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Changes in Land Distribution of Polar Bears in Western Hudson Bay

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ABSTRACT. We examined the capture locations of polar bears (*Ursus maritimus*) on land in western Hudson Bay over 19 years (1986–2004) to assess temporal trends in the distribution of the population. We found that the distribution of bears of most age and sex groups shifted northward and eastward over the study. The causes of these shifts may be related to an altered population structure, changing environmental conditions, or a combination of both factors. Segregation by age, sex, and reproductive status persisted over time as found in earlier studies, but more females with young were within 5 km of the coast after 2001 than before. The distribution changes were correlated with the timing of sea-ice breakup, which now occurs, on average, about three weeks earlier than it did 30 years ago. While environmental conditions may have influenced polar bear distribution, the reduction in the number of large adult males along the coast may also have affected distribution patterns, allowing adult females to remain closer to the coast in more recent times.

Key words: polar bear, *Ursus maritimus*, western Hudson Bay, distribution, population structure, sea-ice breakup, temporal trends

RÉSUMÉ. Nous avons examiné les lieux de capture d'ours polaires (*Ursus maritimus*) sur la terre ferme dans l'ouest de la baie d'Hudson pendant 19 ans (de 1986 à 2004) afin d'évaluer les tendances temporelles caractérisant la répartition de la population. Nous avons remarqué que la répartition des ours de la plupart des groupes d'âge et de sexe se déplaçait vers le nord et vers l'est au cours de l'étude. Cela pourrait être attribuable à une structure de population modifiée, à l'évolution des conditions environnementales ou à un ensemble des deux facteurs. La ségrégation en fonction de l'âge, du sexe et de l'état reproducteur a persisté avec le temps, tel que dénoté dans le cadre d'études antérieures, mais plus de femelles avec des jeunes se trouvaient en-dedans de cinq kilomètres de la côte après 2001 qu'avant. Les changements en matière de répartition ont été corrélés au moment de la débâcle de la glace de mer qui maintenant se produit, en moyenne, environ trois semaines plus tôt qu'il y a 30 ans. Bien que les conditions environnementales puissent avoir exercé une influence sur la répartition des ours polaires, la réduction du nombre de gros mâles adultes le long de la côte pourrait également avoir modifié les tendances caractérisant la répartition, permettant ainsi aux femelles adultes de rester plus près de la côte ces dernières années.

Mots clés : ours polaire, *Ursus maritimus*, ouest de la baie d'Hudson, répartition, structure de population, débâcle de la glace de mer, tendances temporelles

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INTRODUCTION

Climate is a primary factor that influences the distribution of animals and the geographic range of species (Andrewartha and Birch, 1982). Climate change has been occurring at an accelerated rate and is predicted to be amplified at high latitudes (Manabe et al., 1992; Comiso, 2003). If temperatures continue to increase as predicted (IPCC, 2007; Walsh, 2008), the range of some Arctic and alpine species is expected to shift northward or to higher elevations as the animals seek suitable habitats or environmental conditions. Such distribution shifts have been documented for several species (Parmesan et al., 1999; Thomas and Lennon, 1999; Root et al., 2003; Parmesan, 2006). Arctic sea ice is particularly sensitive to change as a result of climate warming. Reductions in extent, thickness, and duration of ice cover are well documented (Maslanik et al., 1996; Parkinson, 2000; Tucker et al., 2001; Rigor and Wallace, 2004; Serreze et al., 2007), and these declines are predicted to continue (Holland et al., 2006; Stroeve et al., 2007). The changes in sea ice have affected Arctic marine mammals through loss of habitat (Laidre et al., 2008), declining health and condition (Burek et al., 2008), altered prey availability and foraging behaviour (Bluhm and Gradinger, 2008), and increased human activities (Hovelsrud et al., 2008). The polar bear (*Ursus maritimus*) is an ice-dependent species that has been identified as sensitive to climate warming and alterations to sea ice (Stirling and Derocher, 1993;

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Derocher et al., 2004; Stirling and Parkinson, 2006; Laidre et al., 2008; Wiig et al., 2008).

The range of the Western Hudson Bay (WH) polar bear population is near the southern limit for the species. Although the primary habitat of polar bears is sea ice, during the summer and autumn, when Hudson Bay is ice-free, the WH population shows a high degree of fidelity to terrestrial summering areas (Stirling et al., 1977, 2004; Derocher and Stirling, 1990a; Ramsay and Stirling, 1990). Sea-ice breakup along the Manitoba coast occurs from mid-June to mid-July as northwest winds and counter-clockwise currents push the melting ice southward until the last ice melts along the Ontario coast about three weeks later (Wang et al., 1994). The bears come ashore along the southwest coast of the Bay. The ice begins to re-form along the northwestern coast of Hudson Bay to Cape Churchill in late October to mid November (Markham, 1986; Wang et al., 1994). The bears return to the sea ice to resume hunting seals, except for pregnant females, which remain on land in birthing dens to rear cubs until spring (Watts and Hansen, 1987).

While ashore, bears segregate by age, sex, and reproductive status (Derocher and Stirling, 1990a). Pregnant females and females with young show a high degree of fidelity to an inland denning area, whereas adult males remain near the coast (Latour, 1981; Derocher and Stirling, 1990b). Subadults are broadly distributed throughout the area (Latour, 1981; Derocher and Stirling, 1990b). The most likely hypothesis to explain this segregation is female avoidance of adult males, which are more abundant along the coast (Taylor et al., 1985; Derocher and Stirling, 1990a). Summer fidelity of females to the denning area was also suggested to familiarize cubs with suitable denning areas, whereas the predominance of adult males along the coast was attributed to energy conservation (Derocher and Stirling, 1990a). During their four to five months on land, the bears eat little, reduce their activity, and rely on their fat reserves for energy (Knudsen, 1978; Derocher and Stirling, 1990b; Hobson and Stirling, 1997).

In western Hudson Bay, sea ice has been breaking up earlier over three decades (1971–2001) because of significant increases in temperature (particularly in spring) (Skinner et al., 1998; Stirling et al., 2004; Gagnon and Gough, 2005a; Stirling and Parkinson, 2006). The progressively earlier breakup has resulted in declines in bear condition, reproductive success, survival of younger bears, and population size (Stirling and Derocher, 1993; Derocher and Stirling, 1995; Stirling and Lunn, 1997; Stirling et al., 1999; Stirling and Parkinson, 2006; Regehr et al., 2007). During field studies, female bears with young were seen closer to the coast in recent years (2002–04) (N.J. Lunn, unpubl. data).

The WH population is the most studied polar bear population in the world, providing an opportunity to examine the temporal dynamics of distribution in relation to a changing climate. In this study, we examine the distribution of polar bears of all age, sex, and reproductive groups during the ice-free period over 19 years (1986 – 2004) and the relation of changes in distribution to the timing of sea-ice breakup.

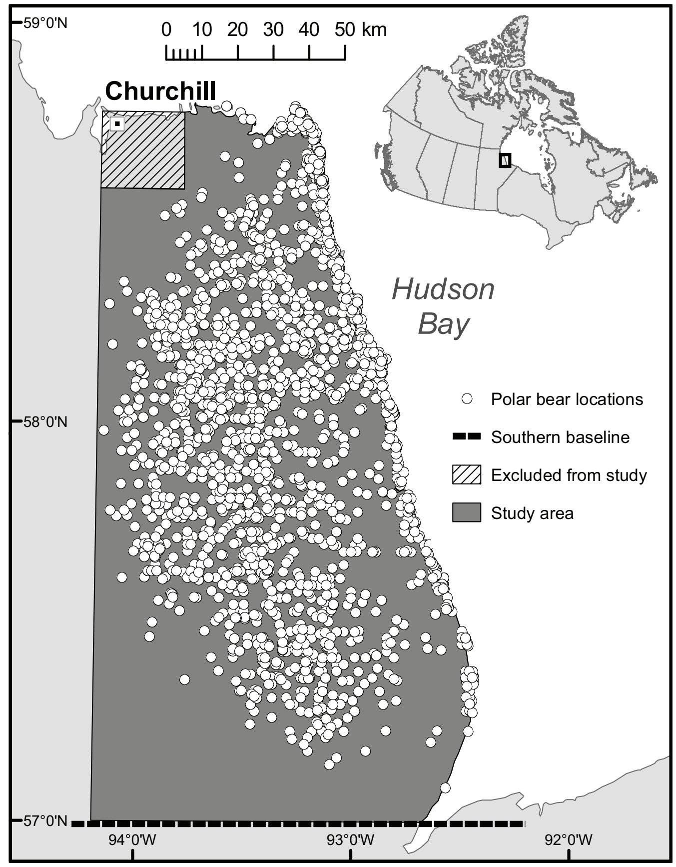

FIG. 1. The study area in western Hudson Bay, northern Manitoba, showing the distribution of polar bear captures from 1986 to 2004.

MATERIALS AND METHODS

From 1986 to 2004, polar bears were captured non-selectively from a helicopter in northeastern Manitoba between August and October by the Canadian Wildlife Service (Stirling et al., 1989). During the study period, capture effort was widely and completely distributed over the study area between 58˚49′ N and 57˚00′ N, and inland to 94˚10′ W (Fig. 1). We captured all observed polar bears regardless of age, sex, or reproductive status, except the few individuals that entered water and could not be safely sedated. We recorded the location, sex, and reproductive status of the bears. Age of bears was determined by cementum annuli counts from a premolar extracted at capture (Calvert and Ramsay, 1998). Each individual was uniquely marked with a numbered tag in each ear and a tattoo applied to the inside of the upper lip. Where applicable, the Environment Canada Prairie and Northern Region Animal Care Committee and the University of Alberta BioSciences Animal Policy and Welfare Committee approved handling protocols for free-ranging polar bears, which were consistent with the Canadian Council on Animal Care guidelines.

For bears captured more than once in a given year, we used only the first capture location in analyses. Bears captured near Churchill (between 58˚47′ N and 58˚35′ N, 94°12′ W and 93°48′ W) were excluded from analyses because their distribution may have been influenced by humans (Towns et al., 2009). We analyzed locations of bears captured from 23 August to 7 October because at that time bears have reached their preferred habitat, are relatively inactive, and show limited movements (Derocher and Stirling, 1990a; Lunn et al., 2004). Following Derocher and Stirling (1990a), we categorized polar bears into five groups based on age and sex: adult males (≥ 5 years of age), solitary adult females (≥ 5 years of age), family groups (adult females with dependent cubs), independent subadult females (1–4 years of age), and independent subadult males (1–4 years of age).

The Manitoba coastline provided the baseline for quantification of the east-west distribution of polar bears (Fig. 1). We constructed a baseline at the southern edge of the study area (57°00′ N) as a reference for the north-south distribution. The shortest distance from the capture location of a bear to the coast provided the east-west distribution, and that to the southern baseline, the north-south distribution. These distances were determined using ArcGIS 9.0 (Environmental Systems Research Institute (ESRI), Redlands, California, USA).

To examine the distribution of the population quantitatively, we constructed 95% and 50% areas of use from fixed kernel estimates for 1986–96 and 1997–2004. Kernel estimates were constructed using default parameters from the Animal Movements extension program for ArcView GIS 3.2 (Hooge et al., 1999). For each of the two time periods, we calculated a centroid of the 95% and 50% kernels; then we calculated the difference in distances between the centroids using ArcGIS 9.3. We selected these two periods because visual inspection of the data suggested that a shift in distribution occurred in 1996–97.

Following Stirling et al. (1999), breakup dates for 1986–2004 were based on ice concentration values within the population management boundaries of the WH and Southern Hudson Bay polar bear populations. We calculated dates of sea-ice breakup using weekly regional ice charts for Hudson Bay (Canadian Ice Service, http://ice-glaces.ec.gc.ca/WsvPageDsp.cfm?ID=11715&Lang=eng&QryRsrt=true). We defined sea-ice breakup as the date by which total ice cover was 50% during spring melt (Etkin, 1991).

We tested distance measures for each age and sex group for normality and homogeneity of variance using Kolmogorov-Smirnov and Levene's tests (Zar, 1999). We used non-parametric tests when data could not be normalized with standard transformations (Zar, 1999). We used Spearman rank correlations to examine relationships between polar bear distance from the coast and southern baseline against 1) time and 2) sea-ice breakup. Because our subjective impression was that more females with offspring were near the coast in 2002–04 than in 1986–2001, a one-tailed Fisher's exact test compared the proportion of family groups within 5 km of the coast for the two periods. Linear regression was used to estimate how much the distribution changed for the five polar bear groups using 1986 locations relative to 2004 locations. We examined the segregation of each polar bear group using a Kruskal-Wallis test and Mann-Whitney post-hoc test.

All tests were considered significant at $p \leq 0.05$ except when a Bonferroni adjustment was used for age and sex segregation analysis, in which case pairwise comparisons were considered significant at $p \leq 0.005$. Medians ± 1 SE are presented unless otherwise stated. Statistical analyses were conducted using SPSS 13.0 software (SPSS Inc., Chicago, Illinois).

RESULTS

For 1986 to 2004, we had 2304 locations of 1213 bears captured between August and October (adult males, n = 771; family groups, n = 580; solitary adult females, n = 458; subadult females, n = 262; subadult males, n = 233). Bears were caught at 0–82 km (median: 23 km) from the coast. Adult males, solitary adult females, family groups, and subadult males were found closer to the coast over time (Spearman rank correlations: $r_s = -0.26$, $p < 0.001$; $r_s = -0.17$, $p < 0.001$; $r_s = -0.13$, $p = 0.001$; $r_s = -0.16$, $p = 0.014$, respectively), indicating an eastward shift in distribution. Subadult females did not show any trend ($r_s = 0.05$, $p = 0.46$). From 1986 to 2004, the eastward shift averaged 13 km for adult males, 14 km for solitary adult females, 10 km for family groups, and 7 km for subadult males. Inspection of the data suggested that 1989 was a possible outlier, although reanalyzing the data without that year did not alter results. In 2002–04, more family groups (35.1%, 27/77) were 5 km or less from the coast than in 1986–2001 (11.1%, 50/451) (one-tailed, Fisher's exact test: $p < 0.0001$).

Bear locations ranged from 10 to 200 km (median: 119 km) from the southern baseline. Using Spearman rank correlations, we found a northward shift over time for adult males ($r_s = 0.10$, $p = 0.006$) and family groups ($r_s = 0.11$, $p = 0.007$), but no north/south trend over time was noted for solitary adult females ($p = 0.061$), subadult females ($p = 0.058$), or subadult males ($p = 0.12$). From 1986 to 2004, on average, adult males shifted 18 km north and family groups 20 km north.

The 95% fixed kernel area estimate of locations in 1986–96 encompassed 13 594 km^2, while the 50% core area estimate encompassed 2055 km^2 (Fig. 2). During 1997–2004, the 95% (12 167 km^2) and 50% (1113 km^2) kernel estimates reflect 10% and 46% decreases in areas of use. The difference in distance between centroids for 1986–96 and 1997–2004 was 5 km for the 95% fixed kernel estimate and 32 km for the 50% fixed kernel estimate (Fig. 2). The north and eastward shift in the population is evident largely in the 50% core area, which is concentrated in the NE in 1997–2004.

Overall, polar bear groups were segregated from one another in the east-west (Mann-Whitney U post hoc test: $p \leq 0.001$) and north-south directions (Mann-Whitney U post hoc test: $p \leq 0.019$), with two exceptions: the north-

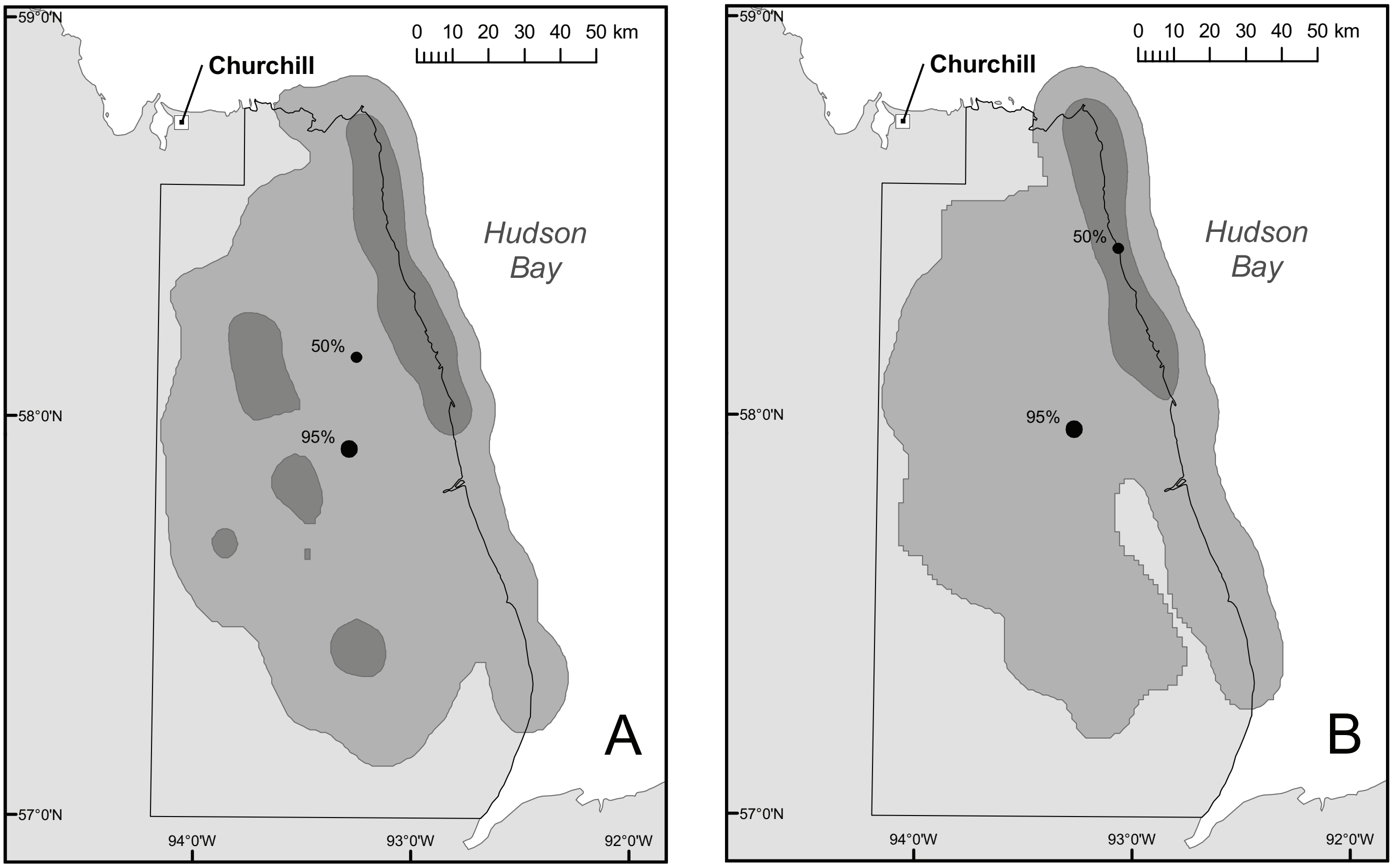

FIG. 2. Centroids of the 95% (light grey) and 50% (dark grey) fixed kernel distribution of the western Hudson Bay polar bear population for A) 1986–96 and B) 1997–2004.

south distances of adult males did not differ from those of either subadult males or subadult females.

Distance from the coast was positively correlated with date of sea-ice breakup for adult males (Spearman-rank correlations: $r_s = 0.16$, $p < 0.001$), solitary adult females ($r_s = 0.22$, $p < 0.001$), subadult females ($r_s = 0.13$, $p = 0.034$), and subadult males ($r_s = 0.18$, $p = 0.007$), but not for family groups ($r_s = 0.03$, $p = 0.52$). In contrast, the distances from the southern baseline showed no correlation with date of breakup (Spearman-rank correlations: adult males: $r_s = -0.03$, $p = 0.38$; solitary adult females: $r_s = -0.02$, $p = 0.70$; family groups: $r_s = -0.03$ $p = 0.51$, subadult females: $r_s = -0.07$, $p = 0.24$; subadult males: $r_s = 0.03$, $p = 0.62$).

DISCUSSION

The distribution of polar bears of the WH population changed over the study period. Although differences between age and sex groups were found, a general shift eastward and northward was evident. Both the Hudson Bay ecosystem and the WH polar bear population have undergone significant change over the last several decades (Skinner et al., 1998; Stirling et al., 1999, 2004; Stirling and Parkinson, 2006; Regehr et al., 2007). In particular, sea-ice breakup is about three weeks earlier than 30 years ago, the population has decreased in size by about 22% since 1987, and the proportion of adult males in the population has declined (Stirling and Parkinson, 2006; Regehr et al., 2007). We hypothesize that both altered population structure and changes in the date of breakup as a result of climate warming play a role in explaining the distributional shifts that we observed. However, their respective effects are not mutually exclusive, making it difficult to determine the leading factor in the distributional shift.

As in earlier findings (Derocher and Stirling, 1990a), spatial segregation of age and sex groups was retained over time. Although the proportion of adult male bears is lower, they are still more common in the coastal areas, while solitary adult females still prefer the inland area. The eastward shift, however, indicates that males are not traveling as far inland or there are fewer males inland. Solitary adult females did not show a statistically significant northward shift over time; however, a northward shift in den sites occurred between the 1970s and the 1980s and may have been related to sea-ice conditions (Ramsay and Stirling, 1990). Similarly, a landward and eastward distribution shift due to changes in sea ice (e.g., reduced availability and quality of ice) was noted in the denning areas of polar bears in the northern Alaskan region (Fischbach et al., 2007).

Studies of other ursids have documented age and sex segregation. Avoidance of adult males may affect the distribution, movement, and habitat use of subordinate conspecifics (Wielgus and Bunnell, 1994; McLoughlin et al., 2002; Gende and Quinn, 2004). Changes in the abundance and structure of the population may have influenced the shift in polar bear distribution over time. From 1987 to 2004, the WH population declined from 1194 (95% CI = 1020 – 1368) to 935 bears (95% CI = 794 – 1076) (Regehr et al., 2007). The majority of polar bears harvested from this population are young males, skewing the population towards females in a 2:1 ratio (Derocher et al., 1997). The high harvest of young males may have reduced recruitment into the adult male population and thus resulted in fewer adult males along the coast. A reduction in the number of adult males may lessen their role in the distribution of other age and sex groups, allowing subordinate animals to occupy the coastal areas, as demonstrated by the increase in the proportion of females with young near the coast in recent years. The distributional shift is small relative to the distances over which polar bears can travel (Amstrup et al., 2000; Mauritzen et al., 2001), but it suggests a behavioural change.

Shifts in polar bear distribution were correlated with sea-ice breakup. While the timing of sea-ice breakup was correlated with the distance from the coast of all age and sex groups of polar bears except family groups, the timing of breakup was not related to the northward shift. Bears need to accumulate sufficient fat reserves while on the sea ice to sustain them through the ice-free period. Earlier ice breakup means less time to hunt. As a result, bears come ashore in poorer condition (Stirling et al., 1999). Remaining closer to the coast reduces the energetic cost of moving inland and may allow bears to conserve fat stores (Derocher and Stirling, 1990a). Even though sea-ice breakup was not related to the distributional shift of family groups, breakup may indirectly affect the distribution of family groups on land through effects on body condition. Milk is energetically costly to produce (Arnould and Ramsay, 1994), and the declining condition of mothers with young may influence the energy mothers allocate to movement while on land. Changes in distribution relative to sea ice have also been documented in other polar bear populations. During the fall open-water season in the southern Beaufort Sea, there are more polar bears coming ashore in years when the sea ice retreats farthest from the shore (Schliebe et al., 2008).

Determining the relative roles of environmental factors (e.g., sea-ice breakup) and population structure on the distributional shifts of the WH polar bear population was difficult because both factors changed simultaneously. We know that climate change, through warming temperatures, has adversely affected the population, its habitat, and its prey. The distribution shift has management implications since nutritionally stressed polar bears are moving northward towards the town of Churchill, resulting in a rising number of human-bear interactions (Towns et al., 2009). The WH population is at or near the southernmost range of polar bear populations and thus will likely show the first impacts of climate change. Climate projections predict that warming will continue, with significant loss of sea-ice cover (Gough and Wolfe, 2001; Comiso, 2003; Gagnon and Gough, 2005b; Holland et al., 2006; Walsh, 2008). Continued monitoring of this population is therefore essential.

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