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Abundance estimate of beluga in eastern Hudson Bay and James Bay, summer 2011

J.-F. Gosselin, T. Doniol-Valcroze and M.O. Hammill

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

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Canada

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ABSTRACT

The management of beluga whales hunted around Nunavik relies on the estimation of abundance of summering stocks, including the endangered eastern Hudson Bay stock. Systematic aerial line-transect surveys to estimate abundance of beluga whales were conducted in James Bay and eastern Hudson Bay from 19 July to 18 August 2011. The flights followed east-west lines with a spacing of 18.5 km in all strata except in the central portion of eastern Hudson Bay, a high coverage area where spacing was reduced by half, *i.e.* 9.3 km. Unlike 2008, this stratum could not be surveyed twice because of unfavourable weather conditions. A total of 232 beluga clusters were detected between perpendicular distances of 190 m and 2173 m from the track line. When fitted to the ungrouped perpendicular distance data, the hazard-rate model (AIC = 3306.43) was selected over the half-normal model (AIC = 3308.99) and yielded an effective strip half width of 765 m (CV 6.8%). A total of 173 beluga groups with an average size of 3.38 (CV 15.7%) were detected on 4,182 km of lines in James Bay providing a surface abundance index of 7,154 (CV 27.3%). No animal was seen over the 995 km surveyed in the low coverage area of eastern Hudson Bay. Sixty-three groups of belugas were detected on the survey of the high coverage area of eastern Hudson Bay (6,684 km), with an average size of 3.21 (CV 37.2%), resulting in a surface abundance index of 1,433 (CV 47.1%). Abundance indices were corrected for the proportion of time animals are available at the surface to be detected (availability bias) but not for the proportion at the surface that are missed by observers (perception bias). The abundance index for James Bay, after correcting for submerged belugas, was 14,967 (CV 30.2%, 95% CI: 8,316 – 26,939). The abundance index in eastern Hudson Bay corrected for submerged animals and adding the 354 individuals counted in the Little Whale River estuary during coastal survey was 3,351 beluga whales (CV 48.9%, 95% CI: 1,552 – 7,855). This was the sixth visual systematic survey of James Bay and eastern Hudson Bay. High abundance indices in James Bay seem to be linked to the presence of high densities in the northwestern portion of the Bay. More information on movements and genetic identity from this large number of individuals is required to evaluate the stock relationship of belugas in this area. Belugas have a clumped distribution and abundance indices, especially for small populations such as eastern Hudson Bay, may be strongly influenced by the detection of a small number of large groups. Increasing sampling effort is one way of reducing the clumping problem, but the second survey planned for the high coverage area of eastern Hudson Bay could not be completed in 2011. The six available survey indices are comparable for the assessment of population trends. However, abundance indices of belugas from visual surveys could be improved by increasing sampling effort, by improving the estimation of group size and by developing more specific correction factors for availability and perception biases.

Estimation de l'abondance des bélugas de l'est de la baie d'Hudson et de la baie James, été 2011

RÉSUMÉ

La gestion des bélugas chassés au Nunavik repose sur l'estimation de l'abondance des stocks y passant l'été, incluant le stock de l'est de la baie d'Hudson qui est en danger de disparition. Des relevés systématiques aériens d'échantillonnage en ligne pour estimer l'abondance des bélugas furent complétés dans la baie James et l'est de la baie d'Hudson du 19 juillet au 18 août 2011. Les vols suivaient des lignes orientées d'est en ouest avec un espacement de 18,5 km dans toutes les strates sauf dans la partie centrale de l'est de la baie d'Hudson, zone de couverture plus dense où l'espacement était réduit de moitié, *i.e.* 9,3 km. Contrairement à 2008, cette strate n'a pu être survolée deux fois à cause de conditions météorologiques défavorables. Un total de 232 groupes de bélugas fût détecté entre les distances de 190 m et 2 173 m perpendiculaires au trajet de l'avion. Le modèle « hazard-rate » (AIC = 3 306,43) fût sélectionné plutôt que le modèle demi-normale (AIC = 3 308,99) pour l'ajustement sur la distribution des distances perpendiculaires non-regroupées, a fourni une demi-largeur de bande de détection efficace de 765 m (CV 6,8 %). Un total de 173 groupes de bélugas avec une taille moyenne de 3,38 (CV 15.7 %) furent détectés sur 4 182 km de lignes dans la baie James produisant ainsi un indice d'abondance d'animaux à la surface de 7 154 (CV 27,3 %). Aucun animal ne fut observé sur les 995 km survolés dans la strate de faible couverture de l'est de la baie d'Hudson. Soixante-trois groupes de bélugas furent détectés dans la zone de couverture intense de l'est de la baie d'Hudson (6 684 km) avec une taille moyenne de 3,21 (CV 37,2 %) produisant un indice d'abondance d'animaux en surface de 1 433 (CV 47,1 %). Les indices d'abondance furent corrigés pour la proportion de temps que les animaux sont disponibles en surface pour être détectés (biais de disponibilité), mais pas pour la proportion en surface qui est manquée par les observateurs (biais de détection). L'indice d'abondance pour la baie James, après correction pour les animaux en plongée était 14 967 (CV 30,2 %; intervalle de confiance à 95 %: 8 316 – 26 939). L'indice d'abondance dans l'est de la baie d'Hudson corrigé pour les animaux en plongée et en ajoutant les 354 individus comptés dans l'estuaire de la Petite-Rivière-à-la-Baleine lors du relevé côtier était de 3 351 bélugas (CV 48,9 %; intervalle de confiance à 95 %: 1 552 – 7 855). Ceci était le sixième relevé visuel systématique de la baie James et de l'est de la baie d'Hudson. Des indices élevés d'abondance dans la baie James semblent être liés à la présence de fortes densités dans la région nord-ouest de la baie. Davantage d'information sur les mouvements et l'identité génétique de ce grand nombre d'individus est nécessaire pour évaluer la relation des stocks de bélugas dans cette région. Les bélugas ont une distribution agglomérée et les indices d'abondance, particulièrement ceux de petites populations comme celle de l'est de la baie d'Hudson, peuvent être fortement influencé par la détection d'un petit nombre de larges groupes. Augmenter l'effort d'échantillonnage est l'une des solutions pour réduire le problème de distribution agglomérée, mais le second relevé planifié pour la zone de couverture intense de l'est de la baie d'Hudson n'a pu être complété en 2011. Les six indices d'abondance disponibles sont comparables pour l'évaluation de la tendance des populations. Cependant, les indices d'abondance de bélugas provenant de relevés visuels pourraient être améliorés en augmentant l'effort d'échantillonnage, en améliorant l'estimation de la taille des groupes et en développant des facteurs de correction plus spécifiques pour les biais de disponibilité et de détection.

INTRODUCTION

Beluga whales, *Delphinapterus leucas*, are observed during the summer along the coasts of Hudson Bay, in James Bay and in Ungava Bay. Molecular genetic studies indicate at least two stocks: a western Hudson Bay stock and an eastern Hudson Bay stock (Brennin et al. 1997; Brown Gladden et al. 1997; De March and Postma 2003). Genetic studies (Turgeon et al. 2012) and satellite telemetry (Bailleul et al. 2012) have shown that these two stocks overwinter together where they likely interbreed. Beluga in James Bay appear to constitute a distinct breeding population (Postma et al. 2012).

Commercial whaling during the eighteenth, nineteenth, and early twentieth centuries initiated the decline of beluga stocks in northern Quebec, but high subsistence harvests have likely limited their recovery (Doan and Douglas 1953; Finley et al. 1982; Reeves and Mitchell 1987a; Reeves and Mitchell 1987b). Concerns for beluga in eastern Hudson Bay and Ungava Bay led to their designation as ‘endangered’ by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2004; Reeves and Mitchell 1989, Richard 1993).

Beluga harvesting represents a traditional activity for native people living along the coasts of Nunavik. Beginning in 1986, limits were placed on harvesting as a result of low estimates of beluga abundance in eastern Hudson Bay and Ungava Bay. In spite of these controls, population modelling incorporating harvest information since 1974, and fitted to data from three aerial surveys flown during the period 1985–2001 indicated that the number of beluga in eastern Hudson Bay continued to decline as late as 2001 (Hammill et al. 2004). This led to more stringent management measures, including complete closures to hunting of beluga whales in eastern Hudson Bay and Ungava Bay in some years and directing more of the harvest to Hudson Strait (Lesage et al. 2009). In recent years, the population appears to have stabilized at around 3,200 animals (Doniol-Valcroze et al. 2012a).

Beluga harvesting by Nunavik Inuit has been managed under the jurisdiction of DFO. The signing of the Nunavik Inuit Land Claims Agreement (NILCA) transferred co-management responsibility to the Nunavik Marine Region Wildlife Board (NMRWB) established under the agreement. In this context, the current study presents abundance indices obtained from systematic line-transect aerial surveys conducted during summer 2011 in James Bay and eastern Hudson Bay.

MATERIALS AND METHODS

STUDY AREA AND SURVEY DESIGN

The visual line-transect survey flown in summer of 2011 covered all of James Bay, and the eastern Hudson Bay arc from the coast to 81°W of longitude which is 60 km west of the Belcher Islands (Fig. 1). We used the same stratification in James Bay and eastern Hudson Bay as used for the previous surveys in 2004 and 2008 (Gosselin 2005, Gosselin et al. 2009). The limits of each stratum lies in regions of relatively low density determined from previous aerial surveys, satellite tracking of beluga whales captured in eastern Hudson Bay and James Bay (Bailleul et al. 2012), and traditional ecological knowledge (Lewis et al. 2009). Transect lines were oriented in an east-west direction. There were 24 lines in James Bay, 8 lines in the low coverage area of eastern Hudson Bay and 31 lines in the high coverage area. Lines in James Bay and in the low coverage areas of eastern Hudson Bay were spaced 18.5 km (10 nautical miles) apart, whereas spacing in the high coverage areas of eastern Hudson Bay was 9.3 km (5 nautical miles). The length of transect lines (used to estimate density) and the area of strata (used to estimate abundance) were both measured in GIS (Arcview 3.2) using zone 17 of the Universal Transverse Mercator (UTM) projection, with 81° W as the central meridian. The intent was to survey the high coverage areas of eastern Hudson Bay twice and the low coverage areas of James Bay and eastern Hudson Bay once using a systematic line transect design. A survey of Ungava Bay similar in coverage to that of 2008 was also planned. The second survey of the high coverage area of eastern Hudson Bay and the survey of Ungava Bay were finally abandoned due to weather delays in eastern Hudson Bay.

Coastal surveys were flown while on transit between lines, as well as between transects and the airports. In eastern Hudson Bay, the estuaries of the Little Whale River and of the Nastapoka River were visited every time a transit was passing by, weather permitting. During coastal surveys, the planes were flying offshore at a distance where observers were comfortable that they would detect all animals from the plane to the coast. Digital pictures were taken when large numbers of belugas were detected and the animals were counted on adjacent pictures using the maximum count of non-overlapping areas as group size.

DATA COLLECTION

Flights were conducted using two Cessna-337 Skymasters flying at a target altitude of 305 m (1000 feet) and a target speed of 185 km/h (100 kts). Each plane flew every second line of the survey design. At least two observers were continuously onboard the plane, one in the co-pilot seat and one behind the pilot. An Inuit observer was also present behind the co-pilot observer for most of the flights. Unlike previous surveys, the planes were not equipped with bubble windows.

Observers measured distances using inclinometers (Suunto) when animals passed abeam. When groups were detected away from the transect line, the angle relative to bearing was also measured using an anglemeter. Position and altitude of the plane were recorded every 10 s using a GPS (Garmin GPS 76, GPS Map 60C) connected to a laptop running an electronic map software (Fugawi). Observers were instructed to give priority to the estimation of group size, especially when beluga densities were high, followed by perpendicular distance and other variables if time permitted. Transects were generally flown in passing mode, but closing mode or multiple passes were done if very large concentrations were detected from the lines.

Weather and observation conditions were also recorded at the beginning, at the end and at regular intervals along the lines or whenever changes in sighting conditions occurred. The conditions noted included sea state (Beaufort scale), subjective visibility (5 levels: excellent, good, medium, reduced, none), angle of searching area affected by sun reflection along with sun reflection intensity [4 levels: 1- intense when animals were certainly missed in the center of reflection angle; 2- medium when animals were likely missed in the center of reflection angle, 3- low when animals were likely detected in center of reflection angle and 4- none when there was no reflection]. All the information was recorded on digital voice recorders by each observer.

DATA ANALYSIS

The density and abundance were estimated using the software Distance (Version 6.0, Release 2; Thomas et al. 2009). The analyses were completed using the ungrouped distances and clusters defined as groups of beluga whales within a few body lengths of each other.

The overall distribution of perpendicular distances was examined for left and right truncations, which were determined so that only the outliers close to and away from the track line were discarded. The detection curve was selected between half normal and hazard rate models using AIC. The survey was conducted with the same crew throughout the survey (one day was flown with a replacement observer who had previous experience with beluga survey) and the criteria to fly the survey remained the same throughout the survey. Therefore, a single detection curve was used to estimate density and abundance in all strata.

The expected cluster size in each stratum was estimated using the size bias regression method of the natural log of cluster size against the probability of detection (Ln(s) vs g(x)). The regression was used if significant at α = 0.15; otherwise the mean cluster size was used (Buckland et al. 2001).

Because observers were instructed to give priority to group size estimation, some observations were lacking a perpendicular distance measurement (usually when high densities of beluga whales were encountered). These observations were not included in the selection of the detection function nor in the regression of natural log of cluster size against probability of detection [Ln(s) vs g(x)]. However, these observations were all assumed to be within truncation distances as we expect that the effective searching width was narrowed in higher densities. Therefore, these observations were included in the estimation of encounter rates and expected cluster size for the estimation of density and abundance. This was done in Distance by adding all observations without perpendicular distance to observations within truncation distances and by fitting a uniform model with the following multipliers estimated from observations within truncation distances: the estimated probability of detection, *P* (along with SE and degrees of freedom) which is associated with the estimation of the effective strip half width (ESHW) and a constant truncation multiplier [= right truncation/(right truncation - left truncation)].

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

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

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

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:

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

The distribution of density is assumed to be log-normally distributed, and the 95% CI was estimated using:

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

where

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

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

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):

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

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, ESHW* and $\hat{E}(s)$.

The total abundance index for eastern Hudson Bay was obtained by the addition of low coverage areas (HN and HS) and the high coverage area (HC). The abundance indices for each stratum were not corrected for perception bias and thus represent the number of animals detected at the surface by a single platform. Corrections were applied for availability bias to account for diving animals multiplying the systematic abundance estimate by P_S = 0.478 (SE=0.0625, df=71) as the proportion of time beluga remain visible from an aerial survey platform estimated in the St Lawrence estuary (Kingsley and Gauthier 2002). Beluga detected in estuaries were assumed to represent total counts and were added to the corrected estimates.

RESULTS

SURVEY COMPLETION

The survey of James Bay was conducted from south to north from July 19 to July 25, 2011, with one interruption of 3 days from the 22 to 24 July between lines 5349 and 5359. We then completed James Bay and the southern low coverage area (HS) on July 25 and 26 (JB5359 to HS5519). The first pass of the high coverage area (HC) was completed from July 26 to August 17. There were numerous interruptions during that time: two 1-day delays on July 29 (after line HC5559) and July 31 (after line 5619), a 9-day interruption from August 3-9 (after line HC5659), and a 6-day interruption from August 11-16 (after line HC5739). The HC stratum was eventually completed on August 17. The northern low coverage area (HN) was completed on August 18. After a long period of bad weather until the beginning of September, the second pass of the high coverage area of eastern Hudson Bay was abandoned because of concerns that some beluga might leave the study area before the stratum could be completed. Some lines in the northern part of HC were not covered completely due to fog.

BELUGA SIGHTINGS

A total of 248 groups corresponding to 825 individual beluga whales were detected while on effort along transect lines (183 clusters for 615 individuals in James Bay and 65 groups for 210 beluga whales in eastern Hudson Bay (Table 1). No beluga was observed in the lower coverage areas of eastern Hudson Bay (HN and HS).

All the estuaries along the eastern Hudson Bay coast were visited at least twice during the survey. The Nastapoka River estuary was visited ten times on three different days (2, 10 and 17 August), and no beluga whales were seen in the estuary. The Little Whale estuary was visited three times on the two days that the lines were flown directly in front of the estuary (5549 to 5619). Daily maximum of 354 and 330 beluga whales were counted on pictures of the Little Whale River estuary on 28 and 30 July respectively. The maximum of 354 belugas was added to the systematic survey estimate as the large group of belugas remained in the estuary on both days the area was surveyed.

Of the 615 beluga observed in James Bay, only 24 (12 groups) were located within the Nunavik Marine Region (NMR) and 591 (171 groups) were in the Nunavut Settlement Area (NSA) (Figure 2). Of the 210 whales sighted in eastern Hudson Bay, 170 (46 groups) were located in the NMR (including 125 beluga in 25 groups in the Equal Use and Occupancy Area (EUOA), and 40 (19 groups) were sighted in the NSA (Figure 3).

DETECTION CURVE

Out of the 248 groups sighted, 3 groups (2, 6 and 23 whales) were missing perpendicular distances measurements in James Bay and 1 group (10 whales) was missing a distance measure in eastern Hudson Bay. Animals were not detected under the plane and only 11 groups (37 individuals) were detected within 190 m of the track line. Animals were detected at regular intervals of perpendicular distance beyond 190 m which was used as the left-truncation. Beluga whales were detected regularly as far as 2173 m away, a distance which was used as the right truncation, and which discarded only one animal with an estimated detection distance of 2970 m. Buckland et al. (2001) suggest to truncate all observations further than the distance to which the hazard rate model on overall distances estimates a probability of detection equal to 0.15. However, using a right truncation of 1322 m instead of 2173 m did not improve the fit near the trackline or in general (Cramer-von Mises with cosine and uniform weighting function: p =0.9 vs 0.9 and p = 0.9 vs 0.8 for 1322 m and 2173 m respectively) nor did it reduce the efficiency of the hasard-rate model (Effective strip half width CV: 8% vs 7% for 1322 m and 2173 m respectively). Therefore, the latter value was kept as the right truncation distance.

The hazard-rate model was selected as the key function model as it provided a lower AIC (3306.43) than the half-normal model (AIC = 3308.99) when applied over the 232 observations remaining between the truncations distances of 190 m to 2173 m from the track line. This provided an effective strip half width of 765 m (Fig. 4). Fitting a different detection for James Bay and eastern Hudson Bay did not reduce the AIC (3310.21), supporting the use of a single detection curve for both strata. Given these truncation distances and the detection function, the multipliers to apply to the uniform model to include observations without perpendicular distances were an estimated probability of detection, P, of 0.3522 (SE = 0.0240, df = 230) and a truncation multiplier of 1.0958.

ENCOUNTER RATES

In James Bay, 173 groups were detected within the truncation distances (including groups without distance measurements), resulting in an encounter rate of 0.0414 groups/km (CV 21.2%). In the high coverage stratum of eastern Hudson Bay, 63 groups were detected within the truncation distances (including groups without distance measurements), resulting in an encounter rate of 0.0094 groups/km (CV 28.1%).

GROUP SIZE

The 173 groups detected in James Bay had a mean group size of 3.38 with a CV of 15.7% (Fig. 5). Mean group size was similar for the 63 groups detected in the higher coverage area of eastern Hudson Bay with 3.21 whales per cluster, but with a much larger CV (37.2%). This high CV is mostly due to one large group of 75 whales (without which the CV would be 14%). The regression of the natural log of cluster size on the probability of detection was not significant. Therefore, the mean cluster size was used as the expected cluster size $\hat{E}(s)$ to estimate density.

DENSITY AND ABUNDANCE ESTIMATES

Using the same detection curve for all strata (i.e., the same ESHW), and mean group sizes specific to each stratum, resulted in abundance indices of 7,154 beluga (95% CI: 4,189 – 12,220) for James Bay and 1,433 beluga (95% CI: 589 – 3,484) for eastern Hudson Bay (Table 2). These density and abundance indices were not corrected for availability bias and therefore represent the number of animals detected at the surface by a single platform. The high coefficient of variation of 47.1% observed in eastern Hudson Bay is associated with high clumping of beluga whales in the area, as indicated by the high CVs of both encounter rate (28.1%) and cluster size (37.2%). Decomposition of the variance shows that the encounter rate and the group size are responsible for 35.5% and 62.4% of the total variation, respectively.

Correcting for submerged animals and adding the count of 354 belugas from Little Whale River resulted in an abundance estimate of 3,351 beluga whales (CV 48.9%, 95% CI: 1,552 – 7,855) in eastern Hudson Bay. The abundance estimate for James Bay, after correcting for submerged beluga, was 14,967 (CV 30.2%, 95% CI: 8,316 – 26,939).

DISCUSSION

The 2011 survey is the sixth of a series of systematic surveys undertaken since 1985 in James Bay and eastern Hudson Bay (Smith and Hammill 1986; Kingsley 2000; Gosselin et al. 2002; Gosselin 2005; Gosselin et al. 2009) (Table 3).

JAMES BAY

At almost 15,000 beluga, the 2011 estimate of abundance for James Bay is much higher than the 2004 estimate (8,364) but lower than that of 2008 (19,439). Its CV of 30% is comparable to that of previous years (24%–30% for 1993–2004) and much lower than that of 2008 (66%).

During the last assessment, it was remarked that the 2008 estimate would correspond to a rate of increase of approximately 18% per year from the 2004 estimate, a rate much higher than the 2-4% generally assumed for beluga and other species with similar life history (Kingsley 1989; Barlow and Boveng 1991; Kasuya et al. 1988; Hammill et al. 2004). In contrast, compared to the

2001 survey estimate of 17,285, it represented a more plausible annual rate of increase of 1.7%. However, the 2008 survey was also the most imprecise of the time series.

The 2011 estimate is more precise and supports the possibility that the JB population falls in the higher range of the estimates (>10,000, as suggested by the 2001, 2008 and 2011 surveys) rather than the lower range (< 10,000, as suggested by the 1985, 1993 and 2004 surveys). We also note that a population of ca. 5,000 beluga in 1985 growing at a rate of 4% would number ca. 14,000 individuals (assuming exponential growth and no removals). It is therefore not impossible to reconcile these estimates.

However, we also note that a high proportion of sightings in the 2011 survey occurred in the northwestern portion of the bay (Fig. 2). A similar pattern was also observed during the 1993, 2001 and 2008 surveys, but not during the1985 and 2004 surveys (Smith and Hammill 1986, Kingsley 2000, Gosselin 2005, Gosselin et al. 2002, 2009). The northwestern James Bay area was not surveyed in 1985 due to the presence of heavy consolidated pack ice which was assumed to contain few belugas (Smith and Hammill 1986). In the 2004 survey, a lower proportion of sightings was from the northwestern James Bay area, and the survey from this year corresponded to the lowest abundance estimate of the series. Beluga whales are also found along the Ontario coast, and the variability in sightings in the northwestern James Bay area may reflect movement between the two areas, although this is not supported by the limited genetic data and limited satellite telemetry information from James Bay which suggest that James Bay animals form a distinct group on their own (Postma et al. 2012; Bailleul et al. 2012) More information is needed from the northwestern area of James Bay and the southeastern Ontario coast of Hudson Bay to understand the stock relationships of beluga in this area.

EASTERN HUDSON BAY

At about 3,350 beluga, the EHB abundance estimate is higher than that of 2008 (2,646) but lower than the 2004 estimate of 4,274 beluga. Overall, it is in line with previous surveys (Table 3) and with model predictions of the stock abundance for that year (Doniol-Valcroze et al. 2012a).

Survey conditions differed slightly from previous years because of the lack of bubble windows, which limited visibility close to the track line (underneath the plane). This might explain the larger left-truncation used in 2011 than in 2004 and 2008. As long as we can assume that the probability of detecting a beluga at the surface close to the left-truncation limit was at its maximum and that it was maintained to a certain distance to produce a shoulder in the distribution of detections, then the hazard-rate or half-normal models should still provide a precise estimate of effective strip half width. The difference in AIC values between the hazard-rate and the half-normal models was smaller than in previous years, suggesting that it was harder to discriminate between the two detection curves in a survey using flat windows than with bubble windows. However the cv of 6.8% of the of effective strip half width is within the range of cv (4.8% to 11.2%) estimated in surveys from 1993 to 2008.

The 2011 survey in EHB suffered from several logistical problems (mostly a combination of plane maintenance and bad weather) that resulted in numerous interruptions and delays. These delays raise two concerns: the possibility that animals moved between lines, resulting in some animals being missed or counted several times; and the possibility that some beluga might have started migrating away from the area.

Interruptions between lines are usually not cause for concern when estimating density unless large numbers of animals undertake directional movements which could introduce bias

(Buckland et al. 2001). Although we lacked concurrent data from satellite telemetry studies, satellite transmitters deployed in eastern Hudson Bay from 1999 to 2004 showed that, in August, most individuals perform repeated inshore-offshore movements of a few hundred kilometres between river estuaries and offshore areas, but no directed north-south movements were observed (Bailleul et al. 2012; Doniol-Valcroze et al. 2012b). This type of repeated movements would not be expected to bias density estimates.

Similarly, we have no reason to believe that EHB beluga had already started their migration by the end of the survey on 18 August which would have introduced a negatively biased abundance estimate. Movements from tagged animals have shown that migration usually starts in late September and peaks in October (Kingsley et al. 2001; Bailleul et al. 2012).

Some portions of lines in the northwest part of the central stratum of eastern Hudson Bay were not surveyed. This area accounted for about 13% of the central stratum. Movement information obtained from satellite transmitters shows that animals tagged in the estuaries of the Little Whale River and Nastapoka River use this area during the months of July and August (Lewis et al. 2009). Therefore, abundance of eastern Hudson Bay was estimated by applying the average whale density on the surveyed transects to the entire central stratum area. In previous surveys an average of 5%, (median of 1.3%; range 0 to 25%) of the belugas observed during the Hudson Bay survey were detected in the area that was not surveyed. If the lines had been surveyed and the equivalent of 0%, 1.3%, 5% or 25% of belugas (*i.e.* 0, 3,10 or 66 individuals) had been detected on those lines, the resulting abundance estimate for eastern Hudson Bay including the coastal count would have been 89%, 90%, 93% or 115% of the abundance of 3,351 estimated, which is well within the current 95% confidence interval.

We note that the CVs of 2008 and 2011 are comparable (47% vs. 49%), despite the fact that these problems did not occur during the 2008 survey (which was completed quickly and with few interruptions). The analyses showed that the high CV in 2011 is due to the occurrence of a few large clusters (uneven distribution of group size among sightings) and to variable encounter rates (uneven distribution of clusters among lines). These two factors, which represent clumping at two different scales, are common sources of uncertainty when conducting census of small populations with clumped distributions (Gosselin et al. 2007). Unfortunately, they can have dramatic effects on abundance estimates. The impact of encountering a few large groups of beluga whales is illustrated by the mean cluster size in eastern Hudson Bay increasing by 53% from 2.11 to 3.23 beluga/cluster because of one group of 75 individuals (Fig. 5). This situation is not unique to the 2011 survey, as a large group of 52 belugas was detected in 2001 which had the effect of increasing the average group size by 47% (1.7 to 2.5). Given the impact these large groups have on the abundance estimate, it would be important to improve our confidence in the estimation of large group size or to include a specific estimation of error around the estimate of large group size. This is not possible with the 2011 data, but future survey planning should include protocol to assess this important factor using cameras, double platform or a combination of methods.

This latter group of 52 whales had been detected near the Little Whale River estuary in 2001. A major group of 354 belugas detected in the Little Whale Estuary accounted for 11% of the EHB estimate in 2011. Beluga whales are known to form summer aggregations in and around estuaries, which if not taken into account illustrates how important clumping might be on a very fine spatial scale. In our eastern Hudson Bay surveys, we have excluded estuary counts from our transect estimates to add them in separately as total counts. However, if these aggregations were to persist outside of the estuary, then one solution would be to stratify considering the areas close to the estuaries as separate strata.

One proposed way of dealing with clumping in the systematic survey is to increase the effort to obtain more observations for each of the three components of density estimation (particularly for encounter rate and expected cluster size) and to reduce the relative importance of each observation in the abundance estimate. However, with 5 nautical miles spacing in eastern Hudson Bay and with estimated effective coverage of 20%, there is only limited room for increasing the effort through reduction in spacing between lines or through the use of adaptive sampling (Thompson and Seber 1996). Another way to increase effort is to repeat surveys as was done in 2008. But as seen in 2008 and in surveys conducted in the St Lawrence Estuary, obtaining more precise estimates may require several surveys over an extended period of time, which would prove problematic in eastern Hudson Bay because migrations start in September (Gosselin et al. 2007, 2009; Lewis et al. 2009). Another solution to increase effort would be to reduce the number of years between surveys, which would also help with modeling efforts.

A better understanding of movements and habitat use within the summer season could theoretically allow better stratification of survey design. This stratification might lead to an increase in the number of sightings during a survey, which would provide more precise estimation of mean cluster size and encounter rates. In eastern Hudson Bay and James Bay, recent information on habitat use could be obtained through a spatial analysis of past survey data (Smith and Hammill 1986; Kingsley 2000; Gosselin et al. 2002; Gosselin 2005; Gosselin et al. 2009), satellite telemetry data (Lewis et al. 2009; Bailleul et al. 2012; Hammill, unpublished data), and spatial representation of traditional ecological knowledge (Lewis et al. 2009). However, complex stratification of survey design should be done with care, and our current understanding of movements and habitat use may not be sufficient for the improvement of survey design.

The systematic visual surveys produce density and abundance estimates of belugas at the surface, but to estimate abundance these estimates need to be corrected for availability (animals underwater when plane passes over) and perception (animals at the surface but missed by observers) biases (Laake and Borchers 2004). The availabiltiy bias correction factor used here was developed to correct photographic surveys of St Lawrence estuary beluga and estimated the proportion of time animals were visible from a hovering aircraft (Kingsley and Gauthier 2002). It assumes instantaneous observation of the whales. However, the EHB beluga survey is a visual survey flown using a fixed wing aircraft. The availability correction factor for these surveys will likely be lower, *i.e.* will not increase the abundance as much, as the availability correction used here, because any given point at the surface of the water remains in the observer field of view for a variable amount of time during a visual survey. However, we have not applied any correction for perception bias that would also increase the abundance estimates. To estimate availability and perception bias for surveys in James and Hudson Bays, more detailed information on diving behaviour of belugas in these areas are needed as well as utilization of double platform sampling in future visual aerial surveys.

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Table 1. Summary of beluga sightings detected on transects during surveys in James Bay and eastern Hudson Bay (summer 2011). The percentage of individuals observed in the Nunavik Marine Region (NMR) and Nunavut Settlement Area (NSA) are provided. The group observed in the Little Whale river estuary was detected during coastal surveys and is considered a total count.

Stratum	N groups	N individuals	in NMR	in NSA
James Bay	183	615	4%	96%
Eastern Hudson Bay				
low coverage	0	0	–	–
high coverage	65	210	81%	19%
Little Whale estuary	1	354		

Table 2. Density and abundance estimation for James Bay and eastern Hudson Bay in summer of 2011 showing results for the sub-strata of eastern Hudson Bay. These estimations include clusters within truncation distances and clusters that were detected without perpendicular distances but that were assumed to be within truncation distances. Coefficients of variation in percent are shown in parentheses.

Stratum	N groups	Effort (km)	Encounter rate (groups/km)	ESW (m)	Density (groups/km^2)	Mean group size	Density (indiv/km^2)	Area (km^2)	Abundance index
James Bay	173	4,182	0.0414 (21.2)	765 (6.8)	0.0270 (22.3)	3.38 (15.7)	0.0914 (27.3)	78,272	7,154
Eastern Hudson Bay									
low coverage	0	995	0	765 (6.8)	0	0	0	18,752	0
high coverage	63	6,684	0.0094 (28.1)	765 (6.8)	0.0062 (28.9)	3.21 (37.2)	0.0198 (47.1)	72,552	1,433

Table 3. Abundance estimates of beluga populations in James Bay and eastern Hudson Bay (EHB) estimated from six systematic aerial surveys. Abundance estimates have been corrected for availability bias and beluga counted in estuaries, but not for perception bias (Kingsley and Gauthier 2002). The 1985 survey data were collected using strip-transect techniques (Smith and Hammill 1986). The other five surveys flew along the same lines as the 1985 surveys, but data were collected using line-transect techniques (Kingsley 2000; Gosselin et al. 2002; Gosselin 2005; Gosselin et al. 2009; this study). Data from 1993 and 2001 were re-analysed assuming a strip width of 1000 m on each side of the aircraft to adjust the 1985 survey estimates by multiplying the strip-transect estimates by a line transect on strip transect ratio and then adding in estuary counts (Gosselin 2005). The 1985 estimate only includes variance around the availability correction factor which explains the lower CV value.

Stratum	**Year**	**Abundance**	**CV**
James Bay	1985	4,720	13%
	1993	8,205	24%
	2001	17,285	24%
	2004	8,364	30%
	2008	19,439	66%
	2011	14,967	30%
EHB	1985	4,282	13%
	1993	2,729	40%
	2001	2,924	48%
	2004	4,274	37%
	2008	2,646	47%
	2011	3,351	49%

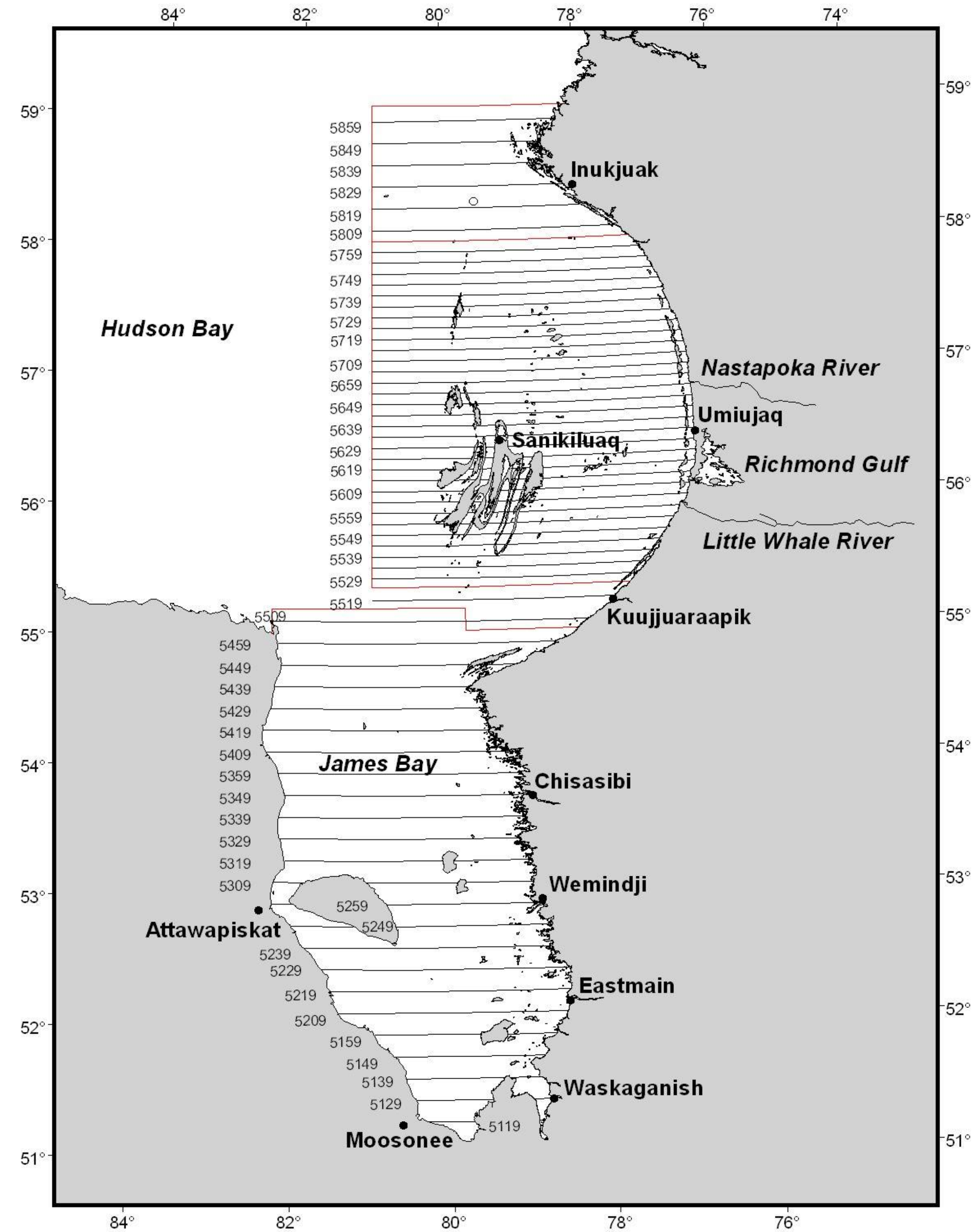


Figure 1. Transect lines planned in James Bay and eastern Hudson Bay in summer 2011. The thin red lines show the limits of James Bay and the low and high coverage strata in eastern Hudson Bay.

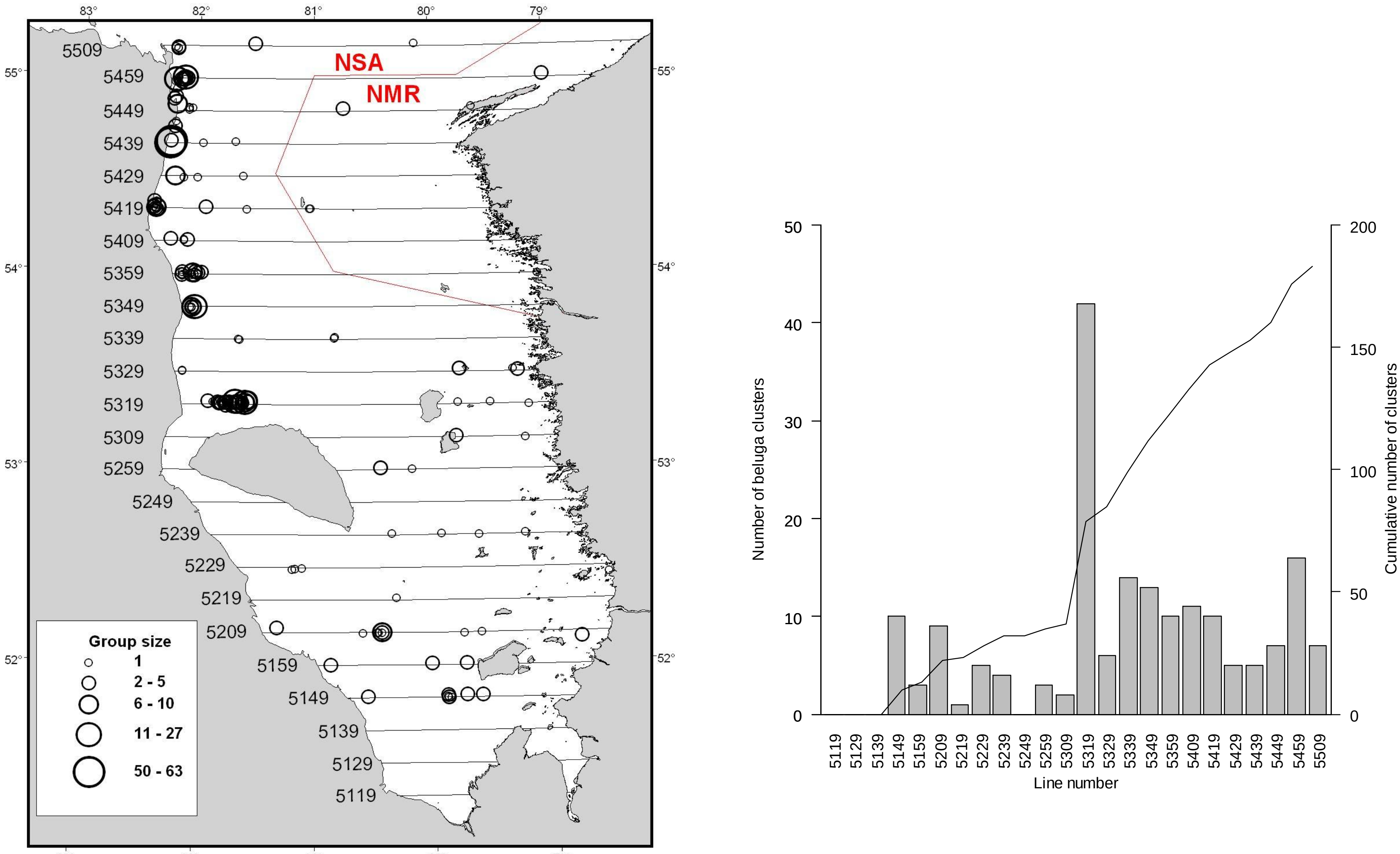


Figure 2. Left: Geographic distribution of detected clusters and lines surveyed in James Bay. Right: Frequency of the number of clusters detected per line and the cumulative number of clusters from south to north during the survey of James Bay. NMR is the Nunavik Marine Region (NILCA) and NSA is the Nunavut Settlement Area (NILCA).

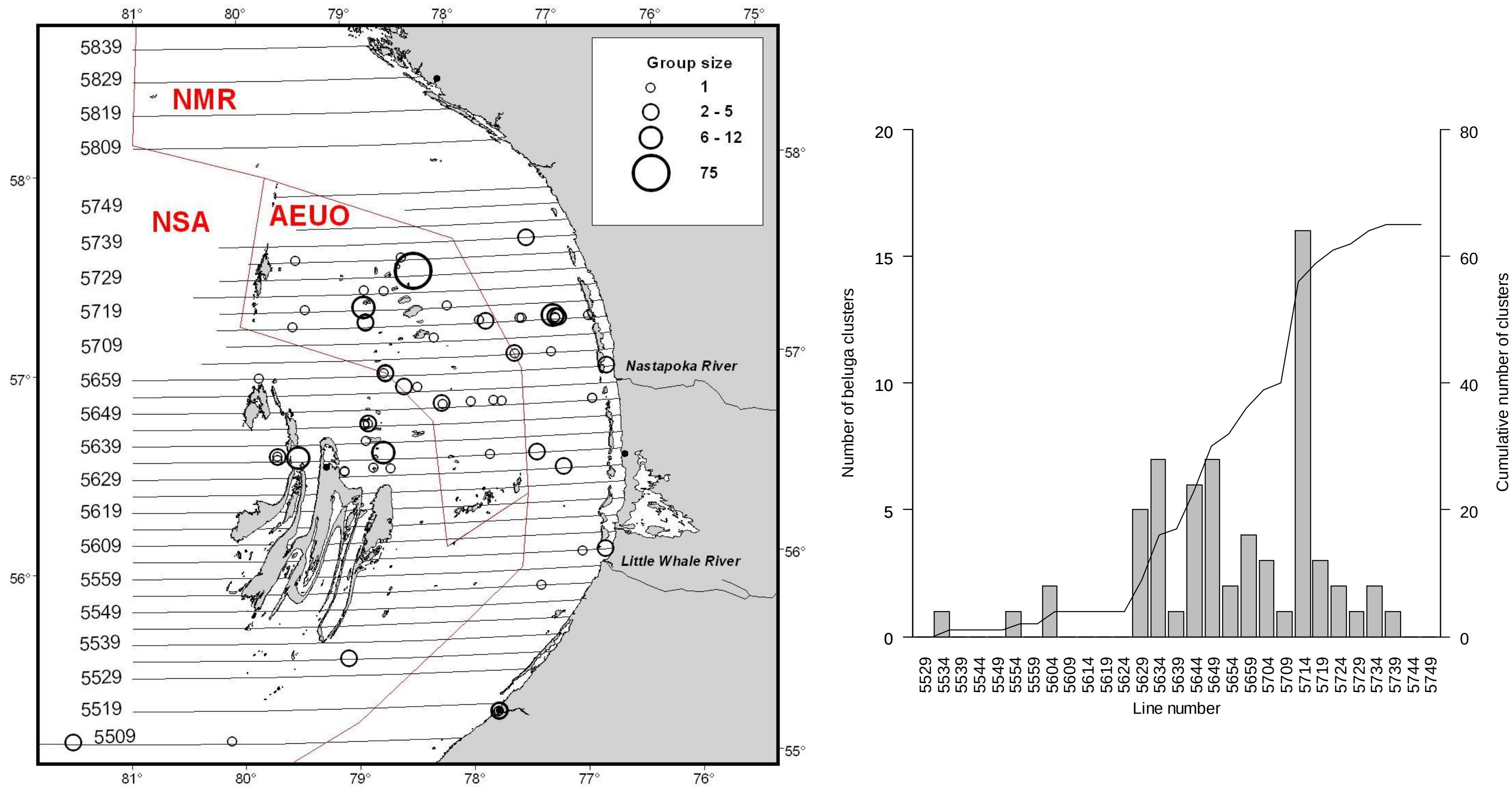


Figure 3. Left: Geographic distribution of detected clusters and lines surveyed in eastern Hudson Bay. Right: Frequency of the number of clusters detected per line and the cumulative number of clusters from south to north during the survey of eastern Hudson Bay. NMR is the Nunavik Marine Region (NILCA), NSA is the Nunavut Settlement Area (NLCA) and AEUO is the Area of Equal Use and Occupancy (NILCA).

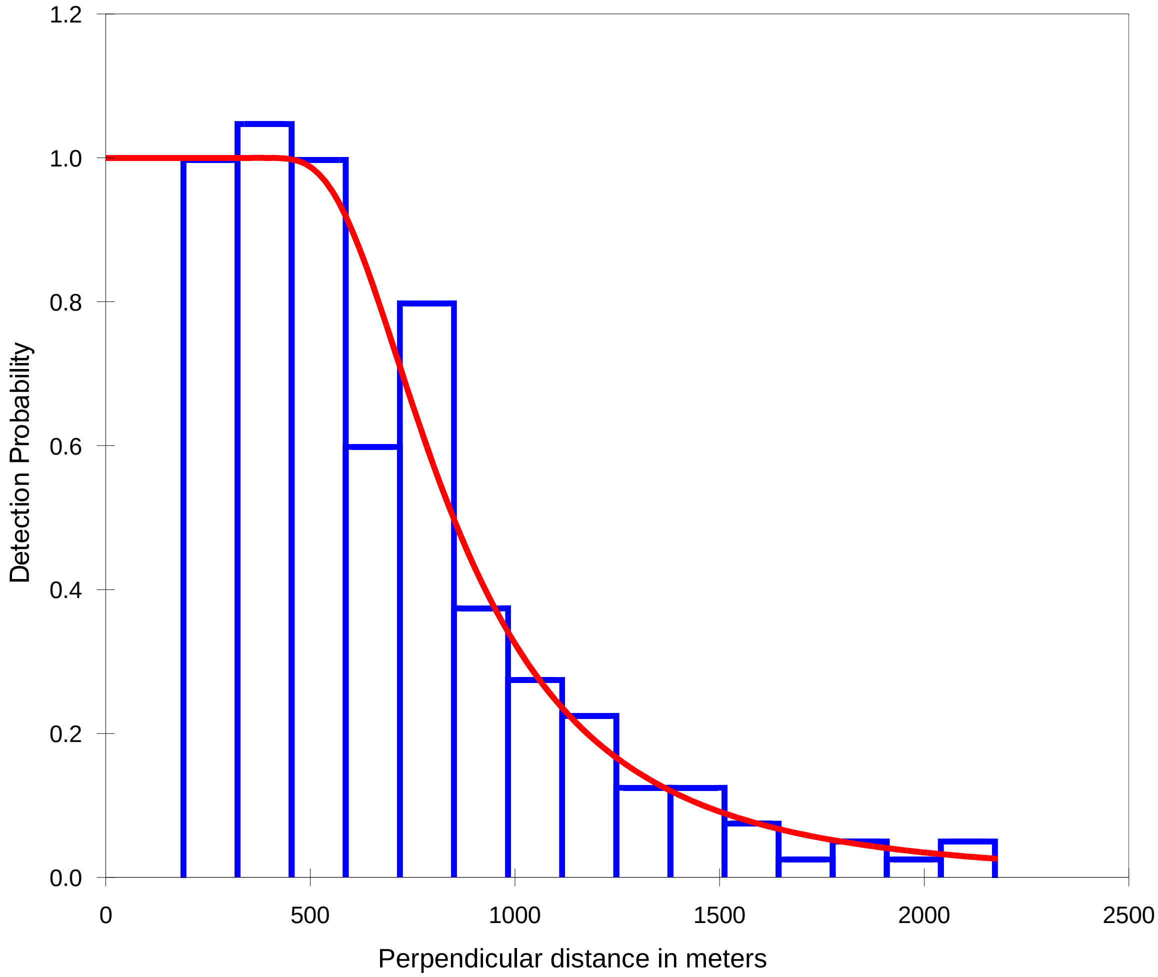
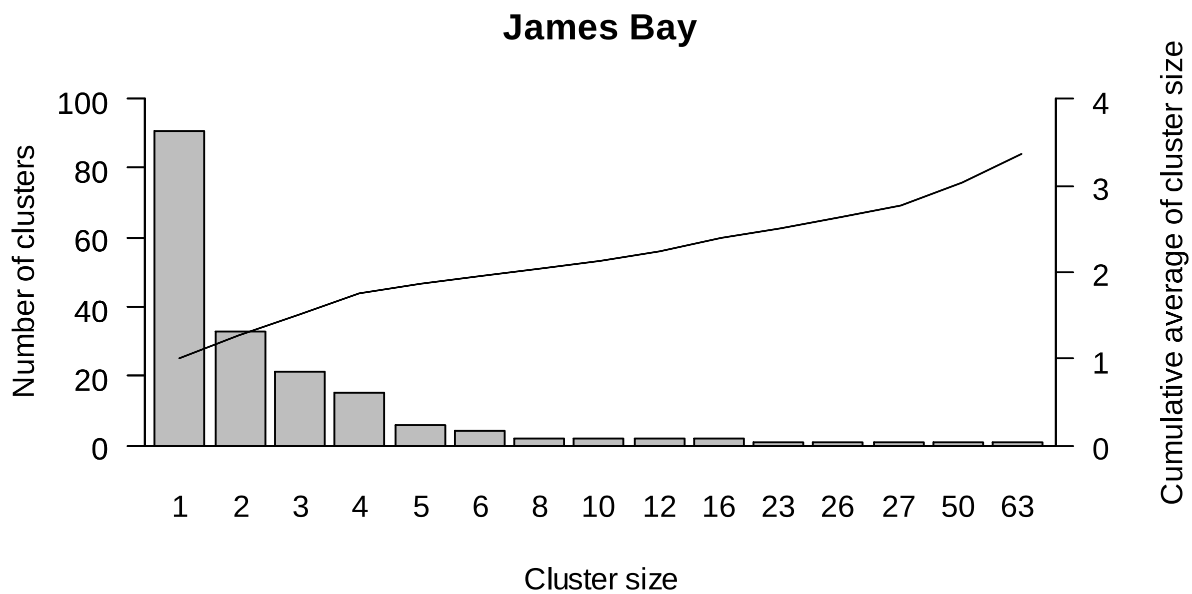


Figure 4. Distribution of perpendicular distances of 232 clusters of beluga whales detected in James Bay and eastern Hudson Bay and the fitted hazard rate detection function providing an effective strip half width of 765 m. The perpendicular distances are grouped in 15 bins, but the model was fitted to the ungrouped dataset.



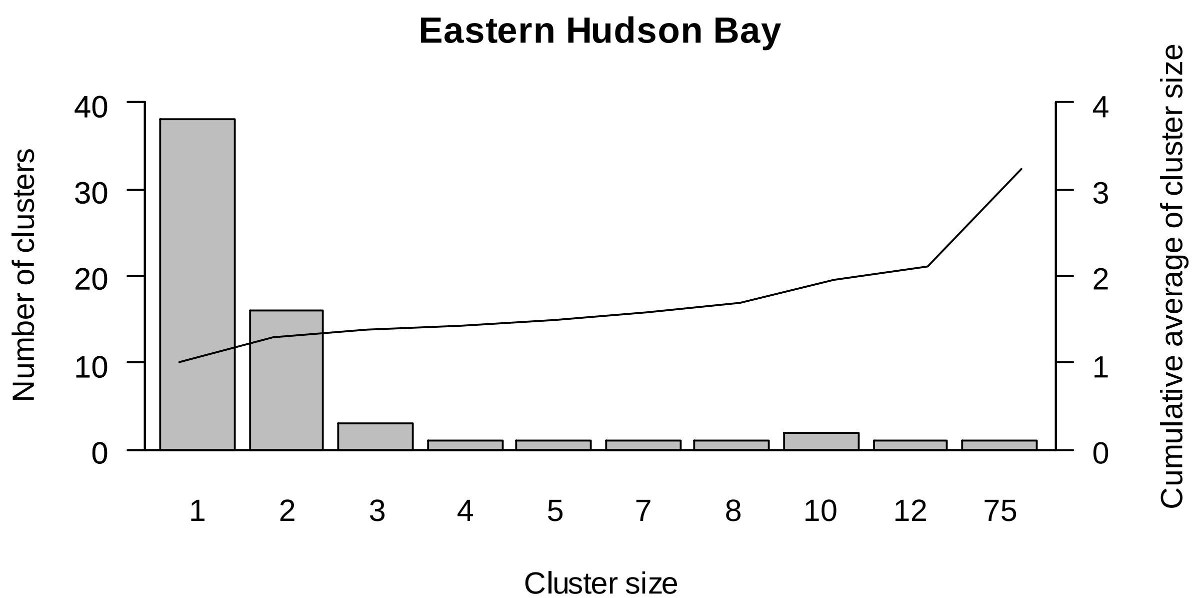


Figure 5. Frequency distribution of cluster sizes in James Bay and in eastern Hudson Bay. The cumulative average cluster size shows the effect of large clusters on the expected cluster size for each stratum.