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A tale of two polar bear populations: ice habitat, harvest, and body condition

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Abstract One of the primary mechanisms by which sea ice loss is expected to affect polar bears is via reduced body condition and growth resulting from reduced access to prey. To date, negative effects of sea ice loss have been documented for two of 19 recognized populations. Effects of sea ice loss on other polar bear populations that differ in harvest rate, population density, and/or feeding ecology have been assumed, but empirical support, especially quantitative data on population size, demography, and/or body condition spanning two or more decades, have been lacking. We examined trends in body condition metrics of captured bears and relationships with summertime ice concentration between 1977 and 2010 for the Baffin Bay (BB) and Davis Strait (DS) polar bear populations. Polar bears in these regions occupy areas with annual sea ice that has decreased markedly starting in the 1990s. Despite differences in harvest rate, population density, sea ice concentration, and prey base, polar bears in both populations exhibited positive relationships between body condition and summertime sea ice cover during the recent period of sea ice decline. Furthermore, females and cubs exhibited relationships with sea ice that were not apparent during the earlier period (1977–1990s) when sea ice loss did not occur. We suggest that declining body condition in BB may be a result of recent declines in sea ice habitat. In DS, high population density and/or sea ice loss, may be responsible for the declines in body condition.

Keywords Body size · Climate change · Morphometrics · Population density · Sea ice · *Ursus maritimus*

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Introduction

Polar bears (*Ursus maritimus*) have experienced relatively rapid reductions in sea ice habitat across their range (Stirling and Parkinson 2006; Durner et al. 2009). Reductions in habitat over the past several decades have been associated with declines in body condition (Stirling et al. 1999; Rode et al. 2010), vital rates (Regehr et al. 2007, 2010), and population size (Regehr et al. 2007). However, data to examine these relationships have only been available for four of 19 recognized polar bear populations: the Southern Beaufort Sea, Northern Beaufort Sea, Western Hudson Bay, and Southern Hudson Bay populations (Stirling et al. 1999, 2011; Obbard et al. 2006; Regehr et al. 2007, 2010; Rode et al. 2010). The Western Hudson Bay polar bear population has declined in size in response to sea ice loss and a simultaneous continued harvest that at some point was no longer sustainable (Regehr et al. 2007). The Southern Beaufort Sea population is responding to sea ice loss as evidenced by reduced survival and poor body condition (Regehr et al. 2010; Rode et al. 2010). These two populations have geographic characteristics that may make them more susceptible than other populations to declines in sea ice. The Western Hudson Bay population occurs in the southern extent of the geographic range of polar bears and the Southern Beaufort Sea population relies on a narrow band of productive habitat over a continental shelf (Durner et al. 2009) where increasing summertime retreat of the Arctic pack ice away from the shelf results in reduced foraging opportunities. In Southern Hudson Bay, body condition of polar bears has declined, but no relationship between body condition and the timing of ice melt was found (Obbard et al. 2006) and in the Northern Beaufort Sea, sea ice conditions have remained relatively stable to date and therefore, are not having a negative effect on population size or survival rates (Stirling et al. 2011). Several studies, based on knowledge of bear ecology, population dynamics and/or model projections suggest that populations in divergent (i.e., annual sea ice that is advected from shore toward the central polar basin in the summer) and seasonal-ice ecoregions (i.e., sea ice is formed and disappears annually, Durner et al. 2009), will experience nutritional and eventually demographic effects of declining sea ice habitat in the near future (Derocher et al. 2004; Stirling and Parkinson 2006; Amstrup et al. 2008). However, it is unclear how differences in harvest rate, population density, and/or feeding ecology among populations may affect the ability of a polar bear population to respond to declines in the amount and quality of ice habitat.

Polar bears can effectively hunt ice seals, their primary prey, almost exclusively from sea ice. Capturing seals in open water is less effective and not frequently observed (Furnell and Oolooyuk 1980). Thus, one of the primary mechanisms by which sea ice loss is expected to affect polar bears is through reduced body condition and growth patterns resulting from reduced access to prey (Stirling et al. 1999; Rode et al. 2010). Though reduced access to prey may act in a density independent fashion (reduced foraging opportunities or increased energy expenditure to search for food), populations that occur at higher densities may be more sensitive to a reduction in sea ice availability. Density effects on various species of bears, associated with variation in harvest management practices, have been documented by several studies (Boyce et al. 2001; Miller et al. 2003; Schwartz et al. 2006; Obbard and Howe 2008). Little is known about density effects on polar bear populations, but it has been generally assumed that harvest, which legally occurs in the USA (Alaska), Canada and Greenland, typically maintains populations below the threshold where non-linear density effects would substantively reduce population productivity (Taylor 1994; Taylor et al. 2005).

Polar bears are harvested in many parts of the Arctic (e.g., Obbard et al. 2010), thus, some polar bear populations have experienced harvest and a recent seasonal reduction in habitat simultaneously. Theoretically, if the effects of habitat loss on polar bears are exacerbated at higher densities, harvest could reduce population density and thereby reduce the degree to which habitat loss might negatively affect polar bear populations. Studies of other marine top predators have shown either a density-effect that is overwhelmed by the effect of poor environmental conditions [de Little et al. 2007; effects of reduced food availability associated with environmental conditions regardless of density in southern elephant seals (*Mirounga leonina*)] or a compounding effect of high density and poor environmental conditions [for blue petrels (*Halobaena caerulea*), Barbraud and Weimerskirch 2003; i.e., low harvest could result in greater effects of habitat loss and high harvest could reduce the effects of habitat loss]. We explore the potential interactive effects of harvest and habitat loss on the body condition of bears in the Baffin Bay (BB) and Davis Strait (DS) polar bear populations (Fig. 1). Harvest management and population density in these two populations differ, although both have experienced a reduction in summer sea ice (Stirling and Parkinson 2006).

The BB and DS populations (Fig. 1) both occur in habitats where sea ice is formed and disappears annually (i.e., the "seasonal ice ecoregion" as defined by Amstrup et al. 2008). Although sea ice in this area increased until the mid-1990s (BB) and early 2000s (DS), sea ice extent has declined by about 9% per decade from 1979 to 2006 (UNEP 2007; Perovich and Richter-Menge 2009). With the exception of females in winter maternity dens, bears of all ages hunt seals on the annual sea ice through the winter and spring until breakup in early summer. Females with newborn cubs return to the ice to feed in early spring.
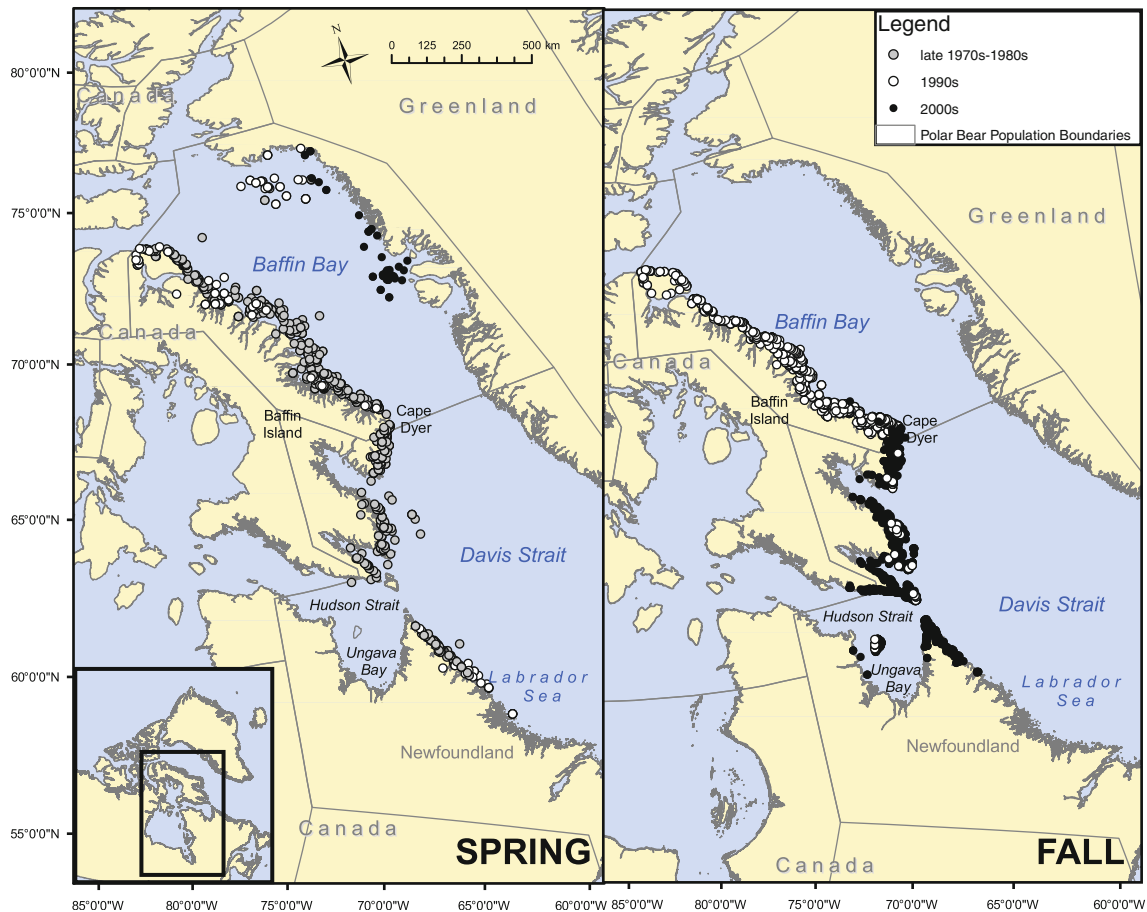
Fig. 1 Locations and timing of polar bear scientific captures in Baffin Bay and Davis Strait. Map includes the boundaries of the Baffin Bay and Davis Strait polar bear populations, and neighboring polar bear populations, in eastern Canada and western Greenland. *Gray* represents bears captured in the late 1970s–1980s, *white* represents bears captured in the 1990s, and *black* represents bears captured in the 2000s (until spring 2010)

Following breakup and the loss of all or almost all sea ice, all bears in both populations must depend on their stored fat resources while fasting on land until freeze-up. Though the general sea ice ecology of these regions is similar, BB is the more northerly with greater sea ice coverage that persists later in the season than DS (Stirling and Parkinson 2006).

These two populations differ four-fold in the current estimated rate of harvest. BB is a heavily-harvested population with a mean annual harvest of 212 bears per year (5-year mean, 2005–2009) and an assessed population size of 1546 (95% CI 690–2402; Obbard et al. 2010; average harvest rate of ca. 13.7%). DS is a population that currently has a low harvest rate (60 bears per year, 2.7%; Obbard et al. 2010) and an estimated population size of 2158 (95% CI 1833–2542; Peacock 2009) in 2007. While harvest rate cannot directly affect the body condition of animals in the population, harvest rate could act indirectly on body condition by reducing population density if the population was experiencing density effects.

During the late 1970s, 1980s, 1990s and 2000s, population capture programs, varying in purpose, area sampled,

season, and sample size (Fig. 1), occurred in both populations and included collection of morphometric measurements that can be used to assess body condition. These data sets provide a unique opportunity to examine long term trends in body condition relative to available sea ice for two populations in which effects of sea ice loss are currently unknown and various aspects of ecology and management differ. We examined trends in body condition relative to available sea ice for these populations and considered how differences in their ecology and harvest rates were related to the changes in body condition we identified.

Study area and methods

Range

The DS population of polar bears occurs on the sea ice between Canada and Greenland, south of 66°N, extending to the southern reaches of Labrador (Taylor et al. 2001; Fig. 1). During winter and spring, DS polar bears occur on

the ice in an area of approximately 420000 km^2 (Taylor and Lee 1995), in Davis Strait proper, the Labrador Sea, and west to Ungava Bay, and eastern Hudson Strait of Québec and Nunavut (Taylor et al. 2001). From August through mid-November, the area is ice-free in most years and bears in DS concentrate on offshore islands and coastal strips of land along the Canadian coast (in Newfoundland and Labrador, Québec and Nunavut). The BB population has its northern boundary at 77°N in the North Water Polynya, and is bounded by west Greenland to the east and Baffin Island to the west (Taylor et al. 2001). From approximately August through mid-November, BB is ice-free in most years and the vast majority of polar bears in that population concentrate on the coast of Baffin Island in Canada (Taylor et al. 2001, 2005; Peacock 2009). The boundary between DS and BB at 66°N near Cape Dyer on Baffin Island and the entrance to Kangerlussuaq/Søndre Strømfjord in Greenland has been supported with genetic, capture/recovery, and satellite telemetry data (Taylor and Lee 1995; Paetkau et al. 1999; Taylor et al. 2001).

Harvest and population status

Polar bears in DS now occur at a density (5.1 bears/1000 km^2 in 2007; subpopulation area from Taylor and Lee 1995) higher than that measured for any seasonal-ice population, including Western Hudson Bay, Southern Hudson Bay, and BB (approximately 3.5 bears/1000 km^2 estimated for each of these populations; Taylor et al. 2005; Regehr et al. 2007; Obbard 2008).

In BB, the abundance estimate of the population was 2074 (95% CI 1544–2604) polar bears in 1997 (Taylor et al. 2005). At this time, the authors concluded that if the combined kill from Canada and Greenland totaled 88 bears per year, it would be sustainable. A harvest rate of 138 bears per year or more was projected to result in population decline with $\lambda = 0.974 \pm$ SE 0.041. In 2005, a population viability analysis using current harvest rates simulated an estimated population size of 1546 (95% CI 690–2402; Aars et al. 2006). However, between 2005 and 2009, the mean total reported harvest was 212 bears per year (Obbard et al. 2010) which is above the level considered sustainable for the population.

To gain insights into whether harvest removals can affect population density and thereby indirectly affect body condition, we summarized available records on harvest for BB and DS for the time periods that corresponded to available data on body condition. The accuracy of harvest records from Greenland has varied over time and may include potential over and under-reporting because until 2006 reporting was voluntary and not independently confirmed. Until 1987 the harvest of polar bears in Greenland was recorded in the "Hunters Lists of Game". During 1987–1992 there was no official recording of the polar bear

harvest. Since 1993 the harvest has been reported in the "Piniarneq"-system and summarized by the Greenland management authorities. In 2006, quotas were introduced for the harvest of polar bears in Greenland which has resulted in it becoming mandatory to report harvest. In Canada, harvest data for BB and DS between 1968 and 2007 were obtained from the records of the governments of Nunavut (records before 1999 were collected by the Northwest Territories), Newfoundland and Labrador and of Québec, and for Greenland harvests from BB between 1988 and 1992 from Born (1995). Essentially all harvested bears are reported in Nunavut and Newfoundland and Labrador given the small size of the communities, presence of conservation officers in each community, harvest reporting required by agreements with co-management partners, and, in Nunavut, financial compensation to the hunters for samples from the harvested bears. In Québec, harvest reporting is not required, and monitoring is variable. Between 2002 and 2007, harvest was estimated by the Canadian polar bear technical committee to be 11 ± 5 bears per year. The total harvest for DS should be considered a minimum known harvest.

Feeding ecology

Harp seals (*Pagophilus groenlandicus*) and ringed seals (*Pusa hispida*) have been identified as the primary prey species for polar bears in DS based on fatty acid profiles (Iverson et al. 2006; Thiemann et al. 2008), whereas ringed seals constitute the main prey of polar bears in BB, with other species such as bearded seal (*Erignathus barbatus*), beluga whale (*Delphinapterus leucas*), and harbour seal (*Phoca vitulina*) composing the majority of the remainder of the diet (Thiemann et al. 2008; Born et al. 2011). During the ice-free period, polar bears primarily fast on their stored fat reserves but they may also consume minimal amounts of terrestrial food sources, such as vegetation, berries, and birds (Russell 1975; Derocher et al. 1993).

Capture, handling, and measurement of polar bears

We pooled all records of scientific captures of polar bears in the DS and BB populations from 1970 through 2010. Polar bears were captured in DS and BB as part of ongoing efforts to monitor the status of the two populations (Stirling and Kiliian 1980; Stirling et al. 1980; Taylor et al. 2001, 2005; Peacock 2009; Canadian Wildlife Service, unpublished data; Greenland Institute of Natural Resources, unpublished data). Sample sizes varied both spatially (Fig. 1) and among years (Table 4 in Appendix). Seasonality of captures also varied with some captures in both populations occurring in the spring (April 1–May 31) and fall (Aug 10–Nov 30).

We divided analyses for both populations into two periods due to differences in trends in sea ice between the 1970s and 1990s and the 1990s and 2000s, variation in data availability across periods (Table 4 in Appendix), and variation in capture season (spring versus fall). Declines in sea ice for both populations did not occur until the mid-1990s. Periods overlapped somewhat due to sample size constraints and variation in the season of capture (i.e., some 1990s data were used in each set of comparisons). In the case of DS, sample sizes for fall captures in the 1990s were low, thus body condition trends in the fall were examined for only the composite period (1970s–2000s). Time frames used for analysis were: 1978–1994 (spring captures) and 1978–2007 (fall captures) for DS; and 1978–1995 and 1992–2010 (spring captures) and 1991–2006 (fall captures) for BB.

Latitude and longitude were included as linear (unprojected coordinates in decimal degrees) covariates in candidate models to account for potential spatial effects of capture location (Table 1). We did not conduct analyses when sample sizes were less than ten times the number of terms in the largest candidate model (Harrell 2009).

We used two measures to assess the condition of polar bears: axillary girth (i.e., the circumference around the chest at the axillae; hereafter girth) and zygomatic width of the skull (i.e., the maximum straight line distance between the zygomatic processes; hereafter skull width). Girth is closely correlated to body mass of polar bears (southern Beaufort Sea: $r_p = 0.94$, $y = 0.33x - 173.8$; $P < 0.0001$; $n = 1361$; US Geological Survey, unpublished data; Chukchi Sea: $r_p = 0.90$; $y = -372.3 + 5.0x$; $P < 0.0001$; $n = 122$; US Fish and Wildlife Service, unpublished data) and body mass is related to reproductive output in female polar bears (Derocher and Stirling 1994, 1996) as well as other ursids (Noyce and Garshelis 1994). Though polar bear condition has often been assessed using some measure of mass relative to length, Rode et al. (2010) found that body mass was more closely related to litter mass than other measures that accounted for body length. Because skull measurements of live bears include a fat layer that have been shown to vary with annual sea ice conditions (Rode et al. 2010), and vary between populations of ursids that experience different environmental conditions (Derocher and Stirling 1998a; Zedrosser et al. 2006), skull width was included as an additional indicator of condition when data were available.

Calipers were used to measure the skull width to the nearest millimeter. Girth was measured by aligning a nonstretchable cord around the chest immediately behind the forelimbs while the bear was sternally recumbent. Measurements taken upon recapture of individuals in the same or subsequent years were excluded from the analyses. Efforts have continually been made among co-authors to ensure standardization of skull width and girth measures over time, among populations and capture efforts. These efforts included overlapping time in the field by one coauthor with another to ensure that methods of measurement were consistent.

Quantifying annual availability of ice habitat

We quantified the availability of sea ice between May 15 and October 15 each year. This period includes the summer, open-water period when bear foraging is most constrained by sea ice conditions and overlaps important annual foraging periods in the spring and fall. This time frame is also when annual variation in ice has been most apparent. Mean weekly ice concentration reported by the Canadian Ice Service (CIS, http://ice-glaces.ec.gc.ca; Ice Graph Version 1.0) for the Baffin Bay and Davis Strait regions between May 15 and October 15 was calculated for each year (referred to as "summer ice concentration"). The area defined as Baffin Bay and Davis Strait by the Canadian Ice Service is inclusive of high use areas by bears in this region. Specifically the ice habitat areas include 80% fixed kernel contours identified for the two populations (Taylor et al. 2001). In Baffin Bay, ice habitat covered the majority of the area identified by the population boundaries, whereas ice habitat in Davis Strait included the more northern portion of the identified population boundary

Table 1 Factors included in linear models exploring the relationships between axillary girth and skull width for polar bears in the Baffin Bay and Davis Strait populations during two periods of differing sea ice regimes between 1978 and 2010

Abbreviated factor name	Description
year	Year a bear was captured
age	Bear age estimated by counting cementum layers in teeth or as a result of a being captured as a dependent young
cdate	Julian capture date (0–365 days)
coy	Binomial variable used for females: not accompanied by cubs-of-the-year (i.e., alone or accompanied by yearlings or two-year olds) versus accompanied by cubs-of-the-year
ice	Mean of biweekly ice concentration (proportion of 100) between 15 May and 15 October
litsize	Litter size: Binomial variable: litter size of one versus litter size ≥2
sex	Binomial variable used in models of yearling girth and skull size
long	Unprojected (flat) longitudinal coordinate of the capture location in decimal degrees World geodetic system (WGS) 1984 Unprojected (flat) latitudinal coordinate of the capture location
lat	In decimal degrees WGS 1984

which is the area most heavily used by bears in the population. CIS generates a mean ice concentration value as a fraction for one day per week for BB and DS using a variety of data sources, including data from the National Oceanic and Atmospheric Administration, special sensor microwave imager data, and RADARSAT data as well as field observations that allow for ground-truthing. We examined relationships with this measure of summer ice concentration in the previous year for bears captured in the spring and in the current year for bears captured in the fall.

Data analysis

Trends in harvest and summer ice concentration in both populations were examined using linear regression. These analyses used the same periods identified for examining trends in body condition.

Analyses of trends in body condition over time and relationships with ice concentrations were conducted separately for three sex–age classes: males 2 years and older, females 2 years and older, and dependent cubs, which included both cubs-of-the-year (coy) and yearlings (unless otherwise specified as a result of data limitations). These three classes were chosen because covariates that may affect morphometric measures (e.g., presence of cubs with females or litter size of dependent cubs) may differ among these classes.

Age was included as a categorical covariate for dependent cubs (because age was either 0 or 1 only) and as a continuous integer covariate for males and females 2 years and older (i.e., 2, 3, 4. etc.). Because age has a nonlinear relationship with axillary girth and skull width of males and females 2 years and older, the deviation of measures of axillary girth and skull width relative to predicted values from a fitted growth curve were used as dependent variables in all analyses. A variety of growth curves have been proposed for large, long-lived mammals. We initially explored the use of four growth curves that have been applied to large mammals, including a Gompertz curve, a modified Gompertz curve, a logistic curve and a modified von Bertalanffy growth curve (Leberg et al. 1989). Similar to Laidre et al. (2006), we found that all of the growth curve models examined fit the data (i.e., had significant coefficients and fit) and produced curves identical in appearance. We therefore chose to apply the modified von Bertalanffy length curve, which has been found to be the best fit for polar bears in other studies (Derocher and Wiig 2002). The modified von Bertalanffy length growth curve has the equation $l_\alpha = L(1 - e^{-k(t-A)})$ where l_α = axillary girth in centimeters (or skull width in mm) at age a, L = asymptotic axillary girth in centimeters (or skull width in millimeters), k = growth rate constant (years^{-1}) and A = a fitting constant (years), and e is the base of the

natural logarithm. Growth curves were fit to a subset of data that included the timeframe with the largest sample size for each data set for a single season (Table 2; e.g., if the dataset ranged from the 1990s to 2000s, and the sample size in the 2000s was largest, a growth curve was fit to data collected in the 2000s; fall and spring data were not included in the same growth curve estimation). This approach allowed for comparison across time frames and for the curvilinear relationship between age and morphometric measures to be accounted for within the analysis.

We used generalized linear models to identify relationships between body condition and mean summer ice concentration (ice) or year. Year and ice were included in models as continuous independent variables (covariate). Because these two measurements could reflect different temporal scales, we did not include year and ice in the same model; a relationship between bear condition and ice could illustrate an annual response to changing ice conditions, whereas a trend with year could illustrate the cumulative effects of changing environmental conditions, population density, or other unmeasured temporal factors.

In addition to controlling for age (age), we also controlled for capture date (cdate) which can also affect girth and skull width (Table 1). Some variables, such as litter size, differed between analyses for different sex and age classes (Table 5 in Appendix). The number of cubs in a litter (litsize) can affect cub size (Derocher and Stirling 1998b) and was included in models for cubs. Furthermore, due to the potential for cub production to affect female body condition, females were categorized as accompanied by coy or not and this variable (coy) was included as a fixed effect. Rode et al. (2010) found minimal effects of older dependent young on adult female condition. Although cub size does not appear to differ between males and females until sometime after the first year (Derocher et al. 2005), we included sex in all models of cub condition to control for potential differences. Latitude (lat) and longitude (long) were included as linear covariates in all models in an attempt to account for potential spatial bias in sampling.

Main effects and interactions of main effects that were considered to be biologically meaningful were initially in candidate models (Table 5 in Appendix). For example, interactions between age and year or ice were included due to the potential for bears of different ages (e.g., subadults versus adults) to exhibit different responses. Prior to comparing candidate models, model collinearity between predictor variables was examined using condition indices and variance proportions (Gotelli and Ellison 2004). Condition indices above 15 and variance proportions of 0.50 or higher were used to identify variables that should not be included in the same model (i.e., if predictor variables exhibited collinearity they were not included in the same model but were instead run independently among candidate

Table 2 Parameters of modified von Bertanlanffy growth equations ($y = L(1 - e^{-k(t-A)})$) fit to axillary girth (cm) and zygomatic skull width (cm) measures of polar bears captured in Baffin Bay and Davis Strait between 1978 and 2010

	L	k	A	F	P
Girth					
BB spring females 1970s and 1980s (127)	119.0	0.60	−1.1	$F_{2,57} = 182.7$	<0.0001
DS spring females 1970s and 1980s (74)	122.6	0.71	−0.73	$F_{2,48} = 270.5$	<0.0001
BB spring males 1970s and 1980s (165)	165.3	0.30	−1.3	$F_{2,94} = 606.1$	<0.0001
DS spring males 1970s and 1980s (78)	172.4	0.25	−1.5	$F_{2,67} = 611.9$	<0.0001
BB fall females 1990s (217)	131.4	0.37	−3.0	$F_{2,214} = 142.0$	<0.0001
DS fall females 2000s (442)	128.7	0.71	−1.2	$F_{2,438} = 395.9$	<0.0001
BB fall males 1990s (438)	234.0	0.32	−2.4	$F_{2,421} = 2914.9$	<0.0001
DS fall males 2000s (629)	166.0	0.34	−1.8	$F_{2,624} = 956.6$	<0.0001
Skull width					
BB spring females 1970s and 1980s (155)	21.0	0.58	−0.98	$F_{2,152} = 1647.4$	<0.0001
DS spring females 1970s and 1980s (27)	21.1	0.25	−3.5	$F_{2,24} = 43.0$	<0.0001
BB spring males 1970s and 1980s (128)	25.0	0.42	−1.1	$F_{2,125} = 580.7$	<0.0001
DS spring males 1970s and 1980s (28)	26.5	0.18	−3.3	$F_{2,25} = 107.9$	<0.0001
BB fall females 1990s (205)	20.8	0.32	−3.3	$F_{2,175} = 730.6$	<0.0001
DS fall females 2000s (506)	20.7	0.44	−2.3	$F_{2,503} = 1445.8$	<0.0001
BB fall males 1990s (178)	27.8	0.16	−4.5	$F_{2,202} = 1518.6$	<0.0001
DS fall males 2000s (629)	27.4	0.22	−3.2	$F_{2,626} = 2647.2$	<0.0001

Sample sizes are provided in parentheses. A is a fitting constant (years), k is the growth rate constant (per year), and L is the asymptotic skull width or axillary girth

models). Anderson–Darling tests of normality were used to examine residual distributions to identify possible outliners. We also examined regression residuals for evidence of heteroscedasticity. Linearity was confirmed for all covariates by examining the relationship between predicted values and residuals. Linear models are robust to non-normality (Green 1979) and were therefore used when data were slightly skewed from a normal distribution.

Model selection

Akaike Information Criterion (AIC) values were used to compare candidate models that included one or more explanatory variables and interactions between variables based on knowledge about bear biology. Models with the lowest AIC explain the most variation with the fewest parameters. Because models with ΔAIC < 2 should receive consideration in making inferences (Burnham and Anderson 2002), only models with ΔAIC < 2 are reported in the results. However, year or ice was considered an important factor in describing condition only when ΔAIC < 2, the P value for the covariate was <0.05, the full model was significant ($P < 0.05$), and the model weight was >0.30. Models that contained interactive effects were removed from candidate models if those interactions did not appear to be biologically significant (i.e., upon graphing there was only a slight variation in slope and trends were similar across parameter values). All statistical analyses were conducted in SPSS (version 15.0, SPSS, Chicago, IL, USA).

Results

Trends in summertime ice concentration

Within the BB and DS polar bear population boundaries, mean summertime ice concentration between May 15 and October 15 exhibited no trend in the earlier time frames over which body condition measures were examined (1977–1995), but exhibited declines during the latter period (DS 1990–2007, BB 1990–2010; Fig. 2). Ice concentration also declined in both areas when examining trends over the entire time period of the study, 1970 and 2007 (BB: $y = 7.1 - 0.003year$; $F_{1,29} = 9.0$, $P = 0.006$; DS: $y = 4.86 - 0.002year$; $F_{1,29} = 7.7$, $P = 0.01$). Mean summertime ice concentration in BB (0.36 ± 0.07 SD) between May 15 and Oct 15 between 1990 and 2007 was twice that of DS (0.15 ± 0.04; $F_{1,34} = 120.99$, $P < 0.0001$).

Harvest levels

Total mean reported polar bear harvest in Canada and Greenland in DS was 32 ± 9 (SD) and 43 ± 11 bears per year between 1971 and 1995 and 1990 and 2007, respectively (i.e., during the two periods in which trends in body

Fig. 3 Annual combined Canada-Greenland polar bear harvest in Baffin Bay and Davis Strait between 1970 and 2007

year (Fig. 3; $y = -12610.0 + 6.4year$, $F_{1,15} = 10.6$, $P = 0.005$). The combined harvest in DS increased by less than one bear per year between 1971 and 1995 (Fig. 3; $y = -1347.2 + 0.7year$, $F_{1,23} = 12.0$, $P = 0.002$) and by 1–2 bears per year between 1992 and 2007 (Fig. 3; $y = -3225.5 + 1.6year$, $F_{1,14} = 13.8$, $P = 0.002$).

Growth curves

The parameters of fit growth curves used to calculate residuals for analysis are provided in Table 2.

Body condition metrics in Davis Strait

The girth of male and female polar bears age 2 years and older in DS declined between 1978 and 1994 (Table 3; Table 6 in Appendix). Their girth measures were also larger in the spring following years with lower mean ice concentrations between this period (Table 3; Table 7 in Appendix). Data were insufficient to examine trends for cubs, or skull width for any sex–age class in DS during this timeframe.

Declines in girth of DS polar bears also were apparent between 1978 and 2007. Girth of cubs and females age 2 years and older declined during this period (data were insufficient to examine long term trends for males age 2 years and older). In contrast to the earlier period (1978–1994), all sex–age classes exhibited positive relationships between ice and body condition; larger measures of girth in the fall corresponded with higher mean ice concentration between 1978 and 2007.

Body condition metrics in Baffin Bay

Between 1978 and 1995, trends in girth were variable across sex–age classes in BB (Table 3, Table 8 in Appendix).
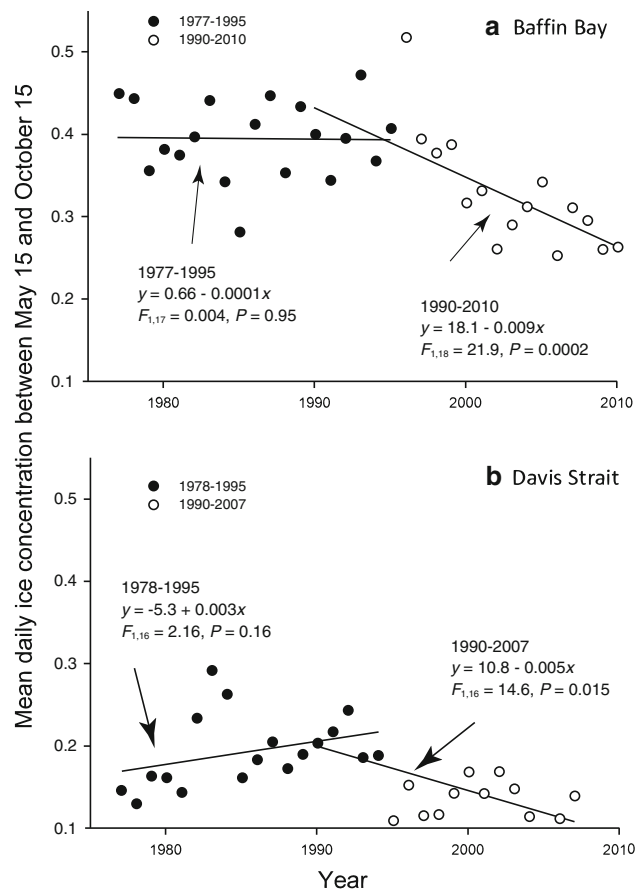
Fig. 2 Mean daily summer sea ice concentration (May 15–October 15) in **a** Baffin Bay and **b** Davis Strait between the 1970s and 2000s from the Canadian Ice Service (CIS, http://ice-glaces.ed.gc.ca). Though body condition from captured polar bears is not available until 1978, ice data starting in 1977 were used for spring caught polar bears. Time periods differed for the two populations slightly as result in differences in available data

condition were examined). Harvest in Canada included all human-caused moralities, including hunting, defense of life, and illegal kills. During these periods, Greenland harvest averaged <3 bears/year from the DS population.

In BB, 62 ± 22 bears per year were taken by Canadian hunters between 1977 and 1995 and 65 ± 16 bears per year between 1992 and 2006. In Greenland, between 1970 and 1987, hunters reported harvesting 19 ± 14 polar bears per year. Including an estimate of harvests that were not reported during this time, the total number harvested was 29 ± 24 (Born 1995). Though there was no official recording system to monitor harvest in Greenland from the BB population between 1988 and 1992, Born (1995) estimated the annual harvest to be 43 ± 9 bears during this time. From 1993 to 2003, the mean number of bears harvested per year was 93 ± 42 (Aars et al. 2006).

Between 1993 and 2009 (note combined data are not available from 1992), combined harvest of Greenland and Canada from BB increased by approximately 6 bears per
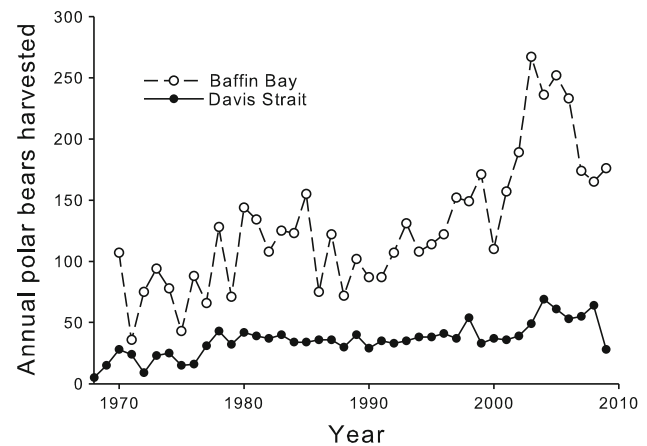
Table 3 Summary of the relationship between axillary girth and skull width (results in parentheses) and annual mean sea ice concentration between 15 May and 15 October for various sex–age classes of two polar bear populations (*BB* Baffin Bay, *DS* Davis Strait) during the specified periods

	BB 1978–1995 spring captures		DS 1978–994 spring captures		BB 1992–2010 spring captures		BB 1991–2006 fall captures		DS 1978–2007 fall captures	
	year	*ice*	*year*	*ice*	*year*	*ice*	*year*	*ice*	*year*	*ice*
Males 2+ years	0 (0)	0 (0)	− (−)	−	−	+	− (0)	+ (0)	NA	+
Females 2+ years	− (+)	0 (0)	−[c]	−[d]	−[e]	+	− (0)	+ (0)	−	+
Cubs	+/−[a]	0/+[b] (0)	NA	NA	NA	NA	− (0)	+ (0)[f]	−	+

"+" indicates a positive relationship with *year* or *ice*, "−" indicates a negative trend, "0" indicates no relationship, "NA" = not applicable due to insufficient data. Cubs includes cubs-of-the-year and yearlings

[a] Cubs-of-the-year exhibited no trend and yearlings exhibited a decline over time

[b] Cubs-of-the-year exhibited no relationship and yearlings exhibited a positive relationship with ice concentration

[c] Younger females exhibited a more negative slope than older females

[d] The slope of this relationship was more negative for younger females

[e] This relationship had weak support ($\Delta AIC = 1.93$, $w = 0.05$, P (model) $= 0.089$; P (*year*) $= 0.68$

[f] Cubs exhibited an *age* × *ice* interaction for girth resulting from yearlings exhibiting a more positive relationship (greater slope) than cubs-of-the-year; there was weak evidence for a negative relationship between ice availability and skull width. The model including ice was the 4th ranked model, $w = 0.11$, $P = 0.59$

Cubs-of-the-year and males age 2 years and older exhibited no trend though yearlings and females age 2 and older exhibited a decline in girth during this time. Differences in trends for cubs-of-the-year and yearlings were identified from an interactive effect between year and age (Table 8 in Appendix). Girth of yearlings was higher following years when mean ice concentration was high, but no other sex–age class exhibited relationships with ice concentration between 1978 and 1995. Trends in skull width followed patterns observed for girth for most analyses, with no relationships between ice concentration and body condition metrics for any sex age class during the earlier period and no apparent declines in body condition over time.

In contrast, the girth for all sex/age classes in BB exhibited declines during the latter period based on both spring (1992–2010) and fall captures (1991–2006; Table 3; Table 8 in Appendix). All sex–age classes in both the spring and fall capture samples exhibited increased girth in (spring) or following (fall) years with higher mean ice concentration (Table 3; Table 9 in Appendix). Though there was some support that skull width declined for cubs and females 2 years and older during this time as evident by a negative year effect in one of the top 3 models, model weights were low <0.30. Similarly a positive relationship between ice concentration and skull width for females age 2 and older occurred in one of the top 3 models, but model weight was low.

In nearly all data sets for both BB and DS, latitude and longitude were collinear and in many cases capture date and latitude were collinear. As a result those covariates were often included in separate, competing models.

Discussion

Both the BB and DS polar bear populations exhibited a positive relationship between the abundance of sea ice and body condition in recent years suggesting that sea ice currently affects annual variation in body condition. A negative trend in body condition over time was also observed across all sex–age classes for 3 data sets (a spring and fall capture sample from BB and a fall sample from DS) that ranged through the 2000s. These trends were not consistent during the earlier period (1970s–1990s) for BB when sea ice habitat had not yet begun to decline or increased. Though a decline in body condition was observed for DS between 1978 and 1994, there was no relationship between body condition and sea ice conditions at that time. In the case of DS, the decline in sea ice between the 1990s and 2007 coincides with a timeframe when harvest rate was low and population density was high. Declines in body condition there could be the result of density-dependent effects resulting from population growth and/or a result of the observed decline in summer sea ice concentration between the 1990s and 2007. In BB, however, population density is low and harvest rate has been high, thus it is unlikely that an increasing population size explains the decline in body condition that occurred. Though it is possible that a decline in prey abundance could be the cause of a decline in the body condition of polar bears in BB, data are not available on trends in prey abundance in this region. Relationships between annual sea ice availability and body condition suggest that accessibility of prey from the sea ice platform explains at least

part of the observed decline in body condition in BB. Though sample sizes were limited in some cases, consistency in results across sex–age classes and among multiple, independent analyses along with our ability to largely account for potential geographic bias support that the observed trends in the data are representative of actual trends in these populations.

In the case of Baffin Bay, declines in body condition observed in our study are supported by observations of local people in some regions. Forty-six percent of Inuit community members in a traditional ecological knowledge study in 2005 among Nunavut Inuit reported that polar bears in Baffin Bay were skinnier than 15 years ago (Dowsley and Wenzel 2008). However, a study in northwest Greenland concluded that some polar bears in the vicinity of the North Water may have become thinner in recent years, but interviews of 62 hunters on the whole did not indicate any obvious changes in the physical condition of bears in this region (Born et al. 2011). In DS, Kotierk (2010) reports only one of 31 elder/hunter respondents who live in communities in northern Davis Strait population observed that polar bears are "thinner now" whereas in other cases hunters in DS have reported a decline in body condition (M. Taylor, personal communication). The degree to which changes in body condition that can affect reproduction might be observable when not measured is not clear. It is possible that the trends observed in our study may not be detected from on the ground observations without physical measurements.

The consistency in the trends in body condition and the relationships with ice concentration data for the two populations occurred between the 1990s and 2000s despite differences in population growth, harvest rate, ice concentration and rate of decline, and diet. In DS there was a marked increase in the harp seal population from the 1970s to 2009 (DFO 2010) which has been suggested as one of the factors related to an apparent increase in the size of the polar bear population in this region (Stirling and Parkinson 2006; Peacock 2009). Fatty acid studies confirm that harp seals make a significant contribution to the diets of polar bears in southern DS (Iverson et al. 2006; Thiemann et al. 2008). Though prey abundance appears to have increased in DS, the relationship between annual variation in ice concentration and body condition in DS suggests that ice may ultimately affect access to available prey.

The two populations in this study had an estimated fourfold difference in harvest rate between the 1990s and 2000s when declines in body condition were observed. Contrasting the changes in harvest level for these two populations, the recorded annual harvest in BB increased by 40 and 60 bears, respectively, over the two periods whereas DS harvest increased by only 17 and 8 bears, respectively. These changes in harvest occurred in BB

while the population size was thought to be stable or declining (in the later period 1992–2010) and in DS while the population was thought to be stable or increasing (during both periods). Thus, per capita harvest rates likely increased in BB, but decreased in DS over the period of our study. The degree to which sea ice conditions affect body condition in the two populations could not be directly compared, but coefficients of relationships between sea ice conditions and body condition and trends in body condition over time were similar (Tables 6, 7, 8, 9 in Appendix) suggesting that declines in sea ice habitat affected body condition at both high and low harvest rates.

The rate of ice habitat loss in BB based on the ice metric used in this study was higher than in DS despite BB being more northerly. However, the data used in our study suggest that BB generally maintains nearly twice the mean ice concentration of DS between May 15 and October 15. Summer ice concentration alone is unlikely to represent all the characteristics of ice conditions important to polar bears because factors such as water depth, percent coverage of water, floe size and other factors influence the abundance of seals (Stirling et al. 1982; Kingsley et al. 1985) and have been shown to affect polar bear habitat selection (Durner et al. 2009). However, our results suggest that body condition of polar bears is sensitive to the metric used in this study, annual variation in summer ice concentration, in DS and BB.

The results of this study suggest that sea ice has recently begun to have an effect on the annual body condition of polar bears in BB and DS. In the case of BB, it is likely that declines in body condition over time are, at least in part, a result of recent declines in sea ice habitat. In DS, sea ice may be playing a role in the observed decline in body condition, but an increase in population size is a confounding factor. These relationships are generally consistent with observations in other populations, such as Western Hudson Bay and Southern Beaufort Sea where changes in the date of breakup and declines in the amount of ice present over the most productive marine areas during the most critical feeding period from spring through early summer has been significantly correlated with annual variation in sea ice habitat and/or declines in body condition of polar bears (Stirling et al. 1999; Regehr et al. 2007, 2010; Rode et al. 2010).

In BB, these relationships occurred together despite the continuation of a substantial harvest that would have reduced densities significantly. Given that BB is currently being harvested at one of the highest rates of any polar bear population, it is unlikely that a harvest that was deliberately increased in order to reduce densities, even at the highest levels typical for polar bear populations, would be capable of negating the effects of reduced sea ice habitat on body condition.

Appendix

See Tables 4, 5, 6, 7, 8 and 9.

Table 4 Numbers of polar bears captured during studies (1978–2010) in which axillary girth or skull width were measured for each year by population (*BB* Baffin Bay and *DS* Davis Strait) and season of capture (spring vs. fall)

	78	79	80	81	82	83	84	85	...	91	92	93	94	95	.	97	.	99	...	05	06	07	.	09	10
BB spring	32	50	19	59	16	41	41	87			56	22		15										16	29
BB Fall										27	18	144	193	194		22				48	17	17			
DS spring	56	73			7					12	19	14	10			2									
DS fall	15										13					14		3		540	470	126			

Table 5 Independent variables included in candidate linear models exploring trends in axillary girth and skull width and relationships with sea ice concentration for each sex–age class of polar bears captured in Baffin Bay and Davis Strait between 1978 and 2010

Sex–age class	Independent variables
Males 2 years and older	*age*, *cdate*, *year* or *ice*, *cdate* × *year* (or *ice*), *lat*, *age* × *year* (or *ice*), *long*, *lat* × *cdate*[a]
Females 2 years and older	*age*, *cdate*, *year* or *ice*, *cdate* × *year* (or *ice*), *lat*, *age* × *year* (or *ice*), *long*, *lat* × *cdate*[a], *coy*
Cubs[b]	*age*, *cdate*, *year* or *ice*, *cdate* × *year* (or *ice*), *lat*, *age* × *year* (or *ice*), *long*, *lat* × *cdate*[a], *sex*, *litsize*

[a] *lat* × *cdate* interaction was included since these two variables were usually correlated

[b] *Age* for cubs was either 0 for cubs-of-the-year or 1 for yearlings

Table 6 Model results examining trends over time (i.e., *year* effect) in measures of axillary girth of polar bears in Davis Strait

Model	ΔAIC	*w*	χ^2 model	*P* model (*year*)
1978–1994 spring captures				
Males 2+ years Girth (69)				
$2664.2 - 0.97lat - 1.3year$	0	0.46	25.5	<0.0001 (<0.0001)
$2043.6 - 1.0year$	0.21		23.3	<0.0001 (<0.0001)
$2112.7 - 0.07cdate - 1.06year$	1.72	0.37 0.08	23.8	<0.0001 (<0.0001)
Females 2+ years Girth (72)				
$2760.0 - 4.3coy - 1.4year - 167.9age + 0.09year \times age - 1.1lat$	0	0.59	14.0	0.008 (*)
$1825.6 - 4.8coy - 0.9year - 158.9age + 0.08year \times age$	0.73	0.29	11.2	0.025 (*)
$1638.8 - 0.8year - 63.0age + 0.08year \times age$	1.84	0.09	8.1	0.045 (*)
Females 2+ years Skull width				
Data insufficient				
Cubs				
Data insufficient				
1978–2007 fall captures				
Males 2+ years (459)				
Data insufficient[a]				
Females 2+ years Girth (361)				
$140.5 - 5.8coy - 2.4lat$	0	0.67	30.9	<0.0001

Table 6 continued

Model	ΔAIC	w	χ² model	P model (*year*)
444.2 − 5.9*coy* − 2.4*lat* − 0.15*year*	1.35	0.26	31.5	<0.0001 (0.42)
62.2 − 5.3*coy* + 1.6*long* − 0.16*cdate* − 0.07*year*	1.56	0.21	33.3	<0.0001 (0.73)
Cubs-of-the-year Girth (361)[b]				
2895.5 + 4.8*sex* − 5.7*cdate* − 26.4*lat* − 0.6*year* + 0.09*cdate* × *lat*	0	0.88	32.1	<0.0001 (0.002)
2903.7 + 4.8*sex* − 0.18*litsize* − 5.7*cdate* −26.4*lat* − 0.6*year* + 0.1*cdate* × *lat*	1.99	0.12	32.1	<0.0001 (0.002)

The dependent variable for males and females age 2 years and older is the residual of measured axillary girth minus axillary girth predicted by von Bertanlanffy growth curves fit to data collected (see Table 2). The dependent variable for cubs (cubs-of-they-year and yearlings) is axillary girth (cm). Models with the lowest 3 ΔAIC values are reported unless *year* or *ice* are included in models that were not the top 3 but had a ΔAIC < 2. If no models were significant at α = 0.05, only the model with the lowest ΔAIC value is reported. AIC weights (*w*), model χ² statistics, and model *P* values are also provided. *P* values for the year parameter in the model are provided in parentheses. Sample sizes are included in parentheses after the sex–age class. Sex–age class groups for analysis are listed in italics. "*" indicates that there was a significant interaction of one of the covariates with the year effect

[a] Few males were captured during the 1970s and 1990s and those that were captured represented a much younger segment of the population (i.e., only 1 male was over the age of 5) than the sample collected in the 2000s

[b] Sample size for yearlings was insufficient for analyses

Table 7 Model results examining relationships between axillary girth of polar bears and the annual mean ice concentration (i.e., *ice* effect) between May 15 and October 15 in Davis Strait

Model	ΔAIC	w	χ² model	P model (*ice*)
1978–1994 spring captures				
Males 2+ years (69)				
23.02 − 169.5*ice*	0	0.57	25.8	<0.0001 (<0.0001)
62.38 − 192.96*ice* − 0.58*lat*	1.02		26.8	<0.0001 (<0.0001)
−137.73 + 1182.05*ice* + 2.77 *lat* − 23.1*ice* × *lat*	1.94	0.20 0.08	27.8	<0.0001 (*)
Females 2+ years (72)				
88.26*age* − 238.15*ice* − 0.92*lat* − 4.17*coy* + 15.18*age* × *ice*	0	0.38	19.4	0.002 (*)
149.73 − 251.7*ice* + 15.16*age* × *ice* − 5.1*coy* − 1.0*long* − 0.83*lat* − 2.28*age*	0.2	0.31	21.2	0.002 (*)
100.22 − 2.39*age* − 236.14*ice* − 1.0*lat* + 15.6*age* × *ice*	0.61	0.21	16.8	0.002 (*)
Cubs				
Data insufficient—only 3 years (ice conditions) with *n* > 3				
1978–2007 fall captures				
Males 2+ years (459)				
Data insufficient[a]				
Females 2+ years (361)				
107.23 − 8.3*coy* + 239.9*ice* − 0.09*cdate* + 0.33*age* − 1.91*lat*	0	0.32	58.6	<0.0001 (<0.0001)
125.92 − 8.5*coy* + 239.58*ice* + 0.33*age* − 2.6*lat*	0.07	0.30	55.6	<0.0001 (<0.0001)
95.47 − 7.8*coy* + 234.4*ice* − 0.18*cdate* + 0.31*age* + 1.66*long*	0.91	0.13	57.7	<0.0001 (<0.0001)
Cubs-of-the-year (361)[b]				
1314.66 + 5.2*sex* + 133.4*ice* − 20.5*lat* − 4.3*cdate* + 0.07*cdate* × *lat*	0	0.85	45.9	<0.0001 (<0.0001)
1315.3 + 5.2*sex* + 133.6*ice* − 0.16*litsize* − 20.5*lat* − 4.3*cdate* + 0.07*cdate* × *lat*	1.99	0.12	45.9	<0.0001 (<0.0001)

The dependent variable for males and females age 2 years and older is the residual of measured axillary girth minus axillary girth predicted by von Bertanlanffy growth curves fit to data collected (see Table 2). The dependent variable for cubs (cubs-of-they-year and yearlings) is axillary girth (cm). Models with the lowest 3 ΔAIC values are reported unless *year* or *ice* are included in models that were not the top 3 but had a ΔAIC < 2. If no models were significant at α = 0.05, only the model with the lowest ΔAIC value is reported. AIC weights (*w*), model χ² statistics, and model *P* values are also provided. *P* values for the year parameter in the model are provided in parentheses. Sample sizes are included in parentheses after the sex–age class. Sex–age class groups for analysis are listed in italics. "*" indicates that there was a significant interaction of one of the covariates with the ice effect

[a] Few males were captured during the 1970s and 1990s and those that were captured represented a much younger segment of the population (i.e., only 1 male was over the age of 5) than the sample collected in the 2000s

[b] Sample size for yearlings was insufficient for analyses

Table 8 Model results examining trends (i.e., *year* effect) in measures of axillary girth of polar bears in Baffin Bay

Model	ΔAIC	w	χ^2 model	P model (*year*)
1978–1995 spring captures				
Males age 2+ years Girth (212)				
$38.9 - 0.55lat$	0	0.49	1.8	0.18
Males age 2+ years Skull width (98)				
$-1.07 + 0.011cdate$	0	0.56	1.1	0.30
Females age 2+ years Girth (111)				
$434.86 - 0.35year - 0.45age + 1.9cdate - 0.029cdate \times lat + 4.12lat$	0	0.49	20.3	0.001 (0.008)
$725.58 - 0.41age - 0.14cdate + 0.47lat - 0.37year$	0.82	0.21	17.5	0.002 (0.006)
$1234.93 - 82.9age - 0.13cdate + 0.38lat - 0.63year + 0.04year \times age$	1.14	0.16	19.2	0.002 (0.008)
Females age 2+ years Skull width (134)				
$-111.16 + 0.06year + 0.03age + 0.009cdate$	0	0.38	11.9	0.008 (0.012)
$-121.2 + 0.06year + 0.009cdate$	0.7	0.19	9.2	0.01 (0.006)
$-109.1 + 0.05year + 0.03age + 0.01cdate + 0.2coy$	0.86	0.16	13.1	0.01 (0.013)
Cubs Girth (73)				
$991.28 + 1649.29age - 0.47year + 0.20cdate - 0.81year \times age - 8.59litsize$	0	0.51	151.0	<0.0001 (*)
$792.94 + 1689.19age - 0.35year + 0.19cdate - 0.44lat - 0.83year \times age - 8.81litsize$	0.67	0.26	152.3	<0.0001 (*)
$496.1 + 1628.56age - 9.4litsize - 0.32year + 2.04cdate + 2.91lat - 0.03cdate \times lat + 0.80age \times year$	1.46	0.10	153.5	<0.0001 (*)
Cubs Skull width				
Data insufficient				
1992–2010 spring captures (girth only; data insufficient for skull width)				
Males age 2+ years (41)				
$2060.04 - 1.6lat - 0.65long - 0.95year$	0	0.50	11.2	0.011 (0.002)
$2154.3 - 0.99year - 0.35age - 0.68long - 1.75lat$	0.46	0.31	12.8	0.012 (0.001)
$1117.36 - 0.50year - 1.77lat$	1.9	0.07	7.3	0.026 (0.029)
Females age 2+ years (241)				
$15.15 + 0.51age - 0.25long$	0	0.36	6.6	0.037
$-1.1 + 0.55age$	0.04	0.35	4.5	0.033
$7.7 + 0.54age + 0.08cdate - 0.28long$	1.16	0.11	7.4	0.06
$61.5 + 0.59age - 0.28long + 0.15cdate - 0.85lat$	1.61	0.07	9.0	0.06
$133.7 - 0.53age - 0.066year$	1.93	0.05	4.8	0.089 (0.68)
Cubs				
Sample size too small ($n = 31$) for both girth and skull width				
1991–2006 fall captures				
Males age 2+ year Girth (362)				
$3489.0 - 1.71year - 1.02lat - 0.26cdate$	0	0.53	42.5	<0.0001 (0.002)
$3485.78 - 1.73year - 0.41long - 026cdate$	0.64	0.28	41.8	<0.0001 (0.002)
$3522.88 - 1.73year - 1.03lat - 0.09age - 0.27cdate$	1.61	0.11	42.8	<0.0001 (0.002)
Males age 2+ year Skull width (296)				
$-232.3 + 0.12year + 0.027age$	0	0.29	5.0	0.08 (0.10)
Females age 2+ year Girth (241)				
$-0.13cdate - 1.12lat - 2.97coy - 1.58year + 3256.34$	0	0.65	33.5	<0.0001 (0.001)
$-1.5year + 0.15age - 0.14cdate - 1.1lat - 3.64coy + 3115.6$	0.88	0.27	34.7	<0.0001 (0.002)
Females age 2+ year Skull width(176)				
$-0.44 + 0.046age$	0	0.83	21.2	<0.0001
$42.3 + 0.046age - 0.02year$	1.74	0.14	21.5	<0.0001 (0.61)
Cubs Girth (277)				
$3006.65 + 23.52age - 0.18cdate - 1.34year - 3.9lat + 1.42long$	0	0.89	192.3	<0.0001 (0.004)

Table 8 continued

Model	ΔAIC	w	χ^2 model	P model (year)
Cubs Skull width (213)				
$16.5 + 2.8age + 0.25sex$	0	0.34	224.4	<0.0001
$143.3 + 2.8age + 0.26sex - 0.06year$	0.19	0.28	225.98	<0.0001 (0.21)
$142.7 + 2.9age + 0.27sex - 0.06year - 0.23litsize$	0.63	0.18	227.5	<0.0001 (0.21)

The dependent variable for males and females age 2 years and older is the residual of measured axillary girth minus axillary girth predicted by von Bertanlanffy growth curves fit to data collected (see Table 2). The dependent variable for cubs (cubs-of-they-year and yearlings) is axillary girth (cm). Models with the lowest 3 ΔAIC values are reported unless *year* or *ice* are included in models that were not the top 3 but had a ΔAIC < 2. If no models were significant at α = 0.05, only the model with the lowest ΔAIC value is reported. AIC weights (*w*), model χ statistics, and model *P* values are also provided. *P* values for the year parameter in the model are provided in parentheses. Sample sizes are included in parentheses after the sex–age class. Sex–age class groups for analysis are listed in italics. "*" indicates that there was a significant interaction of a covariate with the year effect

Table 9 Model results examining relationships between axillary girth of polar bears and the annual mean ice concentration between May 15 and October 15 in Baffin Bay

Model	ΔAIC	w	χ^2 model	P model (ice)
1978–1995 spring captures				
Males 2+ years Girth (212)				
Same as Table 7 in Appendix				
Males 2+ years Skull width (92)				
$1.27 + 0.01cdate - 0.04long$	0	0.28	3.79	0.15
Females 2+ years Girth (111)				
$7.19 + 0.47age + 0.07cdate - 0.26long$	0	0.38	14.3	0.002
$16.7 + 0.46age - 0.28long$	0.2	0.30	12.1	0.002
$6.96 + 0.5age - 1.35coy + 0.07cdate - 0.27long$	1.27	0.28	15.0	0.005
Females 2+ years Skull width (134)				
$-5.5 + 0.04age + 0.075lat$	0	0.39	8.0	0.019
$-5.9 + 0.04age + 0.24coy + 0.08lat$	0.33	0.28	9.6	0.02
$-5.7 + 0.04age + 0.005cdate + 0.26coy + 0.07lat$	1.43	0.09	10.5	0.03
$-5.1 + 0.04age + 0.24coy + 0.08lat - 2.0ice$	1.54	0.08	10.4	0.03 (0.37)
Cubs Girth (73)				
$41.7 + 1.6age - 8.5litsize + 0.19cdate + 67.1ice - 100.1age \times ice$	0	0.55	150.5	<0.0001 (*)
$66.6 + 39.99age - 8.0litsize + 0.19cdate$	0.98	0.21	145.5	<0.0001
$57.4 + 0.02age - 8.7litsize + 0.17cdate - 0.2lat + 67.6ice - 104.2age \times ice$	1.61	0.11	150.9	<0.0001 (*)
Cubs-of-the-year Skull width (68)[a]				
$5.3 - 1.4litsize + 0.03cdate$	0	0.54	18.6	<0.0001
$5.1 - 1.4litsize + 0.04cdate + 0.5sex$	0.36	0.37	20.3	<0.0001
1992–2010 spring captures				
Males 2+ years (41)				
$8.58 - 0.73long + 250.48ice - 0.45cdate$	0	0.68	12.55	0.006 (<0.0001)
$8.77 + 249.4ice - 0.03age - 0.73long - 0.45cdate$	2.0	0.09	12.56	0.014 (<0.0001)
Females 2+ years				
$22.6 + 153.35ice + 2.9age - 0.55long - 0.74ice \times age - 15.8coy$	0	0.33	14.4	0.03 (*)
$4.3 - 14.2coy + 58.3ice + 0.55age - 0.47long$	0.5	0.20	11.48	0.02 (0.08)
$10.52 + 51.3ice + 0.56age - 0.45long$	1.0	0.12	8.98	0.03 (0.13)
Cubs				
Sample size too small $n = 31$				
1991–2006 fall captures				
Males 2+ years Girth (362)				
$54.72 + 81.3ice - 0.29cdate - 1.05lat$	0	0.57	44.40	<0.0001 (0.001)

Table 9 continued

Model	ΔAIC	w	χ² model	P model (ice)
8.07 + 80.77ice − 0.29cdate − 0.41long	1.09	0.19	43.31	<0.0001 (0.001)
709.6 + 77.18ice − 2.71cdate − 10.6lat + 0.04cdate × lat	1.17	0.18	45.23	<0.0001 (0.001)
Males 2+ years Skull width (293)				
1.97 − 0.03long	0	0.30	2.58	0.11
Females 2+ years Girth (241)				
94.32 + 44.7ice + 0.23age − 0.19cdate − 0.94lat − 3.3coy	0	0.38	30.33	<0.0001 (0.025)
99.98 + 41.7ice − 0.19cdate − 0.96lat − 2.24coy	0.77	0.17	27.55	<0.0001 (0.037)
94.85 + 43.4ice − 0.19cdate − 0.89lat	1.02	0.13	25.31	<0.0001 (0.031)
Females 2+ years Skull width (176)				
−0.44 + 0.05age	0	0.51	21.2	<0.0001
−1.8 + 0.05age + 3.45ice	0.78	0.23	22.4	<0.0001 (0.27)
−0.4 + 0.05age + 0.04coy	1.9	0.08	21.3	<0.0001
Cubs Girth (277)				
191.3 − 19.3age + 78.1ice + 105.6age × ice − 0.24cdate − 0.69lat + 2.7litsize	0	0.54	190.0	<0.0001 (*)
189.03 − 19.3age + 78.4ice + 105.3age × ice − 0.24cdate − 0.69lat	1.04	0.19	186.97	<0.0001 (*)
154.7 − 20.6age + 82.2ice + 108.6age × ice − 0.23cdate − 0.23long − 2.7litsize	1.54	0.12	188.47	<0.0001 (*)
Cubs Skull width (213)				
16.5 + 2.6age + 0.2sex	0	0.48	245.2	<0.0001
16.3 + 2.5age + 0.2sex − 0.14litsize	1.11	0.16	245.9	<0.0001
16.3 + 2.6age	1.12	0.16	241.9	<0.0001
17.19 + 2.6age + 0.2sex − 1.9ice	1.48	0.11	245.5	<0.0001 (0.59)

The dependent variable for males and females age 2 years and older is the residual of measured axillary girth minus axillary girth predicted by von Bertanlanffy growth curves fit to data collected (see Table 2). The dependent variable for cubs (cubs-of-they-year and yearlings) is axillary girth (cm). Models with the lowest 3 ΔAIC values are reported unless *year* or *ice* are included in models that were not the top 3 but had a ΔAIC < 2. If no models were significant at α = 0.05, only the model with the lowest ΔAIC value is reported. AIC weights (*w*), model χ² statistics, and model *P* values are also provided. *P* values for the year parameter in the model are provided in parentheses. Sample sizes are included in parentheses after the sex–age class. Sex–age class groups for analysis are listed in italics. "*" indicates that there was a significant interaction of a covariate with the year effect

[a] Sample size for yearlings was insufficient

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