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Abundance indices of beluga in James Bay, eastern Hudson Bay and Ungava Bay in summer 2001.

Indices d'abondance de bélugas dans la baie James, l'est de la baie d'Hudson et la baie d'Ungava durant l'été 2001

Jean-François Gosselin, Véronique Lesage, Mike O. Hammill and Hugo Bourdages

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

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Abstract

Aerial systematic line transect surveys of beluga whales, *Delphinapterus leucas*, were conducted in James Bay, eastern Hudson Bay and Ungava Bay from 14 August to 3 September 2001. Coastal surveys were conducted on 28 August in Eastern Hudson Bay, on 4 September in Ungava Bay and on 5 September in Hudson Strait and along the northeastern Hudson Bay coast. An effective strip width of 638 m was estimated from the 717 beluga observed on east-west lines in James Bay (557 beluga) and eastern Hudson Bay(160 beluga). An estimated 7,901 (SE = 1,744) and 1,155 (SE = 507) beluga were present at the surface in the offshore areas of James Bay and Hudson Bay respectively. An additional 39 animals were observed in estuaries during the coastal survey resulting in an index estimate of 1,194 (SE = 507) in eastern Hudson Bay. No beluga were observed in Ungava Bay. Three beluga were observed along the coast near Salluit. Observations from the 1993 and 2001 systematic surveys were analysed using both line transect and strip transect methods to allow comparisons with the strip transect survey conducted in 1985. From 1985 to 2001, the number of beluga summering in James Bay increased fourfold, while numbers in eastern Hudson Bay have declined by almost half.

Résumé

Des relevés aériens systématiques par échantillonnage en ligne de bélugas, *Delphinapterus leucas*, ont été complétés dans la baie James, l'est de la baie d'Hudson et la baie d'Ungava du 14 août au 3 septembre 2001. Des relevés côtiers ont été complétés le 28 août dans l'est de la baie d'Hudson, le 4 septembre dans la baie d'Ungava, ainsi que le 5 septembre dans le détroit d'Hudson et le long de la côte nord-est de la baie d'Hudson. Une largeur efficace de bande fut estimée à 638 m à partir des 717 bélugas observés sur les lignes orientées d'est en ouest dans la baie James (557 bélugas) et l'est de la baie d'Hudson (160 bélugas). On estime respectivement à 7 901 (erreur-type = 1 744) et 1 155 (erreur-type = 507) le nombre de bélugas présents au large des côtes de la baie James et de la baie d'Hudson. Trente-neuf individus de plus ont été observés dans les estuaires pendant le relevé côtier produisant ainsi un indice de 1 194 (erreur-type = 507) dans l'est de la baie d'Hudson. Aucun béluga n'a été vu dans la baie d'Ungava. Trois bélugas ont été vus le long de la côte près de Salluit. Les observations des relevés systématiques de 1993 et de 2001 ont été analysées selon les deux méthodes d'échantillonnage en ligne et d'échantillonnage en bande pour permettre la comparaison avec le relevé en bande de 1985. De 1985 à 2001, le nombre de béluga passant l'été dans la baie James a quadruplé, alors que le nombre passant l'été dans l'est de la baie d'Hudson a diminué de près de moitié.

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 carrying 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 (Reeves and Mitchell 1989). 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. A second aerial survey flown in 1993 provided abundance estimates of 3,141 (SE=787) and 1,014 (SE=421) beluga in James Bay and eastern Hudson Bay respectively. Again in Ungava Bay, no whales were observed on transect. Results from the 1993 aerial survey were taken into account and a new 5-year management plan was agreed upon to limit beluga harvesting in northern Quebec. This plan expired in March 2001. A new plan which attempted to limit harvesting in eastern Hudson Bay, but allowed for increased harvesting in Hudson Strait was signed in April 2001. The overall plan was put in place, with the proviso that harvests would be re-examined if new information became available.

Although the 1993 survey followed the same transect lines as the 1985 survey, the data were collected and analysed as a line transect survey. These two methods are based on different assumptions. Strip transect method assumes 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 modelled by fitting a function to the distribution of perpendicular distances from the track line. 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 2001, the aerial surveys of James Bay, eastern Hudson Bay and Ungava Bay were repeated. During these surveys, the same lines followed in 1985 and 1993 were re-flown. Survey results were analysed following the line transect techniques outlined in Kingsley (2000) and using the strip transect methods reported by Smith and Hammill (1986) to compare estimates provided by both methods.

Material and methods

Systematic line transect survey

The survey area for this study included James Bay, the eastern Hudson Bay coast, Hudson Strait and Ungava Bay. James Bay, the Hudson Bay arc and Ungava Bay were also surveyed in 1985 and 1993. For comparability, we flew the same east-west transects as had been flown in these earlier surveys from 14 August to 3 September (Figure 1). In James Bay, the lines were spaced 10 minutes apart, from 51°10' N to 55°20' N, extending from coast to coast. In eastern Hudson Bay, east-west lines spaced 10 minutes apart were flown between the coast and 81° W between 55°30' N and 58°50' N. Within the arc, additional lines were flown, which resulted in a 5 minutes spacing between 55°30' N and 57°40' N. In Ungava Bay, transects were flown in an east-west direction every 10 minutes of latitude from 61°00' N to 59°30' N and every 5 minutes from 59°20' N to 58°20' N. Strata were divided according to locations and transect spacing (Figure 2).

The survey was flown from mid-August to early September. Observations were recorded by the same two observers seated in the back of a Cessna-337 (Skymaster) equipped with a GPS and bubble windows flying at 457.2 m (1,500 ft) at a targetted airspeed of 240 km/h (130 kt). Flights were conducted when sea conditions did not exceed Beaufort 4. For each animal, the angle from the horizontal was measured to the nearest degree using a Suunto inclinometer. Angles from the line were measured on a anglemeter fixed to the side of the windows. The distance from the transect line was estimated as the product of the sin of the horizontal angle and the distance from the plane calculated using the following formula:

$$r = \nu / \tan(\psi) \qquad (1)$$

where:

Ψ = angle of declination between the horizontal and the sighting

ν = vertical height of the observer (altitude) = 1,500 feet = 457 m

The position of the observers and the size of window frame prevented seeing below an angle of 67°, which corresponded to a perpendicular distance of 194 m.

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 15-30 minutes and when noticeable changes were detected. All information was recorded on microcassettes and manually entered at night.

Coastal survey

Coastal surveys were completed after each segment of Hudson Bay and Ungava Bay had been completed to estimate the number of beluga that might have been present in large estuaries while the systematic offshore survey was conducted. These surveys were flown with the same

Cessna-337 (Skymaster) flying at an altitude of 305 m (1,000 feet) with some lower flying to 152 m (500 feet) for narrow estuaries or bays. An additional third observer from the co-pilot seat participated to the coastal survey of the eastern Hudson Bay arc which was flown in two flights on 28 August with a start and a return to Inukjuaq. The first flight south to Long Island covered the mainland coast and Richmond Gulf. The second flight surveyed the offshore coasts of the Nastapoka Islands continuing north of Inukjuaq to Cape Dufferin, with a return through Hopewell Sound. The Ungava Bay coasts were surveyed by two flights on 4 September. A morning flight covered the coast form Kuujjuaq to Killiniq, including all large estuaries and bays with special attention at Whale River, Mucalic area and George River estuary. A second flight covered the coast and all bays from Kuujjuaq to Quartaq, with special attention for Leaf and Payne river estuaries and also covered all coasts around Diana Bay. On the 5 September, the Hudson Strait and the north-east Hudson Bay coasts were surveyed from the west side of Diana Bay to Cape Dufferin, with special attention in Wakeham Bay, Deception Bay, Sugluk Inlet, and all the Islands and passages in Ivujivik area. Distance from the coast was kept short enough so that the observer on the coast side of the plane was confortable that he could not miss beluga between the plane and the coast. Beluga on both sides of the plane were monitored and beluga observation time and distance were recorded on microcassettes. The total count of beluga within estuaries was added to the estimated number of beluga on the offshore systematic survey to estimate beluga abundance in each stratum. Animals out of estuaries were discarded as they were theoritically already included in the lines of the systematic survey that extended to the coast.

Data analysis
To allow comparison with results from previous surveys of 1985 and 1993, data were analysed using strip transect methods (Smith and Hammill 1986), and using the same line transect methods of Kingsley (2000).

Line transect techniques assume that the probability of detecting an animal, noted as $g(x)$, decreases with perpendicular distance from the track line, but that all animals on the track line are detected (i.e. $g(0) = 1$) (Buckland *et al.* 1993). However, because the observers could not see directly under the plane, a sine^2 function was fitted to the observations between the aircraft and the point of maximum detection (g_{max}=1). Decreasing $g(x)$ of observations to the right of the maximum of detectability (g_{max}= 1) was modelled using a modified Richards' (1959) sigmoidal growth curve, with a restrained inflection point below 0.9 of probability of detection (Kingsley 2000, Sugden *et al.* 1981):

$$g(x) = \left[1-(1-m)e^{\left[-h(x_0-x)/m^{m/(1-m)}\right]}\right]^{1/(1-m)} \tag{2}$$

where x is the perpendicular distance in meters, h is the maximum reduction rate in detection (per m), x_0 is the distance (m) at maximum reduction rate, and m is the fitting parameter with the property that $m^{1/(1-m)}$ is detection at inflection point. The distribution of the pooled perpendicular distances of individual whales from all strata was examined to truncate distant observations and outliers for which distance estimation may be imprecise. A single combined sine^2 and Richards' modified function was fitted to the pooled truncated distribution of perpendicular distances by maximum likelihood. A single effective strip width (ESW) for all of James Bay and eastern Hudson Bay was estimated as the integral of the combined sine^2 and Richards sighting curve.

The total number of detectable beluga in each stratum, $\hat{N}$, was estimated as the sum of the number of beluga counted in estuaries, N_E, during coastal surveys and the number of beluga detectable at the surface during the systematic offshore survey, $\hat{N}_S$.

$$\hat{N} = N_E + \hat{N}_S \tag{3}$$

The number estimated at the surface, $\hat{N}_S$, is the product of the number of beluga counted on the transects weighted by the proportion of the area of the stratum covered according to the estimated ESW:

$$\hat{N}_s = \tilde{k} T_s B_s \qquad (4)$$

where T_s is the transect spacing in km and B_s is the total count of beluga for each stratum (Kingsley 2000). Individuals detected on boundary transects between strata with different spacing were given half-weight in each stratum. The expansion factor, $\tilde{k}$, is the bias-reduced estimate of the expansion factor, $\hat{k}$, which is the reciprocal of the two-sided ESW (in km):

$$\hat{k} = \frac{1}{2 \cdot ESW} \qquad (5)$$

Individuals were used as detected object for line transect analysis. This clearly violates the assumption that detections are statistically independent events since beluga were detected in groups. The number of effective sightings of 101.6, estimated as the number of animals divided by the contraharmonic mean group size, was therefore only slightly above the minimum recommended by Buckland *et al.* (1993). As likelihood used to fit the model to the recorded observations may be biased for small sample size, a standard bias reduction was applied to the estimated expansion factor, $\hat{k}$ (Kingsley 2000; Efron 1982):

$$\tilde{k} = n\hat{k} - (n-1)\hat{k}_{(\cdot)} \qquad (6)$$

where $\hat{k}_{(\cdot)}$ is the mean of the all estimations calculated omitting one of the n clusters, and $\tilde{k}$ is the bias-reduced expansion factor.

Variance in the estimation of population size for line transect is the sum of two components, the variance of sampling, V_s, and the variance associated with the estimation of the expansion factor, V_k, which comes from the uncertainty related to the modelling of the detection function on the observed perpendicular distances. The use of individuals as detected object may also raise concerns about the estimation of these two components of variance. Sampling variance of systematical transect surveys, is estimated from the serial differences in counts between consecutive lines. As the distance for dependency between individuals in relation to clusters is short compared to the distance spacing between lines, dependency between consecutive lines is not considered to be affected by the use of individuals or clusters. However, the second component of variance from the estimation of the expansion factor, may be affected by the within line dependency of the observations and was therefore estimated by the robust Jackknife procedure, using clusters as resampling units. The two components of variance for each stratum were estimated using the following equations (Kingsley 2000; Efron 1982):

$$V_s = \tilde{k} T_s \cdot (\tilde{k} T_s - 1) \cdot \frac{J_s}{J_s - 1} \cdot \frac{\sum_{j=1}^{J_s - 1} (B_j - B_{j+1})^2}{2}, \qquad (7)$$

where J_s is the number of transect in stratum *s*, and *Bj* is the number of beluga counted on the j^{th} transect.

$$V_k = \mathrm{var}(\tilde{k}) \cdot (T_s B_s)^2 , \tag{8}$$

where

$$\mathrm{var}(\tilde{k}) = \frac{n-1}{n} \cdot \sum_{i=1}^{n} (\hat{k}_{(i)} - \hat{k}_{(\cdot)})^2 \tag{9}$$

and $\hat{k}_{(i)}$ is the estimated expansion factor when the i^{th} observation is omitted.

Strip transect method
The number of beluga in each stratum was also estimated using strip transect method (Smith and Hammill 1986). To reproduce a strip width of 1,000 m on each side of the aircraft (Smith and Hammill 1986), from the distance data collected in 2001 and 1993, all observations from 260 m to 1,260 m from the aircraft were used for strip analysis.

The estimation of the weighted number of beluga in each stratum and its associated variance also followed equation 3 and 7 mentionned above for the line transect analysis, where the bias-reduced expansion factor $\tilde{k}$ is replaced by *k*, the reciprocal of the 2 sided strip width, *i.e.* equation 5, replacing ESW by 1,000 m. Beluga counts on boundary transects between strata with different transect spacing were given half weight in each stratum.

The stratum ratio of line on strip transect estimate was averaged for both years, and used to produce line transect estimates of surface detectable beluga from the strip transect estimates of 1985.

Clumping factor
The tendency of beluga to aggregate can be assessed using the ratio of clumping factors C_1/C_2 (Smith and Hammill 1986, Smith *et al.* 1985; Kingsley *et al.* 1985). This ratio compares the overall variance of density for the whole stratum as it would be calculated for random sampling (C_1), with the variance for systematic sampling based on differences in density between consecutive transects (C_2). A value of one of this ratio, would indicate an homogenous distribution of beluga between transects throughout the stratum.

The total density of the stratum, $\hat{R}_s$ is expressed as the ratio of the total number of beluga on the estimated expanded area for the whole stratum:

$$\hat{R}_s = \frac{\sum N_j}{\sum X_j} , \tag{10}$$

$$N_j = kB_j \tag{11}$$

$$X_j = kA_j \tag{12}$$

where A_j represents the area of the j^{th} transect, and N_j and X_j represent respectively the expanded count of beluga and the expanded area of the j^{th} transect.

Variance of density for random sampling is calculated as follows:

$$S_1^2 = \left\{ J_s \sum_{j=1}^{J_s} {d_j}^2 \right\} \Big/ \left\{ (J_s - 1) \cdot (\sum X_j)^2 \right\} \tag{13}$$

and the variance for systematic sampling based on serial difference in density as

$$S_2^2 = \left\{ J_s \sum_{j=1}^{J_s - 1} (d_j - d_{j+1})^2 \right\} \Big/ \left\{ 2 \cdot (J_s - 1) \cdot (\sum X_j)^2 \right\} \tag{14}$$

where,

$$d_j = N_j - \hat{R}_s X_j \tag{15}$$

Finally, each of the clump factor used in the ratio C_1/C_2 is obtained by

$$C_z = S_z^2 \sum_{j=1}^{J_s} B_j \, , \qquad z = 1, 2. \tag{16}$$

Results

Lines in James Bay were flown from south to north from the 14 to 17 August. Conditions were clear and winds generally below Beaufort 2. No flights were made on 15 August owing to high winds. In eastern Hudson Bay, the southern lines 55°30' N to 56°45' N were flown from the 18 to 20 August. Winds along these lines were less than Beaufort 2. The remaining lines in eastern Hudson Bay, including the western ends of lines 56°00' N to 56°25' N (west of the Belcher Islands) which could not be surveyed on the 19 August because of fog, were surveyed from the 24 to the 27 August after the northern stratum. In Ungava Bay, systematic lines were flown from north to south with lines 61°00' N to 59°20' N surveyed on the 29 and 30 of August. Winds were light throughout the systematic survey of Ungava Bay (mean Beaufort 1.2), but fog and low clouds over water delayed the survey of the remaining southern lines to 3 September.

The position of observers and the size of the rear windows prevented any detection below an angle of 67°, or 194 m. The precision of the distance measurements decreased as the angle approached the horizontal. The pooled frequency distribution of the ungrouped perpendicular distances recorded for individual whales during the systematic survey of James Bay and eastern Hudson Bay indicates that observations become sparse beyond an angle of 15° or 1,706 m from the trackline (Figure 3). Consequently, we truncated the 717 observations at 1,800 m. Given the low effective number of sighting in eastern Hudson Bay, the remaining 696 perpendicular distances of individual whales from James Bay and eastern Hudson Bay were pooled to fit the combined sine^2 and Richards to model the detection function (Figure 4). According to the model, maximum detection was reached by 294 m and remained high for a narrow band slightly above 50 m and then started decreasing after 346 m. Integration of the function from 0 to 1,800 m provided an effective strip width of 604 m, leading to an expansion factor, $\hat{k}$, of 0.828/km, a bias-reduced expansion factor, $\tilde{k}$, of 0.784/km (SE 0.123/km) and a corresponding ESW of 638 m.

In James Bay, a total of 557 belugas were detected in 304 groups for a mean group size of 1.82 (SD = 1.49, maximum: 12)(Table 1). Sightings were concentrated in two areas, to the north of Akiminski Island and along the northwest coast of the bay (Figure 5). The unique bias-reduced expansion factor $\widetilde{k}$ of 0.784/km applied to the 544 whales detected within 1,800 m from the plane track on the 18.52 km spaced lines of James Bay produced a stratum estimate of 7,901 beluga (SE = 1,744) at the surface (Table 2).

One hundred and sixty beluga were detected as 64 different groups during the systematic survey of the southern stratum of eastern Hudson Bay. One particularly large group of 52 individuals was detected on line 56°35' N, in 3-5 m of water on the western coast of Gillies Island (part of Nastapoka Islands) (Figure 6). The average group size was 2.5 (SD = 6.6) (Table 1). This declined to 1.7 (SD = 2.3) when the group of 52 was omitted. The gregarious behavior of beluga in eastern Hudson Bay is also indicated by the contraharmonic mean (CHM) of group size which represents for the average beluga, the size of the group in which it has been detected. This means that a beluga in eastern Hudson Bay is on average in a group of 20, while in James Bay, a beluga is on average in a group of 3 (Table 1). Beluga observations along the southern lines of 55°30' N to 56°45' N accounted for 78% (125) of the total number of sightings during the systematic survey of eastern Hudson Bay, from the 18 to 20 August. All observations of beluga occurred in the eastern halves of the lines where winds were generally lighter (mean Beaufort was 2.0 for 42 observations) than in the western halves (mean Beaufort was 1.7 for 40 observations). No beluga were detected in northern eastern Hudson Bay stratum flown from the north to the south on 23 August. In the southern eastern Hudson Bay stratum, the 159 whales detected on the 9.26 km spaced transects provided an estimate of 1,155 beluga (SE = 507).

No beluga were detected in Ungava Bay. Systematic lines were surveyed from north to south with lines 61°00' N to 59°20' N surveyed on the 29 and 30 of August. Winds were light throughout the systematic survey of Ungava Bay (mean Beaufort 1.2 for 78 observations), but fog and low clouds over water delayed the survey of the remaining southern lines until 3 September.

The difference in uncertainty between strata reflected the difference in the sampling component of the total variance as the component associated with the estimation of *k* was estimated from the pooled distances. The uncertainty due to sampling associated with these estimates was more important for the southern eastern Hudson Bay strata with a C.V. of 43.8%, compared to a CV of 22.1% for James Bay (Table 4). The percentage of the total variance that was associated with sampling in eastern Hudson was 87%. This high variance is a reflection of difficulties associated with surveys of small clumped populations. During this survey, sightings consisted of a small number of groups, including a very large group of 52 animals. Overall, 81.1% (129/159) of all beluga were detected on only 4 non-consecutive transects which results in an increased variance.

Strip transect results for both years

For the strip transect analysis with a strip width of 2,000 m, all observations outside of the perpendicular distance range of 260 m to 1,260 m were omitted. In 2001 and 1993, the 511 and 248 animals retained on the 18.52 km spaced lines in James Bay produced respective estimates of 4,732 (SE = 712) and 2,296 (SE = 566) beluga at the surface (Table 3). In 2001, the 134 animals, retained on the 9.26 km spaced lines of the southern eastern Hudson Bay stratum, provided an estimate of 620 (SE = 263). In 1993, 99.5 and 24.5 animals were retained for the southern and northern strata, for respective surface detectable estimates of 461 (SE = 135) and 227 (SE = 154). This resulted in surface estimate of 688 (SE = 205) for eastern Hudson Bay in 1993 (Table 3).

The strip transect analysis provided lower estimates than line transect. The stratum ratio of line to strip transect estimates, averaged for both 1993 and 2001, was 1.52 for James Bay and 1.67 for eastern Hudson Bay. The method used had little effect on sampling error for the larger James Bay estimate, where CVs of line and strip transect methods were respectively, 25.1% and 24.7%

in 1993, and 22.1% and 15.1% in 2001. The same situation was observed for eastern Hudson Bay in 2001, where line and strip transect CVs were respectively 43.8% and 42.4%. However, in 1993, the strip transect analysis provided a CV of 29.8%, which was lower than the CV of 41.5% obtained from the line transect (Table 4).

Total abundance of beluga in each stratum was estimated by the addition of the counts in estuaries to the estimate of detectable beluga provided by the systematic strip and line transect surveys (Table 4). Neither the systematic strip nor the line transect take into account the proportion of animals that were underwater during the passage of the plane.

The ratio C_1/C_2 close to a value of 1 in eastern Hudson Bay for both 1993 and 2001 surveys indicates a uniform distribution of beluga in the stratum (Table 5). The clumping factor of 2.1 for James Bay in 2001 is higher than the clumping factor of 1.1 in 1993 and 1.0 reported by (Smith and Hammill 1986) in 1985. This higher clumping factor in 2001 suggests that the pattern of distribution of beluga within the Bay has changed over the years. Both of these observations likely illustrate an increase that is not uniform over the whole bay, with this increase occuring mostly in the two zones of concentration north of Akiminski Island and along the northwest coast of the Bay (Figure 5).

The coastal survey in eastern Hudson Bay was flown on 28 August and no whale was seen on the morning flight from 7h59 to 11h57, which followed the mainland coast and the Richmond Gulf coasts from Inukjuaq to Pointe Louis XIV, around Long Island and back to Kuujjuarapik (Figure 7). Winds were high from the south-west, from Beaufort 4 in Inukjuaq to 3.5 when we landed. Winds were lighter (Beaufort 2.5) during the second flight from 13h40 to 16h34 that followed the outside of the Nastapoka Islands to Cape Dufferin, around McCormack Is and back inside Hopewell Sound to Inukjuaq. A total of 69 whales were seen on the second flight, of which 39 were seen at the mouth of Little Whale River (56°00'36" N, 76°47'24" W), 11 were seen 7 km south of that position (55°56'24" N, 76°49'48" W), and another 16 outside Gordon and Mowat Islands (56°54'00" N, 76°41'24" W), in front of the Nastapoka River. The 39 animals detected in the Little Whale River estuary represent 24.4% of all animals detected in eastern Hudson Bay and represent 3.4% of the systematic offshore estimate. No belugas were seen during the coastal survey in Ungava Bay on 4 September. Winds were from the north and increased from Beaufort 2 in the morning from Kuujjuaq to Killiniq, to Beaufort 3 in the afternoon from Kuujjuaq to Quartaq. On 5 September, during the coastal survey of Hudson Strait and northeastern Hudson Bay coast, 3 beluga were detected close to Salluit, including a mother-calf pair in Sugluk Inlet. Strong winds from the south-west were lighter in the afternoon, and sea conditions along the coast averaged Beaufort 2.

Discussion

Three aerial surveys, in 1985, 1993 and 2001, have now been flown to evaluate beluga abundance in the waters adjoining northern Quebec. All three surveys have flown the same survey lines, but data from the 1985 survey were collected and analysed using strip transect methods (Smith and Hammill 1986). Strip transect methods assume that all animals at the surface, located between the aircraft and the outer limit of the transect are detected. The application of line transect methods, where data on numbers of animals and their distance from the aircraft are collected allows the 100% detection assumption to be tested. The modelling of the sight distribution curve showed that many animals are missed between the aircraft and a distance of 294 m from the aircraft. In the 2001 survey, the detectability of animals also decreased from a distance of 350 m out to a distance of 1,800 m, resulting in an effective strip width of 638 m. These data indicate that under similar conditions, a strip transect design with a stated transect width on either side of the aircraft will substantially underestimate beluga abundance. We attempted to develop a correction factor that could be applied to the 1985 survey results and which would make them more comparable to both the 1993 and 2001 surveys, where the data had been collected using line transect techniques (Kingsley 2000; this study). Correction factors developed from the 1993 and the 2001 surveys were similar and suggested that the 1985 aerial survey had underestimated beluga abundance by 34%. However, this correction factor may overestimate the difference between strip transect and line transect surveys to an unknown extent. Under strip transect conditions, all observation effort is concentrated within the 1,000 m strip thus likely increasing the chance of detection. In line transect surveys, the observer extends his search effort to greater distances, which may have a negative impact on sightings close to the aircraft. Efforts to measure distances from the aircraft, instead of simply noting numbers may also decrease detectability.

In the 1993 aerial survey, Kingsley (2000) fitted a sine^2 curve to the observations between the aircraft and the estimated point of g_{max}, and then a Richard's curve was fitted to the points to the right of g_{max}. Applying the same approach to the 2001 survey, we found that the plateau of probability curve was only 50 m, compared to a shoulder of 200 m in 1993 (Kingsley 2000). A narrower shoulder increases the sensitivity of the estimates to the type of curve that is fitted to the data, which results in a narrower ESW and a reduced sampling effort compared to the 1993 survey. This also increases the sampling component of variance. More observations were used in 2001 than in 1993 to adjust the probability curve, so this larger variance is likely a reflection that the 2001 observer team had limited experience compared to the 1993 observers.

Estimates for the number of beluga in James Bay show an increasing trend from 1985 to 2001, from a low of 1,213 to 4,732 for strip transect estimates, and from a low of 1,842 to 7,901 for line transect. This represents an annual increase of 7% to 12% using the different intervals (Table 4), which exceeds the 2-4% currently considered as likely rates of population increase, and the possible 5% using favourable estimates of mortality for species with similar life histories (Reilly and Barlow 1986). Currently, there is no regular harvesting of beluga in James Bay. The stock relationships of animals from this area, to the 'Western Hudson Bay' and 'Eastern Hudson Bay' beluga stocks are also unknown. It is tempting to propose that there is movement of beluga in and out of James Bay to the Ontario coast of Hudson Bay, or between the larger stock of animals from western Hudson Bay centered around Churchill, Manitoba. A second although admittedly less likely possibility, is that a proportion of beluga that used to summer in eastern Hudson Bay have moved further south since 1985. This would be in line with the hypothesis that beluga are avoiding estuaries because of disturbance. If this is the case, then James Bay would represent a refuge or a reservoir of additional eastern Hudson Bay animals. However, the increase in beluga abundance in James Bay is much greater than could be accounted for by the decline observed in eastern Hudson Bay, the paucity of aerial survey sightings along lines to the south of Great Whale River, and the absence of movement towards James Bay by animals followed by satellite telemetry (Kingsley *et al.* 2001) provide less support for this hypothesis. It is evident that an understanding of the stock relationships of animals in James Bay to other Hudson Bay stocks has important management implications.

The eastern Hudson Bay estimate is similar to 1993, but represents a 43% or 55% decrease since 1985 depending on whether comparisons are made using line transect corrected estimates or strip transect methods. The presence of the large group of 52 individuals in an area of about 0.25 km^2 in a small bay on the western side of Gillies Island (Nastapoka Islands), represented 32.5% of all animals detected in this stratum and had a major impact on the estimate. The high contraharmonic mean of group size of 20.3 in 2001 and 10.5 reported by Kingsley (2000), and the detection during the coastal survey of another group of 39 animals in the Little Whale estuary in an area of about 2 km^2, indicate that beluga are particularly gregarious in this area. If this group had not been seen on transect, then the systematic survey estimate would have declined from 1,155 to 777. Adding the 39 animals seen in estuaries during the coastal survey, would have resulted in an estimate of 816.

The aerial surveys point to a reduction in the distribution of beluga in offshore areas between 1985 and 2001 (Figures 6, 8 and 9). In 1985, a number of animals were seen offshore throughout the arc, and around the Belcher Islands. An evident reduction in the distribution of groups was observed in 1993, and this trend continued in 2001. Other differences were observed during the 2001 survey compared to the 1993 and 1985 surveys. The results from the 2001 eastern Hudson Bay coastal survey suggest that a lower number and proportion of beluga were using estuaries compared to 1993 and 1985. The number of beluga counted in estuaries was 474 in 1985 (33% of strip transect index; 23% of line transect index), 18 (3%; 2%) in 1993 and 39 (6%; 3%) in 2001. Although the effort was different between years, results show a decrease in the proportion of the population in estuaries or in the use of these sites by the Eastern Hudson Bay beluga during the summer. Susceptibility to near shore hunting in estuaries mentionned by Smith and Hammill (1986) could account for the lower numbers in estuaries in recent years. Other possible explanations proposed by managers and Inuit hunters, include an overall reduction in population size due to over-harvesting or avoidance of estuaries due to increased disturbance in the estuaries.

Beluga are present and are seen in Ungava Bay during the summer, but the absence of sightings during both the coastal and systematic surveys indicates that their numbers are extremely low. There used to be a substantial hunt for beluga in Ungava (see Reeves and Mitchell 1987) and substantial numbers were seen in estuaries such as the Mucalic as recently as the 1960's. During the transect surveys flown in 1985 and 1993, and during the current survey, no whales were observed within the effective transect distances. The 2001 survey also differs from the previous surveys in that no animals were seen in the coastal surveys either. The survey of Ungava Bay was completed a couple of days later than planned because of days of strong winds, which delayed our survey in Hudson Bay and because of 3 days of fog and low clouds in Ungava Bay. This raised some concern about beluga having left their summering estuaries by the time the systematic and coastal surveys were completed on 3 and 4 September respectively. However, we do not believe that this is likely owing to the extensive coverage of Ungava Bay, the fact that the survey started on 29 August at 61°00' N of latitude, which covers some of the area where 844 whales were observed during November 1980 (Finley *et al.* 1982). Furthermore, a group of 20 animals was seen during coastal aerial surveys at the Whale River as late as 27 August in 1993, and smaller groups of 6, 3 and 2 on 26 and 28 September 1982 (Smith and Hammill 1986).

The absence of whale observations in Ungava Bay, contrasts with reports of sightings by Inuit and harvesting earlier in the summer. It is possible to estimate a minimum population size needed to detect beluga on transect (Smith and Hammill 1986). Assuming a clumping factor of 10, and the current proportion of the area covered by the survey after 1,800 m truncation (25.5%), then a population of 157 animals is needed before an estimate with a CV of 50% could be obtained. Kingsley (2000) used off transect observations to estimate a possible population of 50 animals (upper confidence limit of 157) in Ungava Bay.

Beluga in the waters adjoining northern Quebec (Nunavik) are still hunted for subsistence reasons. The aerial surveys completed in 2001, confirm the presence of large numbers of beluga in James Bay, but considerable uncertainty remains concerning the stock relationships of these animals to other beluga occurring in Hudson Bay. The absence of beluga seen on transect in Ungava Bay is the same as reported for the 1993 and 1985 surveys and underlines the scarcity of animals in this region. Complete protection from hunting of beluga in this area is needed if there is to be any recovery of this stock. In Hudson Bay, the aerial survey estimates were similar to those obtained in 1993, but were much lower than the 1985 estimates, confirming a decline in population size since 1985. However, the 2001 estimates are very sensitive to the presence of a single large group seen on transect near the Nastapoka Islands. The slight increase shown by point estimates from 1993 to 2001, is not significant due to the high coefficient of variation associated with these surveys. Furthermore, the paucity of sightings offshore (106) and along the Hudson Bay coast compared to the previous surveys, the decline in mean age of the catch from eastern Hudson Bay (Lesage *et al.* 2001), and the low numbers seen in the Nastapoka River in recent years, compared to the 1980's and early 1990's suggest that this population continues to decline.

Management of exploited populations requires a precise estimate of the abundance index. Paradoxally, as the need for precise estimates increases as a population declines, the effectiveness of surveys often decreases owing in part to the clumped distribution of the species under study. In order to improve our estimates, additional methods of analysis or survey design are needed. In the current survey design for eastern Hudson Bay, animals are detected on 1.8 km on each side of the plane (total 3.6 km), but transect lines are 9.26 km apart. Assuming no change in the distribution of whales, a doubling of the number of transects, should lead to a significant reduction in the survey coefficient of variation. Significant reductions in the CV may also be achieved by taking into account the spatial distribution of sightings within transect lines in addition to the differences in distribution of whales between survey lines into the survey variance (McLaren *et al.* 2001).

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Table 1. Size of groups of beluga detected during the systematic aerial survey conducted from 14 to 27 August 2001.

	Group size			Effective number of sightings
	Mean	CHM[1]	SD	
James Bay	1.82	3.03	1.49	179.14
eastern Hudson Bay	2.5	20.3	6.6	7.8
Overall	1.94	6.93	3.12	101.38

[1] The contraharmonic mean (CHM) of group size represents for the average beluga, the size of the group in which it has been detected

Table2 . Line transect estimate of surface detectable beluga in James Bay and eastern Hudson Bay, using the combined sine^2-Richards modified curve to model decrease in detection function. The systematic aerial survey was conducted from 14 to 27 August 2001.

	Nb beluga used[1] B_s	Nb of transects J_s	Transect spacing(km) T_s	Number in stratum $\hat{N}_s$	variance (sampling) V_s	variance (estimation of *k*) V_k	SE
James Bay	544	25.5	18.52	7,901	1,513,021	1,528,102	1,744
eastern Hudson Bay south	159	26	9.26	1,155	223,977	32,635	507
eastern Hudson Bay north	0	7.5	18.52	0			
Ungava Bay south	0	13	9.26	0			
Ungava Bay north	0	10	18.52	0			

[1] Number of beluga used in the analysis after truncation.

Table 3. Strip transect estimate of surface detectable beluga present in James Bay and eastern Hudson Bay in August 1993 and 2001. Strip transect analysis was using observations detected between 260 m and 1260 m of perpendicular distance from the plane.

	Year	Count of beluga B_s	Nb of transects J_s	Transect spacing(km) T_s	Number in stratum $\hat{N}_s$	variance (sampling) V_s	SE
James Bay	1993	248	26.5[1]	18.52	2,296	320,492	566
	2001	511	25.5[1]	18.52	4,732	506,794	712
eastern Hudson Bay south	1993	99.5[1]	26	9.26	461	18,222	135
	2001	134	26	9.26	620	69,183	263
eastern Hudson Bay north	1993	24.5[1]	7.5[1]	18.52	227	23,784	154
	2001	0	7.5[1]	18.52	0		
eastern Hudson Bay Total	1993	124	33.5		688	42,007	205
	2001	134	33.5		620	69,183	263

[1] Decimal values in beluga count and number of transect arose from giving half weight of boundary transect to each stratum.

Table 4. Indices of beluga populations in James Bay, eastern Hudson Bay and Ungava Bay estimated from three systematic aerial surveys conducted in summer of 1985, 1993 and 2001.

		Systematic offshore estimate				Coastal count	Abundance estimate	
		Strip tran.		Line-tran.		Estuary	Strip tran.	Line-tran.
Stratum	Year	$\hat{N}_s$ (SE)	%CV	$\hat{N}_s$ (SE)	%CV	N_E {Total}	$\hat{N}$ (SE)	$\hat{N}$ (SE)
James Bay	1985	1,213 (290)[1]	23.9	*1,842*[4]			1,213 (290)[1]	*1,842*[4]
	1993	2,296 (566)	24.7	3,141 (787)[2]	25.1		2,296 (566)	3,141 (787)[2]
	2001	4,732 (712)	15.1	7,901 (1744)	22.1		4,732 (712)	7,901 (1744)
eastern Hudson Bay	1985	968 (165)[1]	17.1	*1,615*[4]		474 {481}[1]	1,442 (165)	*2,089*[4]
	1993	688 (205)	29.8	1,014 (421)[2]	41.5	18 {115-148}[2]	706 (205)	1,032 (421)
	2001	620 (263)	42.4	1,155 (507)	43.8	39 {69}	659 (263)	1,194 (507)
Ungava Bay	1985	0[1]						
	1993			88[3]				
	2001	0		0		0		0

[1] Results from Smith and Hammill 1986.
[2] Results from Kingsley 2000.
[3] Results from Kingsley 2000, with sightings made outside
[4] Data collected in 1985 did not allow a line transect analysis, so the value is the product of the strip transect estimate and the mean ratio of line/strip transect estimates for the given stratum for the two following surveys.

Table 5. Clumping factor estimated for beluga of James Bay and eastern Hudson Bay during the systematic aerial surveys of 1993 and 2001. A value of 1 for C_1/C_2 indicates uniform distribution, while higher values indicates clumping.

	Year	S_1^2	S_2^2	C_1	C_2	C_1/C_2
James Bay	1993	0.270	0.262	18.124	17.042	1.063
	2001	0.233	0.163	27.750	13.530	2.051
eastern Hudson Bay, south	1993	0.345	0.328	11.892	10.791	1.102
	2001	0.483	0.482	31.202	31.068	1.004
eastern Hudson Bay, north	1993	0.655	0.722	10.290	12.521	0.822
	2001					

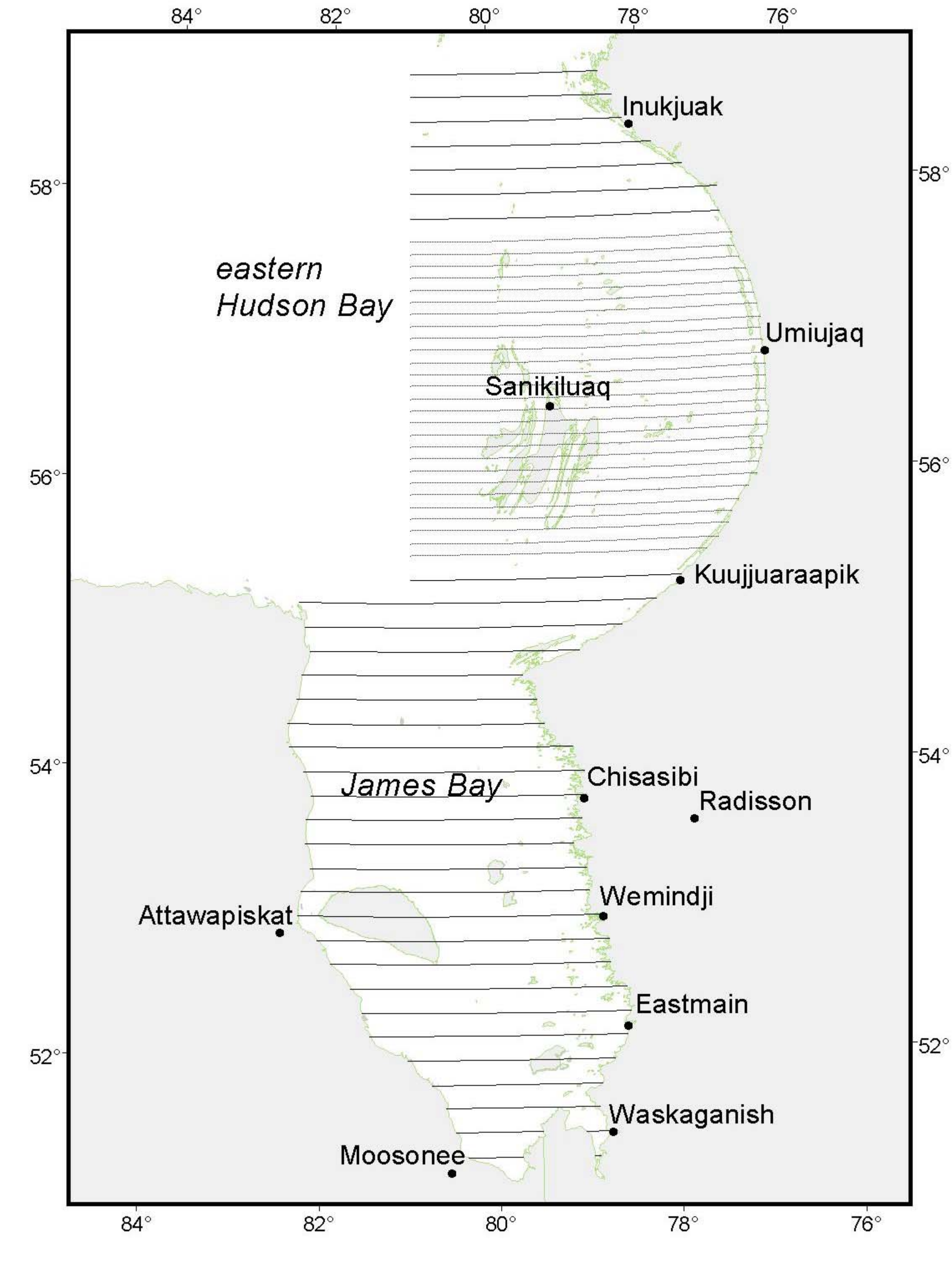

Figure 1. Lines surveyed during the systematic aerial survey conducted from 14 to 27 August 2001. The James Bay, the south and the north eastern Hudson Bay strata are distinguished by the different line formats.

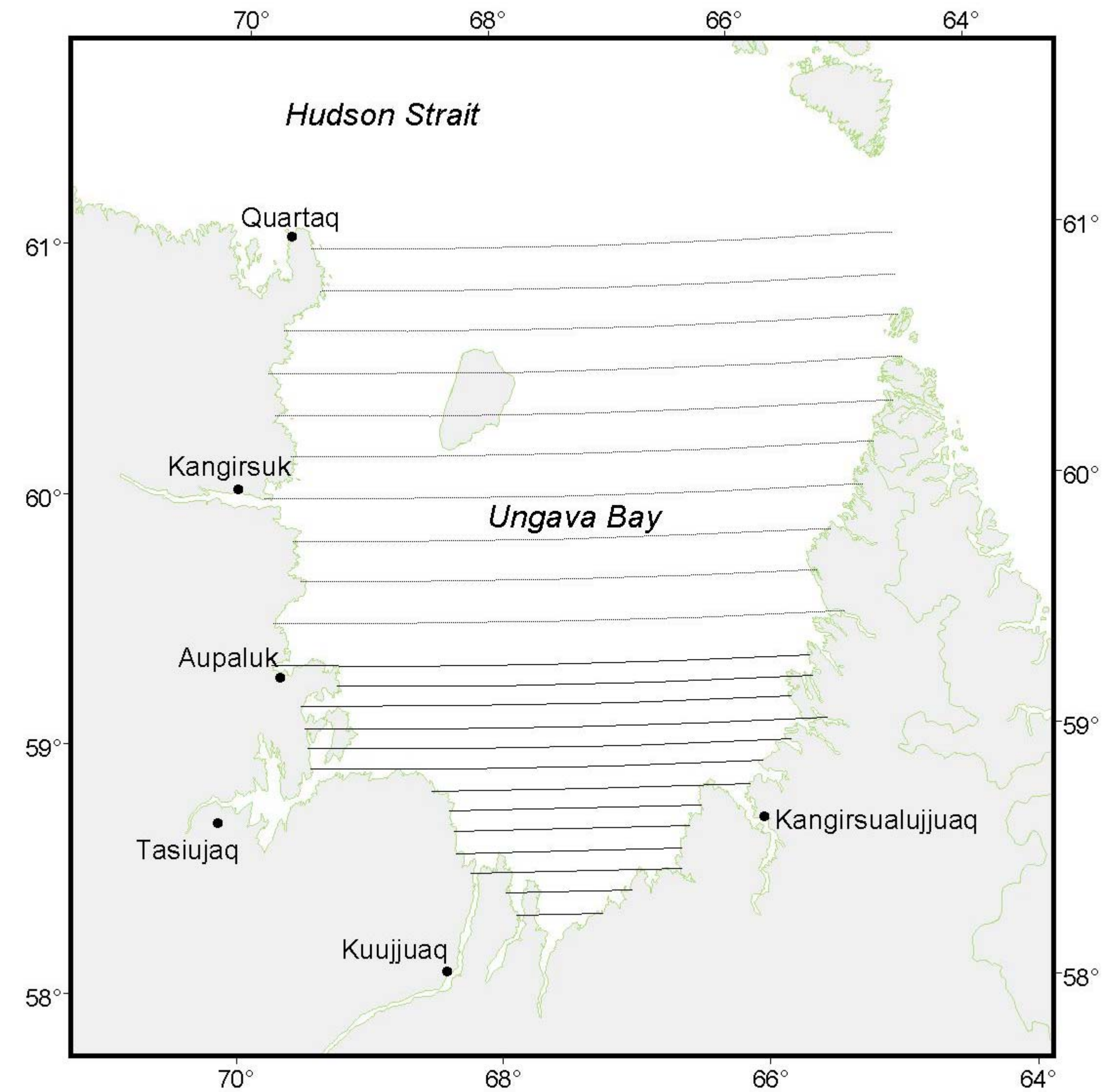

Figure 2. Lines surveyed during the systematic aerial survey conducted from 29 August to 3 September 2001. The north and south Ungava Bay strata are distinguished by the different line formats.

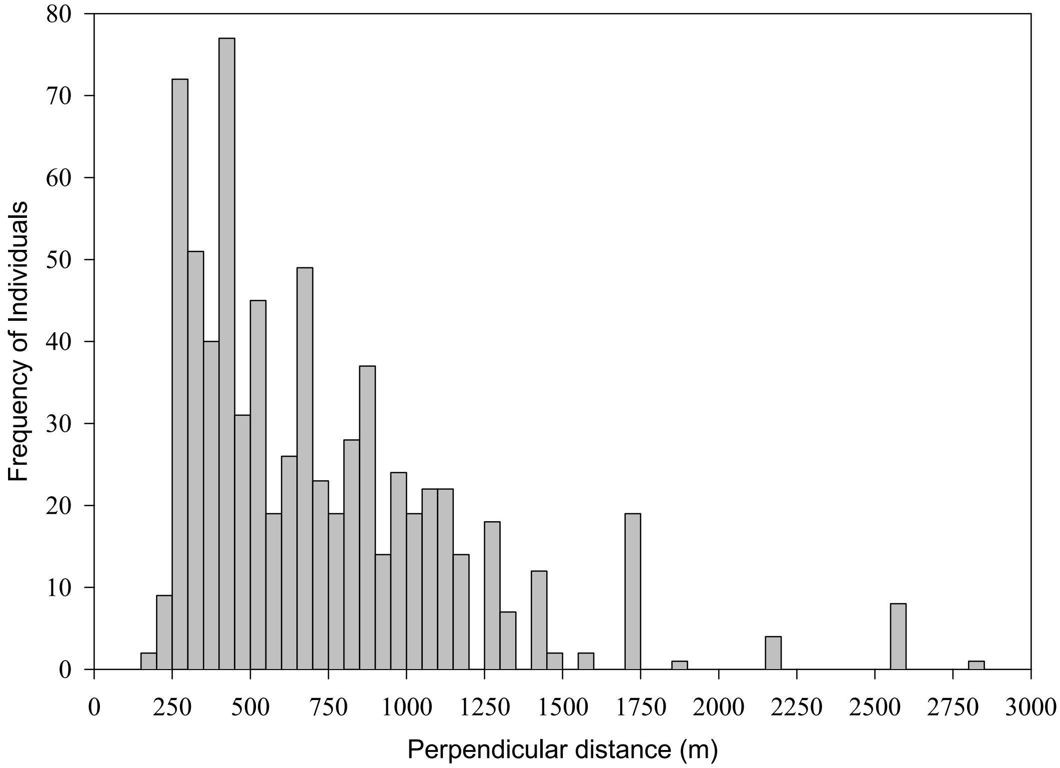

Figure 3. Frequency of detected perpendicular distances from the track line of individual beluga detected during systematic aerial survey of James Bay and eastern Hudson from 14 to 27 August 2001. Observations are grouped in 50 m bins on the graph, but the combined $sine^2$-Richards' curve was fitted to the ungrouped data.

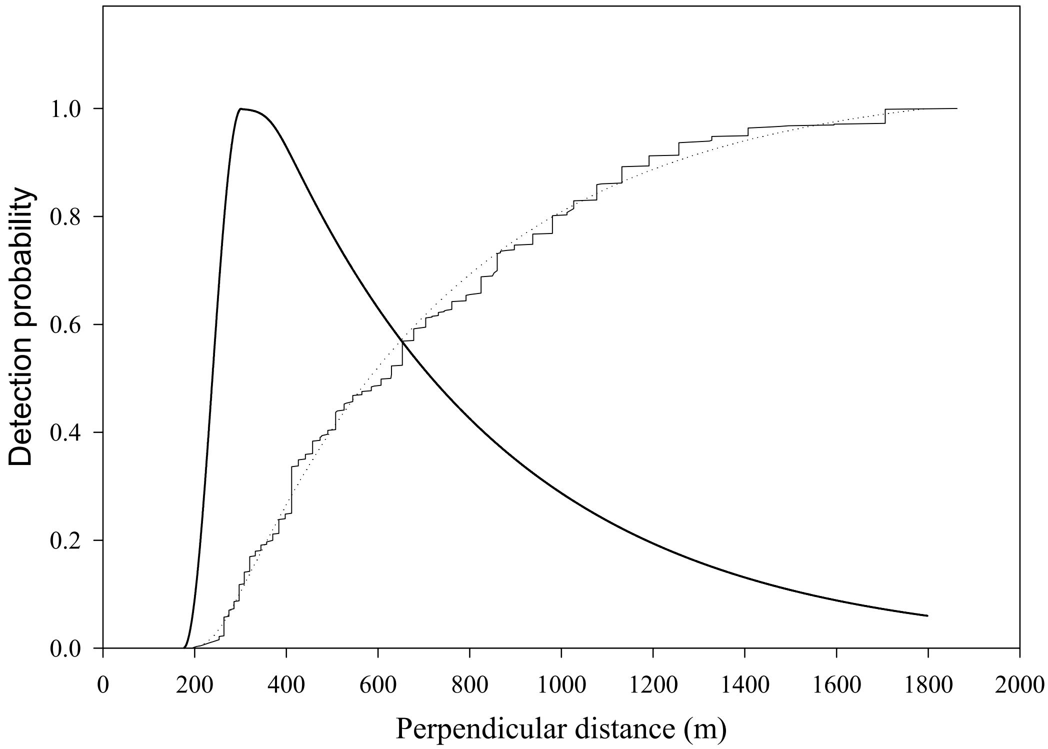

Figure 4. Detection probability function fitted to the ungrouped perpendicular observations of individual beluga during the systematic line transect survey of James Bay and eastern Hudson Bay in August 2001. A combined sine^2-Richards' curve model was fitted to the pooled observations of whales from James Bay and eastern Hudson Bay strata.

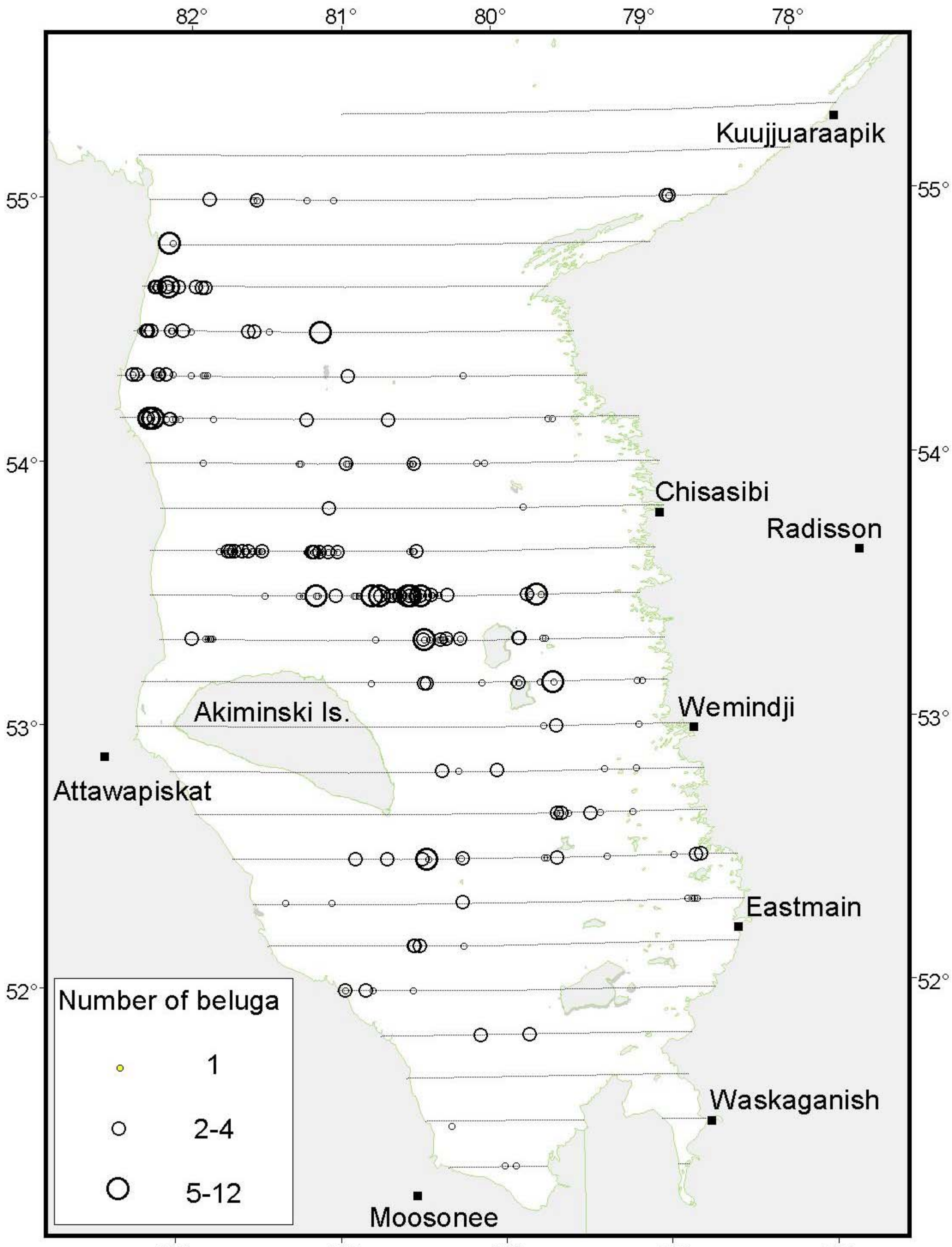

Figure 5. Distribution of beluga detected during the systematic aerial survey of James Bay from 14 to 17 August 2001.

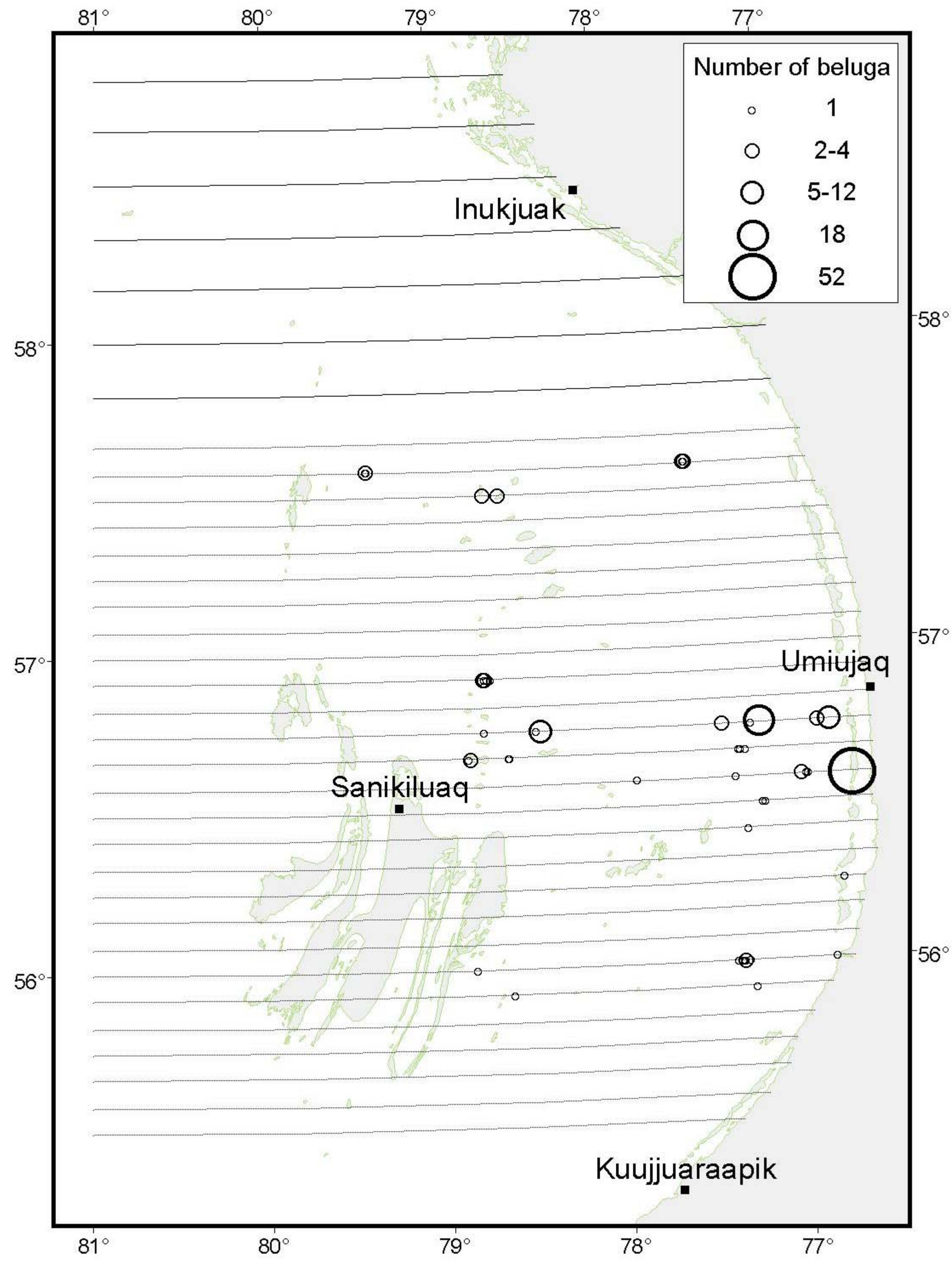

Figure 6. Distribution of beluga detected during the systematic aerial survey of eastern Hudson Bay from 18 to 27 August 2001.

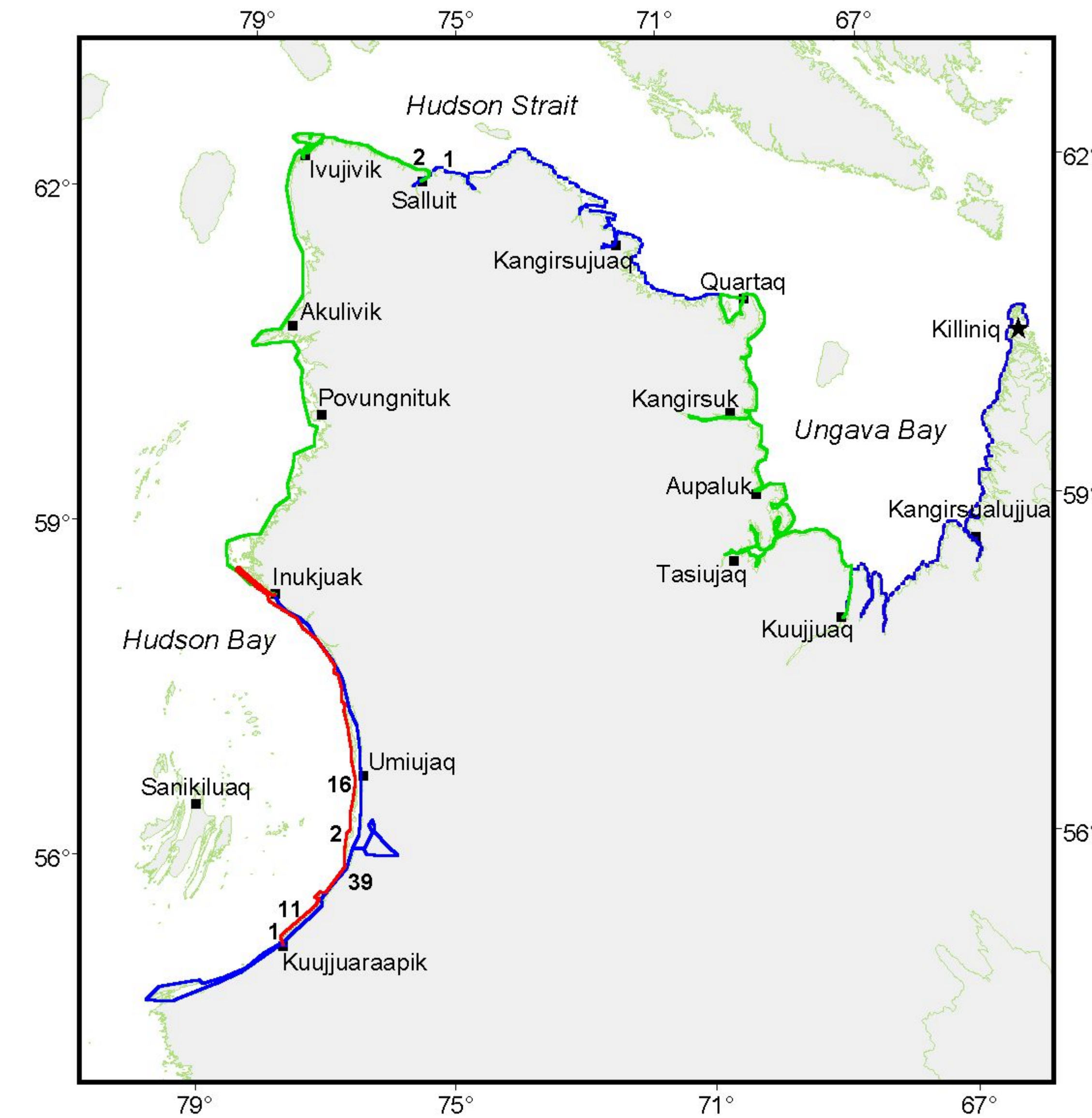

Figure 7. Coastal survey showing the position and number of beluga detected. Surveys were conducted on 28 August in eastern Hudson Bay arc, 4 September in Ungava Bay, and 5 September in Hudson Strait and northeastern Hudson Bay.

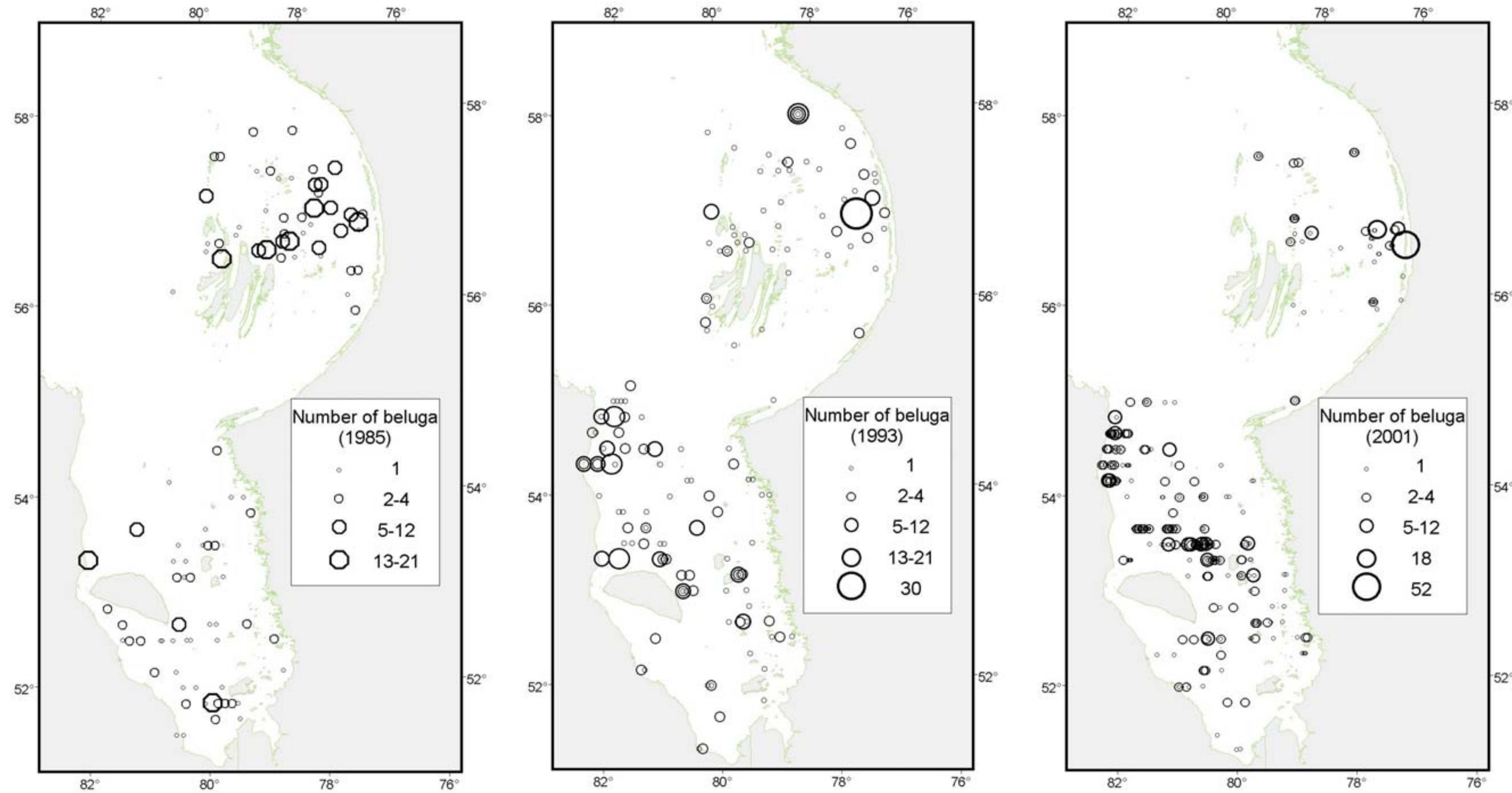

Figure 8. Differences in geographic distribution of groups detected during the aerial systematic surveys of 1985, 1993, and 2001. Group size was estimated in 1993 and 2001, while in 1985, symbol size represent the number of animals detected in 2 minutes of flying.

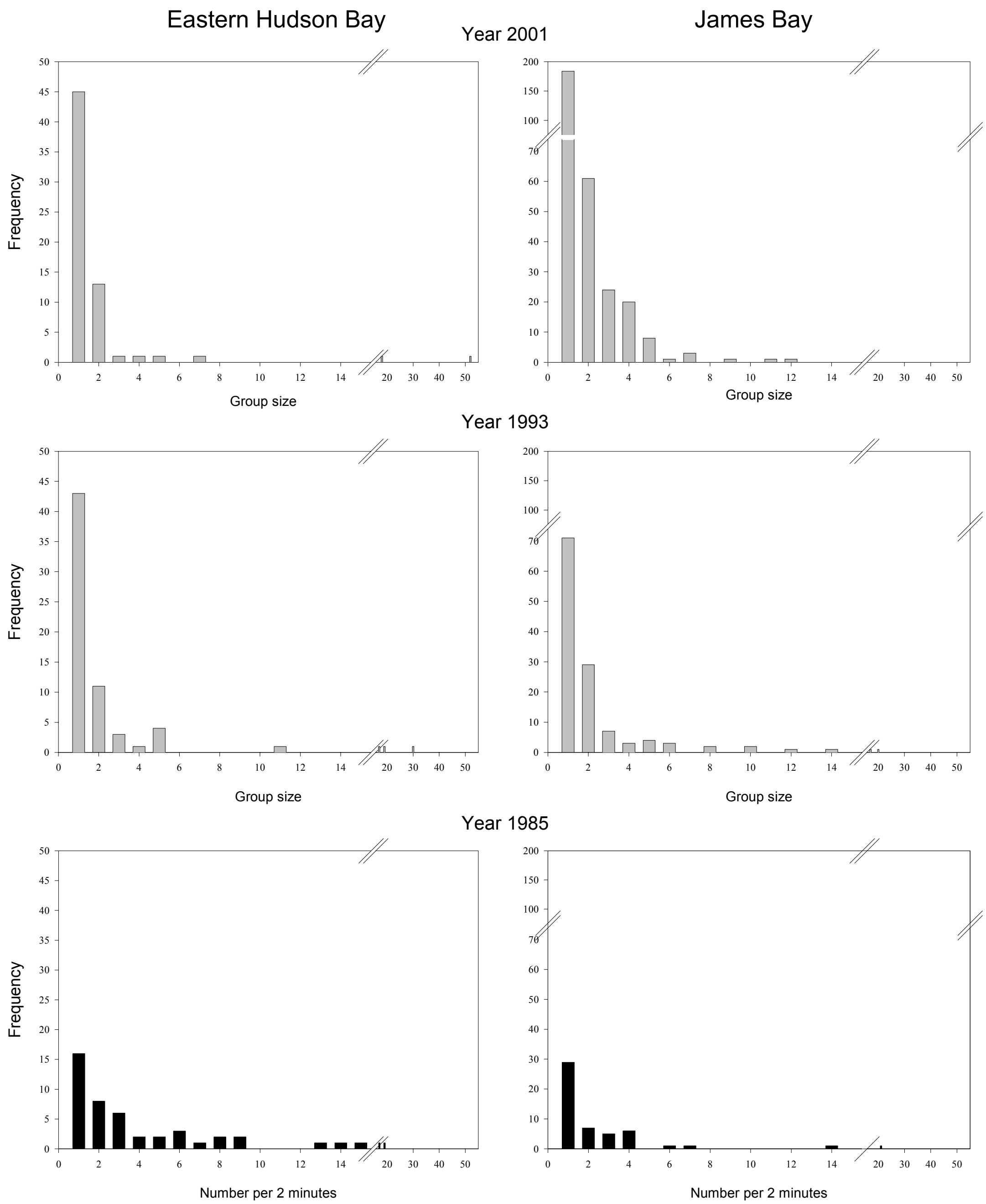

Figure 9. Distribution of group size and of number of beluga detected during 2 minutes intervals in eastern Hudson Bay and James Bay during the 2001, 1993 and 1985 systematic aerial surveys.