

WESTERN HUDSON BAY POLAR BEAR AERIAL SURVEY, 2011

FINAL REPORT

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SUMMARY

Although capture-based studies in the Western Hudson Bay polar bear subpopulation (WH) have documented declines in abundance, survival, and body condition, these findings are inconsistent with local knowledge and perceptions. To address on-going debate about current abundance and continue the development of non-invasive research methods, we conducted a comprehensive aerial survey of WH, including Nunavut, Manitoba, and Ontario. We used a combination of overland transects oriented perpendicular to the coastline and extending up to 100 km inland, coastal contour transects, and small island sampling during the August, 2011 survey. We implemented both distance sampling and sight-resight protocols while sampling from helicopter and fixed wing platforms. We recorded a total of 711 polar bear sightings, concentrated along the coastline and in the central and southern Manitoba and Ontario portions of WH, although bears were also regularly sighted inland in the Wapusk National Park region. We examined 4 datasets using distance sampling and sight-resight analyses and generated an abundance estimate of about 1,000 bears (95% CI: about 715 – 1398). We hypothesize that a distributional shift within WH toward southeastern Manitoba and Ontario, particularly among adult males, has occurred in recent years. The aerial survey-derived estimate is consistent with the 2004 capture-based estimate but inconsistent with projections suggesting continued decreases in abundance. Limited spatial sampling, large numbers of bears summering in southeastern WH, and high fidelity exhibited by bears during late summer may have negatively biased capture-derived abundance estimates. However, potential bias in the capture-based estimate does not necessarily negate the declining trend, estimates of vital rates, and observed decreases in body condition. We note that mean litter sizes and number of dependent offspring observed in 2011 in WH were less than recent research in other seasonal ice subpopulations, suggesting relatively poor reproductive output. We emphasize that all sources of data should be considered when evaluating WH subpopulation status.

INTRODUCTION

Status of the Western Hudson Bay Subpopulation

Scientific evidence, primarily based on a long-term tagging program, suggests that the abundance of polar bears in Western Hudson Bay (WH) increased during the 1970's, remained

stable for a period in the 1980's and has subsequently declined (Derocher and Stirling 1995a; Lunn et al. 1997; Regehr et al. 2007). Between 1984 and 2004, estimated abundance decreased by approximately 22% from 1200 to 935 bears (Regehr et al. 2007). Associated declines in survival, reproductive output and body condition during this period have been attributed to earlier sea ice breakup in Hudson Bay as a result of global climate warming (Stirling et al. 1999; Regehr et al. 2007). An increase in incidences of reported human-polar bear conflicts in the region has also been interpreted as a sign that the subpopulation is undergoing significant change and has created public safety concerns (GN unpublished data; Stirling and Parkinson 2006; Towns et al. 2009; Peacock et al. 2010). The extension of the ice-free season has forced bears to spend longer periods on land without access to their primary food (seals), leading to poorer condition and an increased tendency to seek alternative food sources such as those available around settlements and camps (Stirling and Parkinson 2006). Population viability analysis based on 2004 demographic data (Regehr et al. 2007) project that the WH subpopulation will continue to decline (Obbard et al. 2010). In addition, climate models predict that sea ice habitats in Hudson Bay will further deteriorate, resulting in additional declines in abundance (Amstrup et al. 2008).

There is general consensus between science and the traditional ecological knowledge (TEK) and local observations of Inuit in the WH region that polar bear abundance has increased since the 1970's (Tyrell 2006). There is also agreement that polar bear distribution has changed, that more bears are being sighted around communities, that sea ice breakup is occurring earlier and that climate change is negatively influencing seal populations (NWMB 2007). However, in contrast to scientific evidence, Inuit perceptions of WH do not support the notion that abundance has declined since the mid-1980's (Tyrell 2006). Reports of more bears summering on land in the Nunavut portion of Hudson Bay (i.e., the Kivalliq region) and increased incidences of problem bears around camps and communities have been attributed to factors such as higher abundance, habituation of bears to human activities such as ecotourism, changes in behavior due to capture and handling for scientific research, and increasing use of unmanaged garbage dumps in communities along the Hudson Bay coastline (Stirling and Parkinson 2006; Dyck et al. 2007; NWMB 2007; Stirling et al. 2008a).

The disparity between scientific findings and TEK has generated significant debate over the management and conservation of WH polar bears. Although harvest is not considered the primary threat to conservation in this subpopulation, to a large extent the controversy has focused on harvest management. This conflict has led to calls for new research to help inform status assessment and resolve the apparent differences between these bodies of knowledge.

Updating the Abundance Estimate for WH

With a research program dating back more than 4 decades (e.g., Jonkel et al. 1972; Stirling et al. 1977; Derocher and Stirling 1995a; Regehr et al. 2007), WH is the most thoroughly studied polar bear subpopulation and ranks as one of the most intensively researched large mammal populations world-wide. Capture and tagging have been central to long-term monitoring in WH. In addition to abundance and demographic estimates (e.g., Derocher and Stirling 1995a; Lunn et al. 1997; Regehr et al. 2007), the WH capture program has facilitated studies of movements, habitat use, genetics, body condition, energetics, growth, physiology, diet, effects of sex-selective harvest, and contaminant levels (e.g. Atkinson and Ramsay 1995; Derocher and Stirling 1995a, 1995b; Paetkau et al. 1995; Derocher et al. 1997; Clark and Stirling 1998; Norstrom et al. 1998; Stirling et al. 1999; Lie et al. 2005; Richardson et al. 2005; Parks et al. 2006; Thiemann et al. 2008; Towns et al. 2010). The diverse range of information generated by these studies has provided a broad ecological context for assessing subpopulation status.

In response to calls for updated information on WH, a new analysis of capture and recovery data has been initiated by Environment Canada in collaboration with the United States Fish and Wildlife Service. The analysis, incorporating data collected since the 2004 study (Regehr et al. 2007), will provide estimates of abundance and vital rates (survival and recruitment) current to 2011. However, among Inuit in the region, calls for new research were based in part on concerns related to the methods used in physical capture studies and a desire to see alternative research methods employed. These concerns fall into three categories. First, although several studies have failed to detect impacts on body condition, survival and reproduction resulting from polar bear capture and handling (Ramsay and Stirling 1986; Amstrup 1993; Derocher and Stirling 1995b; Messier 2000), concerns remain about the invasiveness of this method¹. This has led some to question whether intensive tagging operations in WH have contributed to the observed declines in abundance and vital rates (NWMB 2007; Dyck et al. 2007). Second, the capture and release of polar bears is viewed by many Inuit to be inconsistent with cultural beliefs regarding interactions with animals. Third, almost all of the polar bear research in WH has been based on the capture of bears in Manitoba, focused in a study area between Churchill and the Nelson River. Available scientific evidence suggests that relatively few bears spend the ice-free period along the Nunavut coastline of WH (Peacock and Taylor 2007; Stapleton et al. 2010a), and proportions of tagged and untagged bears in this region are not statistically different from the primary study region in Manitoba (Peacock and Taylor 2007). Additionally,

¹ Negative effects on movement and body condition have been demonstrated in other Ursid species captured via methods similar to those used on polar bears (Cattet et al. 2008).

multiple studies have suggested that focusing tagging operations in a core study area in Manitoba has not significantly biased mark-recapture estimates of abundance and survival (Lunn et al. 1997; Regehr et al. 2007; Peacock and Taylor 2007).² Nevertheless, Inuit contend that a significant and increasing number of WH bears are spending the ice-free period onshore in Nunavut; thus, failing to extend tagging operations across the entirety of WH has negatively biased abundance and vital rate estimates (NWMB 2007).

To address Inuit concerns about capture-based estimates and better inform status assessment, we conducted a comprehensive aerial survey of the entire WH subpopulation (including Nunavut, Manitoba and Ontario) during the 2011 ice-free period. In addition to responding to population-specific needs, the aerial survey was part of a broader, on-going Government of Nunavut-led initiative to develop more rapid and less invasive alternatives to physical capture programs as a means to monitor the abundance of polar bear subpopulations. While aerial surveys are well-established and widely implemented to monitor other wildlife species, their application to polar bears has been limited. However, recent studies in the Barents Sea (Aars et al. 2009), Foxe Basin (Stapleton et al. 2011), and Baffin Bay (Stapleton et al. 2010b) suggest that aerial surveys may be used to successfully estimate abundance in certain regions. Additionally, because it has been the focus of an intensive, long-term mark-recapture program, WH provides the opportunity to significantly advance aerial survey development. Although capture studies have focused in a core study area in Manitoba, mark-recapture based estimates are considered to represent the entire WH subpopulation (e.g., Obbard et al. 2010). Hence, side-by-side comparison of aerial survey and capture-derived estimates enables us to examine the methods' respective biases and precision, promotes the acceptance of new techniques in the scientific community, and can suggest possible technique modifications.

Objectives

The objectives of this study were to:

- 1) Generate an accurate and precise estimate of polar bear abundance in WH via aerial survey.³

² However, Peacock and Taylor (2007) noted the importance of expanding the study area to address any negative bias, or an increasing negative bias due to a potential distributional change (e.g., Towns et al. 2010), in demographic estimates due to incomplete coverage of the subpopulation.

³ Study design was based on a target coefficient of variation of 15 – 20%

- 2) Compare an aerial survey-derived abundance estimate with an updated (through 2011) physical mark-recapture based abundance estimate.
- 3) Evaluate potential biases in and relative precision of aerial survey and physical mark-recapture abundance estimates.
- 4) Provide training in aerial survey methods to community members to facilitate enhanced public participation in polar bear monitoring.
- 5) Evaluate the distribution of polar bears in WH during the 2011 ice-free season with respect to ecological variables.

MATERIALS AND METHODS

Study Area

Western Hudson Bay (WH), located at the southern extent of the global polar bear distribution, stretches across roughly 435,000 km² of Hudson Bay and the adjacent coastline including portions of Nunavut, Manitoba, and Ontario. This region is seasonally ice-free from about July through November and shares borders with the Foxe Basin and Southern Hudson Bay subpopulations. Like other subpopulations, WH boundary delineation is based on data derived from a variety of sources including capture-recapture and capture-recovery (i.e. harvest) studies (Stirling et al. 1977; Derocher and Stirling 1990; Kolenosky et al. 1992; Taylor and Lee 1995; Derocher et al. 1997; Lunn et al. 1997; Stirling et al. 2004), aerial surveys (Stirling et al. 2004), satellite telemetry (Stirling et al. 1999; Peacock et al. 2010), and genetic analysis (Paetkau et al. 1995, 1999; Crompton et al. 2008). Although the boundaries are semi-discrete and interchange occurs among neighboring subpopulations (Stirling et al. 1999; Crompton et al. 2008), their separation is most complete during the late summer and early fall ice-free season when bears are on land (Peacock et al. 2010). The northern boundary of WH is located between the communities of Chesterfield Inlet and Rankin Inlet, and the subpopulation extends south and east to about 40 km beyond the Manitoba – Ontario border (Figure 1). In addition to Rankin Inlet, the communities of Whale Cove and Arviat (Nunavut) and Churchill (Manitoba) are located within the boundaries of WH.

Survey Design and Field Methods

We conducted the aerial survey in August, 2011. During the ice-free season, bears are largely confined to land, minimizing the area necessary to survey and thus facilitating a more efficient study. Additionally, as noted above, range overlap between subpopulations within the Hudson Bay complex (WH, Foxe Basin, and Southern Hudson Bay) reaches a minimum in late summer and early fall, since polar bears exhibit a high degree of fidelity during this period (Derocher and Stirling 1990; Lunn et al. 1997; Stirling et al. 2004; Parks et al. 2006). The absence of ice and snow during late summer months also means that polar bears are readily observable against a dark landscape, ideal conditions for an aerial survey. Finally, the timing of the study coincided with the start of the maternity denning period⁴ and occurred before non-denning bears begin to make directional northerly movements in the late fall, prior to freeze-up (e.g., Stirling et al. 1977; Derocher & Stirling 1990; Stirling et al. 2004).

We implemented a systematic, stratified study design to allocate sampling effort and improve estimate precision. The base map used to delineate the shoreline and small offshore islands was constructed from CanVec 1:50,000 scale GIS layers (available through Natural Resources Canada). We considered multiple sources of information to define the inland extent of the study area and to delineate strata, including:

- Information on the distribution of bears from published papers (e.g., Derocher and Stirling 1990; Lunn et al 1997; Stirling et al. 2004; Richardson et al 2005; Towns et al. 2010);
- Pilot aerial survey data collected during 2010 in the Nunavut portion of WH (Stapleton et al. 2010a);
- Local knowledge about polar bear distribution provided by Nunavut hunters during a workshop held in Churchill in July, 2010;
- Polar bear capture records from Environment Canada in Manitoba (2003 – 2010);
- Coastal and denning surveys conducted by Manitoba Conservation; and

⁴ Pregnant bears in WH enter dens as early as August (Clark et al. 1997; Clark and Stirling 1998; Lunn et al. 2004; Richardson et al. 2005).

- Satellite telemetry data on the movements of collared polar bears, collected by Environment Canada and University of Alberta during summer and fall, 2010.

We *a priori* defined 4 strata based on presumed polar bear densities for the aerial survey: a high density zone based on the core study area from Environment Canada's long-term research in Manitoba, including Wapusk National Park and extending up to 100 km inland; a moderate density stratum, extending from the shoreline to 15 km inland elsewhere in Manitoba as well as Ontario; a low density zone, from 15 km to 60 km inland elsewhere in Manitoba and Ontario; and a low density Nunavut stratum, extending from the coastline to 60 km inland from the Nunavut – Manitoba border to the community of Arviat, and from the shoreline to 50 km inland from Arviat to the northern boundary of WH (Figure 1). The Nunavut stratum additionally included 2 large islands.

We used a combination of overland transects, coastal contour transects, and small island sampling to survey WH. Polar bears tend to congregate along or near the shoreline during the ice-free season (Derocher and Stirling 1990; Towns et al. 2010), so overland transects were oriented roughly perpendicular to the coast (i.e., against the coastal density gradient; hereafter denoted as perpendicular transects) to improve precision and minimize potential biases (Figure 1; Buckland et al. 2001). Perpendicular transects spanned from the shoreline to 50 – 100 km inland, depending on which stratum was being sampled. Transects were extended over any exposed tidal flats to facilitate reliable estimation of abundance from perpendicular transects and small island sampling alone. However, it was not possible to accurately delineate exposed tidal flats in GIS, necessary for their inclusion in analysis. Hence, perpendicular transect distances were measured to the shoreline and polar bear sightings on tidal flats were considered to have occurred on land for analysis. Because sampling of tidal flats occurred at the same intensity as the near-shore inland strata, any effect on the abundance estimate was negligible.

After reaching the most inland point of transects, we flew roughly parallel to the shoreline to join the adjacent perpendicular transect and returned to the coast. Data collected during this cross-leg were generally not included in analyses. However, for 3 pairs of transects, we were unable to reach the far inland extent of the stratum due to logistical constraints. To incorporate sampling in the far inland portions of the strata in these instances, we included data collected along this cross leg.

Survey effort was allocated among strata to maximize encounters while ensuring adequate coverage of all regions. Because polar bears are concentrated along the coast and the Wapusk National Park region is a well-documented denning site (e.g., Richardson et al. 2005), we focused sampling in the high density and near-shore inland zones. Perpendicular transects were systematically spaced at 6, 7, and 10 km intervals in the high density, moderate density, and low density Nunavut strata, respectively (Figure 1). Every other pair of transects in the moderate density zone in Manitoba and Ontario was extended through the low density (far inland) stratum, such that transect spacing there averaged 14 km. We were able to survey Nunavut at a higher intensity than the low density stratum in Manitoba and Ontario due to the use of a fixed wing platform (see below).

We additionally surveyed from independent, comprehensive coastal contour transects (Figure 2). Contour transects were flown at or slightly below the high-water line (HWL) with one side of the aircraft dedicated to monitoring tidal flats and near-shore waters (i.e. swimming bears)⁵. We surveyed along coastal contours as close to high tide as possible to minimize tidal flat exposure and reduce the need to double-back to ensure that the coastal zone was comprehensively covered. Observers looked for bears as far as they could reasonably see, not within a pre-defined strip width. Because perpendicular transects were extended to the shoreline and over tidal flats (where applicable), some bears along the shoreline could be sighted from both perpendicular and coastal transects (accommodated by analyses; see below and Figure 2). Bears sighted on tidal flats or in nearshore waters were considered within the coastal zone (i.e., on land, where area could be estimated with GIS) in order to calculate density and extrapolate to unsurveyed areas. We additionally sampled as many small islands as possible within WH.

The Nunavut and Manitoba – Ontario portions of the aerial survey were conducted from fixed wing (Turbo Beaver) and helicopter (Bell 206L) platforms, respectively. Separate platforms were used to complete the survey in a logistically efficient manner and enhance opportunities for community participation. The fixed wing survey crew consisted of 4 dedicated observers⁶ (community representatives), with front and rear observer teams each comprised of 2 spotters, as well as a data recorder (a GN Biologist). The helicopter crew consisted of staff from the GN, Manitoba Conservation, and Parks Canada. Here, the pilot and observer in the co-pilot seat comprised the first team, and 2 individuals seated in the rear of the helicopter comprised the second team.

⁵ Clark and Stirling (1998) reported that 4% of captured bears were located on tidal flats.

⁶ Members of Hunters' & Trappers' Organizations from communities in the Kivalliq region of Nunavut

For each aircraft, sampling protocols facilitated the collection of data for both distance sampling (Buckland et al. 2001) and sight-resight (i.e., double-observer platform, a mark-recapture variant; Pollock and Kendall 1987) analyses. Sightings were not announced until both teams of observers were afforded a full opportunity to independently spot a bear. Transects were flown at an above-ground level altitude of about 120 m and groundspeed of roughly 150 km / hr with both platforms. Flight parameters were based on polar bear aerial surveys conducted in Foxe Basin during 2009 and 2010 (Stapleton et al. 2011).

We recorded flight paths and bear locations at the time of first observation via GPS and measured perpendicular distances from sighted bears to the flight path in a GIS (Marques et al. 2006). We estimated sex and age class remotely⁷, documented group size and approximated body condition using a qualitative fatness index (1 – 5⁸, with 1 being leanest and 5 being most obese; Stirling et al. 2008b). Groups were defined as multiple individuals whose detections were non-independent (e.g., a family group including an adult female and her cubs or a fraternity of 2 or more adult males). For each bear sighting, we also recorded factors that may have influenced detection probability, including activity when first observed (e.g., lying down or running), weather conditions and habitat characteristics, such as topography and habitat structure within 30 m of an individual bear (all on qualitative 1 - 3 scales).

During the late summer and early fall, polar bears in WH, particularly pregnant females, may retreat to earthen dens (Jonkel et al. 1972; Lunn et al. 2004). Denning bears that are completely unavailable for sighting during sampling cannot be incorporated in an aerial survey-derived abundance estimate. We investigated dens with recent digging or other signs of activity to determine occupancy, when possible.

⁷ With the exception of adult females and their accompanying offspring, we acknowledge that there was uncertainty in age and sex classifications, especially sub-adults and unaccompanied adult females. Data from a recent tagging study in Davis Strait (Government of Nunavut, unpublished data) suggest that experienced observers are able to identify adult males and lone adult females from the air with 94% (n=329) and 63% (n=111) accuracy, respectively. Thus we suggest that our estimates of age and sex composition are a reasonable approximation of the true composition of bears observed during the 2011 survey. Furthermore, our data should be free of systematic geographic bias.

⁸ We acknowledge that assigning fatness scores remotely may differ from scoring bears during physical handling. However, our fatness scores were assigned by an individual highly experienced with both polar bear capture and aerial surveys and should be free of systematic bias.

Analyses

Perpendicular Transects

We used distance sampling (DS) to estimate abundance using data collected from perpendicular transects. DS, a well-established technique implemented for a variety of taxa, is based on the premise that an animal's probability of detection decreases with increasing distance from the survey transect. Perpendicular distances from the transect path to the animal are directly measured or calculated from auxiliary data. Fitting a function to sightings distances data enables the estimation of abundance (and density) within the survey strip, which is then extrapolated across the study area to derive an estimate of total abundance. Preliminary histograms of WH polar bear sightings distance data suggested a strongly supported detection function (i.e., detections declined with increasing distance), indicating that DS was an appropriate analytical method (Figure 3).

A key assumption of DS is that sampling is random with respect to the distribution of bears (Buckland et al. 2001). Since polar bears concentrate along the shore during the ice-free season, bears sighted from coastal contour transects may partially reflect this coastal density gradient (as opposed to solely reflecting a distance-based detection function). Coastal contour transect data are thus inappropriate for DS analysis. However, because perpendicular transects (oriented against the density gradient) extended to the coastline and over tidal flats, we were able to include the coastal zone in DS analysis via perpendicular transects. Alternatively, we were able to exclude these coastal zone data from DS analysis and independently estimate the number of bears in the coastal strip using the coastal contour transect data in sight-resight analyses (see below). We therefore compiled datasets including and excluding the perpendicular transect data from the coastal zone to generate 2 estimates of abundance.

Detection of all objects on the transect line (i.e., detection probability = 1 at distance 0) is another fundamental assumption of distance sampling (Buckland et al. 2001). Violation of this assumption would produce a negatively biased abundance estimate. During the survey, our impression was that virtually all animals on and near the transect line were detected, and we initially proceeded with analyses incorporating all perpendicular transect sightings data (see *Discussion* for further evaluation of this assumption). We note that both teams of observers in the fixed wing had a blind spot of nearly 170 m on either side of the aircraft; hence, 170 m was subtracted from all observations to establish the transect line at an appropriate distance from the aircraft.

Although conventional DS and multiple covariate distance sampling (Marques and Buckland 2003) require complete detection at distance 0 to generate reliable abundance estimates, mark-recapture distance sampling (MRDS; Laake and Borchers 2004) facilitates the estimation of detection on the transect line using sight-resight data, thereby correcting for circumstances in which detection at distance 0 is <1 . In the helicopter platform, front observers were able to survey on and near the flight path, while rear observers had a blind spot of about 70 m on both sides of the helicopter. To fully evaluate survey data and assess detection at distance 0 using MRDS, bears must be available to both teams of observers. Therefore, we created an additional left-truncated dataset in which observations within 75 m of the helicopter were censored and 75 m was subtracted from all other sighting distances (Borchers et al. 2006). This procedure established the transect line at a point in which all bears were visible to both teams of observers. Fixed wing data were adjusted to ensure that bears were available for sighting by both front and rear observers (described above), so these data were not further altered. In sum, we analyzed 4 combinations of datasets with DS: including and excluding the coastal zone perpendicular transect data as well as untruncated and left-truncated (75 m) transect datasets.

We initially fit conventional DS models in program Distance (Version 6.0, Release 2; Thomas et al. 2009) to evaluate detection functions and to assess whether group size influenced detection (via the regression method implemented in Distance). Following this preliminary review, we fit all DS models in the MRDS engine of Distance. The 2 untruncated transect datasets were modeled as single observer studies, and the left-truncated transect datasets were modeled as double observer surveys. Data in all analyses were right-truncated at roughly 5% to smooth the tail of the detection function and improve model fit and parsimony (Buckland et al. 2001). For the double observer surveys, we employed the point independence mark-recapture model (Laake and Borchers 2004) and specified distance as the only covariate.

We fit DS models with hazard and half-normal key functions and used a forward stepwise procedure to evaluate the impact of covariates. We considered visibility (weather) and habitat structure near (within 30 m of) a sighting as covariates in these models. Covariates were collected on a qualitative 1 to 3 scale, but we condensed into binary categories because of underrepresentation of values. We specified a global detection function and used stratum-specific encounter rates and group sizes to estimate density and abundance by stratum. Stratum abundance estimates were subsequently summed to obtain an overall abundance estimate.

Sample size constraints compelled us to pool data collected from fixed wing and helicopter platforms for all DS analyses. Additionally, we condensed the Nunavut stratum and the low

density, far inland zone in Manitoba and Ontario into a single stratum due to few encounters in these areas. Although sampling intensity was greater in Nunavut, estimated densities were very low in these two strata and individual encounter rates were similar. Therefore, pooling these data had a negligible impact on the overall DS-derived abundance estimates.

We employed Akaike's Information Criteria for model selection (Burnham and Anderson 2002) and examined q-q plots and chi-square, Kolmogorov-Smirnov, and Cramer-von Mises tests to evaluate goodness of fit. Individual transects, within stratum, were considered sampling units for variance estimation. We used the Innes et al. (2002) method to estimate variance, since this technique does not require independence among variance components (stratum-specific abundance estimates were not fully independent because we estimated a global detection function). We assigned equal model weights ($w = 0.5$) to the untruncated and left-truncated estimates for each of the datasets including and excluding the coastal zone data and generated model-averaged estimates of abundance and unconditional variance. Model-averaging enabled us to account for variability in the estimation of the detection functions and associated densities.

Coastal Transects and Small Islands

We used sight-resight analyses to provide a separate estimate of coastal zone abundance with coastal contour transects. This technique uses data collected by independent observers to estimate individual detection probabilities. Individual detection probabilities, in turn, are used to estimate the number of bears within the survey strip that were not observed by either team. Here, we employed the Huggins mark-recapture model (Huggins 1989, 1991), a closed population model in which the likelihood is conditional on capture (i.e., sighting). The Huggins model facilitates the inclusion of covariates to explain variability in detection probabilities.

Front and rear observer teams comprised our first and second sampling periods, respectively, and we considered discrete groups of polar bears (as defined above) the sampling unit. We assumed that we effectively sampled the coastal zone 500 m inland of the high-water line (since coastal contour transects were often flown slightly below the HWL to improve coverage of the tidal flats). We allowed detection probabilities to remain constant or vary between observers and used a backwards stepwise process to assess the importance of covariates potentially impacting detection, including habitat structure, group size, and activity at first sighting. (Visibility was graded as uniform along coastal contour transects and thus not included as a covariate.) Models were fit in Program MARK (White and Burnham 1999) and AIC adjusted for small sample sizes (AICc) employed for model selection. Detection probabilities

from the most supported model and a generalized Horvitz-Thompson estimator were used to estimate the number of groups present in the sampled areas.

For small islands, the front team of observers spotted all groups that were sighted within the half-strip width of 750 m. Therefore, it was unnecessary to estimate individual detection probabilities via the Huggins model (i.e., front observers detection was estimated at 1). For both the coastal contour transects and the small island sampling, we extrapolated group density estimates across the coastal zone and small islands and multiplied estimates by mean group sizes. We calculated group sampling variance following Buckland et al. (2001) and extrapolated and multiplied variances via the delta method (Powell 2007).

Total Abundance

Sampling and analytical protocols enabled us to generate two partially independent WH abundance estimates. First, total abundance was derived by summing estimates from coastal contour transects, perpendicular transects excluding coastal zone data, and small island sampling. The second estimate incorporated estimates from the complete perpendicular transects and small islands. We summed point estimates and their variances to obtain 2 abundance estimates, assigned equal model weights to these estimates, and model-averaged to obtain an overall abundance estimate.

RESULTS

Survey Effort and Observations

We surveyed >100 combined hours from the 2 survey platforms during the August 13 – 29 study period. Sampling was completed under a mixture of weather conditions, ranging from sunny and clear to cloudy with intermittent rain. We did not fly when ceilings were <300 m, horizontal visibility <3 km, or winds >20 km / hour.

A total of 711 polar bear sightings were recorded, including 41 and 670 observations in Nunavut and Manitoba – Ontario, respectively (Figure 4). Because the coastal contour and perpendicular transects were conducted independently, we were unable to calculate the number of unique bears that were sighted. However, sampling itineraries in Nunavut enabled us to estimate that no more than 31 unique bears were sighted there. Several aggregations of 4 or more bears, including 5 groups with 8 to 10 bears and a group with 21 individuals, were documented in far southeastern WH and near Cape Churchill. Fifty cubs-of-the-year (COY) and

22 yearlings were observed. Mean litter sizes were 1.43 (SD: 0.50; n = 35) and 1.22 (SD: 0.43; n = 18) for COYs and yearlings, respectively⁹.

Distribution

Polar bear sightings were not uniformly distributed across WH (Figure 4; Table 1). The highest concentrations of bears were documented in the high density stratum, encompassing the historical Environment Canada study area including Wapusk National Park, and along the coast of southeastern WH. The distribution and number of bears observed in Nunavut during 2011 (Figure 4) were consistent with the 2010 pilot aerial survey and the 2007 capture research in the Nunavut portions of WH (Figure 5; Peacock and Taylor 2007).

In general, observations were highly concentrated along or near the coast throughout the subpopulation (Figure 4). However, inland bears >10 km from the coastline were often recorded in the high density stratum and less frequently observed in the southeastern portion of WH. Thirty-five bears were sighted >40 km from the nearest coastline, most within the high density stratum; the furthest inland bear was sighted about 75 km from the shore.

To further examine distribution and facilitate comparison with earlier studies, we divided bears observed in Manitoba and Ontario into groups corresponding with two distinct geographic regions. We defined Area 1 as the region extending from the Manitoba-Nunavut border to the Nelson River, including the primary long-term study area for Environment Canada's capture program [approximating Area 5 in Stirling et al (2004)]. Area 2 was defined as the region extending from the Nelson River to the eastern boundary of WH, approximating Area 4 in Stirling et al. (2004). A total of 182 bears were sighted from coastal contour transects (including small islands) in Area 1, while 216 bears were spotted from contour transects in Area 2 (Table 1). We note that 41% (88) of the individuals sighted in southeastern WH (Area 2) were spotted within Ontario.

Remotely assessed sex and age-class distribution were generally similar across these broadly defined geographic regions (Table 1). Notably, however, we observed a greater proportion of adult males in the southeastern portion of WH (Area 2), while proportionately more solitary adult females and family groups were sighted from perpendicular transects in the central and northern portions of WH (Area 1). Body condition scores among bears in the southeastern region were generally consistent with or better than those of bears further north for all sex and age classes (Table 2).

⁹ Litter sizes and cub observations were calculated from all observations in Manitoba and Ontario and only unique bears in Nunavut.

Abundance Estimation

Perpendicular Transects

We flew approximately 8,000 km along perpendicular transects, including >2,900 km in the high-density stratum, nearly 1,100 km in the moderate density Manitoba zone, and about 4,000 km in the Nunavut and far inland Manitoba strata. Two perpendicular transects in the high density stratum were sampled twice, but only the initial flights were included in analyses because of non-independence. We included 139 and 62 polar bear groups in DS analysis (after right-truncation at ~5%) for the datasets that included and excluded the coastal zone, respectively. The substantial sample size difference highlights the high concentration of bears in the coastal strip and the associated density gradient.

Observed group sizes along perpendicular transects ranged from 1 to 8 (x : 1.44; SD: 0.94). A group of 6 bears, including 2 family groups (each with an adult female and a single cub of the year) and 2 independent bears, was sighted in Nunavut, congregating around harvested whale carcasses. Because the far inland Manitoba – Ontario and Nunavut strata were pooled and we viewed this aggregation as an anomaly that would not reflect group sizes in interior Manitoba – Ontario, we instead calculated a stratum-specific mean group size for this observation. Preliminary analyses did not indicate an effect of group size on detection probabilities, a finding that was consistent with our field observations. Goodness of fit metrics suggested adequate model fit for all highly supported models ($P > 0.05$ for all Chi-square, Kolmogorov-Smirnov, and Cramer-von Mises tests).

MRDS analyses (i.e., the left-truncated datasets) indicated nearly perfect detection on the adjusted transect line, estimated at 98% and 97% for datasets including and excluding the coastal zone, respectively. Model selection was similar among analyses and supported the inclusion of covariates to explain variability in detection probabilities (Table 3). Because there was some within-dataset variability in density and abundance estimates derived from the most highly supported models, we first obtained model-averaged estimates for models within ΔAIC of 2 for each dataset combination.

Abundance estimates from the untruncated and left-truncated transect analyses were consistent within datasets that included the coastal zone (untruncated: N : 929, SE: 186; left-truncated: N : 899, SE: 200) or excluded this region (untruncated: N : 561, SE: 124; left-truncated: N : 472, SE: 102). Combining the untruncated and left-truncated datasets via model-averaging yielded abundances of 914 (SE: 194) and 517 (SE: 122) for datasets including and excluding the coastal zone, respectively.

We note that the exclusion of the coastal zone data from DS analyses produced narrower half-strip widths (Figure 6). This finding supports our field observations: minimal habitat structure along the coast produced excellent sighting conditions, but vegetation and other habitat features increased farther inland, obscuring polar bears and reducing visibility.

Coastal Transects and Small Islands

Nunavut's coastline is highly irregular in portions of northern WH, making it challenging to conduct and analyze a comprehensive coastal contour transect. This finding, coupled with the low number of observations in the pooled low density stratum ($n = 6$), compelled us to rely exclusively on perpendicular transects to estimate coastal zone abundance in Nunavut; we did not generate a separate coastal contour estimate there. In Manitoba and Ontario, however, we sampled >95% of the coastline and included 190 polar bear groups in sight-resight analysis. Our highest ranked model incorporated separate detection probabilities for the front and rear observers and covariates for habitat structure and group size. Detection and abundance estimates were very consistent among the best supported models. Thus, we used detection probabilities from the most highly supported model ($p_{\text{front}}: 0.97$, SE: 0.014; $p_{\text{rear}}: 0.86$, SE: 0.027) to generate a group abundance estimate ($N: 192$ groups; SE: 1.7) for the sampled areas, inflated across the unsurveyed coastal areas, and multiplied by mean group size ($x: 1.45$; SD: 1.6) to derive a coastal zone abundance estimate from coastal transects in Manitoba and Ontario ($N: 291$ individuals; SE: 23.8).

We sampled about 85% and 60% of islands in Manitoba – Ontario and Nunavut, respectively, observed 102 and 9 bears (41 and 7 groups) and obtained estimates of 120 (SE: 19.8) and 15 (SE: 1.6) total bears on and near small islands in the 2 areas. Additionally, 2 groups of bears – a family group including a female with 2 cubs of the year and a single adult female – were sighted beyond the maximum inland extent of the defined study site (>75 km and >60 km inland, respectively). Because we were unable to incorporate these individuals elsewhere in the analysis, they were added to final calculations.

Total Abundance

Summing estimates from the complete perpendicular transects (i.e., including the coastal zone), small island sampling, and the 4 out-of-study area bears yielded an abundance estimate of 1,053 (SE: 195). Estimates from perpendicular transects excluding the coastal zone data, coastal contour transects, and small island sampling, as well as the 4 bears observed out of the study area, produced a total abundance of 947 (SE: 126). Model averaging these estimates

yielded an abundance of 1,000 (CV: 17.2; 95% Lognormal CI: 715 – 1,398) for WH during the 2011 ice-free season.

DISCUSSION

Distribution of Polar Bears in Western Hudson Bay

Nunavut

Residents of communities along WH's Nunavut coastline have reported more frequent encounters with polar bears since the 1970's (Tyrell 2006), resulting in a perception locally that abundance has increased (Dowsley and Taylor 2006; NWMB 2007). These observations have also been interpreted as evidence that a larger proportion of the subpopulation is summering on land in Nunavut, generating concern that the Manitoba-focused mark-recapture sampling has yielded biased results (NWMB 2007). Indeed, a northwards distributional shift into Nunavut could result in greater capture heterogeneity or entirely exclude some bears from sampling. However, there is no scientific evidence to support such a large-scale range shift. A capture-based study (Peacock and Taylor 2007), a recent pilot aerial survey (Stapleton et al. 2010a) and this study all found relatively few bears in the Nunavut section of WH during late summer. For example, only about 6% of sightings during the 2011 survey were in Nunavut, suggesting that the vast majority of individuals still summer in Manitoba. We further note that the distribution of bears in Nunavut was very consistent among these 3 studies. During the summer, polar bears in this region were found at relatively low densities, concentrated along the coast and on offshore islands. The highest densities were observed south of Arviat towards the Manitoba border (Figures 3 and 4). Finally, capture work indicated that the proportion of marked bears in Nunavut did not statistically differ from the proportion of marked bears in Manitoba, illustrating that mark-recapture based estimates are not significantly biased by a lack of sampling in Nunavut (Peacock and Taylor 2007).

We note that Towns et al. (2010) documented a progressive northward and eastward shift (i.e. towards the coast) of bears captured in the core Environment Canada study area in Manitoba (roughly our high density stratum) between 1986 and 2004. The distributions of some age and sex classes shifted by up to 20 km during this period. Causes are unknown, but distributional shifts could be related to changes in population structure or environmental conditions (Towns et al. 2010). Similarly, Ramsay and Stirling (1990) noted a northward shift of maternity dens in the same area between the 1970s and 1980s. Given the lack of long-term data on the distribution and density of bears in the Kivalliq region, we cannot test the

hypothesis that a comparable change in summertime distribution is extending into Nunavut. Increased occupancy of the coastal strip in Nunavut, however, would be consistent with Inuit reports of more bears since human activities are generally focused along the coast. Regardless, our survey findings indicate that the proportion of the subpopulation currently summering in Nunavut is low, and there is no evidence of a major distributional change into Nunavut that could affect the accuracy of on-going mark-recapture studies.

Manitoba and Ontario

Similar to previous studies (e.g. Stirling et al. 1977; Derocher and Stirling 1990; Lunn et al. 1997; Towns et al. 2010), we found marked differences in polar bear distribution between two broad geographic regions (Figure 4). In the area extending from the Nelson River north to Churchill and the Nunavut border (here denoted as Area 1), the highest densities of bears occurred along the coastline. However, we also encountered a significant number of individuals far inland (>10 km), mostly within the bounds of Wapusk National Park. In contrast, virtually all polar bears in the region from the Nelson River eastward into Ontario (denoted as Area 2) were highly concentrated in a relatively narrow strip along the coast. These patterns of distribution have been well-documented previously and attributed to several factors, including variation in the availability of suitable inland habitats for denning, the avoidance of conspecifics and thermoregulation (Stirling et al. 1977; Derocher and Stirling 1990; Lunn et al. 1997; Clark and Stirling 1998; Richardson et al. 2005).

In comparison to Area 1, little is known about the ecology of polar bears summering in Area 2. This region lies outside the study area for most research conducted since the 1960's and has received relatively little sampling effort for mark-recapture studies (Kolenosky et al. 1992; Lunn et al. 1997; Lunn et al. unpublished data). However, Inuit elders in the Kivalliq region of Nunavut have noted that, in the days before the introduction of harvesting quotas, most bears were harvested in the Churchill region and beyond the Nelson River (NWMB 2007), suggesting that this region was historically important as a summering area for polar bears in WH. The 2011 survey indicated that this area remains an important summering area. Nearly half of the polar bear sightings in Manitoba – Ontario occurred in Area 2 (outside the primary capture sampling area), illustrating that a large segment of the subpopulation came ashore and spent some portion of the ice-free period in this region during 2011.

To more fully evaluate polar bear distribution during the 2011 aerial survey, we examined the hypothesis that the high proportion of bears encountered in southeastern WH (i.e., Area 2) was influenced by large-scale movements of bears from the adjacent Southern Hudson Bay (SH) subpopulation. First, although they represent a small (n=7) and sex-biased (i.e., all females)

sample, bears outfitted with satellite collars in SH during 2011 did not exhibit unusual movements during the ice-free season and were well within the bounds of SH during the late summer and fall (M. Obbard and K. Middel, unpublished data). Additionally, an aerial survey was conducted in SH in September 2011, extending from James Bay in southeastern Hudson Bay westward to the Ontario – Manitoba border (i.e., into WH; see *Future Research and Recommendations*). More than 650 sightings were recorded within the Ontario portion of SH, including nearly 600 observations >70 km from the shared WH – SH boundary (M. Obbard et al., unpublished data), demonstrating that a high number of bears remained within the SH boundaries during the 2011 ice-free season. [The current abundance estimate for the SH subpopulation is 900 – 1000 bears (Obbard et al. 2007).] Combined, these data suggest that a large influx of bears into WH from SH during 2011 is unlikely to have significantly impacted our results.

To assess if the high proportion of bears encountered in southeastern WH (i.e., Area 2) during the 2011 aerial survey was consistent with previous years, we examined data from coastal survey counts conducted in the same region by the Manitoba Department of Conservation (MDOC, unpublished data). These data were previously analyzed by Stirling et al. (2004) for the 1970 to 1997 period. We extended this analysis to include data collected since 1997. Similar to Stirling et al. (2004), we restricted our analysis to surveys conducted in late August to early September. During our 2011 survey, the coastal contour transects for this region were flown on August 21st and 22nd and are thus comparable with previous coastal surveys.

Stirling et al. (2004) reported a significant increase in polar bears counted along the coast between the Nelson River and the Manitoba – Ontario border (i.e., Area 2). Data collected since 1997 suggest a continuation of this trend (1970 – 2011: $r^2 = 0.45$; $P < 0.0001$; Figure 7b). Furthermore, the number of bears counted along this stretch of coast and nearshore islands during the 2011 aerial survey was consistent with the recent MDOC coastal count surveys. Since bears in this area are concentrated along the coastline, the vast majority of individuals are observable during coastal surveys. Consequently, the trend in survey counts likely accurately indexes changes in abundance within this area. We note, however, that there is substantial inter-annual variation in coastal counts, perhaps driven by annual patterns of ice breakup (Stirling et al. 2004).

The long-term increasing trend in coastal survey counts in Area 2 could be attributed to an increase in overall subpopulation abundance and / or a distributional shift. Documented declines in WH abundance, survival, reproduction and body condition (Stirling et al. 1999;

Stirling and Parkinson 2006; Regehr et al. 2007) and the remarkably low proportions of cubs and yearlings seen in this study do not support the hypothesis that increasing numbers of bears in Area 2 are the result of overall subpopulation growth.

Similarly, multiple lines of evidence suggest that an influx of bears from neighboring subpopulations appears to be an unlikely cause of the long-term trend. First, Stirling et al. (2004) found no relationship between the number of bears counted in southeastern WH (here, Area 2) and in Southern Hudson Bay (SH), suggesting that exchange between the subpopulations did not account for annual variation in counts within each subpopulation. Using mark-recapture data, Lunn et al. (1997) also documented that WH and SH are largely segregated, even in areas close to the subpopulations' shared boundary. More recently, sampling in southeastern WH (Area 2) yielded 50 individuals captured from 2003 to 2004 (N. Lunn, unpublished data). Eleven individuals were subsequently recaptured between 2004 and 2005¹⁰. Although more capture effort was expended in Area 1 than 2, 1 and 8 bears were recaptured in the sites, respectively, and 2 additional bears were captured in SH (M. Obbard, unpublished data). Despite small sample sizes, these numbers reinforce that polar bears exhibit high inter-annual fidelity during the ice-free period. We acknowledge, however, that shifts in subpopulation boundaries have been hypothesized as a potential impact of climate change (Derocher et al. 2004), but additional data are required to fully evaluate current boundaries.

A shift in the distribution of bears within WH, specifically bears entering Area 2 from other parts of WH, appears to be a more plausible hypothesis to explain increasing coastal counts. Using historical MDOC coastal survey data for Area 1 [i.e., extending previous analyses by Stirling et al. (2004)], we found no significant change in counts between 1970 and 2011, illustrating that the increased occupancy of the coastline documented in Area 2 is not occurring elsewhere in WH ($r^2 = 0.10$; $P = 0.06$; Figure 7a). However, this does not discount the possibility of a shift in late summer distribution from Area 1 to Area 2. In comparison to Area 2, coastal surveys in Area 1 may be a relatively insensitive indicator of abundance since many bears in this area are found inland (where they are unavailable for observation). Furthermore, coastal counts in this area may be confounded by inter-annual variation and long-term changes in the distribution of bears between the coastal and inland zones. Indeed, as previously noted, Towns et al. (2010) documented a northerly and easterly (i.e., coastward) shift in occupancy in Area

¹⁰ The recapture period examined was limited because, to our knowledge, mark-recapture sampling has not occurred in Area 2 since 2005.

1.¹¹ Such changes could well mask a decline in abundance in Area 1 if one relied exclusively on coastal counts.

Stirling et al. (2004) concluded that coastal survey counts were a reliable indicator of long-term population trends in WH. However, pooled coastal survey data for Areas 1 and 2 (MDOC, unpublished data) demonstrate an increase in the total number of bears observed along the WH coastline in Manitoba between 1970 and 2011 ($r^2 = 0.48$; $p < 0.0001$; Figure 8). We also note that the total number of bears sighted from coastal transects during our 2011 survey was very consistent with this trend. These findings contrast with mark-recapture results indicating that abundance has declined since the 1980's (Regehr et al. 2007). To reconcile these seemingly contradictory observations, we hypothesize that the current trend in coastal survey counts may reflect a shift in distribution within the subpopulation rather than a change in overall abundance. More bears are coming ashore in southeastern WH (in comparison to the Churchill area), where they spend all or part of the ice-free period occupying a narrow band along the coast. As such, they are more readily observable during coastal surveys than bears in Area 1. Trends in coastal counts therefore may reflect a real increase in abundance locally (within Area 2) and an overall increase in coastal occupancy (rather than abundance) at the subpopulation level.

Multiple factors could be responsible for a southeastern distributional shift of WH polar bears during the ice-free period. Changes in the quality, quantity and distribution of sea ice habitat could have a profound effect on distribution. Sea ice breakup in Hudson Bay is occurring on average 2 – 3 weeks earlier than 30 years ago (Stirling and Parkinson 2006; Scott and Marshall 2010). Stirling et al. (2004) reported that the timing of breakup was approximately 1 week later along the southeastern coast of WH (Area 2) relative to central and northern Manitoba (Area 1). The increasing numbers of bears coming ashore and summering along the southeastern Manitoba coastline may therefore indicate that the extra time bears gain on the ice by coming ashore at this location is becoming increasingly important. Presumably, bears use this time as an opportunity to improve body condition by feeding, a behavior that may now outweigh any benefits accrued from coming ashore further north nearer Churchill.

More detailed analyses of historical coastal survey data would provide additional insights about the distribution of WH polar bears and facilitate testing several predictions. For example, solitary (pregnant) adult females appear to be more constrained in where they come ashore

¹¹ Regehr et al. (2007) also noted a shift in distribution towards the coast between 1987 to 2004, finding that within the mark-recapture study area (Area 1 in this report), bears were increasingly likely to be captured along the coast.

from the sea ice, likely because of the need to seek suitable denning habitat (Stirling et al. 1999). In contrast, adult males may exhibit greater flexibility in landfall location since they tend to remain along the coast and have less specific habitat needs (Stirling et al. 2004). Indeed, Stirling et al. (2004) documented a small yet significant difference between adult males and solitary adult females in the mean distance between successive capture locations, indicating that males tend to show lower fidelity. Thus, broad changes in use of summer range will likely first be apparent in adult males.

The geographic distribution of different age, sex and reproductive classes observed during the aerial survey (Tables 1 and 4) were consistent with patterns of spatial segregation reported elsewhere (Derocher and Stirling 1990; Lunn et al. 1997; Towns et al. 2010). In Area 1, the coastline was dominated by adult males, while we observed a greater balance of sex and age classes in inland regions of Wapusk National Park, including more solitary adult females and family groups. In contrast, the composition of bears was very similar between coastal contour and perpendicular transects in Area 2, with adult males accounting for the vast majority of encounters on both types of transects. The compositional similarity between Area 2's contour and perpendicular transects suggests that a representative demographic sample of bears in this region can be obtained from coastal survey flights alone.

Reports that fewer adult males are occupying the coast in Area 1 (Towns et al. 2010) may reflect a real change in population structure as a result of factors such as sex-selective harvesting (Derocher et al. 1997; Taylor et al. 2008). However, since this observation is based on capture data collected in Area 1, a distributional shift away from the area where capture operations are taking place could also account for this change. We note that adult males comprised a greater proportion of bears observed during the aerial survey in Area 2 than Area 1 (Tables 1 and 4), consistent with the hypothesis that an increasing number of adult males are coming ashore further south in Area 2. These results are also similar to the most recent capture sampling in southeastern WH (2003 – 2005; Table 4), but are inconsistent with previous descriptions suggesting that the Area 2 coastline was characterised by a more balanced mix of age, sex and reproductive classes (i.e., less adult male-dominated) than the Area 1 coast (Lunn et al 1997).

Finally, while bears exhibit strong fidelity in late summer, harvest data suggest that there may be differences in the geographic areas used at other times of the year by bears residing in Area 1 in comparison to Area 2. Twenty-one bears were captured in WH from 2003 to 2005 and subsequently harvested between 2004 and 2011, including 17 and 4 individuals captured in Areas 1 and 2, respectively. Whereas the 17 bears from Area 1 were harvested in WH (16) and

Foxe Basin (1), the 4 bears from Area 2 were harvested in SH (3) and WH (1; Figure 9). These data suggest that a re-examination of subpopulation boundaries in southern and western Hudson Bay may be warranted.

In summary, there was no evidence indicating that polar bear distribution in Manitoba – Ontario was unusual during the 2011 ice-free season. Thus, we suggest the high number and proportion of bears in southeastern WH (Area 2) during 2011 accurately reflects a 40-year trend of increasing use of this area during late summer. We hypothesize that a distributional shift within WH, resulting from bears (particularly adult males) foraging on remnant ice floes off the southeastern coast of WH, is a primary factor contributing to this trend.

Body Condition

Previous research has linked earlier sea ice breakup with poorer body condition in WH, neighboring SH, and other seasonal ice subpopulations (Stirling et al. 1999; Obbard et al. 2006; Stirling and Parkinson 2006; Rode et al. 2012). Similarly, differences in body condition between WH and SH subpopulations have been attributed to geographic and temporal variability in sea ice breakup and absence (Stirling et al. 1999; Obbard et al. 2006; Stirling and Parkinson 2006). Declines in body condition were initially detected in WH (Stirling et al. 1999) before similar changes were documented in SH (Obbard et al. 2006), reflecting general patterns of earlier sea ice breakup and absence in WH relative to SH.

Data collected during the aerial survey suggest that the body condition indices of bears in southeastern WH (i.e. Area 2) were comparable to or better than body conditions observed elsewhere in WH for all sex and age classes (Table 2). The difference was particularly evident among adult males (Table 2) and is consistent with historical records of distribution in relation to body condition (I. Stirling, personal communication). This observation supports the hypothesis that bears coming ashore in this region spend longer on the sea ice, presumably to maximize foraging opportunities.

Reproduction

The aerial survey results suggest that reproductive performance in WH is relatively poor, consistent with findings of capture-based studies (Regehr et al. 2007; N. Lunn, personal communication). In comparison to similar aerial surveys recently conducted in the neighboring Foxe Basin (Stapleton et al. 2011) and Southern Hudson Bay subpopulations (M. Obbard unpublished data), as well as mark-recapture studies in other seasonal ice sub-populations, mean litter sizes were the lowest recorded. Moreover, we documented proportionately fewer

cubs-of-the-year and yearlings (Table 5).¹² These findings are a strong indication that WH is currently less productive than other subpopulations in the Hudson Bay complex, and nearby regions (Peacock et al. 2010).

Abundance of Polar Bears in Western Hudson Bay

Aerial Survey-Based Estimation

We generated an aerial survey-based abundance estimate for WH using a combination of sampling and analytical techniques. While our results provide an estimate of current polar bear abundance, this figure alone does not provide an indication of population status or trend. Multiple surveys repeated at regular intervals would be required to assess trend with aerial surveys (see also *Comparison of Aerial Survey and Mark-Recapture Estimates* below). The study design, which incorporated delineation of multiple strata, perpendicular and coastal contour transects, and sight-resight and distance sampling protocols, enabled us to achieve our target precision level (projected coefficient of variation: 15 – 20%; actual CV: 17.2%). We note, however, that precision in the WH aerial survey was poorer than recent FB aerial surveys (Stapleton et al. 2011) due to highly variable encounter rates among transects (resulting from clumped coastal distribution) and less robust detection functions (perhaps resulting from habitat differences between the subpopulations and fewer overall encounters in WH). Greater sampling intensity in high density regions and additional survey stratification may improve precision in future surveys.

Abundance estimates derived from the untruncated DS datasets were consistent with estimates based on left-truncated datasets (see also *Methodological Assumptions*). Similarly, abundance estimates in which coastal bears were derived from perpendicular transects extending through the coastal zone (i.e., distance sampling) were consistent with estimates in which the coastal zone abundance was based on separate contour transects (i.e., sight-resight). To incorporate uncertainty in model selection and estimated detection functions as well as variability among techniques, we used model-averaging at multiple stages of the analyses. While model-averaging slightly inflates precision, we believe that this procedure resulted in a more accurate estimate.

We note that the inclusion of a separate, sight-resight estimate for bears in the coastal strip improved overall precision. This finding is consistent with recent studies in FB (Stapleton et al. 2011). Although fewer observations were available to estimate the distance sampling detection

¹²We note that differences in sampling protocols likely contributed, in part, to this finding.

function, the high precision of the coastal contour-derived abundance estimate (CV: 8%) offset any reduction in precision from the exclusion of coastal zone data from DS analyses. We additionally note that, because bears along the coast exhibited a clumped distribution, estimating their abundance with comprehensive coastal contours facilitated the reduction of encounter rate variability in DS analyses.

We sampled from both a helicopter and fixed wing aircraft during the aerial survey due to logistical constraints. The 2 platforms differ in their respective benefits and limitations, including the increased range and inclusion of a dedicated data recorder in the fixed wing versus the increased flexibility and visibility of a helicopter. Insufficient detections from the fixed wing compelled us to pool data from the 2 platforms in our analyses. However, our experiences with helicopter and fixed wing surveys elsewhere suggest that pooling data from the 2 platforms had a negligible effect on our results. The consistency in number and distribution of sightings in Nunavut between this study (fixed wing) and previous, helicopter-based research (Peacock and Taylor 2007; Stapleton et al. 2010a) also support this assertion. Moreover, distance sampling models are robust to pooling of data with different detection functions (Buckland et al. 2001). With more observations, analyses should be conducted independently (e.g., to estimate platform-specific detection functions), or a covariate should be incorporated to model effects of the survey platform.

Methodological Assumptions

Like other estimation methods, the ability of distance sampling to generate a reliable abundance estimate is contingent on meeting a set of assumptions. Failure to meet these assumptions can introduce bias and diminish the reliability of the results, depending on the nature and extent of the violation. We attempted to minimize potential biases in the aerial survey through our study design. Two assumptions of DS – complete detection on the transect line (or accommodating incomplete detection through appropriate field and analytical protocols) and random sampling with respect to the distribution of bears (in other words, bears distributed independently of transects) – were described above. Our study design, specifically the use of systematically spaced transects oriented against the coastal density gradient and the analysis of coastal transects via sight-resight models rather than DS, adequately addresses sampling assumptions. Similarly, we implemented MRDS field protocols and examined data in both pooled (i.e., single-observer) and double-observer analyses to evaluate detection on the line. MRDS analyses estimated 97 – 98% detection at distance 0 with the left-truncated datasets. The consistency in results between the untruncated and left-truncated datasets further suggests that we detected virtually all animals on the transect line (as flown) from the

helicopter, despite the rear observers' blindspot. This finding is not surprising, since large white bears are very conspicuous and readily observable against a dark landscape.

Detection of bears at their initial location (i.e., prior to any responsive movement) is another core DS assumption (Buckland et al 2001). Because polar bears in WH have been subject to an annual capture program over the past several decades, we anticipated that there may be some evidence of responsive movements. However, >75% of bears sighted within 500 m of the aircraft along perpendicular transects were stationary when first detected, and sighting distance histograms (Figure 3) do not suggest significant responsive movement (i.e., sightings peaked in the distance bins closest to the transect and declined thereafter). We further note that the survey was flown at speeds much faster than a polar bear can travel, such that any impact of movement prior to detection was likely minimal (Buckland et al. 2001).

Finally, accurate measurement of distances to sightings from the transect path is critical (Buckland et al. 2001). We used methods adapted from Marques et al. (2006) that we previously implemented in large-scale polar bear aerial surveys in Foxe Basin (Stapleton et al. 2011). Thus, we are confident that our measures of perpendicular distance between the aircraft flight path and polar bears were accurate. Because our study met and evaluated fundamental DS assumptions through proper study design and analysis, this aerial survey additionally fulfilled the implicit assumption that polar bear distances from the transects (i.e., observed and unobserved bears) follow a uniform statistical distribution (Fewster et al. 2008).

Abundance estimates derived from mark-recapture methods (here, sight-resight) will be negatively biased if heterogeneity in detection probabilities is not adequately modeled. Sight-resight methods may be particularly subject to negative bias since observations of bears between front and rear observers were nearly instantaneous and from very similar vantage points. In other words, sighting periods were not completely independent, such that bears with reduced detection probabilities were less likely to be spotted by either team of observers. On small islands, the detection of all bears within the defined strip width by front observers meant that sight-resight analysis was unnecessary (i.e., $p_{\text{front}} = 1$). However, we estimated sighting probabilities and modeled heterogeneity for coastal contour transects (Huggins 1989, 1991). This analysis yielded high individual detection probabilities and supported the inclusion of multiple covariates to explain variability in detection and reduce bias. Although other unconsidered variables may have been informative for modeling heterogeneity, our adoption of conservative strip widths likely minimized the impacts of any unmodelled heterogeneity. Additionally, the habitat along the coast and on small islands generally presented excellent conditions for

sighting bears, reducing the likelihood that a significant source of heterogeneity was not included in modelling.

Other Potential Biases

We considered several sources of data (i.e., local knowledge, historical scientific data and more recent scientific records) and weighed resource and logistical constraints to delineate the extent of the study area and boundaries of survey strata. The available evidence suggests that the defined study area encompassed nearly all bears located within the bounds of the WH subpopulation during August, 2011. However, we note that 2 groups were sighted beyond the inland extent of the study area in Manitoba, indicating that our delineation was not comprehensive. Polar bears located far from the shore during the ice-free season have been occasionally reported in the region, including a bear sighted in Shamattawa, Manitoba, some 140 km south of the mouth of the Nelson River in southern WH during 2010 (<http://www.cbc.ca/news/canada/manitoba/story/2010/08/30/mb-polar-bear-shamattawa-manitoba.html>) and another sighted in northeastern Saskatchewan, more than 400 km from the Hudson Bay coastline, during 1999 (Goodyear 2003). Such observations suggest that additional polar bears may have been located outside the bounds of our inland sampling during the survey, resulting in an underestimate of abundance. Although it is impossible to quantify the extent of these occurrences, we believe that the resultant negative bias would be minimal, given other existing distribution and movement data used in study design.

Similarly, we cannot discount the presence of some bears in far offshore waters during the survey period. Although we extended perpendicular transects over tidal flats and surveyed during ferry flights between small islands, safety concerns and logistical efficiency precluded systematically and intensively surveying offshore waters. Hudson Bay was completely ice-free several weeks prior to the commencement of the aerial survey (Canadian Ice Service Weekly Regional Ice Charts, available at <http://ice-glaces.ec.gc.ca/>). In Manitoba, our sampling itinerary began at the Nunavut border and continued southward to the Ontario border, such that southeastern Manitoba and Ontario were surveyed about 4 weeks after the last remnant ice floes remained off the coasts there. Additionally, telemetry data indicate that bears predictably arrive ashore about 3.5 weeks after ice breakup, defined as the date at which total ice cover decreases to 50% (Stirling et al. 1999). Lunn et al. (1997) and Stirling et al. (1999) further report onshore arrival dates in mid to late July during the late 1990s. Polar bears in WH remain onshore in WH throughout the ice-free season (Stirling et al. 1977) and their movements are markedly reduced (Parks et al. 2006). Thus, any bears swimming in WH's offshore waters likely represent an insignificant portion of the total population. For comparison, in recent Foxe Basin

aerial surveys, only 1 of 816 and 6 of 1,003 bears were observed in waters > 1 km from the nearest land and ice during 2009 and 2010, respectively, despite significant time spent ferrying over open water between islands, ice floes, and land (Stapleton et al. 2011).

Polar bears that are entirely hidden from observation are not incorporated in an aerial survey abundance estimate, resulting in negative bias. In the Manitoba portions of WH, such availability bias could arise from two sources. First, dense vegetation and small trees encountered in inland regions may completely obscure polar bears from view. Estimated detection functions including and excluding the coastal zone illustrate how detection changes when it is estimated from sightings in inland areas alone versus when open coastal regions are included (Figure 5). Not surprisingly, including habitat structure as a covariate to explain heterogeneity in detection was supported in all datasets. While we are unable to quantify this potential source of availability bias, our impression was that although trees and brush impeded detection and reduced sighting probabilities, it is likely that very few bears on or near the transect line were completely concealed by vegetation.

Polar bears in WH, particularly pregnant females, may use earthen dens during the ice-free season, entering them as early as August (Stirling et al. 1977; Clark et al. 1997; Clark and Stirling 1998; Lunn et al. 2004; Richardson et al. 2005). Although we cannot correct for bears that were underground and entirely unavailable for observation during the survey, several lines of evidence provide insight into the magnitude of this potential bias. During the survey, we observed numerous dens, some signs of recent digging and sighted bears of various sex and age-classes in known denning areas. However, we did not document any bears in dens or near mouths of dens, suggesting that overall denning activity was low. Similarly, reports from the Environment Canada capture program indicated that use of dens during August, 2011, appeared to be very low (N. Lunn, personal communication). In addition to maternity denning, seasonal den occupancy may serve as a means to conserve energy, thermoregulate or avoid insects (Jonkel et al. 1972). Thus, warmer temperatures could lead to increased rates of den occupancy. However, temperatures during the aerial survey were slightly cooler than the seasonal norm, with a mean daily high of 15.1°C (versus the 20 year average of 16.3°C). Finally, in Manitoba, more than 50% of adult females observed from perpendicular transects were solitary, indicating that our detection of the sex and age-class most likely to occupy dens during the survey period was comparable to other adult female reproductive classes (Table 1). Collectively, these pieces of evidence suggest that the prevalence of denning bears during the 2011 aerial survey was minimal. However, we acknowledge that availability bias arising from

bears obscured in dens or by other habitat features may have impacted our results and would produce a negative bias in the abundance estimate.

Finally, the study period was selected, in part, because polar bears exhibit seasonal directional movement later in the fall (Stirling et al. 1977, Derocher and Stirling 1990). In addition, field work was completed within a narrow temporal window (Manitoba and Nunavut WH were surveyed over 11 and 15 day periods, respectively), and the aircraft were able to cover large expanses of land within a single day. Therefore, distributional shifts within WH during the study period did not impact our results.

Because this study met analytical assumptions and potential sources of bias were likely minimal, we believe that the aerial survey-based estimate of 1,000 bears (95% CI: ~715 – 1398) accurately reflects the number of polar bears within the bounds of WH during August, 2011. We note, however, that any biases in the aerial survey would likely result in an underestimate of the true polar bear abundance in WH.

Comparison of Aerial Survey and Mark-Recapture Estimates

At present, we cannot directly compare estimates of abundance derived from the 2011 aerial survey with a current mark-recapture (MR) estimate¹³. We note that our aerial survey abundance estimate (1,000; 95% CI: 715 – 1,398) is consistent with the 2004 MR estimate (935; 95% CI: 794 – 1,076; Regehr et al. 2007). However, analyses suggested that abundance is declining without the additive effects of harvest (Regehr et al. 2007; Obbard et al. 2010), so an updated MR abundance estimate is anticipated to be significantly less than the 2004 estimate. Indeed, population simulations integrating the most recent MR estimates of WH abundance, survival and recruitment (Regehr et al. 2007), combined with known harvest from 2004 to 2011 (GN unpublished data), project that abundance declined to around 650 (SE: 84)¹⁴ by 2011 (York and Taylor, unpublished data).

While we are unable to undertake a comprehensive comparison of aerial survey and mark-recapture results at present, it is informative to examine the 2 methods as they are implemented in WH. The assumptions and potential biases of the WH aerial survey, as well as the distribution of bears during the 2011 ice-free period, were reviewed above, leading us to conclude that the 2011 aerial survey yielded an essentially unbiased estimate of abundance for the entire WH subpopulation. Similarly, by assessing the assumptions of mark-recapture

¹³ Mark-recapture analyses incorporating data collected up to 2011 remain in progress and will yield a revised abundance estimate.

¹⁴ Simulations assume vital rates remained constant during the study period.

methods (as applied in WH), we can more fully evaluate potential inconsistencies in aerial survey and capture-derived abundance estimates.

Equal probability of capture is a key assumption of capture-recapture methods. Unmodeled heterogeneity in capture probabilities produces a negatively biased abundance estimate and may impact vital rate estimates. Thus, obtaining a random sample of individuals that represents the entire population of interest during capture periods (or completely modeling unequal capture probabilities to eliminate capture heterogeneity) is necessary to generate reliable results.

In WH, capture sampling effort historically has concentrated around Churchill and in Wapusk National Park (e.g, Regehr et al. 2007), with limited and less frequent sampling elsewhere [e.g., Nunavut (Peacock and Taylor 2007) and southeastern WH (Lunn et al. 1997)]. Despite this geographically limited sampling, WH capture analyses are considered to reflect abundance and trends for the entire subpopulation (e.g., Obbard et al. 2010), generally under the assumption that adequate ‘mixing’ ensures random sampling and thus estimate reliability. However, multiple studies have reported that WH polar bears show a high degree of fidelity during the ice-free period. Distances between successive year-to-year capture locations of individual bears are relatively small, suggesting inter-annual fidelity to specific sites within WH during the ice-free period (Derocher and Stirling 1990; Stirling et al. 2004). Similarly, telemetry data demonstrate that bears exhibit high fidelity within the ice-free season, low net annual displacement (Parks et al. 2006), and fidelity in where they come ashore (Derocher and Stirling 1990; Stirling et al. 2004). Such fidelity would seem to indicate that the allocation of sampling effort across a limited portion of the subpopulation may subject MR methods in WH to capture heterogeneity and associated negative biases. In short, the MR estimate may not reflect the complete WH subpopulation, but rather a smaller area within WH.

Very low densities of WH polar bears in Nunavut during the early ice-free season (Peacock and Taylor 2007; Stapleton et al. 2010a; this study) suggest that any bias arising from limited sampling in this region is likely minimal. The proportion of marked bears in a recent capture sample (Peacock and Taylor 2007) and among bears harvested in Nunavut also support this hypothesis (Regehr et al. 2007). With respect to the limited extent of sampling in other parts of WH, Lunn et al. (1997) reported that estimated population size did not differ based on the inclusion or exclusion of the few capture data from southeastern WH (Area 2). However, sampling was limited and inconsistent in this region (i.e., sampling during 1984 – 1986 and 1994 – 1995), thus limiting their inferences. In contrast, Regehr et al. (2007) noted a difference in WH abundance estimates derived from Environment Canada (EC) data versus pooled EC – MDOC

capture data (point estimates: 762 versus 934), attributing this finding to undersampling of subadults that tended to occupy areas closer to Churchill and were unavailable for capture by EC. This finding illustrates the potential for spatial sampling issues to impact abundance estimates in WH. Moreover, these observations seem to contrast with the assumption that research focused in the core study area yields a random sample of individuals within WH.

The high density of bears residing along the coast of southeastern WH during the ice-free season may present particular challenges with MR estimation, given the limited sampling there and the tendency for bears to exhibit fidelity to specific sites. Little is known about the movements of bears in this region. However, several pieces of evidence suggest that individuals coming ashore in southeastern WH may be unavailable for MR sampling or have significantly lower capture probabilities when sampling is restricted to the EC core study area (Area 1). Data from 2003 - 2005 (when sampling last took place in southeastern WH) indicate that 9 of 50 bears first handled in Area 2 during 2003 – 2004 were recaptured in WH the following year; although >4 times more total captures occurred in Area 1, 8 of these 9 bears were recaptured in Area 2 (N. Lunn, unpublished data). This finding suggests strong fidelity of bears to southeastern WH. Additionally, studies focused around Churchill and in Wapusk National Park indicate that movement rates during the ice-free period are relatively low (Parks et al. 2006), and that a general northward movement of bears does not occur until late fall, prior to freeze-up (Stirling et al. 1977; Derocher and Stirling 1990; Stirling et al. 2004). If bears in southeastern WH exhibit similar movement patterns, they may be present in Area 2 at the time MR sampling is occurring and therefore unavailable for capture if sampling is restricted to Area 1¹⁵. The hypothesized distributional shift towards southeastern WH may further compound sampling issues. Increasing numbers of individuals coming ashore in Area 2 may result in exclusion of a larger segment of the population from MR estimates.

A thorough assessment of WH subpopulation status and trend will require the completion of MR analyses and consideration of all WH data (e.g., litter sizes, survival rates) as well as aerial survey and other data for SH. At present, we can conclude that although the 2011 aerial survey abundance estimate is consistent with the MR estimate from 2004 (Regehr et al. 2007), it is not consistent with the predicted continued decline based on vital rates (Regehr et al. 2007) nor projected abundance derived from simulations using MR-based estimates (York and Taylor, unpublished data).

Additionally, the aerial survey results raise questions about the underlying assumptions associated with mark-recapture as applied in WH. Specifically, we are uncertain that sampling

¹⁵ Mark-recapture sampling typically occurs in late August and September

within a core study site (i.e., the Environment Canada study area) facilitates random sampling of bears from across the wider WH subpopulation, given the widespread documentation of fidelity during the ice-free season and the significant number of bears summering in southeastern WH. Failure to meet assumptions of random sampling or adequately model the associated capture heterogeneity would yield a negatively biased abundance estimate. Thus, incomplete sampling across the entire subpopulation likely resulted in an underestimate of abundance, or an abundance estimate that does not pertain to the entire subpopulation.

Negative bias in previous MR abundance estimates does not necessarily negate the long-term declining trends in vital rates, reproductive output and body condition observed in WH (Stirling et al. 1999; Regehr et al. 2007). Earlier MR abundance estimates also may have been subject to negative bias due to limited spatial sampling, and the aerial survey results may simply adjust the WH abundance baseline. However, the hypothesized distributional shift towards southeastern WH and lack of sampling there could further bias abundance, vital rate estimates and other measures of status.

On-going Analyses and Recommendations

The primary objective of this study was to generate an aerial survey-based abundance estimate. However, aerial surveys provide a wealth of ancillary data that can further inform status assessment and address other ecological and management questions. The WH data are being integrated into a broader analysis including Foxe Basin aerial survey data to investigate environmental (e.g., habitat features, ice breakup and absence), anthropogenic (e.g., proximity to communities) and ecological (e.g., proximity to conspecifics, segregation of family groups from solitary bears) determinants of polar bear distribution during the ice-free season. Such information may be useful in developing future study designs, informing environmental impact assessments and mitigating potential human – wildlife conflicts. Body condition indices will similarly be examined with respect to ice breakup and absence.

Additionally, an aerial survey was completed in the Ontario portion of the Southern Hudson Bay subpopulation (SH) during September, 2012 (Obbard et al. unpublished data). Analyses are currently in progress, with results anticipated by late spring, 2012. Although existing data suggest that nearly all SH polar bears spend the ice-free season in Ontario (M. Obbard, personal communication), a complementary survey is scheduled for Quebec portions of SH during late summer, 2012. Combined, the SH and WH surveys, as well as the recent Foxe Basin study, will provide a comprehensive picture of polar bear abundance in the Hudson Bay complex.

Our results suggest that aerial surveys provide an effective means to estimate polar bear abundance in seasonally ice-free subpopulations. Given the recent changes in Hudson Bay sea ice (Gough et al. 2004; Gagnon and Gough 2005) and associated impacts on body condition and vital rates (e.g., Stirling et al. 1999; Regehr et al. 2007), regular monitoring of subpopulations in the Hudson Bay complex will be critical to document changes in abundance, distribution and demographics and inform management regimes. Our preliminary recommendation is that no more than 5 years elapse between successive surveys to minimize potential negative impacts of over-harvest in a reduced population. To better construct a future monitoring program, WH will be analyzed alongside FB aerial survey data to evaluate the sampling intensity required to achieve target levels of precision. We will also use these datasets to conduct a power analysis to assess our ability to detect changes in abundance. We note that our statistical power will be reduced in comparison to recent work in FB (Stapleton et al. 2011) due to the lower precision in the WH survey. Finally, resource constraints are an important consideration of a long-term monitoring program. Because they require only a single research season to generate an abundance estimate, aerial surveys are a competitive monitoring method for abundance estimation in terms of financial investment. However, capture-based studies are still required to estimate vital rates and also facilitate other research objectives.

The WH aerial survey identified key topics that warrant additional study. Specifically, how bears located in the southeastern portion of WH fit into greater Hudson Bay population dynamics remains uncertain. We recommend multiple lines of research to address related questions. First, a telemetry program will be required to assess movements of bears in southeastern WH, update subpopulation delineation between SH and WH and evaluate the extent and use of potential denning areas. Second, the Environment Canada capture and tagging program should be extended across the entire WH subpopulation to ensure that potential capture heterogeneity is minimized (or can be adequately modeled), increasing confidence in estimated abundance and vital rates. Inclusion of the entire region in capture work will additionally yield more detailed information on demographics and body condition. Finally, more detailed analyses of Manitoba Conservation's annual coastal surveys, including an assessment of patterns of sea ice breakup, will quantify the occurrence, magnitude, and potential drivers of any distributional shifts in WH.

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Figure 1. Strata delineated and planned survey transects for the Western Hudson Bay polar bear aerial survey, August, 2011.

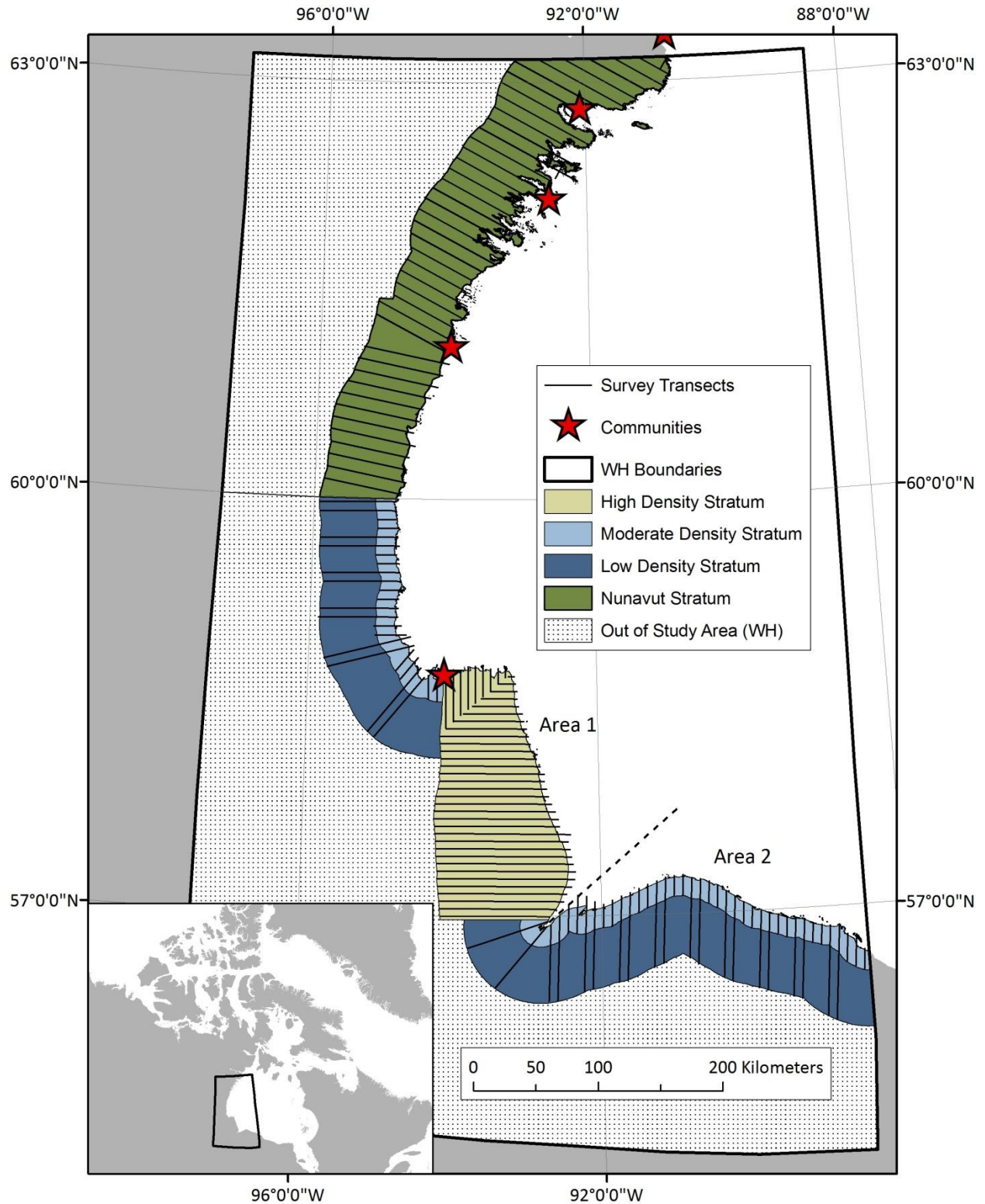


Figure 2. The Western Hudson Bay polar bear aerial survey included sampling from perpendicular transects and independent, coastal contour transects. Because perpendicular transects extended through the coastal zone, bears near the shoreline could be sighted from both perpendicular and contour transects.

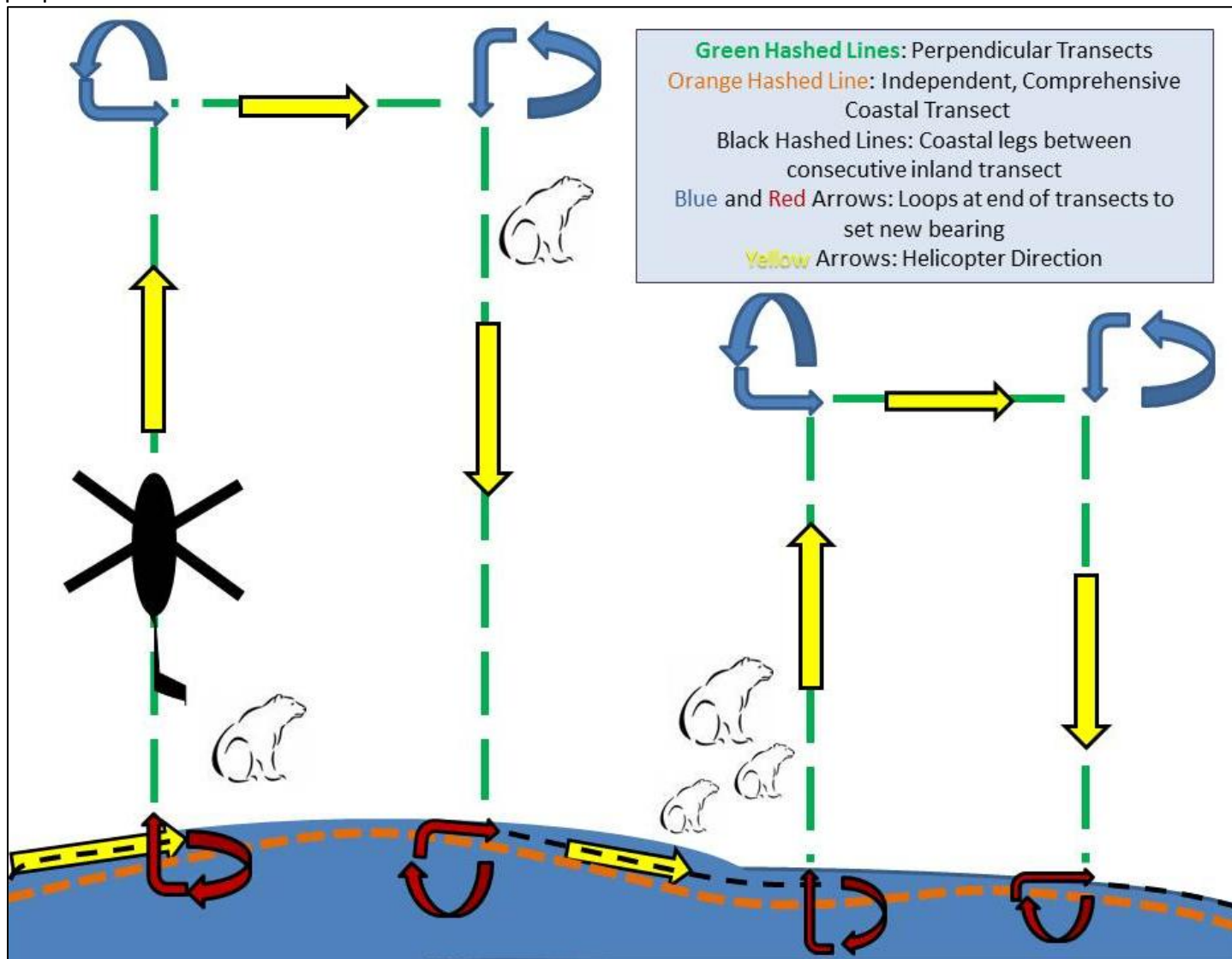
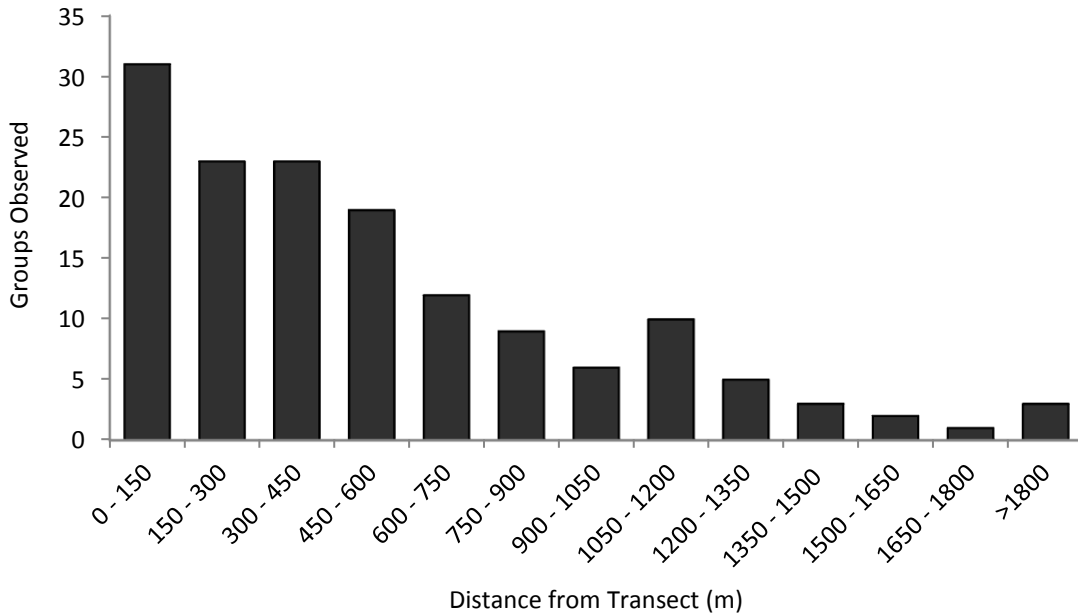


Figure 3. Histograms showing the distribution of sightings from the original transect line for sightings of polar bears from perpendicular transects during the Western Hudson Bay aerial survey, August, 2011. All strata are pooled. (a) All sightings, including perpendicular transects extending through the coastal zone. (b) Only sightings inland of the coastal zone.

(a)



(b)

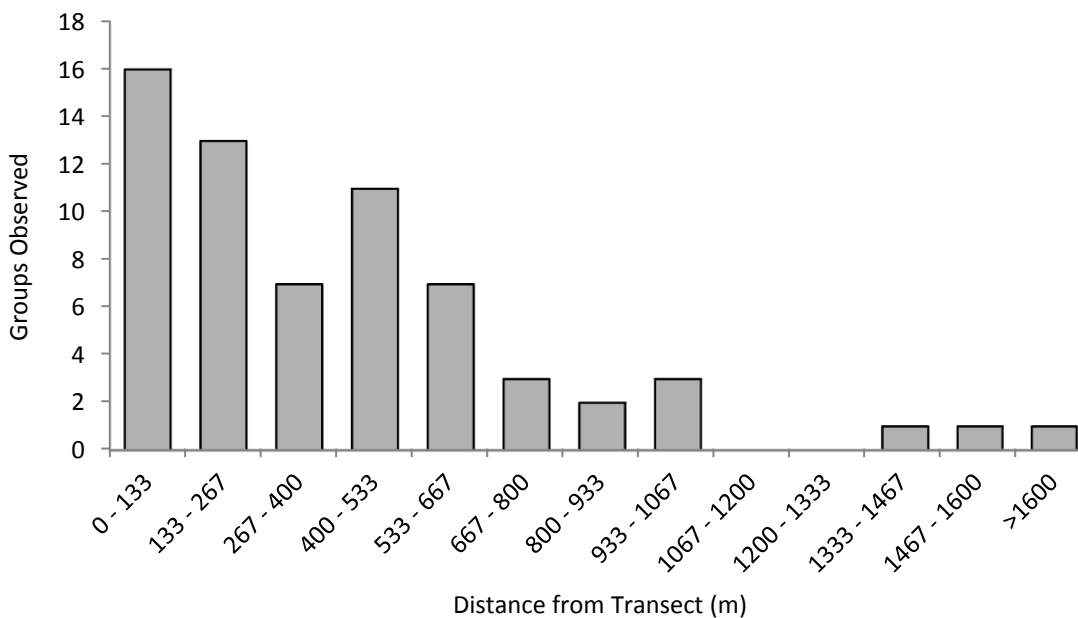


Figure 4. Polar bear sightings recorded during the Western Hudson Bay aerial survey, August, 2011.

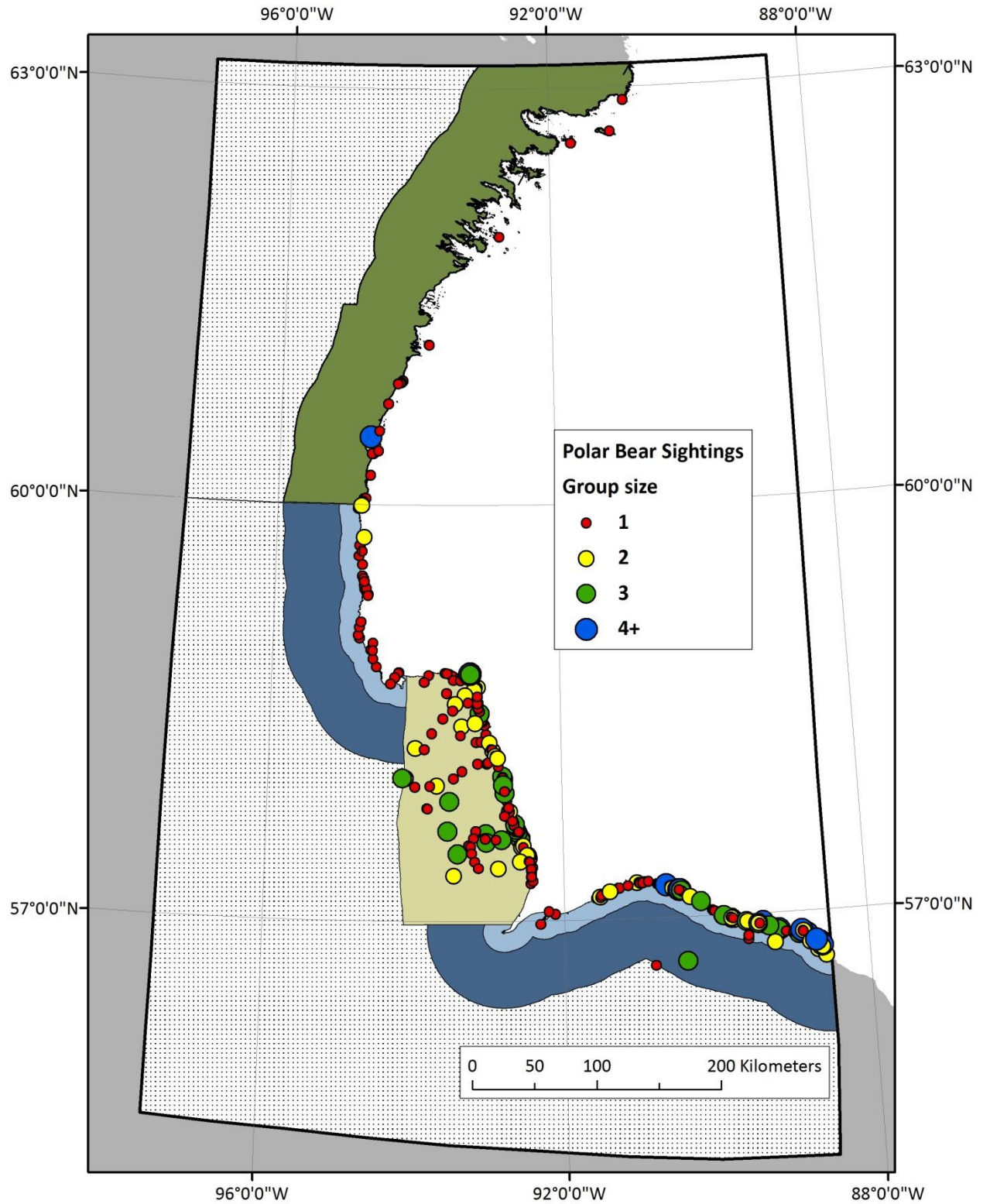


Figure 5. Polar bear observations and transects flown during the 2010 pilot aerial survey in Nunavut.

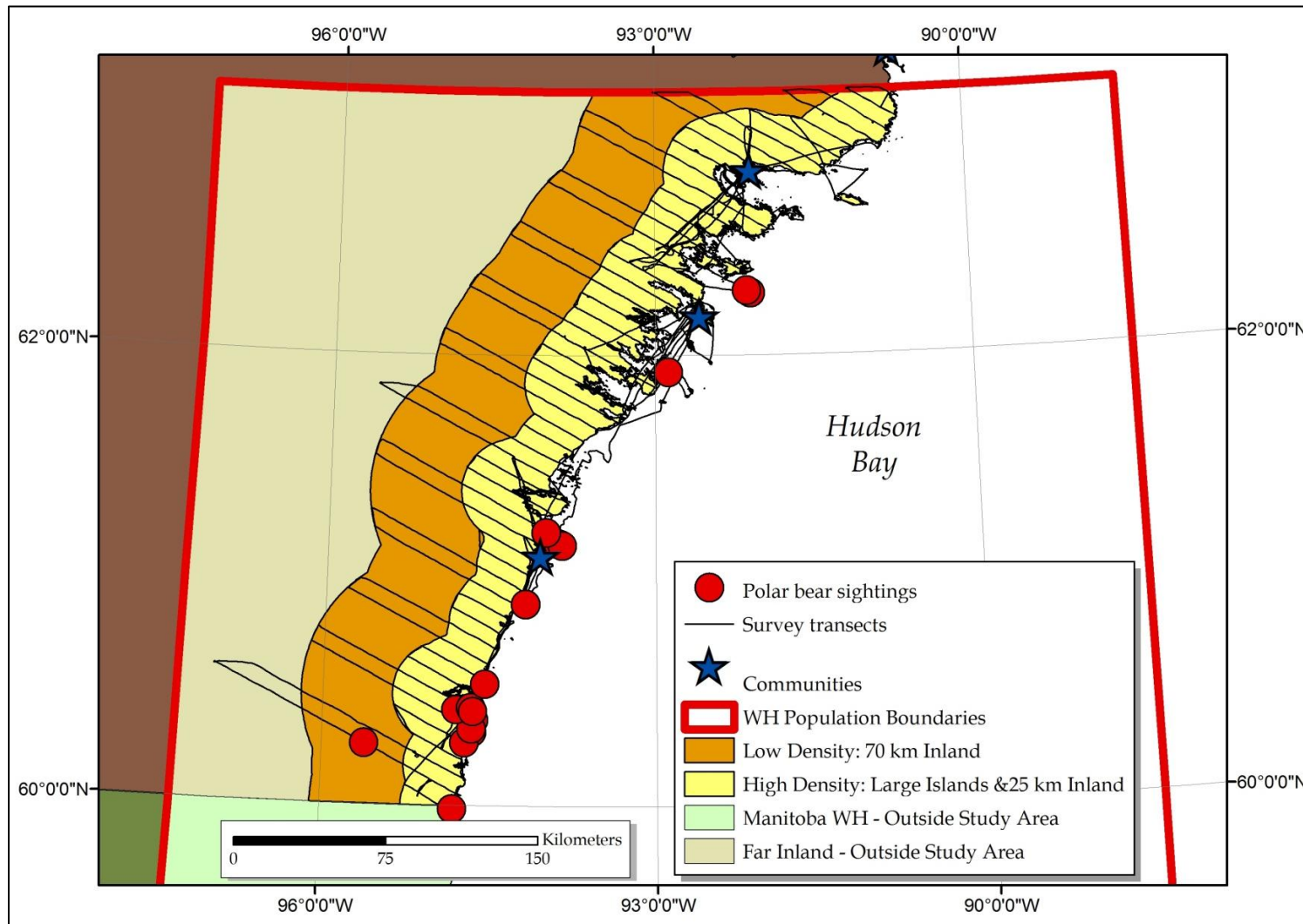


Figure 6. Detection functions estimated from polar bear sightings during the Western Hudson Bay aerial survey, August, 2011. Data are from untruncated transects, and all strata are pooled. The blue line illustrates the average detection function (based on observed covariates) from the most highly supported model including perpendicular transect data from the coastal zone. The yellow line represents the average detection function from the most supported model excluding perpendicular transect data from the coastal zone.

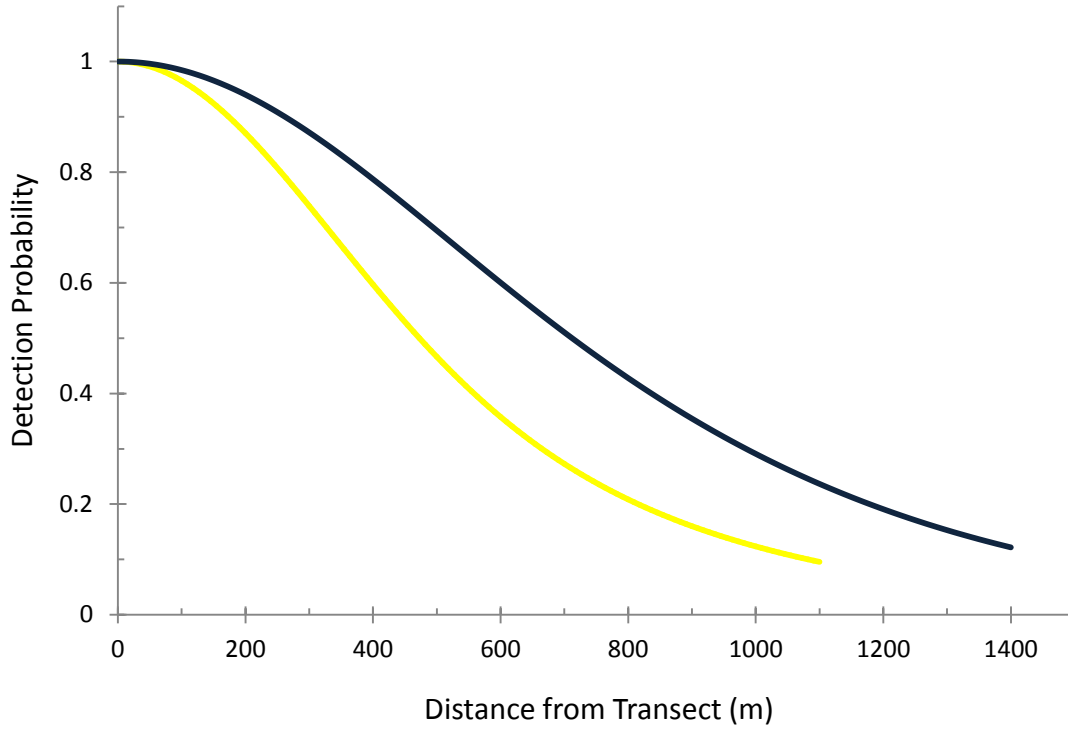
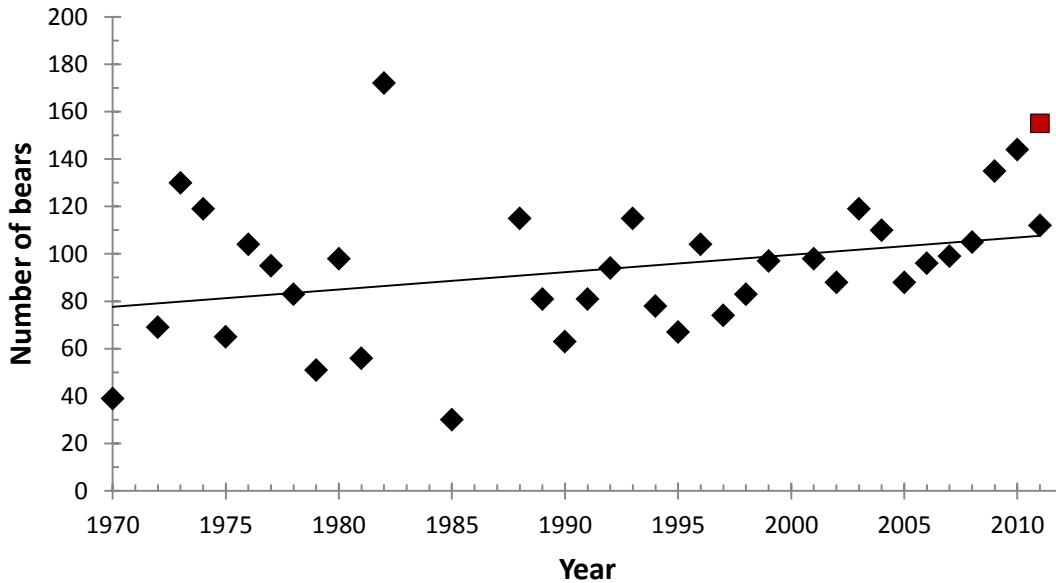


Figure 7. Polar bear counts from coastal surveys conducted between August 15 and September 15 from 1970 to 2011 in Western Hudson Bay in: (a) the area extending from Churchill to the Nelson River (approximating Area 1 in this study); and (b) the area extending from the Nelson River to the Manitoba – Ontario border (Manitoba Department of Conservation unpublished data; Stirling et al. 2004; Area 2). The observations from this survey, including all bears sighted along the coast and on small islands during the coastal contour transects, are denoted by red squares. The 2011 transects were flown on August 15 and August 21 – 24.

(a)



(b)

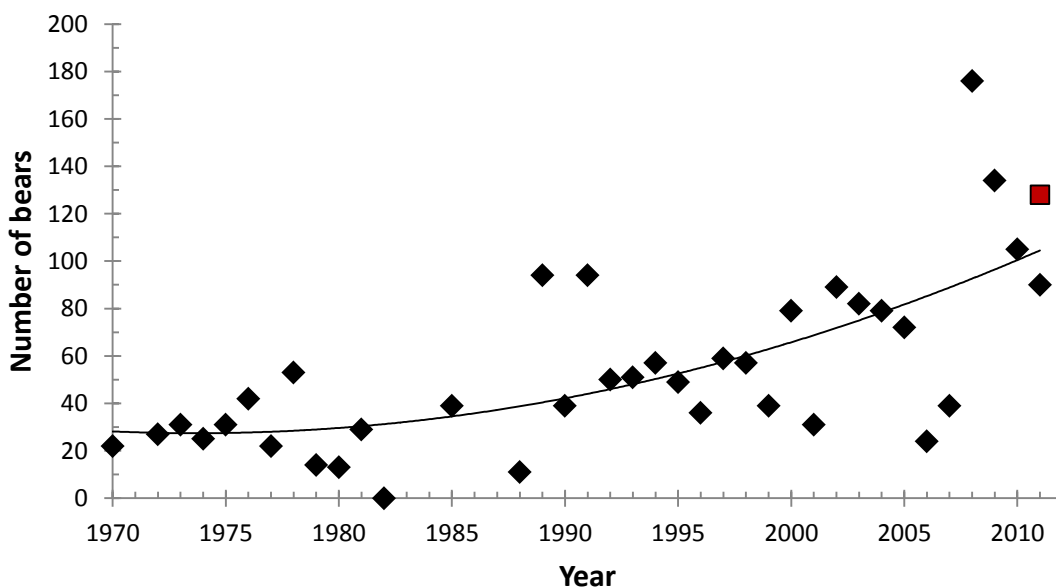


Figure 8. Polar bear counts from coastal surveys in the Manitoba portion of Western Hudson Bay, extending from the Manitoba – Ontario border to Churchill (Manitoba Department of Conservation unpublished data; Stirling et al. 2004). The red diamond represents 2011 aerial survey data gathered from coastal contour transects in the same area.

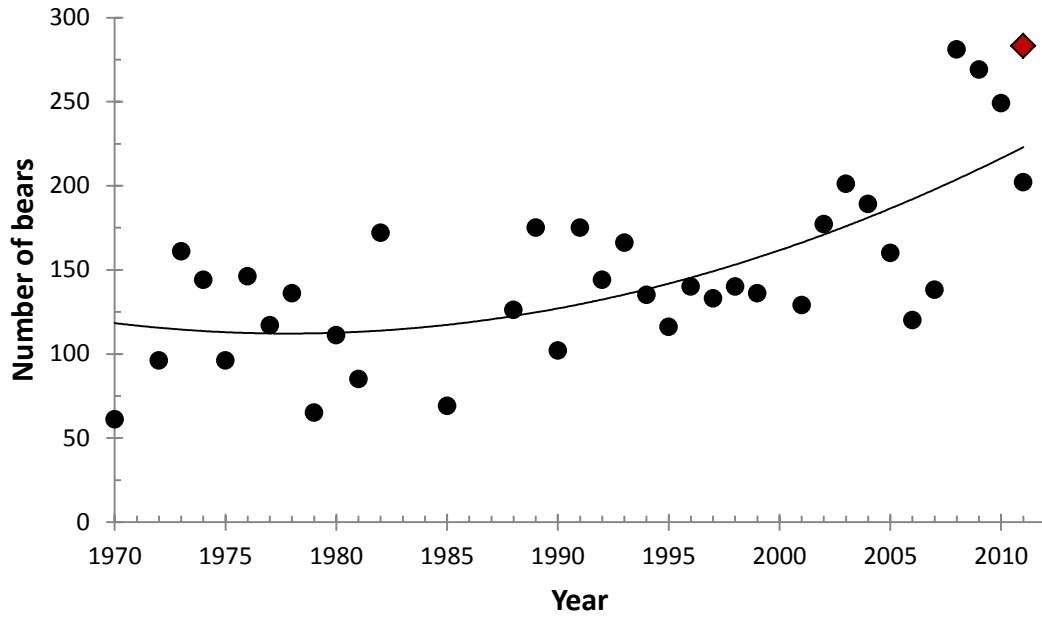


Figure 9. Harvest recovery locations of polar bears tagged in Areas 1 and 2 during 2003 – 2005.

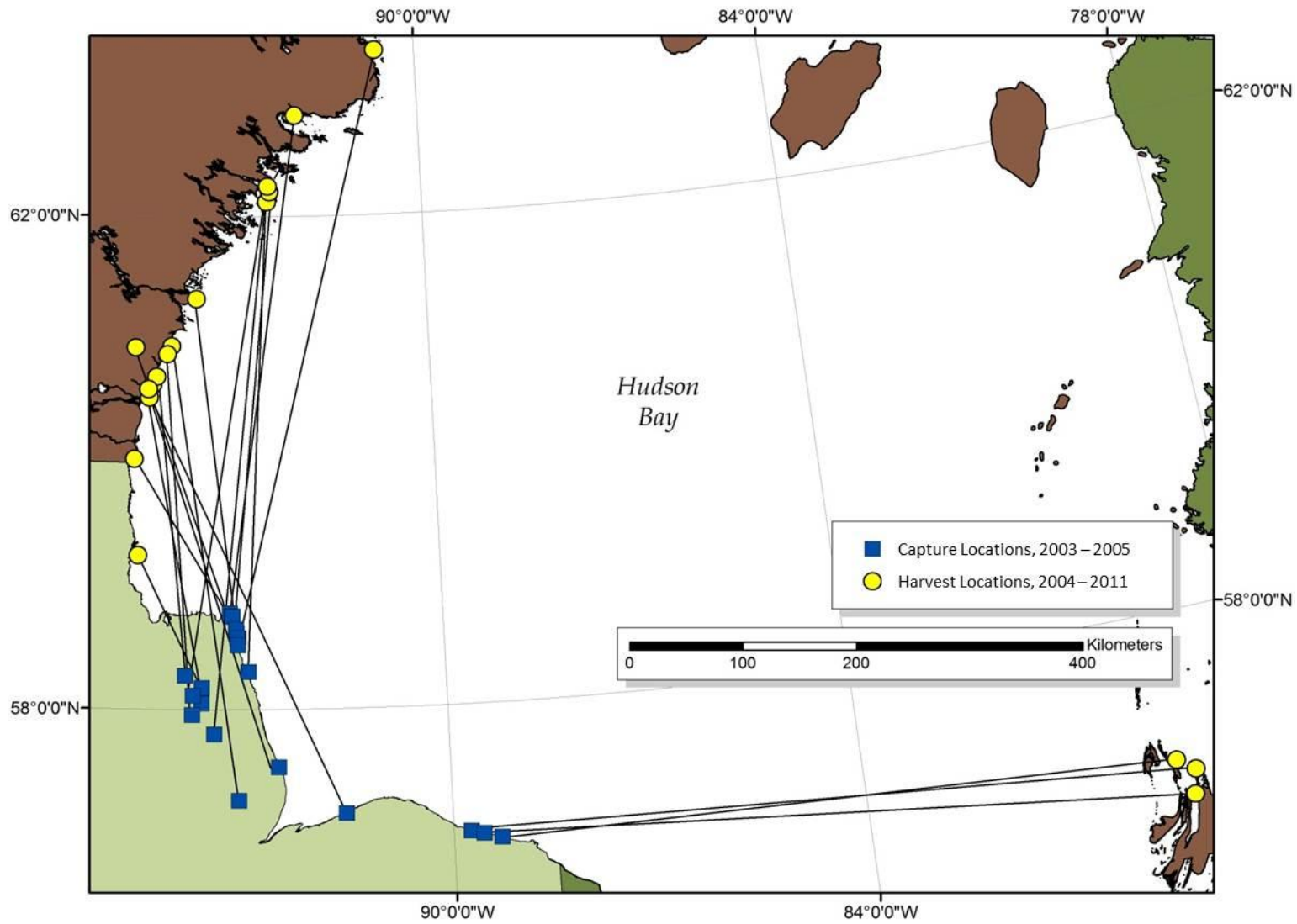


Table 1. Polar bears sighted in Manitoba and Ontario on coastal contour transects (including small islands) and perpendicular transects during the WH aerial survey, conducted during August, 2011. All bears included in distance sampling analyses, plus 2 far inland (out of study area) groups and 5 groups sighted during repeat flights of transects, are included with perpendicular transect data. Area 1 extends from the Nunavut – Manitoba border to the Nelson River, approximating Environment Canada’s long-term study area and Stirling et al.’s (2004) Area 5. Area 2 extends from the Nelson River eastward to the WH border, similar to Stirling et al. (2004)’s Area 4. Twenty-seven and 88 bears were sighted on coastal transects north of Churchill and east of the Manitoba - Ontario border, respectively [i.e., outside the bounds of zones sampling in Stirling et al. (2004)].

Age/Sex/Reproductive Status	Coastal contours		Perpendicular transects	
	Area 1	Area 2	Area 1	Area 2
Adult males	93	136	35	43
Adult females: Solitary	15	9	24	4
w/ cubs of the year	6	5	15	4
w/ yearlings	3	7	4	3
Sub-adults	47	39	28	14
Unknown sex and age-class	3	5	0	3
Cubs of the year	11	6	21	5
Yearlings	4	9	4	3
Total	182	216	131	79

Table 2. Body condition index scores (1 – 5; Stirling et al. 2008b) of polar bears sighted in Manitoba on coastal contour transects (including small islands) and perpendicular transects during the WH aerial survey, August, 2011. All bears included in DS analyses, plus 2 far inland (out of study area) groups and 5 groups sighted during repeat flights of transects, are included with perpendicular transect data. Area 1 extends from the Nunavut – Manitoba border to the Nelson River, approximating Environment Canada’s long-term study area and Stirling et al.’s (2004) Area 5. Area 2 extends from the Nelson River eastward to the WH border, similar to Stirling et al. (2004)’s Area 4. Twenty-seven and 88 bears were sighted on coastal transects north of Churchill and east of the Manitoba – Ontario border, respectively [i.e., outside the bounds of zones defined in Stirling et al. (2004)]. Data are presented as mean (sample size, standard deviation).

Age/Sex/Reproductive Status	Coastal Contours		Inland Transects	
	Area 1	Area 2	Area 1	Area 2
Adult males	2.95 (93, 0.33)	3.47 (136, 0.35)	3.07 (35, 0.35)	3.41 (43, 0.35)
Adult females: Solitary	3.37 (15, 0.61)	3.78 (9, 0.62)	4.02 (24, 0.60)	4.13 (4, 0.63)
w/ cubs of the year	3.0 (6, 0)	3.3 (5, 0.27)	3.1 (15, 0.21)	3.0 (4, 0)
w/ yearlings	3.0 (3, 0)	3.08 (7, 0.20)	3.25 (4, 0.29)	3.0 (3, 0)
Sub-adults	2.99 (47, 0.07)	3.04 (39, 0.13)	2.84 (28, 0.51)	3.11 (14, 0.21)
Unknown sex and age-class	3.25 (2, 0.35)	3.0 (5, 0)	N/A	3.33 (3, 0.58)
Cubs of the year	3.0 (11, 0)	3.17 (6, 0.26)	3.03 (20, 0.11)	3.0 (5, 0)
Yearlings	3.0 (4, 0)	3.06 (9, 0.18)	3.25 (4, 0.29)	3.0 (3, 0)

Table 3. Summary of most supported models ($\Delta AIC < 2$) for distance sampling analyses of the WH polar bear aerial survey, conducted during August, 2011. In the column *Model*, the first term signifies the key function and subsequent terms represent covariates (Struc = Habitat structure within a 30 m radius of the polar bear; Vis = visibility).

Dataset	Model	ΔAIC	Parameters	Global density¹ (bears per km²)	Coefficient of variation (%)
<i>All Inland Sightings, Untruncated transect</i>	Half-normal / Struc + Vis	0.000	3	0.011	17.6
	Hazard / Struc + Vis	0.106	4	0.013	20.7
<i>All Inland Sightings, Left-truncated transect</i>	Half-normal / Struc + Vis	0.000	3	0.11	18.5
	Hazard / Struc + Vis	0.593	4	0.13	22.5
<i>Sightings excluding coastal zone, Untruncated transect</i>	Half-normal / Struc + Vis	0.000	3	0.007	20.3
	Hazard / Vis	0.331	3	0.008	23.3
	Hazard / Struc + Vis	1.030	4	0.008	24.2
	HN / Vis	1.059	2	0.007	18.8
	HN / Struc	1.630	2	0.007	20.0
<i>Sightings excluding coastal zone, Left-truncated transect</i>	Half-normal / Struc	0.000	2	0.006	21.5
	Half-normal / Struc + Vis	1.301	3	0.006	21.6

¹Global density estimates refer to density within the region estimated by distance sampling. For example, datasets excluding sightings in the coastal strip do not incorporate those bears in the global density estimate.

Table 4. Proportion of polar bears in different sex and age classes within Areas 1 and 2 of WH as observed during the 2011 aerial survey and as captured during Environment Canada research 2003-05.

Age/Sex Class	<i>Area 1</i>			<i>Area 2</i>		
	2011 Aerial Survey		EC Captures ¹ (2003-05)	2011 Aerial Survey		EC Captures ¹ (2003-05)
	Coastal Transects	Perpendicular Transects		Coastal Transects	Perpendicular Transects	
Adult Males	0.51	0.27	0.28	0.63	0.54	0.60
Family Groups	0.13	0.34	0.46	0.13	0.19	0.12
Other	0.36	0.39	0.26	0.24	0.27	0.28

¹ N=373 and 73 for Areas 1 and 2 respectively.

Table 5. Polar bear litter sizes and number of dependent offspring observed (as proportion of total observations) during recent ice-free season studies in central and eastern Canada. Data are presented as mean (standard error).

Subpopulation	Litter Size		Proportion of Total Observations		Source
	<i>Cubs of the year</i>	<i>Yearlings</i>	<i>Cubs of the year</i>	<i>Yearlings</i>	
Western Hudson Bay (2011)	1.43 (0.08)	1.22 (0.10)	0.07	0.03	This report
Southern Hudson Bay (2011)	1.56 (0.06)	1.54 (0.08)	0.16	0.12	M. Obbard (unpublished data)
Baffin Bay (2011)	1.57 (0.06)	1.51 (0.09)	0.19	0.10	GN (unpublished data)
Foxe Basin (2009-2010)	1.54 (0.04)	1.48 (0.05)	0.13	0.10	Stapleton et al. (2011)
Davis Strait (2005-2007)	1.49 (0.15)	1.22 (0.28)	0.08	0.09	Peacock et al. (In Review)