covered only 1967–1984, we suggest an additional analysis of capture–recapture data for handling effects that extends their time period to the present.

Almost concurrently with research activities at WH, some of the bears in the WH population are exposed to tourists and tourism activities during the fall. Since about 1980, polar bear viewing from large customized vehicles has been practiced near the town of Churchill. Polar bears leave the ice during June/July and slowly migrate north to the shores of Hudson Bay (approximately 35 km east of Churchill) where they congregate and wait the early freeze-up of the Bay, usually during November. Tour companies transport visitors into the congregation area (approximate coordinates are: 58°45′N to 58°48′N, and 93°38′W to 93°50′W) during October/November to view the bears (Dyck, 2001). Although the viewing period is short, usually between 1 October and 15 November, it is very intense, with about 6000 tourists and 15 large tundra vehicles per day in the area (Dyck and Baydack, 2006). Baiting, harassment and chasing of bears have been documented to occur (Watts and Ratson, 1989; Herrero and Herrero, 1997). The Polar Bear Technical Committee has expressed concern over these activities, suggesting that harassment of bears during this time of the year might be very stressful due to their fasting (Calvert et al., 1998). In the first baseline study conducted in the area to address tundra vehicle behaviour and vigilance (i.e., a motor act that corresponds to a head lift interrupting the ongoing activity) of resting polar bears, Dyck and Baydack (2004) found significant increases in vigilance behaviour of resting male polar bears in the presence of vehicles. The authors speculated that increased vigilance could lead to increased heart rates and metabolic activity, subsequently adding other factors that possibly contribute to the negative energy balance of bears while on land.

Another bear–human interaction occurs in the form of the Polar Bear Alert Program (PBAP) at Churchill. The Manitoba provincial management agency initiated the program in 1969 to protect local residents from bears, and vice versa (Kearney, 1989). The area around the town is patrolled, and bears that enter certain zones will either be deterred, captured, handled, or destroyed. From its inception up to 2000, an average of 48 bears per year (a total of 1547 bears) have been handled (Kearney, 1989; Calvert et al., 1991b, 1995b; Lunn et al., 1998; for a detailed PBAP description, see Kearney, 1989). Handling procedures are similar to those during research activities, and effects can be assumed to be similar.

Considering CWS-related research activities and the PBAP activities between 1977 and 1995, a total of 3558 bears (not including university-research handled bears) have been handled (last column in Table 1). This is about three times greater than the actual estimated WH population of 1100 (Derocher and Stirling, 1992), indicating that all bears are, on average, subject to repeated handling. Moreover, these activities occur when bears are either fasting or leaving their dens and are already energetically stressed. It is plausible that these repeated bear–human interactions have adversely stressed the bears over the past 30 years.

3. Food availability and competition

Between 1978 and 1990, the WH polar bear population was estimated to be around 1100 bears (Derocher and Stirling, 1992). Derocher and Stirling (1995) estimated the mean size of the population between 1978 and 1992 to be around 1000 bears. Up to 1997, the population did not change significantly, and was estimated to be around 1200 bears (Lunn et al., 1997a; Fig. 6 in Stirling et al., 1999). When published yearly population estimates from Derocher and Stirling (1995) and Lunn et al. (1997a) are examined, several tendencies are apparent. First, the Derocher and Stirling (1995) data for 1977–1992 show an increasing trend ($F = 4.16$, $p = 0.06$, $r^2 = 0.23$), although that trend is not statistically significant. Second, the Lunn et al. (1997a) data from 1984 to 1995 indicate a stable population ($F = 0.71$, $p = 0.42$, $r^2 = 0.07$). When both data sets are combined (i.e., the Derocher and Stirling (1995) data from 1977 to 1992 and the Lunn et al. (1997a) data for 1993–1995), a significant increase in the population size is implied ($F = 6.40$, $p = 0.02$, $r^2 = 0.27$). Most recently, however, it was noted that the population since 1995 has been declining to ‘‘less than 950 in 2004’’ (IUCN/Polar Bear Specialist Group, 2005). We clarify that the published estimate by Lunn et al. (1997a), combining Churchill and Cape Tatnam study area (both in WH) datasets, gives a 1995 WH polar bear population of 1233 with a 95% confidence interval that ranges from 823 to 1643 bears, so the actual confidence in the ‘‘decline’’ of the WH polar bear population in 2004, relative to the 1995 values, is difficult to confirm.

Given these long-term data on population estimates and responses, it is possible that density-dependent processes have been imprinted in the observed records of polar bears at WH. It is important, however, to recognize the great difficulties in demonstrating density dependence in population studies (e.g., Ray and Hastings, 1996; Mayor and Schaefer, 2005), among which is the sensitivity of the phenomenon on spatial scale covered by the population sampling techniques (e.g., Taylor et al., 2001). We concur with Derocher and Stirling (1995) and Stirling et al. (2004) that the WH population was at least stable during the 1984–1995 period (and likely up to 1997; see Stirling et al., 1999, their Fig. 6). Prior to that the WH population was hunted heavily, which led to hunting restrictions (Stirling et al., 1977; Derocher and Stirling, 1995). After the population recovered, and then increased, bear body mass, reproductive parameters, cub survival, and growth declined (Derocher and Stirling, 1992, 1998b). Derocher and Stirling (1992, 1995, 1998b) considered whether these responses reflect density-dependent population control mechanisms. They discarded them either because no accurate population estimates for WH existed, or no change in population size was detected. Typically, density-dependent responses, similar to those exhibited by WH polar bears, are detected in *increasing* populations (Eberhardt and Siniff, 1977; Fowler, 1990). By contrast, however, individuals of a population *near* carrying capacity (given that the WH population remained relatively stable for so long) can also exhibit traits that were observed for this polar bear population, namely poorer physical condition, lower survivorship, and lower rates of reproduction (Kie et al., 1980, 2003; Stewart et al., 2005). It is possible that the WH population has been stable for so long because carrying capacity has been reached, and intraspecific competition increased with increasing polar bear density, resulting in the documented responses.

It is important to note that the southern half of Hudson Bay is shared between polar bear populations of WH and southern Hudson Bay (SH) (Derocher et al., 1998). Polar bears of SH have exhibited better body condition as compared to their WH counterparts (Stirling et al., 1999, 2004) but prolonged ice conditions in that area seem not to be the explanation because

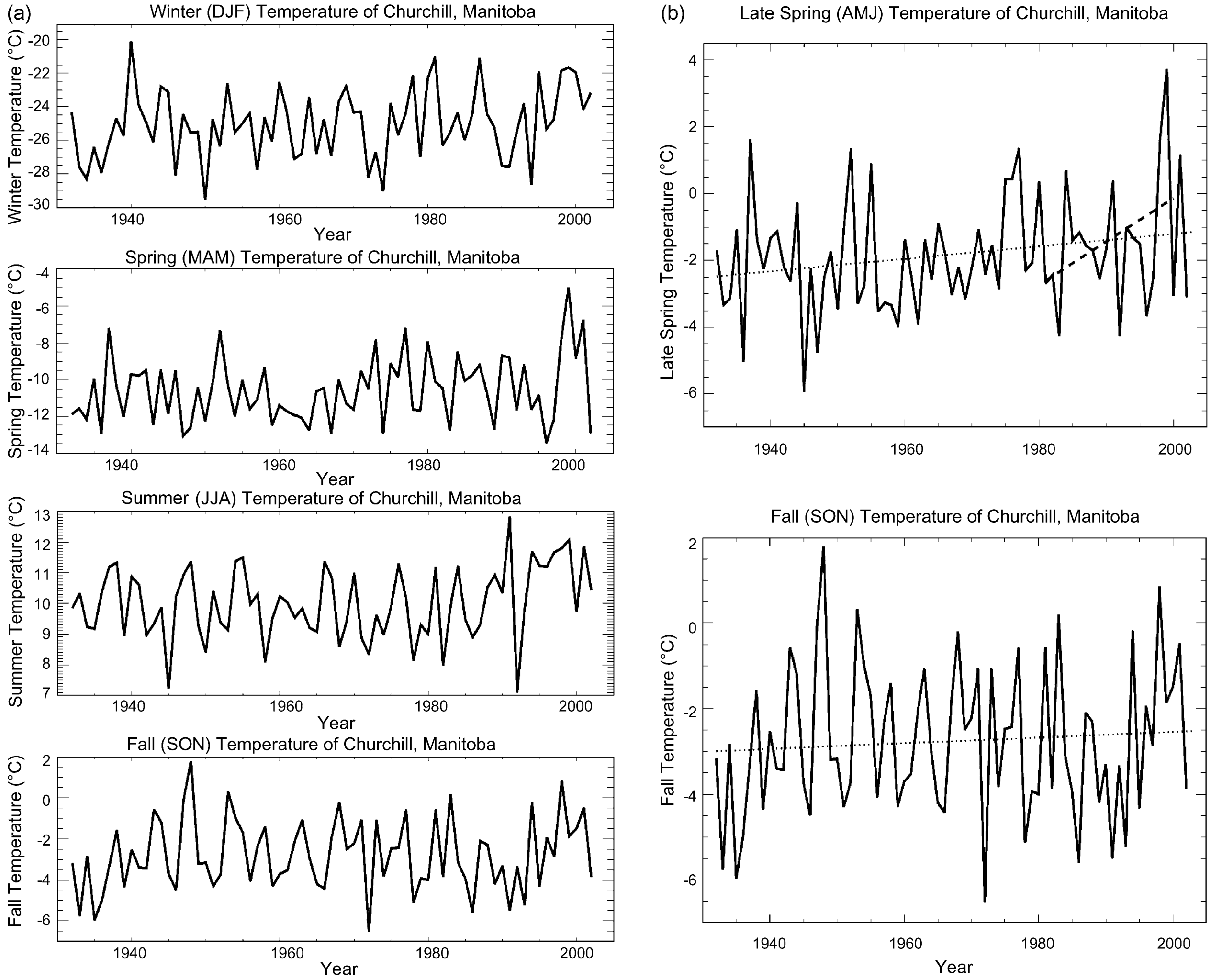

Fig. 1 – (a) Climatological winter (the average of December, January and February), spring (the average of March, April and May), summer (the average of June, July and August) and fall (the average of September, October and November) surface air temperatures of Churchill, Manitoba, which are assumed to be representative of temperatures around the western Hudson Bay from 1932 through 2002. (b) Late spring (defined as the average of April, May and June, following the discussion in Stirling et al., 1999; top panel) and fall (bottom panel) temperatures with statistically insignificant (i.e., with $p > 0.05$; again chosen in order to follow discussion in Stirling et al., 1999) trend lines (dotted) fitted through the 1932–2002 interval. The dashed trend line fitted through 1981–1999 verifies the late spring warming episode noted by Stirling et al. (1999) for that limited period.

recent updated analysis by Gagnon and Gough (2005a) suggested tendencies toward earlier ice break-up (hence shorter overall duration of sea-ice cover) in James Bay and along the southern shore of Hudson Bay. Population estimates, which have been conducted almost entirely via aerial surveys, indicate an increasing trend for this SH population from 1963 to 1996 (i.e., see Table 2 and Fig. 4c of Stirling et al., 2004). Although both populations are recognized as independent (e.g., Derocher and Stirling, 1990a,b; Kolenosky et al., 1992; Taylor et al., 2001), possible overlap can occur on the sea-ice. If population density for SH has been increasing, whereas food supply has been insufficient due to increased competition, then some SH bears may have expanded their hunting forays, leading to competition for food with WH bears. Yet there has not been a drastic decline in the WH population detected. One reason may be that the bears have learned to hunt seals during the ice-free period along the shores in tidal flats. This phenomenon has been observed for several years at Churchill in the polar bear viewing area (Dyck, personal observations).

Data on the bear food supply is needed to draw more clear conclusions about the interplay between population densities and worsening physical attributes of polar bears. The main prey of polar bears are ringed (*Phoca hispida*) and bearded seals (*Erignathus barbatus*) (Stirling and Archibald, 1977; Smith, 1980), but seal population data are too limited at present to resolve this issue (Lunn et al., 1997b).

4. Air temperature and climate variability around Hudson Bay

Fig. 1a shows the surface air temperature records[2] of nearby Churchill, Manitoba (assumed here to be representative of WH) from 1932 to 2002 for the four climatological seasons. The large interannual variability of the seasonal temperatures suggests that establishing a meaningful long-term trend in any of these relatively short records would be difficult and that a trend determination, especially over short periods, will be highly sensitive to the time interval considered (e.g., Pielke et al., 2002; Cohen and Barlow, 2005). Fig. 1b attests that no statistically significant warming trend (dotted trend lines plotted over the full records in Fig. 1b) can be confirmed for either the late spring (defined here as the average of April, May and June, following discussion in Stirling et al., 1999) or fall seasons when the full record from 1932 through 2002 is considered. Thus, the hypothesis that a warming trend is the principal causative agent for the supposed earlier spring melt and later fall freeze of the sea-ice around WH cannot be confirmed. Further, that the temperature trend is not statistically different from zero indicates it is not obviously forced by anthropogenic greenhouse gases as commonly assumed and extrapolated to suggest implications for polar bear ecology in future scenarios of climate change. Such extrapolations remain premature at best.

An apparent tendency towards late spring warming can be derived by examining the period from 1981 to 1999, illustrated by the dashed trend curve in Fig. 1b. Clearly, the choice of end points is very influential on the results. The trend fails to persist when data through 2002 are included and we make no inferences about any concurrent ecological responses. Thus, although our independent results for temperature change and variability over the WH do not contradict Stirling et al. (1999) for the limited period from 1981 to 1999, the longer record reveals a fuller range of air temperature variability that argues against assuming a persistent warming trend.

Gough et al. (2004) recently identified snow depth as the primary governing parameter for the interannual variability of winter sea-ice thickness in Hudson Bay because of its direct insulating effect on ice surfaces. By contrast, the concurrent winter or previous summer air temperatures yield only weak statistical correlations with ice thickness. Detailed high-resolution modelling efforts by Saucier et al. (2004) that considers tides, river runoff and daily meteorological forcing, found tidal mixing to be critically important for ice-ocean circulation within, and hence the regional climate of, the Hudson Bay basin.

We further examined records of winter and spring air temperatures at Frobisher Bay (now called Iqaluit, Nunavut) by the Hudson Strait and the respective winter and spring Arctic Oscillation (AO) circulation indices[3] (Fig. 2) to better

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[2] Our data source is the quality-controlled version of records from the NASA Goddard Institute for Space Studies web site: http://www.giss.nasa.gov/data/update/gistemp/station_data/. Churchill and Frobisher Bay data shown here are from the 7-station- and 5-station-merged records, respectively. Missing Churchill temperatures from NASA GISS database for 1993–1996 were replaced by data points from Churchill Airport given by CLIMVIS Global Summary of the day available from the U.S. National Climatic Data Center.

[3] Arctic Oscillation (AO) is a natural, planetary-scale pattern or mode of atmospheric circulation variability that is characterized by a seasaw of the air mass anomaly between the Arctic basin and the midlatitude zonal ring centered at about 45°N. A high (positive) AO value is defined as lower-than-normal atmospheric pressure over the Arctic and colder stratosphere, which are associated with strong subpolar westerlies. A low (negative) AO value represents higher-than-normal Arctic atmospheric pressure, less cold polar stratosphere and weak subpolar westerlies. The AO index is available from http://horizon.atmos.colostate.edu/ao/Data/index.html. Because of the relatively larger variability and stronger coupling of stratospheric and tropospheric air circulation during the cold season, AO is mainly a winter phenomenon However, AO has been demonstrated to be relevant to temperature and precipitation fields in other seasons as well (Gong and Ho, 2003; Kryjov, 2002; Overland et al., 2002). Please see Wallace (2000), Baldwin (2001) and Thompson and Wallace (2001) for complete tutorials. Although there have been several suggestions that the post-1969 or post-1989 AO index remained in an 'unusual', highly positive phase as a result of forcing by anthropogenic carbon dioxide, the current generation of climate models and modelling efforts are not sufficiently mature to confirm or refute such a proposal (Soon et al., 2001; Soon and Baliunas, 2003). Furthermore, it has been pointed out that AO index has been mostly neutral or negative in the most recent 9 years (1996–2004) despite the notable high-positive AO phase during the 1989–1995 interval earlier (e.g., Cohen and Barlow, 2005; Soon, 2005). Cohen and Barlow (2005) argued that even though the AO may contribute to regional warming in the Arctic and even the Northern Hemisphere for a particular period, but the pattern and magnitude of temperature signal induced by AO are physically quite different from the large-scale features produced by global warming trend in the last 30 years, thus disallowing any direct attribution of AO to radiative forcing by anthropogenic greenhouse gases.

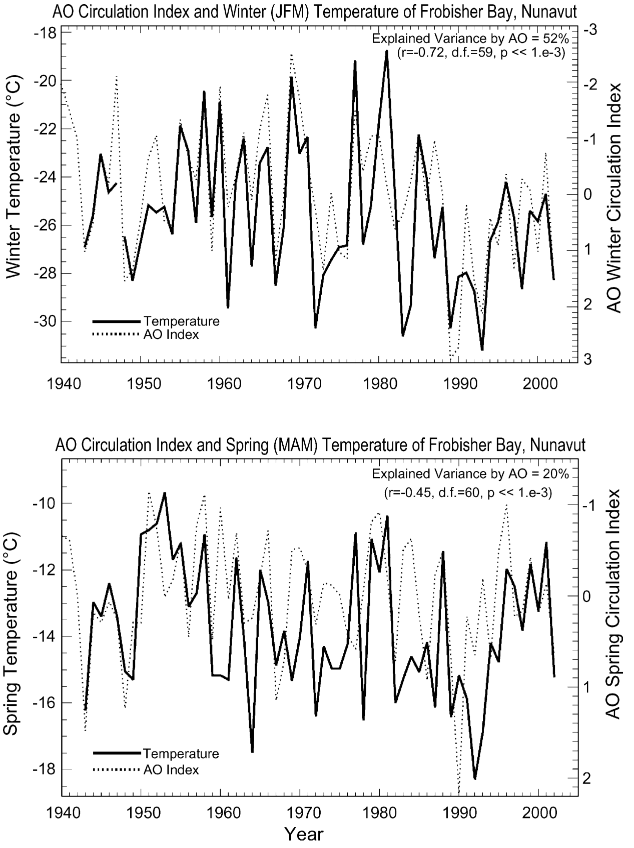

Fig. 2 – Statistically significant (i.e., $p \ll 0.001$) correlation between temperature (solid) at Frobisher Bay (now as Iqaluit), Nunavut and the Arctic Oscillation (AO) index (dotted) for winter (as averages of January, February and March; top panel) and spring (as averages of March, April and May; bottom panel). The axis for AO indices has a reversed scale such that high positive AO values mean colder temperatures at Frobisher Bay. 52% and 20% of the variance of the winter and spring temperatures for the 1943–2002 interval are explained by the respective AO indices. Both the standard Pearson's r and non-parametric Kendall's τ were computed, and statistical significance of the results are established based on both statistical measures.

characterize the regional pattern of air temperature variability. Fig. 2 shows two important points. First, note the rather strong cooling trend (at a rate of about 0.4 °C per decade since the 1950s) for the winter and spring temperatures of Frobisher Bay. Regional differences in the pattern of the temperature variability, especially on the multidecadal timescale, are large. This pattern of large temperature gradients between the southwestern and northeastern corners of the Hudson Bay oceanic basin has been well noted by Ball (1995), Catchpole (1995) and Skinner et al. (1998)—these authors also provided a comprehensive discussion on climate regimes around WH, including a broad, historical perspective on the range of natural variabilities. Among other things this indicates that a hypothesis of late spring warming negatively affecting the WH polar bear population ecology cannot be universally extended to other locations.

The second point of Fig. 2 is that the air temperature and climatic conditions around the Hudson Strait and Hudson Bay areas have a close association with the AO circulation index. The correlations shown in Fig. 2 are statistically significant, with AO variability explaining up to 20–50% of the interannual temperature variances at Frobisher Bay.

To examine the link between the AO index and Frobisher Bay air temperatures, both series were regressed on a matrix of monthly dummy variables to remove fixed seasonal effects. The residuals of these regressions (denoted AO_r and FR_r) were then tested in a vector autoregression to determine leading patterns of Granger causality (see Hamilton, 1994, Chapter 11). While AO_r shows a significant Granger-causal pattern on FR_r no such pattern exists in the other direction. This means the current value of the AO index significantly improves forecasts of monthly Frobisher Bay air temperatures, but the current air temperature does not improve forecasts of the AO. Finally, FR_r was regressed on its first two lags, AO_r and the first three lags of AO_r to remove serial correlation in the mean. After a trend term that was insignificant was removed, the r^2 from this regression was 0.39 (with an adj-r^2 of 0.38). A Wald test of the joint AO_r terms yielded a chi-square (d.f. = 4) statistic of 235.6. A p-value on the hypothesis of no influence of the current and lagged AO anomalies on the current monthly temperature anomaly is less than 0.00001.

The AO circulation index appears to be physically relevant for two reasons. First, from an examination of the statistics of sea level pressure and sea-ice motion from the 1979 to 1998 data collected by the International Arctic Buoy Programme, Rigor et al. (2002) confirmed that the AO circulation pattern can explain at least part of the thinning sea-ice trend observed over the Arctic Ocean. Polyakov and Johnson (2000) and Polyakov et al. (2003a) further emphasized the importance of the relative phasing of the decadal and multidecadal (i.e., 50–80 years) oscillatory modes of Arctic atmospheric circulation variability in explaining the recent Arctic sea-ice areal extent and thickness trends. Rigor et al. (2002) clarified that instead of assuming that the warming trend in surface air temperature caused the sea-ice to thin, it is the AO-induced circulation pattern that produces the tendencies for sea-ice to thin and sea-ice area to retreat (see further discussion on regional sea-ice trends and mechanisms in Zhang et al., 2000; Kimura and Wakatsuchi, 2001; Polyakov et al., 2003b; Söderkvist and Björk, 2004). In turn, it was the changes in sea-ice that caused the air temperature to warm because of an increasing heat flux from the interface with the ice-free ocean. Beyond atmospheric AO, Shimada et al. (2006) recently documented and highlighted the key role played by the inflows of warm Pacific summer water through the Bering Straits in causing the large sea-ice areal reduction in the Arctic that began in the late 1990s. Thus, such a complex physical picture connecting oceanic and atmospheric processes with sea-ice variability is dramatically different from Stirling et al. (1999)'s suggestion in which warm spring air temperature is considered to be the ultimate cause for the earlier spring sea-ice break-up[4] and poorer conditions of polar bears.

The second reason to discuss the AO index is related to a recent finding that climatic change effects associated with the AO index are propagated through two trophic levels within a high-arctic ecosystem (Aanes et al., 2002). From the statistical analyses of the 1987–1998 growth series of *Cassiope tetragona* (Lapland Cassiope) and the 1978–1998 abundance series of an introduced Svalbard reindeer (*Rangifer tarandus platyrhynchus*) population near Broggerhalvoya, on the NW coast of Svalbard, Aanes et al. (2002) found that high positive values of the AO index are associated with decreased plant growth and reindeer population growth rate. Thus, the reindeer population at Svalbard, through the mediation of the climate modulated effects on plant growth, is plausibly connected to climate through a bottom-up sequence. But Aanes et al. (2002) noted that the bottom-up scenario may be density-dependent in that at higher reindeer densities, a reverse top-down sequence of trophic interaction is becoming more important in which grazing has a dominating influence on the forage species and plant communities. The AO index is thus promising as a useful climatic variable for further examination of the dynamic of trophic interactions under various settings of the arctic ecosystem.

It must also be asked whether natural climate oscillations as those described above – reducing sea-ice cover and changing the freeze-and-thaw cycles that affect the food sources of polar bears at higher latitudes – are really as detrimental to biodiversity as suggested. These changes may create more polynyas, which are productive oases in the ice (Stirling, 1997), or increase marine productivity overall (Fortier et al., 1996; Rysgaard et al., 1999; Hansen et al., 2003) primarily because of the modulation of the food web of the lower trophic levels by freshwater-limiting and light-limiting processes. Bears do not feed year-round, but do feed during late spring when seal pups are abundant. More fat deposits may be accumulated during this time, and a “true hibernation state” like black (*U. americanus*) and brown bears (*U. arctos*) could become an evolutionary strategy for the remainder of the year for polar bears. This scenario could be very likely because polar bears evolved from brown bears (Kurtén, 1964). Alternatively, a supplementary feeding strategy could evolve where berries and vegetation are consumed in higher frequencies during the ice-free period, as has been observed for bears of Hudson Bay (Russell, 1975; Derocher et al., 1993).

5. Extrapolating polar bear populations

In light of these considerations we do not consider it a sound methodology to assume that local air temperature trends adequately explain WH population conditions and that extrapolating WH results generates predictions for polar bears and their habitat over the circumpolar Arctic (e.g., Stirling and Derocher, 1993; World Wide Fund for Nature 2002; Derocher et al., 2004). We take particular exception to the suggestion by Derocher et al. (2004, p. 163) that polar bears will not likely survive “as a species”[5] if several computer-generated scenarios of air temperature-driven disappearance of sea-ice “by the middle of the present century” come true. The conjecture seems errant for two reasons. First, most climate models predict a complete disappearance of sea-ice over the central Arctic for only the late summer (i.e., September) while the whole Hudson Bay is always ice-free during this time regardless of the forcing by anthropogenic greenhouse gases (see for example Figs. 8 and 9 in Johannessen et al., 2004). Second, in the cited climate model projections, sea-ice at the Hudson Bay for the late winter or early spring (i.e., March) was never predicted to completely disappear by the end of this century, even under scenarios that posit greenhouse gas accumulations at rates considerably faster than currently or historically observed. In a recent multi-model study of climate projection in the Hudson Bay region, Gagnon and Gough (2005b, p. 291) concluded that “Hudson Bay is expected to remain completely ice covered in those five models by the end of this century for at least part of the year.”

It should also be noted that Gough et al. (2004) had earlier reported that the observed thickening of sea-ice cover during the last few decades on the western coast of Hudson Bay was

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[4] It should be noted that the tendency or trend for earlier spring sea ice break-up in WH from 1979 to 1998 pointed out by Stirling et al. (1999) is not statistically significant (with $p = 0.07$) under the authors' own criterion and admission. Houser and Gough (2003) was also unable to demonstrate statistical significance in the trend of timing of the spring sea ice retreat at the Hudson Strait over the full interval from 1971 through 1999; although they suggest that an earlier spring ice retreat or break-up seems clear for the data starting 1990. We argue that this new tendency may be related to the sustained positive phase for the AO circulation index since 1989 till 1995 or so (see footnote 3) and it remains to be confirmed if that the AO index might remain in that trend of high positive values or the AO variability might undergoes a shift toward the low (negative) AO-value phase as in the 1950s and 1960s. Updated results shown by Gagnon and Gough (2005a) on trends in the timing of ice break-up, although now able to claim “statistical significance” under rigorous statistical testing for James Bay and western half of Hudson Bay [though it should be noted that in several records, threshold *p*-value of less than 0.10, instead of the threshold of 0.05 adopted for example by Stirling et al. (1999), is now used to claim significance], point out that detecting surface air temperature trends is still sensitive to the time interval of data records (see e.g., Cohen and Barlow, 2005). Another real concern is the definition of spring ice break-up and autumn freeze-up where we are not sure if the criterion of 50% ice cover for the onset of melting and freezing seasons has been optimized for the understanding of polar bear population ecology (see Rigor et al., 2000 for other suggestions and threshold criteria), In general we wish to discourage the over reliance on statistical confidence that bypasses clear physical arguments or hypotheses (see e.g., Wunsch, 1999).

[5] However, it should not be too surprising to find somewhat contradictory or more restrictive statements by these same authors from what we faithfully quoted about polar bears facing extinction in the Arctic by Derocher et al. (2004). For example, Dr. Ian Stirling was quoted in WWF (2002) to have said that “For every week earlier that break-up occurs in the Hudson Bay, bears will come ashore roughly 10 kg lighter and thus in poorer condition. With reproductive success tied closely to body condition, if temperatures continue to rise in response to increases in greenhouse gas emissions and the sea ice melts for longer periods, polar bear numbers will be reduced in the southern portions of their range and may even become *locally* [emphasis added] extinct.” (p. 5).

in direct contradiction to the thinning ice scenario that is posited by warming due to an enhanced CO_2 atmosphere. Under these CO_2-warming scenarios, the models predicted not only an earlier spring break-up of sea-ice but also later fall freeze-up at Hudson Bay (Gagnon and Gough, 2005b). Available observations from 1971 to 2003, by contrast, do not show any tendency for a later freeze-up of ice especially at WH or southwestern Hudson Bay (Stirling et al., 1999; Gagnon and Gough, 2005a). Further to the north, Melling (2002, pp. 2–18), in his study of sea-ice around the northern Canadian Arctic archipelago, concluded that "[i]nterannual fluctuations in late-summer ice coverage obscure any evidence of trend [in the Sverdrup Basin]. A decadal cycle contributes variability to the times series of both total and multiyear ice concentrations. Because the reputedly extreme conditions of 1998 are similar to occurrences in 1962 and 1971, there is little basis on which to view them as evidence for anthropogenic change."

We therefore conclude that it is highly premature to argue for the extinction of polar bear across the circumpolar Arctic within this century as incorrectly suggested in Derocher et al. (2004).

Finally, we wish to encourage a renewed archaeological search for information related to polar bear population ecology from 1760 to 1820, when historical evidence (based on early thermometers at trading posts of Churchill Factory and York Factory) suggests that the climatic regimes at WH had shifted from temperate to arctic conditions (see Ball, 1995; Catchpole, 1995). Ball (1983, 1986) documented large changes and abrupt shifts in both floral (i.e., treeline boundary between the boreal forest and the tundra) and fauna (i.e., migration of wild geese) ecosystem responses of the Hudson Bay region that occurred naturally as a consequence of the varying mean locations of the Arctic Front (Bryson, 1966). Ball (1995) suggested that the three consecutive decades from 1770 to 1800 at York Factory consisted of very wet and variable winter conditions oscillating between extremes of heavy snow versus almost snow-free conditions, which made the thriving of wildlife populations difficult. Heavy late winter rains, for example, have been proposed as a cause of the collapse of maternity dens, suffocating the occupants (Stirling and Derocher, 1993). Excessive snowfall was noted to alter oxygen flux through the snow layer of maternity dens and could negatively impacting survival rates of young altricial cubs that need to be nursed for 3 months before they are able to leave the den with their mothers (Derocher et al., 2004). The records compiled by Ball and Kingsley (1984) suggested an interval with a relatively warm late spring (April–May–June) at York Factory of about 2.9 °C for 1779, 1780, and 1782 (no data for 1781) when monthly air temperature readings were available from the Hudson Bay's Company and Royal Society's archives. These data may be applied to assess the resiliency of polar bears under adverse climate conditions. The latest research by Scott and Stirling (2002) have successfully dated, through sophisticated timing and fingerprinting techniques of dendro-sciences, polar bear maternity dens and dens activities inland from the coast of WH, south of Churchill and north of York Factory, since at least 1795, while reports of polar bears have been recorded at least since 1619. These authors concluded that "there does not appear to be a relationship between climate trends and the rates of den disturbance during the overall 1850–1993 period" and that "changes in the frequency and pattern of disturbances at den sites may be related to the pattern of hunting and trading of hides at York Factory during the 19th and early 20th century" (p. 163). Thus, the reality of human activity impacting population ecology of polar bears at WH is clear while empirical evidence for polar bear resiliency under extended records of weather extremes and a wide range of climatic conditions may be stronger than previously thought.

6. Conclusions

The interactions among sea-ice, atmospheric and oceanic circulations, and air and sea temperatures are complex and our understanding of these issues in the Arctic context is limited. We suggest that large interannual variability, which we view as stochastic in nature (e.g., Wunsch, 1999), dominates the climatic changes in WH. Improved understanding of polar bear resiliency and adaptive strategy to climatic changes must consider human–bear interactions, natural population dynamics, and the dominant components of variability of the Arctic ice, ocean and atmosphere that operate naturally on decadal to multidecadal timescales (Vinje, 2001; Polyakov et al., 2003a,b; Soon, 2005). The clear evidence for strong regional differences in the spatial pattern of historical climate change around the Hudson Bay region add a layer of uncertainty to the task of explaining empirical evidence. It is certainly premature, if not impossible, to tie recent regional climatic variability in this part of central Canada to anthropogenic greenhouse gases and, further, to extrapolate species-level conditions on this basis. These complex interactions of man-made and natural factors will ultimately bring about particular ecosystem responses (perhaps yet unintelligible to us) but we find that late spring air temperature has not emerged as a decisive causal factor or reliable predictor. Such a complexity within the Hudson Bay's ecosystem clearly challenges the usefulness of the original proposal in considering polar bears as indicators of climatic warming made by Stirling and Derocher (1993).

The broad claim for the sea-ice to be "gone by the middle of the present century" could be both misleading and confusing in that existing model predictions are for the complete disappearance of late summer, rather than spring, sea-ice over the central Arctic ocean. Climate models actually expected Hudson Bay to be fully covered with sea-ice at least part of the year (including early spring) even under rather extreme forcing assumptions by involving rapid increases in anthropogenic greenhouse gases by the end of this century. This is why extrapolation studies arguing for severe negative impacts of polar bears under a global warming scenario are neither scientifically convincing nor appropriate.

The fate of the charismatic polar bear population is of considerable public concern, and rightly so. Science can best contribute to the goals of conservation by providing the most accurate possible understanding of the factors affecting the population ecology of these impressive animals. Our concern in this paper is that if attention is inappropriately confined to a single mechanism, namely greenhouse warming, opportunities to understand other relevant mechanisms behind changes in bear population and health parameters may be lost in the process. It is also abundantly clear that relying on such a strict single-variable-driven scenarios of global warming by increasing atmospheric carbon dioxide and related melting sea-ice in discussing an issue as complex as the population and well being of polar bears runs counter to the underlying realities and challenges of ecological complexity that emphasizes at least the six co-dimensions of spatial, temporal, structural, process, behavioural and geometric complexities (as e.g., outlined in viewpoints of Li, 2004; Loehle, 2004; Cadenasso et al., 2006).

Therefore, we believe it is premature to make the ‘‘one-dimensional’’ predictions about how climate change may affect polar bears in general and there is no ground for raising public alarm about any imminent extinction of Arctic polar bears. The multiple known and likely stresses interact dynamically and may contribute in an additive fashion to negative effects on polar bears. To quantify the severity of these stress co-factors, however, is very difficult, if not almost impossible, with current limitations on data. Areas of research we would particularly encourage include archaeological investigations, improved data on prey population dynamics, and examination of lower trophic levels to provide more insight into the proximate effects of climate change on Arctic species. We further suggest that the AO circulation index may be useful in tracking the propagation of climatic and meteorological signals through the coupled ecosystems of the Arctic land and sea that promises only the undeniable complexity of multi-trophic level interactions (Fortier et al., 1996; Steinke et al., 2002; Hansen et al., 2003).

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