# Spatial and temporal patterns of problem polar bears in Churchill, Manitoba

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ORIGINAL PAPER

# Spatial and temporal patterns of problem polar bears in Churchill, Manitoba

**Lindsay Towns · A. E. Derocher · I. Stirling · N. J. Lunn · D. Hedman**

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**Abstract** Human–bear interactions near the town of Churchill, Manitoba occur annually because the Western Hudson Bay polar bear population spends 4–5 months on-land each year when the sea ice melts completely. Significant changes have occurred in the Hudson Bay ecosystem and in the bear population as a result of climate warming; however, how these changes may have influenced human–bear interactions near Churchill is unclear. This study examined the temporal and spatial patterns of 1,487 problem bears captured in the Churchill area from 1970 to 2004. We also examined the relationship between problem bears and environmental variables as well as the Nunavut harvest. The number of individual problem bears caught near Churchill varied from 10 to 90 individuals per year and increased over time. Subadult males comprised 39%, subadult females 23%, adult males 18%, females with young 14%, and solitary females 6% of captures. Bears that became problem individuals were in closer proximity to the Churchill area. Nutritional stress and a northward shift in the distribution of the bears that spend the summer on-land in northeastern Manitoba may account for the increase in problem bear numbers. The date of sea ice freeze-up, which is getting progressively later, was the best predictor explaining the annual variation in the occurrence of problem bears. These results provide an understanding of how a warming climate may directly impact polar bear behaviour. This information may allow wildlife managers to predict relative levels of human–bear interactions and thereby implement effective management strategies to improve human safety and the conservation of polar bears.

**Keywords** *Ursus maritimus* · Polar bear · Problem bear · Churchill · Human–bear interactions · Harvest · Sea ice · Distribution · Nutritional stress

L. Towns (✉) · A. E. Derocher · I. Stirling
Department of Biological Sciences, University of Alberta, Edmonton, AB T6G 2E9, Canada
e-mail: l_towns@hotmail.com

I. Stirling · N. J. Lunn
Wildlife Research Division, Science and Technology Branch, Environment Canada, 5320-122 Street, Edmonton, AB T6H 3S5, Canada

D. Hedman
Manitoba Conservation, Box 28, 59 Elizabeth Drive, Thompson, MB R8N 1X4, Canada

## Introduction

Polar bear (*Ursus maritimus*) habitat is not as isolated as it once was. Increasing human population, tourism, and exploration for oil, gas, and minerals has expanded into polar bear range in recent times (Watts and Ratson 1989; Kearney 1989; Lee and Taylor 1994; Bogoyavlenskiy 2004; Hovelsrud et al. 2008). Sea ice conditions have also changed leading to increased chances of interactions between humans and bears (Stirling and Parkinson 2006; Hovelsrud et al. 2008). The town of Churchill, Manitoba on the western coast of Hudson Bay is located in the area inhabited by the Western Hudson Bay (WH) polar bear population. This population spends 4–5 months on-land (i.e., early July to early December) when the sea ice melts every summer with pregnant females remaining for an additional 3–4 months (Stirling et al. 1977). The bears spend the ice-free period south and east of Churchill with adult females with and without young inland, adult males near or along the coast, and subadults broadly distributed (Latour 1981; Derocher and Stirling 1990). Before freeze-up, bears move northward in late autumn placing them

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closer to Churchill (Latour 1981; Derocher and Stirling 1990).

Problems with polar bears occur when they are attracted to dumps and/or food in settlements, threatening life or property, or are provoked by people (Stirling et al. 1977). Escalating human–bear conflicts prompted the implementation of the Polar Bear Control Program in 1969 (Polar Bear Alert Program after 1984). The program was coordinated by the Manitoba Department of Natural Resources (now Manitoba Conservation) and the policy was intended to "ensure the safety of people and the protection of property from damage by polar bears" (Kearney 1989). Resource officers were responsible for controlling bears in and around the town by shooting, trapping, and relocation of some bears. Two dumps were closed in the late 1960s; one dump 10 km east of Churchill remained active until 2005. To help with problem bears, a holding facility was established in 1982 to safely house some bears until the sea ice re-formed and they could be released (Kearney 1989).

The management of polar bears from the WH population is the shared responsibility of Manitoba and Nunavut. An annual subsistence harvest, based on sustainable levels, is permitted by Nunavut. Historically, Nunavut's annual quota for polar bears from WH was 47 animals, which was increased to 56 in 2004/05, reduced to 38 in 2007/08, and further reduced to 8 in 2008/09 (IUCN/SSC Polar Bear Specialist Group 2006; E. Peacock pers. comm. 2008). Although the hunting of polar bears no longer occurs in Manitoba, there is an annual quota of 8 for use in the event that a problem polar bear is killed. Manitoba resource officers relocate some problem bears north of Churchill, which may increase a bear's likelihood of being killed by hunters.

Understanding the ecology of problem bears has become increasingly important because climate warming has been linked to changes in polar bear habitat and their prey (Skinner et al. 1998; Stirling et al. 1999; Ferguson et al. 2005; Gagnon and Gough 2005; Laidre et al. 2008). Changes in the distribution and population dynamics of WH bears were linked to changing climatic conditions (Derocher and Stirling 1995a; Stirling and Lunn 1997; Stirling et al. 1999; Regehr et al. 2007). Predicted rising temperatures could increase the number of human–bear interactions because more bears may become nutritionally stressed while on-land for longer periods of time and, as a consequence, may travel into towns and camps in search of food (Stirling and Derocher 1993; Stirling and Parkinson 2006). In addition, the distribution of WH bears that spend the summer on-land in northeastern Manitoba has shifted northward over time and bears may not have to travel as far to reach human settlements (Towns 2006).

Previous studies of problem polar bears focused on management policies and the age- and sex-composition of bears that fed at the dump (Stirling et al. 1977; Kearney 1989; Lunn and Stirling 1985). The objectives of this paper are to describe (1) the temporal patterns in the number of problem bears in the Churchill area, (2) the age- and sex-composition of problem bears, and (3) the probability that a bear will become a problem based on its proximity to the Churchill area.

Because the study population is hunted, we also examine the number of problem bears harvested in Nunavut. Climatic indices can assist in explaining biological patterns. For example, encounter rates between black bears (*U. americanus*) and humans were correlated to the El Niño-Southern Oscillation (Zack et al. 2003). Therefore, we also explore the relationships between the number of problem bears at Churchill and environmental variables (i.e., sea ice break-up and formation, the North Atlantic Oscillation (NAO), and the Arctic Oscillation (AO)).

## Methods

The core study area (i.e., Churchill area), was approximately 460 km$^2$ encompassing the Churchill town site (ca. 1,000 people), rural areas, and the dump (Fig. 1). For some analyses, the study area (i.e., larger study area) was extended south to the Nelson River (57°00′N) and from the coastline inland to 94°10′W (Fig. 1). The region is located in the transition zone of the boreal forest and Arctic tundra (Ritchie 1960). The coastal area is flat and dominated by sedge-grass-herb meadow community and scrub willow (*Salix* spp). Inland areas are dominated by lichen tundra, riparian and lakeshore habitats, and patches of open spruce (*Picea glauca* and *P. mariana*), and tamarack (*Larix laricina*) (Ritchie 1960).

We defined a problem bear as any bear captured in the core study area as a result of being in the dump, in town, damaging property, and/or threatening life. Reporting of problem polar bears started in 1966 with Manitoba Conservation functioning as the primary management agency. A research program was responsible for many of the captures in the 1960s to early 1980s near Churchill with sampling expanding outside the core study area after 1976 (Stirling et al. 1999).

Location, age, sex, reproductive status, and morphometric measurements from bears caught each summer and autumn were collected from 1966 to 2004. Ages were determined by counts of cementum annuli from a premolar extracted at capture (Calvert and Ramsay 1998). Plastic numbered tags were placed in each ear and a tattoo was applied to each side of the upper lip for long-term identification. Capture effort, methods, and objectives varied over time but in the larger study area, polar bears were captured non-selectively using standard immobilization

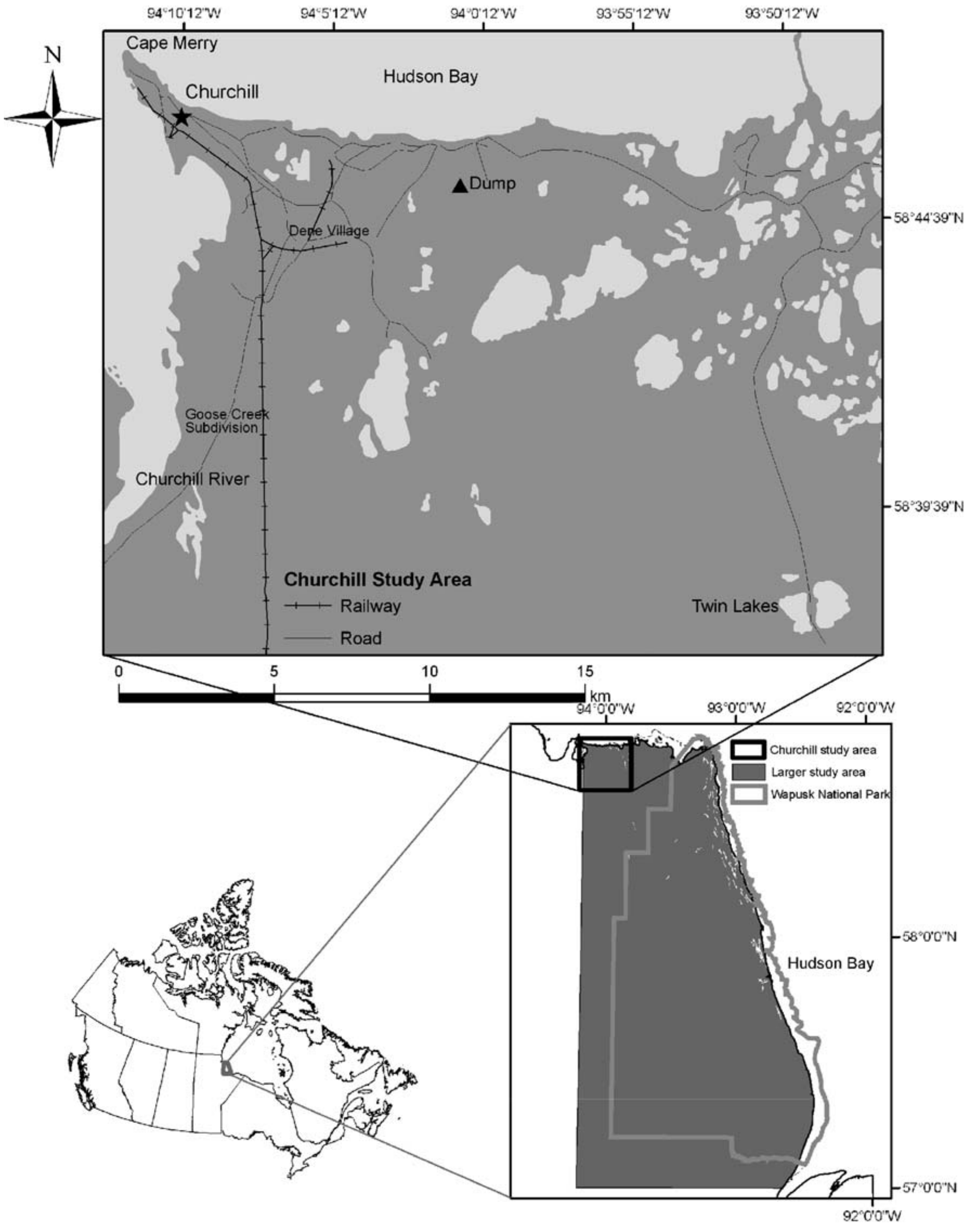


**Fig. 1** The core study area located near Churchill, Manitoba along the western coast of Hudson Bay in northeastern Manitoba and the larger study area south of Churchill. The core study area was not part of the larger study area

techniques mostly from a helicopter, between August and October (Stirling et al. 1989; Derocher and Stirling 1995b; 1990). In the core study area, other modes of capturing included Aldrich leg snares, culvert traps, and free-range immobilization from vehicles. 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.

We analysed information from the first capture each year of an individual in the core study area. Bears caught outside this area were excluded (unless otherwise stated). Only captures between July and December, when Hudson Bay is generally ice-free, were analysed. Pre-1970 data were incomplete and excluded from analyses (Stirling et al. 1977; Kearney 1989). Following Derocher and Stirling (1990), polar bears were categorised into five groups based on age-, sex-, and reproductive-class: adult males (≥5 years of age), solitary adult females (pregnant and non-pregnant ≥5 years of age), family groups (females with cubs-of-the-year or yearlings), subadult females (independent 1–4 years of age), and subadult males (independent 1–4 years of age).

To understand the probability that a bear would become a problem, we examined its distribution outside the core study area before it became a problem using distance from Churchill as the independent variable. We restricted analyses to the first year of capture, to maintain sample independence, when bears had captures in multiple years. We constrained this analysis from 1986 to 2004 when sampling effort was extensive in the larger study area (Derocher and Stirling 1995b). Using ArcMap 9.0 (Environmental Systems Research Institute, Inc., Redlands, CA), we measured the distance from the bear's position in the larger study area to the centre of the core study area. We used analysis of variance (ANOVA) to assess differences in distances travelled to the core study area by age-, sex-, and reproductive-group.

To determine if problem bears were randomly distributed across the larger study area we compared the overlap of its observed mean distance with the lower 90% confidence interval of the random mean distance. Generating random locations, we applied a Monte-Carlo integrated simulation across space using Mathematica 5.0 (Wolfram Research, Champaign, IL) drawing on 144 observations (10,000 replicates) from 1.4 million possible distances across the larger study area to the core study area. Bear locations from areas sampled infrequently were removed as outliers ($n = 7$) before generating random locations and analyses to assess spatial patterns. We used logistic regression to then describe how the probability of becoming a problem bear changed as a function of distance from the core study area. Analysis included locations of problem and non-problem bears from July to October, 1986–2004. Significance of coefficients between the full model (all variables included) and the reduced model (constant included) was examined with a likelihood ratio test (Hosmer and Lemeshow 1989). Model fit was accomplished with a goodness-of-fit test (Hosmer and Lemeshow 1989).

We determined the proportion of bears taken in the Nunavut harvest from 1970 to 2003 that were caught as problem individuals in Churchill earlier in the year. Bears included in analyses were harvested under the regular quota, sports hunt, special tag, and as problem individuals north of 60°N. The Nunavut harvest season runs from 1 July to 30 June. Analysis of the number of problem bears harvested was lagged by 1 year because kills could affect the number of problem bears in Churchill the following year.

Sea ice break-up was defined as the date when total ice coverage in Hudson Bay was 50% during spring melt. Freeze-up was defined as the date when total ice coverage in Hudson Bay was 50% during autumn (Etkin 1991). Break-up and freeze-up dates were based on 34 ice-sampling locations in western Hudson Bay from 1971 to 2003 following Gagnon and Gough (2005).

The NAO and the AO are modes of climate variability exhibiting high interannual and interdecadal variability (Hurrell 1995). The NAO index is the mean deviation from the average sea level pressure between Iceland and the Azores, whereas the AO index is the mean deviation from the average sea level pressure throughout the Northern Hemisphere, north of 20°N (Wallace 2000). Both indices are correlated with annual variation in local weather variables, such as temperature, precipitation, sea surface temperatures and wind anomalies (Etkin 1991; Hurrell 1995; Mysak et al. 1996). Data were explored for relationships between the number of problem bears and NAO and AO. Because there was no basis for *a priori* predictions on the best indices to use, we examined mean NAO indices and mean AO indices for eight periods based on sea ice conditions and bear behaviour. The winter indices included November–December, January–February, March–April, October–April, November–April, and January–April. The spring indices included April–June, and May–June. We used the mean NAO or AO value for each period. Monthly values of the NAO and the AO were also examined. Index values were obtained from the Climate Prediction Center (www.cpc.ncep.noaa.gov).

We used the number of problem bears harvested, sea ice break-up and formation and seasonal and monthly values of the NAO and the AO as independent variables to explore relationships with the number of problem bears in the core study area. We applied univariate analysis to assess the significance of each variable. We tested for collinearity between all significant variables before inclusion into a multiple forward stepwise regression. We examined data from 1971 to 2003 based on the dates available for sea ice break-up and freeze-up. Data from 1992 were considered as a potential outlier because the eruption of Mount Pinatubo in the Philippines resulted in break-up occurring about 3 weeks later than usual (Stirling et al. 1999). Other statistical analyses used data from 1970 to 2004 except for harvest data which we used from 1970 to 2003.

We used non-parametric tests where standard transformations did not normalise the data. The number of problem bears, ages, and distance measures were $\log_{10}$ transformed.

The number of bears killed as problem animals was normalised with a square root transformation. We used linear regression to assess temporal trends of the number of problem bears, the number of problem bears that returned to the Churchill area in subsequent years, and the mean age of problem bears. We used linear regression to assess temporal trends in the distances travelled to the core study area from the larger study area.

Tests were considered significant at $P \leq 0.05$. Statistics are presented as the median ± 1 SE unless otherwise stated. Statistical analyses were conducted using SPSS 13.0 (SPSS Inc., Chicago, IL).

## Results

From 1970 to 2004, there were 1,487 problem bear captures (977 different individuals) with subadult males comprising 39% (574), subadult females 23% (343), adult males 18% (272), females with young 14% (213), and solitary females 6% (85) of captures. For all bears, the mean date of capture was 23 October ± 0.7 days and ranged from 22 October–31 October (±1.0–2.3 days) for the various age-, sex-, and reproductive-groups. The five groups had their first captures between 3 July and 21 August ($\bar{x}$: 19 July ± 9.7 days) and last captures shortly before the bears returned to the sea ice from 28 November to 2 December ($\bar{x}$: 1 December ± 0.84 days).

There was an increase in the number of problem polar bears captured over time (linear regression: $F_{1,33} = 19.09$, $P \leq 0.001$, $R^2 = 0.37$, Fig. 2) across all five bear groups (Spearman-rank correlation: adult males: $r_s = 0.71$, $P \leq 0.001$, $n = 272$; solitary adult females: $r_s = 0.59$, $P \leq 0.001$, $n = 85$; family groups: $r_s = 0.36$, $P = 0.03$, $n = 213$; subadult females: $r_s = 0.43$, $P = 0.01$, $n = 343$; subadult males: $r_s = 0.59$, $P \leq 0.001$, $n = 574$). Of 977 individual problem bears, 72.6% (709) were captured once in the core study area whereas 27.4% (268) were captured more than once ($\bar{x} = 4 \pm 0.9$ times). The number of recaptured animals in the core study area increased over time (linear regression: $F_{1,32} = 20.88$, $P \leq 0.001$, $R^2 = 0.40$) whereas the number of problem bears killed decreased over time (linear regression: $F_{1,33} = 12.81$, $P = 0.001$, $R^2 = 0.28$).

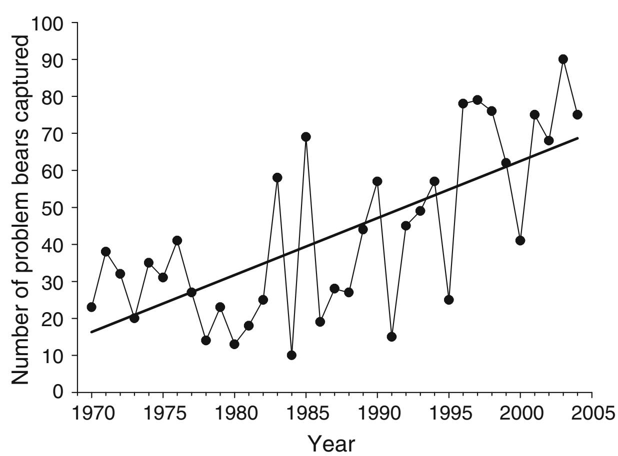


**Fig. 2** Number of problem polar bears captured in the core study area near Churchill, Manitoba from July to December over time, 1970–2004

**Table 1** Mann–Whitney *U* test of the differences in the median number of polar bears of the different age-, sex-, and reproductive-groups caught in the core study area near Churchill, Manitoba, 1970–2004

| | Adult males | Solitary adult females | Family groups | Subadult females |
|---|---|---|---|---|
| Solitary adult females | **263** | – | | |
| | **≤0.001** | | | |
| Family groups | 527.5 | **260** | – | |
| | 0.315 | **≤0.001** | | |
| Subadult females | 460 | **109.5** | **344.5** | – |
| | 0.072 | **≤0.001** | **0.002** | |
| Subadult males | **253.5** | **29** | **145** | **324.5** |
| | **≤0.001** | **≤0.001** | **≤0.001** | **0.001** |

Numbers in the cells represent U statistic and the corresponding *P* value. Bolded cells represent significant results

The median number of bears caught per year differed between the five groups (Kruskal–Wallis test: $X^2 = 75.04$, d$f = 4$, $P < 0.001$) (Table 1). Subadult males were captured the most (15 ± 1.4 bears/year) whereas solitary adult females were captured the least (2 ± 0.4 bears/year). Subadult females were the second largest group caught (8 ± 0.9 bears/year). A median of 6 ± 1.0 adult male bears and 4 ± 0.9 females with young were caught each year. The median number of adult males caught was greater than the median number of adult females (pooling solitary females and females with young, 3 ± 0.5 bears/year) (Kruskal–Wallis test: $X^2 = 8.82$, d$f = 1$, $P = 0.003$).

The mean age of adult females with young ($\bar{x}: 13.0 \pm 0.4$ years) increased over time (linear regression: $F_{1,201} = 15.82$, $P \leq 0.001$, $R^2 = 0.07$) but no trend was detected for solitary adult females ($\bar{x}: 12.7 \pm 0.9$ years) (linear regression: $F_{1,83} = 2.30$, $P = 0.13$) or adult males ($\bar{x}: 10.0 \pm 0.4$ years) (linear regression: $F_{1,270} = 0.09$, $P = 0.77$).

Of the 977 problem bears, 151 were caught in the larger study area earlier in the year (11 July to 28 October). Distance between the first capture in the larger study area and the core study area for bears of different age-, sex-, and reproductive-groups ranged from 19 to 270 km ($\bar{x} = 78 \pm 3.4$ km). Adult male bears, subadult males, family groups, subadult females, and solitary adult female bears moved from the larger study area to the core study area a mean distance of 95 ± 11.2 km ($n = 28$), 77 ± 4.8 km ($n = 62$), 75 ± 6.5 km ($n = 32$), 69 ± 6.6 km ($n = 24$), and 66 ± 12.5 km ($n = 5$), respectively. There was no difference in mean distance from the larger study area to the core study area between groups (one-way ANOVA: $F_{4,150} = 1.59$, $P = 0.18$) and no change was detected over time (linear regression: $F_{1,149} = 0.77$, $P = 0.38$). The overall mean distance moved from the larger study area to the core study area was 76 ± 3 km ($n = 144$, range: 23–180 km). Problem bears were not randomly distributed across the larger study area but were closer to the core study area. The mean distance was significantly less ($P < 0.001$) than the lower 90% confidence interval (106 km) of the mean random distance ($\bar{x} = 112$ km).

The probability of becoming a problem bear was related to a bear's distance (km) from the core study area at first capture (likelihood ratio [2(LL full model–LL reduced model)] = 20.88, d$f$ = 1, $P < 0.001$). The probability of becoming a problem bear increased with closer proximity to the core study area (logistic regression: $P \leq 0.001$). The goodness-of-fit test showed that the model fit well ($X^2 = 6.23$, d$f$ = 8, $P = 0.62$). The logistic regression provides an estimate for the probability of becoming a problem bear ($\pi(x)$) as a function of distance (km):

$$\pi(x) = \frac{\exp(-1.77 - 0.011 * x)}{1 + \exp(-1.77 - 0.011 * x)}$$

where $x$ is the distance from the core study area at first capture.

From 1970 to 2003, 926 bears were caught as problem bears in the core study area and subsequently released. Of these bears, 22.4% (209) were taken in the Nunavut harvest the same season ($\bar{x} = 3.0 \pm 0.6$ bears/year, $n = 101$, range = 0–10) or in later years ($\bar{x} = 3.2 \pm 0.5$ bears/year, $n = 108$, range = 0–10). Communities in Nunavut that harvested bears from the WH population killed 504 bears between 1970 and 2003 with 41.5% (209) having a history of human–bear interactions in Churchill. The number of problem bears harvested in the same year of handling did not explain the yearly variation in the number of the problem bears the following year (multiple regression: $F_{1,31} = 2.61$, $P = 0.12$, $R^2 = 0.08$).

The date of sea ice break-up ranged from 23 June to 3 August and the date freeze-up ranged from 6 November to 1 December. Inspection of the data suggested that 1992 was a possible outlier although reanalysing the data including this year did not alter results. Univariate analyses indicated that freeze-up dates (one-way ANOVA: $F_{1,28} = 5.43$, $P = 0.02$, $R^2 = 0.16$), break-up dates ($F_{1,30} = 4.36$, $P = 0.045$, $R^2 = 0.13$), and the November–December AO index ($F_{1,30} = 5.16$, $P = 0.03$, $R^2 = 0.15$) were correlated with the number of problem bears caught each year. These three variables were not correlated (Pearson correlation: $P > 0.17$). Placing the three significant variables into a forward stepwise regression resulted in freeze-up date being the only significant variable (multiple regression: $F_{1,28} = 5.43$, $P = 0.03$, $R^2 = 0.16$, Fig. 3).

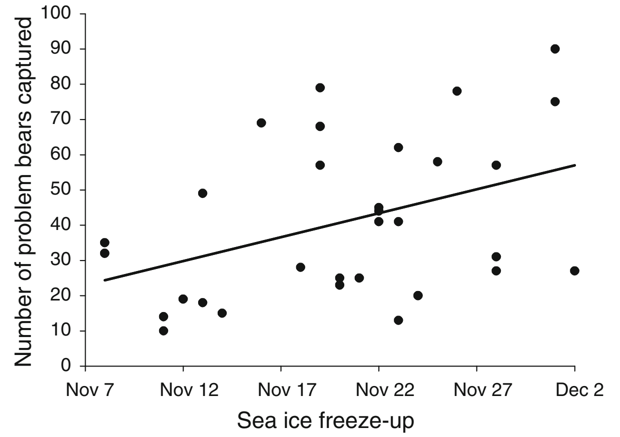


**Fig. 3** Number of problem polar bears captured in the core study area near Churchill, Manitoba relative to sea ice freeze-up, 1971–2003

## Discussion

There has been an increase in the number of problem bears in the core study area across all age-, sex-, and reproductive-groups over time. Since the last studies of problem bears in the 1980s (Lunn and Stirling 1985; Kearney 1989; Leonard 1989) significant changes have occurred in polar bear sea ice habitat, prey, and the WH population itself (Stirling et al. 2004; Gagnon and Gough 2005; Ferguson et al. 2005; Regehr et al. 2007; Laidre et al. 2008). We hypothesised that four factors, not necessarily mutually exclusive, could explain the patterns: (1) increase in the size of the WH population, (2) changes in the management program, (3) increased nutritional stress, and (4) shift in bear distribution.

After harvest controls were implemented in the mid-1960s (Stirling et al. 1977), the population appeared to recover and became relatively stable by the late 1980s (Lunn et al. 1997; Stirling et al. 2004). However, after the late 1980s, the population has declined by 22% with the greatest loss being adult males (Regehr et al. 2007). Therefore, the increase in problem polar bears cannot be explained by an increasing population. The increasing mean age of adult females with young, however, was contrary to what is predicted in a declining population (Bunnell and Tait 1981; Derocher 2005). Adult survival in the WH population was stable whereas subadult survival declined and was correlated to sea ice break-up date

(Regehr et al. 2007). Therefore, reduced recruitment of females into the problem bear population may have resulted in the increase in mean age of females.

Before 1985, the Polar Bear Alert Program policies reflected a control program; after 1985 the policies were revised and the program focused on preventing and mitigating human–bear interactions (Kearney 1989). Resource officers became more adept at capturing bears and the decline in the number of problem bears killed reflects this change. Therefore, management policy may be partially responsible for the increasing number of problem bears but we were unable to assess how much it contributed because catch per unit effort data were unavailable.

Increased nutritional stress of polar bears is a plausible explanation for the increased human–bear conflicts in Churchill. Since the early 1980s, the condition of adult bears and average weights of lone adult females in the fall have declined resulting in increased nutritional stress (Derocher and Stirling 1995a; Stirling and Lunn 1997; Stirling and Parkinson 2006). More frequent rates of human–bear interactions can result from individuals searching for alternate food sources (Rajpurohit and Krausman 2000; Gunther et al. 2004; Oka et al. 2004), especially when primary foods are limited or unavailable (McDonald and Fuller 2005). More problem adult males and their declining condition support nutritional stress during the on-land period as a factor. Similar to earlier findings (Kearney 1989) and other polar bear populations (Stenhouse et al. 1988; Lee and Taylor 1994), subadult male bears were the most common age- and sex-group to interact with people and become problems. Subadults have higher energetic demands (i.e., growth) and may be more prone to nutritional stress compared with other age- and sex-groups (Lunn and Stirling 1985; Mattson 1990) thereby increasing their chances of interacting with humans. The increasing number of bears returning to the Churchill area over time is consistent with increased nutritional stress.

Variation in weather is an important factor in human-wildlife conflicts. Sea ice, the primary habitat of polar bears (Stirling et al. 1993), varies seasonally and annually as a function of weather (Etkin 1991; Wang et al. 1994; Mysak et al. 1996). Significant changes in sea ice conditions can affect species dependent upon it (Stirling et al. 1999; Stirling and Smith 2004; Derocher et al. 2004; Laidre et al. 2008). In Hudson Bay, sea ice is breaking up progressively earlier and forming later due to warming temperatures (Skinner et al. 1998; Stirling et al. 1999; Gagnon and Gough 2005). A shorter sea ice season reduces the fat stores of bears and may increase nutritional stress during the on-land period. Earlier sea ice break-up was related to a decline in adult bear condition (Stirling et al. 1999) as well as a decline in survival of dependent young, juveniles, and older polar bears (Regehr et al. 2007). Date of break-up and the AO were related to the number of problem bears; however, the date of freeze-up was a better explanatory variable. In anticipation of sea ice formation along the northwestern coast of Hudson Bay, bears begin to travel north in late autumn and as the season progresses, more bears congregate along coastal areas (Latour 1981; Derocher and Stirling 1990). Given that increasing temperatures are predicted to continue resulting in earlier break-up and later freeze-up (Walsh 2008), human–bear interactions may be expected to increase. If freeze-up is delayed, the bears have more time to move into the area near Churchill and energy stores will continue to be depleted resulting in bears seeking food and increasing the probability of interacting with humans.

Another possible factor for the increase in the number of problem bears is the northward shift in distribution towards Churchill of WH polar bears that spend the summer on-land (Towns 2006). If warming temperatures continue and bears continue to move north, more human–bear interactions may result. Northward shifts in distribution relative to a changing climate have been predicted and documented in many other species (Thomas and Lennon 1999; Parmesan et al. 1999).

Most problem bears were only caught once which could suggest learned avoidance behaviour (Kearney 1989). Alternatively, the low number of recaptures could indicate the influence of the annual harvest in Nunavut, which has removed many bears that had been problem bears near Churchill. Annual harvest in Nunavut varies but averaged 46.8 bears/year in the 5 years up to 2005 (IUCN/SSC Polar Bear Specialist Group, 2006). Although the number of problem bears killed each year was relatively low compared to the annual harvest average, over time a large number of problem bears were taken in the Nunavut harvest and this affects the problem bear population near Churchill.

## Conclusion

The increase in problem bear numbers was correlated with delayed sea ice formation and the increase occurred during a period with changes in polar bear distribution and declining body condition. The increase in the number of problem bears in the WH polar bear population near Churchill, Manitoba occurred despite a population decline. If the open water period becomes progressively longer due to earlier sea ice break-up and later ice formation, we anticipate further changes in distribution, behaviour, and condition of the bears, leading to an increase in human–bear conflicts. In addition, changing polar bear harvest quotas may alter problem bear dynamics in Churchill. The determination of factors that affect human–bear interactions and being able to predict the magnitude of these interactions in a given year will aid effective management. The Polar Bear Alert Program procedures and policies should reflect the ongoing environmental changes that are occurring in the Hudson Bay ecosystem and the impacts on the WH population. Monitoring both human and environmental factors that contribute to human–bear interactions is important for the long-term conservation and management of the WH polar bear population.

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## References

Bogoyavlenskiy D (2004) Arctic demography. In: Einarsson N, Nymand Larsen J, Nilsson A, Young OR (eds) The human arctic development report. Stefansson Arctic Institute, Akureyri

Bunnell FL, Tait DEN (1981) Population dynamics of bears-implications. In: Fowler CW, Smith TD (eds) Dynamics of large mammals populations. John Wiley & Sons, New York, pp 75–98

Calvert W, Ramsay MA (1998) Evaluation of age determination of polar bears by counts of cementum growth layer groups. Ursus 10:449–453

Derocher AE (2005) Population ecology of polar bears at Svalbard, Norway. Pop Ecol 47:267–275

Derocher AE, Stirling I (1990) Distribution of polar bears (*Ursus maritimus*) during the ice-free period in western Hudson-Bay. Can J Zool 68:1395–1403

Derocher AE, Stirling I (1995a) Temporal variation in reproduction and body mass of polar bears in western Hudson Bay. Can J Zool 73:1657–1665

Derocher AE, Stirling I (1995b) Estimation of polar bear population size and survival in western Hudson Bay. J Wildl Manage 59:215–221

Derocher AE, Lunn NJ, Stirling I (2004) Polar bears in a changing climate. Integr Comp Biol 44:163–176

Etkin DA (1991) Break-up in Hudson Bay: its sensitivity to air temperatures and implications for climate warming. Climatol Bull 25:21–34

Ferguson S, Stirling I, McLoughlin P (2005) Climate change and ringed seal (*Phoca hispida*) recruitment in western Hudson Bay. Mar Mamm Sci 21:121–135

Gagnon AS, Gough WA (2005) Trends in the dates of ice freeze-up and break-up over Hudson Bay, Canada. Arctic 58:370–382

Gunther KA, Haroldson MA, Frey K, Cain SL, Copeland J, Schwartz CC (2004) Grizzly bear-human conflicts in the Greater Yellowstone Ecosystem, 1992–2000. Ursus 15:10–22

Hosmer DW, Lemeshow S (1989) Applied logistic regression. John Wiley & Sons, New York

Hovelsrud GK, McKenna M, Huntington HP (2008) Marine mammal harvests and other interactions with human. Ecol Appl 18(Suppl.):S135–S147

Hurrell JW (1995) Decadal trends in the North Atlantic Oscillation regional temperatures and precipitation. Science 169:676–679

IUCN/SSC Polar Bear Specialist Group (2006) Polar bears: proceedings of the 14th working meeting of the IUCN/SSC Polar Bear Specialist Group, 20–24 June 2005, Seattle. In: Aars J, Lunn NJ, Derocher AE (eds) Occasional Paper of the IUCN Species Survival Commission No. 32 Gland, Switzerland and Cambridge, UK

Kearney SR (1989) The Polar Bear Albert Program at Churchill, Manitoba. In: Bromley M (ed) Bear People Conflicts: proceedings of a symposium on management strategies. Northwest Territories Department of Renewable Resources, pp 83–92

Laidre KL, Stirling I, Lowry LF, Wiig Ø, Heide-Jorgensen MP, Ferguson SH (2008) Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. Ecol Appl 18(Suppl.):S97–S125

Latour PB (1981) Spatial relationships and behavior of polar bears (*Ursus maritimus* Phipps) concentrated on land during the ice-free season of Hudson Bay. Can J Zool 59:1763–1774

Lee J, Taylor M (1994) Aspects of the polar bear harvest in the Northwest Territories, Canada. Int Conf Bear Res Manage 9:237–243

Leonard RD (1989) Polar bear-human conflict on the National Historic Park and Sites in the Churchill area. In: Bromley M (ed) Bear-People Conflicts: proceedings of a symposium on management strategies. Northwest Territories Department of Renewable Resources, pp 75–81

Lunn NJ, Stirling I (1985) The significance of supplemental food to polar bears during the ice-free period of Hudson Bay. Can J Zool 63:2291–2297

Lunn NJ, Stirling I, Andriashek D, Kolenosky GB (1997) Re-estimating the size of the polar bear population in western Hudson Bay. Arctic 50:234–240

Mattson DJ (1990) Human impacts on bear habitat use. Int Conf Bear Res Manage 8:33–56

McDonald JE, Fuller TK (2005) Effects of spring acorn availability on black bear diet, milk composition, and cub survival. J Mamm 86:1022–1028

Mysak LA, Ingram RG, Wang J, Vanderbaaren A (1996) The anomalous sea-ice extent in Hudson Bay, Baffin Bay and the Labrador Sea during three simultaneous NAO and ENSO episodes. Atmos Ocean 34:313–343

Oka T, Miura S, Masaki T, Suzuki W, Osumi K, Saitoh S (2004) Relationship between changes in beechnut production and Asiatic black bears in northern Japan. J Wildl Manage 68:979–986

Parmesan C, Ryrholm N, Stefanescu C, Hill JK, Thomas CD, Descimon H, Huntley B, Kaila L, Kullberg J, Tammaru T, Tennent WJ, Thomas JA, Warren M (1999) Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399:579–583

Rajpurohit KS, Krausman PR (2000) Human-sloth-bear conflicts in Madhya Pradesh, India. Wildl Soc Bull 28:393–399

Regehr EV, Lunn NJ, Amstrup SC, Stirling I (2007) Population decline of polar bears in western Hudson Bay in relation to climate change. J Wildl Manage 71:2673–2683

Ritchie JC (1960) The vegetation of northern Manitoba V. Establishing the major zonation. Arctic 13:210–229

Skinner WR, Jefferies RL, Carleton TJ, Rockwell RF, Abraham KF (1998) Prediction of reproductive success and failure in lesser snow geese based on early season climatic variables. Glob Change Biol 4:3–16

Stenhouse GB, Lee LJ, Poole KG (1988) Some characteristics of polar bears killed during conflicts with humans in the Northwest Territories, 1976–86. Arctic 41:275–278

Stirling I, Derocher AE (1993) Possible impacts of climatic warming on polar bears. Arctic 46:240–245

Stirling I, Lunn NJ (1997) Environmental fluctuations in Arctic marine ecosystems as reflected by variability in reproduction of polar bears and ringed seals. In: Woodin SJ, Marqiuss M (eds) Ecology of arctic environments. Blackwell Science, Cambridge, pp 167–181

Stirling I, Parkinson CL (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 TG (2004) Implications of warm temperatures, and an unusual rain event for the survival of ringed seals on the coast of southeastern Baffin Island. Arctic 57:59–67

Stirling I, Jonkel C, Smith P, Robertson R, Cross D (1977) The ecology of the polar bear (*Ursus maritimus*) along the western coast of Hudson Bay. Canadian Wildlife Service Occasional Paper No. 33

Stirling I, Spencer C, Andriashek D (1989) Immobilization of polar bears (*Ursus maritimus*) with Telazol in the Canadian Arctic. J Wildl Dis 25:159–168

Stirling I, Andriashek D, Calvert W (1993) Habitat preferences of polar bears in the western Canadian Arctic in late winter and spring. Polar Rec 29:13–24

Stirling I, Lunn NJ, Iacozza J (1999) Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic 52:294–306

Stirling I, Lunn NJ, 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

Thomas CD, Lennon JJ (1999) Birds extend their ranges northwards. Nature 399:213

Towns L (2006) Spatial and temporal patterns of polar bear distribution (*Ursus maritimus*) in western Hudson Bay during the ice-free period. MSc Thesis, University of Alberta

Wallace JM (2000) North Atlantic Oscillation/annular mode: two paradigms—one phenonmenon. Quart J Royal Meteorol Soc 126:791–805

Walsh JE (2008) Climate of the Arctic marine environment. Ecol Appl 18(Suppl):S3–S22

Wang J, Mysak LA, Ingram RG (1994) A numerical simulation of sea ice cover in Hudson Bay. J Phys Oceanogr 24:2515–2533

Watts PD, Ratson PS (1989) Tour operator avoidance of deterrent use and harassment of polar bears. In: Bromley M (ed) Bear-People Conflicts: proceedings of a symposium on management strategies. Northwest Territories Department of Renewable Resources, pp 189–193

Zack CS, Milne BT, Dunn WC (2003) Southern oscillation index as an indicator of encounters between humans and black bears in New Mexico. Wildl Soc Bull 31:517–520