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Viewpoint

Response to Dyck et al. (2007) on polar bears and climate change in western Hudson Bay

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ABSTRACT

The “viewpoint” article by Dyck et al. (2007) [Dyck, M.G., Soon, W., Baydack, R.K., Legates, D.R., Baliunas, S., Ball, T.F., Hancock, L.O., 2007. Polar bears of western Hudson Bay and climate change: are warming spring air temperatures the “ultimate” survival control factor? *Ecol. Complexity* 4, 73–84. doi:10.1016/j.ecocom.2007.03.002.] suggest that factors other than climate warming are responsible for a decline in the polar bear population of Western Hudson Bay. They propose: (1) that there is no evidence that the climate has warmed significantly in western Hudson Bay, (2) that any negative effects on the polar bear population likely result from interactions with humans (such as research activities, management actions, or tourism), (3) that studies suggesting climate warming could influence polar bear populations are confounded by natural fluctuations and (4) that polar bears will adapt to climate warming by eating vegetation, hunting other marine mammal species, and evolving new physiological mechanisms. In our examination of their alternative explanations, and the data available to evaluate each, we found little support for any.

Research conducted since 1997 (when the last data were collected for the analyses in Stirling et al., 1999 [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 climate change. *Arctic* 52, 294–306.]) continues to be consistent with the thesis that climate warming in western Hudson Bay is the major factor causing the sea ice to breakup at progressively earlier dates, resulting in polar bears coming ashore to fast for several months in progressively poorer condition, resulting in negative effects on survival of young, subadult, and older (but not prime) adults and reproduction. When the population began to decline, the hunting quota for Inuit in Nunavut was no longer sustainable, which in turn probably resulted in the decline accelerating over time as a result of overharvesting (Regehr et al., 2007 [Regehr, E.V., Lunn, N.J., Amstrup, S.C., Stirling, I., 2007. Survival and population size of polar bears in western Hudson Bay in relation to earlier sea ice breakup. *J. Wildl. Manage.* 71, 2673–2683.]).

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1. Introduction

Stirling et al. (1999) reported that between 1981 and 1998, the condition of adult male and female polar bears (*Ursus maritimus*) accompanied by dependent cubs declined, and consequently so did reproduction, and the proportion of independent yearling cubs captured during the open water season in summer and autumn in western Hudson Bay (WH), Manitoba, Canada. They attributed the decline in condition of the bears in autumn to their having progressively less time to feed on seals at the most important time of year (late spring and early summer) because the warming climate caused the sea ice to breakup earlier. Thus, the bears were forced onto land at progressively earlier dates to begin a longer fast on less stored fat until freeze-up in autumn. As of 1997 (the last year data were collected for that paper), these changes had not yet caused a detectable decline in the size of the population. However, Stirling et al. predicted that if the trends of warming temperatures and progressively earlier breakup of the sea ice continued into the future, they would eventually cause a population decline. Monitoring of that polar bear population has continued and Regehr et al. (2007) documented a decline from about 1200 in 1987 to 935 in 2004. As well, survival of juvenile, subadult, and senescent-adult polar bears varied significantly as a linear function of spring sea-ice breakup date (i.e., the earlier the breakup date the lower their survival). The decline, started by the effects of progressively earlier breakup of the sea ice, was aggravated by an annual harvest by Inuit hunters that was no longer sustainable.

Dyck et al. (2007) recently proposed a series of alternative explanations for the observed changes in the polar bear population in WH reported by Stirling et al. (1999). In particular, these authors suggested that air temperatures had not increased in WH, other factors could explain trends toward earlier timing of ice breakup, that increased human interactions with polar bears might play a significant role in the changes observed in the population, and that polar bears will somehow adapt to changes in their ecosystem that may result from climate warming. In this paper, we argue that the overall thrust of their conclusions and alternative explanations are either unsupported or incorrect. In some cases they have ignored existing literature on polar bears, sea ice, and climate warming specific to the polar bear population in question. Thus, we conclude that their explanations are unsupported by the available data.

The main arguments of Dyck et al. (2007) fall into three basic categories, each with several parts: (1) whether or not climate warming is occurring in WH and influencing breakup of the sea ice, (2) whether human activities (research, tourism, and the Polar Bear Alert Program) and/or food competition are cumulatively having the negative effect on the polar bear population that has been attributed to climate warming and, (3) whether polar bears can adapt to and thereby avoid the negative impacts of changes in ice conditions caused by climate warming. Thus, we will respond to each of these issues separately.

2. Evidence of the role of climate warming in affecting the western Hudson Bay polar bear population

2.1. Increasing air temperatures in western Hudson Bay

One of the most important errors in Dyck et al. (2007) was their examination of climate changes over time frames that did not correspond to when the changes in the WH polar bear population were documented. They present surface temperatures recorded at Churchill (situated on the coast) as representative of the offshore sea-ice area inhabited by the polar bear population of WH and, based on temperature records from 1932 to 2002, conclude there has been no significant increase. Although they note there is regional variation in temperatures over the whole of Hudson Bay (Etkin, 1991; Skinner et al., 1998; Gagnon and Gough, 2005), and that the temperature in WH increased during the Stirling et al. (1999) study, i.e., 1981–1997 (when bear condition declined) they suggest that the trend did not continue. However, Gagnon and Gough (2005), which they cite, confirmed that between 1971 and 2001, the average annual temperature increased at 6 of 7 weather stations distributed throughout Hudson Bay and specifically by 0.5 °C per decade at Churchill. Furthermore, two additional studies analyzed surface air temperatures recorded by satellite and documented increases of 1.2–1.6 °C/decade in offshore areas of WH between 1981 and 2005 (Comiso, 2006; Serreze and Francis, 2006). These latter studies also confirm that in the spring, the warming graded from about 1.2 °C/decade offshore to about 0.4 °C/decade along the coast (close to the 0.5 °C/decade reported by Gagnon and Gough (2005) at Churchill from meteorological data). Thus, there is little doubt that temperatures in WH bay have increased and continue to do so.

Dyck et al. (2007) further argue that some areas are actually cooling and that factors other than air temperature are affecting sea-ice conditions both in WH and elsewhere. They focus on historical information and cite a cooling trend in eastern Hudson Bay and Davis Strait (Skinner et al., 1998). By analyzing only historical meteorological data from Iqaluit, Nunavut (beyond the range of the WH polar bear population), they conclude the trend is one of cooling air temperatures and, further, that there is a relationship between air temperature and the Arctic Oscillation (AO) at this particular site. From these analyses, they conclude (1) that temperature increases in WH are not indicative of broader regional changes and (2) that the AO rather than air temperature plays a prominent role in affecting sea-ice conditions. However, as previously clarified, region-wide analyses of temperatures in Hudson Bay including more current data have shown clear increasing trends in the WH region (Gagnon and Gough, 2005) which parallel increasing surface air temperatures that have been documented Arctic-wide (Overland et al., 2004). Furthermore, intensive Arctic-wide analysis and modeling efforts have concluded that the consistent, unidirectional changes in the sea ice cannot be explained by the AO, North Atlantic Oscillation (NAO) or Northern Annular Mode (NAM), but are driven by rising air temperatures (Overland and Wang, 2005, 2007; Comiso, 2006; Serreze et al., 2007). Lastly, they ignore recent analyses of temperature that confirm the opposite of

their conclusion, that is, that one of the most rapidly warming locations in the Arctic is now in Davis Strait, just south of Iqaluit (Comiso and Parkinson, 2004; Comiso, 2006). Thus, the relationship between AO and air temperatures at Iqaluit presented by Dyck et al. do not aid our understanding of either the issue of whether increasing WH temperatures are indicative of trends elsewhere, or the importance of the AO in affecting sea-ice conditions.

Gough et al. (2004b) examined trends in the length of the ice-free season in Southern Hudson Bay (SH) and the influence of ENSO, NAO (closely related to AO) and volcanic eruption (Mt. Pinatubo in 1991). Specifically, they analyzed time series of sea-ice breakup and freeze-up from 1971 to 2003 using three different statistical techniques: simple linear regression, Mann–Kendall test, and multivariate autoregression. While the statistical significance of the results increased to $p = 0.02$ with the inclusion of all three sources of variability, Gough et al. (2004b) reported that this was largely the result of including the Mt. Pinatubo eruption. Their analysis indicates the robustness of the sea-ice breakup trends detected in various studies. More importantly, accounting for the effects of multi-decadal oscillations improved the detection of a net trend suggesting that these oscillations are not driving the detected increase in the duration of the ice-free season but rather reduce our ability to detect long-term trends by increasing the climatic noise.

Dyck et al. (2007) also suggest that several factors in addition to the AO, such as tides, currents, and snow depth, play a significant role in affecting sea-ice conditions. They refer to a study by Saucier et al. (2004), which concludes that tidal mixing, and meteorological forcing influence the regional climate of Hudson Bay. Saucier et al. did not address climate change but explored the variability of sea ice–ocean processes over short to seasonal scales, although one purpose of their study was to develop a tool to eventually look at the sensitivity of the system to such things as climate warming. They conclude that “...coupling between the sea ice–ocean and the atmosphere at the regional scale can improve the predictions of all components of the HB regional system (p. 323)”. Saucier (personal communication, 2007) confirmed “that the early breakup of sea ice over recent years has had little to do with tides, and certainly much to do with large scale atmospheric forcing”.

Similarly, Dyck et al. (2007) cite Gough et al. (2004a) as evidence that snow cover plays a more important role in determining ice thickness than either the concurrent winter or previous fall air temperatures. However, this conclusion is incorrect for several reasons. First, Dyck et al. do not make the distinction that Gough et al. examined seasonal sea ice in Hudson Bay, not multi-year ice which is the focus of most other climate change studies. Thus, the relationship between snow depth and sea-ice thickness detected by Gough et al. cannot necessarily be generalized to multi-year ice. Second, thicker peak seasonal sea ice in WH is unrelated to later breakup (Gagnon and Gough, 2005) which is the ice metric most relevant to that polar bear population. Lastly, it should be noted that Gough et al.’s observation of thicker peak seasonal sea ice in western Hudson Bay results from the reduced insulation associated with lower snowfall and reduced snow depth. Ice that is insulated by deep snow has a warmer ice

surface and is therefore thinner than ice covered by a thin layer of snow. While this relationship complicates the direct effects of increased air temperatures on ice thickness, Gough et al. (2004a) conclude that despite these effects “warmer temperatures will result in a thinning of Hudson Bay ice in an enhanced CO₂ atmosphere”. Thus, inferring that the dependence of peak seasonal sea ice thickness on snow depth is the dominant factor determining sea ice thickness in general (seasonal or multi-year), or, more importantly the length of the seasonal sea-ice season, is erroneous.

2.2. Timing of sea-ice breakup and effects on polar bears in WH

Dyck et al. (2007) emphasize that in Stirling et al. (1999) the trend toward earlier breakup was significant at the 0.07 level of probability, or not quite at the generally accepted probability level of 0.05. However, Dyck et al. failed to note that two additional references (Stirling et al., 2004; Gagnon and Gough, 2005), both of which they cite, confirm that the trend continued in the same direction and, by 2002, was statistically significant at $p = 0.0044$ level of probability. More importantly, Dyck et al. overlook that there was a statistically significant relationship between the condition of adult male polar bears and adult females accompanied by dependent young and the date of breakup, i.e., the earlier the date of breakup, the poorer the condition of the bears and the lower the survival rates of cubs, subadults, and old age classes (Stirling et al., 1999; Regehr et al., 2007). This latter point is particularly important as it confirms that during the same time period when polar bear condition declined, ice breakup occurred earlier and air temperatures were increasing.

2.3. Population trend in WH and density dependence

Dyck et al. (2007) propose that, based on data available to them, that the “‘decline’ of the WH (western Hudson Bay) polar bear population in 2004, relative to the 1995 values, is difficult to confirm.” (p. 3). Their suggestion that the population increased between 1977 and 1992 is due to spurious population estimates that resulted before the study expanded to be able to cover the full geographic area occupied by the population while it was on land (Regehr et al., 2007, quoted in IUCN/SSC PBSG, 2006). Derocher and Stirling (1995a, p. 220) specifically stated “Given that we did not find a change in population size, density dependence cannot be supported as a cause for changes in body mass, reproduction, and cub survival”. That paper presented only two reasons for the observed changes and once density dependence was discounted only “long-term changes in environmental conditions” (p. 220) remained as a possible cause of the changes. Contrary to Dyck et al.’s conclusion, the population declined by about 22%, from about 1200 in 1987 to 935 in 2004 (Regehr et al., 2007). The population is now well below historic levels so if density dependent effects were driving the changes in body mass, reproduction, growth, and cub survival then, a response should have been noted in the last decade. Large mammals such as polar bears would likely have a convex relationship between population size and per capita growth rates and thus would only show density dependent responses as the

population neared carrying capacity (Sutherland and Gill, 2001). Therefore, a 22% decline in population size should have resulted in a rapid response, the lack of which indicates that density dependent changes were not responsible for the observed changes in the population. Furthermore, Ginzburg et al. (1990) cautioned against using density functions in conservation assessments when data are insufficient to reliably describe the relationships.

2.4. Timing of sea-ice breakup and trends in SH

Dyck et al. (2007) propose that polar bears in Southern Hudson Bay have exhibited “better body condition as compared to their WH (western Hudson Bay) counterparts”, which they conclude illustrates the lack of a generalized response of polar bears to changing ice conditions. However, this statement is made out of context and is unsupported by recent studies (some of which were unavailable to them at the time they wrote their critique). Stirling et al. (1999) noted that bears of all ages and sex classes in SH were heavier than their counterparts in WH because, at that time, the ice broke up three weeks or so later there and consequently, the bears in SH were able to feed for longer and accumulate more fat. However, Gagnon and Gough (2005) reported that breakup is now occurring significantly earlier in the Southern Hudson Bay area and the IUCN/SSC Polar Bear Specialist Group (2006, p. 45), and Obbard et al. (2006), reported that bears of all age and sex classes were significantly lighter in the 2000s than in 1984–1986, especially pregnant females. There is a non-significant negative relationship between the condition indices and the duration of ice cover between the two periods, which Obbard et al. (2006) suggest indicates that factors in addition to breakup, such as possible effects of a warming climate on seals (e.g., Stirling and Smith, 2004; Ferguson et al., 2005), may also be affecting bears. Although the total sample size and continuity of the study in SH are less extensive than in WH, the pattern is similar. Furthermore, the declines in SH occurred without any tourism, no Polar Bear Alert Program and a 20-year hiatus in research capture activities (see discussion of proposed human factors in Section 2). Thus, while we agree that factors in addition to ice may be involved, we also note that until about 1997 in WH a statistically significant negative relationship between breakup date and condition of adult males and adult females accompanied by dependent young could be demonstrated, but a statistically significant decline in total population size was not detected until several years later (Regehr et al., 2007). Thus, we predict, as did Stirling and Parkinson (2006), that if the time of breakup continues to occur at progressively earlier dates, and the duration of sea ice declines, the population of polar bears in SH will continue to decline in both condition and abundance, similar to what was documented in WH.

3. Responses to suggested importance of human–polar bear interactions

3.1. Research handling of polar bears

Dyck et al. (2007) propose that extensive handling of polar bears in western Hudson Bay for population studies may be responsible for the exhibited declines in bear condition and

reproduction. They estimated that an annual average of 187 bears were handled from 1977 to 1995 and suggest “. . . it is very likely that many bears were/are exposed to capture activities on a repeated basis (p. 2)”. Given that the research sampling for much of the period under question was directed at mark and recapture analyses, sampling was spread over a wide area in order to obtain a random sample of the total population (Derocher and Stirling, 1995a). In simple terms, for an estimated population of 1200 bears during that period, the probability of a bear being caught each year was approximately 15.6% (187/1200), which suggests that, on average, an individual bear might be handled once every 6 years. Even if doubled to a capture rate of 30%, a bear would only be handled less than once every 3 years.

As well as the study cited by Dyck et al. (2007), which they noted found no statistically significant negative effects of handling on polar bears (Ramsay and Stirling, 1986), five additional studies on polar bears and one on brown bears (*Ursus arctos*) provide further evidence that handling does not appear to displace bears from important habitats or impact individual condition and reproduction. In assessing long-term mass trends of bears in western Hudson Bay, Derocher and Stirling (1995b) found that the body masses of most age and sex classes were declining over time but found no significant difference in the slope of the decline for bears with a previous capture history and bears that had not been caught before. In the largest study ever undertaken to assess possible effects of immobilizing polar bears, Messier (2000) reviewed information from 3237 immobilizations, many of them recaptures of the same individuals in subsequent years following their initial capture. He conducted 25 independent analyses of the long-term effects of tagging, of which 24 showed no measurable effects. Similarly, he conducted 29 independent analyses to test for measurable effects of radio collaring, of which 27 showed no effects, 1 suggested a positive effect and 1 suggested a negative effect. Messier (2000) concluded that, overall, the long-term effects of tagging and radio-collaring polar bears were either not measurable or negligible. Amstrup (1993) also documented no effect of capture, marking, and radio-tracking on litter sizes or stature of cubs. Lunn et al. (2004) noted that although pregnant female polar bears appeared sensitive to being handled at maternity dens in the fall, it did not affect either litter size or the weights of male cubs the following spring. A recent study found that capture and handling of polar bears in the Southern Beaufort Sea between 1982 and 2006 had no negative effect on the size, mass, or condition of any polar bear sex/age class, including individuals captured repeatedly up to 10 times (Rode et al., 2007a). Lastly, a recent study of brown bears, found no difference in habitat use, feeding patterns at salt marshes or salmon streams, or responses to bear-viewing activities between bears immobilized via helicopter darting twice per year and those that were never previously handled (Rode et al., 2006).

Dyck et al. (2007) proposed that “females may suffer from handling by being displaced from feeding sites”, a speculation that does not apply to polar bears in WH. At the time the bears are handled in WH, they are in a fasting mode (Ramsay and Stirling, 1988) and are not feeding.

Dyck et al. (2007) further suggested that because most capture work occurs when bears emerge from dens in the

spring or during the ice-free period when they are “stressed due to lactation”. While lactation is energetically demanding for all species of mammals, female polar bears have evolved over time to deposit and then rely upon stored energy for lactation during spring and autumn as needed (Watts and Hansen, 1987; Ramsay and Stirling, 1988). The ability to fast for extended periods is a normal part of the environment polar bears have evolved to deal with. Not only do pregnant females go into a state of physiological lethargy when they over-winter in maternity dens and give birth to their cubs, polar bears of all age and sex classes have evolved to be able to enter this physiological condition at any time of year in response to shortage of food (Derocher et al., 1990; Ramsay et al., 1991). Thus, rather than being “stressed” they are in a normal physiological state in response to the absence of food during the open water period of summer and fall, or while in a maternity den.

Taken together, the available data do not support the suggestion that capture and handling procedures negatively affect polar bears sufficiently to have contributed to their loss of condition or decline in numbers.

3.2. Tourism

Dyck et al. (2007) propose that tourism may “contribute to the negative energy balance of the bears while on land” (p. 3). However, their description of tourism activities at Churchill is inaccurate and their conclusion is based on an incomplete review of available literature on this topic. On p. 3, they state, “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 await the early freeze-up of the Bay, usually during November.” This summary implies that all the bears in the population congregate where the tourism activities occur, which is incorrect. Only a small proportion of the total population comes into the viewing area in the autumn. There is also considerable variation between years in how many bears enter the viewing area and in some years there are few, to the consternation of the tour operators. Even when maximum numbers of bears are present, the total at any one time would not reach 5% of the total population. At the time of viewing, most of the bears in the population are distributed elsewhere to the south of Churchill, up to 200 km south along the coast and 60 km or more inland. The vast majority of the polar bear population would never see a tourist or tundra vehicle and those few that remain in the tour area might do so for an absolute (and unlikely) maximum of only 40% of the time they were ashore.

Dyck et al. (2007) further state that the polar bear viewing period is short (October 1 to November 15) and is “very intense” (p. 3) claiming that there are “6000 tourists and 15 large tundra vehicles per day in the area (Dyck and Baydack, 2006).” However, the maximum legal limit is 18 vehicles per day and it is unusual for all of them to be active at one time. Further, individual vehicles normally hold between 20 and 40 passengers so the maximum number of tourists in the area on any individual day, plus their drivers and guides, would be less than 700. Dyck and Baydack (2006) completed their fieldwork in 2000. Based on studies conducted in 2003, Lemelin and

Wiersma (2007) estimated that between 2100 and 3000 individual tourists visited Churchill to see the bears during the autumn and that each went out two or three times, making a maximum number of total individual visits of 4200–9000 in a single season—well below the numbers reported by Dyck et al. (2007).

Since 1990 (Manitoba Department of Natural Resources, 1990), it has been illegal to bait polar bears (or any other animals along the Hudson Bay coastline). Tundra vehicles are allowed only on specifically designated routes. Vehicles are not permitted to leave these routes to approach polar bears lying down at a distance. Occupants of the vehicles may stop and watch bears lying beside or close to the designated routes, or those off at a distance. They may also observe and photograph bears that choose to approach the vehicle or play nearby. While incidents of baiting, harassing, and chasing of bears were documented more than a decade ago, these events were rare and have become increasingly so since (Herrero and Herrero, 1997). Such behavior has been illegal for at least 15 years and the legal restrictions are enforced.

The study of the effects of tourists on polar bears published by Dyck and Baydack (2004) was based on 43 bears observed in 2000. At that time (2000), the western Hudson Bay polar bear population consisted of approximately 1000 polar bears (Regehr et al., 2007) so even if there were 43 different bears under observation at the same time, only approximately 4.3% (43/1000) of the population would have been exposed to tourism activities. The area where tourism is allowed to occur occupies approximately 30 km² near Gordon Point, roughly 35 km east of Churchill, Manitoba. In practice however, the potential impact is considerably less because the tundra vehicles are limited to about 35–40 km of designated routes that they are not allowed to depart from. Furthermore, the entire viewing area is only about 1.4% of the approximately 2200 km² land area used by bears from the WH population during the summer and fall. Therefore, only a very small proportion of polar bear habitat is affected by tourism activities and bears could easily avoid these areas if they chose; in fact more than 95% of the bears do avoid the area.

For those bears that do visit Churchill, a significant body of literature supports that the documented changes in behavior reported by Dyck et al. (2007) based on Dyck and Baydack (2004) cannot be equated to negative effects on individual condition or population dynamics (Knight and Cole, 1995; Gill and Sutherland, 2000; Gill et al., 2001). Dyck and Baydack (2004) reported increased vigilance behavior of male bears, defined as a bear lifting its head, and no response by female bears, at Churchill during a time frame when bears are not in critical feeding habitat (Dyck and Baydack, 2004). These relatively minor alterations of behavior in only a subset of bears when they are not engaged in activities important to survival or reproduction more likely indicate that bears visiting Churchill are habituated to human activity than that they have a negative effect on bear condition. Dyck and Baydack (2004) also found that “females bears behaved opposite to males” (p. 343) but did not report that in Dyck et al. (2007). A more recent experimental study in which bears were directly approached by tundra vehicles found that only 25% of the bears walked away and concluded that the bears quickly habituated to the presence of the vehicles (Eckhardt, 2005). The potential for

bears to habituate or adapt to human activity, particularly in circumstances of repeated, and predictable human activity such as occurs at Churchill, is common in bears (Aumiller and Matt, 1994; Herrero et al., 2005; Smith et al., 2005) and has been shown to mitigate negative impacts of tourism activity on bears and other wildlife (Rode et al., 2006, 2007b; Walker et al., 2006). Thus, the suggestion that changes in behavior, such as head-lifting, could be associated with increased heart rates and subsequent energetic effects is unsupported by the current body of literature.

Thus, from our evaluation of the concerns about tourist activities raised by Dyck et al. (2007), we conclude their suggestion that tourism activities could be a factor in the demographic and ecological shifts in polar bears in Western Hudson Bay is not substantiated by the available data.

3.3. Polar Bear Alert Program

The Government of Manitoba maintains several Conservation Officers in Churchill through the autumn to protect people and properties from polar bears, in an activity known as the Polar Bear Alert Program. In this program, bears that may threaten human life or property are captured and either held in a temporary holding facility until the ice re-freezes, at which time they are released, or they are re-located north of Churchill via helicopter. Dyck et al. (2007) propose that the Polar Bear Alert Program may have negatively affected the population by handling an average of 48 bears per year, even though the correct average between 2001 and 2004 was 135, the majority of which are subadults (Lunn et al., 2004). Though, as indicated above, there is no apparent decline in bear condition as a result of handling for WH bears (Derocher and Stirling, 1995b), there is recent evidence that subadult and senescent-adults captured in Churchill have lower survival rates than bears captured elsewhere (Regehr et al., 2007). However, Regehr et al. (2007) point out that differential survival is likely the result of inherent low condition of bears attracted to Churchill rather than an effect of human–bear interactions there. Furthermore, even when including these effects, Regehr et al. (2007) confirmed ice breakup date as the best predictor of the survival of juvenile, subadult, and senescent-adult bears in WH which negates the suggestion that the program is having a negative effect on the population. Kearney (1989) concluded that the Polar Bear Alert Program has successfully reduced the number of problem bears killed near the town to an inconsequential level and is now considered to be important to the maintenance of a healthy polar bear population.

4. Limitations on polar bear adaptation to projected climate change

4.1. Hunting of species other than ringed seals

Dyck et al. (2007) make several suggestions regarding the degree to which polar bears may be able to adapt to loss of sea ice as a platform from which to hunt seals. While it is true that seals are occasionally taken from a small local population of harbour seals (*Phoca vitulina*), harbour seals consist of less than

15% of the total diet of WHB polar bears while the main prey are ringed (*Phoca hispida*) and bearded seals (*Erignathus barbatus*)” (Iverson et al., 2006). Consumption of other live or scavenged marine mammal species (Stirling and Øritsland, 1995; Iverson et al., 2006) and capture of seals in open water (e.g., Furnell and Ooloooyuk, 1980) are also known to occur but these events are important to the nutrition of only a limited number of individual animals for variable periods of time and, overall, are inconsequential to the total amount of energy required to support the estimated number of polar bears in the world today (20,000+, IUCN/SSC PBSG, 2006). Using both field observations of hunting behavior and size-specific metabolic requirements, (Stirling and Øritsland, 1995) estimated that, on average, a polar bear requires 43 ringed seals (or ringed seal equivalents) a year to survive (larger bears would require more and smaller bears less). Large numbers of polar bears require enormous numbers of ringed seals or equivalents (most species of which also require ice for pupping and molting). In rough numbers, the current world population estimate of 20,000+ polar bears (IUCN/SSC Polar Bear Specialist Group, 2006) would require almost 900,000 ringed seals (or ringed seal equivalents) each year, the majority of which would be pups. Hunting of harp seals (*Pagophilus groenlandicus*), hooded seals (*Cystophora cristata*), bearded seals, and walrus (*Odobenus rosmarus*) (where applicable) would reduce the number of ringed seals needed but, ultimately, large numbers of polar bears require enormous numbers of ringed seals or equivalents. Although the total population size of ringed seals is unknown, estimates range to about 4 million or more, making them one of the most abundant seal species in the world (Kingsley, 1990). Similar to polar bears, however, ringed seals are also highly evolved to live and breed in association with sea ice. Several studies suggest that their reproductive success and total population size will decline as a result of earlier ice breakup dates and thinning ice (Harwood et al., 2000; Stirling and Smith, 2004; Ferguson et al., 2005; Stirling, 2005).

4.2. Dependence on significant amounts of terrestrial vegetation

Dyck et al. (2007) propose that because polar bears evolved from brown bears, they could evolve a supplementary feeding strategy where berries and vegetation are consumed in higher frequencies during the ice-free period. Evidence from physiological studies (i.e., serum urea and serum creatinine ratios and stable isotopes) clearly indicate that polar bears are not presently consuming enough terrestrial food while on land to even be detectable using conventional analyses (Ramsay and Stirling, 1988; Ramsay and Hobson, 1991; Hobson and Stirling, 1997). Furthermore, published studies that show clearly that even brown bears that are smaller than polar bears are unable to make a living solely on berries and vegetation (e.g., Welch et al., 1997; Rode and Robbins, 2000; Rode et al., 2001; Robbins et al., 2007) and further that large body mass and bear population densities are closely related to the amount of animal matter in the diet (Hilderbrand et al., 1999). It is particularly telling that the smallest black bears (*Ursus americanus*) and brown bears in the world are found in the Arctic tundra near the coast of northern Labrador and the Beaufort Sea, respectively because terrestrial meat resources

accessible to bears at high latitudes are meager (Hilderbrand et al., 1999).

Polar bears are large animals that, similar to their brown bear relatives, require energy dense foods in the form of fat and protein, to maintain body size and population densities (Hilderbrand et al., 1999; Felicetti et al., 2003). They got that way by eating seals, not berries (Robbins et al., 2007). Their survival in anything like the large numbers present today is dependent on large and accessible seal populations and vast areas of ice from which to hunt.

4.3. Evolution of “a true hibernation state”

Dyck et al. (2007) suggest that polar bears might evolve a “true hibernation state” like black (*U. americanus*) and brown bears. However, black and brown bears are not true hibernators (i.e., reduction of core body temperature to within a few degrees of ambient) but rather exhibit an extended period of winter lethargy. Large mammals are prevented from being true hibernators by the tremendous energetic costs associated with arousal from a low metabolic state (Feldehamer et al., 1999, p. 131). As a result, the largest mammals known to exhibit true hibernation are marmots (Genus *Marmota*) and winter lethargy is only sustained in large mammals by using stores of accumulated body fat (Humphries et al., 2003). Winter lethargy in brown and black bears occurs in response to the near complete lack of available food during winter months. In contrast, polar bears have evolved the ability to move between a fasting and a feeding metabolism on a facultative basis, depending on changing food availability throughout the year, an adaptation to life on the labile sea ice (Derocher et al., 1990). This ability to take advantage of seasonally fluctuating food availability and avoid extended torpor and associated physiological costs (Humphries et al., 2003) has allowed polar bears to maximize access to food resources and thereby set them apart as the largest species of bear. To speculate that polar bears might revert to an ancestral state of over-winter lethargy for all age- and sex-classes within the short time-frame of projected sea ice decline is unrealistic and untestable.

Current evidence indicates it is unlikely that extended hibernation, consumption of terrestrial foods, or capture of seals in open water will be sufficient mechanisms to counter the loss of ice as a platform for hunting seals. Polar bear survival and maintenance of present population densities is dependent on large and accessible populations of ice-breeding seal species and vast areas of ice from which to hunt.

5. Conclusions

Briefly, Dyck et al. (2007) propose that there is no evidence that the climate has warmed in western Hudson Bay, that any negative effects on polar bears may be significantly influenced by interactions with humans (such as research activities or tourism), that studies that suggest climate warming is influencing polar bears are confounded by natural fluctuations such as the NAO and AO, and finally that polar bears will simply adapt to climate warming by eating vegetation, hunting other marine mammal species, and evolving new physiological mechanisms. We agree that the relationships

between the ecology and climate of arctic marine ecosystems are complex and that there is still much that is not fully understood. However, in this paper we have reviewed the basis of claims made by Dyck et al. (2007) and concluded that their conclusions and alternative explanations are largely unsupported by the data available.

In contrast, research conducted since 1997 (the date of collection of the last data reported in Stirling et al., 1999) continues to be consistent with the thesis that climate warming in western Hudson Bay is the major factor causing the sea ice to breakup at progressively earlier dates, resulting in polar bears coming ashore to fast for several months in progressively poorer condition. That in turn has resulted in reduced reproduction and survival of young, subadult, and older (but not prime) adults. As the population began to decline, the hunting quota for Inuit in Nunavut was no longer sustainable so the decline accelerated over time (Regehr et al., 2007).

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REFERENCES

- Amstrup, S.C., 1993. Human disturbances of denning polar bears in Alaska. *Arctic* 46, 246–250.
- Aumiller, L.D., Matt, C.A., 1994. Management of McNeil River State Game Sanctuary for viewing of brown bears. *Int. Conf. Bear Res. Manage.* 9, 51–61.
- Comiso, J.C., 2006. Arctic warming signals from satellite observations. *Weather* 61, 70–76.
- Comiso, J.C., Parkinson, C.L., 2004. Satellite-observed changes in the Arctic. *Phys. Today* 57, 38–44.
- Derocher, A.E., Stirling, I., 1995a. Estimation of polar bear population size and survival in western Hudson Bay. *J. Wildl. Manage.* 59, 215–221.
- Derocher, A.E., Stirling, I., 1995b. Temporal variation in reproduction and body mass of polar bears in western Hudson Bay. *Can. J. Zool.* 73, 1657–1665.
- Derocher, A.E., Nelson, R.A., Stirling, I., Ramsay, M.A., 1990. Effects of fasting and feeding on serum urea and serum creatinine levels in polar bears. *Mar. Mammal Sci.* 6, 196–203.
- Dyck, M.G., Baydack, R.K., 2004. Vigilance behaviour of polar bears (*Ursus maritimus*) at Churchill, Manitoba. *Can. Biol. Conserv.* 116, 343–350.

- Dyck, M.G., Baydack, R.K., 2006. Aspects of human activities associated with polar bear viewing at Churchill, Manitoba. *Can. Hum. Dim. Wildl.* 11, 143–145.
- Dyck, M.G., Soon, W., Baydack, R.K., Legates, D.R., Baliunas, S., Ball, T.F., Hancock, L.O., 2007. Polar bears of western Hudson Bay and climate change: are warming spring air temperatures the “ultimate” survival control factor? *Ecol. Complexity* 4, 73–84.
- Eckhardt, G., 2005. The effects of ecotourism on polar bear behavior. M.S. Thesis. Brock University, Orlando, FL, USA.
- Etkin, D.A., 1991. Break-up in Hudson Bay: its sensitivity to air temperatures and implications for climate warming. *Clim. Bull.* 25, 21–34.
- Feldehamer, G.A., Drickamer, L.C., Vessey, S.H., Merritt, J.F., 1999. *Adaptation, Diversity, and Ecology: Mammalogy*. McGraw-Hill, Boston, MA, USA.
- Felicetti, L.A., Robbins, C.T., Shipley, L.A., 2003. Dietary protein content alters energy expenditure and composition of the mass gain in grizzly bears (*Ursus arctos horribilis*). *Phys. Biochem. Zool.* 76, 256–261.
- Ferguson, S.H., Stirling, I., McLoughlin, P., 2005. Climate change and ringed seal (*Phoca hispida*) recruitment in Western Hudson Bay. *Mar. Mammal Sci.* 21, 121–135.
- Furnell, D.J., Ooloooyuk, D., 1980. Polar bear predation on ringed seals in ice-free water. *Can. Field-Nat.* 94, 88–89.
- Gagnon, A.S., Gough, W.A., 2005. Trends in the dates of ice freeze-up and breakup over Hudson Bay. *Can. Arctic* 58, 370–382.
- Gill, J.A., Sutherland, W.J., 2000. Predicting consequences of human disturbance from behavioral decisions. In: Gosling, L.M., Sutherland, W.J. (Eds.), *Behaviour and Conservation*. Cambridge University Press, Cambridge, UK, pp. 51–64.
- Gill, J.A., Norris, K., Sutherland, W.J., 2001. Why behavioural responses may not reflect the population consequences of human disturbance. *Biol. Conserv.* 97, 265–268.
- Ginzburg, L.R., Ferson, S., Akçakaya, H.R., 1990. Reconstructibility of density dependence and the conservative assessment of extinction risks. *Conserv. Biol.* 4, 63–70.
- Gough, W.A., Gagnon, A.S., Lau, H.P., 2004a. Interannual variability of Hudson Bay ice thickness. *Polar Geogr.* 28, 222–238.
- Gough, W.A., Cornwell, A.R., Tsuji, L.J.S., 2004b. Trends in seasonal sea ice duration in Southwestern Hudson Bay. *Arctic* 57, 298–304.
- Harwood, L.A., Smith, T.G., Melling, H., 2000. Variation in reproduction and body condition of the ringed seal (*Phoca hispida*) in Western Prince Albert Sound, NT, Canada, as assessed through a harvested-based sampling program. *Arctic* 53, 422.
- Herrero, J., Herrero, S., 1997. *Visitor Safety in Polar Bear Viewing Activities in the Churchill Region of Manitoba, Canada*. Report for Manitoba Natural Resources and Parks Canada, Calgary.
- Herrero, S., Smith, T., DeBruyn, T.D., Gunther, K., Matt, C.A., 2005. From the field: brown bear habituation and people-safety, risks, and benefits. *Wildl. Soc. Bull.* 33, 1–12.
- Hilderbrand, G.V., Schwartz, C.C., Robbins, C.T., Jacoby, M.E., Hanley, T.A., Arthur, S.M., Servheen, C., 1999. The importance of meat, particularly salmon, to body size, population productivity, and conservation of North American brown bears. *Can. J. Zool.* 77, 132–138.
- Hobson, K.A., Stirling, I., 1997. Low variation in blood ¹³C among Hudson Bay polar bears: implications for metabolism and tracing terrestrial foraging. *Mar. Mammal Sci.* 13, 359–367.
- Humphries, M.M., Thomas, D.W., Kramer, D.L., 2003. The role of energy availability in mammalian hibernation: a cost-benefit approach. *Phys. Biochem. Zool.* 76, 165–179.
- IUCN/SSC Polar Bear Specialist Group. 2006. Aars, J., Lunn, N.J., and Derocher, A.E. (Eds.) *Polar bears: Proceedings of the 14th Working Meeting of the IUCN Polar Bear Specialist Group, 20–24 June 2005, Seattle, Washington, USA., IUCN Occasional Paper of the IUCN Species Survival Commission* 32. 189 pp.
- Iverson, S.J., Stirling, I., Lang, S.L.C., 2006. Spatial, temporal and individual variation in the diets of polar bears across the Canadian arctic: links with and indicators of changes in prey populations. *Symp. Zool. Soc. Lond.* 98–117.
- Kearney, S.R., 1989. The Polar Bear Alert Program at Churchill, Manitoba. In: Bromly, M. (Ed.), *Bear–People Conflict: Proceedings of a Symposium on Management Strategies, Yellowknife*. Northwest Territories Department of Renewable Resources, pp. 83–92.
- Kingsley, M.C.S., 1990. Status of the ringed seal, *Phoca hispida*, in Canada. *Can. Field-Nat.* 104, 138–145.
- Knight, R.L., Cole, D.N., 1995. Wildlife responses to recreationists. In: Knight, R.L., Gutzwiller, K.J. (Eds.), *Wildlife and Recreationists: Coexistence through Management and Research*. Island Press, Covelo, CA.
- Lemelin, R.H., Wiersma, E.C., 2007. Perceptions of polar bear tourists: a qualitative analysis. *Hum. Dim. Wildl.* 12, 45–52.
- Lunn, N.J., Stirling, I., Andriashek, D., Richardson, E., 2004. Selection of maternity dens by female polar bears in western Hudson Bay and the effects of human disturbance. *Polar Biol.* 28, 350–356.
- Manitoba Department of Natural Resources, 1990. Section 6 of the Trapping of Wild Animals Regulation, M.R. 245/90, made under The Wildlife Act (C.C.S.M. c. W130).
- Messier, F., 2000. *Effects of Capturing, Tagging, and Radio-collaring Polar Bears for Research and Management Purposes in Nunavut and NWT*. Department of Biology, University of Saskatchewan, Saskatoon, SK, 64 pp.
- Obbard, M.E., Cattet, M.R.L., Moddy, T., Walton, L.R., Potter, D., Inglis, J., Chenier, C. 2006. Temporal trends in the body condition of southern Hudson Bay polar bears. *Climate Change Research Information Note Available from <http://sit.mnr.gov.on.ca>* 3, 1–8.
- Overland, J.E., Wang, M., 2005. The Arctic climate paradox: the recent decrease of the Arctic Oscillation. *Geophys. Res. Lett.* 31, L021752.
- Overland, J.E., Wang, M., 2007. Future regional Arctic sea ice declines. *Geophys. Res. Letters* 34, L17705.
- Overland, J.E., Spillane, M.C., Percival, D.B., Wang, M., Mofjeld, H.O., 2004. Seasonal and regional variation of pan-Arctic surface air temperature over the instrumental record. *J. Clim.* 17, 3263–3282.
- Ramsay, M.A., Hobson, K.A., 1991. Polar bears make little use of terrestrial food webs: evidence from stable-carbon isotope analysis. *Oecologia* 86, 598–600.
- Ramsay, M.A., Stirling, I., 1986. Long-term effects of drugging and handling free-ranging polar bears. *J. Wildl. Manage.* 50, 619–626.
- Ramsay, M.A., Stirling, I., 1988. Reproductive biology and ecology of female polar bears (*Ursus maritimus*). *J. Zool. (Lond.)* 214, 601–634.
- Ramsay, M.A., Nelson, R.A., Stirling, I., 1991. Seasonal changes in the ratio of serum urea to serum creatinine in feeding and fasting polar bears. *Can. J. Zool.* 69, 298–302.
- Regehr, E.V., Lunn, N.J., Amstrup, S.C., Stirling, I., 2007. Survival and population size of polar bears in western Hudson Bay in relation to earlier sea ice breakup. *J. Wildl. Manage.* 71, 2673–2683.
- Robbins, C.T., Fortin, J.K., Rode, K.D., Farley, S.D., Shipley, L.A., Felicetti, L.A., 2007. Optimizing protein intake as a foraging strategy to maximize mass gain in an omnivore. *OIKOS* 116, 1675–1682.

- Rode, K.D., Robbins, C.T., 2000. Why bears consume mixed diets during fruit abundance. *Can. J. Zool.* 78, 1640–1645.
- Rode, K.D., Robbins, C.T., Shipley, L.A., 2001. The constraints on herbivory by bears. *Oecologia* 128, 62–71.
- Rode, K.D., Farley, S.D., Robbins, C.T., 2006. Behavioral responses of brown bears mediate nutritional effects of experimentally introduced tourism. *Biol. Conserv.* 133, 70–80.
- Rode, K.D., Amstrup, S.C., Regehr, E.V., 2007a. Polar bears in the Southern Beaufort Sea III: Stature, mass, and cub recruitment in relationship to time and sea ice extent between 1982 and 2006. USGS Administrative Report. Alaska Science Center, Anchorage, AK.
- Rode, K.D., Farley, S.D., Fortin, J.T., Robbins, C.T., 2007b. Nutritional consequences of experimentally introduced tourism in brown bears. *J. Wildl. Manage.* 71, 929–939.
- Saucier, F.J., Senneville, S., Prinsenber, S., Roy, F., Smith, G., Gachon, P., Caya, D., Laprise, R., 2004. Modeling the sea ice-ocean seasonal cycle in Hudson Bay, Foxe Basin and Hudson Strait. *Can. Clim. Dyn.* 23, 303–326.
- Serreze, M.C., Francis, J.A., 2006. The Arctic on the fast track of change. *Weather* 61, 65–69.
- Serreze, M.C., Holland, M.M., Stroeve, J., 2007. Perspectives on the Arctic's shrinking sea-ice cover. *Science* 315, 1533–1536.
- Skinner, W.R., Jefferies, R.L., Carleton, T.J., Rockwell, R.F., Abraham, K.F., 1998. Prediction of reproductive success and failure in lesser snow geese based on early season climatic variables. *Glob. Change Biol.* 4, 3–16.
- Smith, T.S., Herrero, S., DeBruyn, T.D., 2005. Alaskan brown bears: habituation and humans. *Ursus* 16, 1–10.
- Stirling, I., 2005. Reproductive rates of ringed seals and survival of pups in Northwestern Hudson Bay, Canada, 1991–2000. *Pol. Biol.* 28, 381–387.
- Stirling, I., Øritsland, N.A., 1995. Relationships between estimates of ringed seal (*Phoca hispida*) and polar bear (*Ursus maritimus*) populations in the Canadian Arctic. *Can. J. Fish. Aqu. Sci.* 52, 2594–2612.
- Stirling, I., Parkinson, C.L., 2006. Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian Arctic. *Arctic* 59, 261–275.
- Stirling, I., 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., Iacozza, J., 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climate change. *Arctic* 52, 294–306.
- Stirling, I., Lunn, N.J., Iacozza, J., Elliott, C., Obbard, M., 2004. Polar bear distribution and abundance on the southwestern Hudson Bay coast during open water season, in relation to population trends and annual ice patterns. *Arctic* 57, 15–26.
- Sutherland, W.J., Gill, J.A., 2001. The role of behaviour in studying sustainable exploitation. In: Reynolds, J.D., Mace, G.M., Redford, K.H., Robinson, J.G. (Eds.), *Conservation of Exploited Species*. Cambridge University Press, Cambridge, pp. 261–280.
- Walker, B.G., Boersma, D.P., Wingfield, J.C., Boersma, P.D., 2006. Habituation of adult *Magellanic penguins* to human visitation as expressed through corticosterone secretion. *Conserv. Biol.* 20, 146–154.
- Watts, P.D., Hansen, S.E., 1987. Cyclic starvation as a reproductive strategy in the polar bear. *Symp. Zool. Soc. Lond.* 57, 305–318.
- Welch, C.A., Keay, J., Kendall, K.C., Robbins, C.T., 1997. Constraints on frugivory by bears. *Ecology* 78, 1105–1119.