UNIVERSITY OF ALBERTA

Polar bear (*Ursus maritimus*) maternity den site selection and the effects of forest fires on denning habitat in western Hudson Bay

by

Evan Shaun Richardson ©

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ABSTRACT

In western Hudson Bay, polar bears (*Ursus maritimus*) den primarily in riparian areas along banks of lakes, rivers and creeks adjacent to open lichen tundra sites. Habitat characteristics important for the establishment of dens included vegetation cover, slope, bank height and aspect. Forest fires were found to have significant impacts on denning habitat through removal of vegetation and degradation of permafrost that led to a decrease in the stability of denning habitat and increased rate of collapse of dens. Long-term population monitoring, den surveys and satellite movement data all indicate that bears do not use burned areas. Although the availability of maternity denning habitat is likely not limiting in this population at present, the potential threat of increased lightning and forest fire activity as a result of climatic warming could result in significant loss of critical maternity denning habitat and resource managers need to be aware of this potential threat.

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1. INTRODUCTION

Polar bears (*Ursus maritimus*) have a circumpolar distribution, the southern limit of which is determined by the annual distribution of landfast and pack ice during the winter (DeMaster and Stirling 1990). Between 21,500 and 25,000 polar bears occur worldwide in 20 relatively discrete populations across 5 northern nations (Lunn *et al.* 2002) (Figure 1-1). Throughout most of their range, polar bears make limited use of terrestrial environments remaining on the sea ice year-round preying on ringed seals (*Phoca hispida*) and to a lesser extent bearded seals (*Erignathus barbatus*) (Stirling and Archibald 1977; Smith 1980; Amstrup 2003). However, in Hudson and James bays at the southern portion of their range, polar bears are forced ashore during an extensive ice-free period that lasts from mid-July to early November (Stirling *et al.* 1977) (Figure 1-1).

Polar bears in western Hudson Bay arrive onshore shortly after ice breakup (Stirling *et al.* 1977; Lunn *et al.* 2004). Most adult males and subadults of both sexes remain along the coast, while adult females with and without cubs move inland (Stirling *et al.* 1977; Derocher and Stirling 1990; Lunn *et al.* 2004). Bears remain relatively inactive while on land (Latour 1981; Lunn and Stirling 1985), subsisting on fat deposited during the previous spring (Nelson *et al.* 1983; Derocher and Stirling 1990; Ramsay *et al.* 1991). In November, all polar bears except pregnant females return to the sea ice as it beings to reform (Derocher *et al.* 1993).

Polar bears differ from other ursids in that overwinter dormancy is limited to parturient females that use maternity dens for reproduction (Ramsay and Stirling 1990). Pregnant females remain on land, fasting for up to 8 months using stored fat reserves to meet basic energetic demands as well as the increased energetic demands of gestation and lactation (Watts and Hansen 1987; Polischuk *et al.* 2001). Breeding takes place on the sea ice during spring (Lønø 1970; Ramsay and Stirling 1986) and implantation is delayed until autumn (Mead 1989) when most pregnant females begin to occupy dens (Harington 1968; Messier *et al.* 1994; Ferguson *et al.* 2000; Lunn *et al.* 2004).

While female bears may occupy maternity dens on drifting sea ice (Lentfer 1975; Amstrup and Garner 1994), the majority of maternity dens discovered to date in Canada (Harington 1968; Ramsay and Stirling 1990; Stirling and Andriashek 1992; Messier *et al.* 1994; Ferguson *et al.* 1997), Svalbard (Larsen 1985; Wiig 1995), Greenland (Born *et al.* 1997), and the Russian arctic (Uspenski and Kitchinski 1972; Garner *et al.* 1990) have been found on land. Although females show fidelity to terrestrial denning areas they do not show fidelity to individual den sites (Ramsay and Stirling 1990; Amstrup and Garner 1994; Scottt and Stirling 2002) due to the temporal and spatial variability of most denning habitat (i.e. snow drifts). Generally, throughout most of their range polar bears occupy maternity dens excavated in snowdrifts (Harington 1968; Amstrup 2003). However in the Churchill region of Manitoba bears are believed to give birth to their young in late November and early December (Derocher *et al.* 1992) by which time snowdrifts suitable for the construction of den sites have not formed in most years (Scott and Stirling 2002). In this region, its appears that bears give birth to their young in dens dug into frozen peat which are expanded into overlying snowdrifts later in the winter (Jonkel *et al.* 1972; Ramsay and Stirling 1990; Clark *et al.* 1997). Family groups remain in dens and cubs are nursed to a weight of 10-12 kg (Ramsay and Stirling 1988) before they return to the sea ice in late February and early March (Stirling *et al.* 1977; Ramsay and Stirling 1990; Derocher *et al.* 1993). In the western Hudson Bay population approximately 150-200 females produce cubs each year (Derocher and Stirling 1995). Scott and Stirling (2002) estimated more than 90% of these bears den in the area south of Churchill (see Figure 1-2).

The denning areas south of Churchill Manitoba is approximately 8300 km^2 in size and represents one of the three largest known polar bear denning areas in the world (Figure 1-1). The estimated size of the denning area represents current knowledge of the distribution of polar bear den sites recorded by the Canadian Wildlife Service over the last 30 years. Denning in the Churchill region was first reported by Hearne (1795), although Jonkel *et al.* (1972) were the first to describe the use of earth dens in the study area. The Churchill denning area is located in the broad transition zone between the boreal forest and the arctic tundra (Ritchie 1960; Brook 2001). Much of the region is underlain by continuous permafrost, resulting in poor drainage and extensive bogs and fens (Brook 2001). Inland areas are characterized by open lichen tundra, numerous lakes and small tundra ponds. Forest cover is restricted to riparian areas along the edge of lakes, rivers and streams. Coastal areas are dominated by sedge meadows and salt marshes interspersed with relict beach ridges. Most of the denning area lies within the Cape Churchill Wildlife Management Area and Wapsuk National Park. Thus, denning polar bears in this area are protected under both provincial and federal jurisdictions.

Disturbance of bears in maternal dens as a result of natural or anthropogenic causes may lead to den relocation or abandonment of dens and reduced survival of young (Ramsay and Stirling 1986; Amstrup 1994; Durner *et al.* 2003). Anthropogenic disturbances can potentially be prevented through spatial and temporal management of human activities (Amstrup 1994), whereas the dynamic nature of natural disturbances may preclude preventative measures in most situations. Stirling and Derocher (1993) suggested that climate change could potentially affect maternity denning through (i) changes in the distribution of sea ice which could limit access to terrestrial denning areas and (ii) unseasonably early rains which could lead to the collapse of maternity dens in snow. To date, only one observation on the collapse of a maternity den site has been reported in the literature (Clarkson and Irish 1991). However, observations made by Stirling and Smith (2004) on subnivean seal lairs along the southeastern coast of Baffin Island revealed that warmer spring weather and unseasonably early rainfall can result in extensive slumping and collapse of snow lairs.

Changes in sea ice conditions over the past two decades have led to significant declines in physical condition of bears as well as cub production in the western Hudson Bay population (Stirling *et al.* 1999). Denning female polar bears in this region may already endure the longest period of food deprivation of any mammal (Amstrup 2003) and rely on dens in the permafrost to conserve energy throughout the ice-free period in both the warm weather of summer and the cold weather of winter. Consequently, any significant changes in the availability of suitable denning habitat may impact the reproductive success of this population. Recently, several large fires have burned through the denning area south of Churchill destroying extensive areas of denning habitat. Current research suggests that lightning strikes, the primary ignition source of fires in the Churchill area, as well as the frequency and extent of fires will increase in the region as a result of climate change (Flannigan and Van Wagner 1991; Price and Rind 1994; Flannigan *et al.* 1998; Flannigan et al. 2000). Additional climate change research by Gough and Leung (2002) indicates that the Hudson Bay region is at risk to permafrost degradation with the potential for substantial reductions of permafrost over the next 50 years. This may affect denning habitat through slumping of banks and changes in drainage patterns which may alter the susceptibility of denning habitat to fire. Trends towards warmer spring air temperatures in the region (Skinner *et al.* 1998) could further extend the fire season increasing the threat of this natural disturbance. Collectively, these factors could have significant impacts on the availability of suitable denning habitat in the western Hudson Bay.

As denning is necessary for polar bear reproduction, protection of maternity denning habitat is crucial. Destruction of maternity denning habitat may limit the availability of suitable den sites and could in time have a significant negative affect on reproductive success. Despite the ecological significance of these sites, our current knowledge of maternity den site selection, the availability of suitable denning habitat and the potential long-term affects of fire on denning habitat in the denning area south of Churchill is inadequate. Addressing these issues is essential to facilitate protection of maternity denning habitat near the northeastern coast of Manitoba, as well as expand our knowledge of denning ecology of polar bears.

The objectives of this thesis are to identify critical denning habitat for polar bears in western Hudson Bay, and to determine the effects of forest fires on denning habitat. The second chapter of this thesis describes in detail polar bear maternity den site selection and makes use of resource selection functions to map the relative probability a given location in the study area may be used as maternity denning habitat. Chapter 3 describes the impacts of forest fires on polar bear maternity denning habitat, forest fire dynamics within the denning area and the potential threat of increased habitat loss as a result of climate change in the western Hudson Bay. Finally, chapter 4 is a summary of thesis findings and contains management recommendations for the conservation of polar bear maternity denning habitat in the western Hudson Bay.

1.1. Literature Cited

Amstrup, S.C. 2003. Polar bear (*Ursus Maritimus*). Pages 587-610 *in* Feldhamer, G.A. Thompson, B.C., and Chapman, J.A. Wild Mammals of North America: Biology, Management and Conservation.

Amstrup, S.C., and Gardner, C. 1994. Polar bear maternity denning in the Beaufort Sea. Journal of Wildlife Management 58:1-10.

Born, E.W., Wiig, O., and Thomassen, J. 1997. Seasonal and annual movements of radio-collared polar bears (*Ursus maritimus*) in northeast Greenland. Journal of Marine Systems 10:67-77.

Brook, R.K. 2001. Structure and dynamics of the vegetation in Wapusk National Park and the Cape Churchill Wildlife Management Area of Manitoba: community and landscape scales. Masters of Natural Resource Management University of Manitoba. 290pp.

Clark, D.A., Stirling, I., and Calvert, W. 1997. Distribution, characteristics, and use of earth dens and related excavations by polar bears on the western Hudson Bay lowlands. Arctic 50:158-166.

Clarkson, P.L., and Irish, D. 1991. Den collapse kills female polar bears and two newborn cubs. Arctic 44:83-84.

Derocher, A.E., and Stirling, I. 1990. Distribution of polar bears (*Ursus maritimus*) during the ice-free period in western Hudson Bay. Canadian Journal of Zoology 68:1395-1403.

Derocher, A.E., and Stirling, I. 1995. Estimation of polar bear population size and survival in western Hudson Bay. Journal of Wildlife Management 59:215221.

Derocher, A.E., Stirling, I., and Andriashek, D. 1992. Pregnancy rates and serum progesterone levels of polar bears in western Hudson Bay. Canadian Journal of Zoology 70:561-566.

Derocher, A.E., Andriashek, D., and Stirling, I.. 1993. Terrestrial foraging by polar bears during the ice-free period in western Hudson Bay. Arctic 46:251-254.

Demaster, D.P., and Stirling, I. 1990. *Ursus maritimus*. Mammalian Species 145:1-7.

Durner, G.M., Amstrup, S.C., and Fishbach, A. 2003. Habitat characteristics of polar bear terrestrial maternal den sites in northern Alaska. Arctic 56:55-62.

Ferguson, S.H., Taylor, M.K., and Messier, F. 1997. Space use by polar bears in and around Auyuittuq National Park, Northwest Territories, during the ice-free period. Canadian Journal of Zoology 75:1585-1594.

Ferguson, S.H., Taylor, M.K., Rosing-Asvid, A., Born, E.W., and Messier, F. 2000. Relationships between denning polar bears and conditions of sea ice. Journal of Mammalogy 81:1118-1127.

Flannigan, M.D., and Van Wagner, C.E. 1991. Climate change and wildfire in Canada. Canadian Journal of Forestry Research 21:66-72.

Flannigan, M.D., Bergern, Y., Englemark, O., and Wotton, BM . 1998. Future wildfire in circumboreal forest in relation to global warming. Journal of Vegetation Science 9:469-476.

Flannigan, M.D., Stocks, B.J., and Wotton, B.M. 2000. Climate change and forest fires. The Science of the Total Environment 262:221-229.

Garner, G.W., Knick, S.T., and Douglas, D.C. 1990. Seasonal movement of adult female polar bears in the Bering and Chuckchi seas. International Conference on Bear Research and Management 8:219-226.

Gough, W.A., and Leung, A. 2002. Nature and fate of Hudson Bay permafrost. Regional Environmental Change 2:177-184.

Harington, C.R. 1968. Denning habits of the polar bear (*Ursus maritimus* Phipps). Canadian Wildlife Service Report Series No. 5. 30 pp.

Hearne, S. 1795. A journey from Prince of Wales Fort in Hudson's Bay to the northern ocean in the years 1769, 1770, 1771, and 1772. Toronto: The Champlain Society (1911 edition).

Jonkel, C., Kolenosky, G.B., Robertson, R.J., and Russell, R. 1972. Further notes on polar bear denning habits. International Conference on Bear Research and Management 2:142-158.

Larsen, T. 1985. Polar bear denning and cub production in Svalbard, Norway. Journal of Wildlife Management 49:320-326.

Latour, P.B. 1981. Spatial relationships and behavior of polar bears *Ursus maritimus* Phipps concentrated on land during the ice free season of Hudson Bay. Canadian Journal of Zoology 59:1763-1774.

Lentfer, J.W. 1975. Polar bear denning on drifting sea ice. Journal of Mammalogy 56:716.

Lønø, O. 1970. The polar bear (*Ursus maritimus* Phipps) in the Svalbard area. Norsk Polarinstitutt Skrifter 149:1-115.

Lunn, N.J., and Stirling, I. 1985. The significance of supplemental food to polar bears during the ice-free period of Hudson Bay. Canadian Journal of Zoology 63:2291-2297.

Lunn, N.J., Schliebe, S., and Born, E.W. (comps and eds.) 2002. Polar bears: Proceedings from the 13th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, Nuuk, Greenland. IUCN, Gland, Switzerland and Cambridge, UK. Vii + 153pp.

Lunn, N.J., Stirling, I., Andriashek, D., and Richardson, E. 2004. Selection of maternity dens by female polar bears in western Hudson Bay. Polar Biology (*in press*).

Mead, R.A. 1989. The physiology and evolution of delayed impantation in carnivores. Pages 437-464 *in* Carnivore behavior, ecology, and evolution. Edited by J.L. Gittleman. Cornell University Press. Ithaca, N.Y.

Messier, F., Taylor, M.K., and Ramsay, M.A. 1994. Denning ecology of polar bears in the Canadian Arctic archipelago. Journal of Mammalogy 75:420-430.

Nelson, R.A., Folk, G.E Jr., Pfeoffer, E.W., Craighead, J.J., Jonkel, C.J., and Steiger, D.L. 1983. Behavior, biochemistry, and hibernation in black, grizzly, and polar bears. International Conference on Bear Research and Management 5:284-290.

Polischuk, S.C., Hobson, K.A., and Ramsay, M.A. 2001. Use of stable-carbon and – nitrogen isotopes to assess weaning and fasting in female polar bears and their cubs. Canadian Journal of Zoology 79:499-511.

Price, C., and Rind, D. 1994. Possible implications of global climate change on global lightning distributions and frequencies. Journal of Geophysical research 99:823-831.

Ramsay, M.A., and Stirling, I. 1986. On the mating system of polar bears. Canadian Journal of Zoology 64:2142-2151.

Ramsay, M.A., and Stirling, I. 1988. Reproductive biology and ecology of female polar bears (*Ursus maritimus*). Journal of Zoology (London) 214:601-634.

Ramsay, M.A., and Stirling, I. 1990. Fidelity of female polar bears to winter-den sites. Journal of Mammalogy 71:233-236.

Ramsay, MA., Nelson, R.A., and Stirling, I. 1991. Seasonal changes in the ratio of serum urea to creatinine in feeding and fasting polar bears. Canadian Journal of Zoology 69:298-302.

Ritchie, J.C. 1960. The vegetation of northern Manitoba V. Establishing the major zonation. Arctic 13:211-229.

Scott, P.A., and Stirling, I. 2002. Chronology of terrestrial den is by polar bears in western Hudson Bay as indicated by tree growth anomalies. Arctic 55:151-166.

Skinner, W.R., Jefferies, R.L., Carleton, T.J., Rockwell, R.F., and Abraham, K.F. 1998. Prediction of reproductive success and failure in lesser snow geese based on early season climatic variables. Global Change Biology 4:3-16.

Smith, T.G. 1980. Polar bear predation of ringed and bearded seals in the land-fast sea ice habitat. Canadian Journal of Zoology 58:2201-2209.

Striling, I., and Archibald, W.R. 1977. Aspects of predation of seals by polar bears. Journal of the Fisheries Research Board of Canada 34:1126-1129.

Stirling, I., and Andriashek, D. 1992. Terrestrial maternity denning of polar bears in the eastern Beaufort Sea area. Arctic 45:363-366.

Stirling, I., and Derocher, A.E. 1993. Possible Impacts of climate warming on polar bears. Arctic 46:240-245.

Stirling, I., and Smith, T.G. 2004. Implications of Warm Temperatures and an Unusual Rain Event on the survival of Ringed Seals on the Coast of Southeastern Baffin Island. Arctic 57:(in press).

Stirling, I., Jonkel, C., Smith, P., Robertson, R., and Cross, D. 1977. The ecology of the polar bear (*Ursus maritimus*) along the western coast of Hudson Bay. Canadian Wildlife Service Occasional Paper 33:64 pp.

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

Uspenski, S.M., and Kistchinski, A.A. 1972. New data on the winter ecology of the polar bear (*Ursus maritimus*) on Wrangel Island. IUSN Publications New Series 23:181-197.

Wigg, O. 1995. Distribution of polar bears (*Ursus maritimus*) in the Svalbard area. Journal of Zoology (London) 237:515-529.

Watts, P.D., and Hansen, S.E. 1987. Cyclic starvation as a reproductive strategy in the polar bear. Symposia of the Zoological Society of London 57:305-318.

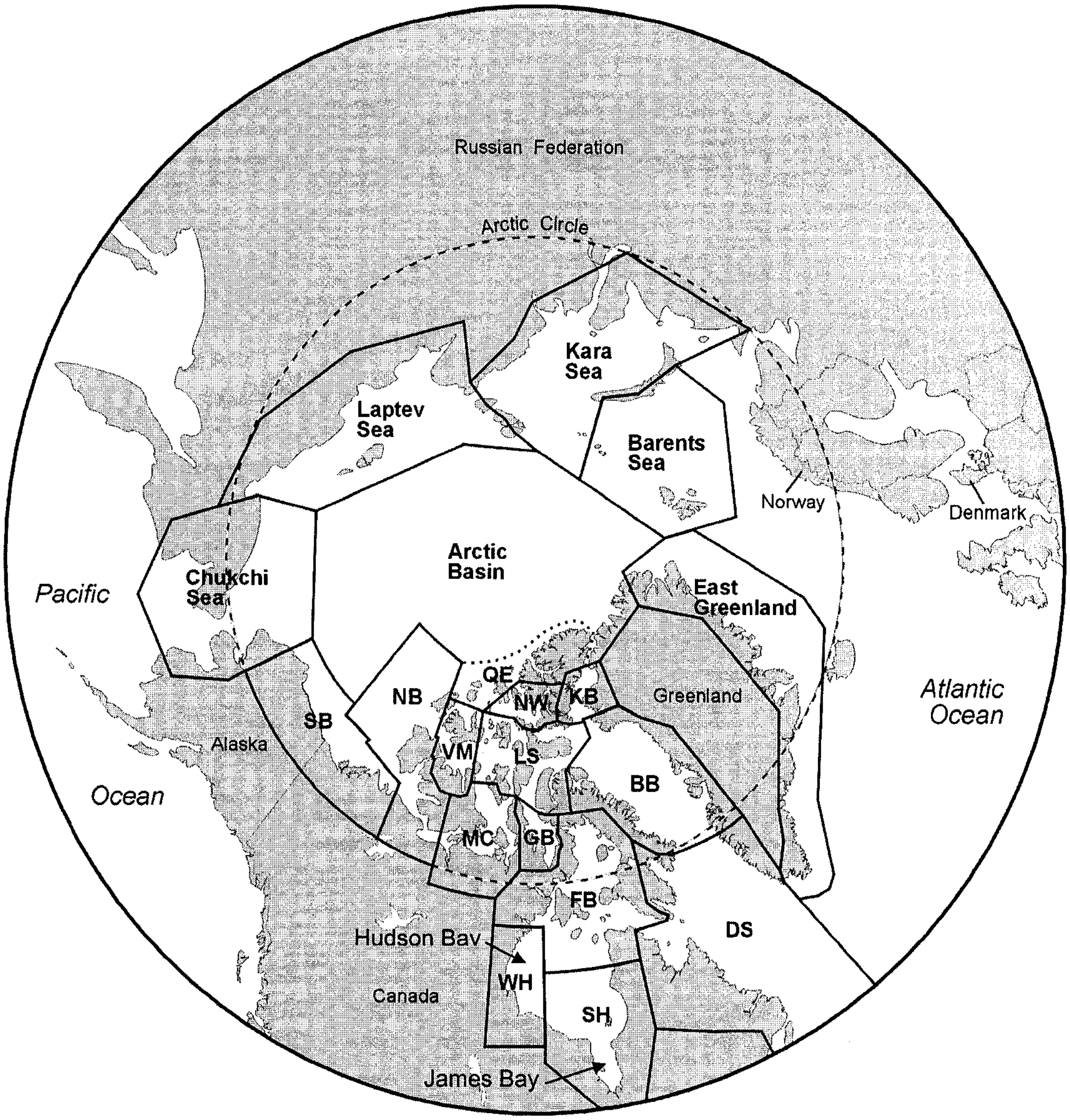

Figure 1-1. Circumpolar distribution of polar bear populations. The study population resides within the western Hudson Bay (WH) boundary. (modified from Lunn *et al.* 2002).

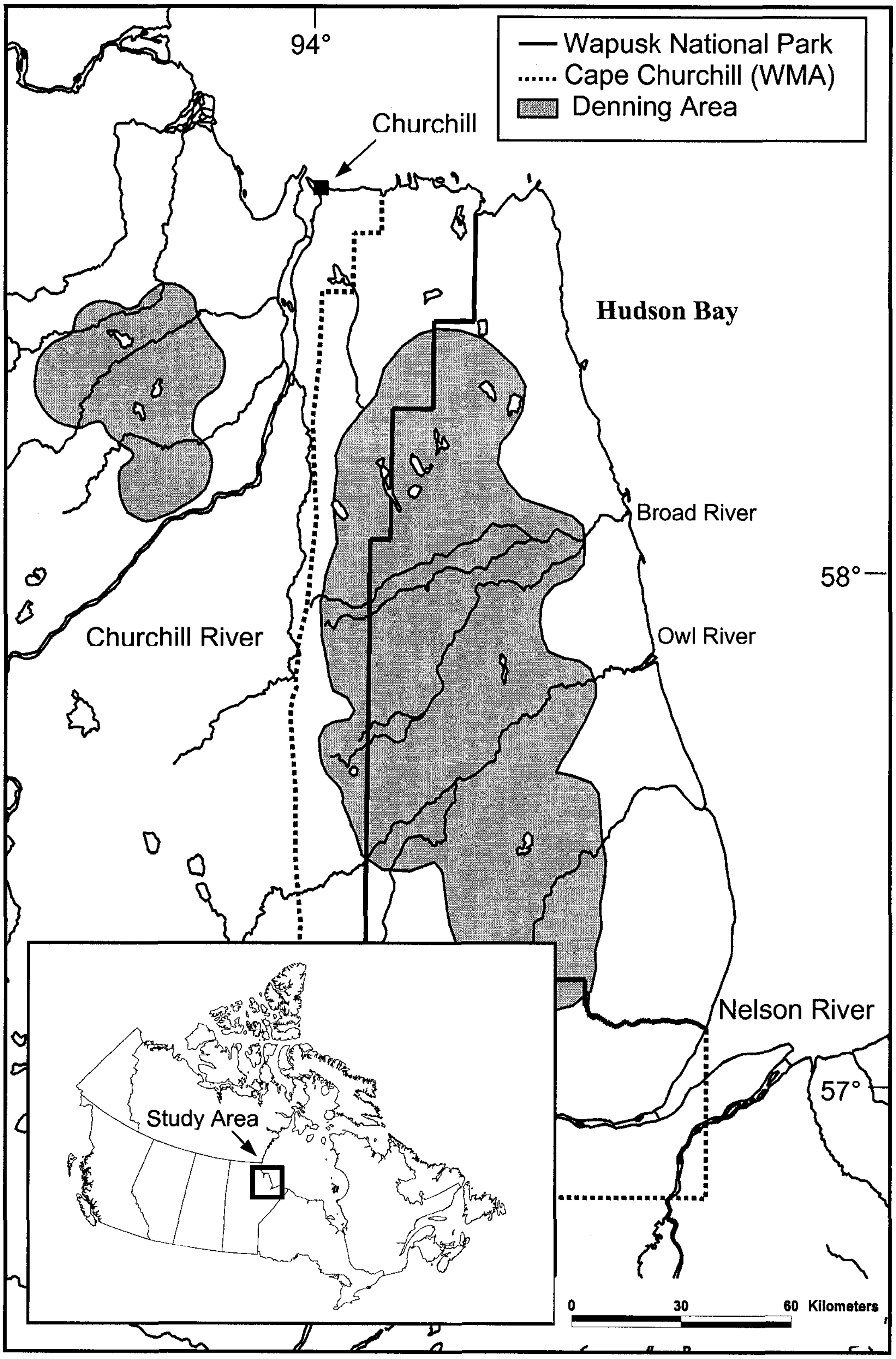

Figure 1-2. Study area located in the Churchill region of Manitoba.

2. POLAR BEAR MATERNITY DENNING HABITAT IN WESTERN HUDSON BAY, CHURCHILL, MANITOBA

2.1. Introduction

Over most of their circumpolar range, female polar bears (*Ursus maritimus*) dig snow dens in which to give birth and nurture their young. These parturition sites provide protection from cold temperatures and are important for the survival and development of cubs (Blix and Lentfer 1979). Previous studies examining maternity den sites have primarily focused on identification of structural aspects and site level habitat characteristics associated with snow dens (Harington 1968; Uspenski and Kistchinski 1972; Lentfer and Hensel 1980; Larsen 1985; Clark *et al.* 1997; Durner *et al.* 2003). In addition, considerable efforts have been made to describe the distribution of denning in relatively localized areas of the Arctic (e.g. Van de Velde OMI *et al.* 2003).

Throughout most of the Arctic, dens are distributed at relatively low densities (Stirling *et al.* 1984) although three areas with high concentrations of dens have also been reported (Uspenski and Ksitchinski 1972; Stirling *et al.* 1977; Larsen 1985). The distribution of dens is considered to be a function of several factors including the availability of suitable denning habitat (i.e. snowdrifts), sea ice conditions, den site fidelity and anthropogenic influences (Schweinsburg 1979; Belikov 1980; Lentfer and Hensel 1980; Hansson and Thomassen 1983; Stirling and Andriashek 1992). Despite the substantial number of studies documenting the distribution of denning areas, little information exists on the availability of suitable denning habitat in relation to the actual distribution of maternity dens. Accurate and predictable identification of denning habitat in most areas to date has been limited to the identification of landscape characteristics where snowdrifts form (e.g. Durner *et al.* 2003).

In the Churchill region of Manitoba, polar bears appear to give birth to their young between mid-November and mid-December (Derocher *et al.* 1992) by which time snow drifts sufficient for the construction of den sites have not yet formed in most years (Scott and Stirling 2003). As a result, polar bears in this region make use of peat dens dug into the permafrost in riparian areas to give birth to their young (Clark *et al.* 1997; Scott and Stirling 2003). To date, research on dens in the western Hudson Bay has focused on the distribution of dens, den site fidelity, structural characteristics, and most recently denning chronology (Jonkel *et al.* 1972; Stirling *et al.* 1977; Ramsay and Stirling 1990; Clark *et al.* 1997; Scott and Stirling 2003). Despite the importance of maternity dens for population recruitment, little is known of the specific habitat requirements and the distribution of such habitat in the study area. The availability of suitable denning habitat is likely critical to the survival of the western Hudson Bay polar bear population (Clark *et al.* 1997), and important areas need to be identified in order to ensure they are conserved in the future. Here I describe den site habitat characteristics in the western Hudson Bay lowlands to determine resource requirements of denning polar bears. Resource selection functions (RSF) (Manly *et al.* 1993) were used to create a predictive model identifying the distribution and abundance of critical denning habitat for use in polar bear management planning.

2.2. Methods

2.2.1. *Locating Dens*

Den sites were located and visited non-selectively throughout the study area (from 57°00' and 58°75'N latitude and 92°25' and 94°75'W longitude) between mid-August and early October 2001 and 2002 while flying in a Bell 206B helicopter during surveys for polar bears, as part of a long-term population study. In addition, den sites were searched for actively throughout the study area as part of this study. Den sites located previous to this study were plotted on topographic map sheets and were also visited opportunistically. The exact location of each den was determined using a Global Positioning System (GPS). Den locations were imported into Arcview 3.2 (Environmental Systems Research Institute, Inc., Redlands, Calif. ESRI) to produce a Geographical Information System (GIS) map layer of the distribution of all dens.

2.2.2. *Den Habitat Characteristics*

Features of relief in which dens were excavated were noted and included lake, creek, and river banks as well as peat hummocks. In addition, the location of each den site on the landform was recorded as being at the top, middle or bottom. The slope along the face of the bank at each den site was measured using an inclinometer. Bank height was measured or calculated as the side of a right triangle using the slope and the length from the top to the bottom of the feature (i.e. hypotenuse length) (Durner *et al.* 2003). Aspect of the den was taken to the nearest degree using a compass. Vegetation cover and physical characteristics were described for each den site. Vegetation composition was measured as the percent cover of each plant species in a 10x10 m plot centered over top of the den. Plant species were further grouped by major life form type (tree, shrub, herb, lichens, and moss) and unvegetated areas were classified as bare ground. Physical characteristics recorded included depth to permafrost, substrate stability, and substrate type. Depth to permafrost was measured at three locations for each den: (1) inside the den along the back wall; (2) behind the den along the top of the bank; and (3) along either side of the den along the bank using a steel probe with 1 cm markings. To obtain an index of substrate stability as it might be experienced by a bear seeking a den, the force (kg) which is required to break the substrate surface using an "Ursometer" (a 4 tined garden rake attached to a 120 kg capacity scale) pulled perpendicular to the surface was measured on an ordinal scale from 0-80kg. Substrate composition was assessed based on excavated materials present at each den site and was classified as peat, sand or gravel. Den use was classified as active or inactive based on evidence of recent use (digging and/or fresh scats). Dens were classified as unoccupied or occupied depending on whether bears were present.

A paired unexcavated comparison site was established 50 m away from each den along the same landform and was measured for the same habitat characteristics as den sites, to determine if the habitat characteristics measured were important in den site selection at a fine scale. Comparison sites were restricted to the same landform because random selection of comparison sites would of resulted in sampling sites with different abiotic characteristics (eg. lakes, rivers, open tundra etc.), which are not known to support den sites.

2.2.3. *Statistics*

Habitat characteristics were tested for normality using Kolomorogov-Smirnoff and Shapiro-Wilks tests. Features of den sites and comparison sites were compared using Mann-Whitney *U* tests as habitat characteristics were highly skewed and could not be normalized using standard transformation techniques. The aspects of den entrances were tested for normality using Rayleigh's test for circular uniformity (Zar 1996). For data that were found to be non-normal, a mean angle was calculated (Zar 1996). All tests were considered significant at a p-value of 0.05.

2.2.4. *Habitat Modelling*

Den locations were imported into ArcMap 8.1 (ESRI) and overlaid on habitat layers derived from both vector and raster based GIS files. Cover types were derived from a habitat classification using a multispectral LANDSAT image (pixel size 30 x 30m) taken on 27 July 1996 (Brook 2002). The original accuracy assessment indicated that the image correctly classified cover types greater than 88% of the time (Brook 2002). The original classification included 16 cover types, which were reclassified into 7 cover types for habitat modelling (Table 2-1). A water layer (WATER) was derived using NTS 1:250,000 topographic map sheets (vector data) that were converted to raster based data files and merged with the water habitat class from the Wapusk National Park vegetation map. Any "used" or "available" sites that were located in water were removed from analysis. PCI Geomatica (PCI Geomatics) was used to create a tasselled cap image transformation (Crist and Ciscone 1984) from the same 1996 LANDSAT image used to create the vegetation map. The resulting greenness (GREEN), wetness (WET) and brightness (BRIGHT) images were converted into GIS raster layers. Edge habitat between forest and upland lichen tundra (GREENEDGE, NDVIEDGE) was identified using the EDGE detection algorithm in PCI which assesses the maximum change in grey level values between a central pixel and its neighbours in a 3x3 moving window. Proximity variables were created using the PROXIMITY algorithm in PCI which provided the proximity in pixels from a given location to the nearest pixel of a given habitat type (DISTWATER,DISTLICHEN,DISTFOREST). Distance to coast (DISTCOAST) was derived from a vector shapefile of NTS 1:250,000 map sheets of the Hudson Bay coastline.

A total of 1,245 known den locations from the Canadian National Polar Bear Database (Canadian Wildlife Service) were plotted on each of the habitat layers to represent habitat "use" in the study area. Habitat "availability" was determined by distributing 17,909 random points within the Ecological Integrity Statement (EIS) study area (excluding water). Random points were restricted to the (EIS) study area for Wapusk National Park, as this represented the boundary of the available GIS layers. Resource selection functions were used to determine habitat selection based on use vs. availability of each habitat variable. Resource selection was determined using the formula:

$W^* = \exp(\beta_0+\beta_1 X_1+\beta_2 X_2+\ldots\ldots+\beta_p x_p)$ (Manly *et al.* 1993)

Where W^* = an index of the probability of use of a given site (resource selection probability function), β_1 is the selection coefficient of X_1 resource variable (Manly *et al.* 1993).

2.2.5. *Model Selection and Validation*

Univariate analysis was used to assess the significance of each variable in predicting the response variable (Hosmer and Lemeshow 1989). All significant variables were entered into a Pearson correlation matrix to identify collinearities in significant variables (i.e $r_s \geq 0.7$). Variables that were found to have collinearities were removed. All significant variables were then entered into a full model. Variables that were not significant in the full model were removed one at a time and reduced models were fitted. Likelihood ratio tests (Hosmer and Lemeshow 1989) between the full model (all variables included) and reduced models were used to assess the contribution of each remaining variable to the model. Variables were removed until the most parsimonious model was achieved. Performance of the final model was assessed using a k-fold cross validation technique (Fielding and Bell 1997; Boyce *et al.* 2002). Five k-fold groups were used in which 20% of the data were retained for model testing and the remaining 80% of the data were used for model training. To assess model performance, the pattern of predicted RSF scores (presence-only testing data) against categories of RSF score bins was examined (Boyce *et al.* 2002). RSF bins were stratified using a histogram-equalized stretch technique, which assigns bins on the basis of equal frequency of occurrences (Lillesand and Kiefer 1994; Boyce *et al.* 2002). A high Spearman-rank correlation between bin rank (i.e. 1-10) and area-adjusted frequency of cross-validated points within individual bins indicates good predictive performance of a model (Boyce *et al.* 2002).

2.3. Results

2.3.1. *Den Site Characteristics*

A total of 101 dens were visited in the study area from September 2001 to October 2002 (Figure 2.1). Dens were located between 12.63-79.97 km (51.50 ± 15.54) from the Hudson Bay coastline. Bears constructed dens primarily in riparian areas along the edges of lakes (n = 46), rivers (n = 47) and creeks (n = 8). Within riparian areas, dens were located primarily at the top (n = 80) of landforms, although some dens were located in the middle (n = 16) and to a lesser degree at the bottom (n = 5). Mean slope at den (36.0° ± 8.8° (SD)) and comparison sites (33.4° ± 13.0°) did not differ significantly (P = 0.235) (Table 2-2). The mean bank height at dens 6.8 ± 4.7 m (range: 0.8-18.4m) was not significantly different from that of comparison sites 7.2 ± 8.5 m (range: 0.44 – 20.94m) (P = 0.411) (Table 2-2).

Aspects of den sites were significantly different from random when all dens were analyzed together (Z = 3.47, $U = 2.63$, $P < 0.005$) with a mean azimuth of 122.5°. When lake and river/creek dens were analyzed separately only dens on lakes had a non-uniform distribution. Lake den azimuths differed significantly from uniform (Z = 9.755, $U = 4.417$, $P < 0.001$) and had a mean azimuth of 104.5 degrees (Figure 2.2). Creek/River dens showed a uniform distribution (Z = 1.32, $P > 0.20$) (Figure 2.3).

Vegetation cover at den sites consisted primarily of tree cover with a mean percent cover of (29.2 ± 16.0) which was significantly greater ($P < 0.001$) than at comparison sites (21.9 ± 14.5) (Table 2-2). Den sites and comparison sites had similar amounts of lichen cover (27.4 ± 16.4) and (24.0 ± 18.3) respectively ($P = 0.094$). There was no significant difference in the percent shrub cover between den sites (17.9 ± 11.2) and comparison sites (20.2 ± 11.6) ($P = 0.094$). However percent herb cover at dens (16.7 ± 11.5) was significantly less than that of comparison sites (22.5 ± 13.5) ($P = 0.002$). Dens sites also had significantly less moss cover (7.4 ± 10.3) than comparison sites (12.3 ± 14.2) ($P = 0.034$). On average den sites had a significantly more bare ground (7.0 ± 7.4) over than did comparison sites (3.2 ± 6.3) ($P < 0.001$).

Depth to permafrost was greatest along the side of banks with a mean depth of (49.3 ± 29.8 cm). Depth to permafrost at the top of banks was slightly less with a mean depth of (35.2 ± 17.8 cm) and was the least inside dens with a mean depth of (23.3 ± 12.4 cm). Comparison sites showed similar values of (28.6 ± 12.3 cm) and (38.9 ± 20.9 cm) for the top and side of banks respectively (Table 2-2). Depth to permafrost was significantly greater at den sites than that of comparison sites along both the top and side of banks ($P < 0.001$) and ($P < 0.001$) respectively (Table 2-2).

Mean substrate stability on top of dens was (48.1 ± 21.6 kg) and was not significantly different from comparison sites (48.6 ± 21.7 kg) ($P = 0.936$). Substrate stability on the side of dens was less (44.3 ± 21.0 kg) than comparison sites (45.2 ± 22.1 kg), although this difference was not significant ($P = 0.682$). However, within den sites, substrate stability at the top and side of dens was significantly greater than that inside dens (12.9 ± 9.6 kg) ($P < 0.001$) and ($P < 0.001$) respectively.

Bears showed little variation in selection of different substrate types and denned almost exclusively in peat substrates (n = 100) with the exception of one den excavated in sand (n = 1) along the Owl River. Of the 101 dens visited, only one was occupied by a suspected pregnant female bear. Activity levels at den sites remained low for the study period with only 4 active den sites. However, much of the fieldwork in 2002 was conducted before bears moved inland to den so this is likely not representative of autumn den use.

2.3.3. *Denning Habitat Model*

Initial univariate analysis indicated 13 of the 17 habitat variables significantly contributed to the response variable (Table 2-3). Collinearities existed between GREEN and NDVI as well as GREENEDGE and NDVIEDGE. As NDVI and NDVIEDGE explained a greater portion of the deviance, GREEN and GREENEDGE were removed from further analysis. All significant variables were entered into a multivariate model (i.e. full model see Table 2-4). Likelihood ratio tests on reduced models (Tables 2-5 to 2-7) were used to assess the significance of individual variables. Reduced models with the variables SW, LSW, and BRN removed were equally as good as the full model at predicting used locations (Table 2-5 to 2-7). LTUN contributed significantly to the prediction of the response variable, however the negative selection coefficient for (LTUN) lichen tundra contrasted with the close association of den sites with lichen tundra observed during site level analysis, therefore the variable was removed. Validation results indicated that all models consistently predicted used sites in higher score RSF bins (Figure 2.4). Spearman rank correlations between RSF bins and area-adjusted frequencies were extremely high (Table 2-9).

2.4. Discussion

2.4.1. *Den Site Characteristics*

Bears showed a preference for specific habitat characteristics at den sites. At the landform scale, bears denned almost exclusively within frozen peat banks in riparian areas (lakes, rivers and creeks) that provided sufficient relief for the construction of dens. In Alaska, Durner *et al.* (2001) reported snow dens in association with similar landscape features including coastal banks, river banks, floodplain banks, tributaries and lake shores where snow accumulates in the winter. Similarly, grizzly bears (*Ursus arctos*), the closest relative of the polar bear (Kurtén 1964), are known to use earth dens on Richards Island along the banks of lakes, creeks and river channels (Harding 1976; Nagy *et al.* 1983b). Harding (1976) suggested that grizzlies may exhibit a preference for bank habitat because of the ease of digging on a horizontal plane as well as the potential to dig on an upward-sloping plane which helps to exclude snow and creates a warm air trap, which is often characteristic of snow dens excavated by polar bears (Harington 1968). Polar bears in western Hudson Bay likely den in peat banks for similar reasons.

Along banks, dens were most commonly located at the top. On the islands of James Bay, where polar bears are also known to construct earth dens, Doutt (1967) noted that most of the dens observed were located at the top of sand ridges. Similarly, Jonkel *et al.* (1972) noted that bears on the Twin Islands in James Bay constructed dens in the middle or lower portions of slopes and extended them higher each year as the overhang collapsed. Bears may show a preference for dens located at the top of banks as they may provide certain microhabitat characteristics favourable for denning including (1) a spruce root matrix which provides stability to the roof of den sites preventing the overhang from collapsing and (2) dens located at the tops of banks are above the water table in riparian areas providing a dry environment for denning.

Polar bears in the study area selected den sites in areas of moderate slope similar to that of snow dens occupied by bears in other areas. Durner *et al.* (2001) reported slopes ranging from 15.5 – 50° with a mean of 40° ± 13.5° (SD). In a more recent study, Durner *et al.* (2003) reported similar values ranging from 8 to 48° with a mean of 32.2° ± 9° (SD). On Richards Island, Harding (1976) reported slopes at most grizzly bear dens ranged between 30 and 50°. Similarly, Pearson (1975) noted that grizzly bears in the Yukon usually denned in slopes of 30 – 40°. Nagy *et al.* (1983b) reported a mean slope of 32.7° at grizzly bear dens sites in the Tuktoyuktuk Peninsula and Richards Island in the Northwest Territories. The consistency of slopes at den sites for grizzly and polar bears likely represents a trade-off between the stability and ease of digging at sites on shallow slopes over that of vertical slopes and the additional difficulty of trying to dig in level ground. Furthermore, observations in this study of an absence of earth dens on level ground are consistent with early research conducted in the study area by Jonkel *et al.* (1972), indicating the importance of slope in den site selection.

In addition to slope, bank height also appears to be an important factor determining den site selection. In Alaska, Durner *et al.* (2003) found that bank height varied from 1.4 – 33m and had a mean of 4.4 ± 5.3 m (SD). In an earlier study, Durner *et al.* (2001) reported bank heights ranging from 1.3 to 34 m with a mean of 5.4 ±7.4 (SD). Although ranges in bank height in this study were similar to those above, of greater significance is the consistency of the minimum bank heights in which dens were dug, which likely represents the minimal relief required for den structures (i.e. den tunnels and chambers).

The internal dimensions of polar bear dens in the study area were similar to those reported for snow dens. In the Canadian Arctic, Harington (1968) reported a mean chamber height of 97 cm. Lentfer and Hensel (1980) reported a mean chamber height of 78 cm for snow dens in Alaska. Den chamber heights on Wrangel Island were 80 cm (Uspenski and Kistchinski 1972). Larsen (1985) noted a range in chamber heights from 70-130 cm and Clark *et al.* (1997) reported an average chamber height of 90 ± 13 cm (SD) for recently used peat dens in our study area. Taken together, these values suggest that an approximate minimum of 1.0 m of relief is likely required for the construction of a maternity den. However, since the average bank height was 6.8 ± 4.7 m, and most dens are dug near the top of the bank, few dens were located in banks less 1.0 m in relief.

Jonkel *et al.* (1972), Ramsay and Stirling (1990) and Clark *et al.* (1997) all noted that maternity dens in the study area most commonly have southerly aspects. In this study the distribution of dens was clustered around a mean azimuth of 122.5°, which is oriented away from the prevailing NW winds in the Churchill region of Manitoba. Harington (1968), Harding (1976) and Larsen (1985) all reported that polar and grizzly bear dens were located primarily on leeward slopes and suggested a preference for these sites because more snow accumulates there. Snow accumulation on leeward slopes may be further enhanced by the presence of vegetation at den sites (Pearson 1975; Nagy *et al.* 1983b; Scott and Stirling 2003). Alternatively, several observers have suggested that den entrance orientation at arctic fox (*Alopex lagopus*) dens may provide microclimate advantages (Chesemore 1969; Smits and Slough 1988; Prestrud 1992). Thus, there may also be similar thermoregulatory advantages for parturient female polar bears. In addition south facing slopes receive more radiation, potentially increasing permafrost thaw and the ease with which dens are excavated.

Several authors have suggested that the presence of roots from vegetation may help stabilize the ceilings of terrestrial dens dug by bears as well as wolves (Craighead and Craighead 1972; Jonkel *et al.* 1972; Pearson 1975; Harding 1976; Nagy *et al.* 1983; Nagy *et al.* 1983b; Heard and Williams 1992; Norris *et al.* 2002). However, this hypothesis has never been quantitatively assessed. Substrate stability measurements in the root matrix present at the top of dens in this study indicate that the presence of trees and other vegetation play an important role in stabilizing terrestrial den sites (Table 2-2). Comparison between substrate stability inside dens (i.e. unvegetated) and outside along the side and top of banks indicate that vegetation may increase substrate stability up to 4 fold (Table 2-2), thus stabilizing the ceilings of terrestrial dens.

Although roots from vegetation provide a significant degree of stability to den sites, the fibrous nature of peat substrates likely provides a greater degree of stability over that of particulate substrates such as gravel and sand, which have limited cohesion between soil or rock particles. Doutt (1967) noted that on the Twin Islands in James Bay, the top and sides of a fresh den excavated by a polar bear in a sand bank started to collapse only a few weeks after it had been used. Although extensive gravel/sand banks exist in the study area (eg. Owl and Broad rivers) and are known to be used for denning in southern Hudson Bay (Doutt 1967; Jonkel *et al.* 1976; M. Obbard pers. comm.), bears in the study area denned almost exclusively in peat. In addition to the stability of peat substrates, preliminary data from temperature recordings inside peat dens and an artificial den dug in gravel/sand indicate that dens in peat have a significantly warmer microclimate than dens in gravel/sand (I. Stirling, unpubl. data). Although the southern Hudson Bay polar bear population is the only other polar bear population known to use peat dens, use of peat dens by grizzly bears has been described by Nagy *et al.* (1983a) and Nagy *et al.* (1983b). The preference for denning in peat likely results from a combination of being easier to dig in than gravel, as well as its structural and insulative qualities.

The depth to permafrost was variable within den sites as well as between den sites and adjacent comparison sites. Within-site variability likely resulted from both vegetation cover and excavation of the active layer by bears. Observed differences in permafrost depth between dens and comparison sites likely resulted from denning activity (excavation of peat as well as removal of vegetation). Exposed bank faces along the sides of landforms had deeper active layers and likely facilitated excavation of dens on a horizontal plane. Harding (1976) suggested that the ease of digging in exposed and thawed or partially thawed soils might also contribute to making denning in banks advantageous. Permafrost measurements taken directly into the side of banks in this study support the hypothesis that a deeper active layer along the side of banks may make them more attractive for digging. The active layer was the shallowest inside dens, potentially as a result of the cooler microclimate (Clark *et al.* 1997) and the excavation of the active layer by bears in recently used dens.

Throughout most of their range, polar bears den relatively close to the coast with the exception of those in Hudson Bay, which travel to inland denning areas (M. Obbard pers. Comm.; Amstrup 2003). In Alaska, Durner *et al.* (2003) reported a mean distance from the coast of 1.7 ± 4.5 km with a range from 0-24.7 km. The mean distance of den sites on the Simpson Peninsula from the coast reported by (Van de Velde OMI *et al.* 2003) was 5.51 ± 9.44 km for female bears. Harington (1968) reported that 61% (n= 69) of dens were within 8 km of the coast. Messier *et al.* (1994) reported an average distance of 8.6 ± 1.5 (SE) km for polar bear maternity den sites in the Viscount Melville Sound in the Canadian Arctic. Van de Velde OMI *et al.* (2003) suggested that selection of dens sites may be influenced by the distribution of adult males, availability of suitable snow drifts and an energetic preference for not travelling any farther than necessary in the spring to return to the sea ice to hunt seals. I suggest that the primary reason bears in the Hudson Bay do not den close to the coast is because of the lack of suitable denning habitat. Bears have to move to inland areas to den because well-developed peat banks are not available near the coast. In other portions of their range, availability of sufficient snow drifts determines the distribution of polar bear dens (Belikov 1980; Lentfer and Hensel 1980; Hansson and Thomassen 1983; Durner *et al.* 2003). Similarly it appears that the availability of suitable denning habitat (i.e. peat banks) appears to determine the distribution of dens in the western Hudson Bay.

2.4.2. *Denning Model*

The denning model indicated a positive association between dens and areas in close proximity to water (DISTWATER), which helped characterize lake, river and creek banks that were selected for at the den site level. Bears also used areas for denning that were in close proximity to lichens (DISTLICHEN) and that were positively associated with brightness values (BRIGHT). Observations of upland lichen sites behind dens indicated that these sites are well drained and often contain day beds that were used by bears. Dens located south of the Nelson River in Manitoba are often found in peat hummocks, which are covered in lichens and often have small spruce trees, in areas surrounded by bog and fen habitats. In these lowland areas, bears appear to favour peat hummocks as they are the only sites with sufficient height and drainage for denning. The preference for denning in areas with high brightness values in close proximity to lichens may be attributed to the fact that these sites are well drained. The importance of tree cover and vegetation in riparian areas was evident from the positive association of used sites with normalized differential vegetation edge index (NDVIEDGE) and high NDVI values (NDVI). These two variables effectively described the lichen tundra riparian interface that was selected for at the site level.

The evaluation of RSF models through out-of-sample data sources provides insight into the predictability and robustness of models (Boyce *et al.* 2002). Evaluation of the denning habitat model indicated that the model performed well in predicting used sites (Table 2-9). The high correlation observed between RSF bins and area adjusted frequencies may be a result of the very large portions of the study area that had low RSF values in relation to the sample sizes of cross-validation groups. Although the denning model performed well in predicting used sites, the importance of site level characteristics (i.e. bank height, slope, aspect, and tree cover) in den site selection must also be considered when assessing the "suitability" of denning habitat. The distribution of denning habitat identified by the denning habitat model is concurrent with the known distribution of den sites in the Churchill region (Figure 2-1 and 2-6).

Incorporation of fine-scale spatial analyses of landscapes can improve understanding of species habitat requirements and the factors influencing habitat selection (Fernandez *et al.* 2003; Nielsen *et al.* 2003). In this study, the examination of den site habitat characteristics enabled me to quantify factors that are most important in polar bear den site selection and significantly aided in the development of biologically meaningful variables for habitat models (e.g. NEDGE and DWATER). The data on den locations (i.e. used sites) collected over the past three decades indicate that dens are persistent features on the landscape, and that the denning habitat map likely represents long-term patterns of den site selection in this population.

Predictive maps of polar bear denning habitat (Figure 2-6) will provide valuable tools for resource managers to help protect polar bear denning areas in the western Hudson Bay.

2.5. Conclusions

Several factors appear to be important in the establishment of den sites including peat banks sufficient in height for construction of dens, areas of intermediate slope, and sufficient tree cover. Although bank height and slope did not differ significantly between den and comparative sites these factors likely play an important role in polar bear den site selection. The spruce root matrix at most den sites provides support to the ceilings of den structures. The preference for these site level characteristics is believed to be the primary reason why bears in the Hudson Bay den significantly farther inland than bears in other populations.

Understanding the link between species specific resource requirements and landscape patterns is an important step to provide causal insights into the habitat selection process (Boyce and McDonald 1999; Fernandez *et al.* 2003; Nielsen *et al.* 2003). In this study, development of a denning habitat model, based on a detailed understanding of polar bear resource requirements, has provided insight into the distribution and availability of suitable denning habitat in the Churchill region of Manitoba. Knowledge of the distribution of denning habitat is necessary to avoid potential impacts of anthropogenic disturbance on denning bears. Furthermore, in order to assess the potential impacts of habitat loss (e.g. due to forest fires) a detailed understanding of habitat availability is needed. This information will allow resource managers to develop effective management strategies for the conservation of polar bear maternity denning habitat in western Hudson Bay.

2.6. Literature Cited

Amstrup, S.C. 2003. Polar bear (*Ursus maritimus*). Pages 587-610 *in* Feldhamer, G.A. Thompson, B.C., and Chapman, J.A. Wild Mammals of North America: Biology, Management and Conservation.

Belikov, S.E. 1980. Distribution and structure of dens of female polar bears in Wrangel Island. International Conference on Bear Research and Management 3:117.

Blix, A.S., and Lentfer, J.W. 1979. Modes of thermal protection in polar bear cubs at birth and on emergence from the den. American Journal of Physiology 263:67-74.

Boyce, M.S., and McDonald, L.L. 1999. Relating populations to habitats using resource selection functions. Trends in ecology and Evolution 14:268-272.

Boyce, M.S., Vernier, P.R., Nielsen S.E., and Schmiegelow, F.K.A. 2002. Evaluating resource selection functions. Ecological Modelling 157:281-300.

Brook, R.K. 2001. Structure and dynamics of the vegetation in Wapusk National Park and the Cape Churchill Wildlife Management Area of Manitoba: community and landscape scales. Masters of Natural Resource Management University of Manitoba. 290pp.

Chesemore, D.L. 1969. Den ecology of the arctic fox in northern Alaska. Canadian Journal of Zoology 47:121-129.

Craighead, F.C., and Craighead, J.J. 1972. Grizzly bear prehibernation and denning activities as determined by radiotracking. Wildlife Monographs 32:1-34.

Crist, E.P., and Ciscone, R.C. 1984. Application of the tasselled cap concept to simulated thematic mapper data. Photogrammetric Engineering and Remote Sensing 50:343-352.

Clark, D.A., Stirling, I., and Calvert, W. 1997. Distribution, characteristics, and use of earth dens and related excavations by polar bears on the western Hudson Bay lowlands. Arctic 50:158-166.

Derocher, A.E., Stirling I., and Andriashek, D. 1992. Pregnancy rates and serum progesterone levels of polar bears in western Hudson Bay. Canadian Journal of Zoology 70:561-566.

Doutt, J.K. 1967. Polar bear dens on the Twin Islands, James Bay, Canada. Journal of Mammalogy 48:468-461.

Durner, G.M., Amstrup, S.C., and Ambrosius, K.J. 2001. Remote identification of polar bear maternal den habitat in northern Alaska. Arctic 54:115-121.

Durner, G.M., Amstrup S.C., and Fishbach, A. 2003. Habitat characteristics of polar bear terrestrial maternal den sites in northern Alaska. Arctic 56:55-62.

Fernández, N., Delibes, M., Palmores, F., and Mladenoff, D.J. 2003. Identifying breeding habitat for the Iberian lynx: inference from a fine-scale spatial analysis. Ecological Applications 13:1310-1324.

Fielding, A.L., and Bell, J.F. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24:38-49.

Hansson, R., and Thomassen, J. 1983. Behavior of polar bears with cubs in the denning area. International Conference on Bear Research and Management 5:246-254.

Harding, L.E. 1976. Den site characteristics of arctic coastal grizzly bears (*Ursus arctos* L.) on Richards Island, Northwest Territories, Canada. Canadian Journal of Zoology 54:1357-1363.

Harington, C.R. 1968. Denning habits of the polar bear (*Ursus maritimus* Phipps). Canadian Wildlife Service Report Series No. 5. 33p.

Heard, D.C., and Williams, T.M. 1992. Distribution of wolf dens on migratory caribou ranges in the Northwest Territories, Canada. Canadian Journal of Zoology 70:1504-1510.

Hosmer, D.W., and Lemeshow, S.1989. Applied Logistic Regression. John Wiley & Sons, Toronto.

Jonkel, C., Kolenosky, G.B., Robertson, R.J., and Russell, R. 1972. Further notes on polar bear denning habits. International Conference on Bear Research and Management 2:142-158.

Jonkel, C., Smith, P., Stirling, I., and Kolenosky, G.B. 1976. The present status of the polar bear in the James Bay and Belcher Island area. Canadian Wildlife Service Occasional Paper 26. 42 p.

Kurtén, B.1964. The evolution of the polar bear, *Ursus maritimus* Phipps. Acta Zoologica Fennici 108-1-30.

Larsen, T. 1985. Polar bear denning and cub production in Svalbard, Norway. Journal of Wildlife Management 49:320-326.

Lentfer, J.W., and Hensel, R.J. 1980. Alaskan polar bear denning. International Conference on Bear Research and Management 3:109-115.

Lillesand, T.M., and Kiefer, R.W. 1994. Remotes Sensing and Image Interpretation, third ed.. Wiley, New York, p.750.

Manly, B.F.J., McDonald, L.L., and Thomas, D.L. 1993. Resource Selection by Animals: statistical design and analysis for field studies. Chapman & Hall, London, United Kingdom.

Messier, F., Taylor, M.K., and Ramsay, M.A. 1994. Denning ecology of polar bears in the Canadian Arctic archipelago. Journal of Mammalogy 75:420-430.

Nagy, J.A., Russell, R.H., Pearson, A.M., Kingsley, M.C.S., and Goski, B.C. 1983a. Ecological Studies of Grizzly Bears in the Arctic Mountains, Northern Yukon Territory, 1972 to 1975. Canadian Wildlife Service Edmonton, Alberta.

Nagy, J.A., Russell, R.H., Pearson, A.M., Kingsley, M.C.S., and Larsen, C.B. 1983b. A Study of Grizzly Bears on the Barren Grounds of Tuktoyaktuk Peninsula and Richards Island, Northwest Territories, 1974 to 1978. Canadian Wildlife Service Edmonton, Alberta.

Nielsen, S.E., Boyce, M.S., Stenhouse, G.B., and Munro, R.H.M. 2003. Development and testing of phenologically driven grizzly bear habitat models. Ecoscience 10:1-10.

Norris, D.R., Theberge, M.T., and Theberge, J.B. 2002. Forest composition around wolf (*Canis lupus*) dens in eastern Algonquin Provincial Park Ontario. Canadian Journal of Zoology 80:866-872.

Pearson, A.M. 1975. The northern Interior grizzly bear *Ursus arctos* L. Canadian Wildlife Service report Series 34:86 pp.

Prestrud, P. 1992. Denning and home-range characteristics of breeding arctic foxes in Svalbard. Canadian Journal of Zoology 70:1276-1283.

Ramsay, M.A. and Stirling, I. 1990 Fidelity of female polar bears to winter den sites. Journal of Mammalogy 71:233-236.

Schweinsburg, R.E. 1979. Summer snow dens used by polar bears in the Canadian high Arctic. Arctic 32:165-169.

Scott, P.A., and Stirling, I. 2003. Chronology of terrestrial den is by polar bears in western Hudson Bay as indicated by tree growth anomalies. Arctic 55:151-166.

Smits, C.M.M. and Slough, B.G. 1993. Abundance and summer occupancy of arctic fox, (*Alopex lagopus*) and red fox, (*Vulpes vulpes*) dens in the northern Yukon Territory, 1984-1990. Can. Field-Nat. 107:13-18.b

Stirling, I., and Andriashek, D. 1992. Terrestrial maternity denning of polar bears in the eastern Beaufort Sea area. Arctic 45:363-366.

Stirling, I., Jonkel, C., Smith, P., Robertson, R., and Cross, D. 1977. The ecology of the polar bear (*Ursus maritimus*) along the western coast of Hudson Bay. Canadian Wildlife Service Occasional Paper 33:64 pp.

Stirling, I., Calvert, W. and Andriashek, D. 1984. Polar bear ecology and environmental considerations in the High Arctic. In: Olson, R., Geddes, F., and Hastings, R., eds. Northern Ecology and Resource Management. Edmonton: University of Alberta Press. 201-222.

Uspenski, S.M., and Kistchinski, A.A. 1972. New data on the winter ecology of the polar bear (*Ursus maritimus*) on Wrangel Island. IUSN Publications New Series 23:181-197.

Van de Velde, F. OMI, Stirling I., and Richardson, E. 2003. Polar bear (*Ursus maritimus*) denning in the area of Simpson Peninsula, Nunavut. Arctic 56:191-197.

Zar, J.H. 1996. Biostatistical Analysis, Third Edition. Prentice-Hall, Upper Saddle River, New Jersey.

Table 2-1. Definition of habitat variables used for the development of denning habitat models.

Variable	*Definition*	Abbreviation
Larch/Shrub Wetland [a]	Sphagnum Larch Fen; Willow Birch Shrub Sedge Larch Fen	LSW
Sedge Wetland [a]	Sedge Rich Fen; Sedge Bulrush Poor Fen; Graminoid Salt Marsh	SW
Forest [a]	Sphagnum Spruce Bog; Lichen Spruce Bog	FOR
Lichen tundra [a]	Lichen Meltpond Bog; Lichen Peat Plateau	LTUN
Upland tundra [a]	Dry Health Upland; Unvegetated Ridge	UTUN
Burn [a]	Recent Burn; Regenerating Burn	BRN
Un-vegetated shoreline [a]	Unvegetated Shoreline	UNVEG
Water	Lakes, rivers, streams and standing water.	WATER
Normalized Difference Vegetation Index (NDVI)	Measure of the proportion of photosynthetically absorbed radiation	NDVI
Greenness	Measure of reflectance of green vegetation (Crist and Cicone 1984)	GRN
Brightness	Measure of reflectance of bare soil (Crist and Cicone 1984)	BRIGHT
Wetness	Measure of soil moisture (Crist and Cicone 1984)	WET
NDVI Edge	Measure of the maximum change in NDVI values between a central pixel and its neighbours in a 3x3 moving window	NEDG
Green Edge	Measure of the maximum change in greenness values between a central pixel and its neighbours in a 3x3 moving window	GEDG
Distance to Coast	Shortest distance to the Hudson Bay coastline from a given location	DCOAST
Distance to Water	Distance to the closest body of water from a given location	DWATER
Distance to Lichen tundra	Distance to the closest pixel of lichen tundra from a given location	DLICHEN
Distance to Forest	Distance to the closest pixel of forest from a given location	DFOREST

[a] Cover types were developed from a reclassification of 16 cover types derived from a 1996 Landsat TM image of the study area (Brook 2001).

Table 2-2. Habitat characteristics measured at polar bear (*Ursus maritimus*) den sites in the Churchill region of Manitoba.

Den Characteristics	Den site (*n* = 101)	Comparison Site (*n* = 83)	P
Slope°	36.0 ± 8.8 (36)	33.4 ± 13.0 (34)	0.235
Bank height (m)	6.8 ± 4.7 (5.77)	7.2 ± 8.5 (5.61)	0.411
Percent Tree	29.2 ± 16.0 (30)	21.9 ± 14.5 (20)	0.002
Percent Shrub	17.9 ± 11.2 (13)	20.2 ± 11.6 (20)	0.094
Percent Herb	16.7 ± 11.5 (13)	22.5 ± 13.5 (22)	0.002
Percent Moss	7.4 ± 10.3 (1)	12.3 ± 14.2 (10)	0.034
Percent Lichen	27.4 ± 16.4 (30)	24.0 ± 18.3 (30)	0.094
Percent Ground	7.0 ± 7.4 (10)	3.2 ± 6.3 (0)	< 0.001
Permafrost Top (cm)	35.2 ± 17.8 (31)	28.6 ± 12.3 (26)	< 0.001
Permafrost Side (cm)	49.3 ± 29.8 (38.5)	38.9 ± 20.9 (31)	< 0.001
Permafrost Inside (cm)	23.3 ± 12.4 (21)	-	-
Stability Top (kg)	48.1 ± 21.6 (46)	48.6 ± 21.7 (45)	0.936
Stability Side (kg)	44.3 ± 21.0 (41)	45.2 ± 22.1 (43)	0.682
Stability Inside (kg)	12.9 ± 9.6 (10)	-	-

Note: Values are means ± standard deviation (median).

Table 2-3. Univariate logistic regression models for dependent variables in denning habitat models.

Variable	*Coefficient*	*S.E.*	*P*
LSW	0.522	0.125	> 0.001
SW	0.307	0.080	> 0.000
FOR	0.016	0.063	0.794
LTUN	-0.989	0.060	> 0.001
UTUN	13.542	205.308	0.947
BRN	2.117	0.253	> 0.001
UNVEG	13.556	107.892	0.900
NDVI	-0.628	0.181	0.001
GRN	-0.007	0.003	0.008
BRIGHT	-0.005	0.002	0.002
WET	0.003	0.002	0.134
NEDG	17.769	0.422	> 0.001
GEDG	0.271	0.008	> 0.001
DCOAST	0.000	0.000	> 0.001
DWATER	-0.453	0.018	> 0.001
DLICHEN	-0.168	0.010	> 0.001
DFOREST	-0.142	0.019	> 0.001

Table 2-4. Multivariate logistic regression model including significant variables from univariate models. Loglikelihood (LL) = -2822.589

Variable	*Coefficient*	*S.E.*	*P*
LSW	-0.123	0.168	0.462
SW	0.102	0.111	0.359
LTUN	-0.295	0.100	0.003
BRN	-0.262	0.299	0.381
NDVI	3.711	0.376	> 0.001
BRIGHT	0.006	0.002	0.002
NEDG	15.766	0.607	> 0.001
DWATER	-0.209	0.017	> 0.001
DLICHEN	-0.156	0.014	> 0.001
DFOREST	-0.125	0.033	> 0.001

Table 2-5. Reduced model (LSW removed) (Loglikelihood = -2822.857).

Variable	*Coefficient*	*S.E.*	*P*
SW	0.123	0.108	0.254
LTUN	-0.282	0.098	0.004
BRN	-0.241	0.298	0.419
NDVI	3.763	0.376	> 0.001
BRIGHT	0.006	0.002	0.002
NEDG	15.760	0.607	> 0.001
DWATER	-0.209	0.017	> 0.001
DLICHEN	-0.156	0.014	> 0.001
DFOREST	-0.122	0.033	> 0.001

Likelihood ratio [2*(*LL Full model – LL Reduced Model*)] = 0.536, *df* = 1, *P* = 0.464.

Table 2-6. Reduced model (LSW and BRN removed). (Loglikelihood = -2823.168).

Variable	*Coefficient*	*S.E.*	*P*
SW	0.134	0.107	0.210
LTUN	-0.271	0.098	0.005
NDVI	3.756	0.369	> 0.001
BRIGHT	0.006	0.002	0.002
NEDG	15.767	0.607	> 0.001
DWATER	-0.209	0.017	> 0.001
DLICHEN	-0.154	0.014	> 0.001
DFOREST	-0.119	0.032	> 0.001

Likelihood ratio [2*(*LL Full model – LL Reduced Model*)] = 1.158, *df* = 2, *P* = 0.560.

Table 2-7. Reduced model (LSW, BRN and SW removed) (Loglikelihood = -2823.962).

Variable	*Coefficient*	*S.E.*	*P*
LTUN	-0.315	0.091	0.001
NDVI	3.723	0.368	> 0.001
BRIGHT	0.006	0.002	0.002
NEDG	15.741	0.606	> 0.001
DWATER	-0.209	0.017	> 0.001
DLICHEN	-0.154	0.014	> 0.001
DFOREST	-0.127	0.032	> 0.001

Likelihood ratio [2*(*LL Full model – LL Reduced Model*)] = 2.746, *df* = 3, *P* = 0.433.

Table 2-8. Final model (LSW, BRN, SW and LTUN removed) (Loglikelihood = -2829.982).

Variable	*Coefficient*	*S.E.*	*P*
NDVI	3.093	0.368	> 0.001
BRIGHT	0.006	0.002	0.002
NEDG	15.642	0.606	> 0.001
DWATER	-0.212	0.017	> 0.001
DLICHEN	-0.161	0.014	> 0.001
DFOREST	-0.101	0.032	> 0.001

Likelihood ratio [2*(*LL Full model – LL Reduced Model*)] = 14.786, *df* = 4, *P* = 0.005.

Table 2.9. K-fold cross validated Spearman-rank correlations (rho) between RSF bin ranks and area-adjusted frequencies for the average and individual test sets.

Test Set	*Spearman-rank correlation (rho)*	*P*
1	1.00	0.01
2	.976	< 0.001
3	1.00	0.01
4	1.00	< 0.001
5	1.00	< 0.001
Average	1.00	< 0.001

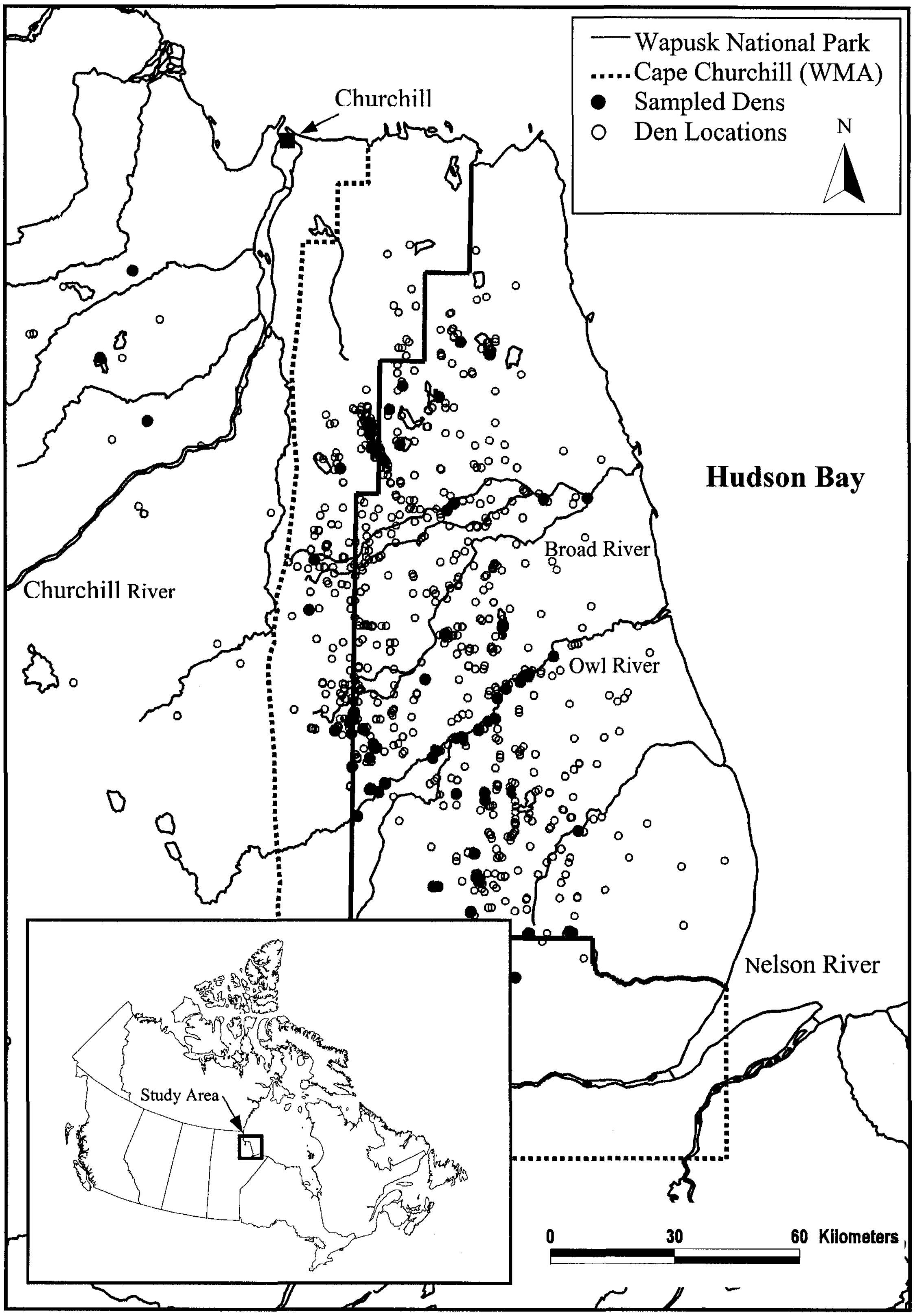

Figure 2-1. Study area in northern Manitoba showing the distribution of sampled dens as well as previous den locations mapped as part of a long-term study on the population dynamics of polar bears in the western Hudson Bay.

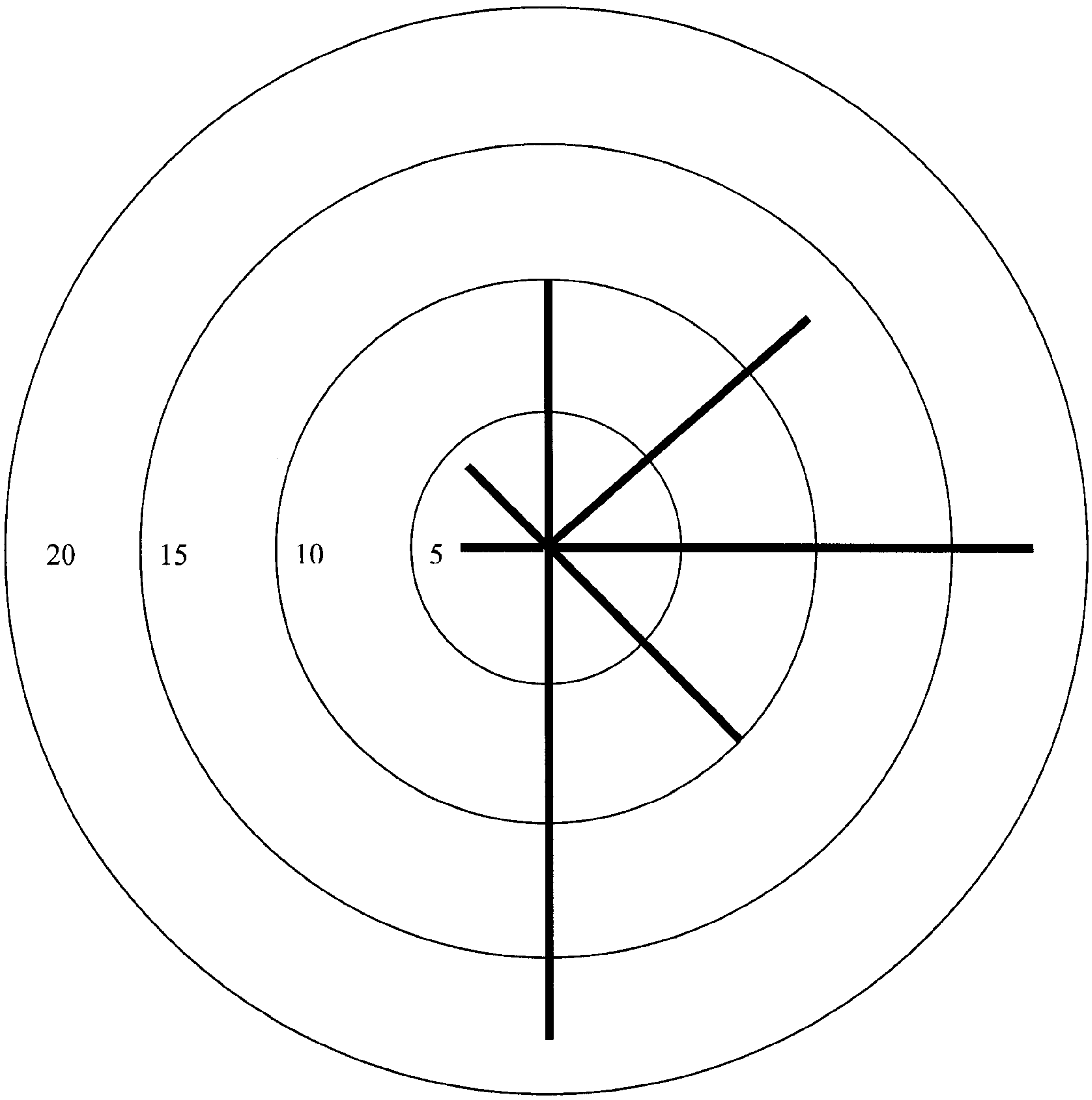

Figure 2-2. Frequencies of den azimuths of polar bear dens located on the banks of lakes. Azimuths are pooled in 45° intervals. The azimuths of entrances on lake banks are significantly different from uniform ($Z = 9.755$, $U = 4.417$, $P < 0.001$).

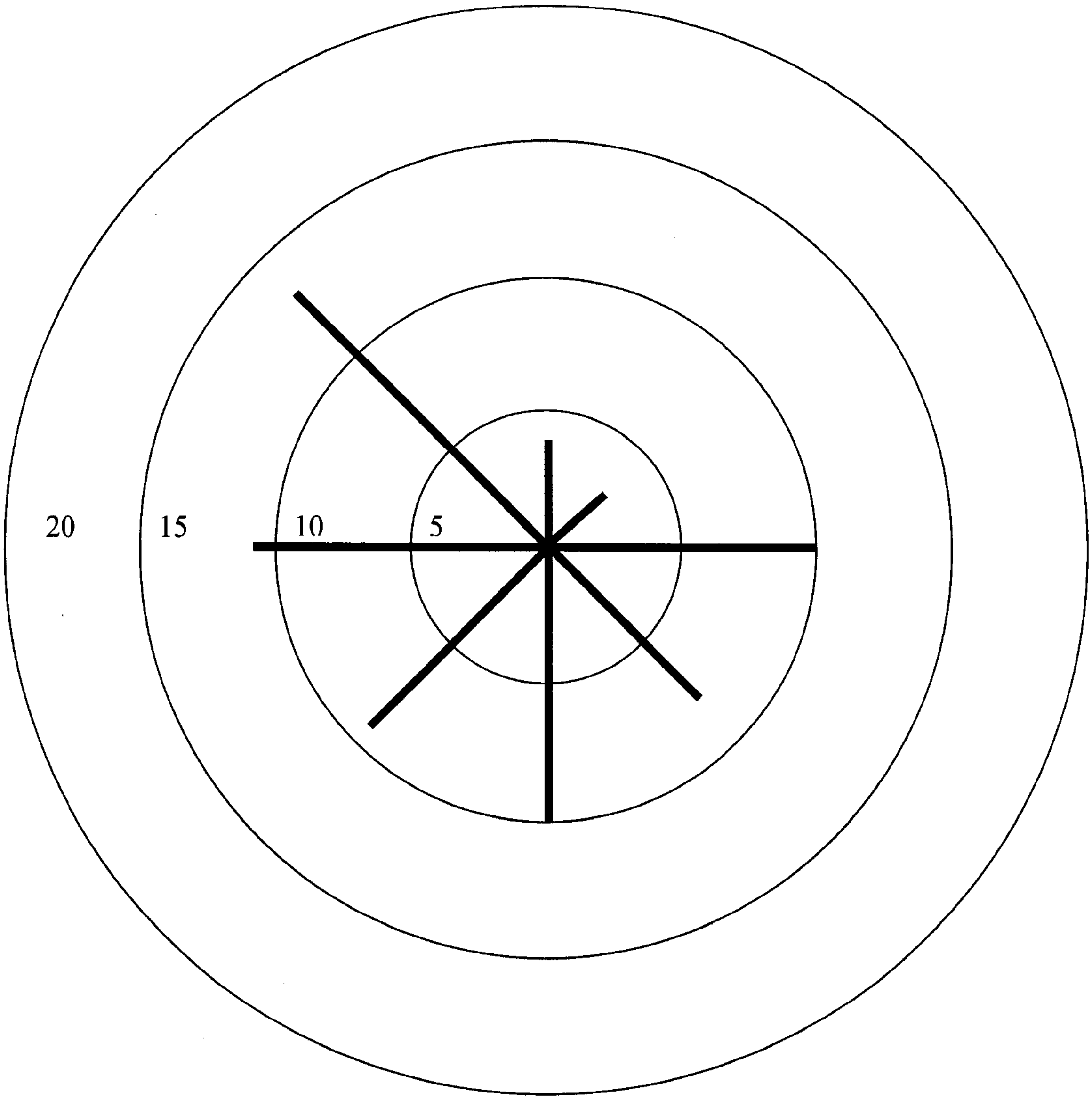

Figure 2-3. Frequencies of den azimuths for polar bear dens located on the banks of river and creeks. Azimuths are pooled in 45° intervals. The azimuths of entrances on river and creek banks are not significantly different from uniform ($Z = 1.32$, $P > 0.20$).

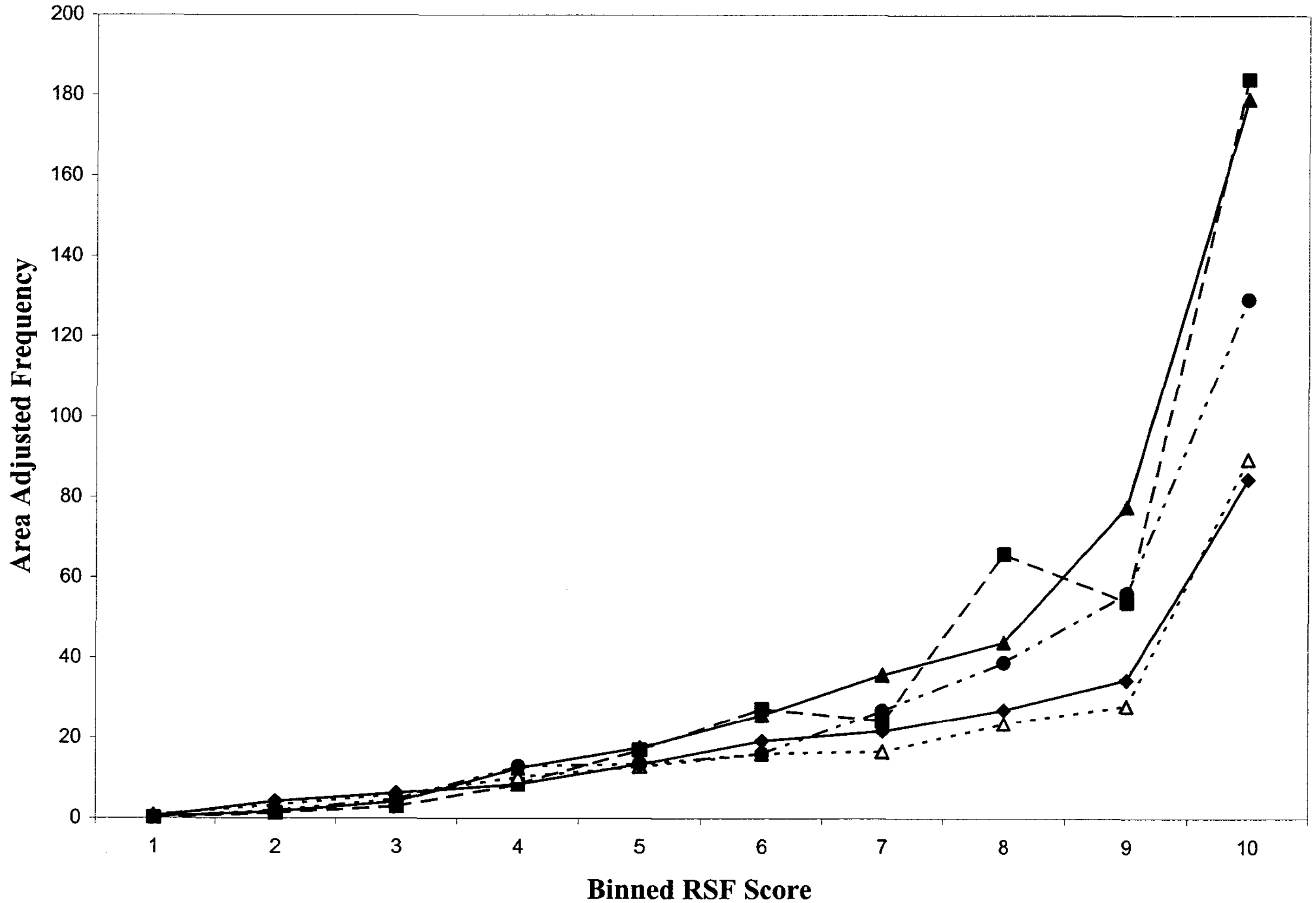

Figure 2-4. Area adjusted frequency of RSF scores within (bins) from withheld den locations of polar for denning habitat models. Frequency values of cross-validation sets (n=5) areas depicted with unique symbols.

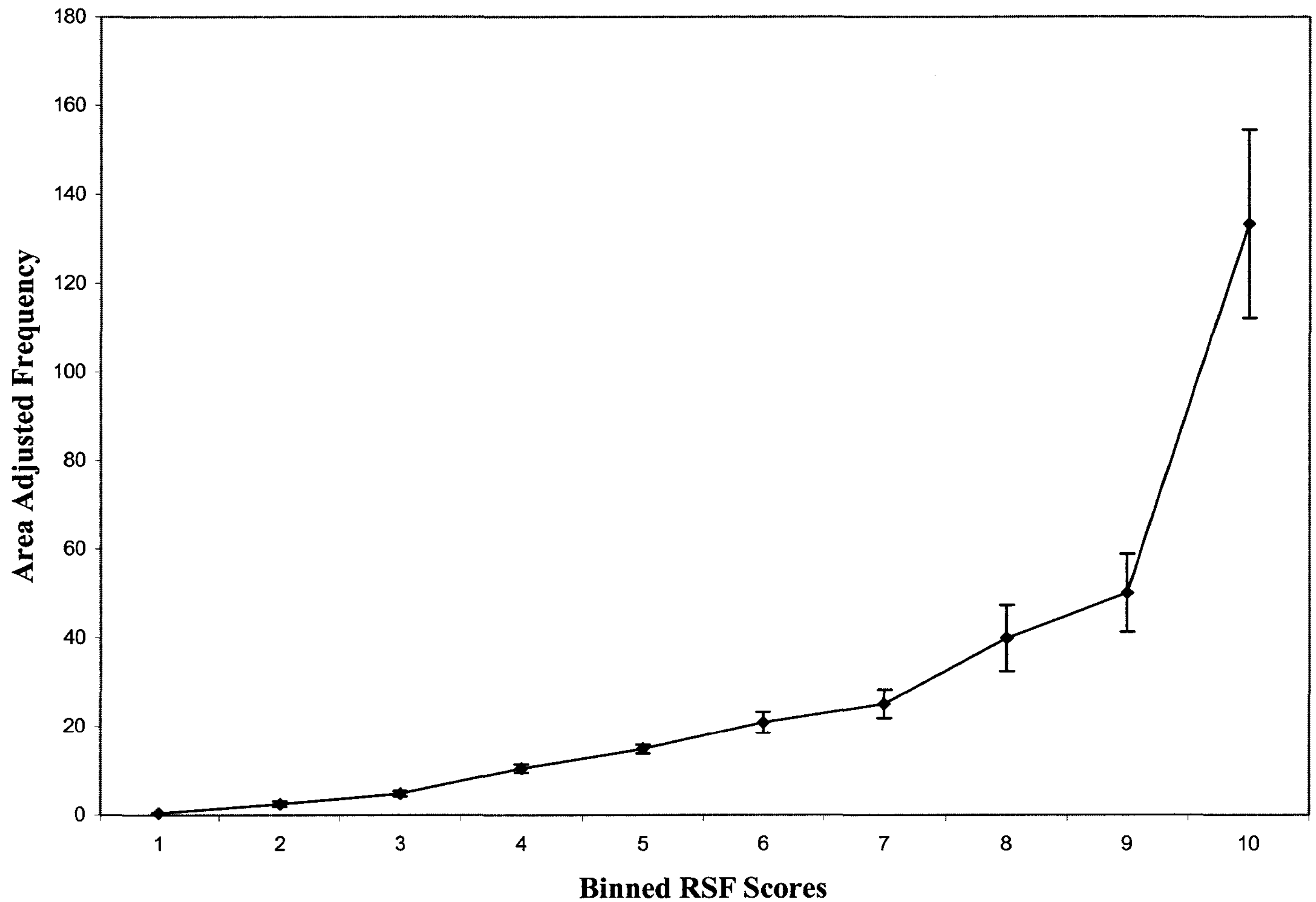

Figure 2-5. Mean (± SE) area adjusted frequency values for RSF scores by bins for cross-validated denning habitat models.

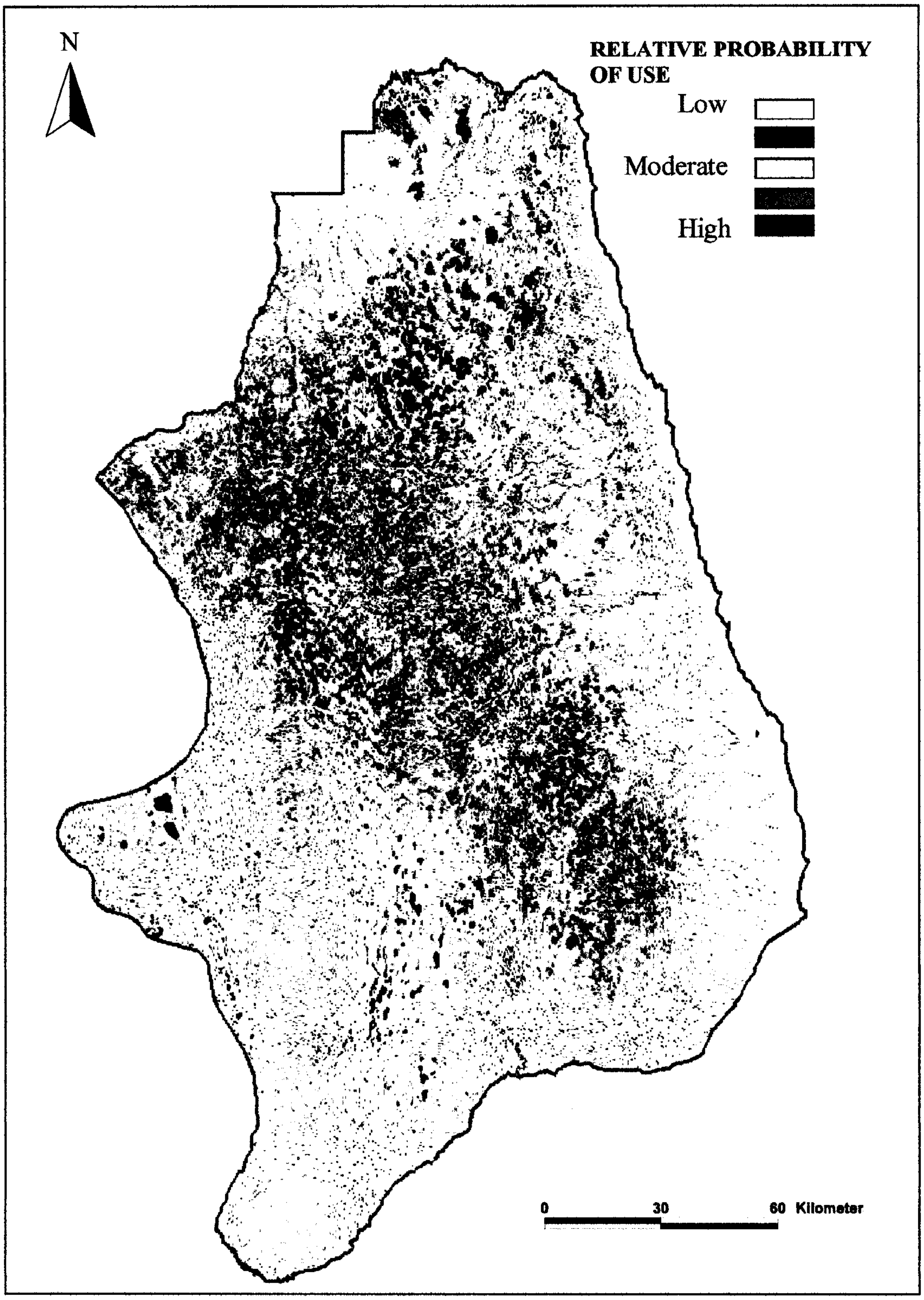

Figure 2-6. Resource selection function (RSF) map of polar bear maternity denning habitat in the Churchill region of Manitoba representing the relative probability of use. Map area boundary represents the extent of the Wapusk National Park Environmental Integrity Statement study area.

3. THE EFFECTS OF FOREST FIRES ON POLAR BEAR MATERNITY DENNING HABITAT IN WESTERN HUDSON BAY.

3.1. Introduction

Polar bears (*Ursus maritimus*) have a circumpolar distribution (DeMaster and Stirling 1990) and throughout most of their range make only limited use of terrestrial environments remaining on the sea ice year-round where possible to prey on ringed seals (*Phoca hispida*) and to a lesser extent bearded seals (*Erignathus barbatus*) (Stirling and Archibald 1977; Smith 1980; Amstrup 2003). However, in Hudson and James Bay at the southern portion of their range polar bears are forced ashore during an extensive ice-free period from mid-July to early November (Stirling *et al.* 1977). Bears remain relatively inactive while on land (Latour 1981; Lunn and Stirling 1985), subsisting on fat deposited during the previous spring (Nelson *et al.* 1983; Derocher and Stirling 1990; Ramsay *et al.* 1991). In November, all polar bears except pregnant females return to the sea ice as it begins to refreeze (Derocher *et al.* 1993). Pregnant females remain on land fasting for up to 8 months using stored fat reserves to meet basic energetic demands as well as the increased energetic demands of gestation and lactation (Watts and Hansen 1987; Polischuk *et al.* 2001).

Throughout most of their range, polar bears occupy maternity dens excavated in snowdrifts (Harington 1968; Amstrup 2003). However, in the Churchill region of Manitoba, bears give birth to their young in late November and early December (Derocher *et al.* 1992) by which time snowdrifts suitable for the construction of den sites have not formed in most years (Scott and Stirling 2002). In this region, it appears that bears give birth to their young in earthen dens dug into frozen peat banks which are later expanded into overlying snowdrifts sometime during the late winter (Jonkel *et al.* 1972;

Ramsay and Stirling 1990; Clark *et al.* 1997). These parturition sites provide warmth from ambient temperatures and are important for the survival and development of cubs (Blix and Lentfer 1979). Consequently, any significant reduction in the availability of suitable denning habitat may impact the reproductive success of this population.

Between 1998-2003, several large fires have burned through the denning area south of Churchill Manitoba, destroying extensive areas of denning habitat. Current research suggests that lightning strikes, the primary ignition source of fires in the Churchill area, as well as the frequency and extent of fires will increase as a result of climatic warming (Flannigan and Van Wagner 1991; Price and Rind 1994; Flannigan *et al.* 1998; Flannigan *et al.* 2000). As a consequence of continued climatic warming, Gough and Leung (2002) suggested that there is a significant risk of permafrost degradation in the Hudson Bay region over the next 50 years. Degradation of permafrost may have a detrimental effect on denning habitat by causing banks in which bears den to slump as well as changing drainage patterns which may increase the vulnerability of denning habitat to fire. Trends towards warmer spring air temperatures in the region (Skinner *et al.* 1998) could further extend the fire season, thus increasing the potential seriousness of this natural disturbance. Collectively, these factors are likely to significantly reduce the availability of suitable denning habitat in western Hudson Bay. Research indicates that disturbance of bears in maternal dens as a result of either natural or anthropogenic causes may lead to den relocation or abandonment of dens and reduced survival of young (Ramsay and Stirling 1986; Amstrup and Gardner 1994; Durner *et al.* 2003; Lunn *et al.* 2004). Potential negative effects of anthropogenic disturbances may be prevented or reduced through spatial and temporal modification of human activities

(Amstrup and Gardner1994), but the dynamic nature of natural disturbances may preclude preventative measures in most situations.

Climatic warming has already been shown to impact polar bears in Hudson Bay by causing the sea ice to melt progressively earlier over the past 25 years. This decrease in sea ice duration limits the time available for bears to prey on seals when they are most accessible in the spring, resulting in a steady decline in the body condition of bears in the western Hudson Bay (Stirling *et al.* 1999). Denning female polar bears in this region may already endure the longest period of food deprivation of any mammal (Amstrup 2003) and rely on dens in the permafrost to conserve energy during the ice-free period as well as for parturition later in the fall. Understanding the potential short-term and long-term impacts of forest fires on polar bear maternity denning habitat will be important to the conservation of the western Hudson bay polar bear population, because the destruction of maternity denning habitat may limit or reduce the availability of suitable den sites, and will likely have detrimental effects on subsequent reproductive success. For this reason, in this chapter, I assess the potential impact of habitat loss as a result of forest fires.

3.2. Methods

3.2.1. *Locating Burned Dens*

Burned areas were identified using fire maps from the Manitoba Department of Conservation, Landsat TM satellite imagery, and hotspot data from the Northern Forestry Centre (Environment Canada). Surveys were conducted in burned areas to locate dens that were potentially impacted by fire. Den sites were located and sampled non-selectively between mid-August and early October 2001 and 2002 while flying in a Bell

206B helicopter during surveys for polar bears, as part of a long-term population study. Den sites located prior to this study were plotted on topographic map sheets and were also visited opportunistically. The exact location of each den was determined using a Global Positioning System (GPS). Den locations were imported into Arcview 3.2 (Environmental Systems Research Institute, Inc., Redlands, Calif. ESRI) to produce a Geographical Information System (GIS) map layer of all dens. During survey flights track logs were recorded with a (GPS) unit to obtain an estimate of survey effort. Burned dens were located and measured for the same site level characteristics as unburned dens.

3.2.2. *Den Characteristics*

Features of relief in which dens were excavated were noted and included lake, creek, and river banks as well as peat hummocks. In addition, the location of each den site on the landform was recorded as being at the top, middle or bottom. All den site characteristics measured in (Chapter 2) were recorded for burned dens sites, however the following represents and abbreviated summary of characteristics that were compared between burned and un-burned den sites.

Vegetation cover and physical characteristics were described for each den site. Vegetation composition was measured as the percent cover of each plant species in a 10x10 m plot centered over top of the den site. Plant species were further grouped by major life form type (tree, shrub, herb, lichens, and moss), un-vegetated areas were classified as bare ground and any burned vegetation was classified as burned. Although vegetation changes with time since disturbance, I did not attempt to further separate burned and unburned sites into different age classes. Physical characteristics recorded included depth to permafrost and substrate stability. Depth to permafrost was measured at three locations for each den (1) inside the den along the back wall (2) behind the den along the top of the bank and (3) along either side of the den along the bank using a steel permafrost probe. To obtain an index of substrate stability as it might be experienced by a bear seeking a den, the force which is required to break the substrate surface using an "Ursometer" (4 tined garden rake attached to a 120 kg seal scale) pulled perpendicular to the surface was measured on an ordinal scale from 0-80 kg. The physical state of each den was classified as stable (roof in tact; no slumping of den structure), slumping (slumping of roof or other portions of the den structure) or collapsed (collapse of the roof or collapse of other portions of the den structure).

3.2.3. *Denning in Burned Areas*

To determine the effects of forest fires on habitat use of specific portions of the denning area, a comparison between pre- and post-fire use of a large burn (Lee Lake burn) in the central portion of the denning area was made (Figure 3-1). The Lee Lake burn occurred in July 1999 and burned an extensive area that included the Canadian Wildlife Service polar bear research camp. This burn caused the largest loss of polar bear denning habitat as a result of fire to date. This particular area was selected as it has been continually surveyed over the past 20 years as part of a long-term population monitoring program. A comparison site of equal size was selected at Fletcher Lake, an area that has received similar amounts of survey effort over the same time period. Global Positioning Systems (GPS) were used to track flight routes over the last three field seasons (mid-August to early-October from 2001-2003) to quantify survey efforts. To obtain an index of use of these areas for denning, a summary of female bears captured during the fall pre- and post-fire in the Lee Lake burn and the Fletcher Lake comparison site from 1984 to

2003 was made using the National Canadian Polar Bear database. While conducting surveys, additional observations of bears seen but not handled in burned areas were also recorded.

In addition to surveys of activity in burned areas, bear movement data from Argos satellite collars (collected 1991-1998) were used to assess use of burned areas by collared females. A total of 44 bear years of data were collected and used to evaluate movements inside and outside known burned areas. Satellite locations were imported into Arcview 3.2 and movement data were superimposed over known burned areas. Burned areas were determined to be used if individual satellite locations occurred within the boundary of a burn.

3.2.3. *Fire and Climate Data*

Data were collected on all positive and negative ground lightning strikes occurring in the study area from April-September for 1998-2003, to obtain an index of the frequency of primary ignition sources. Lightning data were collected by the Canadian Meteorological Service using IMPACT ES and LPAT sensors operating in northern Manitoba. These data were used to obtain an index of the frequency of occurrence of ignition sources. The frequency of lightning strikes in the study area was summarized on a yearly, monthly, and daily basis. Geographic coordinates of all strikes were then entered into Arcview 3.2 for analysis. Information on the frequency and extent of forest-tundra fires in the denning area from 1998-2003 was obtained from the Northern Forestry Centre and Manitoba Conservation. Burned areas (i.e. burn polygons) were identified using hotspot data provided by the Northern Forestry Centre in conjunction with the Canadian Wildland Fire Information System (CWFIS) and the Fire M3 program. In addition, fire boundary maps (1970-1997) outlining the extent of burned areas were obtained from Manitoba Conservation. Weather data from 1970-2003 was collected from Gillam, Manitoba and were used to describe weather conditions in the study area. Although climate data are also available for Churchill, Manitoba, weather conditions there are highly influenced by the Hudson Bay and are less likely to be indicative of climatic conditions in the denning area. Mean monthly temperatures, monthly rainfall and monthly snowfall data from 1970-2003 are presented in (Appendix A, Appendix B and Appendix C).

3.2.4. *Habitat Loss*

The extent of habitat loss was determined using the denning habitat model (Chapter 2) and forest fire data. Burned area polygons were overlain on the denning habitat map and the total number of pixels of suitable denning habitat within each polygon was calculated. Suitable denning habitat was considered to be any habitat that had a relative probability greater than "Low" (see Figure 2-6) of being used by a denning bear. Habitat loss was assessed as the total loss of suitable denning habitat as defined above within a burned area in km^2.

3.2.5. *Statistics*

Habitat characteristics were tested for normality using Kolomorogov-Smirnoff and Shapiro-Wilks tests. Features of burned and unburned den sites were compared using Mann-Whitney *U* tests as habitat characteristics were highly skewed and could not be normalized using standard transformation techniques. All tests were considered significant at a p-value of 0.05. Inferential statistics could not be used to analyze survey data from the Lee Lake burn due to issues with temporal psuedoreplication (see Hurlbert

1984). Thus summary statistics were used to describe observed differences in denning activity.

3.3. Results

3.3.1. *Den Site Characteristics*

Burned dens were located in similar habitats as unburned dens along the edges of lakes (n = 31), rivers (n = 11), creeks (n = 2) and hummocks (n = 4). As in unburned areas, dens were located primarily at the top of landforms (n = 31) with fewer dens at the middle (n = 13) and bottom of landforms (n = 4). Several site level habitat characteristics at burned dens differed significantly from un-burned dens and included vegetation cover, depth to permafrost, substrate stability, and the physical state of dens.

Vegetation cover at burned den sites was limited and consisted primarily of herb and shrub cover. Percent herb cover at dens (16.7 ± 11.5) was significantly greater than that of burned sites (11.6 ± 8.5) ($P < 0.001$). Un-burned den sites and burned den sites had similar amounts of shrub cover (17.9 ± 11.3) and (18.1 ± 12.4) respectively ($P =$ 0.358). Un-burned den sites had a mean percent tree cover (i.e. living trees) of 29.2 ± 16.0 which was significantly greater than that of burned den sites (01.8 ± 5.0) ($P < 0.001$) (Table 3-1). There was no significant difference in the percent moss cover between den sites (7.4 ± 10.3) and burned den sites (4.0 ± 5.7) ($P = 0.187$). Burned dens had significantly less lichen cover (8.6 ± 13.5) than un-burned dens (27.5 ± 16.4) ($P < 0.001$). There was no difference in the amount of bare ground between unburned dens (7.0 ± 7.3) over that of burned dens (8.8 ± 9.8) ($P < 0.001$). Un-burned dens contained no sign of previous burned vegetation and the average percent cover of burned vegetation for burned dens was (51.9 ± 31.2).

At un-burned dens, depth to permafrost was greatest at the side of the dens (49.3 ± 15.3 cm). Depth to permafrost over the top of banks was slightly less with a mean depth of (35.2 ± 9.1 cm) and was the least inside dens with a mean depth of (23.3 ± 6.3 cm). Depth to permafrost at the top, side and inside burned dens was (54.1 ± 8.8), (78.3 ± 13.1) and (41.8 ± 11.2) respectively (Table 3-1). Burned den sites showed significantly greater depths to permafrost at the top ($P < 0.001$), side ($P < 0.001$) and inside ($P < 0.001$) of dens (Table 3-1).

Mean substrate stability on top of dens was (48.1 ± 11.3 kg) and was significantly greater than that of burned den sites (33.0 ± 7.8 kg) ($P < 0.001$). Substrate stability along the side of dens was significantly less for burned dens (27.8 ± 9.3 kg) than un-burned den sites (44.3 ± 11.5 kg) ($P < 0.001$). However, there was no significant difference in substrate stability inside burned (12.2 ± 4.2) and unburned (12.9 ± 5.2) dens ($P = 0.867$) (Table 3-1).

The physical state of burned and un-burned dens was significantly different (G-test $\chi2 = 42.78$, $df = 2$, $P < 0.001$) (Table 3-3). Den sites that had been burned were much more susceptible to collapse with 66% of all burned dens collapsing compared to only 23% of un-burned dens. Burned and un-burned dens had equal amounts of slumping (32%). Comparatively, forty six percent of unburned dens were stable (n = 46) while only 2% (n = 1) burned den was stable.

3.3.2. *Denning in Burned Areas*

Observations from the Lee Lake burn in 1999 indicated that bears initially returned to the area after it had burned and excavated a number of shallow dens primarily in the first year after the fire, although to date no bears have been observed denning in this area since the fire. From 1984–1988, an average of 1.4 ± 0.5 (SE) bears were handled each year in the same area. From 1989-1993, 2.4 ± 0.8 bears were handled each year, and from 1994-1998, 1.8 ± 0.9 bears were handled each year within the Lee Lake burn. In the five years since the Lee Lake fire (1999-2003), no bears have been handled (Table 3.3 and 3.4). In comparison, a greater number of bears have been handled in the Fletcher Lake area in most years (Table 3.3). In the five years since the Lee Lake fire denning activity in the Fletcher Lake area has declined only slightly, in comparison to the almost complete absence of activity in the Lee Lake burn (Table 3.3). GPS mapping of flight routes indicated a total of 1053 km were flown in the Lee Lake burn from 2001-2003 and compared with 1010 km surveyed in the Fletcher Lake site during the same time period. From 1984–1988 an average of 7.2 ± 1.6 (SE) bears were handled each year in the Fletcher Lake comparison site. From 1989-1993 an average of 9.2 ± 1.4 bears were handled each year and from 1994-1998 an average of 10.0 ± 1.2 bears were handled each year within the Fletcher Lake comparison site. In the five years since the Lee Lake fire (1999-2003) an average of 5.2 ± 3.4 bears have been handled in the Fletcher Lake comparison site (Table 3.3 and 3.4). During surveys of burned areas only 2 bears were observed, one in the Lee Lake burn and a second bear in a different burn in the southeast corner of the study area. Both bears were attempting to excavate dens in the burned areas. The first bear had excavated a den but appeared to have broken through the roof at some point in its construction. The second bear had excavated a shallow den, which lacked a roof. Neither bear was known to den at either of these locations.

Of a total of 44 bear-years of movement data, from bears on land (n = 40), only two bears transmitted locations from inside identified burned areas. The two individual bears, X12514 and X10962, were located 11 and 8 times, respectively in burned areas. In the fall of 1997 female X12514 was known to be pregnant and spent an estimated 53 days in a burn south of Churchill close to the Hudson Bay coast. However, on 9 October, she left the burn and proceeded northwest and appeared to establish a den approximately 8 km away in an area that had not been burned. X12514's collar began transmitting the following spring on 18 February and she was subsequently re-sighted with two cubs of the year in the fall of 1998, indicating that she had successfully denned the previous year. Female X10962 spent an estimated 15 days in burned areas from 20 August to 8 November in 1997. Although she moved inland to the denning area, she made no attempt to den in 1997 and returned to the sea ice the same fall.

3.3.3. *Fire and Climate Data*

From 1998 to 2003 a total of 36,330 lighting strikes occurred in the study area. The average number of strikes per year was 6,055 ± 2,648.86 (SD) and ranged from 2,896 in 1998 to 9,734 in 2003. Lightning activity was the greatest during June, July and August with fewer strikes occurring in April, May and September (Table 3-5). The distribution of lightning varied between years and showed localized concentrations resulting from individual lightning storms (Figures 3-4 and 3-5). During the fire season the majority of lightning strikes were restricted to isolated events that lasted from one or two days (ex. on July 23rd and 24th of 2003 1,986 and 2,306 strikes were recorded respectively; representing 44% of all lightning strikes in 2003) (Figure 3-5; Appendices D-F).

Detected forest-tundra fires varied in both area and frequency between years. Fires were recorded in 1998, 1999, 2000 and 2003 and no fires were observed in 2001 or 2002. The greatest number of fires occurred in 1999 with 18 fires burning a total area of 683 km^2. In 2003, 6 fires burned a total area of 204 km^2. During the 2000 fire season, a total of 6 fires burned 31 km^2 of habitat. In 1998, 3 fires burned a total area of 28 km^2 (Table 3-6). In summary, during the last 6 years 33 fires have burned a total of 944 km^2 of the study area. It is important to note, that although smaller fires (> 1 km^2 in area) were not detected in this study, it is acknowledged that large fires account for the majority (~97%) of the total area burned in Canada from 1959-1997 (Stocks *et al.* 2003) and thus the fires detected in this study likely represents the majority of the area burned in the study area from 1998-2003.

3.3.4. *Habitat Loss*

Of the 944 km^2 that burned in the study area over the last 6 years, 67 km^2 (approximately 5.5%) of available polar bear denning habitat was lost. The greatest habitat loss occurred in 1999 where 46 km^2 of denning habitat burned. In 1998, 2000 and 2003 a total of 2 km^2, 0.5 km^2, and 18 km^2 of habitat was burned respectively. The denning habitat model estimated there was 1210 km^2 of suitable denning habitat in the study area in 1996.

3.4. Discussion

Our data suggest that forest-tundra fires significantly impact polar bear maternity denning habitat by destroying essential microhabitat requirements (ie. substrate stability, permafrost, and vegetation cover), resulting in the avoidance of burned areas by denning bears. Fires significantly altered several site level habitat characteristics of dens that appear to be important in den site selection, in addition to the destruction of pre-existing dens. The removal of vegetation at den sites resulted in decreased substrate stability, permafrost degradation, and the collapse of den sites (Figure 3-3). As the structural characteristics of dens and denning sites determine their ability to provide microclimatic stability, shelter against harsh weather conditions and protection from potential predators (Fernández and Palomares 2000), and thus any significant alteration to the continued stability of preferred denning habitat could potentially affect reproductive success.

3.4.1. ***Effects of Forest Fires on Dens and Denning Habitat***

Decreases in substrate stability, which provide support to den structures (chapter 2) resulted from burning and removal of vegetation. Increased rates of collapse and slumping of burned dens indicate that fire has an impact on pre-existing den sites, and may further limit the stability of the surrounding denning habitat. Although no observations have been made of bears being killed in the collapse of either an earth or snow den in this study area, Clarkson and Irish (1991) reported a female and two cubs that were killed in a snow den that collapsed during an unseasonably warm period that was likely accompanied by rain. Stirling and Derocher (1993) suggested that climate change could potentially affect maternity denning through unseasonably early rains, which could lead to the collapse of maternity dens in the snow. As bears are not known to use burned den or areas, the threat of death resulting from den collapse following a fire in the study area is likely negligible. However, bears in the study area do rely on undisturbed earth dens to give birth to their young, and it is believed that most bears tunnel out into snow dens later in the spring (Clark *et al.* 1997), which may make them susceptible to den collapse presumably as a result of unseasonably early rainfall. Observations made by Stirling and Smith (2004) on subnivean seal lairs along the southeastern coast of Baffin Island revealed that warmer spring weather and unseasonably early rainfall resulted in extensive slumping and collapse of snow lairs. As bears in Hudson Bay are at the southern limit of their range, collapse of snow dens being used in the late winter as a result of early rainfall may be more likely than in the High Arctic.

In addition to providing substrate stability, vegetation facilitates the accumulation of snow over den sites in the winter (Scott and Stirling 2003). It has been suggested that grizzly bears (*Ursus arctos*) construct dens directly underneath vegetation due to the increased accumulation of snow in the winter, which may potentially insulate den sites (Pearson 1975; Nagy *et al.* 1983). Temperature measurements taken through the snow column indicate that miroenvironments 25-35 cm beneath the snow surface can be up to 40° F warmer than the surface air temperature (Pruitt 1957). Thus, the loss of this insulating layer may affect the warmth of the denning environment and the availability of suitable snow drifts for bears to tunnel out into in the spring.

Degradation of permafrost as a result of fire has been well documented (Zoltai and Petapiece 1973; Thie 1974; Mackay 1995; Swanson 1996; Burn 1998). In this study, fire significantly increased the active layer in burned areas through the removal of vegetation, which affects permafrost formation (Zoltai and Petapiece 1974; Mackay 1995). Changes in permafrost could possibly impact the suitability of denning habitat in several ways. The cool microenvironment inside dens which allows bears to avoid warm ambient temperatures and insects (Clark *et al.* 1997) will likely be lost as a result of permafrost degradation. In addition, black substrates absorb significantly more solar radiation (Wein and Bliss 1973), resulting in warmer microclimates in burned areas. Secondarily, melting of permafrost may cause slumping of banks, which could lead to decreased stability of denning habitat and den sites. At several sites, large blocks of peat have broken free from the banks and slumped toward the water (Figure 3-3) likely as a result of the cumulative effects of the removal of vegetation and permafrost.

A potential benefit of permafrost degradation may be an increase in the ease with which den sites are excavated. Hammer (1999) noted that grizzly bears appear to have difficulty digging in frozen ground, even with their long claws, which are believed to be, an adaptation to digging (Stirling and Derocher 1990). It is assumed that polar bears would experience similar or greater difficulties in excavating frozen ground/peat at den sites. It appears that in most areas where permafrost is close to the surface, the construction of dens may occur over several years as the permafrost subsides and bears are able to dig further into the bank. Hammer (1999) noted that digging in burned areas was easier than in un-burned areas, which may be related to changes in substrate stability as demonstrated here.

This ease of digging in burned areas may partially explain the numerous fresh excavations observed in the fall of 2000 in the Lee Lake burn. However, despite this activity, no maternity dens have been observed and there is no evidence to suggest that any bears have established and used den sites for parturition in this area. Harington (1968) noted exploratory dens in which bears tested snow drifts in several locations before establishing a den. Similarly, bears in burned areas appeared to make a number of these shallow exploratory digs that were not extended into maternity dens. The activity observed in the Lee Lake burn in 2000 was likely a result of individual females showing fidelity to the area and attempting to den, but apparently without success. Both failed denning attempts and relocation into areas that have not been disturbed would require additional energy expenditure, although it is not known to what extent this would affect reproductive success.

3.4.2 ***Use of Burned Areas by Bears***

The effects of anthropogenic disturbances on various wildlife species have been well documented (Thomas *et al.* 1990; Amstrup 1994; Mace *et al.* 1996; Dyer *et al.* 2001). The effects of accidental or unplanned natural (eg. forest fires) or anthropogenic (eg.oil spills) environmental impacts can not be studied using well-replicated study designs, and thus statistical analysis of impacts is often affected with problems of psuedoreplication (Eberhardt and Thomas 1991; Weins and Parker 1995). Despite these difficulties it is important that resource managers attempt to quantify the impacts of these types of disturbances. In addition, becuase bears are more easily spotted in burned areas the number recorded in the Lee Lake burn prior to fires is likely underestimated. Although, we were limited in our ability to survey throughout some burned areas, observations in this study suggest that pregnant female bears may return to an area after it has burned, but they do not appear to stay and den there. Although denning activity is variable between years, the decline in denning activity since the Lee Lake fire indicates that burned areas are likely not suitable for denning. Only one bear, suspected to be pregnant, because of her large size, was spotted in the Lee Lake burn after the fire. This individual successfully excavated a den but appeared to have broken through the roof at some point in its construction, leaving a large hole over top of the main den chamber. During a subsequent visit to the area a few days latter, the female was found to have abandoned the den site. The large hole in the top of the den likely resulted from the decreased stability of the substrate and was sufficient in size that it would have allowed rain and snow into the main den chamber throughout the fall.

The movement data presented above indicates that while some females bears investigate burned areas, possibly because of having denned there prior to when they burned, I found no evidence that bears denned in burned habitat. Although the observation is anecdotal, only the one bear that investigated a burned area prior to denning was subsequently re-sighted the next year with two cubs of the year. Derocher *et al.* (1993) suggested that foraging on berries may be important for some bears and could potentially explain the use of regenerating burned areas by non-parturient females accompanied by dependent young. Research on activity in the denning area by Lunn *et al.* (2004) indicates that parturient females move inland to the denning area within 2 to 16 days of arriving on the Hudson bay coast and may begin to excavate and reoccupy old dens as early as August. From analysis of serum progesterone Derocher *et al.* (1992) concluded that bears in the study area give birth from late November through early December. This extended period of den occupation may be an important form of energy conservation for bears in the western Hudson bay population. Bears occupying undisturbed den sites would remain cool in the warm weather summer and would likely be within their thermal neutral range, minimizing the amount of energy required to thermoregulate.

3.4.3. *Climate Change and Forest Fires*

Analysis of lightning strike data indicated that there is a recurrent ignition source throughout the study area each summer. Increases in lightning frequency will likely result in more forest-tundra fires and research suggests that lightning activity will continue to increase as a result of climate change (Prince and Rind 1994). Furthermore, Price and Rind (1994) predicted that changes in lightning activity will likely be greatest in northern hemispheres in the summer, when the majority of fires occur in our study area. In years when the climate is hot and dry, such as in 1999, with warm spring temperatures and low precipitation, lightning activity is more likely to start fires, resulting in habitat loss. Furthermore, as resinous shrubs are more flammable than other fuel sources (eg. graminoids) (Auclair 1983), the krummholtz spruce overlying most dens are likely more susceptible to burning. Although fires in forest-tundra tend to vary widely in both intensity and frequency (Henselman 1973), burns in denning habitat appeared to burn slowly and intensely as indicated by penetration of the peat layer and subsequent burning of the root mat of trees at den sites (Figure 3-3).

The spruce krummholz found over top of most dens largely spread by leaders and do not produce large amounts of viable seeds (Black and Bliss 1980; Payette and Gagnon 1985) so post-fire establishment of spruces may be limited (Arsenault and Payette 1992). In addition, establishment of black spruce seedlings may be further limited by the development of a continuous lichen mat in burned areas (Morneau and Payette 1989). Scott and Stirling (2002) reported that trees above den sites may be in excess of 230 years old indicating long-term successional processes. Furthermore, regeneration of burned areas may not return to previous successional states (ie. old growth krummholz spruce).

Accumulation of snow in subarctic sites composed of lichen-spruce krummholz as result of dense conifer foliage (Daly 1984; Arsenault and Payette 1992; Bovin and Bégin 1997) may play an important role in the succession of these sites. Arsenault and Payette (1992) demonstrated that reduction in the accumulation of snow in these areas, ultimately as a result of fire, leads to the succession of lichen tundra vegetation. Thus, changes in successional trajectories may further limit the availability of denning habitat in the study area. Although the availability of suitable denning habitat in the study area does not appear to be limited at present, increased fire frequency and slow succession rates or different successional trajectories back to suitable denning could affect the future distribution and availability of denning habitat for bears in the region.

When considering the potential impacts of habitat loss it is important to consider how much denning habitat might actually be necessary to support the 150-200 bears, which are estimated to den in this annually (see Derocher and Stirling 1995). Published estimates of den densities from other populations include 0.4-0.9 dens/km^2 on Kong Karl's Land, Svalbard (Larsen 1985), 0.5-2.5 dens/km^2 on Wrangel I. and 6.2 dens/km^2 on Herald I. (Osyanikov 1998). Dens may be found in much higher densities in localized areas of Svalbard (Bogen Valley 12.5 dens/km^2) (Larsen 1985) and on Herald I. (Main Valley 12.1 dens/km^2 (Osyanikov 1998). As certain locations in the study area are know to support large number of dens (eg. Fletcher Lake has 52 dens in various states), it is likely that a relatively limited amount of denning habitat could support this population.

3.5. Conclusions

Examination of burned den sites indicated an increased rate of collapse over that of dens in un-burned areas. Removal of vegetation cover and subsequent changes in substrate stability and permafrost accelerated the rates of collapse. Changes in habitat stability, microclimates, and vegetation potentially led to the avoidance of these areas by bears. Fire therefore impacts denning habitat through the direct disturbance of site level habitat characteristics believed to be important for the establishment and occupation of den sites. The long-term impacts of fire on denning habitat remain unknown. However, because of increased rates of den collapse in burned areas, decreased stability of denning habitat and long recovery times, any increase in the frequency and extent of forest-tundra fires will likely result in reduced availability of denning habitat. Although the effects of habitat loss due to forest fires have not been shown to have direct impacts on survival or reproduction in this population, if the rates of habitat loss continue or accelerate, resource managers should be aware of the potential possibility of limited availability of maternity denning habitat in the future. As climate change represents a unique challenge to Parks Canada to meet its conservation mandate under present legislation (Scott *et al.* 2002) and adaptive management strategies will be needed to deal with potential impacts of climate change at the park level. Conservation efforts should focus on protecting areas that are known to have high den densities and are known to be productive (eg. Fletcher Lake and Kelsey Creek) to ensure adequate availability of denning habitat in the long-term.

3.6. Literature Cited

Amstrup, S.C., and Gardner, C. 1994. Polar bear maternity denning in the Beaufort Sea. Journal of Wildlife Management 58:1-10.

Amstrup, S.C. 2003. Polar bear (*Ursus maritimus*). Pages 587-610 *in* Feldhamer, G.A. Thompson, B.C., and Chapman, J.A. Wild Mammals of North America: Biology, Management and Conservation.

Arsenault, D., and Payette, S. 1992. A postfire shift from lichen-spruce to lichen-tundra vegetation at tree line. Ecology 73:1067-1081.

Auclair, A.N.D. 1983. The role of fire in lichen-dominated tundra and forest-tundra. In : Wein, R.W. and MacLean, D.A. (eds.) The Role of Fire in Northern Circumpolar Ecosystems.

Black, R.A. and Bliss, L.C. 1980. Reproductive ecology of *Picea mariana* (Mill.) BSP., at tree line near Inuvik, Northwest Territories, Canada. Ecological Monographs 50:331-354.

Boivin, S., and Bégin, Y. 1997. Development of black spruce (*Picea mariana*) shoreline stand in relation to snow level variations at Lake Bienville in northern Quebec. Canadian Journal of Forest Research 27:295-303.

Burn, C.R. 1998. The response (1958-1997) of permafrost and near-surface ground temperatures to forest fire, Takhini River valley, southern Yukon Territory. Canadian Journal of Earth Science 35:184-199.

Clark, D.A., Stirling, I., and Calvert, W. 1997. Distribution, characteristics, and use of earth dens and related excavations by polar bears on the western Hudson Bay lowlands. Arctic 50:158-166.

Clarkson, P.L., and Irish, D. 1991. Den collapse kills female polar bears and two newborn cubs. Arctic 44:83-84.

Daly, C. 1984. Snow distribution patterns in the alpine krummholz zone. Progress in Physical Geography 8:157-175

Demaster, D.P., and Stirling, I. 1990. *Ursus maritimus*. Mammalian Species 145:1-7.

Derocher, A.E., and Stirling, I. 1990. Distribution of polar bears (*Ursus maritimus*) during the ice-free period in western Hudson Bay. Canadian Journal of Zoology 68:1395-1403.

Derocher, A.E., and Stirling, I. 1995. Estimation of polar bear population size and survival in western Hudson Bay. Journal of Wildlife Management 59:215-221.

Derocher, A.E., Stirling, I., and Andriashek, D. 1992. Pregnancy rates and serum progesterone levels of polar bears in western Hudson Bay. Canadian Journal of Zoology 70:561-566.

Derocher, A.E., Anriashek, D., and Stirling, I.. 1993. Terrestrial foraging by polar bears during the ice-free period in western Hudson Bay. Arctic 46:251-254.

Durner, G.M., Amstrup, S.C., and Fishbach, A. 2003. Habitat characteristics of polar bear terrestrial maternal den sites in northern Alaska. Arctic 56:55-62.

Dyer, S.J., O'Neill, J.P., Wasel, S.M., and Boutin, S. 2001. Avoidance of industrial development by woodland caribou. Journal of Wildlife Management 65:531-542.

Eberhardt, L.L. and Thomas J.M. 1991. Designing environmental field studies. Ecological Monographs 61:53-73.

Flannigan, M.D., and Van Wagner, C.E. 1991. Climate change and wildfire in Canada. Canadian Journal of Forestry Research 21:66-72.

Flannigan, M.D., Bergern, Y., Englemark, O., and Wotton, BM . 1998. Future wildfire in circumboreal forest in relation to global warming. Journal of Vegetation Science 9:469-476.

Flannigan, M.D., Stocks, B.J., and Wotton, B.M. 2000. Climate change and forest fires. The Science of the Total Environment 262:221-229.

Gough, W.A., and Leung, A. 2002. Nature and fate of Hudson Bay permafrost. Regional Environmental Change 2:177-184.

Hammer, D. 1999. Forest fires influence on yellow hedysarum habitat and its use by grizzly bears in Banff National Park, Alberta. Canadian Journal of Zoology 77:1513-1520.

Harington, C.R. 1968. Denning habits of the polar bear (*Ursus maritimus* Phipps). Canadian Wildlife Service Report Series No. 5. 30 pp.

Heinselman, M.L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota Quaternary Research 3:329-382.

Jonkel, C., Kolenosky, G.B., Robertson, R.J., and Russell, R. 1972. Further notes on polar bear denning habits. International Conference on Bear Research and Management 2:142-158.

Jorgenson, M.T., Racine, C.H., Walters, J.C., and Osterkamp, T.E. 2001. Permafrost degradation and ecological changes associated with warming climate in central Alaska. Climate Change 48:551-579.

Larsen, T. 1985. Polar bear denning and cub production in Svalbard, Norway. Journal of Wildlife Management 49:320-326.

Latour, P.B. 1981. Spatial relationships and behavior of polar bears *Ursus maritimus* Phipps concentrated on land during the ice free season of Hudson Bay. Canadian Journal of Zoology 59:1763-1774.

Lønø, O. 1970. The polar bear (*Ursus maritimus* Phipps) in the Svalbard area. Norsk Polarinstitutt Skrifter 149:1-115.

Lunn, N.J., and Stirling, I. 1985. The significance of supplemental food to polar bears during the ice-free period of Hudson Bay. Canadian Journal of Zoology 63:2291-2297.

Lunn, N.J., Stirling, I., Andriashek, D., and Richardson, E. 2004. Selection of maternity dens by female polar bears in western Hudson Bay. Polar Biology.

Mace, R.D., Waller, J.S., Manley, T.L, Lyon, L.J, and Zuuring, H. 1996. Relationships among grizzly bears, roads and habitat in the Swan Mountains, Montana. Journal of Applied Ecology 33:1395-1404.

Mackay, J.R. 1995. Active layer changes (1968 to 1993) following the forest-tundra fire near Inuvik, N.W.T., Canada. Arctic and Alpine Research 27:323-336.

Morneau, C., and Payete, S. 1989. Post-fire lichen-spruce woodland recovery at the limit of the boreal forest in northern Québec. Canadian Journal of Botany 67:2770-2782.

Nagy, J.A., Russell, R.H., Pearson, A.M., Kingsley, M.C.S., and Larsen, C.B. 1983. A Study of Grizzly Bears on the Barren Grounds of Tuktoyaktuk Peninsula and Richards Island, Northwest Territories, 1974 to 1978. Canadian Wildlife Service Edmonton, Alberta.

Nelson, R.A., Folk, G.E Jr., Pfeoffer, E.W., Craighead, J.J., Jonkel, C.J., and Steiger, D.L. 1983. Behavior, biochemistry, and hibernation in black, grizzly, and polar bears. International Conference on Bear Research and Management 5:284-290.

Osyanikov, N. 1998. Den use and social interactions of polar bears during spring in a dense denning area on Herald Island, Russia. Ursus 10:251-258.

Payette, S., and Gagnon, R. 1985. Late Holocene deforestation and tree regeneration in the forest-tundra of Québec. Nature 313:570-572.

Pearson, A.M. 1975. The northern Interior grizzly bear *Ursus arctos* L. Canadian Wildlife Service report Series 34:86 pp.

Polischuk, S.C., Hobson, K.A., and Ramsay, M.A. 2001. Use of stable-carbon and – nitrogen isotopes to assess weaning and fasting in female polar bears and their cubs. Canadian Journal of Zoology 79:499-511.

Price, C., and Rind, D. 1994. Possible implications of global climate change on global lightning distributions and frequencies. Journal of Geophysical research 99:823-831.

Pruitt, W.O. 1957. Observations on the bioclimate of some taiga mammals. Arctic 10:131-138.

Ramsay, M.A. and Stirling, I. 1990 Fidelity of female polar bears to winter den sites. Journal of Mammalogy 71:233-236.

Ramsay, MA., Nelson, R.A., and Stirling, I. 1991. Seasonal changes in the ratio of serum urea to creatinine in feeding and fasting polar bears. Canadian Journal of Zoology 69:298-302.

Schweinsburg, R.E., Spencer, W., and Williams, D. 1984. Polar bear denning area at Gateshead Island, Northwest Territories. Arctic 37:169-171

Scott, D., Malcolm, J.R., and Lemieux, C. 2002. Climate change and modelled biome representation in Canada's national park system: implications for system planning and park mandates. Global Ecology and Biogeography 11:475-484.

Scott, P.A., and Stirling, I. 2002. Chronology of terrestrial den is by polar bears in western Hudson Bay as indicated by tree growth anomalies. Arctic 55:151-166.

Skinner, W.R., Jefferies, R.L., Carleton, T.J., Rockwell, R.F., and Abraham, K.F. 1998. Prediction of reproductive success and failure in lesser snow geese based on early season climatic variables. Global Change Biology 4:3-16.

Smith, T.G. 1980. Polar bear predation of ringed and bearded seals in the land-fast sea ice habitat. Canadian Journal of Zoology 58:2201-2209.

Stirling, I., Jonkel, C., Smith, P., Robertson, R., and Cross, D. 1977. The ecology of the polar bear (*Ursus maritimus*) along the western coast of Hudson Bay. Canadian Wildlife Service Occasional Paper 33:64 pp.

Stirling, I., and Archibald, W.R. 1977. Aspects of predation of seals by polar bears. Journal of the Fisheries Research Board of Canada 34:1126-1129.

Stirling, I., and Derocher, A.E. 1993. Possible impacts of climate warming on polar bears. Arctic 46:240-245.

Stirling, I., and Smith, T.G. 2004. Implications of warm temperatures and an unusual rain event on the survival of ringed seals on the coast of Southeastern Baffin Island. Arctic 57:(in press).

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

Stocks, B.J., Mason, J.A., Todd, J.B., Bosch, E.M., Wotton, B.M., Amiro, B.D., Flannigan, M.D., Hirsch, K.G., Logan, K.A., Martell, D.L., and Skinner, W.R. 2003. Large forest fires in Canada, 1959-1997. Journal of Geophysical Research 107:1-12.

Swanson, D.K. 1996. Susceptibility of permafrost soils to deep thaw after forest fires in interior Alaska, U.S.A., and some ecological implications. Arctic and Alpine Research 28:217-227.

Thie, J. 1974. Distribution and thawing of permafrost in the southern part of the discontinuous permafrost zone in Manitoba. Arctic 27:189-200.

Thomas, J.W., Forsman, E.D., Lint, J.B., Meslow, E.C., Noon, B.R., and Verner, J. 1990. A conservation strategy for the Northern Spotted Owl. Interagency Committee to Address the Conservation of the Northern Spotted Owl. U.S. Department of the Interior, Portland, Oregon, USA.

Timoney, K.P. and Wein, R.W. 1991. The aerial pattern of burned tree vegetation in the subarctic region of northwestern Canada. Arctic 44:223-230.

Watts, P.D., and Hansen, S.E. 1987. Cyclic starvation as a reproductive strategy in the polar bear. Symposia of the Zoological Society of London 57:305-318.

Wein, R.W. 1976. Frequency characteristics of Arctic tundra fires. Arctic 29:213-222.

Wein, R.W. and Bliss, L.C. 1973. Change in arctic *Eriophorum* tussock communities following fire. Ecology 54: 845-852.

Weins, J.A. and Parker K.A. 1995. Analyzing the effects of accidental environmental impacts: approaches and assumptions. Ecological Applications 5:1069-1083.

Zoltai, S.C., and Pettapiece, W.W. 1974. Tree distribution on perennially frozen earth hummocks. Arctic and Alpine Research 6:403-411.

Table 3.1 Habitat characteristics measured at polar bear (*Ursus maritimus*) burned and unburned den sites in the Churchill region of Manitoba.

Den Characteristics	*Burned den* (*n* = 48)	*Un-burned den* (*n* = 101)	*P*
Permafrost Top (cm)	54.1±8.8 (54)	35.2±9.1 (31)	< 0.001
Permafrost Side (cm)	78.3±13.1 (76.5)	49.3±15.3 (38.5)	< 0.001
Permafrost Inside (cm)	41.8±11.2 (38)	23.3±6.3 (21)	< 0.001
Stability Top (cm)	33.0± 7.8 (30)	48.1±11.3 (46)	< 0.001
Stability Side (cm)	27.8±9.3 (25)	44.3±11.5 (41)	< 0.001
Stability Inside (cm)	12.2±4.2 (10)	12.9±5.2 (10)	0.876
Percent Tree	1.8±5.0 (0)	29.2±16.0 (30)	< 0.001
Percent Shrub	18.1±12.4 (11)	17.9±11.3 (13)	0.358
Percent Herb	11.6±8.5 (11)	16.7±11.5 (13)	0.003
Percent Moss	4.0±5.7 (1)	7.4±10.3 (1)	0.187
Percent Lichen	8.6±13.5 (2)	27.5±16.4 (30)	< 0.001
Percent Ground	8.8±9.8 (10)	7.0±7.3 (10)	0.770
Percent Burned	51.9±31.2 (65)	0.0±0.0 (0)	< 0.001

Note: Values are means ± standard deviation (median).

Table 3.2. Physical state of den sites in burned and un-burned areas showing the proportion of stable, slumping and collapsed dens (number of dens). (G-test for heterogeneity $\chi^2 = 42.78$, $df = 2$, $P < 0.001$).

Den state	*Un-burned den (n = 101)*	*Burned den (n = 48)*
Stable	0.46 (46)	0.2 (1)
Slumping	0.32 (32)	0.32 (15)
Collapsed	0.23 (23)	0.66 (32)

Table 3.3. Number of female bears handled in the Lee Lake burn area pre and post-fire and number of bears handled in the Fletcher Lake control area. Survey effort was similar between areas with a total of 1053 km and 1010 km being flown in the Lee Lake burn area and the Fletcher Lake control area between 2001 and 2003.

Year	Lee Lake	Fletcher Lake
1984	1	2
1985	1	3
1986	2	1
1987	3	11
1988	0	19
1989	4	10
1990	0	8
1991	4	7
1992	1	14
1993	3	11
1994	0	8
1995	1	7
1996	2	12
1997	5	6
1998	1	13
1999	0	4
2000	0	2
2001	0	10
2002	0	2
2003	0	8

Table 3.4. Average number of bears caught over five year periods in the Lee Lake area burn and the Fletcher Lake control area (Mean ± SE).

5-Year Period	Lee Lake	Fletcher Lake
1984-1988	1.4 ± 0.5	7.2 ± 1.6
1989-1993	2.4 ± 0.8	9.2 ± 1.4
1994-1998	1.8 ± 0.9	10.0 ± 1.2
1999-2003	0.0 ± 0.0	5.2 ± 3.4

Table 3.5. Total number of lightning strikes in the denning area from 1998-2003.

	1998	1999	2000	2001	2002	2003
April	1	12	0	0	0	0
May	4	466	8	290	0	40
June	110	883	420	1698	6561	1295
July	1652	3184	2737	1933	1565	6257
August	1116	600	1087	1532	94	2141
September	13	31	1	68	530	1
Total	2896	5176	4253	5521	8750	9734

Table 3.6. Frequency of forest-tundra fires, total area burned and potential loss of polar bear maternity denning habitat from 1998-2003.

Year	Number of Burns	Area Burned (km^2)	Potential Habitat Loss (km^2)
1998	3	25.70	2.03
1999	18	683.73	46.08
2000	6	31.43	0.42
2001	0	0.00	0.00
2002	0	0.00	0.00
2003	6	204.03	18.63
Total	33	944.89	67.16

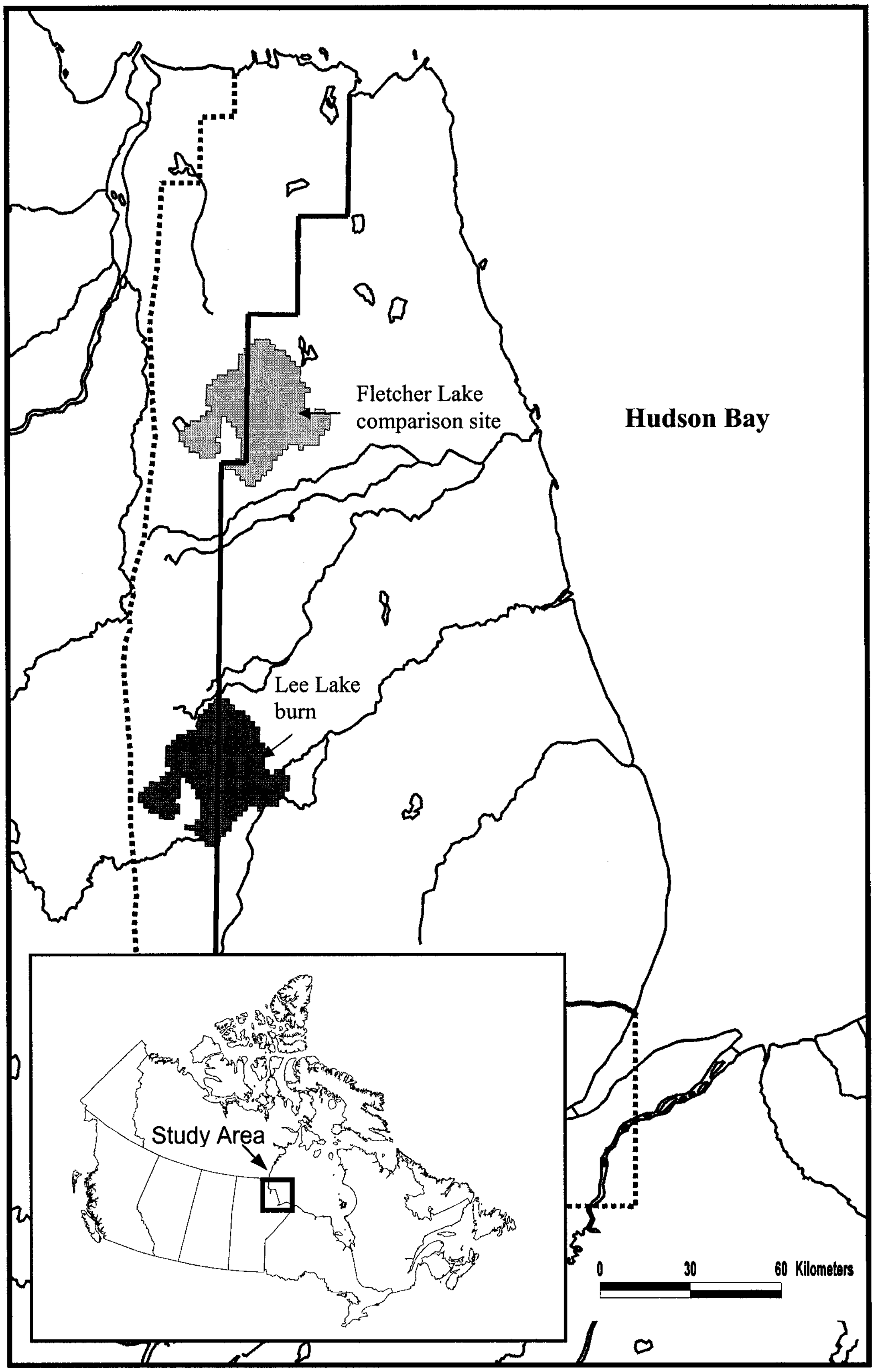

Figure 3-1. Location of Lee Lake burn and Fletcher Lake comparison site in Wapusk National Park, Manitoba.

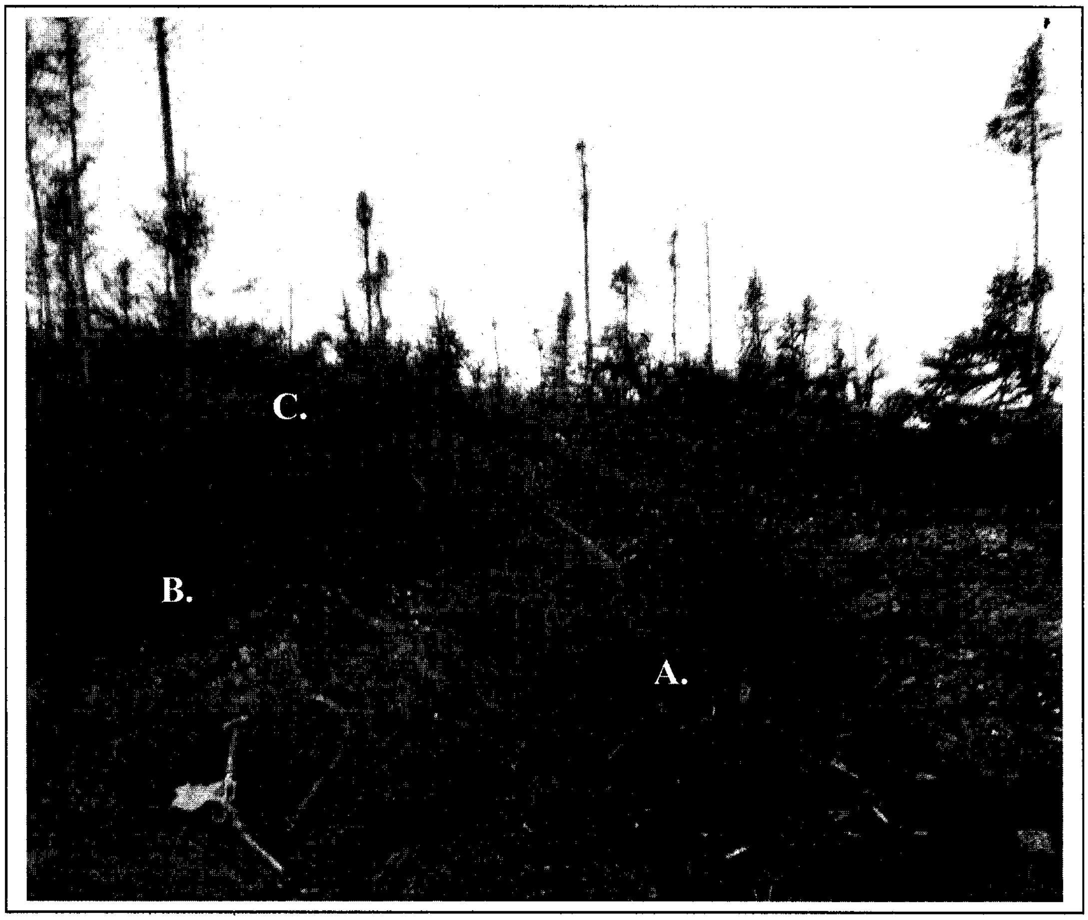

Figure 3-2. Typical polar bear maternity den site along the edge of a lake in Wapusk National Park. (A.) excavated peat form den (B.) vegetated bank habitat along the edge of a lake and (C.) krummholz spruce characteristic of most den sites.

Figure 3-3. Burned maternity den site in Wapsuk National Park showing the removal of vegetation and subsequent collapse of the den as a result of fire. (A.) old den chamber (B.) collapsed roof and (C.) slumping of bank habitat.

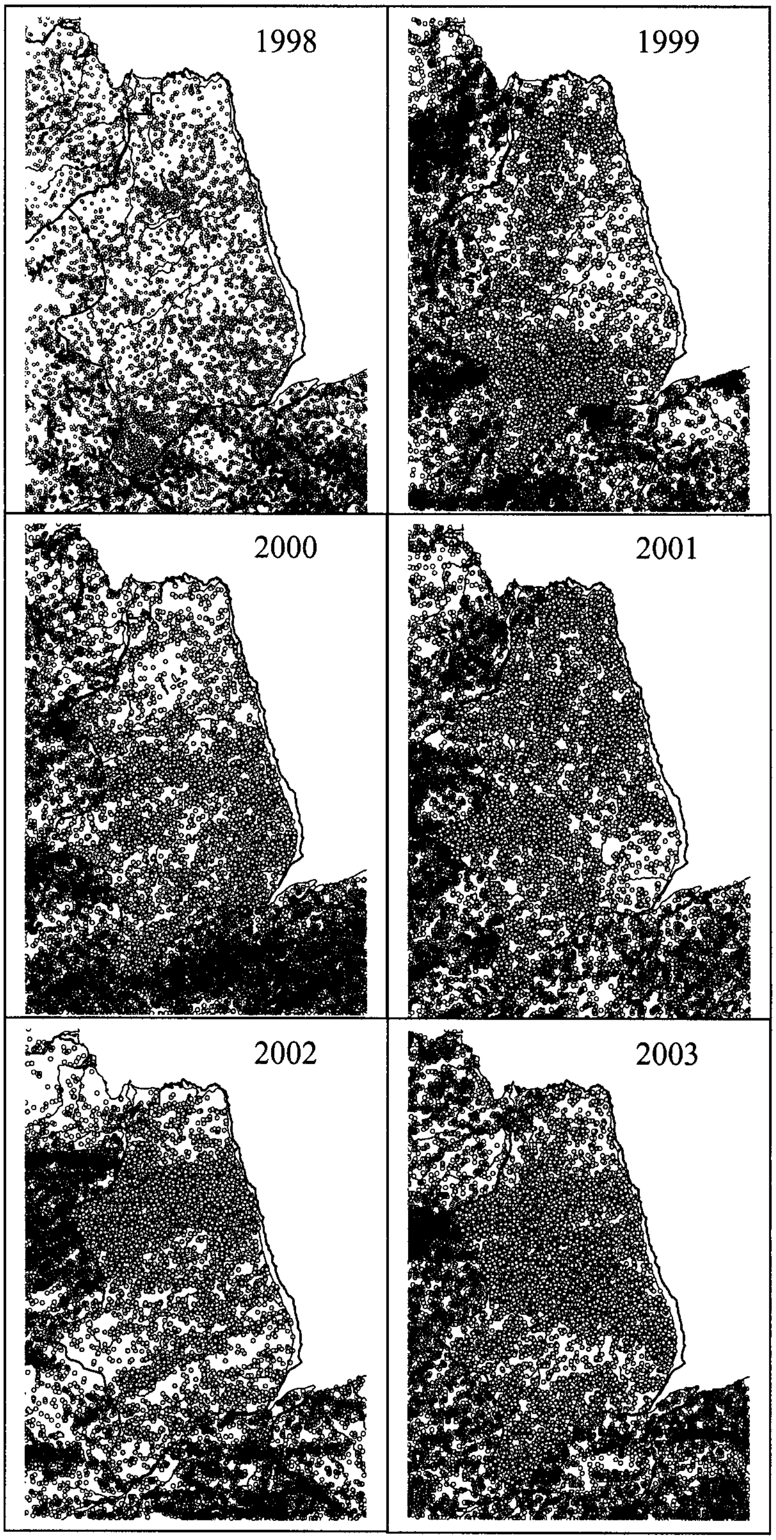

Figure 3-4. Variation in the distribution of ground lightning strikes in the EIS study area from 1998-2003.

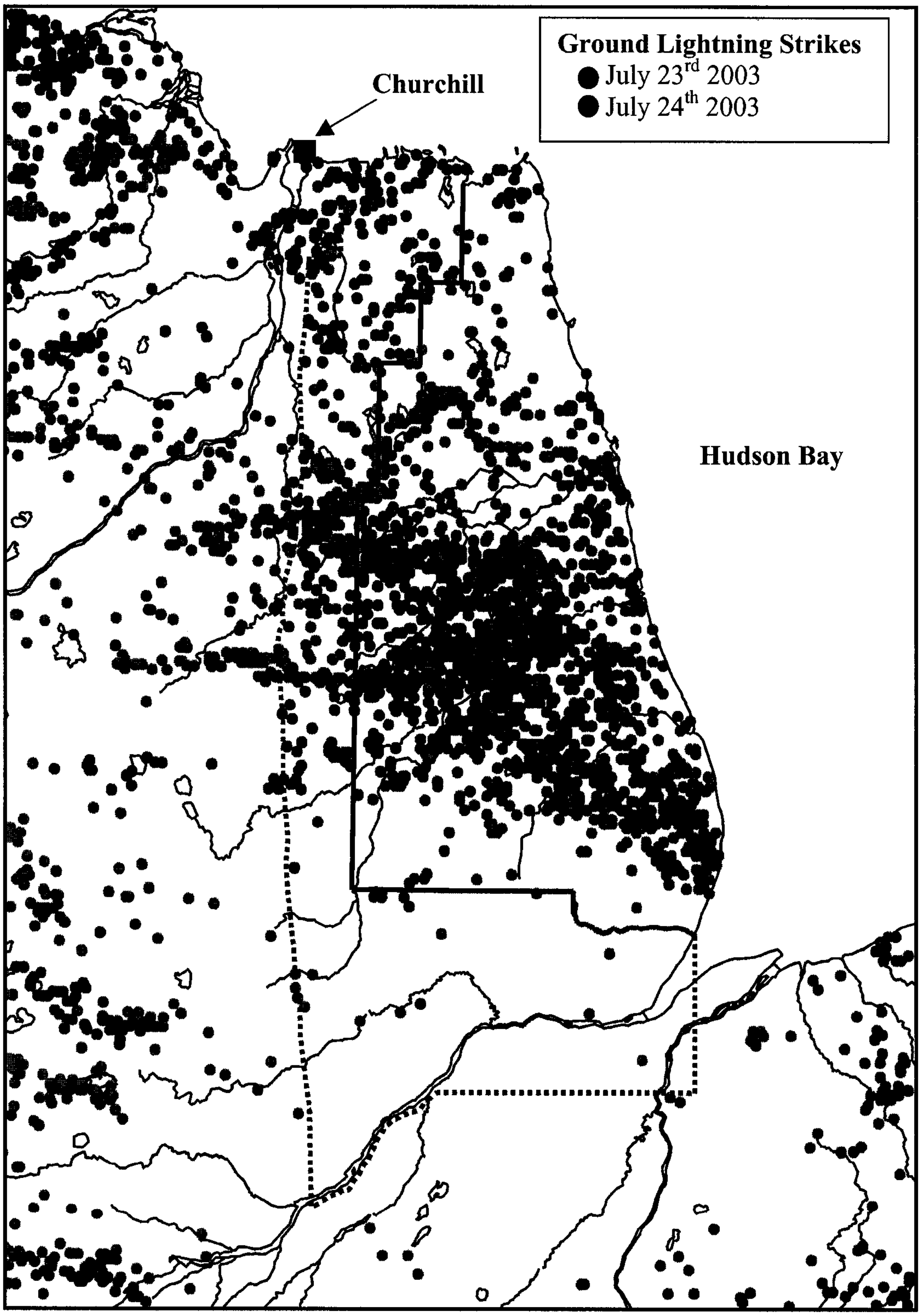

Figure 3-5. Ground lightning strikes in the Churchill region of Manitoba on July 23rd and 24th of 2003.

4. SUMMARY

As denning is critical for successful reproduction of polar bears, identification of maternity denning habitat is vital for the protection of individual polar bear populations (Scott and Stirling 2002) and requires an understanding of both the minimal habitat requirements for den structures, as well as the landforms necessary to support those conditions (Durner *et al.* 2003). My objectives in this thesis were to describe polar bear maternity den site selection, the availability of suitable denning habitat, and the potential affects of forest-tundra fires on denning habitat on the western Hudson Bay polar bear population.

In the Churchill region of Manitoba, den sites were predominately found in riparian areas along the edges of lakes, rivers and creeks that provide sufficient relief for the excavation of dens. Minimum bank height was determined to be an important factor in den site selection, requiring approximately 1 m of relief before dens could be constructed. The relative paucity of peat banks of sufficient height (ie. > 1m) adjacent to coastal areas may partially explain why polar bears in western Hudson Bay den much farther from the coast than bears in other populations (see Amstrup 2003). Bears denned almost exclusively in peat substrates at the tops of banks underneath krummholtz spruce, the roots of which provided stability to the ceilings of dens. Along lake shores, bears showed a preference for den sites that were oriented away from prevailing northwesterly winds. This orientation on leeward slopes may allow for warmer microclimates because of facing toward the sun and greater accumulation of snow over dens (Pearson 1975; Nagy *et al.* 1983). Permafrost depth at den sites was variable, and was likely influenced by denning activity, such as the removal of peat and vegetation. Slopes at den sites were similar to those reported from other studies (Pearson 1975; Harding 1976; Durner *et al.* 2003) and likely represented a trade-off between the ease of digging on slopes and the stability of level ground. Overall, polar bears near the coast of western Hudson Bay selected den sites with similar characteristics as grizzly bears in the western Canadian Arctic (Pearson 1975; Nagy *et al.* 1983), which likely reflects the close evolutionary history of these two species (Kurtén 1964). Among, polar bear populations, the use of terrestrial den sites is unique to those in western Hudson Bay and James Bay, and likely represents an adaptation to the limited availability of suitable snowdrifts (those of sufficient depth and height to excavate a sheltered den) in the region at parturition.

Predictive models of habitat quality can assist in conservation planning efforts (Nielsen *et al.* 2002) and may also be important in quantifying habitat loss as a result of natural or anthropogenic disturbances. Habitat models that incorporate fine-scale spatial analyses of landscapes, can improve understanding of the habitat requirements of a species and the factors influencing their selection of habitat (Fernandez *et al.* 2003; Nielsen *et al.* 2003). In this study, the examination and qualification of den site habitat characteristics (Chapter 2) greatly improved our understanding of polar bear denning habitat requirements and significantly aided in the development of biologically meaningful variables such as NDVI edge (NEDGE) and distance to water (DWATER) for habitat modelling. Providing a link between species resource requirements and habitat variables will result in more biologically meaningful models.

Resource selection functions were used to develop a polar bear denning habitat model with values proportional to the probability of use of resources, in this case habitat variables by denning polar bears. Edge detection analysis was important in describing the interface between bands of krummholz spruce at the top of riparian banks, where most bears denned, and adjacent upland lichen sites. The evaluation of RSF models through out-of-sample data sources provides insight into the predictability and robustness of models (Boyce *et al.* 2002). In this circumstance, the denning habitat model performed well in predicting where used sites should be found (Table 2-9), although the importance of site level characteristics (ie. bank height, slope, vegetation cover etc.) must be taken into consideration when defining "suitable" denning habitat. As these dens persist on the landscape for decades and even centuries (Scott and Stirling 2002), the selected habitats described here likely represent those that have been used over the long-term by this population. Identification of the distribution of potential denning habitat and knowledge on den chronology (see Lunn *et al.* 2004) will allow resource managers to develop management plans for the spatial and temporal regulation of human activities in the denning area to minimize the potential impacts on denning bears.

Understanding the impact of environmental change on animal and plant populations is central to modern conservation biology (Norris and Stillman 2002). However, assessing the impacts of change in the environment due to natural disturbances such as fire are often difficult because of problems with replication and availability of pre- and post-disturbance data (Eberhardt and Thomas 1991; Weins and Parker 1995). Research from this study has shown that forest-tundra fires in maternity denning habitat destroy polar bear dens. Fire disturbance resulted in changes in vegetation, permafrost, substrate stability and rate of collapse of dens. Removal of vegetation and the degradation of permafrost led to decreased stability of dens and denning habitat. Denning surveys, satellite movement data and long-term population monitoring indicate that, although female bears may return to areas after they have burned, they do not appear to den there (Chapter 3).

Habitat loss as a result of forest fires, may limit the availability of preferred denning habitat, especially if forest fire frequency and extent increase as predicted (see Flannigan *et al.* 1998; Flannigan *et al.* 2000). Atmospheric warming and increases in lightning activity as result of climate change are considered to be two important factors which may influence fire frequency and extent in the future (Price and Rind 1994; Stocks *et al.* 1998; Flannigan *et al.* 2000). Predicted increases in cloud-to-ground lighting discharges in the northern hemisphere (Price and Rind 1994), in association with warming trends in western Hudson Bay (Skinner *et al.* 1998), could result in an increase in fire activity and subsequent loss of habitat in the western Hudson Bay. Although the availability of denning habitat does not appear to be limiting at present (Chapter 3), the continued or increased frequency and extent of forest-tundra fires as a result of climate warming may lead to significant increases in habitat loss in the future. Therefore, resource managers need to be aware that the availability of prime denning habitat is limited and may require protection in some circumstances.

Although it appears that large amounts of suitable denning habitat currently exist, I suggest a precautionary approach to the management of this resource, as protection of these areas may be critical for the continued reproductive success of the western Hudson Bay polar bear population. Large fires in areas with high densities of dens and suitable habitat should be controlled to ensure habitat loss is minimal. As most fires are slow burning and the fuel supply is limited, in relation to the data presented in this thesis, only minimal resources would be required to control most fires in the denning area. Continued monitoring of the Lee Lake burn will further facilitate the assessment of the potential long-term impacts of fires on polar bear maternity denning habitat.

Although the persistence of the western Hudson Bay polar bear population is immediately dependent on changes in the availability of sea ice habitat, the cumulative impacts of climate through loss of critical denning habitat could further impact the reproductive success and long term viability of this population.

4.1. Literature Cited

Amstrup, S.C. 2003. Polar bear (*Ursus maritimus*). Pages 587-610 *in* Feldhamer, G.A. Thompson, B.C., and Chapman, J.A. Wild Mammals of North America: Biology, Management and Conservation.

Boyce, M.S., Vernier, P.R., Nielsen S.E., and Schmiegelow, F.K.A. 2002. Evaluating resource selection functions. Ecological Modelling 157:281-300.

Durner, G.M., Amstrup, S.C., and Fishbach, A. 2003. Habitat characteristics of polar bear terrestrial maternal den sites in northern Alaska. Arctic 56:55-62.

Eberhardt, L.L., and Thomas J.M. 1991. Designing environmental field studies. Ecological Monographs 61:53-73.

Fernández, N., Delibes, M., Palmores, F., and Mladenoff, D.J. 2003. Identifying breeding habitat for the Iberian lynx: inference from a fine-scale spatial analysis. Ecological Applications 13:1310-1324.

Flannigan, M.D., Bergerpn, Y., Englemark, O., and Wotton, BM . 1998. Future wildfire in circumboreal forest in relation to global warming. Journal of Vegetation Science 9:469-476.

Flannigan, M.D., Stocks, B.J., and Wotton, B.M. 2000. Climate change and forest fires. The Science of the Total Environment 262:221-229.

Harding, L.E. 1976. Den site characteristics of arctic coastal grizzly bears (*Ursus arctos* L.) on Richards Island, Northwest Territories, Canada. Canadian Journal of Zoology 54:1357-1363.

Kurtén, B.1964. The evolution of the polar bear, *Ursus maritimus* Phipps. Acta Zoologica Fennici 108-1-30.

Lunn, N.J., Stirling, I., Andriashek, D., and Richardson, E. 2004. Selection of maternity dens by female polar bears in western Hudson Bay. Polar Biology (*in press*).

Nagy, J.A., Russell, R.H., Pearson, A.M., Kingsley, M.C.S., and Larsen, C.B. 1983. A Study of Grizzly Bears on the Barren Grounds of Tuktoyaktuk Peninsula and Richards Island, Northwest Territories, 1974 to 1978. Canadian Wildlife Service Edmonton, Alberta.

Nielsen, S.E., Boyce, M.S., Stenhouse, G.B., and Munro, R.H.M. 2002. Modelling grizzly bear habitats in the Yellowhead ecosystem of Alberta: taking autocorrelation seriously. Ursus 13:45-56.

Nielsen, S.E., Boyce, M.S., Stenhouse, G.B., and Munro, R.H.M. 2003. Development and testing of phonologically driven grizzly bear habitat models. Ecoscience 10:1-10.

Norris, K. and Stillman, R. 2002. Predicting the impact of environmental change. Pages 180-197 *in* Norris, K. and Pain, D.J. eds. In: Conserving Bird Diversity general principles and their application.

Pearson, A.M. 1975. The northern Interior grizzly bear *Ursus arctos* L. Canadian Wildlife Service report Series 34:86 pp.

Price, C., and Rind, D. 1994. Possible implications of global climate change on global lightning distributions and frequencies. Journal of Geophysical research 99:823-831.

Scott, P.A., and Stirling, I. 2002. Chronology of terrestrial den use by polar bears in western Hudson Bay as indicated by tree growth anomalies. Arctic 55:151-166.

Skinner, W.R., Jefferies, R.L., Carleton, T.J., Rockwell, R.F., and Abraham, K.F. 1998. Prediction of reproductive success and failure in lesser snow geese based on early season climatic variables. Global Change Biology 4:3-16.

Weins, J.A., and Parker K.A. 1995. Analyzing the effects of accidental environmental impacts: approaches and assumptions. Ecological Applications 5:1069-1083.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	M	M	M	M	M	M	M	M	M	M	M	-26.5
1971	-25.8	-19.1	-16.3	-5.3	5.1	11	13.4	13.3	8.1	1.5	-12.4	-22
1972	-31.4	-28.8	-16.5	-5.9	4.7	11.1	13	13.9	4	-4.3	-14.3	-29
1973	-22.1	-24.6	-8.6	-7.5	5.1	10.7	15.1	16.4	7.6	1.3	-12.7	-25.6
1974	-32.5	-25.3	-21.8	-6.4	3	10.4	16.7	13.1	3.3	-3.1	-7.8	-17.3
1975	-28.2	-22.2	-18.5	-3	5.5	12.4	15.9	13.4	6.5	0.1	-9.5	-23.6
1976	-26	-23.1	-18.4	-0.7	5.4	12.7	15.7	14.5	8.3	-1.1	-12.4	-27.2
1977	-25.7	-20.5	-12.1	-1.3	8.3	12.3	14.8	10.6	7.8	4.1	-10.4	-22.2
1978	-24.6	-19	-18.4	-5.8	4.6	8.8	13.3	10.9	4.9	-1.5	-14.2	-23.5
1979	-26	-29.9	-18.8	-5.2	2.2	10.7	15.5	11.1	4.7	-1.8	-11.8	-16.5
1980	-26.3	-20.9	-16	0.2	6.1	9.1	15.3	13.5	4.5	-1.7	-12.4	-25.2
1981	-19.3	-17	-11.3	-9.9	3.6	10.2	16	15.3	7.3	0	-7.2	-20.6
1982	-31.5	-23.7	-16.1	-7.8	6.6	8.7	14.8	12.1	7.7	1.7	-14.9	-24.7
1983	-23.8	-23.2	-16.3	-6.8	-3	12.1	16.9	16.7	8.6	2.5	-5.5	-26.3
1984	-27.7	-17.2	-15.5	0.4	2.6	13	16.8	16.1	5.8	1.4	-12.2	-27.9
1985	-22.8	-25.4	-13.2	-4.2	4.8	10.6	13.7	13.2	7.3	-0.7	-16.1	-22
1986	-24	-22.3	-15.4	-4.5	6.5	10.2	13.1	12.8	5.4	-1	-18.7	-17.2
1987	-20.6	-18.5	-11.2	-0.8	4.7	13.3	15	11.8	9.2	-1.1	-8.5	-15.9
1988	-27.9	-24.9	-15.4	-4.2	3.5	13.4	15.9	15.3	9.2	-1.5	-10.4	-22.4
1989	-25.3	-22.4	-20.2	-7.3	3.1	10.5	18.5	14	7.3	0.2	-19.1	-25.7
1990	-25.2	-24.9	-10.8	-6.7	3.9	10.9	16.1	14.6	6.8	-2.5	-12.3	-27.9
1991	-29.7	-19.7	-13	-2.7	5.1	13.9	16.7	15.6	6.9	-2.8	-16.6	-22.9
1992	-23.1	-23.2	-14.6	-7.8	3.3	7.6	12.5	13	5.1	-1.2	-9.5	-22.9
1993	-21.3	-23.2	-14.1	-3.4	5.9	10.5	15.3	13.7	5.1	-3.6	-14.2	-22.1
1994	-31.1	-26.8	-14.2	-7.6	4.1	13.8	14.5	13.2	10.5	2.3	-9.5	-16.8
1995	-21.2	-25.1	-13.9	-7.3	2.4	14.3	14	14.7	6.8	-0.4	-16.8	-21.5
1996	-29.3	-20.5	-18.6	-8.3	1.9	12.9	16.6	15.2	9.5	-1.3	-14.3	M
1997	-26	-21.7	-18.2	-6.7	M	12.1	17.6	13.8	9	-2.5	-12.7	-16.1
1998	-27.4	-14.3	-15.6	-0.8	5.7	12.6	16.4	16.8	9.2	M	M	-21
1999	-23.9	-16.9	-10.6	1.8	8.2	13.6	15.4	14.7	7.4	-1.1	-8.6	M
2000	-24.2	-16.7	-8.7	-5.8	4.1	8.8	15.6	14.9	6.9	2.9	-10.4	-26.1
2001	-19.4	-24.3	-12.6	-1.9	7.5	11.7	17.2	15	9.9	0.3	-8.6	-16.7
2002	-24.6	-21.4	-18.6	-8.2	-0.5	11.5	16.4	13.8	7.9	-3.4	-13.3	-17.1
2003	-21.9	-27.7	-16.3	-6.4	7.5	12.4	16.4	M	M	M	M	M
Max	-19.3	-14.3	-8.6	1.8	8.3	14.3	18.5	16.8	10.5	4.1	-5.5	-15.9
Year	1981	1998	1973	1999	1977	1995	1989	1998	1994	1977	1983	1987
Mean	-25.4	-22.3	-15.1	-4.8	4.4	11.4	15.5	14	7.1	-0.6	-12.2	-22.3
Min	-32.5	-29.9	-21.8	-9.9	-3	7.6	12.5	10.6	3.3	-4.3	-19.1	-29
Year	1974	1979	1974	1981	1983	1992	1992	1977	1974	1972	1989	1972
StDev	3.5	3.7	3.3	3	2.4	1.7	1.4	1.6	1.8	2.1	3.3	4

Appendix A: Mean monthly temperature (degrees centigrade) at Gillam, Manitoba from 1970-2003 (TR = trace; M = missing data).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	M	M	M	M	M	M	M	M	M	M	M	0
1971	0	TR	0	6.6	68.6	61	157.2	83.3	38.1	29	0	TR
1972	0	0	TR	1	17.8	27.7	52.6	51.3	60.7	TR	1.3	0
1973	0	0	TR	TR	4.3	16.3	36.3	24.6	46.5	48.5	TR	0
1974	0	0	0	4.8	6.1	43.4	75.7	94.5	27.7	0.5	9.7	TR
1975	0	TR	0	TR	20.6	68.1	33.3	113.8	33.3	3	TR	TR
1976	0	0	0	14.7	27.7	52.1	138.2	65.3	26.2	11.7	TR	TR
1977	TR	TR	2.1	10.7	32.7	52.8	47	86	38.6	33.4	8.2	TR
1978	0	0	TR	3.8	23.6	41.2	133.8	118.1	77.7	40	TR	TR
1979	0	0	TR	0.4	18.8	44.9	98.1	58	54.9	25.6	0.4	TR
1980	0	0	0	6	27.1	116.1	134.8	124.5	55.5	6.6	TR	0
1981	TR	0.2	TR	TR	TR	58.5	75.8	63.7	30.2	99.1	1.4	TR
1982	0	TR	3.2	0.4	50.2	55.6	75	61	43	16.6	TR	TR
1983	TR	TR	TR	0.4	33.2	41.2	64.4	112.2	92	12.8	3.2	0
1984	0	0	0	1	19.8	45.2	69.2	38.8	28.2	8	TR	TR
1985	TR	0	1.2	19.6	40.4	107.2	63.8	18.4	62.5	12.4	0	0
1986	TR	0.2	2	14.7	55.4	70.9	120.4	106.3	33.4	2.6	TR	TR
1987	0.2	0	TR	2.2	25	22.2	30.4	109.8	54.4	6.6	4.2	1.6
1988	0	0	0	2.2	82	42.5	103.6	43.9	44.2	5	TR	TR
1989	TR	0	TR	3	42.4	13.6	76.6	42	48.2	3.8	0	0
1990	0	0	1.1	5.4	7.2	48.4	84.4	94.4	30.8	12	2.4	TR
1991	TR	TR	TR	1.2	27.6	64.6	105.8	48.6	52.2	21.8	2.2	1
1992	TR	TR	1.4	TR	35.4	11.6	18.6	45	58.8	11.6	0.6	TR
1993	0.2	TR	0	TR	22.2	105	84	130	42	8	0	TR
1994	0	0	TR	TR	34.6	62	64.4	52.2	33.8	7	TR	0.2
1995	0	0	0.4	0.2	7	23.6	69.2	115	47	1.2	TR	0
1996	0	TR	0	TR	12.8	88.4	60.2	73.2	21.8	7.8	TR	M
1997	0.2	TR	0	5.8	M	32	42.8	197.5	90.2	97.8	1	TR
1998	0	0.2	TR	0.6	26	57.8	93.5	26.2	26.6	M	M	0.2
1999	TR	0	TR	0.2	23.6	41.1	64.2	65.2	112.7	2.2	0.4	M
2000	TR	0.2	3.4	8.8	41.8	19.1	179.4	52.6	47.6	15.8	TR	0
2001	TR	0	0.2	6.2	60.4	98.8	38.4	51.6	24.8	9.8	0.4	0.4
2002	TR	0	0	1.6	8.2	59.8	47.3	54.4	79.6	10.6	TR	TR
2003	TR	0	TR	3.4	12.2	69.2	52.6	M	M	M	M	M
Total	0.6	0.8	15	124.9	914.7	1761.9	2591	2421.4	1563.2	570.8	35.4	3.4
Max	0.2	0.2	3.4	19.6	82	116.1	179.4	197.5	112.7	99.1	9.7	1.6
Year	1987	1981	2000	1985	1988	1980	2000	1997	1999	1981	1974	1987
Mean	0	0	0.5	3.8	28.6	53.4	78.5	75.7	48.9	18.4	1.1	0.1
Min	0	0	0	TR	TR	11.6	18.6	18.4	21.8	TR	0	0
Year	1971	1972	1971	1973	1981	1992	1992	1985	1996	1972	1971	1970
StDev	0.1	0.1	0.9	5	19.3	27.2	38.4	38.7	21.9	24.3	2.3	0.3

Appendix B: Mean monthly rainfall (mm) in Gillam, Manitoba from 1970-2003. (TR = trace; M = missing data).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	M	M	M	M	M	M	M	M	M	M	M	30.5
1971	34.5	46	22.9	29.2	7.9	0	0	0	TR	35.1	59.9	52.6
1972	9.4	14.7	5.3	14	12.7	8.1	TR	0	13.5	18.5	23.1	13
1973	11.2	28.7	14	54.1	6.4	TR	0	0	TR	7.1	71.6	34.3
1974	17.8	19.3	23.6	4.3	8.4	7.1	0	TR	14.5	6.9	16.5	37.1
1975	20.6	15.7	27.7	6.1	9.7	0	0	0	9.7	29.2	20.8	50.3
1976	44.5	31.2	17.8	18.8	10.9	6.4	0	0.5	7.9	47	25.1	44.5
1977	20.2	17.9	26.4	20.2	10.5	6.6	0	0	0	0.4	11.4	15.7
1978	13.2	8.2	34.4	44.8	22.2	1	0	TR	4.6	23	15.8	27.6
1979	7.7	11	41.4	5.1	42.2	TR	0	0	11.5	8.1	41.8	18.1
1980	26.7	20	37.6	8.3	17.7	8.3	0	0	27.6	16.3	51	49
1981	7.3	20.5	40	46.3	6.1	1.8	0	0	0.8	3.9	30.7	10.1
1982	24.4	25.3	30.6	19.8	4.2	TR	0	TR	12	8.6	44.9	55.9
1983	29.8	28.8	48.1	26.4	48.6	0.2	0	0	0.2	3.8	89	16.8
1984	35.2	22	8.8	41	53	0	0	0	22.2	17.6	78	16.2
1985	21.2	34	19.8	17.8	21.6	5	0	0	20	22.6	29.8	21.2
1986	38.4	13	40.5	58	6.9	1.4	0	0	0.4	31.9	13.4	34.4
1987	42	25.4	32	35	2.6	1.4	0	0	6.6	25.8	20.2	44.4
1988	20.6	16.4	24.8	35.4	55	0	0	0	0	72.7	46.6	24.4
1989	24.6	19.2	16	25	16	TR	0	0	2.6	26.8	29.4	14.4
1990	19.6	16.4	12.2	32.3	3.8	TR	0	0	TR	18.7	117.7	60.3
1991	19.8	18.6	6.2	43.2	4.4	3	0	0	0.6	39.4	65.2	47
1992	35.2	34.6	47.6	33.4	31.6	19.4	0	0	20.2	18.6	44.6	33.2
1993	20.6	27.2	17.8	9.4	6.6	4.6	0	0	28.6	44.2	56.8	18
1994	18	41.8	71.9	5.1	13.8	3.8	0	0	0	35.8	64.4	31.2
1995	45.2	41	14	25.2	18.4	0	0	0	5	11.8	18.6	48.4
1996	14	58	49.6	5	12	TR	0	0	1	114.2	53.8	M
1997	24.4	45.8	16.8	3.8	M	0	0	0	TR	34.6	36.2	37.7
1998	29.1	76	10.6	14.6	2.6	5.8	0	0	0	M	M	9.4
1999	12.8	45	32.6	1.6	11.7	TR	0	0	0.6	6.2	37.4	M
2000	12.8	3.4	17	16.9	6	6	0	0	4	14	61	11.8
2001	22.5	13.6	54.6	3.2	7.6	TR	0	0	0.2	11.6	21	39.8
2002	10.2	18	12.6	60.2	36.8	0.2	0	0	1.4	23.6	46	18.2
2003	13.6	12.2	25.6	3.4	1.4	TR	0	M	M	M	M	M
Total	747.1	868.9	900.8	766.9	519.3	90.1	0	0.5	215.7	778	1341.7	965.5
Max	45.2	76	71.9	60.2	55	19.4	TR	0.5	28.6	114.2	117.7	60.3
Year	1995	1998	1994	2002	1988	1992	1972	1976	1993	1996	1990	1990
Mean	22.6	26.3	27.3	23.2	16.2	2.7	0	0	6.7	25.1	43.3	31.1
Min	7.3	3.4	5.3	1.6	1.4	0	0	0	0	0.4	11.4	9.4
Year	1981	2000	1972	1999	2003	1971	1971	1971	1977	1977	1977	1998
StDev	10.6	15.5	15.6	17.4	15.2	4.1	0	0.1	8.7	22.7	24.8	15.2

Appendix C: Mean monthly snowfall (cm) in Gillam, Manitoba from 1970-2003 (TR = trace; M = missing data).

1998		
Month	Day	Total
April	28	1
Sum		1
May	23	4
Sum		4
June	10	94
	23	2
	26	14
Sum		110
July	4	20
	7	553
	10	1025
	11	5
	14	25
	19	18
	26	4
	27	1
	29	1
Sum		1652
August	1	53
	5	1
	7	36
	12	105
	14	13
	19	673
	20	23
	23	9
	28	124
	29	4
	31	75
Sum		1116
September	10	1
	11	1
	12	11
Sum		13
Total		2896

1999		
Month	Day	Total
April	24	12
Sum		12
May	5	389
	26	3
	27	74
Sum		466
June	5	4
	9	4
	11	34
	18	797
	19	4
	20	7
	23	33
Sum		883
July	7	68
	10	20
	11	138
	20	49
	21	1
	23	1732
	24	756
	25	34
	26	386
Sum		3184
August	13	1
	14	39
	19	25
	20	87
	26	448
Sum		600
September	15	2
	21	28
	25	1
Sum		31
Total		5176

Appendix D: Frequency of daily lightning strikes in the EIS study area from 1998-1999.

2000		
Month	Day	Total
May	29	8
Sum		8
June	23	260
	30	160
Sum		420
July	12	4
	13	3
	15	536
	16	52
	23	52
	24	25
	28	62
	29	340
	30	1662
	31	1
Sum		2737
August	11	32
	20	5
	24	334
	27	715
	28	1
Sum		1087
September	7	1
Sum		1
Total		4253

2001		
Month	Day	Total
May	1	1
	18	8
	19	281
Sum		290
June	8	1
	9	485
	21	554
	22	296
	23	362
Sum		1698
July	2	206
	3	2
	6	25
	7	5
	17	5
	19	990
	20	673
	29	1
	30	26
Sum		1933
August	3	164
	4	47
	5	41
	6	3
	8	2
	16	9
	21	28
	24	1
	25	1211
	26	26
Sum		1532
September	16	5
	29	63
Sum		68
Total		5521

Appendix E: Frequency of daily lightning strikes in the EIS study area from 2000-2001.

2002		
Month	Day	Total
June	21	75
	22	46
	25	28
	26	8
	28	41
	29	4751
	30	125
Sum		5074
July	1	259
	5	301
	6	1
	7	85
	13	63
	15	12
	25	298
	26	13
	29	2
Sum		1034
August	1	1
	9	1
	23	2
	25	15
	28	74
Sum		93
September	11	1
	12	319
	15	1
Sum		321
Total		6522

2003		
Month	Day	Total
May	17	4
	27	36
Sum		40
June	9	4
	12	19
	15	107
	16	444
	17	22
	22	24
	23	124
	24	258
	27	268
	28	25
Sum		1295
July	3	7
	12	591
	13	691
	15	664
	16	1
	23	1986
	24	2306
	29	11
Sum		6257
August	9	5
	12	26
	14	581
	15	3
	17	1494
	19	9
	25	23
Sum		2141
September	5	1
Sum		1
Total		9734

Appendix F: Frequency of daily lightning strikes in the EIS study area from 2002-2003.