

# Bounding the Southern Hudson Bay polar bear subpopulation

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**Abstract:** Polar bears (*Ursus maritimus*) are managed by the 5 nations where they occur (Canada, Greenland/Denmark, Norway, Russia, United States) using discrete subpopulations. In Canada, polar bears are harvested throughout their range, and several subpopulations are managed by more than one jurisdiction; therefore, recent management focused on ensuring sustainable polar bear harvests. Consequently, the subpopulation from which harvested bears are removed and the geographic boundaries of that subpopulation must be correctly identified. However, boundaries of the Southern Hudson Bay (SH) subpopulation have not been verified using satellite radio-telemetry data. Sea ice duration has already declined in Hudson Bay and James Bay, and both the duration and distribution of sea ice are predicted to decline greatly in the next century; therefore, it is important to document current habitat use patterns to assess the potential impacts of climate change. We used a probabilistic approach to describe the utilization distribution for the SH subpopulation based on data from 1997–2003 from 26 adult female bears fitted with satellite collars and assessed whether the currently accepted boundaries represent the population utilization distribution. We conclude that the SH boundaries do reflect the current spatial distribution of adult female bears in this subpopulation. Our analysis provides a benchmark to compare to the future distribution and habitat use of this subpopulation in response to effects of climate change and identifies future research needs to investigate polar bear distribution in James Bay and in the area near the boundary between the SH and Western Hudson Bay management zones.

**Key words:** climate change, Hudson Bay, James Bay, polar bear, population delineation, population distribution, Southern Hudson Bay, subpopulation boundaries, *Ursus maritimus*, utilization distribution

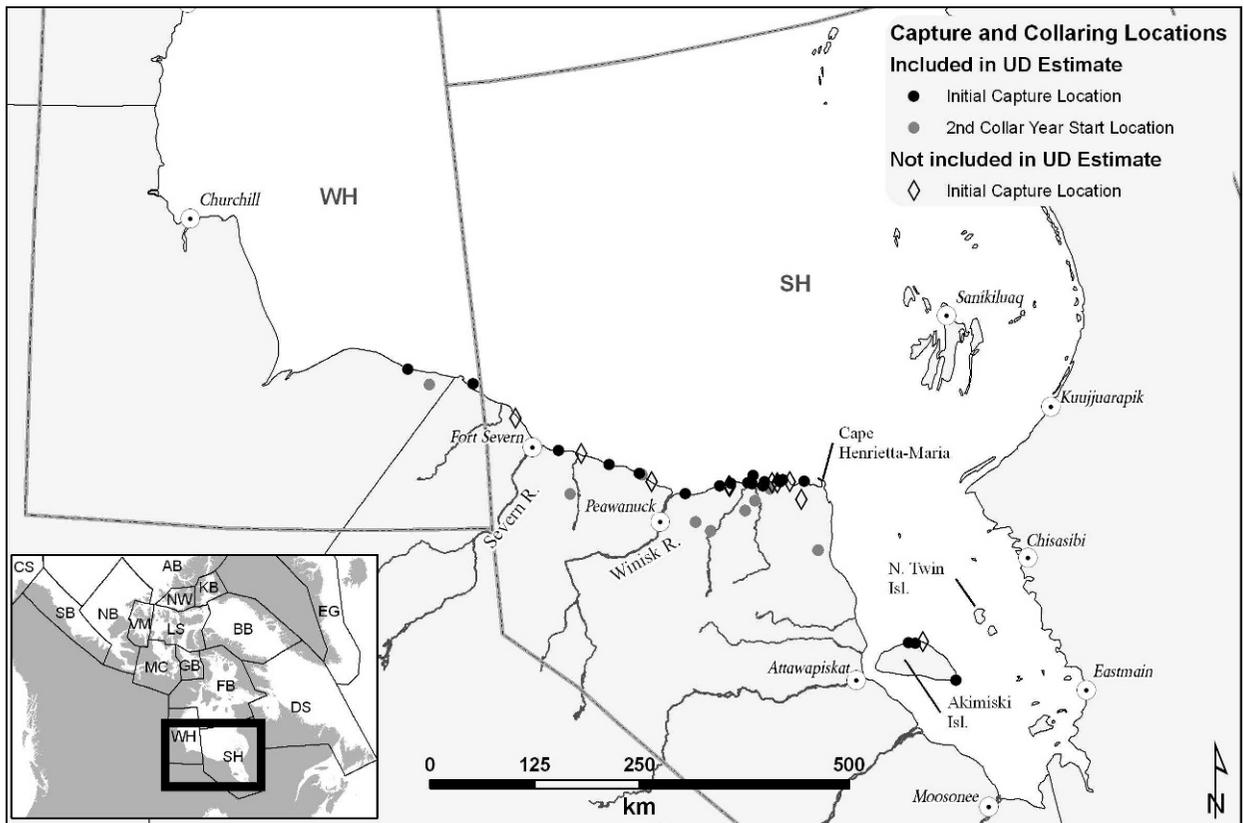
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Polar bears (*Ursus maritimus*) are distributed throughout the circumpolar Arctic in 19 relatively discrete subpopulations (Obbard et al. 2010:31–80). Despite the general lack of geographic barriers to movement, differences in genetic structure (Paetkau et al. 1999, Crompton et al. 2008) and space use (Taylor et al. 2001) occur among these subpopulations. As such, polar bears are managed on a subpopulation basis by the nations of Canada, Greenland/Denmark, Norway, Russia, and the United States where polar bears occur (Prestrud and Stirling 1994, Larsen and Stirling 2009). In Canada, recent management has emphasized sustainable harvest (Lunn et al. 2010), which requires rigorous estimates of population abundance and growth rate. To produce reliable estimates of subpopulation abundance and vital rates, and to assign harvest to the correct subpopulation, bound-

aries of the subpopulation under study must be well defined.

In Canada, subpopulation boundaries were initially proposed based on barriers to movements, reconnaissance surveys, anecdotal sampling of traditional knowledge of Inuit hunters, and management considerations such as political boundaries (Taylor and Lee 1995, Lunn et al. 2010). Boundary revisions occurred based on reviews of individual movements determined from mark–recapture studies, mark–kill data (i.e., tag returns from harvested animals), and VHF and satellite telemetry (Lunn et al. 2010). Currently accepted subpopulation boundaries in Canada (Fig. 1) were established by the Canadian Federal–Provincial–Territorial Polar Bear Technical Committee (PBTC) in 1996 (Lunn et al. 1998). As part of the 1996 PBTC evaluation of subpopulation boundaries, those of the Southern Hudson Bay (SH) subpopulation were refined based on information from tag returns of animals

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**Fig. 1.** Study area showing capture locations for adult female polar bears fitted with satellite radiocollars in Southern Hudson Bay, 1997–2003. Inset shows boundaries (gray lines) of Canadian and neighboring polar bear subpopulations at 31 December 2008 (Lunn et al. 2010): AB: Arctic Basin; BB: Baffin Bay; CS: Chukchi Sea; DS: Davis Strait; EG: East Greenland; FB: Foxe Basin; GB: Gulf of Boothia; KB: Kane Basin; LS: Lancaster Sound; MC: M'Clintock Channel; NB: Northern Beaufort Sea; NW: Norwegian Bay; SB: Southern Beaufort Sea; SH: Southern Hudson Bay; VM: Viscount Melville Sound; WH: Western Hudson Bay.

originally tagged in Ontario from 1984–86 and subsequently harvested or re-captured in Ontario, Manitoba, Nunavut, and Québec, and on limited movement data from animals fitted with conventional VHF radiocollars (Kolenosky et al. 1992). However, the boundaries of the SH subpopulation have never been verified using data from satellite telemetry.

Both the duration and distribution of sea ice in the Hudson Bay region are predicted to change substantially in the next 50–100 years, and polar bear abundance may decline drastically as sea ice declines (Amstrup et al. 2008). These changes in polar bear habitat are predicted to greatly affect the on-ice distribution of polar bears (Durner et al. 2009), and some evidence of this has already been demonstrated for the neighboring Western Hudson Bay (WH)

subpopulation (Parks et al. 2006). The spatial and temporal distribution of sea ice will continue to decline as long as greenhouse gas concentrations rise; however, loss of sea ice is not irreversible provided mitigative actions are taken (Amstrup et al. 2010). Therefore, it is important to document current distribution and habitat use for polar bear subpopulations against which to compare future distribution and habitat use and thereby gauge possible effects of climate change.

Telemetry data can be used to describe the areas occupied by animals, or their utilization distributions (UD; Anderson 1982, Kernohan et al. 2001). Seeking to differentiate among neighboring subpopulations of polar bears in the Chukchi Sea and Beaufort Sea, Amstrup et al. (2004) used a probabilistic approach to calculate population UDs. We

**Table 1. Proportion of all locations in each Argos error class for data obtained for adult female polar bears fitted with satellite radiocollars in the Southern Hudson Bay subpopulation, 1997–2003.**

Location class	Associated error (meters)	Number of locations	Percent of total locations
0	>1500	138	4.1%
1	500–1500	1217	36.1%
2	250–500	931	27.7%
3	<250	491	14.6%
A	unknown	284	8.4%
B	unknown	275	8.2%
Z	invalid	31	0.9%
Total		3367	100%

followed the general approach of Amstrup et al. (2004) to calculate a population UD for the SH subpopulation, and asked whether the currently accepted subpopulation boundaries as described by the Canadian PBTC (Lunn et al. 1998) adequately portrayed that population UD based on satellite telemetry data from adult female polar bears collected from 1997–2003. Our calculation of the population UD for the SH subpopulation will provide a baseline against which the range of this subpopulation may be compared in the future as a metric of the effects of climate change.

## Methods

### *Animal capture and telemetry*

During 1997–2003, when all bears were on land during the ice-free season, we chemically immobilized bears  $\geq 1$  year of age using Telazol<sup>®</sup> (Fort Dodge Laboratories, Inc., Fort Dodge, Iowa, USA) by remote drug delivery of darts deployed from a Bell 206L-1 helicopter (Stirling et al. 1989). We chemically immobilized dependent young  $< 1$  year of age using a pole syringe. We deployed satellite radiocollars on adult females accompanied by yearlings because these bears would return to the ice with their yearlings in late fall of the year of capture, mate in the subsequent spring, and enter maternity dens the following fall approximately a year after handling. The overall study had multiple objectives, so in addition to obtaining data on movement patterns, this approach enabled us to identify locations of maternity dens during the expected minimum 1-year life of the collar. No one has successfully collared adult male polar bears because the diameter of their necks is greater than the width of their heads, and trials with ear-tag transmitters have had limited success (Born et al. 2010); therefore, we collared only adult females in

our study. We fitted candidate bears with Telonics (Telonics, Inc., Mesa, Arizona, USA) ultra-high-frequency platform transmitter terminal satellite collars (Fancy et al. 1988). Collars were set on a duty cycle to transmit locations for approximately 4 hours once every 6 days, though some collars were set to a 2-day cycle from 1 July to 30 November to increase the resolution of on-shore movement patterns.

### *Sampling effort*

To derive an accurate representation of the SH subpopulation UD, it was important to ensure that captured animals were distributed representatively across the known summer range of SH bears and that we had a sufficient sample size to depict the population UD area. The spatial distribution of sampled animals is a source of potential error for a population-level UD estimate; therefore, to avoid this bias we attempted to obtain a spatially distributed sample across the study area that mimicked the distribution and concentration of bears. To determine whether we had a sufficient sample size in our study, we used bootstrapping procedures to generate UDs for incrementally increasing numbers of bears for which we had data to determine whether the population UD size reached an asymptote before our maximum sample size.

**Data handling and analysis.** Before creating a population UD, we standardized the data using methods similar to those of Amstrup et al. (2004). We discarded low quality locations in Argos classes 0 and Z, retained class A and B locations for future screening, and retained all class 1, 2, and 3 locations (Table 1). Radiocollars often transmitted more than one location within a duty cycle; in such cases only the highest quality location was retained. When two or more locations of the highest quality remained for

a duty cycle, only locations within 3 km of each other were used (twice the maximum error for class 1 locations). We used the arithmetic mean of these locations to obtain a single location for that duty cycle. Finally, we manually inspected any class A and B locations for obvious errors (i.e., sudden extensive movements that were biologically implausible) and removed such erroneous locations from the dataset.

We generated separate on-ice and on-shore UD. Since dates of ice formation in autumn vary among years, rather than choosing arbitrary calendar dates to define the on-ice or on-shore periods, we used individual bear locations. On-shore for each bear was defined from its first location on shore until it returned to the ice. Conversely, on-ice for each bear was defined from its first location on ice until it returned to shore. To generate the UD, we first separated the data into 'bear-years', where each bear-year ran from the date of capture to 31 August of the following year. If a bear wore a collar for 2 consecutive years, a second bear-year was started on the following 1 September. We pooled data from bears in consecutive years, even though it is understood that annual variation may be masked (Schooley 1994). We did so because the reproductive status of such bears would change from year to year (e.g., from female accompanied by cubs to female accompanied by yearlings, or from female accompanied by yearlings to solitary pregnant female), and we wanted to ensure our description of space-use included data for females from all reproductive classes. No bears retained collars for 3 years.

Though actual dates vary among years, the eastern half of Hudson Bay typically freezes over within about 2 weeks of first formation of landfast ice along the Ontario coast (K.R. Middel and M.E. Obbard, unpublished data). Based on the rate of movement during freeze-up, bears could travel to the north end of the subpopulation boundary within about 48 days of first returning to the ice assuming rate of movement of 1.1 km/h and traveling 10 hr/day (Parks et al. 2006). Therefore, to ensure we had representative movements for each bear, we included only bears that retained their collars for at least 60 days (with at least 10 relocations) from their first on-ice position.

Southern Hudson Bay bears spend the ice-free season along the Ontario coast of Hudson Bay, along the James Bay shore, and on islands in James Bay, with low movement rates and small spatial

distribution (Obbard and Walton 2004). Because of this tight clustering of locations, we identified all on-shore positions (typically mid-July to late November) and maternity denning locations and used these to create the on-shore UD. To prevent multiple locations of bears in dens from unduly influencing the UD (Amstrup et al. 2004), we averaged locations from denned females so only one location per month was used, recognizing that the probability of use is conditional on the bears being outside the den. Because some collars transmitted to the satellite every 2 days during the on-shore period, we re-sampled data from those collars so that all collars provided locations every 6 days.

We calculated UD using R software for statistical computing (R Development Core Team 2011). We pooled all locations and converted them to a modified Lambert Conformal projection so distances could be measured in meters. Using the R package KernSmooth (Wand 2011) we calculated the bandwidth (or smoothing parameter) independently for each set of locations (on-ice and on-shore locations) using the 1-d plug-in method. We did this because Least Squares Cross Validation (LSCV) failed to estimate a bandwidth and defaulted to the reference bandwidth (*href*), which performs poorly and often over-smoothes the data, leading to a larger, unrealistic home range estimate (Gitzen and Millspaugh 2003, Gitzen et al. 2006). Following Amstrup et al. (2004), we estimated the bandwidth in both the x and y directions, ensuring first that the point cloud was oriented to maximize the variability along the x axis. To do this we used the minimum volume enclosing ellipse function (*mvee*; Lyons and Moshtagh 2011) in R to find the angle ( $\theta$ ) of the major axis for the point cloud and we rotated the data set by multiplying each [xy] location by the rotation matrix:

$$\begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}$$

We estimated bandwidths of the rotated data independently for the major (x) and minor (y) axis using the KernSmooth function *dpik* (Wand 2011), and then used these to generate 2-d fixed kernel estimates for each season (on-ice and on-shore).

To evaluate the effect of sample size on UD size estimation, we used a bootstrapping procedure to estimate UD sizes for varying numbers of bear-years ( $1 - n$ ). We used bootstrapping with replacement

and generated 500 independent UD estimates for each bear group using the same process used for the population UD estimate (i.e., bandwidth was estimated independently for each iteration based on the bears included in the estimate). We calculated the mean UD area, 95% confidence interval, and standard error for each set of bears. We used an asymptote function in R to predict an asymptote value for the 95% UD area (R Development Core Team 2011) using the results of bootstrapping and determined when the asymptote was reached by visual inspection.

To test the effect that individuals on the periphery of the SH subpopulation boundary might have on the estimated UD, we systematically excluded a single bear from the sample and generated a UD with the remaining bears. Using this method and comparing the UD estimates to the bootstrapping estimate of UD area enabled us to identify individuals that had a large influence on the UD size.

## Results

### *Sampling effort*

Between 1997 and 2003, we deployed Argos telemetry collars on 26 adult female polar bears and obtained 3,367 satellite locations (Table 1). After filtering the data for the best quality locations and removing bears that did not retain their collar for at least 60 days, we were left with 1,332 locations, separated into on-ice ( $n = 773$ ) and on-shore ( $n = 559$ ). These 2 data sets were used to generate the population UDs for each season. For on-ice, the number of locations per bear ranged from 12–38 ( $\bar{x} = 25.24$ ,  $SD = 7.67$ ). For on-shore, the number of locations per bear ranged from 2–19 ( $\bar{x} = 11.07$ ,  $SD = 3.89$ ).

From 26 collared bears we had a potential of data for 38 bear-years. However, restricting the data set for the on-ice UD to include only bears that retained collars for at least 60 days with at least 10 locations reduced this to 18 bears and 29 bear-years. For the on-shore UD, we excluded one bear for which there was only a single data point on land. We pooled the locations from the remaining 25 bears (37 bear-years) to create the on-shore UD.

We captured most bears (65.5%,  $n = 17$ ) between Cape Henrietta Maria and the mouth of the Winisk River (Fig. 1). We captured the remaining bears on Akimiski Island (11.5%,  $n = 3$ ), between the Winisk and Severn rivers (11.5%,  $n = 3$ ), and west of the Severn River (11.5%,  $n = 3$ ).

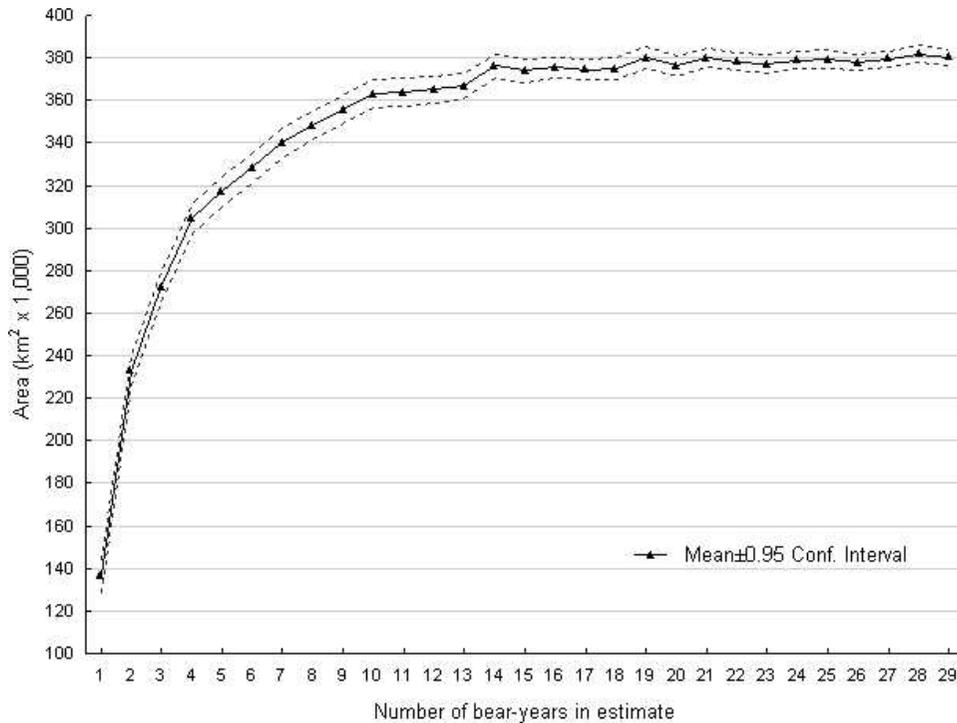
When assessing the effect of sample size on the on-ice population UD, visual inspection showed the results of bootstrapping approached an asymptote at 14 bear-years, with only slight increases in area after that and negligible increase after 21 bear-years at an area of 379,933 ( $SD = 52,341$ )  $\text{km}^2$  (Fig. 2). The final bootstrap estimate for 95% UD area using all 29 bear-years was 380,287 ( $SD = 41,370$ )  $\text{km}^2$ .

### *On-ice utilization distribution*

Kernel smoothing of telemetry locations for bears during on-ice months resulted in a population UD primarily within the boundary defined for SH (Fig. 3). However, UDs that included data from all bears were  $>410,000$   $\text{km}^2$ , much greater than the bootstrap mean of 380,287  $\text{km}^2$ . To understand this discrepancy, we investigated the possible disproportionate influence of bears collared on the eastern or western periphery of the subpopulation area by systematically excluding a single bear from the analysis and generating a UD with data from the remaining bears. This approach indicated that bear X19538, handled at the most westerly location close to, but west of, the boundary between SH and WH (Fig. 1), had a major effect on UD size. By excluding this bear, the 95% contour UD area was 357,310  $\text{km}^2$  (Fig. 3), and the mean UD area by bootstrapping dropped to 326,691 ( $SD = 23,915$ )  $\text{km}^2$ . However, the population UD estimate remained outside the confidence limits of the bootstrap estimate, suggesting the disproportionate influence of additional individuals. We used the same exclusion method to determine whether additional bears were unduly influencing the final UD estimate and found that the bears collared on Akimiski Island were inflating the UD estimate. Examining their space use, it was evident that these bears remained in James Bay for most or all of the on-ice season (Fig. 3). Consequently, we next excluded the 3 bears collared on Akimiski Island from the analysis. As a result, the population UD estimate excluding the WH bear and the James Bay bears was 325,079  $\text{km}^2$ , about 1  $SD$  from the bootstrap mean of 291,601 ( $SD = 26,322$ )  $\text{km}^2$ .

### *On-shore utilization distributions*

Polar bears confined to the shores of Hudson Bay and James Bay during the ice-free season use space much differently than when unrestricted on-ice. On-shore locations were concentrated in a few areas along the Hudson Bay coast of Ontario with some



**Fig. 2.** Mean 95% contour on-ice population utilization distribution (UD) areas for Southern Hudson Bay polar bears based on data from adult females fitted with satellite radiocollars, 1997–2003 and derived through 500 bootstrap estimates by incrementing the number of bear-years included in the UD estimate from 1 to 29. Solid triangles indicate mean values; dotted lines indicate 95% confidence interval.

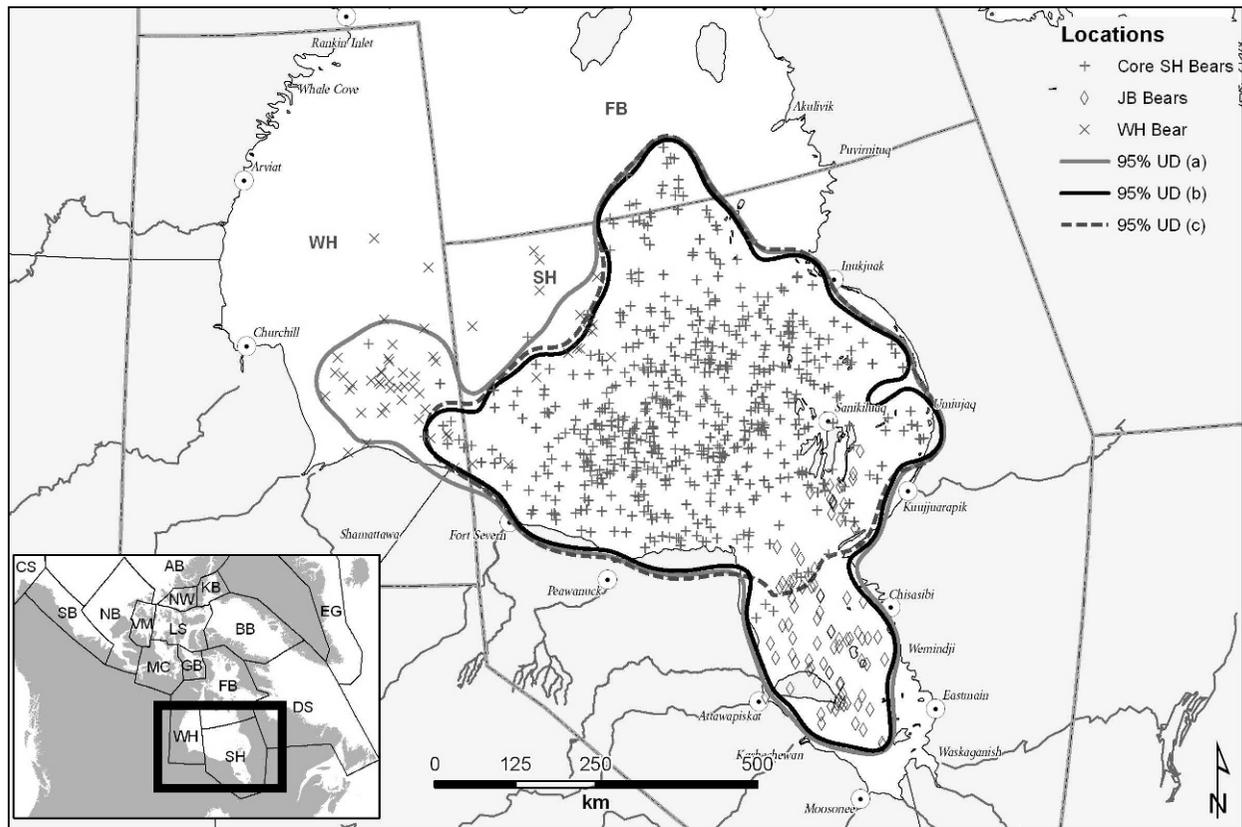
locations on Akimiski Island and North Twin Island, Nunavut. The area of the on-shore UD was 38,963 km<sup>2</sup> (Fig. 4). Though we did not generate separate UD estimates by excluding the bears from the western and eastern periphery of the sampled area, their area of influence is highlighted in insets 1 and 2 (Fig. 4).

## Discussion

When comparing the population UD that excludes the WH bear to the currently depicted subpopulation boundary, we find there is general agreement with the subpopulation boundary (at least as the UD is depicted by space use of adult females). Though we have no detailed information on the on-ice distribution of males, tag returns of SH bears harvested near the Belcher Islands, Nunavut, or near the Québec coast suggest that males occupy similar areas to females (M.E. Obbard, unpublished data). In addition, Amstrup et al. (2001) showed that males had space-use patterns similar to females in the Southern Beaufort Sea subpopulation. Therefore, the currently

depicted boundaries for the SH subpopulation as adopted by the PBTC (Lunn et al. 1998) represent well the recent population utilization distribution and so can be used confidently to manage harvest. However, the contribution of bears from James Bay had a major influence on the population UD area, and these bears spent most or all of the on-ice season in James Bay. In addition, changes in ice duration are occurring rapidly in James Bay (Gagnon and Gough 2005) and James Bay bears may be somewhat distinct genetically from other bears in SH (Crompton et al. 2008). These facts highlight that further research is critically needed in this area, especially on movement patterns of radiocollared bears.

We identified an area of on-ice use by bears from Ontario in the southeastern portion of the neighboring WH subpopulation range (Fig. 3). In our dataset, this pattern largely reflects the data for a single bear (X19538) that was radiocollared from September 1999 to September 2001. Bear X19538's original capture location was within the current on-shore portion of WH in southeastern Manitoba near the Ontario border (Fig. 1). This bear denned in



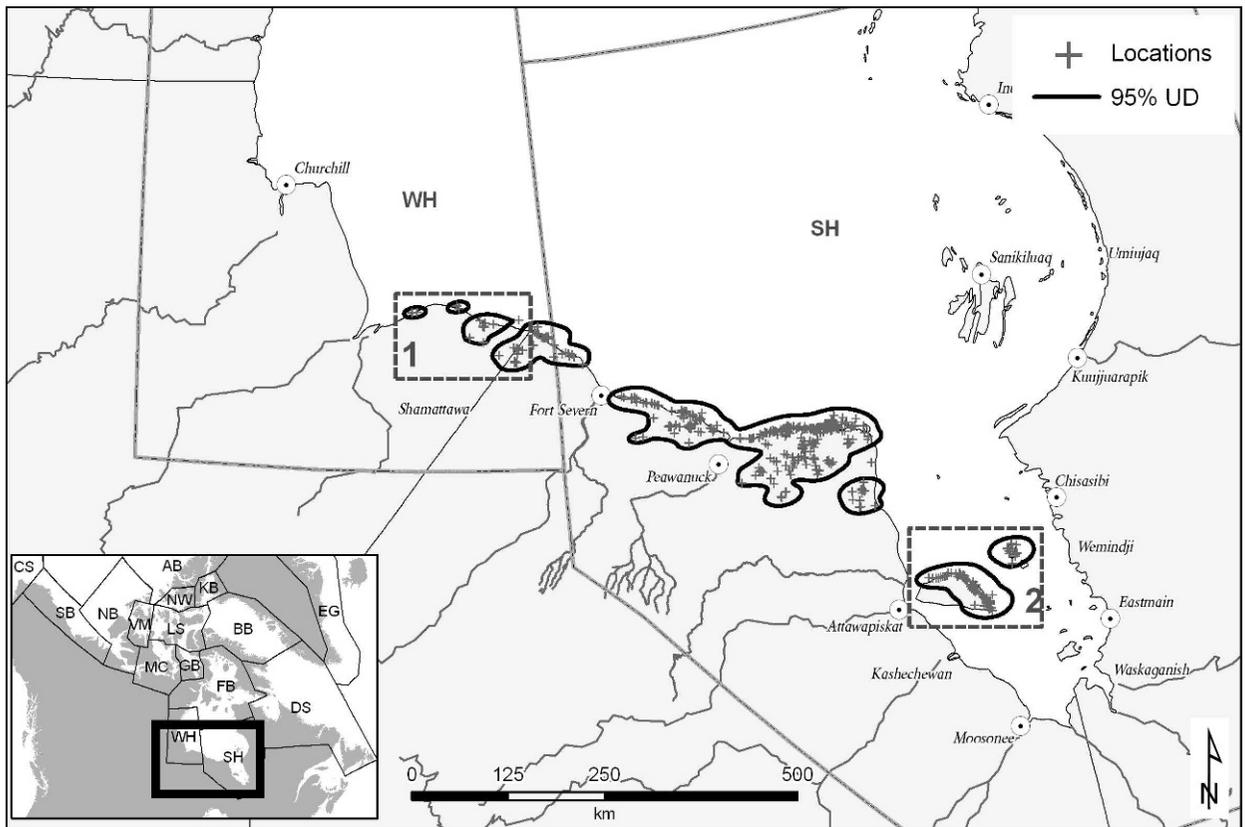
**Fig. 3.** On-ice population level 95% utilization distribution (UD) contours for Southern Hudson Bay (SH) polar bears derived from data for adult females fitted with satellite radiocollars, 1997–2003. The light grey line represents the UD derived by including all bears with at least 60 days of data. The dark grey line represents the UD derived by excluding one bear captured in the Southern Hudson Bay–Western Hudson Bay (WH) overlap area. The dotted line represents the contour derived by excluding bears captured in James Bay and in the SH–WH overlap area. Crosses represent locations for core SH bears. Diamonds represent locations for James Bay bears. X represents locations for WH bear.

Ontario in fall 2000, close to the Ontario–Manitoba border and within the currently depicted on-shore portion of WH in northwestern Ontario. Because most of X19538's on-ice and on-shore locations were within the currently depicted boundaries of WH, she should properly be considered to be a WH bear. However, her space use pattern highlights an important information gap in the region. Additional information on movement patterns and home ranges of bears occupying the overlap area near the SH–WH boundary is urgently needed to assess whether the boundary is correctly placed.

There was slight overlap of the SH on-ice population UD with the southern portion of the Foxe Basin (FB) subpopulation zone (Fig. 3). This, coupled with the slight overlap of the SH on-ice population UD into the eastern portion of the WH

zone suggests that an analysis of movement data for collared bears from all 3 subpopulations in Hudson Bay is warranted as soon as such data become available.

Kernel density estimators, though frequently used to define home ranges, have a significant drawback in that the smoothing parameter ( $h$ ), or bandwidth, choice has substantial influence over the kernel output (Silverman 1986, Worton 1995, Seaman et al. 1999). Changes in the bandwidth for a given data set may dramatically alter the shape of the UD as well as the overall size of the home range, with larger values of  $h$  resulting in oversimplified, larger UDs and overestimates of home range size (Silverman 1986, Seaman and Powell 1996, Kernohan et al. 2001). In a review, Gitzen et al. (2006) found the plug-in equation method of estimating the bandwidth



**Fig. 4.** On-shore population level 95% utilization distribution (UD) contour for Southern Hudson Bay polar bears derived from data for adult females fitted with satellite radiocollars, 1997–2003. The dark line represents the UD derived by including all captured bears with on-shore data. Rectangles enclosed by dotted lines indicate the approximate contribution to the population UD by: (1) the Western Hudson Bay bear; and (2) the James Bay bears, which had a large effect on the on-ice UD area estimates.

performed as well or better than the LSCV method and recommended it as an alternative when LCSV estimates fail as ours did. Therefore, we feel that the approach used here, following Amstrup et al. (2004), provides an accurate depiction of the recent population UD for the SH polar bear subpopulation. Overall, the distribution and concentration of the capture locations for bears in our sample was similar to the distribution and abundance of polar bears observed during late-summer aerial surveys conducted from 1963–1996, which showed a higher concentration of polar bears east of the Winisk River (Obbard and Walton 2004, Stirling et al. 2004). Due to the small change in population UD area after 21 bear-years in our bootstrapping, we suggest that our sample size was sufficient to determine the subpopulation UD area. Therefore, we are confident that our sampling was representative of the distribution of

adult females along the Hudson Bay coast and that our sample size was adequate.

Sea ice distribution and duration will continue to decline unless mitigative efforts to reduce greenhouse gas emissions are successful (Amstrup et al. 2010). In fact, sea ice is declining faster than predicted (Stroeve et al. 2007), and rates of decline can be expected to increase (Serreze et al. 2007). Declines in sea ice have been associated with declines in body condition, reproduction, survival, and abundance in several polar bear subpopulations (Stirling et al. 1999; Obbard et al. 2006; Regehr et al. 2007, 2010; Rode et al. 2010). One physical consequence of such changes in sea ice may be increased habitat fragmentation because of greater expanses of water between floes (Derocher et al. 2004). This has been predicted to result in decreased female mating success through its effects on such factors as

movement rates and the ability of males to successfully track and find females (Derocher et al. 2004, Molnár et al. 2010). For these reasons, it is important to continue to monitor changes in sea ice duration and area, as well as finer scale sea ice attributes such as floe size, since these can be expected to have negative effects on population growth rate and may also inhibit gene flow in the SH subpopulation in the future. Our depiction of the current population UD for the SH subpopulation can be compared to that derived by researchers in the future to measure the impact of changes in sea ice distribution and duration in James Bay and Hudson Bay on polar bear movement patterns and habitat use.

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