University of Alberta

Spatial and temporal patterns of polar bear distribution (*Ursus maritimus*) in western Hudson Bay during the ice-free period

by

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ABSTRACT

The western Hudson Bay polar bear (*Ursus maritimus*) population spends several months (July - November) on land when the sea ice melts. The on-land distribution of polar bears shifted north and east over 1986-2004 and the shifts were correlated with sea ice break-up, the North Atlantic Oscillation, and the Arctic Oscillation for some age- sex- and reproductive-classes. The number of problem bears has increased in Churchill, Manitoba over 1970-2004. Nutritional stressed bears and changes in distribution may account for the rise in problem bear numbers. Sea ice freeze-up explained some of the yearly variation in problem bear numbers. It is critical to identify environmental variables that affect polar bear behaviour and distribution and to understand how the population could respond to changing climatic conditions. Such information is essential for wildlife managers to implement effective management strategies to ensure human safety and the conservation of polar bears.

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Always remember, "Procrastination is for losers". ~ A. Derocher '04

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Chapter 1. INTRODUCTION

1.1. Background

Polar bears (*Ursus maritimus*) have a circumpolar distribution in 20 relatively discrete populations. Worldwide, the total number of polar bears is estimated at 21,500-25,000 (IUCN/SSC Polar Bear Specialists Group 2002). Distribution and movement of polar bears is a function of the seasonal distribution of sea ice (Schweinsburg et al. 1982; Ferguson et al. 2000; Ferguson et al. 2001; Mauritzen et al. 2003) and availability of their primary prey, such as ringed seals (*Phoca hispida*) and to a lesser extent bearded seals (*Erignathus barbatus*) (Stirling and McEwan 1975; Stirling and Archibald 1977; Smith 1980). Most populations remain on the sea ice year round (Amstrup et al. 1986; Amstrup et al. 2000) however, the western and southern Hudson Bay populations are forced to spend several months (early July-November) on-land because of the melting of the ice (Stirling et al. 1977; Derocher and Stirling 1990; Ramsay and Stirling 1990).

The western Hudson Bay polar bear population shows fidelity to a summer terrestrial habitat returning annually to the same general area (Harington 1968; Ramsay and Stirling 1990; Stirling et al. 2004). Once on land, the bears segregate. Adult male bears and subadults of both sexes remain near the coast and adult females with or without young move inland to the denning habitat (Stirling et al. 1977; Derocher and Stirling 1990; Lunn et al. 2004). The bears do not mate or feed during this on-land period (Lunn and Stirling 1985). To reduce energy use, the bears remain relatively inactive and subsist on the fat stores acquired while on the sea ice the previous spring (Latour 1981; Lunn and Stirling 1985; Derocher and Stirling 1990). With the exception of pregnant females, who remain on-land for another 4 months to give birth and rear young, polar bears travel to the northern coast, east of Churchill, Manitoba in late autumn before returning to the sea ice following freeze-up in mid-November (Derocher and Stirling 1990).

Sea ice is a variable habitat, changing as a function of temperature, wind, and currents (Etkin 1991; Wang et al. 1994; Mysak et al. 1996) and driven by large-scale climate phenomena (e.g., North Atlantic Oscillation, NAO) (Hurrell 1995; Mehta et al. 2000; Hurrell et al. 2003). Climate change, specifically warmer temperatures can influence sea ice conditions (Bjorgo et al. 1997; Parkinson 2000; Stirling et al. 2004). Recent studies have documented a decline in ice extent, the thinning of ice, and a shortening of the sea ice season (Maslanik et al. 1996; Parkinson et al. 1999; Tucker et al. 2001; Rigor and Wallace 2004; Gough et al. 2004). The temperature of Hudson Bay has been warming (Skinner et al. 1998) and as a result, sea ice break-up is occurring earlier and freeze-up is occurring later (Stirling et al. 1999, 2004; Gagnon and Gough 2005). The effects of changing climatic conditions on the western Hudson Bay polar bear population has been demonstrated in the decline of adult bear condition and reproductive rates (Derocher and Stirling 1995b; Stirling and Lunn 1997; Stirling et al. 1999) and in an overall decline of the population (Regehr et al. in press).

While several studies have examined distribution and movement of polar bears relative to sea ice conditions (Schweinsburg et al. 1982; Ferguson et al. 1999; Amstrup et al. 2000; Ferguson et al. 2001; Mauritzen et al. 2003), the on-land distribution of bears relative to changing environmental conditions has not been examined. Climate is a primary mechanism affecting distribution and limiting the geographic range of many species (Andrewartha and Birch 1982). As the climate warms species ranges are predicted to shift towards the poles in order to remain within areas to maintain appropriate metabolic temperature tolerance (Root et al. 2003). Northward shifts in distribution has been documented in many species already (Hersteinsson and Macdonald 1992; Thomas and Lennon 1999; Parmesan et al. 1999; Humphries et al. 2002; Valiela and Bowen 2003). Climate change is expected to result in a northward shift of polar bears due to increasing temperatures. However, demonstrating that this shift is occurring is confounded by changes in population structure caused by human hunting (Stirling et al. 1977; Derocher and Stirling 1995a; Derocher et al. 1997; Regehr et al. in press). Warming temperatures has also been predicted to affect the nutritional condition of polar bears and increase human-bear interactions in Churchill, Manitoba (Stirling and Derocher 1993; Derocher et al. 2004).

Churchill has a long history of human-bear interactions because bears are attracted to food sources in town and feed at the dump (Stirling et al. 1977; Lunn and Stirling 1985; Kearney 1989). Several studies have demonstrated the effects of weather on the interactions between humans and bears and often it is related to food availability and the nutritional state of the bear (Rutherglen and Herbison 1977; Garshelis 1989; Zack et al. 2003; Oka et al. 2004). The interaction of changing bear distribution and bears that are food stressed may have serious ramifications for human-bear interactions and subsequently for management policy.

The two objectives of this thesis are 1) to examine the long-term distribution patterns of polar bears in western Hudson Bay during the ice-free period in relation to environmental variables (i.e., sea ice break-up, NAO, Arctic Oscillation (AO)), and 2) to describe the spatial and temporal patterns in the number of problem bears, and determine if these changes could be related to environmental indices (i.e., sea ice break-up and freeze-up, NAO, AO). In the second chapter I describe the distribution of polar bears as a function of distance from the coast and a south baseline, representing the bear's east-west and north-south distribution. I examine distances relative to the bear's age- sex- and reproductive-class and determine if their distribution has shifted over 19 years (1986-2004). To establish if weather variability could be attributed to the bear's distributional shift, I use sea ice break-up dates and seasonal and monthly indices of the NAO and the Arctic Oscillation (AO), representing both local- and large- scale climatic variation. For chapter three I focus on a segment of the western Hudson Bay population that are problem bears in Churchill. I describe the temporal patterns in the number of problem bears from 1970-2004 relative to changes in environmental variables using sea ice freeze-up and break-up dates and seasonal and monthly indices of the NAO and AO. I examine the age- and sex-composition of problem bears and the bears that have previous capture history in Churchill to determine if there has been a change in the number and type of bears captured over time. I describe how problem bears are spatially distributed before they are captured in the Churchill area and provide an estimate of the probability of becoming a problem bear based on a function of distance. In the fourth chapter, I synthesize the key thesis findings, provide future research goals to better understand the effects of climate change on polar bear population dynamics, and lastly discuss some management implications that may help in the conservation of the western Hudson Bay polar bear population.

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Chapter 2. DISTRIBUTION OF POLAR BEARS IN WESTERN HUDSON BAY DURING THE ICE-FREE PERIOD RELATIVE TO ENVIRONMENTAL VARIABLES

2.1. Introduction

Understanding the distribution of organisms and the factors that influence where individuals occur are fundamental components of ecology. Distribution is influenced by many factors, including resource distribution (Wilmshurst et al. 1999; Macleod et al. 2004), habitat selection (Wecker 1963; Heady and Laundre 2005; Jedrzejewski et al. 2005), predation risk (Johnson et al. 2002; Anderson et al. 2005), inter- and intraspecific interactions (Caughley et al. 1980; Schoener 1983), dispersal (Moran and Palmer 1963), and philopatry (Aycrigg and Porter 1997; Randall et al. 2005). Within a population, male and females may distribute themselves differentially due to differences in habitat preference except during the mating season (Bowyer 1984; Clutton-Brock et al. 1987; Hill and Ridley 1987; Smultea 1994). Behaviour of individuals may also be a limiting factor in the distribution of species, particularly in resource selection, inter- and intraspecific interactions, and dispersal (Krebs 1994). Climate is a primary mechanism affecting distribution and an important limiting factor in the geographic range of many species (Andrewartha and Birch 1982). Range shifts are often a result of changes in temperature affecting prey availability, habitat quality, and migration patterns (Stirling and Derocher 1993; Tynan and Demaster 1997; Gardner and Chavez-Rosales 2000; Harwood 2001).

Global warming is occurring at an accelerated rate and is predicted to be amplified at high-latitude environments (Manabe et al. 1992; IPCC 1996; Rigor et al. 2000; Comiso 2003). Polar environments have undergone significant physical and biological shifts attributed to climate warming (Morison et al. 2000; Wigley and Raper 2001; Parmesan and Yohe 2003; Root et al. 2003). With rising temperatures it is expected that species' ranges will shift towards the poles or higher in elevation to remain within their metabolic temperature tolerance (Root et al. 2003). More than 80% of the species that show range shifts have shifted in the expected direction (Payette 1987; Hersteinsson and Macdonald 1992; Thomas and Lennon 1999; Parmesan et al. 1999; Humphries et al. 2002; Root et al. 2003).

The sea ice is a particularly sensitive habitat in the Arctic and recent reports indicate increasing temperatures have caused sea ice extent and thickness to decline as well as shortening the sea ice season (Maslanik et al. 1996; Bjorgo et al. 1997; Parkinson et al. 1999; Tucker et al. 2001; Parkinson 2000; Rigor and Wallace 2004; Gough et al. 2004). The effects of climate warming on Arctic species are poorly understood. Sea ice changes seasonally and annually as a function of temperature, wind, and currents (Etkin 1991; Wang et al. 1994; Mysak et al. 1996). Thus, changes in average sea ice conditions are likely to affect species who depend on the ice for migration, breeding, and foraging (Stirling and Derocher 1993; Tynan and DeMaster 1997; Stirling et al. 1999; Stirling and Smith 2004; Derocher et al. 2004; Gilchrist and Mallory 2005; Laidre and Heide-Jorgensen 2005). Polar bears (*Ursus maritimus*) are one such species dependent on the sea ice, using it as a platform to hunt, mate, and migrate (Smith and Stirling 1975; Stirling 1997; Ferguson et al. 2001a). Bears exhibit numerous strategies to help them cope with living in such a dynamic environment (Watts and Hansen 1987; Stirling and McEwan 1975). For example, some populations remain on the sea ice and migrate with the ice from season to season (Amstrup et al. 1986; Amstrup et al. 2000) while other populations are forced onto land for several months due to the complete melting of the sea ice (Schweinsburg et al. 1982; Stirling et al. 1980; Ramsay and Stirling 1988). Polar bears are able to switch facultatively between a state of feeding to a state of fasting which may be an adaptation to dynamic sea ice conditions and unpredictable periods of food abundance (Watts and Hansen 1987; Derocher et al. 1990; Ramsay et al. 1991).

There are 20 polar bear populations distributed circumpolarly. Each population exhibit different movement strategies and habitat requirements based on sea ice dynamics and prey availability (Stirling and McEwan 1975; Stirling et al. 1980; Martin and Jonkel 1983; Ramsay and Stirling 1988; Ferguson et al. 2000a); however each population displays some degree of philopatry (Larsen 1985; Ferguson et al. 1997; Mauritzen et al. 2001). The polar bears of western Hudson Bay are a population that has well documented fidelity, moving from the sea ice to a terrestrial summer habitat due to complete melting of their primary habitat (Stirling et al. 1977; Ramsay and Stirling 1990; Derocher and Stirling 1990a; Stirling et al. 2004). The annual pattern of ice break-up and freeze-up is driven by a northwesterly gyre, causing ice to disintegrate and re-form in a north-south, east-west direction (Wang et al. 1994). Break-up occurs in late June to early July and the north-west coast of Hudson Bay is one of the first areas to become ice free. Northwest winds push the melting ice southward until the remaining ice builds up along the Ontario coast in late July (Wang et al. 1994). The ice begins to re-form in the north in late October – mid November with maximum ice extent and thickness occurring in April (Markham 1986; Saucier and Dionne 1998; Wang et al. 1994).

The melting of the sea ice forces the bears ashore mid to late summer and once on land they segregate by age- sex- and reproductive status (Derocher and Stirling 1990a).

Pregnant females and females with young travel inland to the denning area while adult males and subadults, both male and female, remain near the coast (Latour 1981; Derocher and Stirling 1990b). A possible explanation for this segregation is avoidance of adult males by pregnant females and females with young (Taylor et al. 1985; Derocher and Stirling 1990a). Other possible reasons for segregation in polar bears include fidelity to preferred denning habitat (Derocher and Stirling 1990a; Richardson et al. 2005), conserving energy for adult males, and philopatry to inland areas to familiarize female cubs to the areas of suitable denning habitat (Derocher and Stirling 1990a). During this on-land period the bears do not feed and remain relatively inactive to conserve energy (Knudsen 1978; Lunn and Stirling 1985), relying solely on their fat stores, which they acquired while on the sea ice hunting seals (Derocher and Stirling 1990b).

Over the last 3 decades numerous changes have occurred in both the Hudson Bay environment (Etkin 1991; Skinner et al. 1998; Stirling et al. 1999, 2004; Gough et al. 2004; Gagnon and Gough 2005) and in the western Hudson Bay polar bear population (Derocher and Stirling 1995b; Stirling and Lunn 1997; Stirling et al. 1999). Stirling et al. (2004) reported that break-up was occurring 3 weeks earlier compared to 30 years ago. The ultimate cause appeared to be warming temperatures in Hudson Bay (Skinner et al. 1998). Stirling and Derocher (1993) predicted that because of warming temperatures, and the pattern of earlier break-up over time, which results in less time hunting, could result in reduced reproduction rates, cub survival, subadult survival, and body mass. Some of these predictions are becoming evident in the western Hudson Bay bears. Throughout the late 1980s and 1990s, natality showed a significant long-term decline (Stirling and Lunn 1997). The condition of adult bears has also declined and was linked to earlier ice break-up (i.e., poor condition with earlier break-up) (Derocher et al. 1995b; Stirling et al. 1999). A recent study has showed that the population is in decline and may be related to climate change (Regehr et al. in press).

Ecologists have historically focused on local weather patterns (e.g., temperature, precipitation, wind) and its influence on demography and population dynamics. However, there has been growing interest in understanding large-scale climatic variability, such as the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) and their role in regulating population dynamics of animals in marine and terrestrial ecosystems (Ottersen et al. 2001; Mysterud et al. 2001; Post and Forchhammer 2002; Walther et al. 2002). The NAO and the AO are modes of atmospheric behaviour. Although the NAO and AO have overlapping patterns, and consequently are highly correlated over time (Thompson and Wallace 1998), they are viewed as separate paradigms to understand the underlying mechanisms causing their fluctuations (Wallace 2000). The NAO represents regionally based climate variability whereas the AO encompasses the whole Northern Hemisphere (Thompson and Wallace 1998; Shindell et al. 1999). The large-scale climate phenomena could help in the explanation of biological responses because they account for a large proportion of annual variation in local temperatures and precipitation patterns (Hurrell 1995; Mehta et al. 2000; Hurrell et al. 2003), sea surface temperatures, wind anomalies, salinity, and runoff (Etkin 1991; Mysak et al. 1996; Saucier and Dionne 1998).

The NAO and AO indices are a major component of global climate change (Hurrell 1995). Atmospheric-ocean coupled general circulation models have demonstrated that changes in large-scale climate indices are related with climate change through natural variability and anthropogenic forcing (Knutson and Manabe 1998; Livezey and Smith 1999; McHugh and Rogers 2005; Shiogama et al. 2005). Enhanced greenhouse gas conditions were shown to strengthen and intensify the NAO and AO (Rauthe et al. 2004; Kuzmina et al. 2005). McHugh and Rogers (2005) suggests the NAO may be an important factor in the warming of the Northern Hemisphere based on a comparison of trends of the NAO index in the late 21st century with those of the late 20th century.

Stenseth et al. (2003) outlines several reasons why using large-scale indices are more advantageous than using just a local-scale index. The reasons include: 1) stronger relations between biological effects and global indices may be evident compared to a single local climate variable, 2) problems with model selection are avoided, 3) allows for predictive measures, and 4) access to indices are readily available on the Internet (Stenseth et al. 2003).

To understand the effects of climate on population dynamics it is important to link climate with local weather variables, and to link both climate and weather with ecological patterns (Stenseth et al. 2003). Several studies examining population dynamics of various species have related long-term changes to large-scale climate phenomena (Forchhammer et al. 1998; Post and Stenseth 1998; Post et al. 1999; Wang et al. 2002; Ferguson et al. 2005; Hebblewhite 2005) but little is known of its effects on large carnivores. A recent study by Derocher (2005) found the reproductive rates and variation in body mass of adult male and female polar bears in Svalbard, Norway were related to the AO index. The effects, if any, of the NAO and AO indices on the on-land distribution of bears in western Hudson Bay are unclear but may be related to the conditions on the sea ice (e.g., temperature, precipitation, snow depth, etc), and/or the sea ice dynamics. Wang et al. (1994), Mysak et al. (1996), and Stern and Heide-Jorgensen (2003) found the Hudson Bay sea ice conditions and extent were related to the winter NAO index.

There are few studies that examine long-term trends in distribution of large mammals and even fewer on carnivores. The studies that do exist focus on the effects of human activity through habitat modification (e.g., agriculture, industrial activity), climate change, and population dynamics (Smith et al. 2000; Riley and Malecki 2001; Clark et al. 2002; Schwartz et al. 2002; Hidalgo-Mihart et al. 2004; Lariviere 2004; Noel et al. 2004; Darimont et al. 2005). The polar bears of western Hudson Bay are the most studied polar bear population in the world and provide a unique opportunity to examine the temporal dynamics of distribution. An earlier study of the distribution of the western Hudson Bay bears excluded temporal analyses and only used data up to 1987 (Derocher and Stirling 1990a). The first objective of this study was to examine the temporal dynamics of polar bear distribution during the ice-free period and determine if the distribution has changed. Although, physical and reproductive parameters have been related to local scale indices, such as sea ice break-up (Stirling et al. 1999), there are no studies on how distribution may be affected by local- and large-scale climate. The second objective was to examine and relate changes in distribution with environmental variables where sea ice break-up represented a local weather index and the NAO and AO represented large-scale climate indices.

2.2.1. Study area

The study area is approximately 20,000 km^2 and lies within the western coast of Churchill, Manitoba (58°49'N), south to the Nelson River (57°00'N) and inland to 94°10'W (Figure 2-1). The area is part of the Hudson Bay Lowlands and has low elevation relief. Wapusk National Park and the Cape Churchill Wildlife Management Area comprise the bulk of the area which lies in the transition zone of the boreal forest and Arctic tundra and has extensive peatland coverage (Ritchie 1960). The coastal habitat is flat and dominated primarily by sedge-grass-herb meadow community and scrub willow (*Salix* spp). In contrast, the inland area is dominated by lichen tundra habitat, riparian and lakeshore habitats, and patches of open spruce (*Picea glauca* and *P. mariana*) and tamarack (*Larix laricina*) surrounding riparian habitats (Ritchie 1960).

2.2.2. Data collection

Data was collected on location and demographic information as well as morphometric measurements from bears captured each summer, and autumn from 1966-2004. Ages were determined by cementum annulation counts through the extraction of a premolar (Calvert and Ramsay 1998). A tag was placed in each ear and a tattoo was applied to the upper lip for long term identification. Live capture techniques were used, however capture effort, methods, and objectives varied over the study. Polar bears were captured non-selectively using immobilization techniques (Stirling et al. 1989) mostly from a helicopter, between August and October (Derocher and Stirling 1990a). Other modes of capturing study bears were Aldrich leg snares, culvert traps, and motor vehicles although these were restricted to areas in the north near the town of Churchill, Manitoba.

modes of capturing study bears were Aldrich leg snares, culvert traps, and motor vehicles although these were restricted to areas in the north near the town of Churchill, Manitoba.

2.2.3. Database

The database contained over 10,000 capture records spanning 1966-2004. I standardized the database to reduce autocorrelation, and capture bias by using only the first capture location per bear per year, removing capture locations that were outside the study area and those that were influenced by humans (Figure 3-1). As a high proportion of the western Hudson Bay population are marked and to address long-term trends, recapture locations were used in subsequent years after the initial capture (i.e., one recapture location per individual per year). To reduce the effects of seasonal movement on my estimate of polar bear location during the ice-free period, I included only those locations from 23 August to 7 October. Temporal restriction of the sampling period was necessarily restricted to this 7-week period because bears are within their preferred habitat and remain relatively inactive during this period (Derocher and Stirling 1990a; Clark and Stirling 1998). I excluded records before 1986 as capture effort and the distribution of sampling effort was biased to northern areas. After 1986 capture effort was intensified and covered the whole study area (Derocher and Stirling 1995a). Following Derocher and Stirling (1990a), I categorized polar bears into 5 different 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).

2.2.4. Distribution metrics

The coastline is a natural geographical feature that provided a reference for quantification of polar bear distribution in the east and west direction. The distributional shift was measured by changes in the distances from the coast (i.e., closer to the coast = eastward shift; further inland = westward shift). An arbitrary baseline at the southern edge of the study area (57°00'N) was used to reference the north-south distribution of polar bears (i.e., closer to the baseline = southward shift; further from the baseline = northward shift). Distance calculations (kilometres) were conducted in ArcGIS 9.0 that calculated the shortest distance from the coast or southern baseline to each bear location.

2.2.5. Environmental variables

Sea ice break-up was defined following Etkin (1991) as the date by which total ice coverage was equal to 50% during spring melt. I used dates of sea ice break-up for western Hudson Bay during 1986-2004 from Stirling et al. (1999) which were provided by J. Iacozza (University of Manitoba). Weekly regional ice charts for Hudson Bay produced by the Canadian Ice Service were analyzed to estimate the timing of break-up (http://ice-glaces.ec.gc.ca/). Dates of break-up were estimated from mid-June (start of break-up) to mid-August (ice-free). A sampling grid with points at intervals at 0.5° latitudes and longitude was overlain on the weekly ice concentration maps. An average of individual ice concentration values was obtained and the values for the 10-week period were then plotted and the date at which ice concentration was 50% was the break-up date (see Stirling et al. 1999 for details).

The NAO and the AO are modes of climate variability. The NAO index is measured as a mean deviation from the average sea level pressure between Iceland and 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 exhibit high interannual and interdecadal variability (Hurrell 1995). Data was explored for relationships to assess the role of a changing climate on the distribution of the polar bears. As there was no basis for making *a priori* predictions on the best index to use, I created 8 mean seasonal NAO indices and 8 mean AO indices based on sea ice conditions and bear behaviour from 1986-2004. The various winter indices included November-December (early winter index), January-February (mid-winter index), March-April (late winter index), October-April, November-April, and January-April. The spring indices included April-June, and May-June. Stern and Heide-Jorgensen (2003) found a strong correlation between ice concentration and the previous year's NAO_{t-1} winter index. Therefore, I included the previous year's NAO (NAO_{t-1}) and AO (AO_{t-1}) index as possible correlates with sea ice break-up and bear distribution. I also examined monthly values of the NAO and the AO. Index values were obtained from the Climate Prediction Centre (www.cpc.ncep.noaa.gov).

2.2.6. Statistics

Distance measures for all bear locations in each polar bear class were tested for normality and homogeneity of variances using the Kolmogorov-Smirnov and the Levenee's tests. Non-parametric tests, Kruskal-Wallis and Mann-Whitney were used for comparisons due to the data being highly skewed and the inability to normalize the data with standard transformations. Spearman rank-order correlation was used to determine relationships between 1) polar bear distribution (i.e., distance from the coast and baseline) and year, 2) distribution and sea ice break-up, and 3) distribution and the seasonal and monthly NAO and AO indices. Only the strongest correlations between bear distribution and the seasonal and monthly NAO and AO indices were reported. All analyses were done using individual bear locations as the primary sampling unit. Scatterplots of results are shown as the median distance of all bear locations from the coast and from the south baseline (km) relative to a particular year and environmental variable. Potential outliers were removed after initial analysis and re-analysed to make certain results were not influenced by the outliers (e.g., adult male distance from the coast in 1989 was removed; however results did not change). Although the data was not normally distributed I used a linear regression to get a sense of how much the distribution has changed for the different polar bear age- sex- and reproductive-classes using the 1986 locations relative to 2004 locations. Sea ice break-up and the NAO and AO indices were normally distributed thus parametric tests were used. Pearson product-moment correlation was used to identify possible relationships between sea ice break-up and year. Seasonal NAO indices, AO indices and monthly values were used in a forward stepwise regression to assess a relationship with sea ice break-up. Variables were retained in the model if significant at $P \leq 0.05$. A one-tailed Fisher's exact test was run on the proportion of family groups within 0-5 km of the coast from 1986-2001 and 2002-2004 to confirm field observations that more females with young were located near the coast since 2002 compared to earlier years (pers. comm. I. Stirling and N.J. Lunn.).

All tests were considered significant at a $P \leq 0.05$ except when a Bonferroni adjustment was used for the analysis of segregation where pair-wise comparisons were considered significant if the Mann-Whitney U test gave a $P \leq 0.005$. Medians ± 1 SE are presented unless otherwise stated. Statistical analyses were conducted using SPSS 13.0 software (SPSS Inc., Chicago, IL).

2.3. Results

Over the study, 23 August to 7 October 1986-2004, there were 2304 capture locations (1213 bears) (adult males, n = 771; family groups, n = 580; solitary adult females, n = 458; subadult females, n = 262; subadult males, n = 233). Recaptures represented 77% of the sample (1765/2304) (Table 2-1).

2.3.1. Distance from the coast

Bears were located between 0-82 km (median: 23 km) from the coast (Table 2-2). Bears have moved closer to the coast over time. Adult males, solitary adult females, family groups, and subadult males distances were closer to the coast over time (Spearman-rank correlations: $r_s = -0.26$, n = 771, $P < 0.001$; $r_s = -0.17$, n = 458, $P < 0.001$; $r_s = -0.13$, n = 580, $P = 0.001$; $r_s = -0.16$, n = 233, $P = 0.014$; Figure 2-2 and 2-4) but subadult females did not show a trend ($r_s = 0.05$, n = 262, $P = 0.455$). In 2002-2004, more family groups (27/77) were ≤ 5 km from the coast compared to 1986-2001 (50/451) (one-tailed, Fisher's exact test: $P < 0.0001$). Adult males, solitary adult females, family groups, and subadult males have shifted eastward 13 km, 14 km, 10 km, and 7 km, respectively, from their location in 1986 relative to their 2004 location.

2.3.2. Distance from the southern baseline

Bear locations ranged 10-200 km (median: 119 km) from the baseline (Table 2-2). In general, bears have moved further north over time. A significant northward shift over time was found in adult males and family groups ($r_s = 0.10$, $n = 771$, $P = 0.006$; $r_s = 0.11$, $n = 580$, $P = 0.007$, Figure 2-5 and 2-6). Solitary adult females and subadult females were not statistically significant ($P = 0.061$ and $P = 0.058$; Figures 2-6 and 2-7). No temporal trend was noted for subadult males ($r_s = 0.10$, $n = 233$, $P = 0.12$). Adult males, solitary adult females, family groups, and subadult females shifted northward 18 km, 20 km, 16 km, and 15 km, respectively, from 1986 to 2004.

2.3.3. Segregation

Overall, polar bear groups were segregated from one another in the east-west (Mann-Whitney *U* test: $P \leq 0.001$) and north-south direction ($P \leq 0.019$) with one exception. The north-south distances of adult males were not different from subadult males and subadult females (Table 2-3).

2.3.4. Environmental variables

The date of sea ice break-up in western Hudson Bay varied from 2 June to 23 July (Appendix A). There was no trend for sea ice break-up to occur earlier during the 19-year period (Pearson product-moment correlation: $r = -0.27$, $n = 19$, $P = 0.265$). Using a forward stepwise regression, the timing of sea ice break-up was negatively related to the February AO index ($F_{1,17} = 0.02$, $P = 0.008$, $R^2 = 0.35$).

Distance from the coast was positively correlated with break-up date for adult males, solitary adult females, subadult females, and subadult males ($r_s = 0.16$, n = 771, $P < 0.001$; $r_s = 0.22$, n = 458, $P < 0.001$; $r_s = 0.13$, n = 262, $P = 0.034$; $r_s = 0.18$, n = 233, $P = 0.007$; Figure 2-8 to 2-10). The distances from the southern baseline of each polar bear age- sex- and reproductive-class showed no trend with break-up (adult males: $r_s = -0.03$, n = 771, $P = 0.38$; solitary adult females: $r_s = -0.03$, n = 458, $P = 0.51$; family groups: $r_s = -0.02$, n = 262, $P = 0.69$, subadult females: $r_s = -0.07$, n = 233, $P = 0.24$; subadult males: $r_s = 0.03$, n = 233, $P = 0.62$).

The exploration of linkages between the distribution of polar bears and the seasonal indices of the NAO and the AO as well as the monthly index values produced tenuous and inconsistent results thus caution is warranted with interpretation of results. The coastal median distances of all bears were positively correlated with the November-April NAO index ($r_s = 0.54$, n = 19, $P = 0.02$, Figure 2-11) while the bears median southern baseline distances were negatively correlated with the November AO index ($r_s = -0.58$, n = 19, $P = 0.009$, Figure 2-12).

A positive correlation was found with the coastal distribution of adult males and the NAO winter index, November-April ($r_s = 0.49$, n = 19, $P = 0.03$) but no correlation was detected for adult males southern baseline distribution with any other seasonal or monthly index. Solitary adult female coastal distribution was positively correlated with the NAO winter index, October-April ($r_s = 0.58$, n = 19, $P = 0.008$) but no correlation was detected for their southern baseline distribution with any seasonal or monthly index. While no link was found between family groups coastal distribution and any seasonal or monthly NAO or AO indices, there was a negative correlation with their baseline distribution and the March AO index ($r_s = -0.46$, n = 19, $P = 0.047$). No correlation was detected for the coastal distribution of subadult females with any seasonal or monthly index but their baseline distribution was positively related to the AO spring index, April-June ($r_s = 0.62$, n = 19, $P = 0.004$). A positive correlation was found between the coastal distribution of subadult males and the AO winter index, October-April ($r_s = 0.75$, n = 19, $P \leq 0.001$) while their baseline distribution was negatively correlated with the NAO early winter index, January-February ($r_s = -0.57$, n = 19, $P = 0.012$)

2.4. Discussion

The polar bears of the western Hudson Bay population exhibited significant shifts in distribution over 19 years (1986-2004). Although not all age- and sex-classes showed this pattern a consistent trend of an eastward and northward shift was evident in adult bears. A local-scale environmental variable (i.e., sea ice break-up) was found to be correlated with the bear's distributional shifts and through exploratory analysis linkages with large-scale climate variables (i.e., NAO and AO) were also detected.

The western Hudson Bay population and their environment have been changing significantly over the last several decades (Skinner et al. 1998; Parkinson 1999; Stirling et al. 1999, 2004; Regehr et al. in press) and based on these findings I proposed two explanations for the distributional shifts. Climate change is one possible reason that I actually analysed; however the second reason of a change in population structure was not analysed but needs to be addressed. These hypotheses are not mutually exclusive and could occur simultaneously thus making it difficult to determine the leading factor in the distributional shift.

could occur simultaneously thus making it difficult to determine the leading factor in the distributional shift.

2.4.2. Climate change

Shifts in polar bear distribution in the western Hudson Bay population were linked to environmental variables, local- and large-scale, representing sea ice break-up, the NAO and the AO. The distributional shift is not large relative to the great distances over which a polar bear moves (Amstrup et al. 2000; Wiig et al. 2003). However, polar bears were described as being energetically inefficient in walking which requires significant use of energy (Hurst et al. 1982; Watts et al. 1991). While sea ice break-up was related to the coastal distribution of all age- sex- and reproductive-classes of polar bears with the exception of family groups, break-up was not related to bear's northward shift. As a result of earlier ice break-up bears were coming ashore in poorer condition (Stirling et al. 1999) and were not traveling as far inland possibly to conserve already depleted fat stores suggesting condition was a limiting factor and the distributional shifts in the population were consistent with energy conservation. Facultative use of shelter dens is another way that bears conserve energy and reduce thermal stress (Jonkel et al. 1972; Schweinsburg 1979; Derocher and Stirling 1990a). The use of shelter dens is associated with sea ice conditions and when food is inaccessible (Ferguson et al. 2000b, 2001a). The western Hudson Bay bears use shelter dens during the on-land period when food is largely unavailable to help reduce energy expenditure (Derocher and Stirling 1990a). Bears need to accumulate sufficient fat reserves while on the sea ice to sustain them through the ice-free period. Stirling et al. (1999) demonstrated if the ice season is

(2005) demonstrated a progressively earlier break-up over a longer period. My study represented a shorter window of time in the long-term trend when the break-up dates were already in a declining phase.

Despite the distributional shifts, fidelity appeared to remain strong for adult males to the coastal areas and the denning area for solitary adult females. Although solitary adult females may not have shown a statistically significant northward shift over time it may prove biologically significant. This finding was similar to the northward shift in den site distribution found by Ramsay and Stirling (1990) in the 1980s compared to the 1970s. Ramsay and Stirling (1990) speculated the shift was related to changes in sea ice condition and I found the northward shift of all bear locations was correlated with the NAO and AO indices.

Philopatry appeared to be important in family groups (i.e., familiarize young to the denning area, Derocher and Stirling 1990a) but the temporal shift suggest the bears exhibit a degree of behavioural plasticity (i.e., return to general area but with some flexibility). Even though sea ice break-up was not related to the distributional shift of family groups, I suspect that break-up indirectly affects family groups' on-land distribution through effects on body condition. Milk is energetically costly to produce (Lunn and Stirling 1985; Ferguson et al. 1997) and the declining condition of females with young may influence the energy females opt to allocate to moving inland. The increase in the proportion of females with young near the coast in recent years was further evidence that large scale shifts in the behaviour of bears has occurred. Two possible explanations for this shift that are not mutually exclusive are the decline in the adult male population (Regehr et al. in press). By moving inland, female bears with young reduce the threat of predation by adult males on their young; however, the decline in adult male numbers along the coast has opened up coastal habitat and thus the risk of predation is reduced. The second reason is related to energy conservation whereby the energetic costs outweighs the benefits of making the trek inland to teach their young the denning area location (Derocher and Stirling 1990a). By remaining near the coast after coming ashore females with young focus their energy into successfully rearing and weaning their young.

The distribution of subadults of both sexes relative to the coast was correlated with sea ice break-up and may reflect their high energetic demands (i.e., growth). Subadults are typically displaced at kill sites by adult males (Lunn and Stirling 1985) suggesting at the time of break-up they may not have sufficient fat reserves and thus would attempt to conserve as much energy as possible. There are a limited number of studies that have examined subadults in western Hudson Bay (Latour 1981; Watts et al. 1991; Derocher and Stirling 1990a). Further research is required to fully understand the dynamics of a changing climate and the impacts it may have on subadult bears.

The linkages detected between the NAO and the AO, and the bear's east- and northward shifts indicate that large-scale climate variables may also be an important factor influencing the distribution of polar bears in addition to the timing of sea ice break-up. Despite the many seasonal indices and monthly values explored, the winter indices had stronger correlations with the baseline and coastal distribution of adult male and female polar bears, family group and subadult male bears compared to the spring indices suggesting climate influences polar bears during this period and may be important for the bear's on-land distribution. Winter is a critical period because it includes the time when female polar bears, family group and subadult male bears compared to the spring indices suggesting climate influences polar bears during this period and may be important for the bear's on-land distribution. Winter is a critical period because it includes the time when the bears are in the poorest physical condition (i.e., depleted fat reserves) when they first return to the sea ice as it reforms in late October-mid November (Markham 1986; Wang et al. 1994). The winter period also includes the time when the bears are on the sea ice hunting and building up fat reserves before they are forced onto land in July. Sea ice break-up and the NAO affects the recruitment of ringed seals in western Hudson Bay suggesting bears may not be able to accumulate sufficient fat reserves when break-up and the NAO negatively impact their primary prey (Ferguson et al. 2005). Although the winter period may be significant it is unclear what environmental conditions the NAO and AO produce on the sea ice during this period that may be of importance to polar bears. The timing of sea ice break-up was correlated with the AO index; however the links between local- and large-scale climate indices are not always straightforward (Stenseth et al. 2003). Whereas local-scale climate variables are only a single variable attempting to describe ecological processes, the large-scale climate variables incorporates several local climate variations (Stenseth et al. 2003; Hallett et al. 2004). Further research needs to examine other possible local-scale climate indices, such as local temperatures, snow depth, precipitation, wind speeds, and currents in relation to the NAO and AO to understand the role that a changing climate has on the population dynamics of polar bears.

Several studies on various species of invertebrates, birds, and small mammals have related local weather patterns, linked to the NAO, to changes in species spatial distribution (Graham and Grimm 1990; Parmesan et al. 1999; Thomas and Lennon 1999; Hill et al. 2001). The NAO, AO, and other large-scale climate indices are good predictors of ecological processes compared to weather variables (Post and Stenseth 1998; Milner et al. 1999; Mysterud et al. 2001; Post and Forchhammer 2002; Post et al. 1999; Stenseth et al. 1999). From my understanding, this study was a first to make a link between large-scale climate variables with the distribution of large carnivores.

Polar bears in western Hudson Bay were still segregated by age- and sex-class but with a few exceptions. I found similar findings as Derocher and Stirling (1990a) where groups were segregated but no differences were detected between adult males with subadults of both sexes. Other ursid studies have documented similar findings of segregation relative to adult male influence on distribution and movement of conspecifics as well as sex-specific habitat use attributed to male avoidance (Garshelis and Pelton 1981; Wielgus and Bunnell 1994, Wielgus and Bunnell 1995; McLoughlin et al. 2002; Dahle and Swenson 2003; Ben-David et al. 2004; Gende and Quinn 2004). Segregation appears to still be an important behaviour of the western Hudson Bay bears in spite of the changes in distribution and energetic constraints suggesting the importance of habitat preference and social hierarchy of adult males over subordinates.

2.4.3. Changes in population structure

Changes in the structure of the population provide an alternate hypothesis to explain the temporal shift in polar distribution in western Hudson Bay. A male-biased harvest and a population decline were two known reasons for this structure change (Derocher et al. 1997; Regehr et al. in press). During the 1950s, there were few harvest restrictions where an estimated 50-100 bears were taken annually and many of the kills were females with cubs (Stirling et al. 1977). It was not until the closing of the York Factory settlement in 1957, military withdrawal from Fort Churchill in 1964, and the implementation of harvest quotas in the 1960s, restricting harvest size and protecting females that polar bears killed were reduced (Stirling et al. 1977; Derocher and Stirling 1995a). Harvest levels appeared sustainable with the majority of kills being young males, creating a skewed sex ratio towards females in a 2:1 ratio (Derocher et al. 1997). The population appeared to be recovering from overharvest and population estimates were relatively stable from the early 1990s to 2004 (Lunn et al. 1997; Stirling et al. 2004). However, recent findings by Regehr et al. (in press) show the population to be declining with an estimate of around 900 individuals, down almost 300 bears from the 1997 (Lunn et al. 1997). The adult male component has been declining steadily since the late 1980s whereas the female component appeared to be relatively stable with a slight decrease in recent years (Regehr et al. in press). Possible explanations for the decline in population includes: 1) a male-biased harvest (Derocher et al. 1997), and 2) adverse effects on population dynamics from changes in climate variables (e.g., earlier sea ice break-up). Several studies on various species have documented how a highly skewed sex ratio can have deleterious effects on fecundity and population growth (Ginsberg and Milner-Gulland 1994; Langvatn and Loison 1999; Hario et al. 2002; Solberg et al. 1999; Saether et al. 2003), which can ultimately lead to population decline. Effects on population dynamics can occur through interactions of density, weather, and population structure (Coulson et al. 2001). Density-related distributional shifts in populations are poorly described. Most studies on species distribution, range shift and population density

Histol 1999; Coulson et al. 2001; Ferguson et al. 2001b; Solberg et al. 1999; Solberg et al. 2001; Gilg 2002; Fox et al. 2005; Shephard et al. 2005; Stewart et al. 2005). However, studies on population dynamics of caribou found distribution changed with abundance (Ferguson et al. 1998, 2001b; Wittmer et al. 2005).

2.5. Conclusion

It was difficult to discern between the effects of climate and population effects to determine which one truly influenced the distribution of polar bears during the on-land period. The behavioural dynamics of polar bears may be related to the change in population structure however the ultimate factor may be climate related because changes in the population dynamics either directly or indirectly lead back to changes in climate. As climate continues to warm it is important to continue to monitor the western Hudson Bay polar bear population and to include large-scale climate phenomena to better understand how polar bears respond to these changes in climate.

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Table 2-1. Number of polar bears of different age- sex- and reproductive-class captured in western Hudson Bay each year, 1986-2004.

Year	Adult males	Solitary adult females	Family groups	Subadult females	Subadult males	Total
1986	41	7	14	21	14	97
1987	67	47	59	20	21	214
1988	80	46	52	19	20	217
1989	69	48	38	26	21	202
1990	50	33	34	21	13	151
1991	45	20	26	11	8	110
1992	39	32	43	9	8	131
1993	26	30	30	7	10	103
1994	29	15	24	7	2	83
1995	21	19	19	11	2	78
1996	42	22	29	13	10	16
1997	38	26	31	29	21	145
1998	39	31	36	18	24	148
1999	35	21	22	6	13	97
2000	25	20	24	3	9	80
2001	21	17	22	7	2	69
2002	17	6	29	1	1	54
2003	45	14	27	19	8	113
2004	42	4	21	14	14	95
Total	771	458	580	262	233	2304

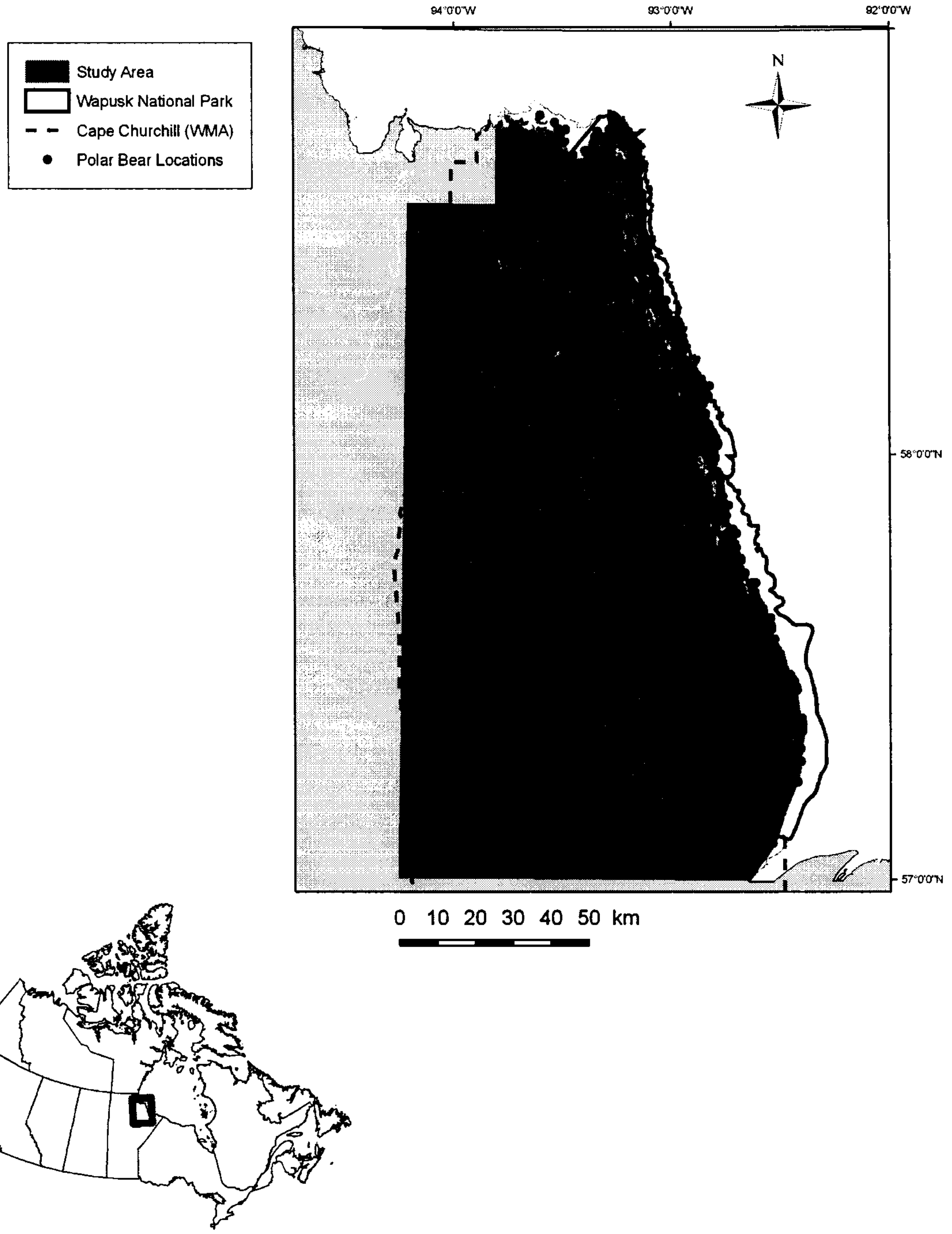
Table 2-2. Distance from the coast and the southern baseline (km) of the different polar bear age- sex- and reproductive-classes in western Hudson Bay from 23 August-7 October, 1986-2004.

	Distance from the coast (km)	Distance from the baseline (km)
Adult males		
n	771	771
Mean (SE)	12.8(0.7)	127.8(1.6)
Median	0.6	131.7
Range	0 - 82	20 - 200
Solitary adult females		
n	458	458
Mean (SE)	43.7(1.0)	96.2(1.8)
Median	45.4	90.4
Range	0 - 82	10 - 196
Family groups		
n	580	580
Mean (SE)	33.4(0.8)	103(1.7)
Median	36.3	106.7
Range	0 - 77	20 - 195
Subadult females		
n	262	262
Mean (SE)	24.2(1.4)	123.4(2.7)
Median	20.9	124.7
Range	0 - 82	25 - 200
Subadult males		
n	233	233
Mean (SE)	15.3(1.3)	131.9(2.7)
Median	2	133.4
Range	0 - 77	34 - 200

Table 2-3. Spatial segregation of polar bears of different age- sex- and reproductive-classes in the east-west and north-south distribution in western Hudson Bay, 1986-2004 (Mann-Whitney U statistic). Bonferroni adjustment: significant at $P \leq 0.005$.

	Distance from the coast		Distance from baseline	
	U	P	U	P
Adult males-Solitary adult females	50209.0	<0.001	104719.0	<0.001
Adult males-Family groups	91912.5	<0.001	153611.5	<0.001
Adult males-Subadult females	65317.0	<0.001	94756.0	0.134
Adult males-Subadult males	75864.0	<0.001	84936.0	0.208
Solitary adult females-Family groups	96010.0	<0.001	119174.5	0.004
Solitary adult females-Subadult females	31940.0	<0.001	38582.5	<0.001
Solitary adult females-Subadult males	18923.0	<0.001	28071.0	<0.001
Family groups-Subadult females	56646.0	<0.001	56641.5	<0.001
Family groups-Subadult males	33762.5	<0.001	42009.0	<0.001
Subadult females-Subadult males	23258.0	<0.001	26791.0	0.019

Figure 2-1. The study area located in western Hudson Bay in northern Manitoba displaying the distribution of polar bear locations from 1986-2004.



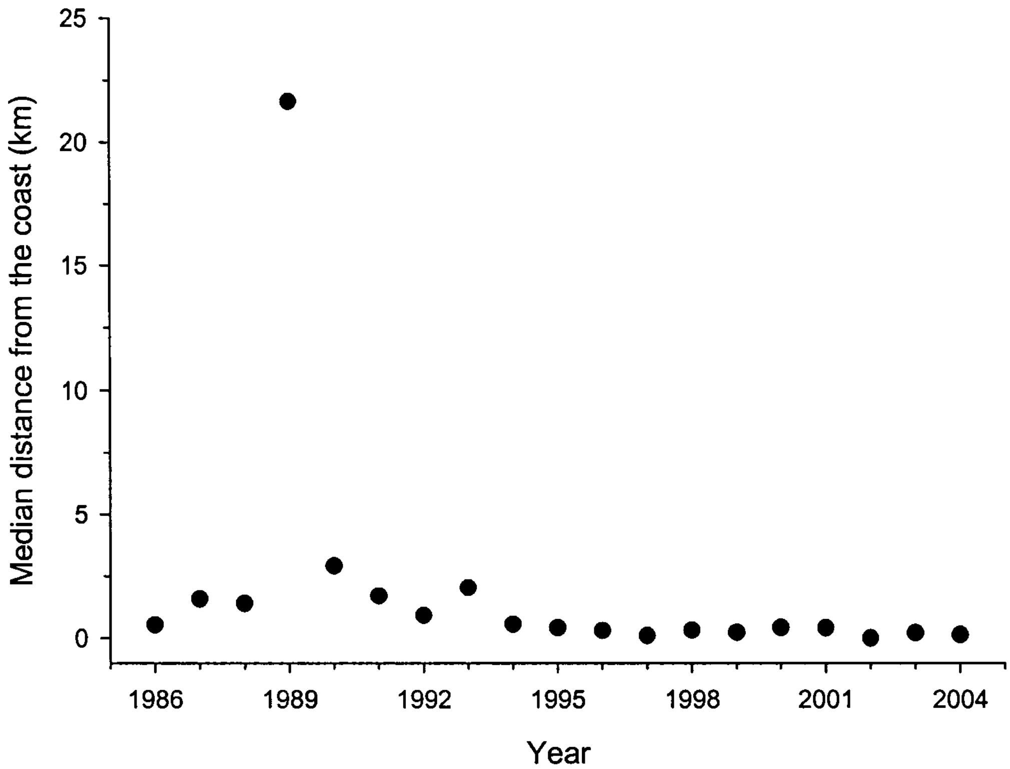


Figure 2-2. Distance from the coast for adult male polar bears during the ice-free season in western Hudson Bay, 1986-2004. The distance inland adult male bears moved were negatively correlated over time (see text for details). The year 1989 was removed as a potential and data reanalyzed; however results were still significant.

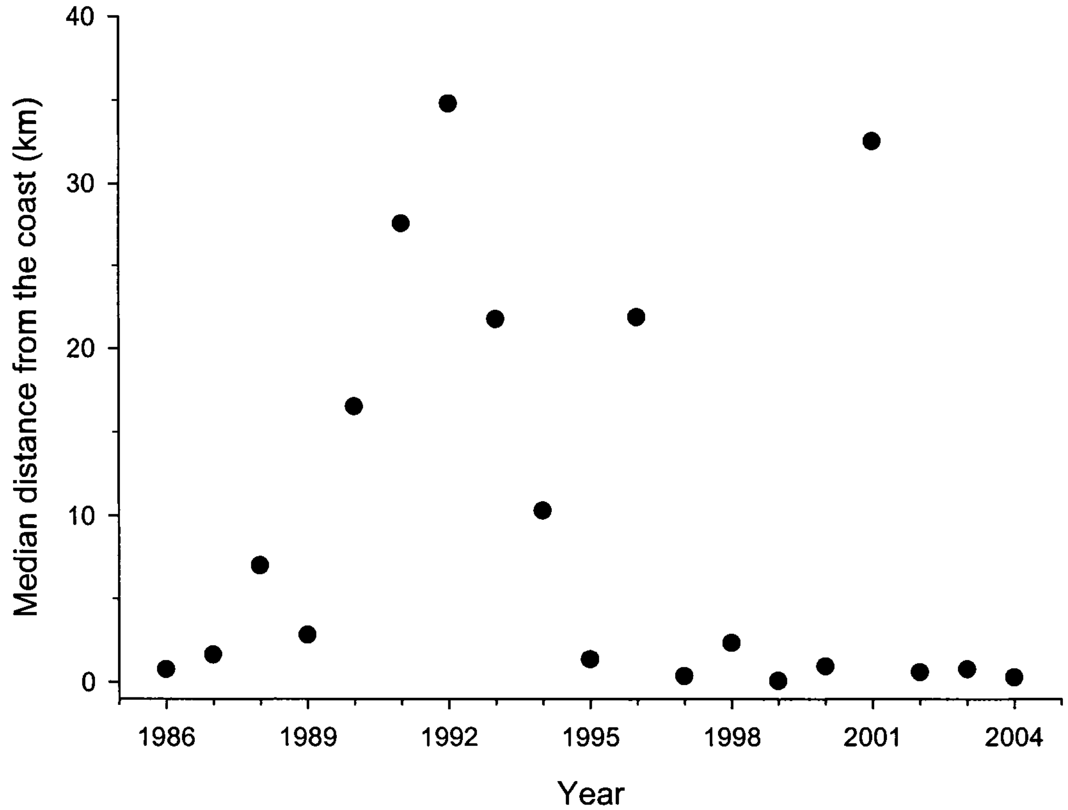


Figure 2-3. Distance from the coast for subadult male polar bears during the ice-free season in western Hudson Bay, 1986-2004. The distance inland subadult male bears moved were negatively correlated over time (see text for details).

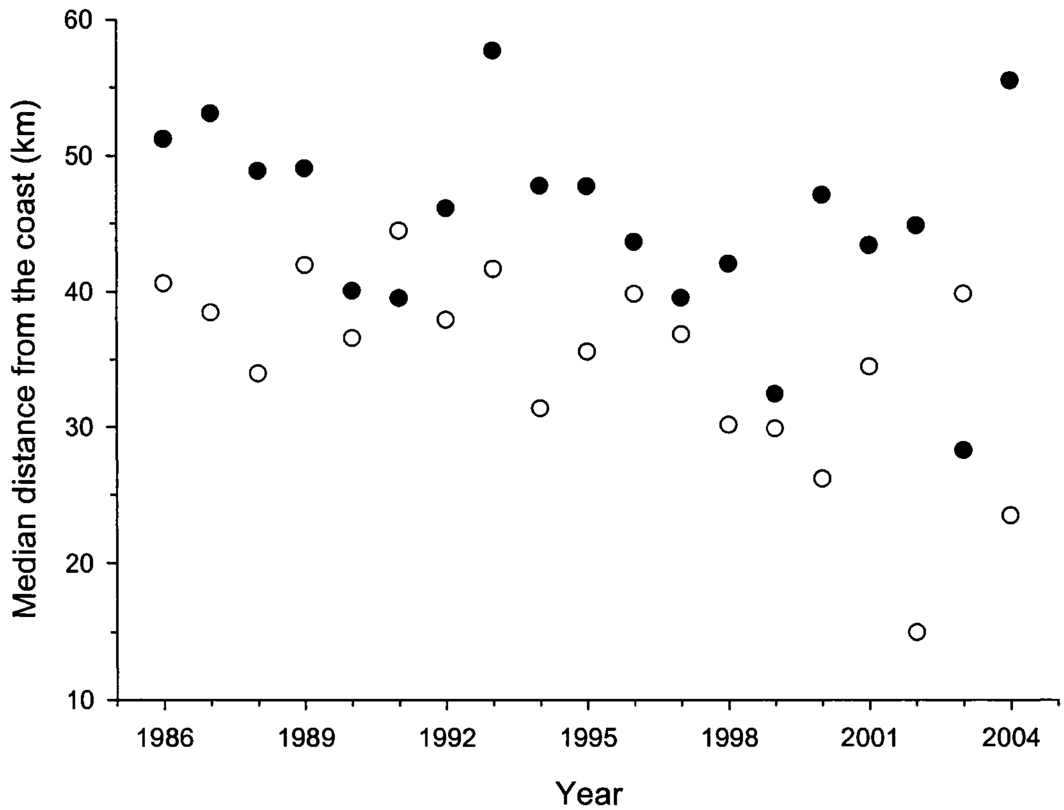


Figure 2-4. Distance from the coast for solitary adult female (black circles) polar bears and family groups (open circles) during the ice-free season in western Hudson Bay, 1986-2004. The distance inland solitary adult female and family group moved were negatively correlated over time (see text for details).

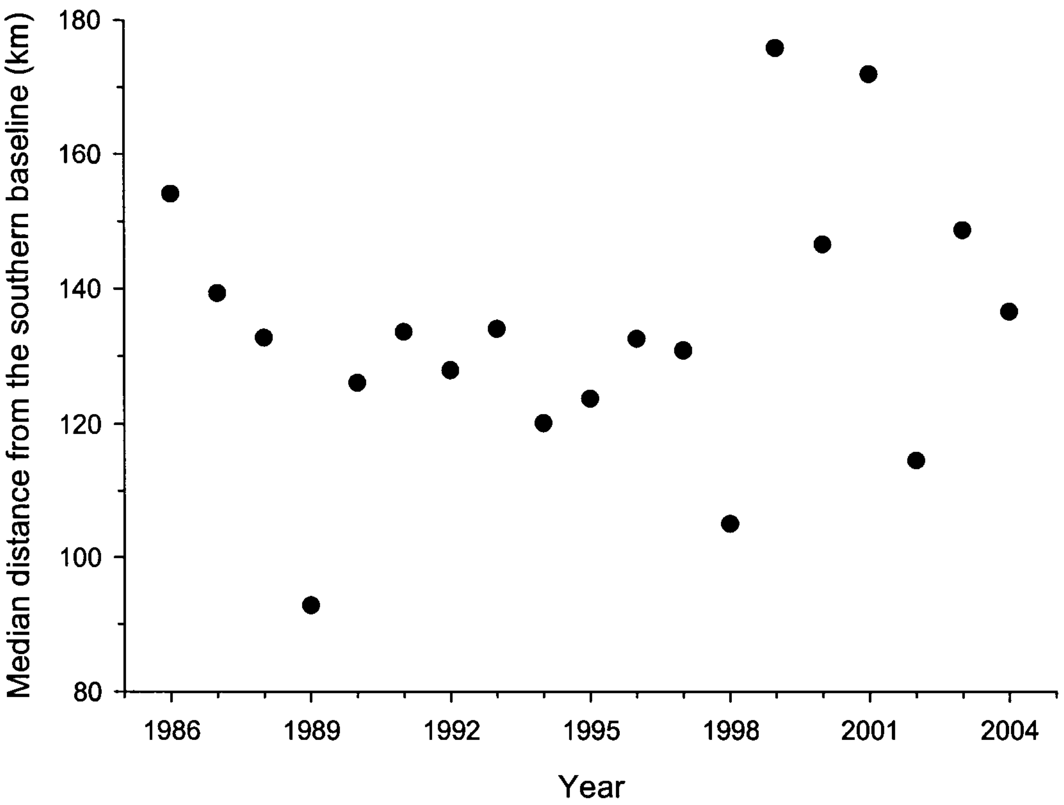


Figure 2-5. Distance from the southern baseline for adult male polar bears during the ice-free season in western Hudson Bay, 1986-2004. The distance moved northward by adult male bears was positively correlated over time (see text for details).

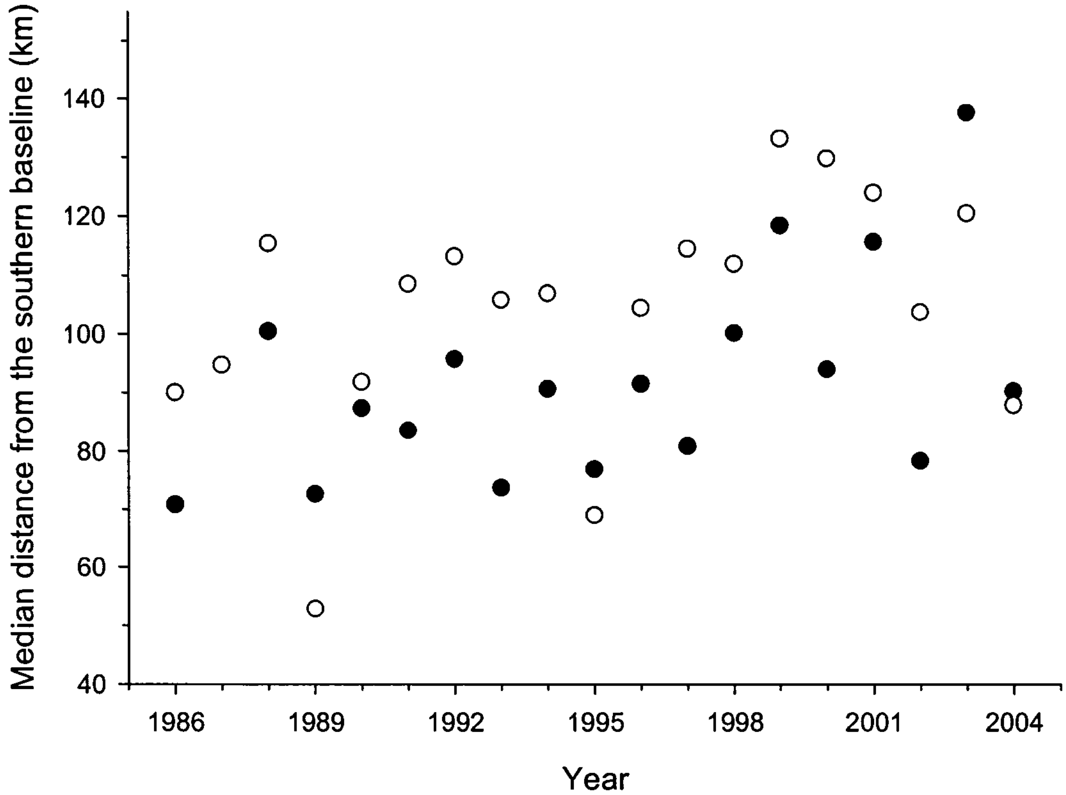


Figure 2-6. Distance from the southern baseline for solitary adult female (black circles) polar bears and family groups (open circles) during the ice-free season in western Hudson Bay, 1986-2004. The distance moved northward by family groups was positively correlated over time and for solitary adult female bears the shift was not statistically significant ($P = 0.061$) (see text for details).

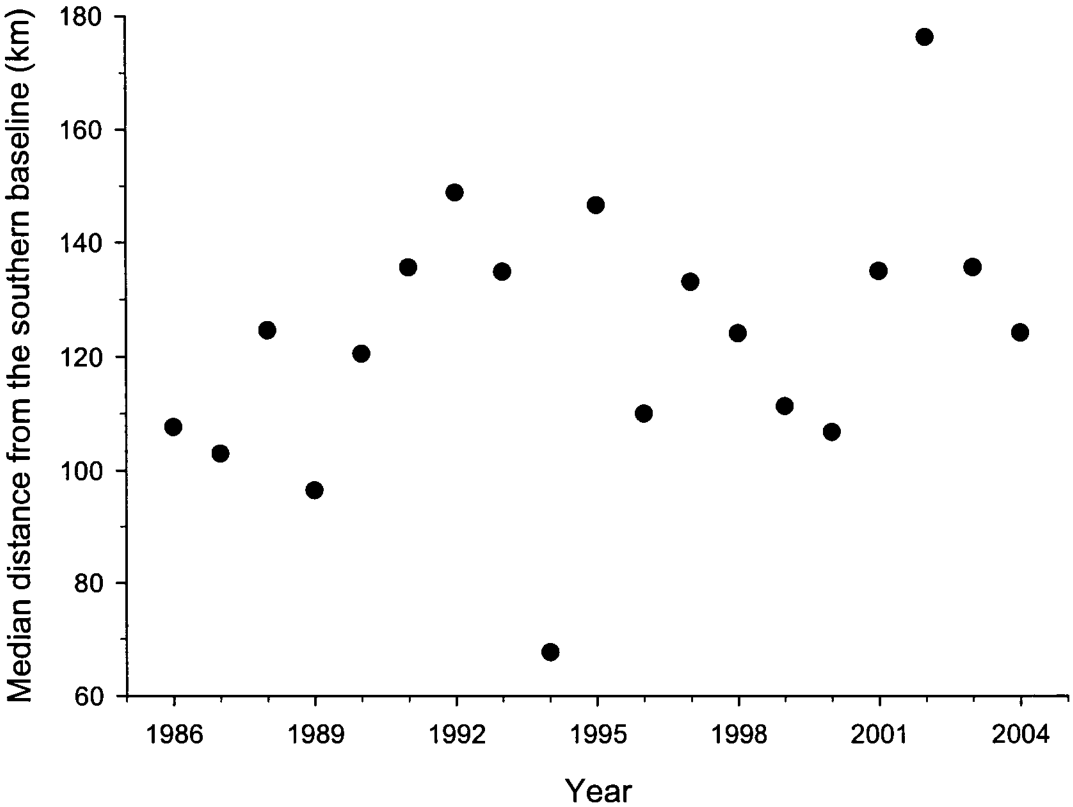


Figure 2-7. Distance from the southern baseline for subadult female polar bears during the ice-free season in western Hudson Bay, 1986-2004. The distance moved northward over time by subadult female bears was not statistically significant ($P = 0.058$) (see text for details).

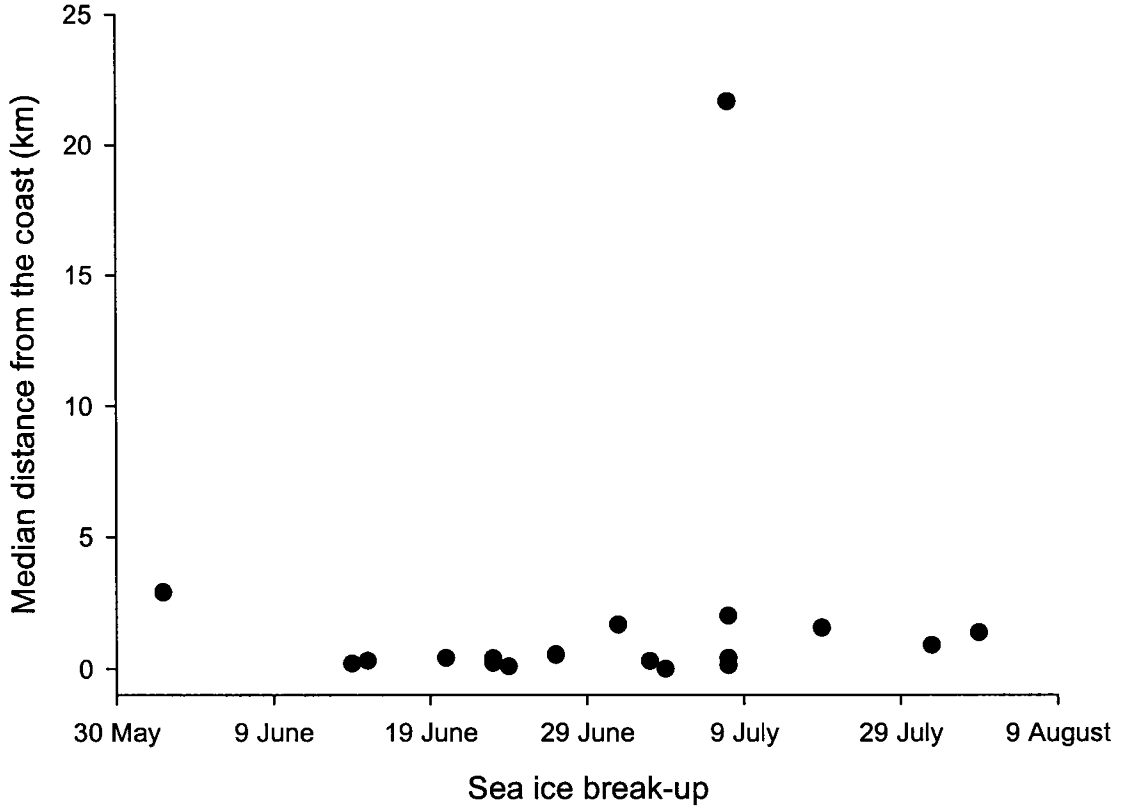


Figure 2-8. Distance from the coast for adult male polar bears was positively correlated with sea ice break-up in western Hudson Bay, 1986-2004 (see text for details).

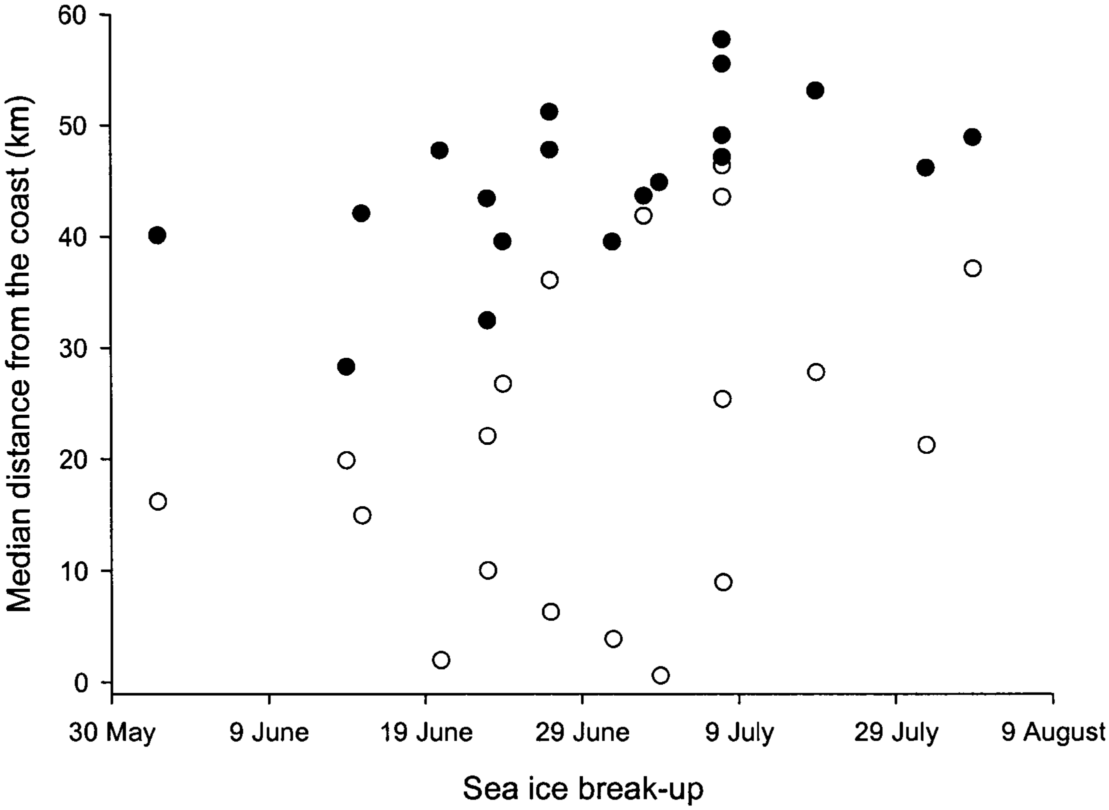


Figure 2-9. Distance from the coast for solitary adult female (black circles) and subadult female (open circles) polar bears during the ice-free season were positively correlated with sea ice break-up in western Hudson Bay, 1986-2004 (see text for details).

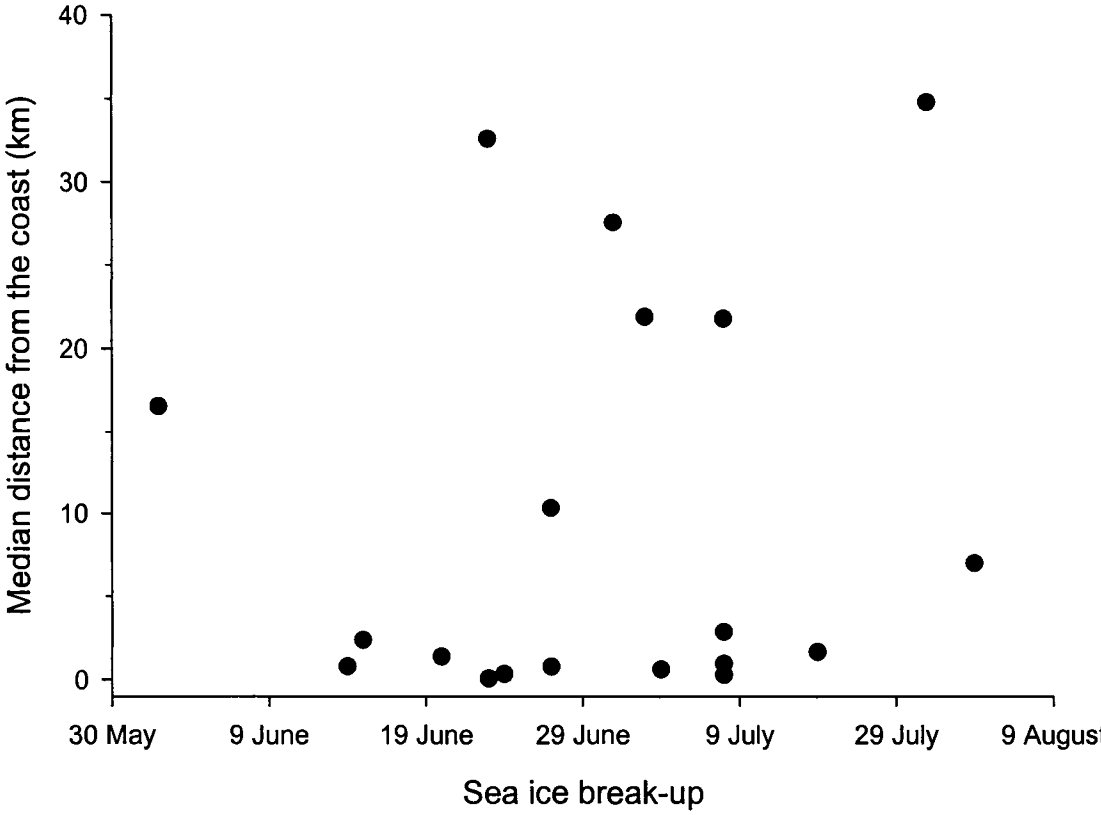


Figure 2-10. Distance from the coast for subadult male polar bears during the ice-free season was positively correlated with sea ice break-up in western Hudson Bay, 1986-2004 (see text for details).

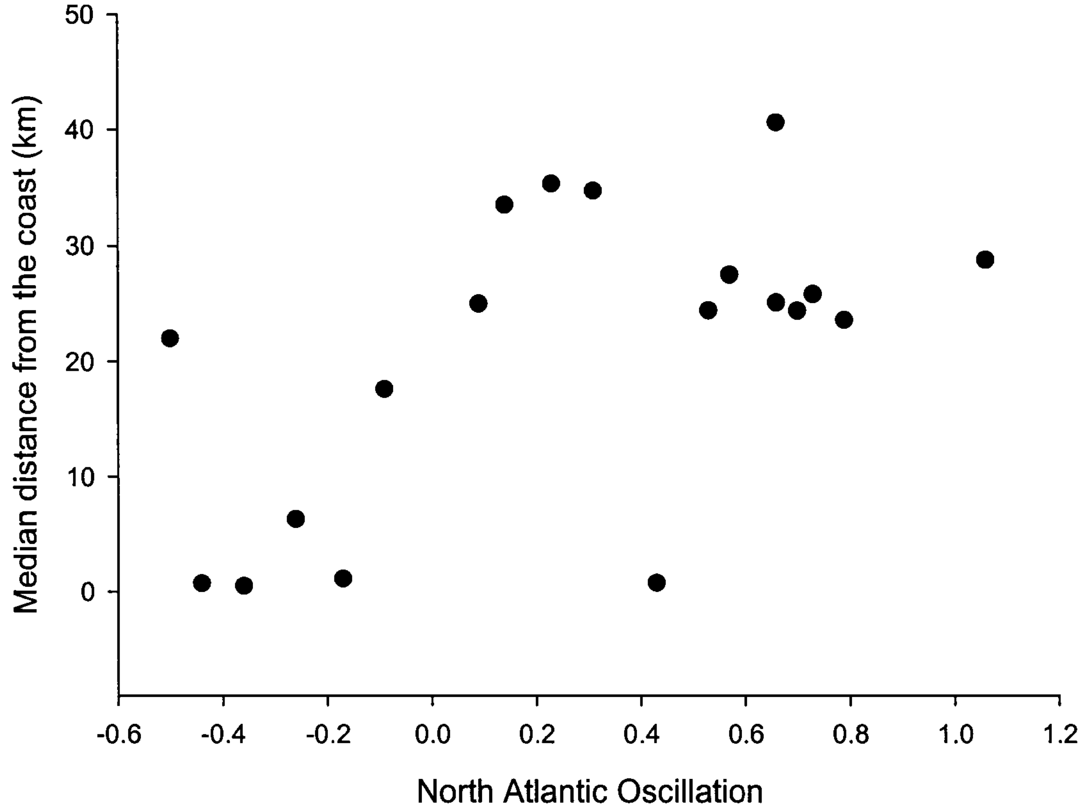


Figure 2-11. Relationship (Spearman-rank correlation: $r_s = 0.54$) between the median coastal distance of polar bears and the previous winter's North Atlantic Oscillation index (NAO_{t-1}) during the ice-free season in western Hudson Bay, 1986-2004. The mean of November-April NAO values were used.

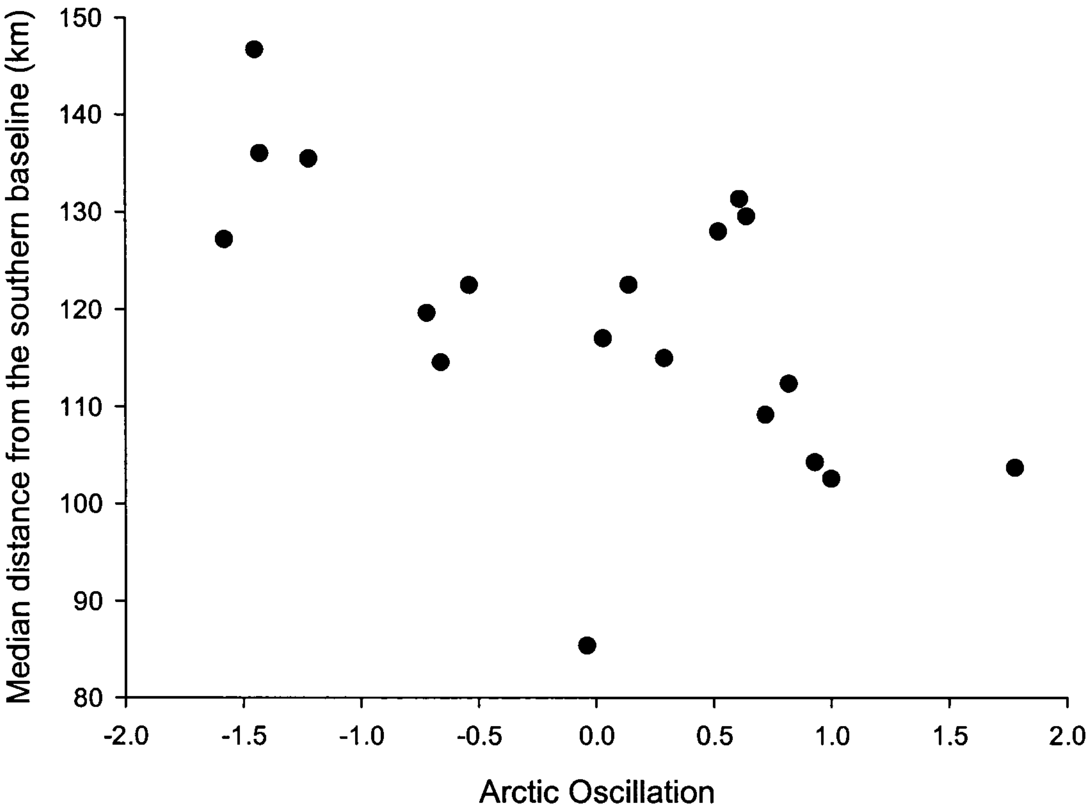


Figure 2-12. Relationship (Spearman-rank correlation: $r_s = -0.58$) between the median southern baseline distance of polar bears and the previous November Arctic Oscillation index (AO_{t-1}) during the ice-free season in western Hudson Bay, 1986-2004. The mean of November AO values were used.

Chapter 3. SPATIAL AND TEMPORAL PATTERNS OF PROBLEM POLAR BEARS IN CHURCHILL, MANITOBA

3.1. Introduction

Whenever humans and wildlife live in close proximity to one another there are bound to be conflicts. What constitutes animals being labelled a "problem" or "nuisance" typically involves the threat to human life and/or property (Rutherglen and Herbison 1977; Herrero and Fleck 1990; West and Parkhurst 2002; Somers and Morris 2002). Human-wildlife conflicts occur as a direct result of human activities and/or environmental factors. Humans cause interactions with wildlife when 1) people and wildlife share similar food resources (McDougal 1987; Rajpurohit and Krausman 2000; Karanth and Madhusudan 2002), 2) the growth and expansion of the human population extends into wildlife habitat (Torres et al. 1996; Hoare 1999; Woodroffe 2000; Treves and Karanth 2003), 3) wildlife habitat is destroyed (Oka et al. 2004), and 4) extirpated species are reintroduced and/or recovered (Bangs et al. 1998). Environmental factors indirectly affect human-wildlife interactions and a growing concern is climate change and how it may affect these interactions (Stirling and Derocher 1993; Derocher et al. 2004). Changes in weather variables such as temperature, precipitation, and snow depth can affect food availability (Mysterud et al. 1999; Selas 2000; Piovesan and Adams 2001), habitat (Maslanik et al. 1996; Stirling and Smith 2004; Gagnon and Gough 2005; Richardson 2004), and species distribution (Parmesan et al. 1999; Valiela and Bowen 2003; Chapter 2) thereby increasing the chance of nutritional stress and/or displacement of animals causing them to interact with humans (Stirling et al. 1999; Oka et al. 2004).

Polar bear (*Ursus maritimus*) habitat is not as isolated as it once was because both the human population and tourism have increased (Watts and Ratson 1989; Bogoyavlenskiy 2004; Dyck and Baydack 2004; Debruyn et al. 2004) making encounters with polar bears more likely (Kearney 1989; Leonard 1989; Lee and Taylor 1994). Polar bears are considered problem animals when they move into northern settlements, camps, or industrial sites and threaten human safety, and/or cause property damage (Lunn and Stirling 1985; Stenhouse et al. 1988; Kearney 1989; Leonard 1989). No other town has received as much attention pertaining to the issue of human-bear conflict as Churchill, Manitoba along the western coast of Hudson Bay. The bears spend several months on land (July to November)when the sea ice melts every summer (Stirling et al. 1977). Bears spend the ice-free period south of Churchill in denning habitat for adult females with and without young or along the coast for adult males (Latour 1981; Derocher and Stirling 1990b). In anticipation of freeze-up, bears move northward in late autumn to the northern coastal limit placing them in closer proximity to Churchill (Latour 1981; Lunn and Stirling 1985; Derocher and Stirling 1990a).

The fur trade, trapping, and exploration brought Europeans to the Churchill area and the first documentation of polar bears (Hearne 1795). Hunting by Inuit at the Hudson Bay Post at York Factory (220 km south of Churchill) and the military stationed in Fort Churchill may have controlled bear numbers (Kearney 1989) because when York Factory closed and the military decreased their activities in the 1950s and 1960s (Stirling et al. 1977), the bears became more of a problem. Problems arose when bears were 1) attracted to the 3 dumps in Churchill and Fort Churchill, a nearby whaling station, and/or food aromas in the settlements, 2) breaking into houses, 3) viewed and provoked by people in the dump, and/or 4) killing dogs (Stirling et al. 1977). The escalating human-bear conflict prompted the implementation of the Polar Bear Alert Program in 1969 (known as the Polar Bear Control Program before 1985). The program was coordinated by the Manitoba Department of Natural Resources and the policy was to "ensure the safety of people and the protection of property from damage by polar bears" (Kearney 1989). Conservation officers were responsible for controlling bears in and around the town site through primary management actions of shooting, trapping, and relocation of some bears north of Churchill. Two of the dumps were closed in the late 1960s however one remained active (10 km east of town site) and continued to be a source of attraction for bears until 2005 when it was closed. Another form of managing nuisance bears was the Polar Bear Compound (D20) established outside of town in 1982. The purpose of this facility was a holding station for bears until the sea ice reformed and they could be released (Kearney 1989).

For centuries, the western Hudson Bay polar bear population was hunted with no restrictions until legislation was passed in 1949 to protect the polar bear by limiting hunting and killing only to native residents (Stirling et al. 1977). Tourism in Churchill is the only use of the polar bears because there is no hunting for them in Manitoba. The management program has changed over time as policies are reviewed, public input is considered, and bear behaviour has changed (Kearney 1989).

Understanding the effects of climate on problem bears has become increasingly important because temperatures have increased in Hudson Bay (Skinner et al. 1998) and are linked to changes in polar bear habitat (Stirling et al. 1999, 2004; Gagnon and Gough 2005), and recruitment and survival of prey (Stirling and Smith 2004; Ferguson et al.

2005; Stirling 2005). Changes in the distribution and population dynamics of western Hudson Bay polar bears have been linked to the changing climatic conditions (Derocher and Stirling 1995b; Stirling and Lunn 1997; Stirling et al. 1999; Regehr et al. in press; Chapter 2). Stirling and Derocher (1993) predicted that rising temperatures would increase the number of human-bear interactions because bears would be nutritionally stressed if the ice-free period was prolonged and bears would travel into human settlements seeking food.

There is little documentation on the problem bears in Churchill. Most studies focused on the age- and sex-composition, bears that fed at the dump, and the management policies adopted to deal with problem individuals (Stirling et al. 1977; Kearney 1989; Leonard 1989; Lunn and Stirling 1985). No studies have examined the temporal and spatial dynamics of the problem bears in Churchill and in relation to changing climatic conditions. Similar to Stirling et al. (1977), I defined problem bears as any bear captured in and around the Churchill town site (see Methods section) as result of being attracted to the dump, damaging property, and/or threatening the life of humans. This study describes the temporal pattern of the number of problem bears in the Churchill area, the age- and sex-composition, and the number of times bears return to the Churchill area with previous capture history in Churchill, and assesses the spatial patterns. I attempt to explain the variation in the number of problem bears by using environmental variables, such as sea ice break-up and formation, the North Atlantic Oscillation (NAO), and the Arctic Oscillation (AO).

3.2. Methods

3.2.1. Study area

The focal study area, referred to the Churchill area from here on in, is approximately 460 km^2 encompassing the Churchill town site, dump, and subdivisions. The Churchill area spans from 58°47′N, 93°48′W west to Cape Merry (58°47′N, 94°12′W), south (58°35′N, 94°12′W) and east to Twin Lakes (58°35′N, 93°48′W). The study area was extended south to the Nelson River (57°00′N) and east following the coastline when examining the spatial distribution of problem bears (Figure 3-1). The extended study area will be referred to as the larger study area. Approximately 1000 people live in Churchill, with settlements at the Churchill town site, the Dene village, and Goose Creek subdivision. The region is located in the transition zone of the boreal forest and Arctic tundra and has extensive peatland coverage (Ritchie 1960). The coastal area is flat and dominated primarily by sedge-grass-herb meadow community and scrub willow (*Salix* spp). In contrast, the inland area is dominated by lichen tundra habitat, riparian and lakeshore habitats, patches of open spruce (*Picea glauca* and *P. mariana*), and tamarack (*Larix laricina*) surrounding riparian habitats (Ritchie 1960).

3.2.2. Data collection

Reports on problem polar bears were not recorded until 1966 when capture records were entered into the Canadian National Polar Bear Database. Several different agencies were involved in the capture of polar bears in the Churchill area with Manitoba Conservation functioning as the primary management agency. The Canadian Wildlife Service maintained a research program and was responsible for the many of captures in the 1960s to early 1980s for research purposes. The Canadian Wildlife Service research moved outside the Churchill area in 1976-78 and eventually moved to the denning area further south. Additional captures were conducted for research by the Government of the Northwest Territories, University of Saskatchewan, University of Montana, and University of Oslo.

Data was collected on location and demographic information and morphometric measurements from bears captured each summer and autumn from 1966-2004. Ages were determined by cementum annulation counts from a premolar extracted at capture (Calvert and Ramsay 1998). 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. In the larger study area, polar bears were captured non-selectively using immobilization techniques (Stirling et al. 1989) mostly from a helicopter, between August and October (Derocher and Stirling 1990a). Other modes of capturing included Aldrich leg snares, culvert traps, and free-range immobilisation from motor vehicles although these were restricted to areas near Churchill.

3.2.3. Database

I used the same original database as in Chapter 2 containing over 10,000 capture records from 1966-2004. I standardized the database to reduce autocorrelation, and sampling bias by using only the first capture of an individual bear in the Churchill area per year, and by removing any bears captured outside the Churchill study area. Based on break-up and freeze-up of the sea ice and when bears are on-land, captures between July and December were included in analyses. Bears captured before 1970 were removed from analyses because data was incomplete (Stirling et al. 1977; Kearney 1989). Following Derocher and Stirling (1990a), I categorized polar bears into 5 different 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 where problem bears are coming from, I investigated their distribution in the larger study area before they entered the Churchill area and compared it to a random sample, using distance as a metric. Using ArcMap 9.0 (Environmental Systems Research Institute, Inc., Redlands, CA), I measured the distance from the bears first capture in the larger study area to the centre of the Churchill area. I only analysed the first year of capture to maintain sample independence when bears had recaptures in multiple years. I constrained this analysis to 1986-2004 when capture effort and the distribution of sampling effort was extensive in the larger study area (Derocher and Stirling 1995a).

3.2.4. Environmental variables

Sea ice break-up was defined following Etkin 1991) as the date by which total ice coverage in Hudson Bay was 50% during spring melt period and 50% for formation during the fall. Break-up and freeze-up dates for 108 points across Hudson Bay from 1971-2003 were provided by A. Gagnon (University of Liverpool) so I could calculate the mean break-up and freeze-dates specifically for western Hudson Bay. The dates provided were based on the methodology of Gagnon and Gough (2005). Weekly regional ice charts for Hudson Bay produced by the Canadian Ice Service were analyzed to estimate the timing of break-up and freeze-up (http://ice-glaces.ec.gc.ca/). A sampling grid with points at intervals at 1° latitudes and longitude were superimposed on the weekly ice concentration charts. At each of these points (n = 108) the ice concentration values were obtained and averaged and the dates for break-up and freeze-up for Hudson Bay were obtained. Out of the 108 points of break-up and freeze-up dates, 34 of the points were in western Hudson Bay and these were used to calculate the mean break-up and freeze-up dates. For the multiple regression analysis, I used data from 1971-2003 whereas all other statistical analyses and descriptive statistics I used data from 1970-2004. Data from 1992 was removed from analysis as a potential outlier because break-up was about 3 weeks later than usual, possibly as a result of the eruption of Mount Pinatubo in the Philippines and an El Niño event (Stirling et al. 1999).

The NAO and the AO are modes of climate variability. The NAO index is measured as a mean deviation from the average sea level pressure between Iceland and 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 exhibit high interannual and interdecadal variability (Hurrell 1995). Data was explored for relationships to assess the role of climate on the number of problem bears. Because there was no basis for making *a priori* predictions on the best index to use, I used 8 mean seasonal NAO indices and 8 mean AO indices based on sea ice conditions and bear behaviour. The various winter indices included November-December (early winter index), January-February (mid-winter index), March-April (late winter index), October-April, November-April, and January-April. The spring indices included April-June, and

May-June. I used the mean NAO or AO value for each season (e.g., mean of the NAO index for October-April for a winter index 1). I also examined monthly values of the NAO and the AO. Index values were from the Climate Prediction Centre (www.cpc.ncep.noaa.gov).

3.2.5. Statistics

Transformations were unable to normalize the distribution of the number of bears arriving in the Churchill area (Shapiro-Wilk and Kolmogorov-Smironov test for all 5 age- sex- and reproductive-classes) with the exception of subadult male bears so non-parametric tests were used. The number of bears captured in Churchill (i.e., total number of bears per year), ages, and distance measures were $\log_{10}$ transformed and the number of bears killed as problem animals was square root transformed for statistical analyses to normalize the data.

Linear regression was used to assess temporal trends of the number of problem bears in the Churchill area, the number of bears that return to the Churchill area with previous capture history, and the mean age composition of problem bears. Analysis of variance (ANOVA) was used to determine if differences occurred in distances traveled to the Churchill area between polar bears of different age- sex- and reproductive-class. Linear regression was used to determine if distances travelled to the Churchill area have changed over time.

When generating random locations and when using statistical analyses to assess spatial trends, I removed potential outliers ($n = 7$) from the data because the areas individuals were captured in were only sampled during years of population estimates (i.e., Button Bay and the Kaska region). To generate random locations, I 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 centre of the Churchill area. The mean was calculated from the 144 observed replicates. I was then able to determine based on the observed mean distance to the Churchill area, where problem bears were coming from compared to the overall mean of the random sample (i.e., closer, further, or no difference).

Logistic regression was used to estimate the probability of becoming a problem bear as a function of distance from the Churchill area. 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 by the Hosmer and Lemeshow (1989) goodness-of-fit test.

Environmental variables (i.e., sea ice break-up, ice formation, seasonal indices and monthly values of the NAO and the AO) were used as independent variables to explain the variation in the number of problem bears each year (1971-2003). Univariate analysis was used to assess the significance of each variable. Tests for collinearity between all significant variables were examined before inclusion of the significant variables into a multiple forward stepwise regression.

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).

3.3. Results

The study included 1487 captures (977 bears) with subadult males comprising 39% (574/1487) and 23% subadult females (343/1487). Adult males represented 18% (272/1487) of captures, females with young 14% (213/1487), and solitary females 6% of captures (85/1487) (Table 3-1). Sixty-two percent of captures (928/1487) represented recaptures. The mean date of capture of polar bears in the Churchill area was 23 October ± 0.66 days and was similar between the age- sex- and reproductive classes (range: 22 October – 31 October). Bears were first captured in the Churchill area between 3 July and 21 August ($\bar{x}$: 19 July ± 9.7 days). The last capture dates of the bears in the Churchill area were all shortly before the bears returned to the sea ice, ranging from 28 November to 2 December ($\bar{x}$: 1 December ± 0.84 days). There was no relationship between mean date of capture and year for any age-sex- and reproductive polar bear class (Pearson moment-product correlation: adult males: r = -0.01, n = 33, $P = 0.95$; solitary adult females: r = 0.1, n = 29, $P = 0.61$; family groups: r = -0.11, n = 35, $P = 0.51$; subadult females: r = -0.05, n = 35, $P = 0.76$; subadult males: r = 0.06, n = 35, $P = 0.75$).

3.3.1. Temporal trends in problem bear numbers

There was a significant increase in the number of polar bears captured over time in the Churchill area (linear regression: $F_{1,33} = 19.09$, $P \leq 0.001$, $R^2 = 0.37$) ranging from 10 captures in 1984 to 90 captures in 2004 (Figure 3-2). There was also an increasing trend in the number of bears captured per year in the Churchill area for each of the 5 different age- sex- and reproductive-classes (Spearman-rank correlation: adult males: r_s = 0.71, n = 272, $P \leq 0.001$; solitary adult females: r_s = 0.59, n = 85, $P \leq 0.001$; family groups: $r_s = 0.36$, n = 213, $P = 0.03$, subadult females: $r_s = 0.43$, n = 343, $P = 0.01$; subadult males: $r_s = 0.59$, n = 574, $P \leq 0.001$, Figure 3-3). The number of bears captured in the Churchill area ranged from 1 to 8 times across years. Of the 977 individual problem bears, 72.6% were captured once and 27.4% were capture more than once. Of the bears that were captured more than once, 144 returned once more, 63 bears returned twice, 28 bears returned three times, 18 bears returned four times, 10 bears returned five times, 2 bears returned for a sixth and seventh time, and only 1 bear returned an eighth time. The number of recaptured animals in the Churchill area increased over time (linear regression: $F_{1,32} = 20.88$, $P \leq 0.001$, $R^2 = 0.40$). The number of bears killed as problem individuals decreased over time (linear regression: $F_{1,33} = 12.81$, $P = 0.001$, $R^2 = 0.28$).

3.3.2. Age- and sex-composition

The median number of bears captured differed between the 5 different polar bear age-sex- and reproductive-classes (Kruskal-Wallis test: $X^2 = 75.04$, df = 4, $P < 0.001$). Subadult males were captured the most (15 ± 1.4 bears/year) compared to other age-sex classes while solitary adult females were captured the least (2 ± 0.36 bears/year) (Table 3-2, 3-3). Subadult females were the second largest group captured in the Churchill area (8 ± 0.94 bears/year) and differed from subadult males, solitary adult females, and family groups (Table 3-2, 3-3). Adult males and family groups were captured a median of 6 ± 1.0 bear/year and 4 ± 0.92 bears/year and did not differ from one another but were captured less than subadult males and more than solitary adult females (Table 3-2, 3-3). The median number of adult male captures was greater (6 ± 1.1 bears/year) than the median number of adult females, including both solitary females and female with young (3 ± 0.5 bears/year) (Kruskal-Wallis test: $X^2 = 8.82$, df = 1, $P = 0.003$).

The mean age of adult female bears (≥ 5 years of age, $\bar{x}$: 13 ± 0.37 years) increased over time (linear regression: $F_{1,286} = 18.26$, $P \leq 0.001$, $R^2 = 0.06$). No pattern was detected for adult males (≥ 5 years of age, $\bar{x}$: 10 ± 0.35 years) (linear regression: $F_{1,270} = 0.089$, $P = 0.77$). Examining solitary adult female bears ($\bar{x}$: 12.7 ± 0.88 years) and adult females with young ($\bar{x}$: 13 ± 0.37 years) separately, the mean age of adult female bears with young captured increased over time (linear regression: $F_{1,201} = 15.82$, $P \leq 0.001$, $R^2 = 0.07$).

3.3.3 Distance to the Churchill area

Of the 977 problem bears captured in the Churchill area, 151 were captured from 11 July to 28 October, 1986-2004, in the larger study area before being captured in the Churchill area in the same year. Overall distance between the first capture in the larger study area and the centre of the Churchill area for bears of 5 different age- sex- and reproductive-classes 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 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). There was no difference in mean distance to the Churchill area between the polar bear classes (one-way ANOVA: $F_{4,150} = 1.59$, $P = 0.18$). Mean distances to the Churchill area did not change over time (linear regression: $F_{1,149} = 0.77$, $P = 0.38$). No temporal trend was detected in the mean distances to the Churchill area when examining the 5 different polar bear classes (linear regression: adult males: $F_{1,26} = 0.173$, $P = 0.68$; solitary adult females: $F_{1,3} = 0.34$, $P = 0.6$; family groups: $F_{1,30} = 0.59$, $P = 0.45$; subadult females: $F_{1,22} = 0.11$, $P = 0.75$; subadult males: $F_{1,60} = 0.22$, $P = 0.64$).

One hundred and forty-four bears of the 151 were used when examining where problem bears were coming from before being caught in the Churchill area (7 locations were removed as outliers). The mean distance of bears moved to the Churchill area was 76 ± 3 km (n = 144, range: 23 - 180 km). The mean distance of bear observations was significantly ($P < 0.001$) less than the lower 90% confidence interval (106 km) of the mean random distances. Therefore, problem polar bears are distributed closer to the Churchill area compared to a random sample ($\bar{x} = 112$ km).

Distance was related to the chances of becoming a problem bear (likelihood ratio [2(LL full model – LL reduced model)] = 20.88, df = 1, $P < 0.001$) and was useful to the model (logistic regression: $P \leq 0.001$). Hosmer and Lemeshow (1989) goodness-of-fit test showed that the model fits well ($X^2 = 6.23$, df = 8, $P = 0.62$). The probability of becoming a problem bear is represented by the logistic function $\pi(x)$,

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

where the exp is the notation to exponentiate a function, and x is the explanatory variable, (i.e., distance from the Churchill area). The logistic regression output provides an estimate for the probability of becoming a problem bear as a function of distance (Figure 3-4).

3.3.4. Environmental variables

Univariate analyses indicated that freeze-up dates ($F_{1,28} = 5.43$, $P = 0.02$, $R^2 = 0.16$), 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 significantly related to the number of problem bears caught in the Churchill area each year. No correlation was found between all 3 variables ($P > 0.17$). Placing the 3 significant variables into a forward stepwise regression, only the freeze-up date was entered into the model (multiple regression: $F_{1,28} = 5.43$, $P = 0.03$, $R^2 = 0.16$, Figure 3-5).

3.4. Discussion

In Churchill, Manitoba there is a long history of interactions with humans because the polar bears spend approximately 4-5 months (i.e., July to November) on-land waiting for the sea ice to reform (Stirling et al. 1977). There has been an increase in the number of problem bears each year and across all age- sex- and reproductive-classes. Since the last studies on problem bears were conducted in the 1980s (Lunn and Stirling 1985; Kearney 1989; Leonard 1989) significant changes have occurred in polar bear habitat, prey, and the bear population itself (Skinner et al. 1998; Parkinson et al. 1999; Stirling et al. 1999, 2004; Gagnon and Gough 2005; Ferguson et al. 2005; Stirling 2005; Regehr et al. in press). Based on these findings I propose 4 factors, not necessarily mutually exclusive, that may be responsible for the rising number of problem bears: 1) population increase of bears, 2) changes in the management program, 3) increased nutritional stress, and 4) shift in distribution.

The rise in problem bear numbers could be interpreted as a population increase and the increasing mean age of adult females would also support this interpretation (Bunnell and Tait 1981; Fraser et al. 1982; Harris and Metzgar 1987; Stirling 2002; Derocher 2005); however, the population is declining (Regehr et al. in press). After harvest controls were implemented in the mid-1960s (Stirling et al. 1977), the population appeared to be recovering and become relatively stable (Lunn et al. 1997; Stirling et al. 2004) however Regehr et al. (in press) documented a decline in the population since the late 1980s with the greatest loss in the adult male bears. The increasing mean age of adult females with young is contrary to what is predicted in a declining population (Bunnell and Tait 1981; Amstrup et al. 1986; Derocher 2005) and may result from either reduced recruitment into the problem bear segment of the population or increased survival of adult females. The population decline argues against the latter thus reduced recruitment is a likely reason for the increase in mean age. Further research needs to address the age structure as whole to determine if lack of recruitment into the problem bear segment is indeed the reason. A population increase can be discounted as a factor responsible for the increase in problem bear numbers.

The second reason proposed is the change in the Polar Bear Alert Program management policies. Prior to 1985, the policies reflected a control program; however after 1985 the policies were revised and the program focused on preventing and mitigating human-bear interactions (Kearney 1989). The decline in the number of problem bears killed reflects the changing nature of the program. Conservation officers were more adept at capturing bears and more aggressive in delivering the program. The change in management may partially be responsible for the increasing number of problem bears however how much of a contributing factor it is, is difficult to assess because of poor documentation and the lack of statistics on the catch per unit effort.

Increased nutritional stress of polar bears is another and more plausible reason explaining why more bears are showing up in Churchill. Since the early 1980s the condition of adult bears and reproductive rates has declined which could be interpreted as bears being nutritionally stressed (Derocher and Stirling 1995b; Stirling and Lunn 1997). When primary food sources are not available or are limited animals switch to alternative food sources (Ben-David et al. 1997; McDonald and Fuller 2005). In *Ursus* species alternative foods typically involves moving into human populated areas (Rogers 1989; Mattson et al. 1992; Samson and Huot 1998; Rajpurohit and Krausman 2000; Gunther et al. 2004; Oka et al. 2004). The increase number of bears in Churchill may be related to animals searching for alternative food sources.

Subadult male bears were the most common age- and sex-class to frequent the Churchill area similar to the findings of Kearney (1989). Subadult males causing more problems than any other age- and sex-class is documented in other polar bear populations (Stenhouse et al. 1988; Lee and Taylor 1994) and in other *Ursus* species (Dau 1989; Garshelis 1989; Clark et al. 2002). Subadults have higher energetic demands (e.g., growth) and may be more prone to nutritional stress compared with other age- and sex-classes (Lunn and Stirling 1985; Mattson 1990) thereby increasing their chances of interacting with humans. In contrast to Kearney (1989), more adult male were being captured as problem bears compared with adult female bears however, females with young still show up more than adult males. It was previously thought that adult males did not show up as much as in the Churchill captures because their energetic demands were less compared to other age- and sex-classes and need not search for alternative foods in Churchill (Lunn and Stirling 1995). More adult males being captured as problem animals and their declining condition (Derocher and Stirling 1995b) suggest they have insufficient fat reserves to sustain themselves over the on-land period. Given the link between ice break-up and bear condition (Stirling et al. 1999) suggests that problem bears are most likely increasing due to changing climatic conditions.

Similar to the findings of Kearney (1989), most bears were only captured once in the Churchill area suggesting a learned behaviour to avoid the area (Kearney 1989) or it could be reflective of the management program pertaining to relocation of problem individuals. The pattern of high capture years followed by a low capture year may be related to problem bears being killed as part of the Nunavut harvest sometime after being relocated north of Churchill whereby they are removed from the problem bear population. Nunavut harvests an average of 49.2 bears/year (IUCN/SSC Polar Bear Specialists Group 2002). Because of the management implications, further research needs to examine the proportion of relocated bears killed as part of the Nunavut harvest.

Variation in weather is an important factor when considering human-wildlife conflicts. Sea ice, the primary habitat of polar bears (Martin and Jonkel 1983), is a variable habitat changing seasonally and annually as a function of climate and significant changes in sea ice conditions will affect species dependent upon it (Stirling and Derocher 1993; Tynan and Demaster 1997; Stirling et al. 1999; Stirling and Smith 2004; Derocher et al. 2004; Gilchrist and Mallory 2005; Laidre and Heide-Jorgensen 2005). 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, 2004, Gagnon and Gough 2005).

The presence of sea ice and the amount of time bears spend on the ice until break-up is critical because it provides a platform from which they hunt seals (Stirling and Archibald 1977; Smith 1980) and accumulate fat reserves. A shortened sea ice season limits the amount of fat bears are able to store and results in fewer reserves to live off during a prolonged on-land period. The decline in adult bear condition in western Hudson Bay (Derocher and Stirling 1995b) was linked to earlier break-up (Stirling et al. 1999). Freeze-up was a better explanatory variable of the number of problem bears; however, break-up, and the AO were also important. In anticipation of sea ice formation along the northern coast of the Hudson Bay in mid-November the bears begin to travel north in September and October (Derocher and Stirling 1990a). As the season progresses, more bears congregate along the northern coast (Latour 1981; Derocher and Stirling 1990b) and if freeze-up is delayed more bears will be waiting along the coast and the potential for bears to roam into the town site and/or the dump and interacting with humans is greater (Stenhouse et al. 1988; Kearney 1989). As soon as the ice reforms sufficiently the bears head out onto the ice and begin hunting. Zack et al. (2003) found a relationship between the El Niño-Southern Oscillation and the relative encounter rates of black bears with humans in New Mexico. Other studies have demonstrated the influence of weather on human-wildlife interactions (e.g., Rutherglen and Herbison 1977; Garshelis 1989; Mech et al. 1988; Oka et al. 2004).

The last reason explaining the increase in the number of problem bears in Churchill is the northward shift in distribution of the western Hudson Bay population which was linked to the AO (Chapter 2). Analyses showed bears that caused problems were in closer proximity to the Churchill area before being captured in Churchill and bears that were closer to town were more likely to become a problem. The continued warming of the climate and shifting sea ice conditions may result in more problem bears if the population continues to shift north. Northward shifts in distribution relative to a changing climate have been predicted and documented in many other species (Payette 1987; Hersteinsson and Macdonald 1992; Thomas and Lennon 1999; Parmesan et al. 1999; Humphries et al. 2002; Root et al. 2003). If polar bears continue to be food stressed and condition continues to decline, more problem bears may result. It is clear the population increase hypothesis is not the reason for the increase number of problem bears and while the change in management may account for some of the increase, the likely reasons based on the data are the increased food stress of the bears and northward shift of the population which are related ultimately to climate change.

3.5. Conclusion

Understanding bear behaviour relative to a changing climate is necessary for implementing effective management strategies to reduce interactions with humans. Determining the factors that promote human-bear conflicts and removing them or being able to predict the magnitude of problems in a given year will help in the conservation of the western Hudson Bay polar bear population. Determining the factors influencing the number of problem bears in Churchill will enable wildlife managers to make effective management decisions such as the number of personnel to hire and resources needed to deal with problem bears. Changes in the Polar Bear Alert Program procedures and policies should reflect changes that are occurring in the Hudson Bay environment and the polar bear population to maintain effectiveness. Continued monitoring of the western

Hudson Bay population is essential because the population has declined and there may be several confounding factors at play, such as climate change, the increase in the Nunavut harvest, tourism, and the recent closing of the Churchill dump.

3.6. Literature Cited

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Table 3-1. The number of polar bears by age- sex- and reproductive-class captured in the Churchill area from July to December, 1970-2004.

Year	Adult males	Solitary adult females	Family groups	Subadult females	Subadult males	Total
1970	2	1	2	7	11	23
1971	3	0	9	15	11	38
1972	4	1	3	10	14	32
1973	1	2	2	7	8	20
1974	4	1	6	9	15	35
1975	5	2	5	5	14	31
1976	6	2	5	11	17	41
1977	2	2	3	8	12	27
1978	0	1	3	2	8	14
1979	4	0	5	4	10	23
1980	2	0	4	2	5	13
1981	3	0	3	4	8	18
1982	1	0	5	7	12	25
1983	11	6	8	17	16	58
1984	0	1	4	3	2	10
1985	15	4	5	18	27	69
1986	2	0	3	4	10	19
1987	6	2	3	8	9	28
1988	6	1	4	2	14	27
1989	6	3	2	8	25	44
1990	20	4	4	8	21	57
1991	4	1	1	4	5	15
1992	13	3	4	6	19	45
1993	5	5	1	14	24	49
1994	13	3	8	15	18	57
1995	4	1	4	6	10	25
1996	11	6	6	22	33	78
1997	15	3	14	17	30	79
1998	15	5	14	12	30	76
1999	11	7	9	17	18	62
2000	11	3	2	8	17	41
2001	14	2	28	16	15	75
2002	19	2	8	16	23	68
2003	23	8	19	13	27	90
2004	11	3	7	18	36	75
Total	272	85	213	343	574	1487

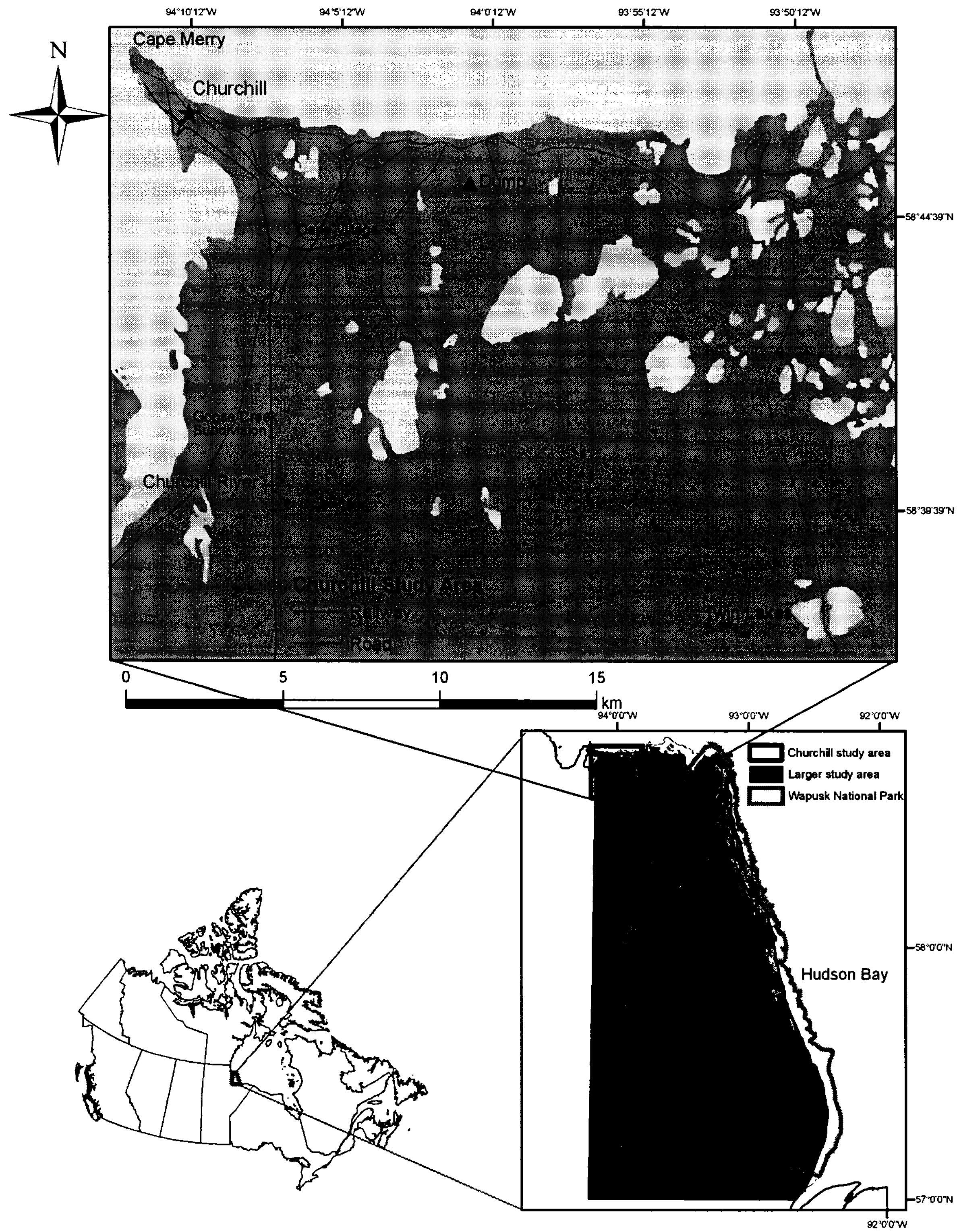
Table 3-2. The number of bears captured and the age of polar bears by different age- sex- and reproductive-classes in the Churchill area from July to December, 1970-2004.

	Number of bears captured	Ages
Adult males		
n	272	272
Mean (SE)	7.8(1.0)	10(0.35)
Median	6	8
Min	0	5
Max	23	26
Solitary adult females		
n	85	85
Mean (SE)	2.4(0.36)	13(0.88)
Median	2	9
Min	0	5
Max	8	31
Family groups		
n	213	203
Mean (SE)	6.1(0.92)	12(0.37)
Median	4	13
Min	1	4
Max	28	26
Subadult females		
n	343	343
Mean (SE)	9.8(0.94)	2(0.05)
Median	8	1
Min	2	2
Max	22	4
Subadult males		
n	574	574
Mean (SE)	16.4(1.4)	2(0.04)
Median	15	1
Min	2	2
Max	36	4

Table 3-3. Mann-Whitney U test of the differences in the median number of polar bears of the different age- sex- and reproductive-classes in the Churchill area, 1970-2004. Numbers in the cells represent U statistic and the corresponding P value. Bolded cells represent significant results.

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

Figure 3-1. The focal study area located near Churchill, Manitoba along the western coast of Hudson Bay in northeastern Manitoba (Churchill area, square below) and the larger study area extends south of Churchill (bottom right).



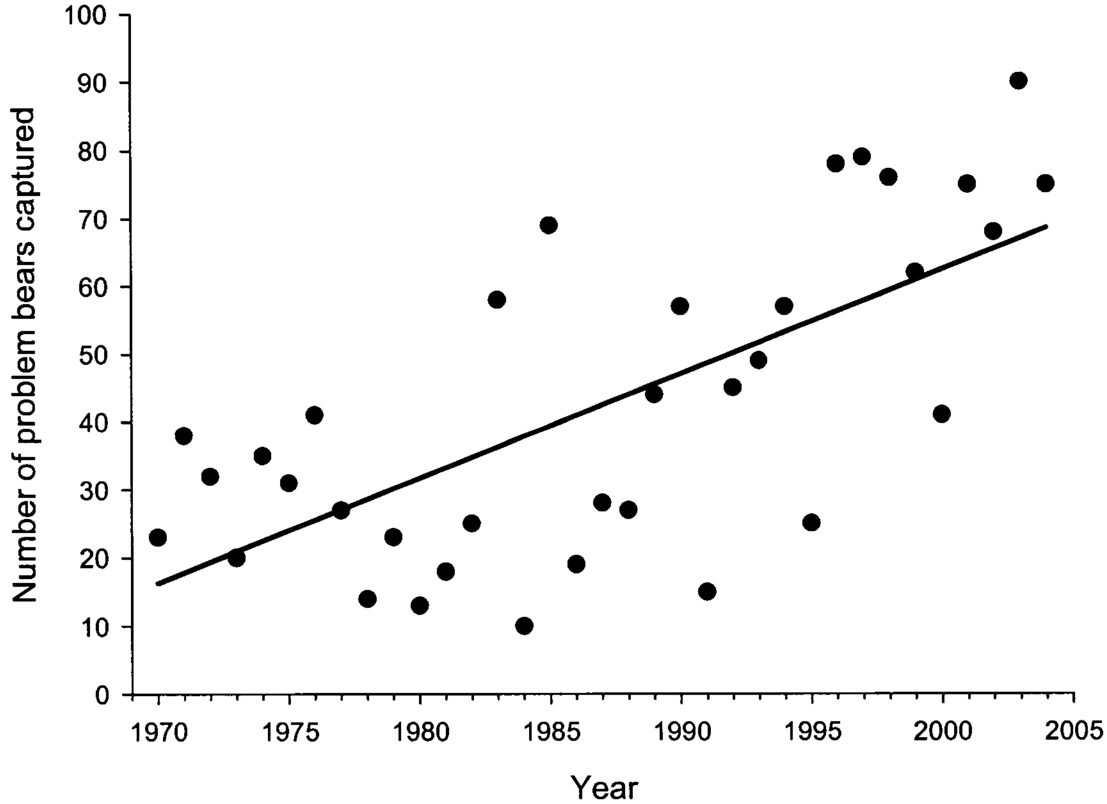


Figure 3-2. Relationship of the number of problem bears captured from July to December over time, 1970-2004. The straight line indicates linear regression.

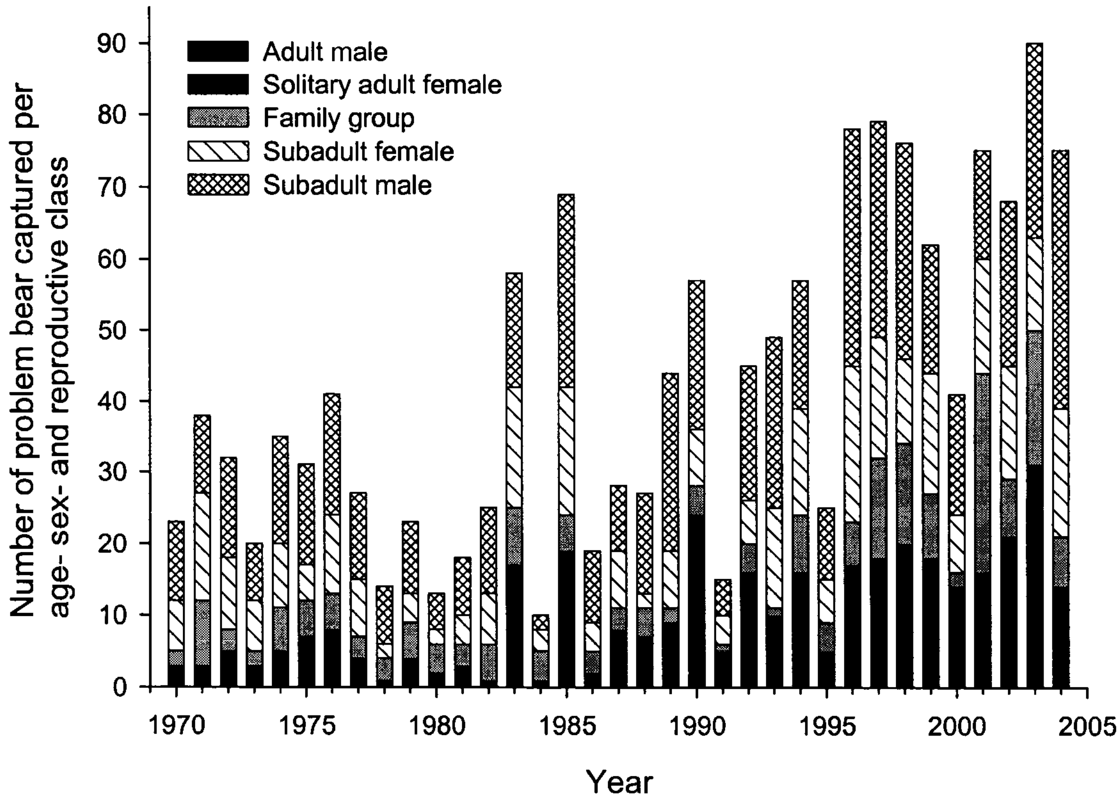


Figure 3-3. The number of captures of the 5 different polar bear age- sex- and reproductive-classes in the Churchill area from July to December, 1970-2004.

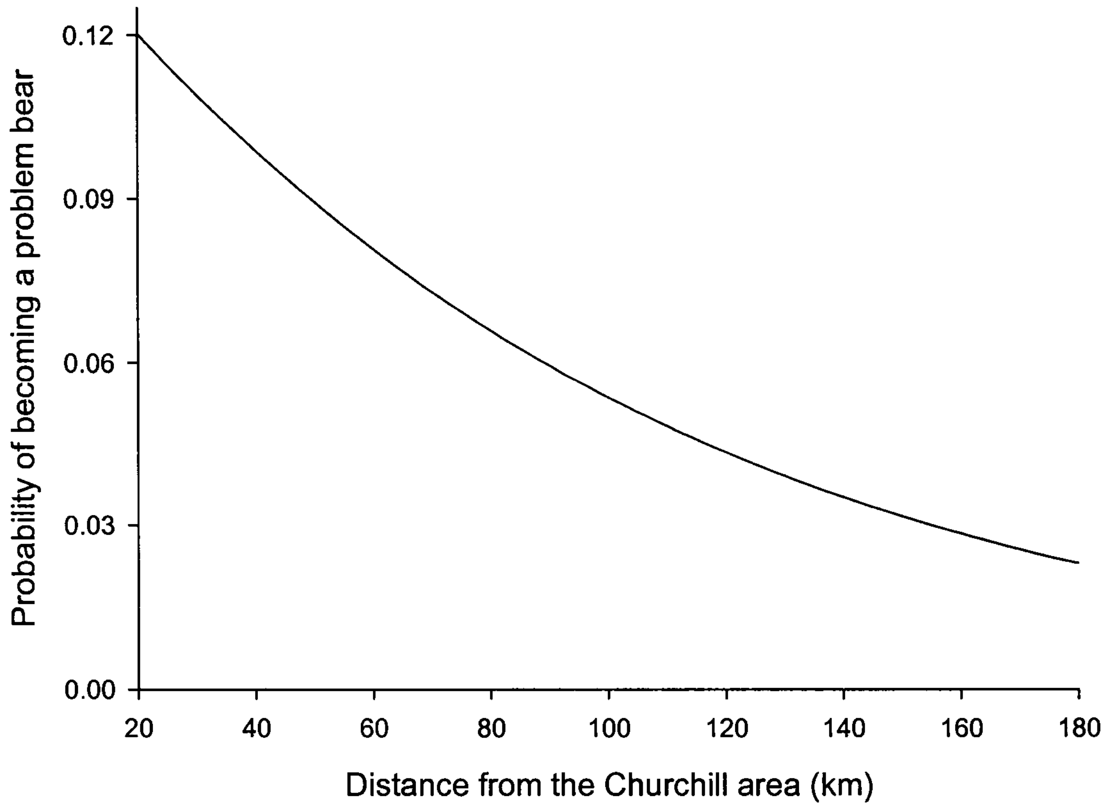


Figure 3-4. Logistic regression on estimating the probability of polar bears becoming a problem as a function of distance from the Churchill area (see text for details). Probability of becoming a problem bear decreases as distance increases away from the Churchill area.

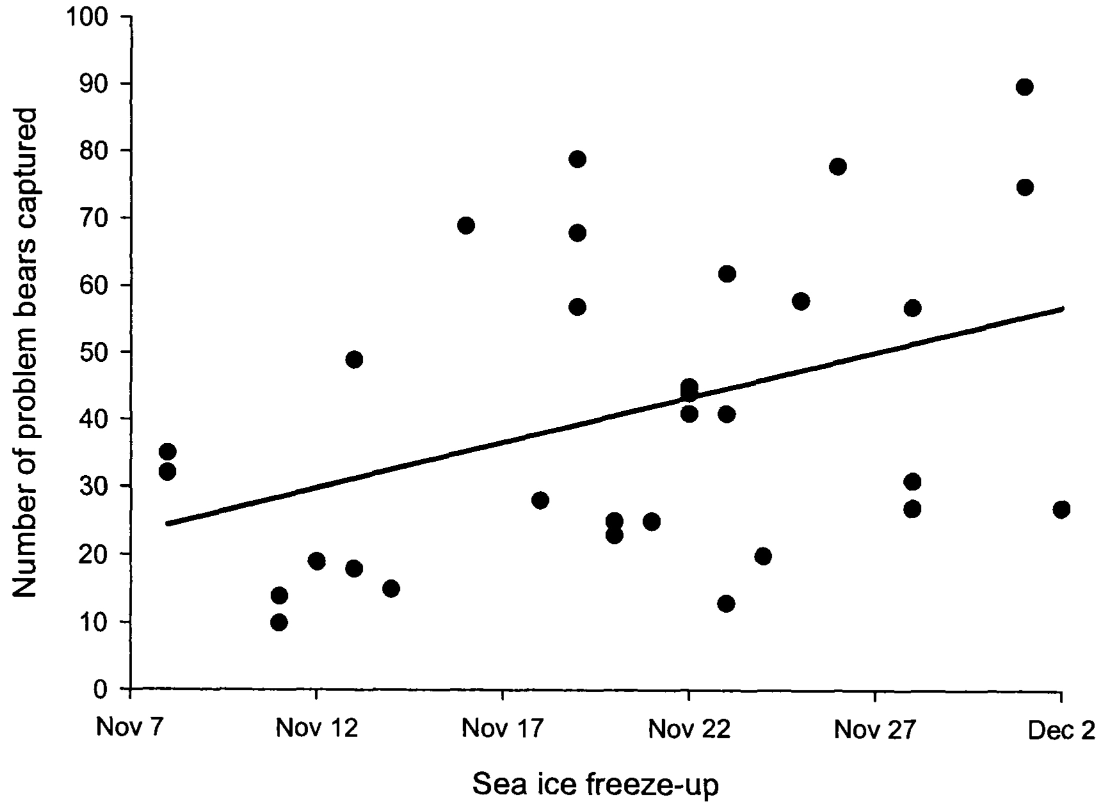


Figure 3-5. Relationship between the number of problem bears captured in the Churchill area from July to October and sea ice freeze-up, 1971-2003. The straight line indicates linear regression.

Chapter 4. SYNTHESIS AND IMPLICATIONS

4.1. Summary

My objectives in this thesis were to describe the long-term patterns of polar bear (*Ursus maritimus*) distribution in western Hudson Bay during the ice-free season relative to environmental variables, using both local-scale (i.e., sea ice break-up) and large-scale (North Atlantic Oscillation (NAO), Arctic Oscillation (AO)) climate indices, and to examine the temporal and spatial patterns of problem bears near Churchill, Manitoba relative to environmental variables. The distribution of polar bears has shifted north and east over 1986-2004 and these changes were correlated with environmental variables. The eastward shift was correlated with sea ice break-up and the winter index of the NAO and the AO index. The ice is breaking up progressively earlier over time (Stirling et al. 2004; Gagnon and Gough 2005b), and as a result the bears are coming ashore in poorer condition (Stirling et al. 1999) and not traveling as far inland as they once did (Chapter 2) suggesting bears are conserving energy by using less energy from already depleted fat stores during the on-land period. Similar to earlier studies (Stirling et al. 1977; Latour 1981; Derocher and Stirling 1990; Ramsay and Stirling 1990) the population remains segregated; however shifts in distribution suggests the bears have a degree of behavioural plasticity. The higher proportion of female bears with young near the coast in 2002-04 compared with 1986-2001 is further evidence of changes in the behaviour of the bears.

The northward shift in bear distribution, also related to the winter AO index brings the bears in closer proximity to Churchill. Given that distance from the town was related to the probability of becoming a problem bear, the shift is likely part of the reason for the increased number of problem bears. Another likely reason for more problem bears over time is linked to the nutritional ecology of the bear. Condition of adult bears is declining (Derocher and Stirling 1995) therefore the bears are more prone to food stress and move searching for alternative food sources. A recent study by Parks (2005) found that home range size of the western Hudson Bay population had declined and suggested the proximate cause may be decreased prey intake while on the sea ice which ultimately could be due to warming climate. The date of sea ice formation explained some of the yearly variation in the number of problem bears suggesting changes in climatic conditions plays a role in human-bear interactions.

4.2. Future Research

Weather influences the distribution, movements, and population dynamics of polar bears (Stirling et al. 1999; Ferguson et al. 2000; Mauritzen et al. 2003; Regehr et al. in press) but to be able to understand the effects of global climate change on both individual behaviour and population dynamics, the relationships between polar bears and the NAO and AO should be explored further. Studies should incorporate large-scale phenomena because they are a major component of global change (Hurrell 1995) and may allow predictive capacity to understand polar bear responses to a changing climate.

Energy conservation may become an increasingly important response for polar bears during the ice-free period if climate continues to warm. Temperatures are rising in western Hudson Bay (Skinner et al. 1998), prolonging the ice-free season (Parkinson et al. 1999; Gough et al. 2004; Gagnon and Gough 2005b), and affecting the reproduction and survival of the ringed seal (*Phoca hispida*) population (Ferguson et al. 2005; Stirling 2005). A better understanding of the distribution and abundance of ringed seals and other prey species, such as bearded seals (*Erignathus barbatus*) (Smith 1980) in Hudson Bay is required. Thus further research can be conducted on the distribution and movements of polar bears relative to prey, and the amount of energy bears intake before they are forced ashore.

Although fidelity is important to the western Hudson Bay population (Stirling et al. 1977; Derocher and Stirling 1990; Ramsay and Stirling 1990), the closer proximity of female bears with young to the coast may warrant further examination relative to reproductive success. Adult females travel inland to preferred denning habitat to give birth to young (Clark and Stirling 1998; Richardson et al. 2005) and adult females with young return to the denning area to familiarize their young with the area (Derocher and Stirling 1990). However, family groups are not moving as far inland, perhaps to conserve energy and/or fill the niche of adult male bears since their numbers are in decline (Regehr et al. in press). Adult females not teaching their young the location of the denning area could affect future reproductive rates and distribution patterns.

I only examined the effects of environmental variables on the temporal patterns of distribution in the western Hudson Bay population; however, other factors may be involved. Changes in the population structure (Derocher et al. 1997; Regehr et al. in press) are possibly fruitful areas for future research. Further, studies need to separate the effects of climate from the effects of a change in population structure to understand the factor(s) responsible for the changes in polar bear distribution. The condition of bears that become problem animals should be compared to those that do not. Comparing the mass of these two groups of bears earlier in the ice-free season might provide insight into the reasons why bears move to Churchill. With the closing of the dump in 2005, continued monitoring of the problem bear situation and the population as a whole will be critical. Craighead and Craighead (1971) found after the closure of the Yellowstone dumps there was a drastic increase in the probability of human-bear interactions and increased mortality rates of bears.

Another issue to explore further is the reason(s) why the majority of bears only show up once in Churchill. One possibility is bears handled as a problem and relocated north of Churchill later in the season are killed as part of the Nunavut harvest. Such investigations will have management implications for the Polar Bear Alert Program whereby changes in the policies may be required.

4.3. Management Implications

Changes in the distribution and population dynamics of polar bears (Derocher and Stirling 1995; Stirling and Lunn 1997; Stirling et al. 1999; Regehr et al. in press) will likely affect the abundance of bears and age- and sex-classes (i.e., adult males) having ramifications on the tourist industry in Churchill, Manitoba. Tourism in Churchill depends on both the distribution and abundance of polar bears and management decisions will affect the bears and the tourism industry as well. Changes in management strategies should consider the viability of the bear population regardless of the effects on the tourist industry to ensure the conservation of the western Hudson Bay population. To prevent or reduce unnecessary-human caused energy expenditure in bears that are already nutritionally stressed, wildlife managers may need to restrict the number of tundra vehicles out at one time and the distance at which bears are approached. Dyck and Baydack (2004) found the presence of tundra vehicles disrupted the bears resting behaviour.

To develop effective management strategies to reduce human-bear interactions, wildlife managers need to be able to predict the causes, types, locations, and trends of conflicts. The types and locations of conflicts are known (Stirling et al. 1977; Lunn and Stirling 1985; Kearney 1989), but changing climatic conditions can influence the number of problem bears (Chapter 3). Based on environmental indices (i.e., timing of ice freeze-up, break-up, winter AO index) managers may be able to anticipate the relative magnitude of problem bears in a given year and allocate the necessary resources for management (e.g., hiring personnel, appropriate equipment) to deliver an effective program.

The predictions made in the early 1990s about the most southern populations (i.e., Hudson and James Bay) showing the first signs of impact of warming temperatures (Stirling and Derocher 1993) have been detected in the population. Future climate projections predict warming to continue and sea ice to disappear within the near future (Gough and Wolfe 2001; Wigley and Raper 2001; Comiso 2003; Gagnon and Gough 2005a), thus it is important to continue to monitor the western Hudson Bay population to understand the response of the bears to a changing climate.

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Year	Julian Day	Calender Day
1986	178	27 June
1987	195	14 July
1988	**205**	**23 July**
1989	189	8 July
1990	153	2 June
1991	182	1 July
1992	**202**	**20 July**
1993	289	8 July
1994	178	27 June
1995	121	20 June
1996	**184**	**2 July**
1997	175	24 June
1998	166	15 June
1999	174	23 June
2000	**189**	**7 July**
2001	174	23 June
2002	185	4 July
2003	165	14 June
2004	**189**	**7 July**

Appendix A: Dates of sea ice break-up in western Hudson Bay from 1986-2004. Dates highlighted in bold represent leap years (Stirling et al. 1999).

Year	Sea ice break-up		Sea ice freeze-up	
	Julian Day	Calender Day	Julian Day	Calender Day
1971	192	11 July	N/A	N/A
1972	**196**	**14 July**	**311**	**6 Nov**
1973	200	19 July	327	23 Nov
1974	202	21 July	311	7 Nov
1975	199	18 July	331	27 Nov
1976	**189**	**7 July**	**326**	**21 Nov**
1977	181	30 June	335	1 Dec
1978	195	14 July	314	10 Nov
1979	186	5 July	323	19 Nov
1980	**191**	**9 July**	**326**	**21 Nov**
1981	188	7 July	316	12 Nov
1982	200	19 July	324	20 Nov
1983	199	18 July	328	24 Nov
1984	**201**	**19 July**	**314**	**9 Nov**
1985	201	20 July	319	15 Nov
1986	189	8 July	315	11 Nov
1987	201	20 July	321	17 Nov
1988	**200**	**18 July**	**331**	**26 Nov**
1989	190	9 July	325	21 Nov
1990	174	23 June	322	18 Nov
1991	190	9 July	317	13 Nov
1992	**216**	**3 Aug**	**325**	**20 Nov**
1993	189	8 July	316	12 Nov
1994	191	10 July	331	27 Nov
1995	187	6 July	323	19 Nov
1996	**199**	**17 July**	**329**	**24 Nov**
1997	185	4 July	322	18 Nov
1998	185	4 July	N/A	N/A
1999	179	28 June	326	22 Nov
2000	**197**	**15 July**	**325**	**20 Nov**
2001	183	2 July	324	20 Nov
2002	176	25 June	322	18 Nov
2003	185	4 July	334	30 Nov

Appendix B: Dates of sea ice break-up and freeze-up in western Hudson Bay from 1971-2003 calculated from Gagnon and Gough (2005). N/A represents years when sea ice freeze-up occurred after the last Canadian Ice Service ice chart was produced. Dates highlighted in bold represent leap years.