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Cover photos (clockwise from top): adult female and yearling at edge of pond; pregnant female in forested area; group of adult males on small offshore island
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Abstract

The Southern Hudson Bay (SH) polar bear subpopulation occurs at the southern extent of the species’ range. Although capture-recapture studies indicate that abundance remained stable between 1986 and 2005, declines in body condition and survival were documented during the period, possibly foreshadowing a future decrease in abundance. To obtain a current estimate of abundance, we conducted a comprehensive line transect aerial survey of SH during 2011–2012. We stratified the study site by anticipated densities and flew coastal contour transects and systematically spaced inland transects in Ontario and on Akimiski Island and large offshore islands in 2011. Data were collected with double observer and distance sampling protocols. We also surveyed small islands in Hudson Bay and James Bay and flew a comprehensive transect along the Québec coastline in 2012. We observed 667 bears in Ontario and on Akimiski Island and nearby islands in 2011, and we sighted 80 bears on offshore islands during 2012. Mark-recapture distance sampling and sight-resight models yielded a model-averaged estimate of 868 (SE: 177) for the 2011 study area. Our estimate of abundance for the entire SH subpopulation (951; SE: 177) suggests that abundance has remained unchanged. However, this result should be interpreted cautiously because of the methodological differences between historical studies (physical capture) and this survey. A conservative management approach is warranted given the previous increases in the duration of the ice-free season, which are predicted to continue in the future, and previously documented declines in body condition and vital rates.

Résumé

INTRODUCTION

For management purposes, polar bears in the Hudson Bay complex are placed in three recognized subpopulations—Foxe Basin (FB), Western Hudson Bay (WH) and Southern Hudson Bay (SH)—based on a combination of ice movement patterns, tag returns from harvested bears, capture-recapture studies, and conventional and satellite radio-telemetry (Lunn et al. 2010; Fig. 1). The SH population, which mainly summers on land in Ontario, occurs at the southern limit of the species’ range. In contrast to subpopulations of polar bears at higher latitudes (i.e., the Archipelago Ecoregion of the Canadian Arctic and the two ecoregions of the polar basin; Amstrup et al. 2008), bears in the Hudson Bay system, as well as Davis Strait and Baffin Bay, occur in the Seasonal Sea Ice Ecoregion (Amstrup et al. 2008) and are forced ashore in summer because the ice melts completely each year (Etkin 1991, Wang et al. 1994a, b; Stirling and Parkinson 2006). Second-year ice is rare in Hudson Bay and is restricted to northeast Hudson Bay when it occurs (Etkin and Ramseier 1993). Because currents flow counter-clockwise in Hudson Bay and prevailing winds are often north-westerly, remnant ice usually occurs latest in the summer off the Ontario coast (Etkin 1991, Saucier et al. 2004). Historically, all of Hudson Bay was completely free of ice from mid-August or earlier to late October or later (Markham 1986, Wang et al. 1994a), and the Hudson Bay coast of Ontario was ice-free from mid-August until early December in most years (Gagnon and Gough 2005). As a result, bears spent 4–5 months ashore until freeze-up occurred in mid-November to early December (Stirling et al. 2004).

Fig. 1. Boundaries of Canadian polar bear subpopulations. SB–South Beaufort, NB–North Beaufort, VM–Viscount Melville, NW–Norwegian Bay, LS-Lancaster Sound, MC M’clintock Channel, GB-Gulf of Boothia, BB-Baffin Bay, DS-Davis Strait, FB-Foxe Basin, WH-Western Hudson Bay, SH-Southern Hudson Bay (Lunn et al. 2010)
Once ashore, the bears in southern areas of Hudson Bay are found along the coastlines of Manitoba and Ontario, on the islands of James Bay and eastern Hudson Bay, and in inland areas (Doutt 1967, Russell 1975, Jonkel et al. 1976, Stirling et al. 1977, Prevett and Kolenosky 1982, Derocher and Stirling 1990a, Kolenosky et al., 1992, Crête et al. 1991, Obbard and Walton 2004). Individual bears show fidelity to general areas used for maternity denning (Ramsay and Stirling 1990, Lunn et al. 2004) and as summer refugia (Derocher and Stirling 1990a, Kolenosky et al. 1992, Stirling et al. 1999, Stirling et al. 2004). For example, the mean distance between consecutive capture locations of 1386 bears first captured in WH was 62.3 ± 2.7 km for males \( (n = 678) \) and 46.0 ± 1.7 km for females \( (n = 708) \) (Stirling et al. 2004).

While onshore, polar bears are segregated by sex, age, and reproductive status. For example, in Ontario, pregnant females may move more than 100 km inland to construct a maternity den, though most maternity denning occurs closer to the coast (Kolenosky and Prevett 1983, Obbard and Walton 2004). Additional segregation occurs because adult male bears tend to aggregate on peninsulas, offshore spits and islands, and areas where there are elevated beach ridges (Latour 1981a, b; Derocher and Stirling 1990b). Subadults and females with dependent young are also found along the coastal plain in Ontario; however, because they generally avoid aggregations of adult males, they are found in intervening habitat along the coast and inland (Prevett and Kolenosky 1982, Kolenosky et al. 1992).

Polar bears on land in Ontario were surveyed by the Ontario Ministry of Natural Resources (OMNR) from fixed-wing aircraft during the ice-free season from 1963 to 1996 (Prevett and Kolenosky 1982; Leafloor 1990, 1991; Obbard and Walton 2004; Stirling et al. 2004). Although these counts provided an index of abundance, they did not provide an estimate of actual abundance; surveys counted an unknown proportion of the subpopulation and were subject to large annual variation. Nevertheless, Prevett and Kolenosky (1982) concluded there was evidence that abundance had increased between 1963 and 1980. Similarly, Leafloor (1990) concluded that there was evidence the population was increasing between 1963 and 1990, based on a significant linear regression (Fig 2). Counts averaged 72.8 from 1963-1970; 107.9 from 1971-1980, and 146.6 from 1981-1990. The mean number of bears counted in the 1980s did not differ from the number in the 1970s, but was higher than the average number observed during 1963–1970 (Duncan’s multiple range test; Leafloor 1990). However, the positive slope of the regression is very likely strongly affected by low counts in the first 4 years (1963-1966; \( \bar{x} = 38.8 \)) and a very high count in 1990 (236) (Fig. 2). Also, the count in 1967 (150) was higher than in any other year in the 1960s, higher than 9 of 10 years in the 1970s, and higher than 6 of 10 years in the 1980s. Leafloor (1991) concluded there was no change in the index between 1980 and 1991, based on a non-significant linear regression \( (r = 0.03) \). Based on the late-summer aerial survey index, abundance may have increased in the 1960s, but the inference is weak.
Early research was focused on James Bay and the Belcher Islands (Russell 1975, Jonkel et al. 1976). These and subsequent studies showed that polar bears occurred during the ice-free season on Akimiski Island, the North and South Twin islands, and other smaller islands in James Bay (Doutt 1967, Russell 1975, Jonkel et al. 1976, Crête et al. 1991, Obbard and Walton 2004), as well as on near-shore and offshore islands in eastern Hudson Bay (Crête et al. 1991, McDonald et al. 1997). Crête et al. (1991) flew aerial surveys over the Twin and Ottawa islands in 1986 and 1987 and observed small numbers of bears, but no systematic surveys have been conducted.

From 1984–1986 an intensive capture-recapture study was conducted along the Ontario coastline of Hudson Bay (Kolenosky et al. 1992). Based on that study, the size of the SH subpopulation was estimated to be 763 ± 323 bears (Kolenosky et al. 1992). This estimate was subsequently adjusted upwards to 1000 for management purposes by the Canadian Polar Bear Technical Committee, largely because some inland areas may have been under-sampled due to the difficulty of locating polar bears in the boreal forest and because areas in James Bay were not sampled (Lunn et al. 1998).

Because the abundance estimate for SH was outdated (1986), and declines in body condition and some reproductive parameters had been demonstrated for the neighbouring WH subpopulation (Stirling et al. 1999), the Ontario Ministry of Natural Resources began a study to monitor body condition of SH bears in 1999 and conducted an intensive capture-recapture effort during 2003–2005 to develop a current abundance estimate for the subpopulation. The 2003–2005 study replicated the capture effort and geographic area of the study conducted from 1984–1986 (Obbard 2008). Analysis of the results of the 2003–2005 study and re-analysis of the data from 1984–1986 indicated the size of the SH subpopulation summering on land in Ontario appeared to
be unchanged from the mid-1980s (1984-86: 641, 95% CI = 401, 881 vs. 2003-2005: 681, 95% CI = 401, 961) (Obbard et al. 2007). However, there was evidence that survival rates declined in all sex and age classes between the two study periods (Obbard et al. 2007), and significant declines in body condition occurred in all sex and age classes (Obbard et al. 2006).

Polar bears occupying James Bay are included in the current designation of the boundaries of the SH subpopulation. Though no capture effort occurred in James Bay south of Hook Point during either intensive capture period, bears were captured on Akimiski Island and on North and South Twin Islands in 1997 and 1998 in order to deploy satellite collars (M. E. Obbard, unpublished data). Based on these capture data, the number of bears occurring on Akimiski Island and North and South Twin islands was estimated using the $M_h$ Chao model for closed populations with small samples and heterogeneity as implemented in Program CAPTURE (Otis et al. 1978). This approach yielded an estimate of 110 (95% CI = 75, 195) bears on these islands. Combining the capture–recapture estimates for the main study area (2003–2005) and the James Bay islands (1997–1998) suggested that, at the upper confidence limit, the total number of bears in the SH subpopulation was likely about 1,000 animals in 2005 (Obbard 2008).

The somewhat contradictory inferences of declines in survival rates and body condition without demonstrated changes in abundance, combined with criticism of capture–recapture studies by some groups and the fact that Nunavut and Manitoba were planning to conduct an intensive aerial survey of the WH subpopulation in 2011 (Stapleton et al. 2012a), led the Ontario Ministry of Natural Resources to conduct an intensive aerial survey of the SH subpopulation within Ontario and on Akimiski Island, Nunavut in 2011. In 2012, the Ministère du Développement durable, de l’Environnement, de la Faune et des Parcs du Québec (MDEFPQ) coordinated an aerial survey of the remaining islands in James Bay, the coastal areas of Québec from Long Island to the SH–FB border, and the offshore islands in eastern Hudson Bay.

**METHODS**

**Study Area**

The boundaries of the SH subpopulation include much of eastern and southern Hudson Bay and James Bay and large expanses of the coastline of Ontario and Québec (Fig. 1) as well as areas up to 200 km inland, though documented use of sites >120 km inland is very rare (Kolenosky and Prevett 1983, Obbard and Walton 2004, Obbard and Middel 2012). The SH management unit also includes small near-shore and offshore islands in James Bay and eastern Hudson Bay within the Eeyou Marine Region and the Nunavik Marine Region as well as the Belcher Islands in Nunavut. Therefore, the SH management unit includes about 465,000 km$^2$ of the surface area of Hudson Bay and James Bay, about 1,270 km of the coastline of Ontario and about 1,731 km of the coastline of Québec plus inland areas and offshore islands (Fig. 3).

We conducted the surveys during the late summer and early fall ice-free seasons of 2011 and 2012. During this time of year, polar bears in SH are confined to land, demonstrating strong fidelity to particular geographic regions (Obbard and Walton 2004, Stirling et al. 2004) and remaining relatively segregated from neighbouring subpopulations in Foxe Basin and Western
Hudson Bay. Completing the survey during the ice-free season minimized the extent of the study area and, when coupled with the recent late summer aerial surveys in Foxe Basin (2009 and 2010; Stapleton et al. 2012b) and Western Hudson Bay (2011; Stapleton et al. 2012a) provided for broader inference on the status and health of the entire Hudson Bay polar bear complex.

Fig. 3. Recognized boundaries of the Southern Hudson Bay polar bear subpopulation.

**Study Design**

2011

We used historical capture records, telemetry data, and local knowledge to design and implement a systematic line transect aerial survey. We defined 2 inland strata in Ontario, including a high density zone extending from the coastline to 20 km inland and a low density stratum extending 20 to 60 km inland (Fig. 4). We also delineated a coastal zone, including land within 500 m of
the shoreline, tidal flats, near-shore islands and spits. Although the SH–WH boundary lies about 40 km east of the Ontario–Manitoba border, sampling in 2011 extended from the Ontario–Manitoba border eastward to James Bay. However, we only considered survey effort and sightings east of the SH–WH border for estimating abundance.

Fig. 4. Strata and survey transects for aerial survey of the Southern Hudson Bay polar bear subpopulation, 25 September–5 October 2011.

We used both overland transects, oriented perpendicular to the coastline, and coastal contour transects. We also comprehensively surveyed small islands, spits and gravel bars offshore of northern Ontario. Because polar bears congregate near the shore during the ice-free season (Derocher and Stirling 1990a, Obbard and Walton 2004, Towns et al. 2010), arranging the overland (hereafter perpendicular) transects against this density gradient minimized estimate bias and improved precision (Buckland et al. 2001, Stapleton et al. 2012a, b). We extended perpendicular transects over exposed tidal flats to facilitate estimating abundance without the coastal contours (see Analyses). However, accurately delineating exposed tidal flats in GIS was not possible; thus, distances for perpendicular transects were measured to the coast and polar bear sightings were considered to have occurred on land for analyses. This procedure had a negligible impact on the abundance estimate, since the tidal flats and high density inland stratum were sampled at the same intensity. Perpendicular transects were spaced at 6- and 12-km
intervals in the high and low density strata, respectively, to ensure adequate coverage of the study area while focusing sampling effort in higher density regions (Fig. 4).

The coastal zone was comprehensively sampled with contour transects flown at or slightly below the high water line from west central James Bay (~225 km from the northwestern corner of James Bay) to the SH/WH border. Because perpendicular transects also sampled the coastal zone, bears there could be sighted from both contour and perpendicular transects. Analytical procedures ensured that bears in the coastal zone were not double-counted in the overall abundance estimate (see Analyses).

2012

Historical data and traditional knowledge suggested that the 2011 study area encompassed nearly all regions polar bears inhabit in SH during the late summer. However, polar bears from SH also occupy other islands in James Bay and eastern Hudson Bay (Doutt 1967, Russell 1975, Jonkel et al. 1976, Crête et al. 1991) and are occasionally found in coastal areas of Québec (McDonald et al. 1997:86). Therefore, to increase confidence in the abundance estimate, we extended our sampling to the remaining islands in James Bay, along the Québec coast, and to the offshore islands in eastern Hudson Bay during late summer 2012 following consultations with members of the Nunavik Hunting, Fishing and Trapping Association and the Cree Trappers Association. That traditional knowledge (Hébert, in prep), anecdotal reports, and recent research in FB (Stapleton et al. 2012b) indicated that very low densities of bears reside elsewhere on mainland Québec during late summer. Hence, we surveyed the Québec coast, including the lac Guillaume-Delisle shoreline, and near-shore islands using only comprehensive coastal contour transects, extending from northeastern James Bay to the northern border of SH (Fig. 5).

We surveyed the Belcher Islands, located in southeastern Hudson Bay, with a combination of overland, perpendicular transects and coastal contours, which facilitated sampling about 50% of the shoreline. We comprehensively surveyed other islands in eastern Hudson Bay such as the Ottawa and Sleeper Islands (Fig. 5). Finally, we comprehensively surveyed all small offshore islands in James Bay (Fig. 6).
Fig. 5. Flight lines for coastal contour transects along the Québec coast and near-shore islands (green), and the Belcher Islands and other islands in eastern Hudson Bay (purple), 5-10 and 18-21 September 2012.
Fig. 6. Flight lines for aerial survey of James Bay islands, 11 September 2012.
**Field Protocols**

During 2011, all sampling was conducted from a Eurocopter EC-130 helicopter, flown at a target above ground level (AGL) altitude of 120 m (400 ft) and a groundspeed of about 150 km/hr (90–100 knots). We based flight parameters on experience from polar bear aerial surveys conducted earlier in Ontario (Prevett and Kolenosky 1982, Obbard and Walton 2004), and in other regions (Stapleton et al. 2012a, b) in order to provide excellent viewing opportunities. In 2012, the coastal contour transects in Québec were surveyed from a Eurocopter AStar AS350-BA helicopter, maintaining the same target speed and AGL altitude. A twin-engine platform was required to access the offshore islands in Hudson Bay and James Bay, so these areas were surveyed from a de Havilland Twin Otter (de Havilland DHC-6). Fixed-wing aircraft flew at an AGL altitude of about 120-150 m (400-500 ft) and groundspeed of 150 km/hr (100 knots).

Protocols enabled the simultaneous collection of data for both sight-resight (i.e., double observer; Pollock and Kendall 1987) and distance sampling (Buckland et al. 2001) analyses during most of the survey. We implemented a double observer platform in which teams of front and rear observers (each with two observers) worked independently to sight polar bears. A partition was constructed to ensure that sightings by the front team did not cue rear observers (Fig. 7a, b), and sightings were only announced after both teams were afforded a full opportunity to spot a bear.

For the helicopter surveys, we used GPSs to record flight paths and bear locations and adapted procedures from Marques et al. (2006) to measure distances from the transect lines to sightings in a GIS (ArcMap 9.3; Environmental Systems Research Institute, Redlands, CA, USA). For the fixed wing survey, we measured angles from the flight path to sightings with an inclinometer and calculated distances. We defined a group (hereafter cluster) of bears as individuals whose sightings were non-independent (i.e., spotting one bear led to the observation of others; e.g., family groups comprised of an adult female and 1 or more dependent young).

For each sighting, we recorded the number of bears in a cluster, a bear’s activity (e.g., running, sitting) when first spotted, field age class (adult, subadult, yearling, cub-of-the-year), body condition (1-5), and other covariates that could affect detection probabilities. These covariates included vegetation height within a 30-m radius (<1 m, 1–3 m, >3 m), vegetation density at the same spatial scale (1 = sparse tundra, 2 = moderate, 3 = dense), visibility (1 = poor [e.g., dense fog or rain], 2 = fair [e.g., light fog, light rain, overcast, excessive glare], 3 = excellent [e.g., clear and sunny, partly cloudy]). For the 2011 survey, all data were entered at the time of the observation into a Panasonic Toughbook running ArcPad 7 (Environmental Systems Research Institute, Redlands, CA, USA; the Toughbook had a built-in GPS that recorded all track files. For the 2012 surveys, data were entered into a laptop computer at the time of observation.
Fig. 7. Interior view of Eurocopter EC-130 helicopter used in aerial survey of Southern Hudson Bay polar bear subpopulation, 25 September–5 October 2011. Photographs taken with fish-eye lens. Panel a) illustrates visibility from the aircraft. Panel b) shows screen in place separating front and rear observers.
Analyses

**Perpendicular Transects**

We used distance sampling (Buckland et al. 2001) to derive an abundance estimate from perpendicular transects. Distance sampling is based on the premise that an individual is best at detecting nearby objects; detectability declines as the distance between the observer and the target increases. A model describing how detection changes with distance is fit to the sightings data, yielding an estimate of the number of animals in the surveyed area which were not observed. This, in turn, yields a density estimate and facilitates extrapolation across the study area to derive an overall abundance estimate.

Because bears along the shoreline or on tidal flats could be sighted from both coastal contour and perpendicular transects, we compiled two datasets that included and excluded the coastal zone sightings from the perpendicular transect data. Perpendicular transects of Akimiski Island did not extend fully through the coastal zone and over tidal flats, so we incorporated data from this site only in the analyses that excluded the coastal zone data. In other words, we estimated the number of bears in Akimiski Island’s coastal zone with only the coastal contour transects (see Coastal Contours and Small Islands below).

Histograms summarizing sighting distances from the flight path indicated support for a distance-based detection function (Fig. 8). However, preliminary double observer analyses suggested that detection at distance zero was significantly less than one, violating a fundamental assumption of distance sampling. Therefore, we elected to use mark-recapture distance sampling for these analyses (MRDS; Laake and Borchers 2004). MRDS relaxes the assumption of perfect detection on the transect line by facilitating estimation of detection at distance zero using double observer data. Because the survey was completed in a helicopter platform, rear observers had a blind spot of ~60 m on either side of the aircraft in which they were unable to sight bears. To ensure that all bears were available to both sets of observers, we left-truncated the sightings data at 60 m (i.e., bears sighted within 60 m of the flight path were discarded, and 60 m was subtracted from all other observations; Borchers et al. 2006).

We completed distance sampling analyses in Program DISTANCE (Version 6.0, Release 2; Thomas et al. 2010). We first fit conventional distance sampling models with uniform, half-normal, and hazard rate key functions and associated series expansion terms (cosine, simple polynomial and hermite polynomial). These preliminary analyses enabled us to evaluate general model fit and examine potential cluster size bias in detection. For both datasets, we right-truncated data at about 2% (i.e., the most distant 2% of observations were discarded). Although right-truncating at 5% is typically recommended to improve model fit (Buckland et al. 2001), our data did not exhibit spurious bumps in the ‘tails’ of the histograms that would require additional truncation (Fig. 8).
Fig. 8. Distribution of distance from the transect line of polar bears that were sighted from perpendicular transects, Southern Hudson Bay, 25 September—5 October, 2011. Observations were left-truncated at 60 m (i.e., 60 m was subtracted from the original measurements) to compensate for the rear observers’ blind spot directly beneath the helicopter. These data were used in the distance sampling analyses. The histogram excludes one observation that was right-truncated in the analysis that excluded the coastal observations, and two observations that were right-truncated in the analysis that included the coastal sightings.

We conducted all additional modeling in the MRDS component of Program DISTANCE. We specified the point independence model, which requires that sightings observations are statistically independent only at a single point rather than across all distances (Laake and Borchers 2004). This model enables separate estimation of the mark-recapture model (i.e., the conditional detection function in which detection by an observer is conditional on being sighted by the other observer as well as the sighting-specific covariates) and the distance sampling model (i.e., the unconditional detection function; Laake and Borchers 2004).

We examined three covariates potentially influencing detectability with both mark-recapture and distance sampling models, including visibility and cluster size. We collected two sighting-specific habitat variables (vegetation height and density), but because they were highly correlated (Pearson’s $r = 0.89$), we only considered vegetation height in modeling. We also examined observer (i.e., front or rear, enabling detection probabilities to vary between observer teams) and distance as covariates with the mark-recapture models.
Because our data were sparse, we permitted a maximum of one and two covariates for the
distance sampling and mark-recapture models, respectively, with the dataset excluding the
coastal sightings (Giudice et al. 2012). (In distance sampling, the hazard rate detection function
requires estimation of both shape and scale parameters, whereas an intercept and covariates must
be estimated with mark-recapture models. Our constraints meant that a maximum of three
parameters would be estimated for each of the mark-recapture and distance sampling models.)
The number of observations was significantly greater with the dataset including the coastal zone
sampling, so we restricted the maximum covariates to two and three for the mark-recapture and
distance sampling models, respectively. We modeled all effects as additive.

We first evaluated mark-recapture models by holding constant the distance sampling model and
incorporating covariates with forward stepwise selection. We then evaluated the full MRDS
models by parameterizing the most-supported mark-recapture models and fitting distance
sampling models, again incorporating covariates with forward stepwise selection. We selected
the most highly supported models with Akaike’s Information Criterion (AIC; Akaike 1981) for
both the initial mark-recapture modeling and the full MRDS modeling. The two datasets yielded
estimates of abundance that reflected the entire region surveyed with perpendicular transects
(i.e., including the coastal data) and the region inland of the coastal zone (i.e., excluding the
coastal data).

Coastal Contours and Small Islands

2011

We used double observer data obtained along coastal contour transects to generate an
independent estimate of abundance for the coastal zone. We used the Huggins capture-recapture
model (Huggins 1989, 1991), which enabled us to include covariates in modeling and to estimate
individual detection probabilities. We surveyed the region 500 m inland of the shoreline, as well
as the exposed tidal flats, small near-shore islands, and spits. We comprehensively surveyed
offshore islands. Data from offshore islands and the coastal zone were pooled for analyses. We
compiled two datasets: (1) including all offshore islands and the entire coastline, and (2)
including all offshore islands and only the coastline of Akimiski Island.

We completed all double-observer modeling in Program MARK (White and Burnham 1999) and
employed AIC adjusted for small sample sizes (AICc; Burnham and Anderson 2002) for model
selection. We defined polar bear clusters as the sampling unit and specified that detection
probabilities either remained constant or varied between observer teams. We used forward
stepwise selection based on AICc to evaluate three covariates: visibility (as scored above),
activity (moving or stationary), and group size. There was insufficient variability in vegetation
height or density to warrant their inclusion as covariates. To estimate the number of clusters
present in the study area, the parameter estimates from the most supported models in each dataset
were input with a generalized Horvitz-Thompson estimator. Some sightings along the coastline
and on offshore islands were not collected with double observer protocols. We adjusted these
counts with detection probabilities estimated from double observer modeling and considered all
of these sightings to have been spotted by both teams of observers (i.e., yielding the highest
inclusion probability – the probability of being sighted by at least one observer – and thus
minimally inflating the estimate). We estimated the number of individuals by incorporating the mean observed group size for each dataset, calculated group size sampling variance following Buckland et al. (2001), and inflated and multiplied variances via the Delta method (Powell 2007).

2012

For the offshore islands in eastern Hudson Bay surveyed by Twin Otter, we used double-observer modeling, estimated detection probabilities, and generated an abundance estimate as outlined for 2011. However, data from the islands in James Bay were collected without a double observer platform. Data were considered total counts due to the small size of these islands and absence of vegetation and significant topographic relief. We did not inflate these counts with detection probabilities estimated from sampling elsewhere in 2012 because the regions were surveyed with different field crews. Very sparse observations in other areas (i.e., the Belcher Islands, surveyed via perpendicular transects and coastal contours; coastline of Quebec) precluded modeling, and observations were added to final estimate.

Total Abundance

Double sampling the coastal zone enabled us to obtain two partially independent abundance estimates in 2011. First, we added estimates from offshore islands, the Akimiski Island coastline, and the perpendicular transect analysis that included the coastal zone. We also summed the abundance estimates from the offshore islands, the complete coastal contour transects, and the perpendicular transects analysis that excluded the coastal zone. We assigned equal model weights ($w = 0.5$) and model-averaged the two estimates (Anderson et al. 2000) to generate a final abundance estimate for the 2011 study area. To obtain an overall abundance estimate for SH, we summed this estimate with the estimate from the 2012 survey.

RESULTS

Survey Effort and Sightings

We completed the 2011 aerial survey of Ontario and Akimiski Island during an 11-day period from 25 September–5 October, 2011. Sampling progressed systematically from Akimiski Island in James Bay, westward to the SH boundary with WH. The survey occurred over 81 total flight hours and covered ~4,527 km along perpendicular transects, including ~2,631 km and ~1,896 km in the high density and low density strata, respectively. We recorded a total of 667 sightings in SH. Because we independently sampled the coastal zone with both perpendicular and contour transects, bears near the shoreline may have been counted twice, and we were unable to calculate the number of unique sightings. Litter sizes averaged 1.56 (SE: 0.06; $n = 70$) and 1.54 (SE: 0.08; $n = 54$) for cubs-of-the-year and yearlings, respectively, including all sightings.

Although bears were occasionally spotted far inland (e.g., 31 bears were observed >10 km from the shoreline), observations were highly concentrated near the coastline (Fig. 9). A single
individual was sighted beyond the inland extent of the defined study area while we flew between two adjacent, far inland perpendicular transects.

Fig. 9. Locations of polar bears sighted during the aerial survey of the Southern Hudson Bay polar bear subpopulation, 25 September–5 October, 2011.

We surveyed the Québec coast of Hudson Bay and near-shore islands in eastern Hudson Bay from 5–10 September 2012, small offshore islands in James Bay on 11 September 2012, and offshore islands in eastern Hudson Bay from 18–21 September 2012. We surveyed the entire Québec coastline (~3,600 km) from Long Island at the northeastern corner of James Bay to the SH–FB border without sighting a single bear (Fig. 10). The surveys of small islands in James Bay and eastern Hudson Bay yielded 80 sightings (Figs. 10, 11).
Fig. 10. Locations of polar bears sighted during the aerial survey of the Québec coast and near-shore and offshore islands in eastern Hudson Bay, 5-10 and 18-21 September 2012.
Fig. 11. Locations of polar bears sighted on islands in James Bay, 11 September 2012.
Abundance Estimation

Perpendicular Transects

2011

Following left- and right-truncation, we included 79 polar bear clusters in the distance sampling analysis that included the coastal zone data and 49 clusters in the analysis that excluded coastal sightings. Analyses incorporated 163 transects for variance estimation, with 116 and 47 transects sampled in the high and low density strata, respectively.

All highly supported models specified a half-normal key function for the distance sampling detection function. The best models also included covariates for both the mark-recapture and distance sampling components (Table 1). Whereas cluster size and observer were included in nearly all of the most supported mark-recapture models, distance from the flight path was not. Vegetation height was included as a covariate in all highly supported distance sampling models for both datasets. All highly supported MRDS models yielded adequate overall Chi-square goodness-of-fit statistics ($P > 0.05$; Table 1), and distance sampling models showed suitable fit with additional metrics (Komologorov-Smirnov and Cramér-von Mises tests: all $P > 0.75$). Because density estimates were consistent among the most highly supported models, we selected the top models in each dataset to derive estimates of abundance. We estimated 667 bears (SE = 141.6; 95% lognormal CI = 441–1,009) with the dataset including the coastal region, and 520 bears (SE = 149.7; 95% CI = 298–907) with the dataset excluding the coastal zone.
Table 1. Summary of modeling results from mark-recapture distance sampling analyses of an aerial survey of the Southern Hudson Bay polar bear subpopulation, September 2011. Models with ΔAIC < 3 are presented. All highly supported distance sampling models include a half-normal key function. In the column Model, covariates are cluster size (Clust), left-truncated distance from the transect (Dist), observer (Obs; front or rear), vegetation height (VegHt), and visibility (Vis). Goodness of fit metrics for the distance sampling detection function also included Komologorov-Smirnov and Cramer-von Mises tests (all $P > 0.75$ for all highly supported models).

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Model:</th>
<th>ΔAIC</th>
<th>Param (Total)</th>
<th>Density: Bears / 1000 km² (95% CI)</th>
<th>GOF: Overall Chi-sq. ($P$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Including coastal sightings</td>
<td>Clust + Obs / VegHt + Vis</td>
<td>0.00</td>
<td>6</td>
<td>35.8 (23.7-54.1) 4.3 (1.5-12.8) 17.3 (11.4-26.2)</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Clust + Obs + VegHt / VegHt + Vis</td>
<td>0.89</td>
<td>7</td>
<td>37.0 (24.1-56.8) 5.6 (1.7-17.9) 18.5 (11.7-29.2)</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Clust + Obs + Vis / VegHt + Vis</td>
<td>1.35</td>
<td>7</td>
<td>35.6 (23.7-53.6) 4.6 (1.5-13.6) 17.3 (11.5-26.2)</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Clust + Obs + Dist / VegHt + Vis</td>
<td>1.85</td>
<td>7</td>
<td>36.6 (24.0-55.9) 4.5 (1.5-13.5) 17.7 (11.6-27.2)</td>
<td>0.08</td>
</tr>
<tr>
<td>Excluding coastal sightings</td>
<td>Obs + Vis / VegHt</td>
<td>0.00</td>
<td>5</td>
<td>25.5 (14.4-45.3) 5.6 (1.9-15.9) 13.6 (7.8-23.8)</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>Obs + Clust / VegHt</td>
<td>2.75</td>
<td>5</td>
<td>22.7 (13.5-38.1) 5.0 (1.7-14.6) 12.2 (7.2-20.4)</td>
<td>0.38</td>
</tr>
</tbody>
</table>

$^{1}$Density estimates refer to density within the region estimated by distance sampling. The dataset excluding coastal sightings does not incorporate those bears in the high-density stratum and global density estimates.

*Coastal Contours and Small Islands*

2011

We included 42 clusters in the double observer analysis with only sightings from offshore islands and the Akimiski Island coastline. The most highly supported model included no covariates and estimated separate detection probabilities for front and rear observers ($p_{\text{front}}$: 0.86, SE = 0.07;
yielding an overall inclusion probability of ~0.95. We included 204 clusters for the analysis with sightings from the entire coastal zone and small offshore islands. The best model in this second analysis also estimated separate detection probabilities for the two teams of observers and included covariates for visibility and bear activity at first sighting (\(\hat{p}_{\text{front}}: 0.80, \ SE = 0.03; \ \hat{p}_{\text{rear}}: 0.67, \ SE = 0.04\)). We applied estimates of detection to 19 (Akimiski Island dataset) and 45 (complete coastal dataset) additional clusters recorded without double observer data. We estimated a total of 64 and 270 clusters with the two datasets. After multiplying by mean cluster sizes (\(\bar{x}_{\text{Akimiski Island}}: 1.56; \ SE = 0.12; \ \bar{x}_{\text{complete}}: 1.65; \ SE = 0.07\)) and inflating variances, we estimated 100 bears (SE = 9.3) on offshore islands and the Akimiski coastline, and a total of 446 bears (SE = 23.0) when the entire coastline was included.

### 2012

We sighted 37 bears on the small islands in James Bay that were comprehensively surveyed without a double observer platform. We sighted 32 clusters while surveying small islands in Hudson Bay. Double observer modeling yielded an estimate of 34 clusters and, after multiplying by mean group size (1.31; SE = 0.64), produced an abundance estimate of 44 bears (SE = 4.5). A single bear was sighted from a coastal contour transect on the Belcher Islands. Since we sampled ~50% of the coastline, we doubled this value and added it to our overall 2012 figure. No bears were observed in Québec or on perpendicular transects. In sum, we estimated 83 bears (SE = 4.5) in the 2012 study area.

#### Total Abundance

The single bear sighted just outside the defined inland extent of the 2011 study area was tallied with the other estimate components, since there was no other means to incorporate it. In 2011, summing the results of the perpendicular transect analysis including the coastal zone with the estimate of bears on small islands and along the Akimiski Island coastline yielded 768 bears (SE = 141.9; 95% lognormal CI = 536–1,100). We obtained an estimate of 967 bears (SE = 151.5; 95% CI = 713–1,312) by adding the estimates from the coastal contour transects, the perpendicular transects excluding the coastal region, and small islands. Model averaging these estimates yielded 868 bears (unconditional SE = 177; 95% CI = 584–1,290) in the mainland Ontario, neighboring islands, and Akimiski Island portions of the SH management unit during the 2011 ice-free season. We added this estimate to our 2012 results and obtained an overall estimate of 951 (SE = 177, 95% CI = 662–1,366) for SH.

#### Reproduction

The aerial survey results suggest that reproductive output in SH was better than in WH in 2011. Mean litter sizes (cubs: 1.56; yearlings: 1.54) and proportions of cubs (0.16) and yearlings (0.12) were higher than those reported during the similarly timed WH aerial survey, and similar to litter sizes reported during the FB aerial surveys in 2009 and 2010 (Table 1). Litter sizes during the 2011 SH aerial survey were also similar to observed litter sizes during recent capture–recapture efforts (2003-2005; cubs: 1.55, yearlings: 1.44; 2007-2009; cubs: 1.65, yearlings: 1.44) (Table 2).
Table 2. Polar bear litter sizes and number of dependent young observed as proportion of all observations during the ice-free season in the Southern Hudson Bay, Western Hudson Bay and Foxe Basin subpopulations.

<table>
<thead>
<tr>
<th>Subpopulation</th>
<th>Litter size</th>
<th>Litter size</th>
<th>Proportion</th>
<th>Proportion</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cub of year</td>
<td>Yearlings</td>
<td>Cub of year</td>
<td>Yearling</td>
<td>Source</td>
</tr>
<tr>
<td>Southern Hudson Bay, aerial survey (2011)</td>
<td>1.56 (0.06)</td>
<td>1.54 (0.08)</td>
<td>0.16</td>
<td>0.12</td>
<td>This report</td>
</tr>
<tr>
<td>Southern Hudson Bay, capture-recapture (2007-09)</td>
<td>1.65</td>
<td>1.41</td>
<td></td>
<td></td>
<td>Obbard, Unpublished data</td>
</tr>
<tr>
<td>Western Hudson Bay, aerial survey (2011)</td>
<td>1.43 (0.08)</td>
<td>1.22 (0.10)</td>
<td>0.07</td>
<td>0.03</td>
<td>Stapleton et al. 2012a</td>
</tr>
<tr>
<td>Foxe Basin, aerial survey (2009-2010)</td>
<td>1.54 (0.04)</td>
<td>1.48 (0.05)</td>
<td>0.13</td>
<td>0.10</td>
<td>Stapleton et al. 2012b</td>
</tr>
</tbody>
</table>

**DISCUSSION**

**Abundance Estimation**

We used multiple sampling and analytical techniques to obtain an aerial survey-based estimate of abundance for the Southern Hudson Bay subpopulation. Our protocols enabled us to generate two partially independent estimates for the 2011 study area. We elected, *a priori*, to incorporate process and model uncertainty in our final estimate of abundance with model averaging. Some variation was expected between the two estimates given inherent errors with sampling and modeling. Although the estimate based nearly exclusively on perpendicular transects yielded a result that was ~20% less than the estimate including coastal contour transects, there was significant overlap of confidence intervals. Model averaging reduced precision, but we believe that the step was important to obtain an estimate that incorporated uncertainty and best reflected true abundance.
We were compelled to conduct the survey over two years due to logistical and resource constraints. However, mainland Ontario and Akimiski Island, where the vast majority of polar bears summer (~90% of our total 2011 - 2012 estimate), were surveyed over a short time (11 days), minimizing the possibility that a large distributional shift affected our results in 2011. Additionally, regional sea ice dynamics were generally consistent between 2011 and 2012 (Canadian Ice Service regional sea ice maps; http://ice-glaces.ec.gc.ca), suggesting that polar bear distribution was unlikely to have shifted within SH between years. Therefore, sampling across portions of two consecutive ice-free seasons likely had a negligible impact on our overall estimate of abundance.

Our study design and field protocols ensured that we met the fundamental assumptions of distance sampling surveys and enabled us to adjust for detection at \( g(0) < 1 \). Similarly, the definition of a narrow strip width and implementation of appropriate survey protocols enabled us to meet most assumptions of closed population (double observer) models. However, we acknowledge that sighting periods were not entirely independent since the sighting periods were almost simultaneous and from similar vantage points. Thus, although we attempted to account for sources of variability with modeling, double-observer estimates may have been susceptible to heterogeneity in detection and underestimated abundance.

We were surprised that our detection at distance zero was significantly less than one. Polar bears are a conspicuous target species, and because our study was conducted on land (i.e., against a darker background), we anticipated that detection would approximate unity (see Stapleton et al. 2012a, b). We speculate that differences between previous aerial surveys in the Hudson Bay region (FB, WH) and SH, particularly the high density of woody vegetation in the inland regions of SH, may have contributed to this result. Although our detection at and near the flight path was ~80% or less, the integration of MRDS protocols and modeling enabled us to adjust for incomplete detection and reduce potential bias in the abundance estimate. However, this finding highlights that perfect detection on the line should not be assumed, regardless of study species or environment; rather, it must be explicitly tested and accommodated by appropriate design and analytical treatment. Other key assumptions met through study design and sampling protocols included (1) random sampling (i.e., allocation of transects) with respect to the distribution of bears; (2) bears sighted at their initial locations before any significant, responsive movements to the approaching aircraft; (3) accurate measurement of bear distances from the flight path (Buckland et al. 2001); and (4) the implicit assumption that the distribution of bears was statistically uniform (Fewster et al. 2008). Stapleton et al. (2012a) presents a thorough review of assumptions and associated design specifications with polar bear aerial surveys.

Delineation of the study area extended 60 km inland and was based on available resources as well as scientific and traditional knowledge. Some pregnant polar bears are known to establish maternity dens beyond this defined inland extent (Kolenosky and Prevett 1983). Indeed, a single adult female was sighted >60 km from the coast while we flew between adjacent inland transects. However, most polar bear maternity dens occur within 40 km of the coast (Obbard and Walton 2004; M.E. Obbard, unpublished data). Therefore, although the delineation was not completely comprehensive and may have resulted in some slight negative bias in the abundance estimate, we believe that bears occurring in SH more than 60 km inland do not comprise a significant proportion of the subpopulation. Additionally, estimated densities in the far inland
stratum were very low (Table 1). Applying the approximate density from this stratum (~5 bears / 1000 km$^2$) to the region 60–70 km inland in Ontario (5080 km$^2$), for example, would result in roughly 25 additional bears, <3% of the total estimate. We further note that the density estimate for the region 20–60 km inland may overestimate densities in regions >60 km inland, because polar bear density declines with greater distances from the coast.

**Trends in Abundance**

The model averaged estimate of abundance from the 2011 aerial survey of mainland Ontario, offshore islands, and Akimiski Island in James Bay (887, 95% CI 602, 1,307) did not differ from the combined capture-recapture estimates from mainland Ontario (2003–2005) and Akimiski Island and the Twin Islands (1997–1998) (681, [95% CI 401, 961] plus 110, [95% CI 75, 195]) (Obbard 2008). Including 2012 survey data from the Belcher Islands, the Québec coastline and other small islands did not significantly change the SH estimate of abundance. Similarly, the 2003–05 capture-recapture estimate for mainland Ontario did not differ from the capture-recapture estimate derived during 1984–1986 (Obbard 2008). The subpopulation may have increased in abundance in the 1960s and 1970s, but the available information from scientific surveys is insufficient to draw firm conclusions.

There is limited documented traditional knowledge on trends in abundance of polar bears in the Southern Hudson Bay subpopulation. McDonald et al. (1997:91) reported that participants in their study stated that polar bears had increased since the 1960s in the Inukjuak and Belcher Islands area, and that Inuit from the Belcher Islands saw few polar bears on the offshore islands of eastern Hudson Bay “40 or 50 years ago” (i.e., in the 1940s and 1950s). Study participants indicated that polar bears had increased in eastern Hudson Bay since the 1930s and more quickly since the 1960s, and suggested that polar bears were relocating to the area in response to an abundance of ringed seals, the extended floe edge, and hunting quotas in effect since the 1970s (McDonald et al. 1997:42).

Combined, the available traditional knowledge and scientific information suggests that although the SH subpopulation may have increased in abundance in the 1960s and 1970s; numbers have not changed since the mid-1980s. However, the implementation of multiple inventory techniques makes the interpretation of long-term trends challenging. For example, negative bias can affect both capture-recapture studies (e.g., via unmodeled capture heterogeneity) and aerial surveys. Nevertheless, significant declines in body condition have been demonstrated (Obbard et al. 2006), such declines continue (Obbard, unpublished data), and declines in survival rates were documented between the 1984–86 and 2003–2005 capture-recapture studies. This suggests a cautious management approach is warranted.

**Reproduction**

The aerial survey results suggest that, in 2011, reproductive performance in SH was better than in the neighbouring Western Hudson Bay subpopulation, and similar to that in Foxe Basin. Although a single year of data is not necessarily indicative of long-term patterns in reproduction and cannot reflect inter-annual variability, the litter sizes and proportions of cubs-of-the-year and yearlings observed in SH were much greater than in WH. Because no data on litter sizes are
available from 2010 for SH, it is difficult to interpret the similar litter size for cubs and yearlings detected during the 2011 aerial survey. One explanation may be that much of the mortality of cubs is due to loss of entire litters.

The Future

Sea ice characteristics and dynamics differ among broad regions of the Arctic, resulting in regional differences in polar bear ecology. In their forecast of future status of polar bears worldwide, Amstrup et al. (2008) recognized four ecoregions based upon differences in historic and projected sea ice conditions. Predicted impacts of climatic warming may occur first for areas near the southern edge of the range in James Bay and Hudson Bay (Stirling and Derocher 1993, Arctic Climate Impact Assessment 2004, Derocher et al. 2004, Stirling and Derocher 2012), which occur in the “Seasonal Ice Ecoregion” (Amstrup et al. 2008). In particular, earlier break-up of sea ice likely reduces opportunities for polar bears to feed and acquire stored reserves needed to sustain them during prolonged fasting during the long ice-free season (Stirling et al. 1999). In recent decades, both the extent (Smith 1998, Parkinson et al. 1999) and duration of the sea-ice cover in Hudson Bay have decreased (Etkin 1991, Stirling et al. 1999, Gough et al. 2004, Gagnon and Gough 2005). For example, from 1980–2009 there is a trend of later date of freeze-up along the Hudson Bay coast of Ontario such that formation of first landfast ice is now 24 days later than in 1980 (Obbard et al. 2013). Consequently, polar bears are spending longer periods ashore—a major ecological problem for bears of SH that is very likely to cause continued declines in body condition and survival rates, and ultimately in abundance.

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**LITERATURE CITED**


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