Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S / **S C C S**

Canadian Science Advisory Secretariat / **Secrétariat canadien de consultation scientifique**

Research Document 2005/011

Document de recherche 2005/011

Not to be cited without permission of the authors *

Ne pas citer sans autorisation des auteurs *

Abundance indices of belugas in James Bay and eastern Hudson Bay in summer 2004

Indices d'abondance des bélugas dans la baie James et l'est de la baie d'Hudson à l'été 2004

Jean-François Gosselin

Fisheries and Oceans Canada
Maurice Lamontagne Institute
P.O. Box 1000, 850 Route de la Mer
Mont-Joli, Quebec
G5H 3Z4

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Research documents are produced in the official language in which they are provided to the Secretariat.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at:

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

Belugas harvested around Nunavik (Northern Quebec) come from different summer stocks, including the endangered Ungava Bay and eastern Hudson Bay stocks. Systematic aerial line-transect surveys were conducted in James Bay and eastern Hudson Bay from 7 August to 1 September 2004. From perpendicular truncation distances of 100 m to 1400 m from the trackline, 250 and 104 groups of belugas were detected over 5288 km and 7987 km of lines flown in James Bay and eastern Hudson Bay respectively. The hazard-rate model was used to estimate effective strip widths of 817 m (CV = 8.9%) in James Bay and 622 m (CV = 11.2%) in eastern Hudson Bay. The weighted average of the expected cluster size at maximum detection from observations with perpendicular distances and the average of clusters with no perpendicular measurement was used to provide the expected cluster size of 1.8 (CV = 18.0%) in James Bay. An average cluster size of 2.1 (CV = 12.0%) was used to estimate density and abundance in eastern Hudson Bay. Five belugas detected in the Moose River were added to the estimated number of animals at the surface in the systematic survey to provide an abundance index of 3998 (95% CI: 2379 - 6721) in James Bay. Five belugas in the Nastapoka estuary considered to have been missed during the systematic survey were added to estimated number at the surface in the offshore area to provide an index of 2045 (95% CI: 1052 - 3982) in eastern Hudson Bay. The 2004 abundance index in eastern Hudson Bay is 44% higher than in 2001, corresponding to a 12% annual increase, which is much higher that normally accepted for beluga populations. The variation between survey estimates illustrates the difficulty of estimating the abundance of small clumped populations. As well, environmental conditions (ice extent and Beaufort conditions) might have influenced the number of belugas in eastern Hudson Bay, and changes in survey protocol (reduction of altitude, delays, different observer teams) might have affected the sampling efficiency between years. Combined with evidence of whale movement between regions, the population estimation of the 2004 survey and its large uncertainty should be considered with caution when used for management purposes.

RÉSUMÉ

Les bélugas chassés au Nunavik (Nouveau-Québec) proviennent de différents stocks estivaux, incluant les stocks de la baie d'Ungava et de l'est de la baie d'Hudson qui sont en voie de disparition. Des relevés aériens systématiques par échantillonnage en ligne ont été complétés dans la baie James et l'est de la baie d'Hudson du 7 août au 1er septembre 2004. Entre les limites de distance perpendiculaire de 100 à 1400 m de la ligne de transect, 250 et 104 groupes de bélugas ont été détectés sur 5288 km et 7987 km de lignes survolés respectivement dans la baie James et l'est de la baie d'Hudson. Le modèle "hazard-rate" fut utilisé pour estimer des largeurs de bandes efficacement échantillonnées de 817 m (CV = 8.9%) dans la baie James et 622 m (CV = 11.2%) dans l'est de la baie d'Hudson. La moyenne pondérée de la taille de groupe attendue au maximum de détection à partir des observations avec des mesures de distances perpendiculaires et la moyenne des groupes sans mesure perpendiculaire, a été utilisé pour obtenir la taille de groupe attendue de 1.8 (CV = 18.0%) dans la Baie James. Une taille de groupe moyenne de 2.1 (CV = 12.0%) a été utilisée pour estimer la densité et l'abondance dans l'est de la Baie d'Hudson. Cinq bélugas détectés dans la rivière Moose ont été additionnés à l'estimation du nombre d'animaux à la surface lors du survol systématique pour obtenir un indice d'abondance de 3998 (95% CI: 2379 - 6721) dans la Baie James. Cinq bélugas dans l'estuaire de la Nastapoka que nous considérons avoir manqués durant le relevé systématique, ont été ajoutés pour produire un indice d'abondance de 2045 (95% CI: 1052 - 3982) dans l'est de la Baie d'Hudson. L'indice d'abondance de 2004 dans l'est de la Baie d'Hudson est 44% plus élevé qu'en 2001, correspondant à un taux de croissance annuel de 12%, ce qui est beaucoup plus élevé que normalement accepté pour les populations de bélugas. La variation des estimés provenant des relevés est une illustration des difficultés associées à l'estimation de l'abondance de petites populations à distribution contagieuse. Il est également possible que d'autres facteurs comme les conditions environnementales (étendue de la glace et les conditions de Beaufort) puissent avoir influencé le nombre de bélugas dans la baie d'Hudson, et que les changements dans le protocole de relevé (réduction de l'altitude, délais, équipes d'observateurs différentes) puissent aussi avoir entraîné des variations de l'efficacité de l'échantillonnage entre les années. Combinés à l'évidence du mouvement des baleines entre les régions, l'estimation de la population du relevé de 2004 et sa large incertitude doivent être traitées avec précaution pour des fins de gestion.

INTRODUCTION

Nearshore aerial surveys flown along the Hudson Bay coast of Quebec in 1978 and 1980 indicated that beluga numbers may have been as low as 160-250 animals, much reduced from the 6,000-7,000 or more animals thought to have occupied the area prior to the high commercial harvests in the area during the 1800's (Breton-Provencher 1980; Finley *et al.* 1982; Reeves and Mitchell 1987). In Ungava Bay, summer coastal surveys suggested even lower numbers of around 50 animals concentrated around the Mucalic River (Finley *et al.* 1982). During the same period, aerial surveys flown in Hudson Strait estimated that as many as 9,000 animals overwintered in this area but dispersed elsewhere during the summer months (Finley *et al.* 1982). These results lead to the hypothesis that beluga from the west coast and east coast of Hudson Bay overwintered in the Hudson Strait area, returning to their respective coasts during the summer months. The possibility of low numbers of beluga in eastern Hudson Bay and Ungava Bay lead to the Department of Fisheries and Oceans to carry out systematic strip transect aerial surveys of James Bay, eastern Hudson Bay and Ungava Bay during the summer of 1985. The surveys consisting of east-west transects running offshore from the coast, estimated beluga abundance of 1,213 (95% CI: 740-1,970) and 968 (95% CI: 650-1,430) whales in James Bay and eastern Hudson Bay respectively (Smith and Hammill 1986). No whales were detected on transects flown in Ungava Bay. Subsequent surveys flown along the Ontario, Manitoba and Northwest Territories coasts of Hudson Bay identified another 27,000 animals (Richard *et al.* 1990).

The presence of summer aggregations along the eastern Hudson Bay coast, and in Ungava Bay, lead to the hypothesis that these animals formed separate stocks, and in the late 1980's eastern Hudson Bay and Ungava Bay beluga stocks were listed as 'threatened' and 'endangered' respectively and both stocks are now listed as 'endangered' since May 2004 (Reeves and Mitchell 1989, Smith 2004). Skin samples collected as part of a hunter sampling program throughout Hudson Bay for genetic analyses indicated that eastern Hudson Bay and western Hudson Bay beluga formed two identifiable populations (Brennin *et al.* 1997; Brown Gladden *et al.* 1997; de March and Maiers 2001). Insufficient material has been obtained from beluga in James and Ungava Bay to determine their relationships to eastern and western Hudson Bay animals.

The hunting of beluga whales is an important traditional activity for northern Canadian Inuit as a means of obtaining food, as a traditional activity helping to define their culture and as a recreational activity (Kingsley 2000). The low population estimates obtained from the 1985 aerial survey lead to the development of a management plan to limit harvesting in order to protect the stock. Aerial surveys flown in 1993 and 2001 provided abundance estimates of 3,141 (SE=787) and 7,901 (SE=1744) belugas in James Bay, and of 1,032 (SE=421) and 1,194 (SE=507) beluga in eastern Hudson Bay respectively. As in 1985, no whales were observed on transect in both Ungava Bay surveys. Results from the three surveys were taken into account for the establishment and amendment of management plans since 1996 to limit beluga harvesting in northern Quebec. The plans attempted to limit harvesting in eastern Hudson Bay and Ungava Bay, but allowed for increased harvesting in Hudson Strait was signed in April 2001. The plans were put in place, with the proviso that harvests are to be re-examined if new information become available.

Although the 1993 and 2001 surveys followed the same transect lines as the 1985 survey, the data were collected and analysed as strip transect survey during the first survey and as line transect surveys in the latter two surveys. These two methods are based on different assumptions. Strip transect methods assume that all animals within a determined strip width are detected and recorded. Animals observed outside of the strip width are not recorded. Density of animals can be estimated as the number of animal detected within the strip divided by the area surveyed (strip width, adding both sides of plane, multiplied by total length of lines). Abundance within a defined zone is estimated by multiplying the density times the total area of the study region divided by the area covered by the transect lines. During a line transect survey, the perpendicular distance from the aircraft of all animals seen along the flight track is recorded. It is assumed that all animals near the plane are detected, but that detectability decreases with distance from the plane. This decrease in detectability is modeled by fitting a function to the distribution of perpendicular distances from the trackline. The integration of this function then serves to estimate an effective strip width, from which we estimate the area effectively surveyed. Density is estimated by the number of animals detected divided by the area effectively surveyed. Abundance is then estimated similarly as for strip transect.

During the summer of 2004, the aerial surveys of James Bay, and eastern Hudson Bay were repeated, as part of a larger inter-regional project to evaluate beluga abundance in the Hudson Bay-James Bay complex. During these surveys, the same lines followed in 1985, 1993 and 2001 were re-flown. Ungava Bay was not surveyed in 2004 because all surveys flown since 1985 in this area (N=5) have failed to detect whales on transect, indicating that the population is likely below 200 animals (not corrected for diving) (Hammill et al. 2004). Here, we present results from the 2004 EHB and James Bay surveys.

MATERIAL AND METHODS

Study area

The survey area in 2004 covered the entire James Bay and the south east side on eastern Hudson Bay (EHB, sometimes referred to as the eastern Hudson Bay arc). The western side and south portion of James Bay are shallow with turbid water along the coast while the north east side and the eastern Hudson Bay coasts are characterized by more rocky shores with several small islands and reefs. Similarly to what was done in previous systematic surveys since 1985, the whole area was generally covered from south to north by east-west lines every 10 minutes of latitude in James Bay and northern stratum of eastern Hudson Bay (Figure 1). Stratification is based on the distribution of animals observed in previous surveys, on satellite tracking of animals tagged in eastern Hudson Bay in summer and on genetics samples. The division between James Bay and eastern Hudson Bay is set half way between Kuujjuaraapik and Long Island (*i.e.* line 5510). This zone has shown no belugas in the 4 surveys, so represent a gap between the higher densities observed in James Bay and the center of eastern Hudson Bay arc. Only one of 33 belugas equipped with satellite transmitter in eastern Hudson Bay moved as far south as line 5510 in August and only one different animal moved as far as Long Island in September (Hammill, unpublished data). Although based on a limited number of samples, the proportion of eastern Hudson Bay is higher in Great Whale River (*i.e.* Kuujjuaraapik: 10/13 samples) than in the Long Island area (2/9 samples, Postma unpublished data). The eastern Hudson Bay arc was further stratified into a high and a low coverage strata covering respectively high and low density regions of the arc. The high coverage stratum with latitudes centered on the Nastapoka and Little Whale river estuaries had line spacing of 5 minutes of latitude, and the low coverage stratum divided into two areas to the north and south of the central stratum had line spacing of 10 minutes of latitude. Transect lines length above water used to estimate density and the area of strata used to estimate abundance were both measured on a universal transverse mercator projection (UTM zone 17, centered 81° W) using GIS (Arcview 3.2). The areas of James Bay, eastern Hudson Bay high and low coverage strata were estimated to be 78,234 km^2, 64,087 km^2 and 27,223 km^2 respectively.

Systematic line transect survey

The survey was conducted from 7 August to 1 September 2004 with 2 fixed high winged aircraft (Cessna 337, Skymaster) with bubble windows flying at a target altitude of 304.8 m (1000') and an airspeed of 185.2 km/h (100 kt). Position and altitude were continuously recorded by D-GPS output into a laptop with mapping software (2 or 10 seconds intervals; Prairies Geomatics D-GPS coupled with Garmin GPS76; OziExplorer and Fugawi mapping softwares). Position and time at the start and the end of transects were also recorded on audio tapes to mark the GPS files and to serve as back-up.

Three different teams of observers were used to complete the survey. Two observers sat in the back seat of each plane recorded meteorological conditions and beluga sightings. Training of observers prior to the survey was done on the ground. Each observer was provided with measuring and recording instruments and 1 or 2 training flights were flown in areas with belugas to familiarise observers with detecting whales and the experimental protocol. A short list of variables to record was glued to the side of the window to reduce missing data, increase efficiency of data recording and therefore optimize observation. For each group of beluga, estimated group size, the angle below the horizontal measured using an inclinometer (Suunto, PM 5/360 PC) when animals were passing abeam, and time synchronised with the D-GPS were recorded on micro-cassettes. All information was entered at night or the following days. Position and altitude of recorded observations were estimated using time and interpolation from adjacent D-GPS outputs.

Flights were only initiated when sea conditions were Beaufort 3 or less. Sea condition (Beaufort), intensity of reflection (absent, low, medium or high) and cloud cover (in eighths) were recorded at the beginning and the end of each transect and at regular intervals of 10-15 minutes and when noticeable visibility changes were detected.

Coastal survey

Coastal surveys have been done during previous surveys (1985, 1993 and 2001) to count animals remaining in estuaries that would not have been available to the offshore systematic survey, but the coastal effort was not as extensive in 2004. However, the coast was surveyed while in transit from airport to transect lines and the coast north and south of the Nastapoka, the Little Whale river estuaries and the Richmond Gulf were covered on the same day the lines in front of these estuaries were systematically surveyed.

Data analysis

Abundance was estimated using line-transect method using the software Distance (Buckland et al. 2001, Hammill et al. 2004, Thomas et al. 2003).

While collecting data in areas where large numbers of whales were observed, priority was given first to the number of animals in the group and then the perpendicular distance, which resulted in some observations lacking distance measurements. The detection function was estimated using all observations with distance. The assessment of size bias with distance was done with observations with both distance and group size. As missing distance recordings only occurred in high density areas, we assumed that all groups detected were within the truncation distances, and therefore all sightings were added for estimation of encountering rate (*n/L*), density ($\hat{D}$) and abundance ($\hat{N}$) in each stratum.

The first step in estimating density and abundance is to estimate what portion of the area was effectively surveyed. Perpendicular distances were estimated using the angle under the horizon measured using the inclinometer and formulae in Lerczak and Hobbs (1998). The overall distribution of perpendicular distances was examined for left-truncation of observations between the trackline and maximum detection and for right truncation of distant outliers and preliminary detection probability of 15 % (i.e. $g(x)$ = 0.15), and only the truncated dataset was used for further analyses. The effective strip width (*ESW*) was estimated as the integration of the detection function fitted on the ungrouped perpendicular distances (x) from the right truncation distance to the left truncation distance. The detection function model between uniform, half-normal and hazard-rate was selected according to the minimum Akaike's Information Criteria (AIC). Post-stratification of the detection model was done when the sum of AIC values of stratified models was lower than the AIC value for the detection model of data pooled across strata.

Estimated group size at maximum detectability, $\hat{E}(s)$ (*i.e.* in area not believed to be affected by distance and therefore not biased) was estimated for each geographical stratum using the size bias regression method (ln of cluster size (s_i) against the detection function value [$g(x)$] ($p < 0.15$)), or using mean cluster size when the regression was not significant. In high density areas, group size was recorded in priority. As a result, some observations lacked a measure of distance. Assuming that the groups without distance in high density areas were within truncation distances, the weighted average of the mean group size of these observations without measured distance and the estimated group size at maximum detectability of observations with distance was used as the estimated group size for the stratum. If the size bias regression method showed no significance, the average group size was used.

The estimated index of density ($\hat{D}$) and abundance ($\hat{N}$) of belugas at the surface during systematic survey of each stratum are estimated in Distance using the following formulae:

$$\hat{D} = \frac{n \cdot \hat{E}(s)}{2L \cdot ESW} \quad (1)$$

$$\hat{N} = \hat{D} \cdot A \quad (2)$$

where n is the number of groups detected, $\hat{E}(s)$ is the expected cluster size in the stratum, L is the sum of lengths of all transects in the stratum and A is the area of the stratum. The associated variance of density and abundance of animals at the surface during systematic survey is estimated by:

$$\mathrm{var}(\hat{D}) = \hat{D}^2 \cdot \left[\frac{\mathrm{var}(n)}{n^2} + \frac{\mathrm{var}(ESW)}{[ESW]^2} + \frac{\mathrm{var}(\hat{E}(s))}{[\hat{E}(s)]^2} \right] \quad (3)$$

The distribution of density is positively skewed, and assuming it is log-normally distributed the 95% CI was estimated using:

$$\left(\hat{D}/C, \hat{D} \cdot C\right) \quad (4)$$

where

$$C = \exp\left[t_{df}(\alpha) \cdot \sqrt{\mathrm{var}(\ln \hat{D})} \right], \quad (5)$$

$$\mathrm{var}(\ln \hat{D}) = \ln\left[1 + \frac{\mathrm{var}(\hat{D})}{\hat{D}^2} \right] \quad (6)$$

and where $t_{df}(\alpha)$ is the critical value of Student's t-distribution at α= 0.05. To consider the few degrees of freedom of some component of variance, the degrees of freedom were computed according to the Satterthwaite (1946) method adapted by Buckland et al (2001):

$$df = \frac{\left[\sum_q [cv_q]^2\right]^2}{\sum_q [cv_q]^4 / df_q} \quad (7)$$

where the coefficient of variation and degrees of freedom are estimated for each of the q components of the estimation of density, which are: n, ESW and $\hat{E}(s)$.

RESULTS

The 2004 survey followed the general plan of flying lines from the south of James Bay and then moved north to the northernmost line of eastern Hudson, although local weather conditions did affect the order in which lines were surveyed and imposed important delays between adjacent lines. Fog was the major limiting factor for survey, and seemed to have been associated with the presence of ice from the northwest part of James Bay to southwest of Belchers islands.

The James Bay stratum was covered on 5 days from the 7 August to 1 September (Figure 1). The 18 southernmost lines (5120 to 5400) were covered on 7 and 8 August. These 18 lines in 2 consecutive days of surveys covered the most important concentrations of belugas detected in James Bay in 2004 (Figure 2). After a 7 day delay, the eastern half of 4 lines (5410, 5430, 5450 and 5510) were done on the 15 August and one half line (5500) on the 18 August. Another delay of 6 days occurred before these half lines and the remaining 2 lines of the stratum were covered on 24 August. Six lines in the southern portion of James Bay (5200, 5210, 5230-5300), first covered on the 7 August, were repeated a second time on 1 September. The number of belugas (43 animals in 33 groups) detected on this latter flight was lower than the number detected on 7 August (186 animals in 103 groups).

The Hudson Bay was surveyed on 5 days from 12 to 30 August (Figure 1). The first 2 lines (5540 and 5530) were covered on 12 August and another 7 lines (5510, 5520, 5550, 5600, 5610, 5535 and 5545) 3 days later on 15 August. There was a 9 day delay before 5 lines (5555, 5605, 5615-5625) could be surveyed on the 24 August and another 5 day delay before the remaining 20 northernmost lines in Hudson Bay could be completed on the 29 and 30 August. The 9 day delay after the 15 August, occurred in the area of highest concentration of belugas detected in eastern Hudson Bay (Figure 2).

Wind conditions were more limiting during flights in eastern Hudson Bay than in James Bay. Average Beaufort values weighted by time per stratum were 1.9 for James Bay, 2.7 and 2.8 for the high and low coverage eastern Hudson Bay strata respectively.

Three hundred and seventy-five groups of belugas were detected, of which 311 had perpendicular distances and were detected as far as 2,967 m from the trackline (Figure 3). Five belugas were seen in the estuary of the Moose River (*i.e.* Moosonee) the day the southernmost lines of James Bay were covered, and were considered to have been missed by the systematic offshore survey, and therefore considered as a coastal count. In eastern Hudson Bay, 26 belugas were counted in the Nastapoka river estuary, on two occasions a few hours after a group of 21 had been detected near the estuary while on a line of the systematic offshore survey on the 29 August. Therefore, the difference of 5 animals was considered as a coastal count. A group of 40 animals detected along the coast south of Kuujjuaraapik on the 18 August, was not considered in the coastal count as it was theoretically sampled by the systematic survey.

The distribution of ungrouped perpendicular distances showed a narrow shoulder with the number of detections increasing from the trackline to a maximum 100 m away and were continuously detected up to 1400 m, which corresponded to detectability estimation down to 15% [*i.e.* $g(x) = 0.15$, Figure 3]. These two values of 100 m and 1400 m were used as left and right truncation distances, leaving a total of 290 groups with distance measurements. A hazard-rate model was the best model for the truncated distances pooled for James Bay and Eastern Hudson Bay (AIC = 4062). Three different teams of observers were used from the beginning at the south of James Bay and Eastern Hudson Bay. As the different crews of observers coincided roughly with the change in geographic stratum during the survey, the hazard-rate model was used to fit different detection curves for James Bay and eastern Hudson Bay. These curves were used to estimate density in each stratum as they improved the fit to the perpendicular distance distribution data as indicated by the sum of the AICs of two curves (James Bay AIC = 2768; EHB AIC = 1291, sum 4059) which was lower than the AIC for the single curve. The two different curves provided effective strip widths of 817 m (CV = 8.9%) for James Bay and 622 m (CV = 11.2%) for eastern Hudson Bay (Figure 4).

In James Bay, within the truncation distances of 100 m to 1400 m from the trackline, 251 groups with a mean cluster size of 2.68 (CV = 16.9%) were detected, including 196 groups with measured distances that showed a mean cluster size of 2.78 (CV = 19.5%; Figure 5). The largest group of 90 individuals was detected to the north of Akiminski Island on line 5320. The regression of the natural log (ln) of the 196 cluster sizes against detection function value [$g(x)$] was significant (p = 0.003) and provided an expected cluster size at maximum detectability, *i.e.* close to the trackline where size bias should be absent or at its minimum, of 1.796 (CV = 6.2%, Figure 6). The 54 clusters for which distance was not measured, showed an average of 1.648 (CV = 18.0%). The weighted average of these values provided an expected cluster of 1.764 (CV = 18.0%) for James Bay (Table 1). The encountering rate and expected cluster size were similarly important as components of variance explaining respectively 44.7% and 44.5% of overall variance in density (*i.e.* Surface index of abundance), with the ESW explaining the remaining 10.7%.

In eastern Hudson Bay, only 1 group of 6 was detected in the northern stratum, and 103 clusters with a mean of 2.087 (CV = 12.0%) were detected in the southern stratum (Figure 5). The largest group detected was 21 on line 5655. The 93 clusters with distance in southern Hudson Bay averaged 1.817 (CV = 13.1%), but as the regression of their natural logarithm value on the detection function value was not significant (p = 0.53), the mean value of 2.087 (CV = 12.0%) was used as the expected cluster size (Table 1, Figure 6).

The encounter rate is the last of the three components of density and abundance that is estimated from the survey data. In James Bay 250 groups of belugas were detected between 100 m and 1400 m from the trackline over 24 lines, including 5 lines covered twice in the southern half of the bay for a total of 5288 km (Table 1). Most of the groups (66%) were seen in the southern half of the Bay from line 5150 to 5250, which had an average encounter rate of 0.1294 animals/km, much higher than the overall average 0.0473 (CV = 18.1%) for James Bay (Table 1, Figure 2). This is also the area where all the sightings with missing distance information were recorded. But when considering cluster size, the area with highest density was on line 5320, just north of Akiminski Island where 249 belugas were counted over 50 km of line. For comparison purposes, the second highest count for a given line was 46 belugas, illustrating the importance of clumping with these belugas. Later when 5 lines were flown a second time in the high density area (lines 5150 to 5300), the number of groups detected on 1 September (n = 42) had decreased to less than half of the number of groups detected on 7 August (n = 91). However, the teams of observers were also different and might have had a different efficiency.

In eastern Hudson Bay, 6675 km of lines were surveyed in the central stratum and 1312 km were surveyed over both north and south portion of the low coverage stratum. Forty-two percent of the detected groups, representing 32% of all individuals in eastern Hudson Bay (70/221 belugas) were detected offshore of the Nastapoka Islands in front of the Richmond Gulf channel over 63 km of 2 lines surveyed on the 15 August (5610: n = 25 groups; 45 belugas) and 24 August (5620: n = 19 groups; 25 belugas; Figure 2). These large numbers of groups on a very few lines explained the high variance associated with the encounter rate in both the central (CV = 31.7%) and the north and south (CV = 97.1%) eastern Hudson Bay strata (Table 1). Encounter rate was the most important component of variance (78.9%) for the central stratum of eastern Hudson Bay, before expected cluster size (11.2%) and the ESW (9.9%).

Applying the ESW, the expected cluster size and encounter rate estimates above to equation (1) provides an estimate of animals detectable at the surface (Table 1). The total number of animals at the surface during the systematic survey was 3993 (95% CI: 2374 - 6716) in James Bay and 2040 (95% CI: 1047 – 3977) in eastern Hudson Bay.

DISCUSSION

The 2004 survey estimate of beluga abundance in eastern Hudson Bay (2,045) is 44% higher than the 2001 estimate (1,418), which corresponds to a 12% annual rate of increase (Table 2). This is much higher than the normally accepted rates of 2% to 4% estimated for beluga and other species with similar life histories, such as narwhal, pilot whale and spotted dolphin (Kingsley 1989; Barlow and Boveng 1991; Kasuya et al. 1988; Hammill et al. 2004). However, the 2004 estimate falls within the 95% CI of both 1993 and 2001 surveys, and therefore the difference in estimates of this short time series may result from the peculiarities associated in evaluating small clumped populations in large areas, from the different conditions encountered between years, or a combination of the two. The geographical distribution and the maximum size of groups of belugas detected over the last 4 systematic surveys illustrate the clumping characteristic of belugas in James Bay and eastern Hudson Bay (Figure 7).

One of the difficulties in estimating abundance in small clumped populations is that the estimates are very sensitive to the detection of few large groups during the survey. In the St. Lawrence River estuary, where we have a longer time-series of surveys, and a much higher level of survey coverage (50% compared to 9% for James Bay and 11% for eastern Hudson Bay in 2004), estimates often fluctuate markedly between surveys (Figure 8). This inter-annual variability is not due to marked changes in beluga abundance, but is most likely associated with the clumped distribution of animals and the detection of these few large clumps during different survey periods.

In 2004, the presence of ice in the western portions of lines in northern James Bay and south of the Belchers, suggested that there was a delay in the clearing of ice from the James Bay and eastern Hudson Bay area relative to the survey dates. In previous surveys, heavy ice conditions were also encountered during the 1985 survey of James Bay. In that first systematic survey, ice conditions and associated fog did not appear to affect the timing in the execution of the eastern Hudson Bay survey as in 2004 (see below). However, the 1985 eastern Hudson Bay estimates were also quite high (compared to the 1993 and 2001 estimates), while the James Bay numbers were relatively low. Although, the ice observed in the region in 2004 would not prevent movement of belugas, it could have affected detectability of whales between ice pans and may also have affected the distribution patterns of eastern Hudson Bay and James Bay beluga.

In 2004, a considerable amount of flying days were lost, compared to other years because of fog. Previous surveys were completed by 5 August in 1985, 24 August in 1993, and 27 August in 2001, within a survey window between the beginning and end of surveys of these two areas of 8 days in 1985, 13 days in 1993 and 14 days in 2001. In 2004, surveys started 7 August, and ended 30 August in EHB with delays of 2 to 7 days on 5 occasions, which limited our ability to complete flights of adjacent lines. This had two major impacts on the survey. Although surveys of this region normally take several days to complete owing to the extremely large area to cover (some lines require 90 minutes to fly), we have in the past assumed that whale movements are random, and because of the relatively short time to complete the survey, the effects of these movements (double counting or missing of groups) have been minimal. However, with the large gaps in time between flights, the possibility of significant movements or changes in distribution of animals is more likely as indicated by the large change in distribution of whales in James Bay (43 belugas detected on 1 September compared to 140 whales on the same lines on 7 August). The changes do not appear to result from small scale local movements, but instead, indicate a larger shift in distribution of whales towards the north. Furthermore, the movement of one out of five animals tagged in the Nelson River in late July early August, to the offshore Belcher Island area in late August (Pierre Richard, Central and Arctic Region, DFO Winnipeg unpublished data) also indicates that there is a possibility of some influx from the large western Hudson Bay stock as survey in eastern Hudson Bay is conducted later in August.

A second problem resulting from the long delays was that the efficiency of observers might have changed over the survey as a succession of three observer teams were used from the 7 August to

1 September. The survey started from line 5210 to 5400 with two teams of observers that had completed the western Hudson Bay survey in the previous week, and were therefore considered as trained. Then from line 5410 in James Bay to line 5625, which included only half of the eastern Hudson Bay area, two observers from the first team left, and the remaining two observers were split between the two planes. This resulted in the pairing of an experienced observer, with an observer that did not have any prior survey experience (12 to 24 August). Finally, two inexperienced observers were added, leaving only one of the initial observers to complete the survey north from line 5630 and a second survey of 5300 to 5230, 5210 and 5200 in James Bay (29 August to 1 September). The experience of observers generally decreased from the first team to the third one. Although, a few training flights were done it is most likely that the limited experience of observers at the end of the surveys could perhaps have decreased detection of animals even close to the aircraft.

Transects and sampling protocols were similar in 2004 to the two previous line-transect surveys of 1993 and 2001. However, as was suggested during the review of the 2001 survey, the target altitude was reduced from 457.2 m (1500') to 304.8 m (1000') to decrease the chance of missing available animals at the surface near the trackline, as one of the major assumptions of line-transect surveys is to detect all animals near the trackline (*i.e.* $g(0)=1$). The lower altitude might in part explain the narrower right truncation distance of 1400 m compared to 1800 m in 1993 and 2001, as animals away from the trackline might be easier to detect from higher altitude, but this shorter distance of detection would have been considered in the estimation of the effective strip width and would not represent a bias. As for effects near the trackline, the lower altitude effectively reduced the left-truncation value, which roughly represents the area under the plane that was not surveyed, to 100 m in 2004 compared to 300 m in 1993 and 250 m in 2001. As observers are closer to the surface at lower altitude, the relative size of belugas to detect near the trackline becomes larger, again suggesting a positive bias in 2004 compared to previous surveys. However, the lower altitude could also imply an opposing negative bias, as similar searching angles and searching patterns of observers, would translate in a smaller scanning area at the surface of the water and at the same ground speed, this area would be available for a shorter period of time. Unfortunately, no measures are available for neither of the possible positive and negative biases. Independent controlled experiments would be required to objectively evaluate if this reduced altitude was effective at improving the detectability of animals on the trackline.

Another improvement suggested since the last survey, was the use of the D-GPS recorded altitudes to correct the pressure altimeter in the planes. The D-GPS recorded altitudes provided average altitude corrections of -12.6 m, -2.9 m and +4.9 m for James Bay, southern and northern eastern Hudson Bay strata respectively. Using the recorded altitude to calculate the perpendicular distance of sightings resulted in an ESW of 817 m in James Bay and 622 m in eastern Hudson Bay, instead of estimates of 803 m and 630 m that would have been determined using the target altitude only. Without these corrections, our estimate of density in James Bay would have been slightly higher and our estimate in eastern Hudson Bay would have been slightly lower.

Beaufort conditions were higher in all strata in 2004 compared to the 2001 survey. The average Beaufort condition weighted by time increased from 1.3 in 2001 to 1.9 in 2004 in James Bay, and from 1.8 to 2.7 in the high coverage eastern Hudson Bay stratum. The value in the low coverage stratum of eastern Hudson Bay was similar for both years at 2.9. Work done in Alaska has shown that sightability of beluga during aerial surveys decreases when Beaufort conditions exceed 2 (DeMaster et al. 2001). Therefore, according to these values, most of the survey in 2004 would have been conducted at Beaufort conditions that would have limited sightability and would suggest a negative bias compared to the 2001 survey.

There are conflicting possible biases of this survey. The lower altitude might have implied a positive bias by improving detection at the surface and by reducing the area missed under the plane. However, this may have been offset to some extent by the fact that observers with similar searching angles would scan a smaller area at the surface and animals at the surface would therefore be available for a shorter period of time at a reduced altitude. Similarly, the high Beaufort conditions and the limited experience of the observers in 2004 might imply a negative bias compared to previous surveys. Unfortunately, we are not able to quantify the relative value of these biases.

The unusually long delays and the use of three different teams of observers, for a total of 9 different observers from which 3 had no previous survey experience and 2 only had limited experience, is not in line with what is considered to be good practices for line transect data collection. Combined with some limited evidence of significant whale movement between lines and regions, the population estimation of the 2004 survey and its large uncertainty should be considered with caution when used for management purposes.

ACKNOWLEDGEMENTS

Mike Hammill and Véronique Lesage provided comments for survey design and on several preliminary versions of the manuscript. Caroline Weetaltuk, Moses Weetaltuk, Pierre Carter, Pierre Richard, Klaus Hocheim, Courtenay O'Brien-Moran, Manon Laliberté, Marie-Joëlle Leblanc, Emmanuelle Séguin et Valérie Harvey formed the different teams of observers. Duane Hicks, Jules Hope-Dubois, Stephen Smeltzer, Mario Tcheon and Dominic Turenne from Hicks and Lawrence, made sure the planes were ready and monitored weather to make sure that all available flying time was efficiently used. David Courtemanche, DFO Québec, provided support with administrative logistics. The project was funded by SARCEP and also by Kativik Regional Government (Michael Barrett and Sandy Gordon) through the Aboriginal Capacity Building and Stewardship Program for Species At Risk (Environment Canada).

REFERENCES

Barlow, J. and P. Boveng. 1991. Modelling age specific mortality for marine mammal populations. Marine Mammal Science 7: 50-65.

Brennin, R., B.W. Murray, M.K. Friesen, L.D. Maiers, J.W. Clayton and B.N. White. 1997. Population genetic structure of beluga whales (*Delphinapterus leucas*): mitochodrial DNA sequence variation within and among North American populations. Can. J. Zool. 75:795-802.

Breton-Provencher, M. 1980. Survey of the beluga population in the Poste de la Baleine region (New Quebec). Rep. Int. Whaling Comm., Cambridge, Doc SC/32/SM16. (Transl. From french by Dept. Fish Oceans).

Brown Gladden, J.G., M.M. Ferguson and J.W. Clayton. 1997. Matriarchal genetic population structure of North American whales *Delphinapterus leucas* (Cetacea: Monodontidae). Molecular Ecol. 7:1033-1046.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers and L.Thomas. 2001. Introduction to distance sampling, Estimating abundance of biological populations. Oxford University Press, New York. 432 p.

de March, B., and L.D. Maiers. 2001. Stock discrimination of belugas (*Delphinapterus leucas*) hunted in eastern Hudson Bay, northern Québec, Hudson Strait, and Sanikiluaq (Belcher Islands), using mitochodrial DNA and 15 nuclear microsatellite loci. Canadian Science Advisory Secretariat. Research Document 2001/050. 39p.

DeMaster, D.P., L.F. Lowry, K.J. Frost, and R.A. Bengston. 2001. The effect of sea state on estimates of abundance for beluga whales (*Delphinapterus leucas*) in Norton Sound, Alaska. Fish. Bull. 99:197-201.

Finley, K.J., G.W. Miller, M. Allard, R.A. Davis and C.R. Evans. 1982. The belugas (*Delphinapterus leucas*) of northern Quebec: distribution, abundance, stock identity, catch history and management. Can. Tech, Rep. Fish. Aquat. Sci. 1132, 57 p.

Hammill, M.O., V. Lesage, J.-F. Gosselin, H. Bourdages, B.G.E. de March and M.C.S.K. Kingsley 2004. Evidence for a decline in northern Quebec (Nunavik) belugas. Arctic 57 (2): 183-195.

Kasuya, T., D.E. Sergeant and K. Tanaka. 1988. Re-examination of life history parameters of long-finned pilot whales in Newfoundland waters. Sci. Rep. Whales Res. Inst. 39: 103-119.

Kingsley, M.C.S. 1989. Population dynamics of the narwhal (*Monodon monoceros*): an initial assessment (Odontoceti: Monodontidae). J. Zool., Lond. 219: 201-208.

Kingsley, M.C.S. 2000. Numbers and distribution of beluga whales, *Delphinapterus leucas,* in James Bay, and Ungava Bay in Canada during the summer of 1993. Fish. Bull. 98:736-747.

Lerczak, J.A. and R.C. Hobbs. 1998. Calculating sighting distances from angular readings during shipboard, aerial, and shore-based marine mammal surveys. Marine Mammal Science 14 (3): 590-599.

Reeves, R.R. and E.D. Mitchell. 1987. History of white whale (*Delphinapterus leucas*) exploitation in eastern Hudson Bay and James Bay. Can. Spec. publ. Fish. Aquat. Sci. 95, 45p.

Reeves, R.R. and E.D. Mitchell. 1989. Status of white whales, *Delphinapterus leucas,* in Ungava Bay and eastern Hudson Bay. Can. Field-Nat. 103:220-239.

Richard, P.R., J.R. Orr, and D.G. Barber. 1990. The distribution and abundance of belugas, *Delphinapterus leucas*, in eastern Canadian waters: a review and update. Pages 23-28 In T.G. Smith, D.J. St. aubin and J.R. Geraci (eds). Advances in research on the beluga whale, *Delphinapterus leucas*. Can. Bull. Fish. Aquat. Sci. 224:

Satterthwaite, F.E. 1946. An approximate distribution of estimates of variance components. Biometric Bulletin 2: 110-114.

Smith, T.G. 2004. Update COSEWIC Status Report on Beluga Whale populations in Canada. *Delphinapterus leucas*. prepared for Committee on the Status of Endangered Wildlife in Canada. 76 p.

Smith, T.G. and M.O . Hammill. 1986. Population estimates of the white whale, *Delphinapterus leucas,* in James Bay, eastern Hudson Bay and Ungava Bay. Can. J. Fish. Aquat. Sci. 43:1982-1987.

Thomas, L., J.L. Laake, S. Strindberg, F.F.C. Marques, S.T. Buckland, D.L. Borchers, D.R. Anderson, K.P. Burnham, S.L. Hedley, J.H. Pollard and J.R.B. Bishop. 2003. Distance 4.1 Release 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

Table 1. Abundance indices of belugas at the surface during the systematic line-transect surveys flown in 1993 (Kingsley 2000), 2001 and 2004 using the software DISTANCE with both left (300m in 1993; 250 m in 2001; 100m in 2004) and right truncation (1800m in 1993 and 2001; 1300m in 2004). Coefficients of variation are shown in parentheses. Area surveyed is 78,234 km^2 in James Bay and 64,087 km^2 in high coverage area of eastern Hudson Bay. In low coverage of Eastern Hudson Bay, the area covered was 27,223 km^2 in 2004 and 29,829 km^2 in previous surveys.

Stratum	Effort (km)	Nb groups	Effective strip width (m)	Sighting rate (group/km)	Estimated group size	Surface index of abundance
1993						
James Bay	4218	119	686 (4.76)	0.0282 (15.4)	2.437 (11.7)	3922 (19.9)
Eastern Hudson Bay high	6677	55		0.0082 (16.1)	2.036 (26.4)	784 (31.2)
Eastern Hudson Bay low	1612	8		0.0050 (65.1)	4.750 (49.8)	513 (82.1)
Ungava Bay south	3156	0				
Ungava Bay north	2498	0				
2001						
James Bay	4206	294	554 (5.53)	0.0699 (19.4)	1.673 (3.5)	8262 (20.4)
Eastern Hudson Bay high	6675	63		0.0094 (31.0)	2.524 (33.7)	1379 (46.1)
Eastern Hudson Bay low	1612	0		0	0	0
Ungava Bay south	1758	0		0	0	0
Ungava Bay north	2498	0		0	0	0
2004						
James Bay	5288	250	817 (8.85)	0.0473 (18.1)	1.764 (18.0)	3993 (27.0)
Eastern Hudson Bay high	6675	103	622 (11.2)	0.0154 (31.7)	2.087 (12.0)	1924 (35.6)
Eastern Hudson Bay low	1312	1		0.0008 (93.9)	6.000 (0.0)	116 (94.6)
Ungava Bay south	0					
Ungava Bay north	0					

Table 2. Indices of beluga populations in James Bay, eastern Hudson Bay and Ungava Bay estimated from three systematic aerial surveys. The 1985 survey data were collected only using strip-transect techniques (Smith and Hammill 1986). The 1993 and 2001 surveys flew along the same lines as the 1985 surveys, but data were collected using line-transect techniques (Kingsley 2000; this study). These data were then analysed assuming a strip width of 1000 m on each side of the aircraft. The 1985 survey estimates then were adjusted by multiplying the strip-transect estimates by a line-transect-strip-transect ratio (Mean=1.87, SD=0.268) calculated using the 1993 and 2001 data analysed with DISTANCE and then adding in estuary counts in EHB of 474, 18, 39 and 5 for 1985, 1993, 2001 and 2004 respectively, and 5 for James Bay in 2004.

		Systematic offshore estimate	Abundance estimate		
		Strip-transect[1]	Strip-transect[1]	Richards line-transect[2]	Distance line-transect
Stratum	Year	$\hat{N}_s$ (SE)	$\hat{N}_s$ (SE)	$\hat{N}$ (SE)	$\hat{N}$ (SE) [95% CI]
James Bay	1985	1213 (290)	1213 (290)	*1842*	*2,256*
	1993	2296 (566)	2296 (566)	3141 (787)	3922 (781) [2645 - 5816]
	2001	4732 (712)	4732 (712)	7901 (1744)	8262 (1687) [5463 – 12,495]
	2004				3998 (1078) [2379 - 6721]
EHB	1985	968 (165)	1442 (165)	*2089*	*2,294*
	1993	688 (205)	706 (205)	1032 (421)	1,314 (489) [631 - 2761]
	2001	620 (263)	659 (263)	1194 (507)	1,418 (635) [615 - 3339]
	2004				2045 (698) [1052 - 3982]
Ungava Bay	1985	0	0	0	0
	1993	0		88	0
	2001	0		0	0

[1] From Hammill et al. (2004).
[2] The 1985 and 2001 values from Hammill et al. (2004); the 1993 values from Kingsley (2000)

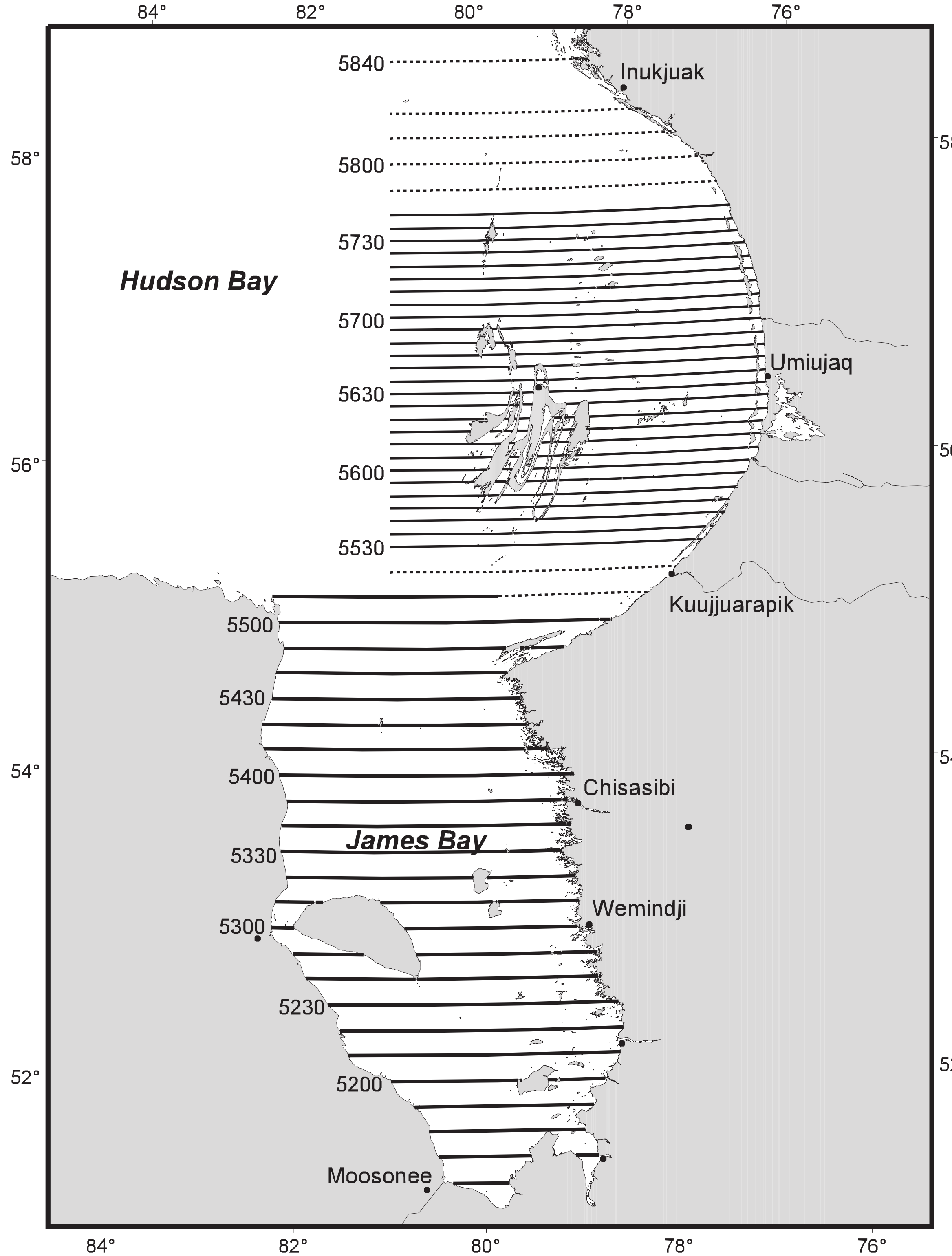


Figure 1. Lines surveyed during the systematic aerial survey conducted from 7 August to 1 September 2004. Lines for James Bay, eastern Hudson Bay high and low coverage strata are shown in bold, normal and dotted lines respectively.

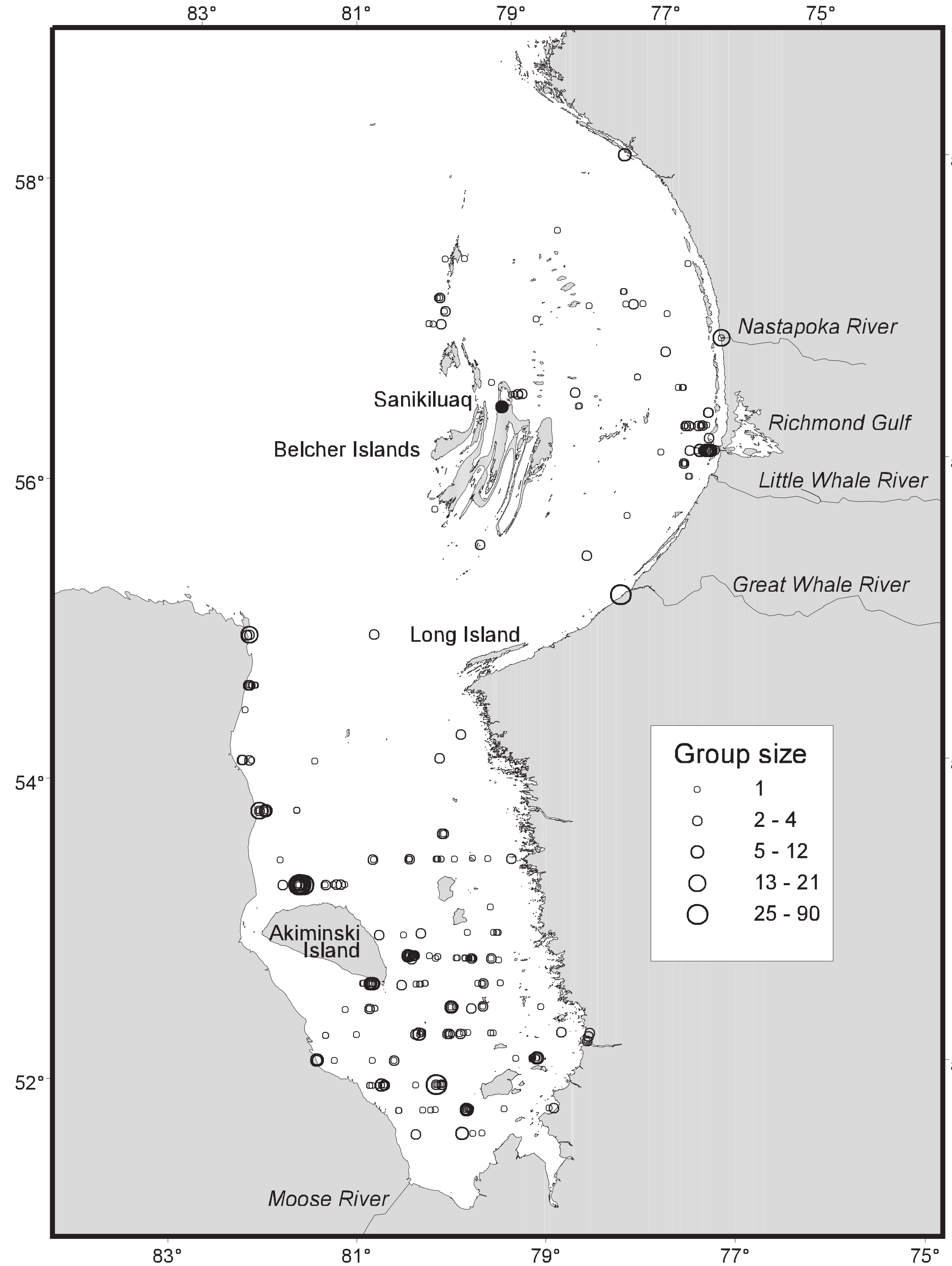


Figure 2. Geographic distribution of beluga groups detected during the systematic aerial survey of James Bay and eastern Hudson Bay conducted from 7 August to 1 September 2004.

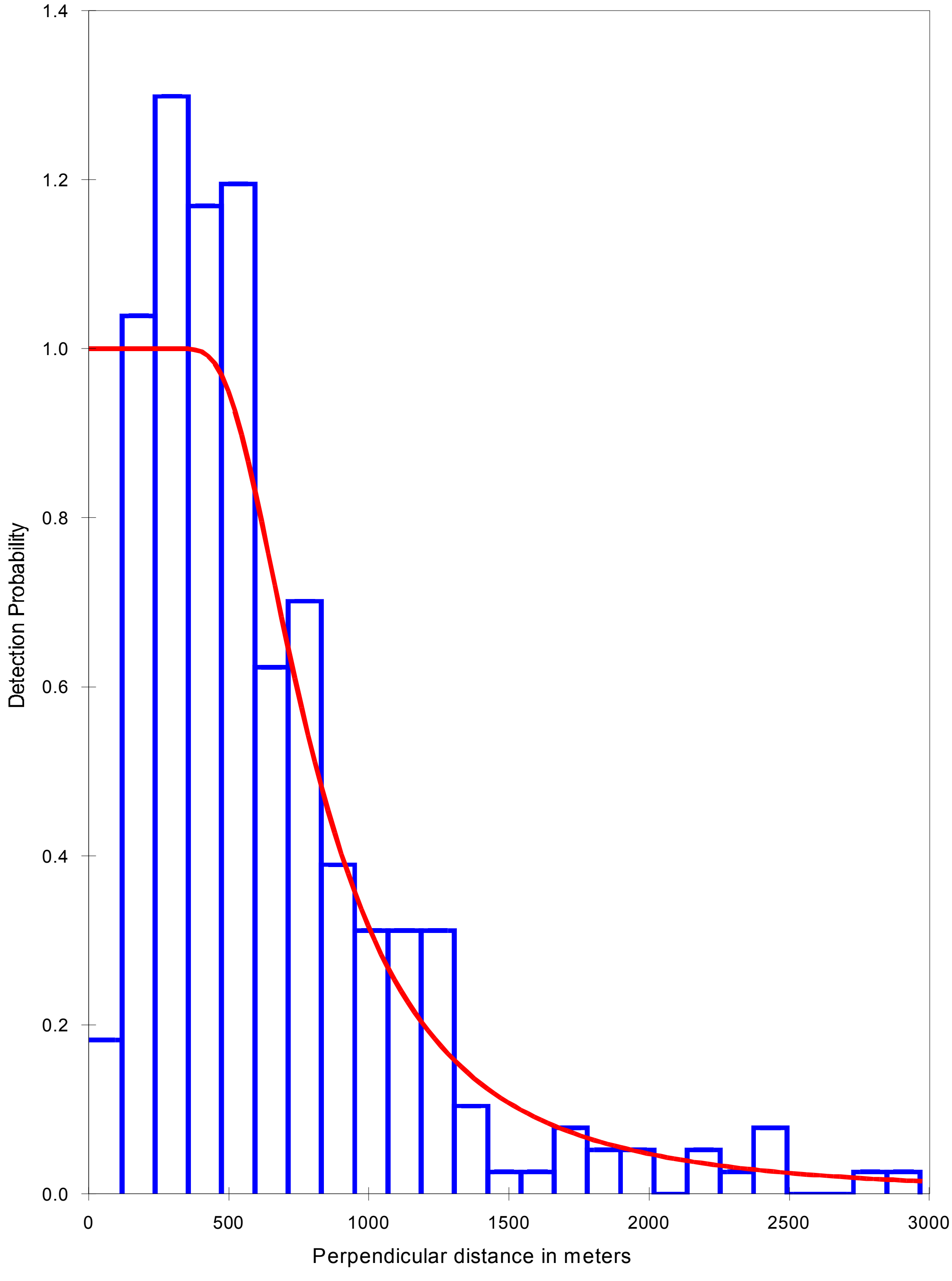


Figure 3. Overall distribution of perpendicular distances from the trackline of 311 groups of belugas recorded by the three teams of observers pooled over the three strata of the 2004 systematic aerial survey. Observations are grouped in 25 bins to the maximum distance of 2,967 m, but the detection models were fitted on the ungrouped data.

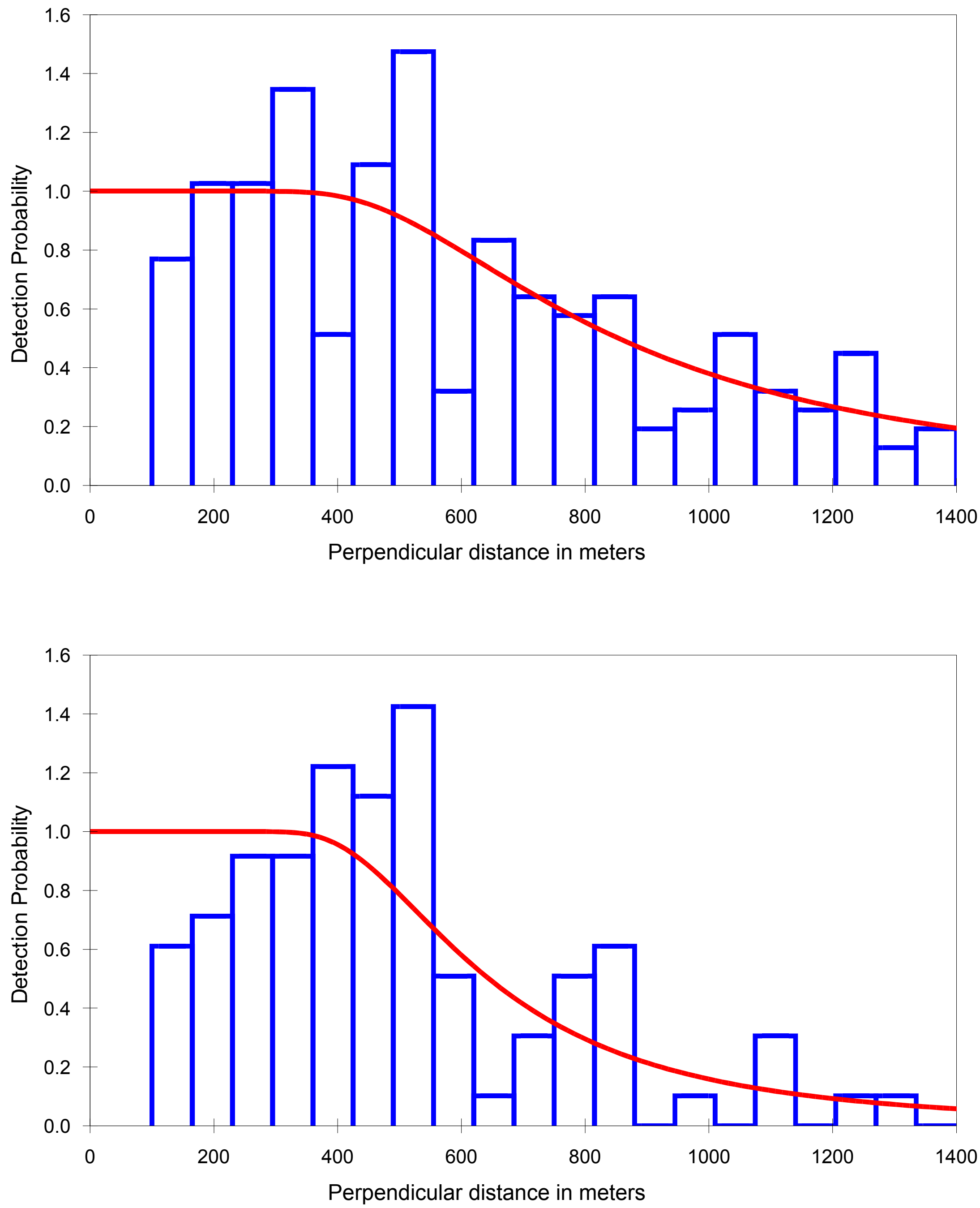


Figure 4. Distribution of perpendicular distances of groups of belugas and the fitted hazard-rate detection functions that provided ESW of 817 m (95% CI : 687-972 m) for James Bay (top) and 622 m (95% CI: 498-776 m) for eastern Hudson Bay (bottom). The perpendicular distances are grouped in 20 bins, but the models were fitted to the ungrouped dataset.

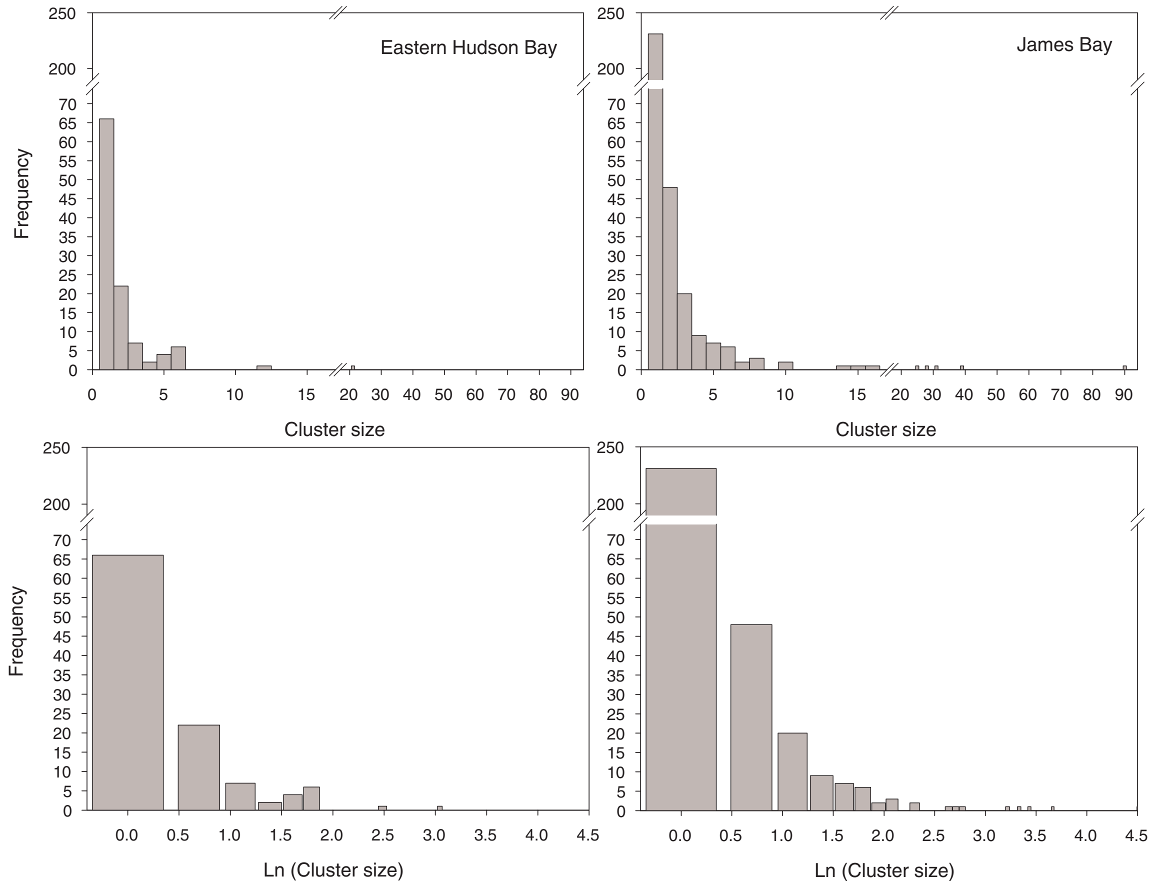


Figure 5. Frequency distribution of cluster size and logarithm of all the groups detected in James Bay (n=251) and in eastern Hudson Bay (n=104) from 7 August to 1 September 2004.

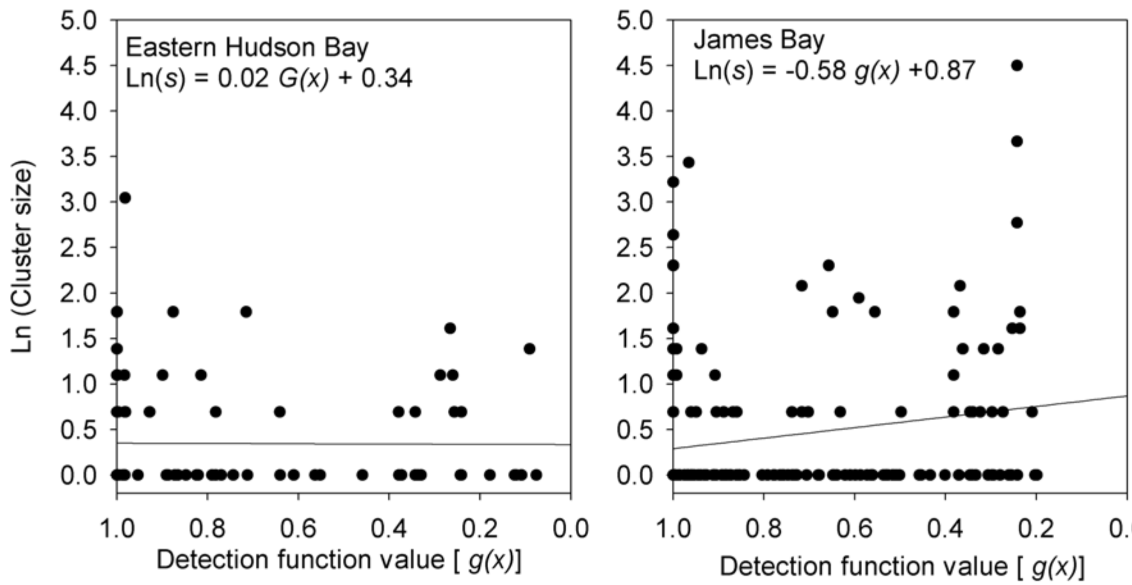


Figure 6. Regression of the logarithm of cluster size [log (*s*)] on estimated value of detection function [*g(x)*] used to evaluate potential size bias with distance from the trackline in both James Bay and eastern Hudson Bay strata. The maximum in detection function [*g*(*x*)=1.0] occurs in the area near the trackline.

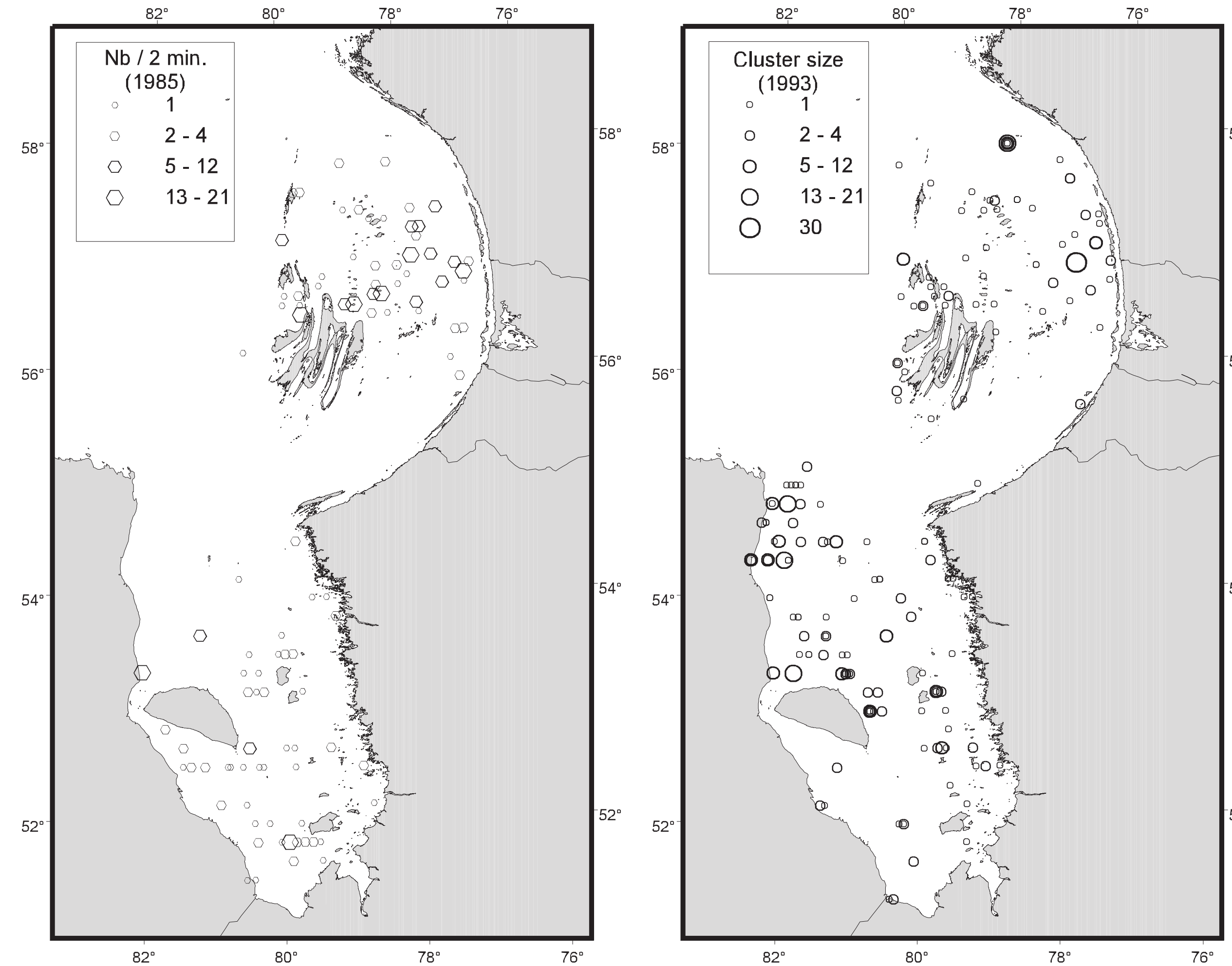
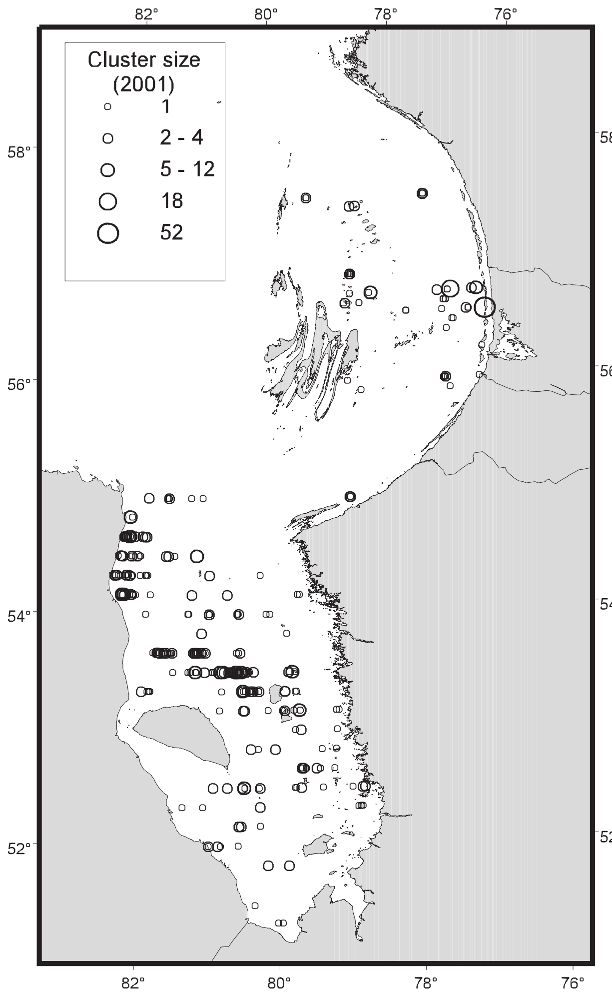


Figure 7a. Distribution of groups of belugas detected during 4 systematic aerial surveys in 1985, 1993, 2001 and 2004. Group size was estimated for the three more recent surveys, but for 1985 the symbol size represents the number of animals detected during two minutes of flying.



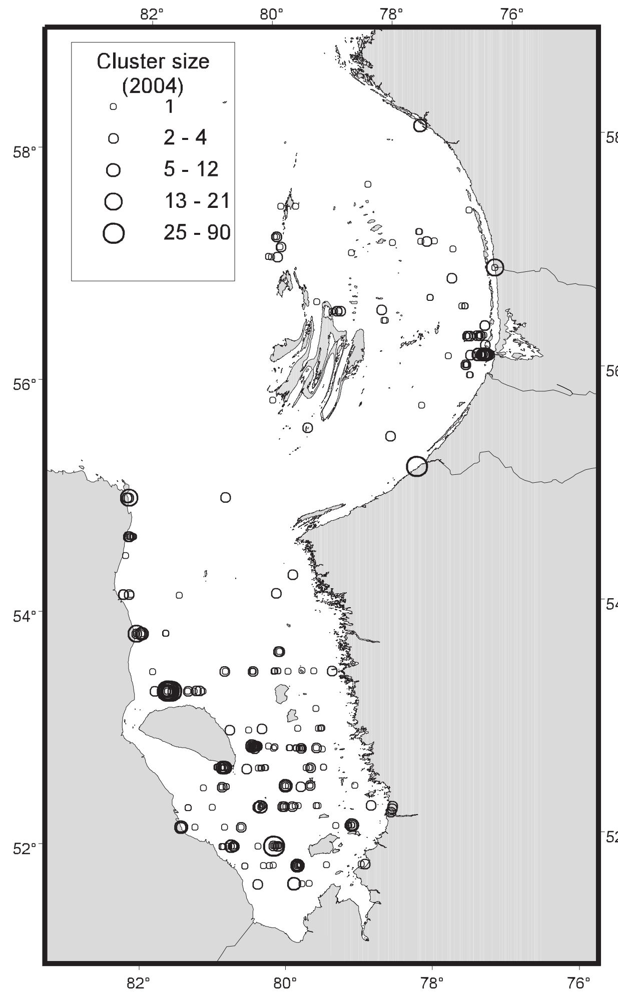


Figure 7b. Distribution of groups of belugas detected during 4 systematic aerial surveys in 1985, 1993, 2001 and 2004. Group size was estimated for the three more recent surveys, but for 1985 the symbol size represents the number of animals detected during two minutes of flying.

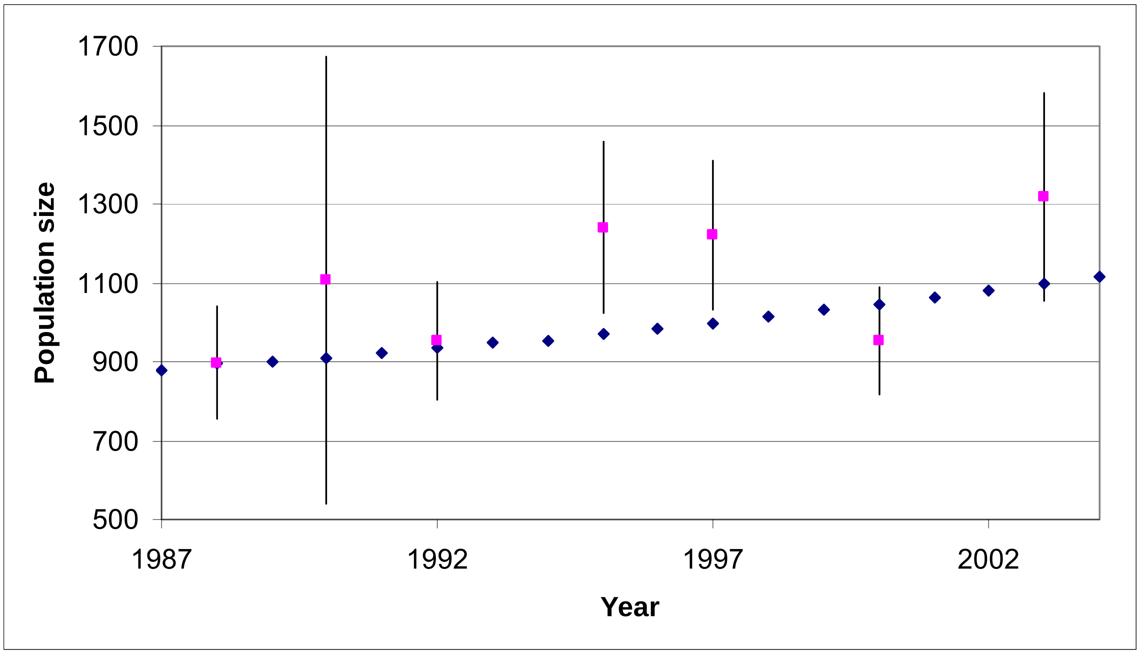


Figure 8. Example of the variability in estimation of a clumped population. Trajectory of St. Lawrence beluga population, using a Pella-Thomlin model, incorporating the number of carcasses recovered on the beach into the model as 'removals'. The model was fit to systematic population estimates (including a preliminary estimate for 2003; bars show 1 SE) with an initial population size of 850 animals in 1985 and a struck and loss correction factor of 1.6 (*i.e.* for every animal recovered, 1.6 animals dies but is not recovered, or birth rates are lower than expected, but because the model does not estimate birth rates it must increase the number of deaths to fit the observed survey data).