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Comparison of strip- and line-transect sampling to estimate density and abundance of ringed seals (*Phoca hispida*) in western Hudson Bay, 2007 and 2008

Comparaison de l'échantillonnage en bande et en ligne pour estimer la densité et l'abondance de phoques annelés (*Phoca hispida*) dans l'ouest de la baie d'Hudson en 2007 et 2008

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ABSTRACT

We conducted aerial surveys of ringed seals (*Phoca hispida*) hauled-out on the ice in western Hudson Bay at the end of May 2007 and 2008. A 400m transect width was divided in four intervals of 100m each to allow for comparison of density estimates computed by strip- and line-transect analyses. Ringed seal density estimates varied from 0.97±0.06 seals/km2 in 2007 to 0.49±0.04 in 2008 and were in general agreement with previously reported density estimates. The right and left observers detected a different number of ringed seals and their detection functions differed, likely due to differences in experience. Strip-transect analysis computed negatively biased but equally precise ringed seal density estimates relative to line-transect estimates, and was considered a robust and appropriate sampling method under our survey conditions and protocol. However, because line-transect sampling offers the possibility to control for factors likely to affect the seal detectability, this method is better suited to compare density estimates over years and/or across regions. Thus, we recommend future surveys of ringed seals on ice use line-transect sampling and suggest survey design and data analysis improvements.

RÉSUMÉ

Nous avons effectué des relevés aériens de phoques annelés (*Phoca hispida*) échoués sur la glace dans l'ouest de la baie d'Hudson à la fin des mois de mai 2007 et 2008. Un transect de 400 m a été divisé en quatre intervalles de 100 m chacun pour permettre la comparaison des estimations de densité calculées à partir d'analyses en bande ou en ligne. Les estimations de densité de phoques annelés ont varié de 0,97±0,06 phoques/km^2 en 2007 à 0,49±0,04 en 2008 et concordent généralement avec les estimations de densité déjà publiées pour cette espèce. Les observateurs situés à gauche et à droite de l'avion ont detecté un nombre de phoques annelés différent, et leurs fonctions de détection étaient également différentes, probablement en raison de leur différence d'expérience en matière de relevé aérien. L'analyse en bande des relevés aériens a produit des estimations de densité de phoques annelés négativement biaisées mais de précision similaire par rapport aux estimations obtenues par l'analyse en ligne, et a été jugée comme étant une méthode d'échantillonage robuste et appropriée dans les conditions et pour le protocole de nos relevés aériens. Cependant, du fait que l'analyse en ligne des relevés aériens offre la possibilité de contrôler des facteurs susceptibles d'avoir une incidence sur la détectabilité des phoques, cette méthode convient mieux à la comparaison d'estimations de densité au cours du temps ou provenant de régions différentes. Nous recommandons donc que les futurs relevés aériens de phoques annelés sur la glace soient effectués par échantillonnage en ligne et proposons des moyens d'améliorer le protocole d'échantillonage et l'analyse de données.

INTRODUCTION

Strip- and line-transect analyses have been used extensively to compute estimates of density and abundance of wildlife populations. Strip-transect sampling assumes that all animals present on transect are detected. This assumption is rarely met for wildlife populations and requires narrow strips, compromising the total number of sightings and precision of density estimates (Burnham and Anderson 1984, Burnham *et al.* 1985). Animals could be undetected for several reasons during surveys, including a decrease of the probability of detecting an animal with distance, observers' abilities, physical variables and characteristics of objects of interest (Caughley 1980, Burnham and Anderson 1984). As a result, strip-transect analysis usually generate negatively-biased estimates (Burnham and Anderson 1984). By recording perpendicular distance of an animal from the survey track line, such bias can be reduced. Line-transect sampling uses this method to adjust density estimates according to a decrease detection probability with distance, thereby computing less biased and possibly more precise estimates (Burnham and Anderson 1984, Burnham *et al.* 1985, Hone 1988). In line-transect sampling, the "complete" detection assumption is relaxed and replaced by a set of four assumptions: 1) all animal on the track line are detected; 2) animals are detected in their original position; 3) distances are recorded with no error; and 4) observations are independent (Burnham and Anderson 1984, Buckland *et al.* 2001). Compared to strip-transect sampling, the weaker assumption of total detection of animals on the track line of line-transect sampling allows the transect strip to be large, increasing the sighting sample size and potentially the precision of density estimates. Other factors than distance possibly affecting the detection probability (*e.g.,* glare, type of substrate) can also be included in line-transect analysis to further improve accuracy and precision (Marques and Buckland 2003). However, line-transect analysis may compute density and abundance estimates with less precision than strip-transect analysis since other components than the encounter rate (*e.g.,* detection probability and cluster size) will add to the sampling variance. This compromise between bias and precision should be considered relative to the study objectives, animals of interest, its habitat and the survey design, before choosing to apply strip- or line-transect sampling.

A number of organizations have designated or proposed ringed seals (*Phoca hispida*) as an indicator species for arctic environmental monitoring, including Fisheries and Oceans Canada's Arctic Operational Monitoring Plan, the Arctic Monitoring and Assessment Program, the Marine Mammal Commission, the Arctic Council's Conservation of Arctic Flora and Fauna working group, and the Circumpolar Biodiversity Monitoring Program. The evolutionary adaptations of ringed seals to exploit the sea ice habitat for reproduction and survival could expose this species to critical challenges with predicted global warming, especially in Hudson Bay where ringed seals occur at the southern range of their distribution (Mansfield 1967). Reduced pregnancy rate (Stirling 2005), pup survival (Holst *et al.* 1999, Ferguson *et al.* 2005), and older age structure of ringed seals (Chambellant *et al.* 2004) and reduced body condition, cub survival and abundance of polar bears (*Ursus maritimus*; Stirling *et al.* 1999, Regehr *et al.* 2007) have been reported in the past 25 years for western Hudson Bay. Management concerns are fuelled by a pattern of decreasing ringed seal abundance estimates by strip-transect analysis in western Hudson Bay provided from aerial surveys of basking ringed seals during springs 1995-2000 that estimated population size declines from 100,000 to 45,000 seals (Lunn *et al.* 2000).

In this study, we replicated the strip-transect survey protocol described by Lunn et al. (1997) during two consecutive years while adding the recording of perpendicular distances necessary for line-transect surveys. Our objectives were 1) to obtain new density and abundance estimates for ringed seals in western Hudson Bay, 2) compare strip- and line-transect estimates and recommend the most appropriate sampling method to count ringed seals hauled-out on ice, and 3) provide suggestions for improving the survey design and data analysis.

METHODS

STUDY AREA

The study area located in western Hudson Bay, Canada (Figure 1), encompassed a zone bounded by the communities of Churchill, Manitoba (58°47'N; 94°10'W) in the south and, Arviat, Nunavut (61°6'N; 94°4'W) in the north, the western Hudson Bay coastline to the west, and by the 89°W longitude to the east (lines 7 to 16 of the survey completed by Lunn *et al.* (1997). Hudson Bay is a large and shallow (mean depth 125m) inland sea with a cyclonic water circulation (Prinsenberg 1986). Hudson Bay is ice-covered from November to June when break-up occurs and is completely free of ice in late summer and early autumn months (Markham 1986; Saucier *et al.* 2004). Open-water leads adjacent to the coast are present throughout the ice-covered season, especially in western Hudson Bay (Markham 1986, Stirling 1997). Despite its low-latitude position, the greater Hudson Bay region that includes Foxe Basin, James Bay, and Hudson Strait harbours a year-round sub-arctic marine mammal biota of Atlantic walrus (*Odobenus rosmarus rosmarus*), ringed, bearded (*Erignathus barbatus*) and harbour (*Phoca vitulina)* seals; bowhead whales (*Balaena mysticetus*), narwhals (*Monodon monoceros*) and beluga whales (*Delphinapterus leucas*); and polar bears.

SURVEY DESIGN

The survey was designed as a systematic transect survey following Lunn et al. (1997), with some modifications to allow for line-transect sampling. Ten transect lines were set perpendicular to the shoreline at intervals of 15' of latitude between Churchill, MB and Arviat, NU (Figure 1). Surveys were flown in late spring when ringed seals typically moult and haul out on the ice to bask in the sun (McLaren 1958, Smith 1973a) and are available to be observed and counted from the air. A Cessna 337 "Skymaster" was used to fly at an altitude of 152.4m and a targeted speed of 260km/h. The transect width was 400m on each side of the plane and was divided into four intervals of 100m, labeled 1 (0-100m), 2, 3 and 4 (300-400m) from the inner part to the outer part of the transect. Bubble windows were not available, so a strip underneath the plane (160m on each side) was not accessible to observers. The two observers were seated at the rear of the airplane and were assigned one side of the plane for the whole survey duration. Wing struts and windows were marked on the ground for each observer using the following formula:

$$y = Xa / A$$

where y is the projected transect width on the ground, X is the desired transect width (400m) at 152m of altitude, A is the flying altitude and a is the specific height of observer eye level in the plane from the ground.

Data were recorded continuously on mini-disc recorders for each observer independently. Waypoints and time of start and end of each transect were recorded by a co-pilot using a GPS. Observers surveyed the 400m transect width and recorded sightings by strips (1 to 4). Sightings outside of transect (*i.e.,* at distance >400m) were recorded as "off" data and were not included in the following estimates of density and abundance. Ringed seals hauled-out on the ice were the target species but seal structures (hole and lairs), bearded seals and other marine mammals were also recorded ("on" and "off" transect). Ringed seals in the water were recorded but not accounted for in the analysis due to species identification difficulties and possible different detection probability from seals on ice (Kingsley *et al.* 1985, Lunn *et al.* 1997). Group size of ringed seals was also recorded. Physical variables such as ice cover (in eighths), ice type (land fast, floe size) and colour, percent cloud cover and visibility were recorded at the beginning of each line and when they changed during a transect.

DATA ANALYSIS

Length of each of the ten transect lines was calculated using the starting and ending coordinates by the great circle method. The effective ground speed was then computed by dividing the length of each line by the time elapsed during flight. Line length was reduced to account for missing effort due to technical (*e.g.,* recorder malfunction) and/or null visibility (*e.g.,* fog) problems. The total study area was calculated by multiplying the total effort (sum of line lengths) by the distance between each line (*i.e.,* 27.795 km corresponding to 15' of latitude).

Weather information from airport weather stations in Churchill, MB and Arviat, NU were obtained from Environment Canada:
http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html
Mean wind speed (km/h) and temperature (degree Celsius) were calculated for each flying day during the time transect lines were flown.

Strip-transect analysis

The density of ringed seals/km^2 of ice, $\hat{D}$, was estimated, by year, by observer, and for both observers combined, following the standard ratio method (Buckland *et al.* 2001):

$$\hat{D} = \sum_{i=1}^{k} n_i / \omega \sum_{i=1}^{k} l_i$$

where k is the number of transect lines, n_i is the number of ringed seal counted on the ith transect line, ω is the strip width and l_i is the length of the ith transect line.
The variance of $\hat{D}$, $\sigma^2(\hat{D})$, was obtained following the method described by Buckland et al. (2001):

$$\sigma^2(\hat{D}) = \hat{D}^2 * \frac{L\sum_{i=1}^{k} l_i \left(\frac{n_i}{l_i} - \frac{n}{L}\right)^2}{(k-1) * n^2}$$

where L is the sum of l_i and n is the sum of n_i
Log-based confidence intervals were estimated following Buckland *et al.* (2001). Lower and upper 95% bounds were obtained by:

$$\hat{D}_L = \hat{D} / C \quad \text{and} \quad \hat{D}_U = \hat{D} * C$$

with

$$C = \exp\left\{1.96 * \sqrt{\log_e\left(1 + \left[cv\left(\hat{D}\right)\right]^2\right)}\right\}$$

where $cv\left(\hat{D}\right)$ is the coefficient of variation of the estimated density.

The abundance of ringed seals in the study area ($\hat{N}$) was estimated by multiplying the estimated density ($\hat{D}$) by the study area (A). The standard error of $\hat{N}$ ($se\left(\hat{N}\right)$) was computed as described in Stirling et al. (1982):

$$se\left(\hat{N}\right) = \hat{N} * cv\left(\hat{D}\right)$$

Line-transect analysis

Ringed seals density and abundance were estimated using the software Distance (Thomas *et al.* 2006). Data were grouped in four intervals of 100 m width each. The lower limit of the first interval was considered to be the track line, *i.e.,* the distance 0 m, since a strip underneath the plane was not available to be surveyed. An implicit assumption of line-transect sampling is that all individuals on the line are detected.

Ringed seals haul-out as individuals but also in groups. Groups either haul out near a single hole or along cracks on the ice, preventing each individual of a group to be sighted independently. Since the lack of sighting independence violates an assumption of line-transect sampling, objects of interest in Distance were not individual ringed seals but groups ("cluster") of ringed seals. Groups of ringed seals hauled-out along a crack running perpendicular to the transect line may represent animals distributed over more than one distance interval. Here the total number of seals in the group was divided by the number of intervals recorded for the sighting and each equal portion of the group was then consider as a sub-group and assigned to one of the intervals. Cluster (group) size was estimated in Distance by regressing the natural logarithm of cluster size against the estimated detection function, in order to control for possible size-bias (small-sized groups not detected at greater distances). Ringed seal density was then estimated by multiplying cluster density by cluster size.

Four covariates were tested for their potential effect on the probability of detecting ringed seals: observer, year, cloud cover and type of ice. From percent cloud cover, we designated three categories: sunny (0-30% clouds); mixed (30-70% clouds) and cloudy (70-100% clouds). Type of ice was categorized as either land fast ice or moving ice. To test for covariate effect, a first set of analyses were run through the MCDS (Multiple Covariates Distance Sampling) engine. If significantly affecting the detection function, covariates were then included in the CDS (Conventional Distance Sampling) analysis as strata (post-stratification).

The best model for the detection function was selected among uniform, half-normal and hazard rate functions with cosine, simple polynomial or hermite polynomial adjustments, using the minimum Akaike's Information Criterion (AIC) principle and biological significance.

Comparison between strip- vs. line-transect sampling

As described in Burnham et al. (1985), we calculated the Percent Relative Bias (PRB) of density estimated by strip-transect compare to line-transect analyses, as well as the efficiency to help discriminate the best sampling method to estimate ringed seal density in western Hudson Bay.

$$PRB = 100 * \left(\hat{D}_{ST} - \hat{D}_{LT}\right) / \hat{D}_{LT} \quad \text{and} \quad Efficiency = cv_{ST} / cv_{LT}$$

where $\hat{D}_{ST}$ is the density estimated by strip-transect and $\hat{D}_{LT}$ is the density estimated by line-transect analyses and, cv_{ST} and cv_{LT} their respective coefficient of variations.

RESULTS

The ten aerial survey lines over western Hudson Bay were flown in three days in both years (Table 1). The total study area encompassed 79758.4 km^2 and 76848.05 km^2 of the western side of Hudson Bay in 2007 and 2008, respectively. A total of 2869.5 km of transect lines (effort) were surveyed in 11.7 hours in 2007, and the effort was 2764.8 km flown in 10.8 hours in 2008 (Table 2). The weather was mostly sunny in 2007 whereas the weather was predominantly cloudy, colder and windier in 2008 (Table 1 and 2).

The surveyed area from west to east typically consisted of a narrow band of land fast ice, a major lead, and an area of moving ice composed of ice floes of different sizes, separated by cracks and minor leads. The moving ice largely dominated both in 2007 and 2008 whereas the land fast ice represented only 2-3% of the area surveyed (Table 2). The extent of the major lead varied substantially from line to line, day to day and year to year. The total effort over ice (*i.e.,* land fast and moving ice) represented 2746.4 km in 2007 and 2564.4 km in 2008.

In 2007, 2106 individual ringed seals in 1048 groups were detected on transect (in the 800m strip) by both observers (Table 2). Seal holes were systematically recorded by only one observer (left side) who counted 330 structures with no seals associated. Crashed or melted lairs were recorded on 39 occasions by both observers. Other marine mammals detected included 19 bearded seals, 10 polar bears, and 81 beluga whales. Ninety two (92) polar bear tracks were observed, as well as 15 cases of recent kills by polar bears (*i.e.,* blood patches near seal structures). Ringed seals hauled-out in groups of two or more individuals represented 44% of the sightings and the average group size was $\bar{x}$ =2.04±2.33 (n=1035). Groups of 10 seals or more were rare (1.4%, n=14), with the largest group recorded on transect of 32 ringed seals along a crack perpendicular to the flight path.

In 2008, 970 ringed seals in 572 groups were recorded on transect (Table 2). Seal holes detected by the left observer totaled 708 counts. Twenty nine (29) lairs were counted from the two sides of the plane. bearded seals (11), polar bears (8) and beluga whales (45) were also observed in 2008. A total of 70 polar bear tracks and 14 cases of kills were counted. Ringed seals were spotted as lone individuals 65% of the time and the average group size was statistically lower relative to 2007 ($\bar{x}$ =1.70±1.27, n=572; U=320969.5, p<0.005). Ten ringed seals along a crack represented the largest and only group of ten or more individuals observed in 2008 (0.17%).

STRIP-TRANSECT ANALYSIS

The distribution of the number of individual ringed seals detected by each observer across the four transect intervals indicated that seals were missed at closer distances (0-100m, first interval; Figure 2). Apart from the right observer in 2007, the maximum number of ringed seals was observed at medium distances (100-200m). Overall we observed a 18% decrease in seals observed between the first two intervals (23% for left observer and 14% for right).

Results from strip-transect analyses revealed that within each year, the density and the abundance of ringed seals differed between observers, with the right observer consistently detecting more ringed seals than the left observer (Table 3). In 2007, the right observer detected ringed seals equally well in the four different intervals whereas the left observer detected fewer seals at further distances. In 2008, the opposite occurred.

Density and abundance estimates also showed a strong inter-annual variation, with the number of ringed seals estimated to be hauled-out on the ice, twofold greater in 2007 relative to 2008 (Table 3).

LINE-TRANSECT ANALYSIS

The fact that some ringed seals were not detected in the first interval (Figure 2) violated the major assumption of line-transect sampling, *i.e.,* that all animals on the track line are detected. Consequently we removed the data corresponding to the first interval from our line-transect analyses (left truncation). As a result, we assumed that all ringed seals on the 100m line, now considered the track line, were detected. The number of groups included in the analysis after truncation was 793 (1600 individuals) and 449 (760 seals) in 2007 and 2008, respectively.

When running Distance with the MCDS engine to assess the possible effects of covariates on the detection function, the best fitted model (*i.e.,* with the lowest AIC) was the normal/cosine model with observer as a covariate. We consequently post-stratified our data by observer when running the CDS analysis. Inclusion of other covariates did not provide a more reasonable fit. Considering the inter-annual variation in density estimates (Figure 2 and Table 3), we decided to run the CDS analysis for each year separately.

The model with the lowest AIC was the uniform/cosine both in 2007 and 2008. However, the model best fitted the data of the left observer with one adjustment whereas no adjustment was required to fit the data from the right observer (Figure 3). Density and abundance estimates varied with year and observer, with higher precision in 2007 (Table 4).

The probability of detection (P) was constant at 1 for the right observer (uniform detection function) but varied for the left observer (Table 4). P contributed to the total variance of the left observer for 24.8% and 36.3% in 2007 and 2008, respectively.

The cluster size (CS) estimated by Distance was 2.41±0.10SE (95%CI: 2.22-2.62) and 1.84±0.07SE (95%CI: 1.70-2) for the right observer and 1.54±0.04SE (95%CI: 1.46-1.63) and 1.37±0.05SE (95%CI: 1.28-1.48) for the left observer, in 2007 and 2008, respectively. CS represented 5.7% and 26.2% of the total variance for left and right observers, respectively, in 2007; in 2008, CS contribution was 6.3% and 14.2% for left and right observers, respectively.

Encounter rates (ER) contributed most of the variability, ranging from 69.6% for the left observer to 73.8% for the right observer in 2007 and from 57.4% for the left observer to 85.8% for the right observer in 2008.

COMPARISON of STRIP- *vs.* LINE-TRANSECT ANALYSES

Since we had to left truncate the data to meet the assumptions of line-transect sampling, new density and abundance estimates were computed by strip-transect analysis using the data collected in the three last strips only (100-400m). Results are shown in Table 3. Line-transect density estimates were compared to both truncated and un-truncated strip-transect estimates.

Truncated strip-transect density estimates from the right observer did not show any bias compared to estimates computed by line-transect analyses. However, truncated and un-truncated strip-transect density estimates from the left observer were negatively biased relative to line-transect estimates resulting in a negative bias for density estimates computed for both observers combined (Table 5). The efficiency was close to 1 for both observers and both years (Table 5).

DISCUSSION

Ringed seal density and abundance estimates from this study were not corrected for the percentage of animals not hauled-out on the ice at the time of survey (availability bias). Several studies have attempted to apply a correction factor to abundance estimate using telemetry (Kelly and Quakenbush 1990, Born *et al.* 2002, Bengtson *et al.* 2005, Kelly 2005) or observation data (Smith 1973b, Finley 1979, Smith and Hammill 1981) to account for ringed seals in the water and therefore not available for detection by air. Small sample size and inter-individual, inter-annual, inter-site, day to day and daily variations in the hauled-out activity of ringed seals limited the ability to derive a single correction factor. The number of animals present but not detected by the two observers (detection bias) was not accounted for either, although it could be substantial (Caughley 1980). Therefore, our density and abundance estimates are expected to be underestimated and should be considered indices.

Ringed seal density estimates reported in this study are in general agreement with results from previous studies (Smith 1973a, Smith 1973b, Smith 1975, Finley 1979, Stirling et al. 1982, Finley et al. 1983, Kingsley et al. 1985, Smith 1987, Kingsley 1990, Lunn et al. 1997, Frost et al. 2004). Regardless of the method used, density estimates for ringed seals varied greatly from 2007 to 2008 in western Hudson Bay. Inter-annual variation of the density of ringed seals hauled-out on the ice has been widely reported in the literature (Stirling *et al.* 1982, Kingsley *et al.* 1985, Smith 1987, Hammill and Smith 1990, Lunn *et al.* 2000, Frost *et al.* 2004). Apart from an actual change of seal abundance, several factors could explain such an inter-annual variation. Ice type and conditions, water depth, temperature, wind speed and cloud cover, and time of the day and year could potentially affect ringed seal presence (emigration/immigration), haul-out activity and detectability (Finley 1979, Smith and Hammill 1981, Stirling *et al.* 1982, Kingsley *et al.* 1985, Kelly and Quakenbush 1990, Lunn *et al.* 1997, Frost *et al.* 2004, Bengtson *et al.* 2005, Kelly 2005, Carlens *et al.* 2006).

We found a difference in density estimates between right and left observers for both years. The difference was particularly high in 2007 when density estimates were computed by strip-transect analysis (64%). When density estimates were corrected for detection probability with distance (line-transect analysis), this difference decreased substantially (30%), suggesting the decrease of animal detection with distance accounted for a substantial part of the difference between observers. Differences between observers could be due to individual abilities to detect, identify and count animals, concentration, fatigue, experience and/or error in marking windows/struts (Stirling *et al.* 1982, Burnham and Anderson 1984, Lunn *et al.* 1997). In our study, the same observers flew both surveys and were seated on the same side of the plane. The right observer had considerable experience in terrestrial aerial surveys whereas the left observer had flown only four aerial surveys before 2007. In 2008, the difference in density estimates between both observers was reduced to around 35% for both strip- and line-transect analyses. The effective strip width and the probability of detection computed by Distance for the left observer also increased compared to 2007, suggesting a gain in experience by the left observer.

We compared strip-transect and line-transect sampling for the estimation of density of ringed seals hauled-out on the ice. Truncated and un-truncated strip-transect density and abundance estimates were negatively biased compared to line-transect estimates but precision was not improved by the latter method. These results agree with previous studies, although, in some cases, precision was found to be improved by line-transect analysis (Burnham and Anderson 1984, Burnham *et al.* 1985, Hone 1988, Ogutu *et al.* 2006). The negative bias of density and abundance estimates computed by strip-transect analysis should be interpreted relative to precision and, in our case, line-transect analysis did not seem to provide significant benefits. Despite violation of the assumption that all seals on transect are detected, strip-transect sampling appeared to be a robust method in the context of our survey design and conditions. However, line-transect sampling may be more appropriate for long term studies designed to produce information on population trends. Indeed, comparison over years of density and abundance estimates computed with line-transect analysis will not be obscured by changes in survey conditions and protocol, nor by changes in observer abilities, since these factors, potentially affecting seals detectability, will, or could be, taken into account with the line-transect method.

The results should be interpreted with respect to the limitations of our data. The number of transect lines flown per year during our study (10) was relatively low relative to suggested requirements to obtain reasonable abundance and precision estimates by line-transect analysis (Buckland *et al.* 2001). Replicating the lines or adding more lines to the study area has the potential to improve estimates and precision of density and abundance computed by Distance.

In our study, the main assumption of line-transect sampling that all animals on the line are detected was violated and we had to left truncate the data. Left truncation is not a preferred option as it does not use all available data (reduced sample size), and could lead to a model that does not comply with the shape criterion (Buckland *et al.* 2001). If the detection function drops quickly at close distances it will not present a shoulder (*i.e.,* detection function equal to 1 for some distance away from the track line) and Distance will compute unreliable estimates. Moreover, as the number of intervals decreases, so does the option to fit more robust and parametered models like the hazard-rate function. Designing a survey with numerous intervals, increasing in width with distance, could help alleviate this problem.

The fact that the number of ringed seals detected in the 0-100m interval was lower than the following intervals could be due to several factors: 1) seals close to the aircraft may have been more likely to dive in response to the noise of the aircraft (Stirling *et al.* 1982, Kingsley *et al.* 1985). Born et al. (1999) showed that about 6% of ringed seals hauled-out on the ice in Greenland were escaping in the water as a reaction to a small aircraft flying at 150m. During our surveys, signs (*e.g.,* moving water in hole) of seals that dove before being detected were observed on several occasions and seals diving while being counted were not unusual. This problem could be addressed by using bubble windows, a second observer in the front seat, and/or a camera underneath the plane; 2) ringed seals at close distances are more briefly in sight than at greater distance and are prone to be missed (Stirling *et al.* 1982, Kingsley *et al.* 1985); 3) it is usually more natural and easier for observers to look outward than downward (Stirling *et al.* 1977, Kingsley *et al.* 1985, Buckland *et al.* 2001). Improving the survey design (see above) could potentially solve these problems, as well as allocating a higher proportion of time searching at short distances (*i.e.,* observer training).

Analyses performed with Distance for the present study were relatively simple and have the potential to be improved with additional analyses that include model averaging, pooled detection function, and cluster size used as covariates. Using data from a second observer or a camera would allow to account for the detection bias by combining line-transect and mark-recapture analyses.

In conclusion, this study provided new density and abundance estimates for ringed seals in western Hudson Bay. We revealed that, under our survey conditions and design, strip-transect sampling was appropriate. However, line-transect analysis computed density estimates less biased and equally precise than strip-transect estimates. Therefore, we recommend that line-transect sampling, with improved protocol and data analysis, be applied for future surveys intending to compare density estimates over years.

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Table 1. Flying date and time and, average weather conditions at the time of survey for 2007 and 2008 aerial surveys of ringed seals in western Hudson Bay.

Date	Line flown	Start time	End time	Wind speed km/h		Temperature °C	
				Churchill	Arviat	Churchill	Arviat
26-May-07	12, 13, 15, 16	12:37:50	19:46:31	24.3	21.8	18.4	3.1
27-May-07	7, 8	11:11:05	13:47:05	21.0	8.8	16.3	0.4
29-May-07	9, 10, 11, 14	12:04:27	19:16:40	19.4	21.6	1.5	0.3
28-May-08	7, 8, 9, 10, 11	10:22:30	20:16:13	23.7	36.5	4.4	2.8
29-May-08	15, 16	13:35:03	16:42:17	18.6	15.0	8.9	1.1
31-May-08	12, 13, 14	10:17:45	15:43:55	18.1	43.9	10.4	3.1

Table 2. Summary of line characteristics, sky condition, percent ice types, and number of ringed seal groups and individuals detected by two observers in 4 and 3 strip intervals (bins) during two aerial surveys in May 2007 and 2008 over western Hudson Bay. LFI: land fast ice; MI: moving ice; see text for sky condition groupings.

	Line length km	Time hr	Ground speed km/h	% Ice type surveyed			Sky condition	Right observer all bins		Left observer all bins		Right observer bins 2-4		Left observer bins 2-4	
				LFI	lead	MI		groups	Individ.	groups	Individ.	groups	Individ.	groups	Individ.
2007															
7	226.82	1.11	204.85	2.33	3.51	94.12	Mixed	44	133	47	77	35	97	34	59
8	262.15	1.01	259.78	n/a	n/a	98.63	Sunny	57	116	56	112	50	81	30	100
9	329.43	1.26	260.81	2.15	4.01	93.83	Sunny	46	95	57	82	53	71	35	55
10	326.13	1.25	260.44	1.41	1.46	97.03	Sunny	68	233	38	76	40	159	20	52
11	302.05	1.16	260.59	0.66	1.24	98.14	Sunny	35	90	65	121	50	74	70	87
12	322.76	1.25	258.42	1.31	1.60	97.12	Sunny	63	163	87	135	28	137	48	106
13	239.79	1.08	221.28	3.41	2.28	94.25	Sunny	49	117	22	29	48	95	28	26
14	311.13	1.19	261.10	2.52	2.94	94.54	Sunny	71	149	46	64	33	111	39	51
15	269.93	1.32	204.58	2.21	9.07	88.64	Sunny	72	129	42	52	41	91	45	37
16	279.33	1.08	258.76	2.47	17.60	80.07	Sunny	43	83	40	50	30	67	36	44
2008															
7	242.19	0.87	279.63	4.29	0	94.79	Mixed	38	81	30	40	18	58	11	28
8	202.89	0.90	224.52	6.12	2.12	91.76	Cloudy	19	40	31	70	34	30	25	55
9	251.41	0.91	276.44	1.96	0.82	96.05	Cloudy	27	50	14	18	18	47	28	13
10	301.91	1.36	221.76	1.22	1.62	96.17	Cloudy	25	43	33	49	31	38	14	40
11	324.93	1.22	266.38	2.46	0.59	96.98	Cloudy	45	67	25	52	17	55	21	48
12	323.75	1.07	303.89	1.83	4.96	93.21	Mixed	26	51	41	71	37	34	22	33
13	315.25	1.04	303.22	2.28	6.62	90.70	Sunny	35	74	17	23	22	63	27	20
14	310.97	1.52	204.18	3.39	13.92	82.37	Sunny	24	39	31	38	24	28	10	35
15	212.54	0.81	260.89	n/a	n/a	99.88	Mixed	43	78	33	39	15	64	25	30
16	278.98	1.13	246.05	3.18	38.37	58.43	Cloudy	22	33	13	14	26	29	24	12

Table 3. Ringed seal density (seals/km^2 of ice) and abundance and associated variability estimated by a) un-truncated (0-400) and b) truncated (100-400m) strip-transect analysis from data collected by two observers during two aerial surveys of ringed seals on ice in western Hudson Bay. Estimated parameter ± SE (standard error). 95%CI: log-based confidence interval at 95% level of significance; %CV: percent coefficient of variation.

a)

	Density	95%CI	Abundance	95%CI	%CV
2007					
Right observer	1.1906±0.1092	0.9951-1.4246	90890±8336	75964-108748	9.2
Left observer	0.7264±0.0839	0.5798-0.9101	55451±6401	42257-69477	11.5
Both observers	***0.9585±0.0623***	***0.8439-1.0887***	***73170±4758***	***64423-83105***	***6.5***
2008					
Right observer	0.5420±0.0581	0.4397-0.6682	38635±4138	31339-47630	10.7
Left observer	0.4036±0.0617	0.2996-0.5437	28768±4400	21354-38756	15.3
Both observers	***0.4728±0.0412***	***0.3987-0.5607***	***33701±2938***	***28418-39968***	***8.7***

b)

	Density	95%CI	Abundance	95%CI	%CV
2007					
Right observer	1.1931±0.0967	1.0181-1.3981	91075±7382	77717-106729	8.1
Left observer	0.7489±0.0940	0.5861-0.9568	57165±7176	44740-73040	12.6
Both observers	***0.9710±0.0630***	***0.8552-1.1024***	***74120±4806***	***65283-84154***	***6.5***
2008					
Right observer	0.5797±0.0631	0.4687-0.7171	41322±4498	33404-51116	10.9
Left observer	0.4082±0.0611	0.3048-0.5466	29092±4358	21725-38957	15.0
Both observers	***0.4939±0.0405***	***0.4208-0.5799***	***35207±2885***	***29991-41331***	***8.2***

Table 4. Ringed seal density and abundance and associated variability estimated by line-transect analysis in Distance from data collected by two observers during two aerial surveys of ringed seals hauled-out on ice in western Hudson Bay. Estimates ± SE; 95%CI: log-based confidence interval at 95% level of significance, 95%CI are in bracket for ESW and P; ESW: effective strip width in meters; P: detection probability; %CV: percent coefficient of variation.

	ESW	P	%CV	Density	95%CI	Abundance	95%CI	%CV
2007								
Right observer	300	1	0	1.1931±0.0971	1.0048-1.4166	91075±7408.5	76702-108140	8.1
Left observer	235 (210-263)	0.78 (0.70-0.88)	5.8	0.9194±0.1064	0.7218-1.1710	70182±8125.5	55100-89391	11.6
Both observers				**1.0562**	**0.9198-1.2128**	**80628**	**70216-92585**	**6.8**
2008								
Right observer	300	1	0	0.5377±0.0642	0.4144-0.6978	41322±4933.1	31842-53624	11.9
Left observer	259 (218-308)	0.86 (0.73-1)	8.8	0.4281±0.0626	0.3177-0.5770	30512±4459.2	22642-41120	14.6
Both observers				**0.5039**	**0.4222-0.6015**	**35917**	**30091-42871**	**8.7**

Table 5. Percent relative bias (PRB) and efficiency of truncated (100-400m) and un-truncated (0-400m) strip-transect compared to line-transect sampling of ringed seal counts by two observers from two aerial surveys over western Hudson Bay, 2007 and 2008.

	2007				2008			
	Truncated		Un-truncated		Truncated		Un-truncated	
	PRB	Efficiency	PRB	Efficiency	PRB	Efficiency	PRB	Efficiency
Right observer	0.00	1.00	-0.21	1.13	0.00	1.02	-6.50	1.00
Left observer	-18.55	1.08	-20.99	1.00	-4.66	1.03	-5.72	1.05
Both observers	***-8.07***	***0.95***	***-9.25***	***0.95***	***-1.98***	***0.94***	***-6.17***	***1.00***

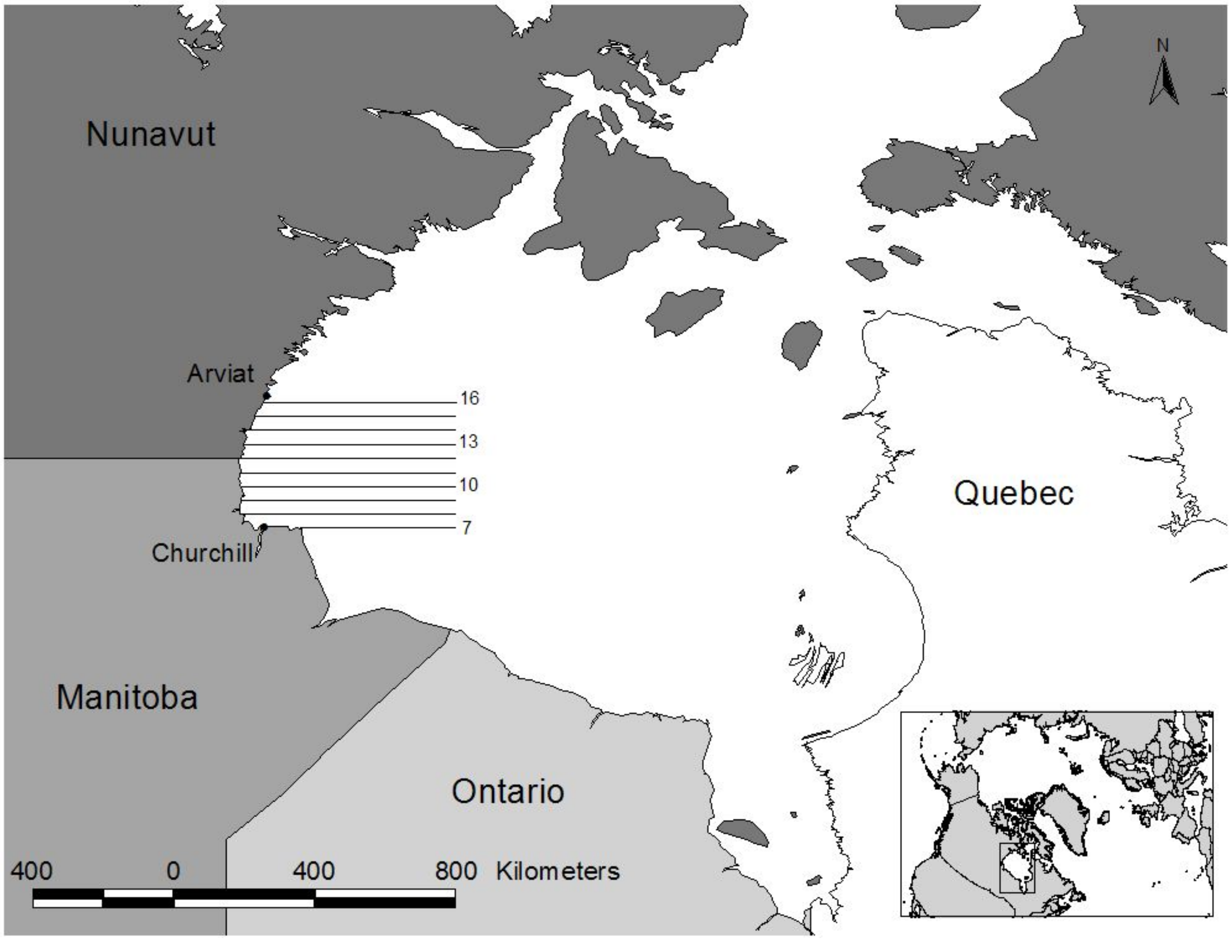

Figure 1. Study area and transect lines flown during aerial surveys in western Hudson Bay, in May 2007 and 2008. Line numbers (7 to 16) refer to survey protocol described in Lunn *et al.* (1997).

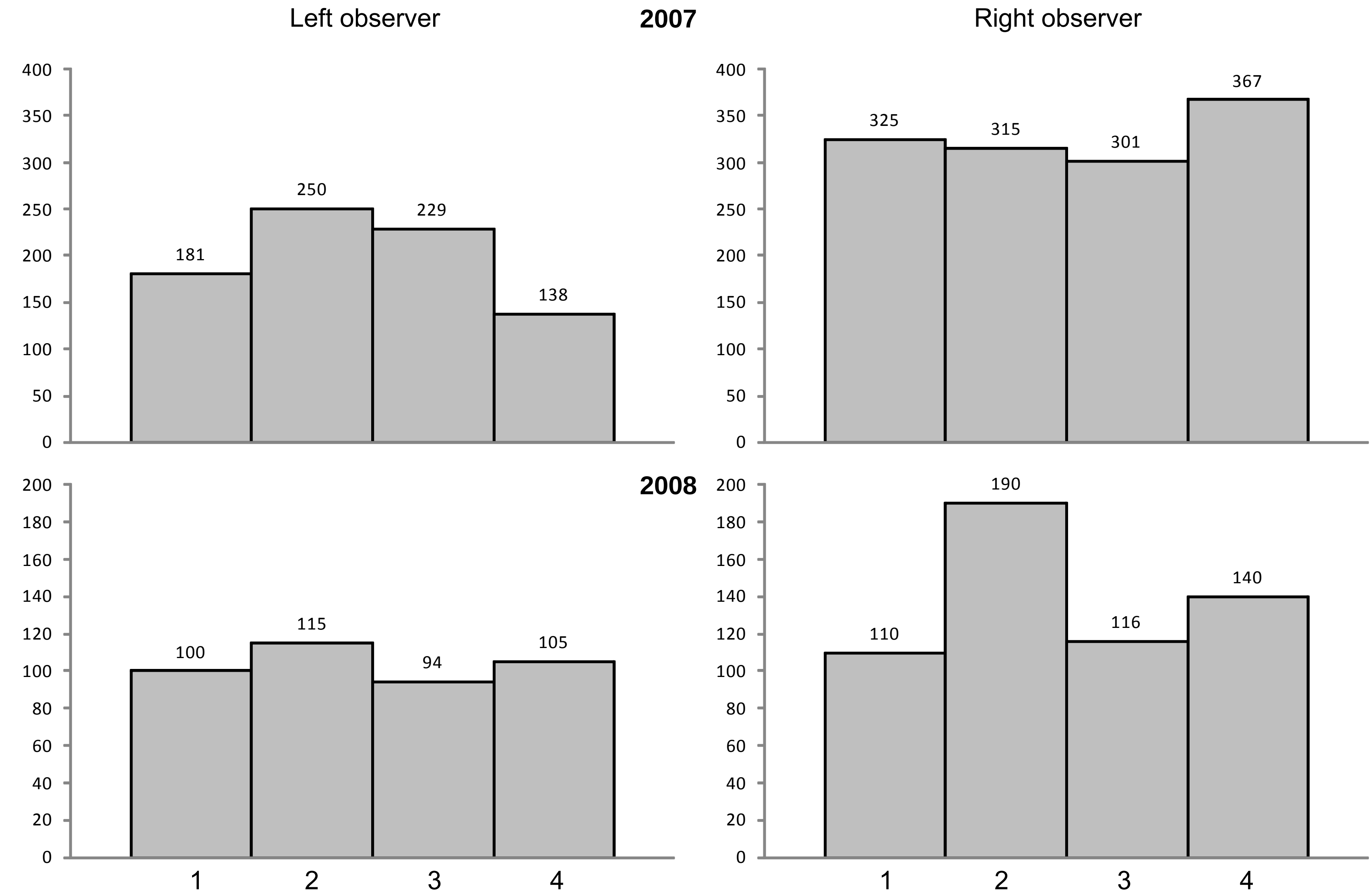

Figure 2. Distribution of individual ringed seals hauled-out on ice detected by two observers from ten survey lines flown in May 2007 and 2008 in western Hudson Bay. The 400m transect was divided into four intervals, labelled 1 (0-100m), 2, 3, and 4 (300-400m).

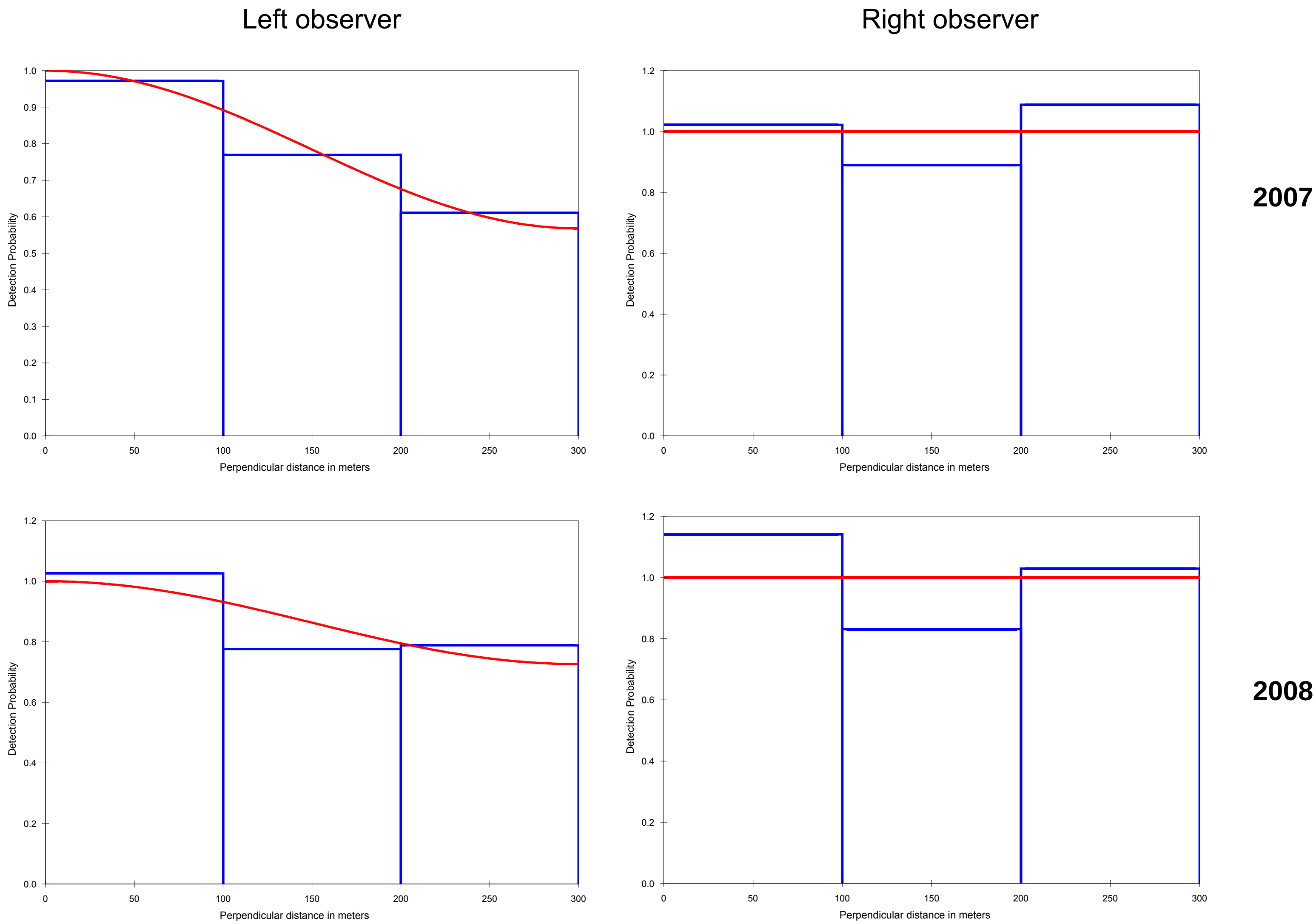

Figure 3. Distribution of ringed seal groups (bars) and detection probability modelled by the uniform/cosine function (line) by the software Distance from two aerial surveys and for two independent observers in western Hudson Bay. Data were left-truncated to remove the first 100m interval.