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Indices of abundance for beluga (*Delphinapterus leucas*) in James Bay and eastern Hudson Bay in summer 2015

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Foreword

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

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ABSTRACT

Systematic aerial line-transect surveys were conducted in James Bay and eastern Hudson Bay from 29 July to 3 September 2015. An area of high coverage was surveyed twice in eastern Hudson Bay. Delays due to weather prevented a survey of Ungava Bay. A total of 324 groups of belugas were detected, but only 307 groups remained after the truncation of groups closer than 143 m from the track line to account for reduction of probability of detection near and under the plane (*re.* left truncation). A single hazard rate was selected over the half normal to estimate the probability of detection from the ungrouped distribution of perpendicular distances to provide an effective strip half width of 764 m (CV = 0.05). A total of 202 groups with an average size of 2.14 (CV = 0.10) were detected over 4,251 km of survey lines in James Bay to provide a surface abundance index of 5,074 (95% CI: 3,354-7,676). On the first and second survey of the high coverage area of eastern Hudson Bay, 58 and 63 groups with average sizes of 6.34 (CV = 0.51) and 1.41 (CV = 0.13) were detected over 7,834 km and 4,655 km of transects to provide respective surface abundance indices of 2,222 (95% CI: 816 - 6.053) and 909 (95% CI: 568 - 1,454). An individual detected over 975 km of survey lines in the northern lower coverage stratum in eastern Hudson Bay provided a surface abundance index of 13 (95% CI: 1 -127). Using a factor of 0.478 (CV = 0.16) to account for the proportion of belugas visible at the surface and adding in a count of 167 belugas observed in the Little Whale River estuary, resulted in corrected abundance indices of 10,615 (95% CI: 6,559 - 17,178) for James Bay and 3,819 (95% CI: 1,664 - 8,765) for eastern Hudson Bay. Two groups of 68 and 177 individuals that accounted for 67% of the belugas detected during the first survey of eastern Hudson Bay illustrate how the highly clumped distribution of belugas may influence abundance indices and population trend assessments.

Indices de l'abondance de béluga (*Delphinapterus leucas*) dans la baie James et l'est de la baie d'Hudson à l'été 2015

RÉSUMÉ

Des relevés aériens systématiques en ligne ont été réalisés dans la baie James et l'est de la baie d'Hudson du 29 juillet au 3 septembre 2015. Une région de couverture intense fut survolée à deux reprises dans l'est de la baie d'Hudson. Des retards en raison des conditions météorologiques ont empêché la réalisation du relevé dans la baie d'Ungava. Un total de 324 groupes de bélugas ont été détectés, mais seulement 307 ont été retenus après la troncature des groupes à moins de 143 m du trajet de l'avion en considérant la réduction de probabilité de détection près et sous l'avion (*re.* troncature à gauche). Un modèle unique de taux au hasard fut sélectionné par rapport à la demi-normale pour estimer la probabilité de détection à partir de la répartition non groupée des distances perpendiculaires afin de fournir une demi-largeur efficace de bande de 764 m (CV = 0,05). Un total de 202 groupes dont la moyenne de taille était de 2,14 (CV = 0,10) furent détectés le long des 4 251 km de ligne dans la baie James produisant un indice d'abondance à la surface de 5 074 (IC 95 %: 3 354-7 676). Lors du premier et second relevé da la zone de couverture intense de l'est de la baie d'Hudson, 58 et 63 groupes de taille moyenne de 6,34 (CV = 0,51) et 1,41 (CV = 0,13) ont été détectés sur 7 834 km et 4 655 km de ligne produisant des indices d'abondance de surface respectifs de 2 222 (IC 95 %: 816 – 6 053) et 909 (IC 95 %: 568 – 1 454). Un individu détecté sur 975 km de ligne dans la strate nord avec une couverture moins intense dans l'est de la baie d'Hudson a produit un indice d'abondance de surface de 13 (IC 95 %: 1 -127). En utilisant une proportion moyenne de 0,478 (CV = 0,16) de bélugas visibles à la surface et en considérant le compte de 167 individus dans l'estuaire de la Petite-Rivière-à-la-Baleine, les indices d'abondance corrigés étaient de 10 615 (IC 95 %: 6 559 – 17 178) pour la baie James et de 3 819 (IC 95 %: 1 664 – 8 765) pour l'est de la baie d'Hudson. Deux groupes de 68 et 177 individus qui représentaient 67 % des bélugas détectés pendant le premier relevé de l'est de la baie d'Hudson illustrent à quel point la distribution très agrégée des bélugas peut influencer les indices d'abondance et les évaluations de tendance de la population.

INTRODUCTION

Beluga whales, *Delphinapterus leucas*, are found throughout the Arctic, but different stocks are recognised based on the discontinuity of their summer distribution, genetics and satellite telemetry (COSEWIC 2004; Brennin et al. 1997; Brown Gladden et al. 1997; de March and Postma 2003; DFO 2001; Postma et al. 2012; Reeves and Mitchell 1989; Richard 1993, 2010).

Four stocks are found around Nunavik: Ungava Bay, James Bay and the eastern and western Hudson Bay stocks. The western and eastern Hudson Bay stocks are separated in summer but overwinter together in Hudson Strait, where both stocks are hunted (Lewis et al. 2009; Bailleul et al. 2012; Luque and Ferguson 2010). These two stocks form an interbreeding population based on genetics (Turgeon et al. 2012). Belugas in James Bay are a distinct breeding population and appear to undertake only limited seasonal movements largely restricted to James and southern Hudson Bay areas (Postma et al. 2012; Bailleul et al. 2012). A fourth stock has been identified in Ungava Bay (Smith and Hammill 1986; COSEWIC 2004; Richard 2010).

Commercial whaling during the nineteenth, and early twentieth centuries initiated the decline of Ungava Bay and eastern Hudson Bay stocks, but high subsistence harvests have likely limited their recovery (Finley et al. 1982; Reeves and Mitchell, 1987a, 1987b, 1989). In 1986, limits were placed on subsistence harvesting based on low abundance estimates in eastern Hudson Bay and Ungava Bay (Smith and Hammill 1986). A population model incorporating harvest statistics since 1974 and abundance estimates from three aerial surveys flown from 1985 to 2001 estimated that the eastern Hudson Bay stock was still decreasing (Hammill et al. 2004). Numbers of sightings in Ungava Bay during the same surveys were too low to provide reliable estimates and it was estimated that less than 200 animals remained in this summering stock (Kingsley 2000; Gosselin et al. 2002). 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). 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 (Doniol-Valcroze et al. 2012).

The signing of the Nunavik Inuit Land Claims Agreement (NILCA) transferred co-management responsibility to the Nunavik Marine Region Wildlife Board (NMRWB) which was established under the agreement. The current management plan was established for a three year period and will be renewed in 2017. The Total Allowable Take of the management plan is based on the objective that the probability of a harvest causing a decline in the stock does not exceed 50%. This study presents the abundance indices obtained from systematic line-transect aerial surveys conducted during summer 2015 in James Bay and eastern Hudson Bay. These abundance estimates will be used as part of the science advice feeding into the new management plan.

METHODS

STUDY AREA AND SURVEY DESIGN

The visual line-transect surveys flown in summer of 2015 covered all of James Bay, and the eastern Hudson Bay 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, 2008 and 2011 (Gosselin 2005, Gosselin et al. 2009, 2013). The limits of each stratum lie 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 (JB), and 8 lines in the low coverage area of eastern Hudson Bay (HN and HS). The high coverage area (HC) was surveyed twice, using two independent sets of 32 lines each represented by HC1 and HC2 in tables and figures (Figure 1). 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, ESRI) using zone 17 of the Universal Transverse Mercator (UTM) projection, with 81°W as the central meridian. A survey of Ungava Bay similar in coverage to that of 2008 was also planned but was 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 knots). Each plane flew every second line of the survey design. Two observers were on the plane, one in the co-pilot seat and one behind the pilot, both stations 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 2 seconds using a GPS (Garmin GPSMap 78s). 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. 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.

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

Line-transect analyses were completed using Distance 7 Beta 3 (Thomas et al. 2010). There is a blind area under the plane, therefore we used left truncation, *i.e.,* truncation of the closest distances within maximum probability of detection. A first step was to determine the distance where the number of sightings increased regularly, *i.e.* a new sighting every few meters and then remained constant. Fine tuning of left truncation distance was finalized by testing a range of potential left truncation distance values using both half-normal and hazard-rate functions to improve the goodness of fit. This was done by giving priority near the track line (*i.e.,* maximizing the *p* value of the C^2 statistic of the Cramér-von Mises test with cosine weighting) while maintaining good fit on the overall distribution (*i.e.,* maximizing the *p* value of the W^2 statistic of the Cramér-von Mises test with uniform weighting). The selected left truncation distance was subtracted from the measured perpendicular distances for further analyses.

A similar approach was used for right truncation of the distribution of perpendicular distances. A range of the most distant perpendicular distances where larger gaps started to appear were tested as right truncation limits to improve the fit near the track line while maintaining good overall fit. The most distant right truncation that maximized the *p* values of both C^2 *and* W^2 as above was retained as right truncation.

The survey was conducted with the same crew throughout the 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. After the selection of truncation distances a single detection function for all strata was selected using AIC between the half-normal and hazard-rate models.

The effect of distance on the estimated cluster size was examined using the size bias regression method of the natural log of cluster size against the probability of detection (Ln(s) vs g(x)), using the sightings from all strata for which perpendicular distance was available. 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 lacked 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 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, *TM*, equivalent to subtracting the left truncation to all sighting perpendicular distances:

$$TM = \frac{maximum\ perpendicular\ distance}{(maximum\ perpendicular\ distance - left\ truncation)} \tag{1}$$

The estimated index of density ($\widehat{D}_i$) and abundance ($\widehat{N}_i$) of beluga whales at the surface during systematic survey of each stratum, *i*, are estimated in Distance using the following formulae (eq. 3.67 in Buckland et al. 2001):

$$\widehat{D}_i = \frac{n_i \cdot \hat{E}_i(s)}{2L_i \cdot \widehat{ESHW}} \tag{2}$$

$$\widehat{N}_i = \widehat{D}_i \cdot A_i \tag{3}$$

where n_i is the number of groups detected, $\hat{E}_i(s)$ is the expected cluster size, L_i is the sum of lengths of all transects and A_i is the area of the stratum *i*. The $\widehat{ESHW}$ is the effective strip half width estimated as a single detection function estimated using the distribution of perpendicular distances of sightings from all strata combined. The associated variance of density and abundance of animals at the surface during systematic survey is estimated by:

$$\widehat{var}\left(\widehat{D}_i\right) = \widehat{D}_i^2 \cdot \left[\frac{\widehat{var}(n/L)_i}{(n/L)_i^2} + \frac{\widehat{var}(\widehat{ESHW})}{(\widehat{ESHW})^2} + \frac{\widehat{var}[\hat{E}_i(s)]}{[\hat{E}_i(s)]^2}\right] \quad (4)$$

$$\widehat{var}\left(\widehat{N}_i\right) = A_i^2 \cdot \widehat{var}(\widehat{D}_i) \quad (5)$$

The 95% CI is estimated assuming that the distribution of density is log-normally distributed, and estimated using:

$$(D_i/C\,, D_i \cdot C) \quad (6)$$

where

$$C = exp\left[t_{df}(\alpha) \cdot \sqrt{var(\ln \widehat{D}_i)}\right] \quad (7)$$

$$var\left(\ln\widehat{D}_i\right) = ln\left[1 + \frac{var(\widehat{D}_i)}{\widehat{D}_i^2}\right] \quad (8)$$

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):

$$df = \frac{\left[\sum_q \left(cv_q\right)^2\right]^2}{\sum_q \left(cv_q\right)^4 / df_q} \quad (9)$$

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/L, ESHW* and *Ê(s).*

The abundance index for eastern Hudson Bay was obtained by taking the weighted average of the estimates of density and abundance from the two surveys flown in the high coverage areas (HC1 and HC2) (equations 10-16) and adding in the abundance and density indices of the low coverage areas (HN and HS), and Richmond Gulf (RG (Figure 1, Table 2).

Poor weather hindered execution of the Hudson Bay survey. In order to complete the second survey of the high coverage area (HC2), the spacing of the second survey was altered by subdividing the high coverage zone into two strata; HC2North, with line spacing of 5 nautical miles) and HC2South, with line spacing of 10 nautical miles. We estimated the area-weighted density of the two strata (HC2North and HC2South) to provide an estimate of density from the second survey (HC2) (equations 10-16 from section 3.7.1 in Buckland et al. (2001) modified for line transect, substituting area covered, A_j*, where j* is substratum HC2North or HC2South, instead of length of transect flown, L_i). We then estimated a mean density from the first survey, HC1, and the second survey, HC2, weighted by effort, which is measured as total distance flown during each survey (*i.e.,* L_i total length of transects flown for each pass *i,*).

$$L = \sum_i L_i \quad (10)$$

The detection function is pooled over strata and the only component of density estimated by stratum are the encounter rate [*(n/L)*$_i$] and the expected group size [$\hat{E}_i(s)$] that can be combined in a single component, $\widehat{M}_i$:

$$\widehat{M}_i = (n/L)_i \cdot \hat{E}_i(s) \tag{11}$$

The density of the high coverage area was estimated as:

$$\widehat{D} = \frac{\sum_i L_i \cdot \widehat{D}_i}{L} \tag{12}$$

with the variance equal to:

$$\widehat{var}(\widehat{D}) = \widehat{D}^2 \cdot \left\{ \frac{\widehat{var}(\widehat{M})}{\widehat{M}^2} + \frac{\widehat{var}(\widehat{ESHW})}{\widehat{ESHW}^2} \right\} \tag{13}$$

where:

$$\widehat{M} = \frac{\sum_i L_i \cdot \widehat{M}_i}{L} \tag{14}$$

$$\widehat{var}(\widehat{M}) = \frac{\sum_i L_i^2 \cdot \widehat{var}(\widehat{M}_i)}{L^2} \tag{15}$$

$$\widehat{var}(\widehat{M}_i) = \widehat{M}_i^2 \cdot \left\{ \frac{\widehat{var}[(n/L)_i]}{(n/L)_i^2} + \frac{\widehat{var}[\hat{E}_i(s)]}{[E_i(s)]^2} \right\} \tag{16}$$

The abundance and associated variance of the high coverage area was estimated using the formulae 3 and 5 above with *A* being 72,273 km^2, the area of the high coverage stratum HC.

The abundance indices for each stratum in Table 2 were not corrected for availability (*i.e.,* animals diving while the plane passed overhead) nor perception (*i.e.,* animals at the surface missed by observers) biases 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 dividing the systematic abundance estimate by the proportion of time beluga remain visible from an aerial survey platform estimated in the St Lawrence estuary, *PS* = 0.478 (se=0.0625, df=71; Kingsley and Gauthier 2002). Beluga detected in estuaries were assumed to represent total counts and were added to the availability corrected estimates.

RESULTS

SURVEY COMPLETION

The 24 lines planned in James Bay were completed in four days from the 29 July to 8 August with a single delay of 7 days from 31 July to 6 August (Figure 2). The 8 lines in the low coverage area (HS, HN) and the 32 lines in the high coverage area (HC1) were surveyed completely on the first survey of Eastern Hudson Bay in 6 days from 8 to 20 August (Figure 3). The second survey of the high coverage area (HC2North, HC2South) was done in two phases, the 9 northernmost lines (HC2North) were done on 24 August with the planned 9.3 km (5 nautical miles) spacing but the western ends of five of these lines could not be completed due to fog (Figure 4). The remaining 11 lines (HC2South) were flown between on 31 August and 3 September with 18.5 km (10 nautical miles) spacing including one that was shortened at the western end due to fog (Figure 4). The 5 lines in the Richmond Gulf were surveyed on 31 August. The weather forecasts and the time left did not allow a survey of Ungava Bay.

BELUGA SIGHTINGS

A total of 324 groups of belugas or 890 individuals were detected while on effort during the survey of James Bay and eastern Hudson Bay from 29 July to 3 September 2015 (Table 1). On the first survey pass of eastern Hudson, 369 belugas were detected including only one individual in the northern stratum (Table 1). Two large groups of 177 and 68 individuals were detected and counted using photographs (Figure 3). The number of belugas counted on the second pass of the high coverage area was much lower with 89 individuals (Table 1).

Twenty belugas in 3 groups were counted, including a group of 18 individuals near Inukjuak, during a coastal survey that covered the coast from Captain Island to the Little Whale River estuary on the 24 August (Figure 5). No belugas were counted in the Little Whale River estuary that day. Thirty-two belugas in 5 groups were counted during the coastal survey from Kuujjuaraapik that covered the coast from Long Island to the Richmond Gulf on 2 September. These 5 groups included one group of 24 belugas in the Little Whale River estuary (Figure 5). The Little Whale River estuary was surveyed on nine occasions over 4 days during the systematic survey and the beluga count averaged 58 individuals (range: 0-167). However, variability was large even within a given day (*e.g.* 0 and 140 individuals seen on two passes done on 31 August). It seemed that a group of beluga remained in the proximity of the Little Whale River estuary for the duration of the survey and the maximum count of 167 belugas was added to the systematic survey estimate. The Nastapoka River estuary was surveyed on 4 occasions on 4 different days (12, 24 and 25 August and 3 September) but no belugas were detected in the estuary.

DETECTION CURVE

The distribution of perpendicular distances from the track line showed only 7 sightings below 143 m and 20 sightings below 179 m, beyond which distance the sightings became more frequent. This suggests potential left truncation distances of 143 m or 179 m based on outliers only. Fitting a hazard rate backwards on perpendicular distances of 500 m away to 0 m suggests that the detection probability was maximal beyond 360 m but with a gradual increase in probability of detection. A similar backward analysis from 300 m to 0 m provided a better fit and suggested that the probability of detection increased rapidly and became maximal beyond 160 m. These four distances of 143 m, 160 m, 179 m and 360 m were tested as potential left truncation values. The 360 m left truncation provided a better fit near the track line and for the overall hazard-rate (C^2 $p=1.0$; M^2 p=1.0) compared to the 179 m, 160 m and 143 m (respective C^2 p = 0.6, 0.3 and 0.6; M^2 p=0.7, 0.5 and 0.7). The half-normal model did not provide a good fit for any of these truncation distances near the track line (C^2 p = 0.1 to 0.001) nor for the overall model (M^2 p=0.05 to 0.001) and therefore, was not used. The 360 m left truncation provides a spike near the track line in the probability of detection model which violates the shape criterion (Buckland et al. 2001). Between the remaining potential left truncation distances, 143 m and 179 m provided a slightly better fit near the track line (C^2 p = 0.6) and overall fit (M^2 p = 0.7) for the hazard-rate model than 160 m (C^2 p = 0.3; M^2 p =0.5). And finally, 143 m provided a more efficient model (CV = 0.05) than 179 m (CV = 0.06) and was used as left truncation distance.

Similarly, for the distant sightings, there is no obvious gap in distribution to 1,438 m. The probability of detection of the hazard-rate model becomes roughly 0.15% at a perpendicular distance of 1,430 m, which is a criterion for right truncation as suggested by Buckland et al. (2001). Three observations beyond 2,368 m could be identified as outliers. Using 1,438 m or 2,368 m as right truncations did not improve the fit near the track line of the hazard rate model for the left truncation of 143 m. Therefore, no right truncation was used.

The hazard-rate (AIC = 4,407.95) was selected over half-normal (AIC = 4,469.72, ΔAIC = 61.77) when fitted to the 307 sightings left after the left truncation of 143 m, and provided an effective strip half width (ESHW) of 764 m (SE = 42, CV = 0.05, Figure 6). Given the truncation distance and the maximum perpendicular distance of 5,938 m, the adjustment to the uniform model to include observations without perpendicular distances was an estimated probability of detection, *P*, of 0.1286 (SE = 0.0070, df = 305) based on the ESHW and a truncation multiplier of 1.0247 (see formula 1 above).

GROUP SIZE

The regression of the ln (cluster size) against the probability of detection (g(x) was not significant for the 307 groups with available perpendicular distance (p = 0.21) and therefore the average cluster size was used in all strata (Table 2). The two large groups of 68 individuals and 177 individuals detected during the first survey of the high coverage area had an important impact on the estimated group size. The average estimated group size was 2.20 for the 366 groups including less than 10 individuals and increased to 3.35 and 6.34 when adding the two large groups (Figure 7). These two groups alone accounted for 67% of the belugas detected during the first survey of the high coverage area. Even without considering these two large groups, belugas in the second survey of the high coverage area were detected in smaller groups with an average group size of 1.41 (CV = 0.13) (Table 2, Figure 7).

ENCOUNTER RATE

In James Bay, a high proportion of beluga were detected on the lines north of Akiminski Island and along the Ontario coast at the western ends of the lines (Figure 2). The encounter rate in James Bay was 3 to 6 times higher than the encounter rates in eastern Hudson Bay high coverage area strata (Table 2).

In the high coverage area of eastern Hudson Bay, roughly the same number of groups observed on the first survey (n=58) were detected during the second survey (n=61), but the effort during the first survey (7,834 km) was 1.7 times greater than for the second survey (4,655 km; Table 1). Therefore, the encounter rate combined for both substrata of the second survey of eastern Hudson Bay (0.0131, CV = 0.17) was higher than on the first survey (0.0074, CV = 0.17; Table 2).

DENSITY AND ABUNDANCE ESTIMATES

A single detection function was used for all strata, but based on the stratum specific average group size and encounter rate, the surface abundance indices without corrections for availability and perception bias were 5,074 (95% CI: 3,354-7,676) in James Bay and 1,746 (95% CI: 760-4,009) in eastern Hudson Bay (Table 2). The abundance is about 2.9 times higher, and density is about 2.7 times higher, in James Bay than in eastern Hudson Bay (Table 2). Most of the sightings in James Bay were recorded on the lines north of Akiminski Island and along the Ontario coast.

Encounter rate is usually the major contributor to the variance of density. In James Bay, encounter rate, group size and the detection function accounted respectively to 71.8%, 21.3% and 6.9% of the variance of density. The respective numbers were 62.7%, 34.0% and 3.3% for the northern sub-stratum (HC2North) and 60.2%, 36.0% and 3.8% for the southern sub-stratum (HC2South) of the second survey in the high coverage area of eastern Hudson Bay. The detection of the two large groups of 68 and 177 individuals during the first survey of the high coverage area of eastern Hudson Bay increased the abundance estimates as well as the variance of this estimate; group size accounted for 89.4% of the variance in density while encounter rate and detection function contributions were respectively 9.6% and 1.0%.

Correcting the previous surface abundance indices for the proportion of submerged animals that cannot be detected from an aerial platform by the factor estimated by Kingsley and Gauthier (2002) as *PS* = 0.478 (se = 0.0625, df =71), provided an abundance index in James Bay of 10,615 (CV = 0.25, 95% CI: 6,559-17,178). The same correction for submerged animals was applied to the surface index in eastern Hudson Bay, to which we then added the count of 167 belugas in the Little Whale River estuary, provided an abundance index of 3,819 (CV = 0.43, 95% CI: 1,664-8,765).

DISCUSSION

The 2015 survey is the seventh of a series of systematic surveys undertaken since 1985 in James Bay and eastern Hudson Bay (Smith and Hammill 1986; Kingsley 2000; Gosselin 2005; Gosselin et al. 2002, 2009 and 2013) (Table 3). The basic approach was similar although, the altitude and the use of bubble windows changed over the series of surveys. Bubble windows were used in 2015, as in 2001, 2004 and 2008, but were not used in 1993 and 2011. The altitude of the survey also changed during the series of survey from 457 m (1500 feet) in 1993 and 2001 to 305 m (1000 feet) from 2004 to 2015. Different observers also had different observation patterns during survey and the left truncation was estimated for each survey given their respective distribution of perpendicular distance of groups. When using Distance (Thomas et al. 2003) for the re-analyses of surveys before 2004, the left truncation used in 2015 (143 m), 2004 (100 m) and 2008 (120 m) for surveys with bubble windows, were smaller than without bubble windows in 2011 (190 m) for surveys using the altitude of 305m (Gosselin 2005; Gosselin et al. 2009, 2013). The left truncation was also smaller with bubble windows in 2001 (250 m) than without bubble windows in 1993 (300 m) for the altitude of 457 m (Gosselin 2005). The left truncation was also smaller for all surveys flown at the altitude of 305 m (100 m to 190 m) than for surveys flown at the altitude of 457 m (250m and 300 m). Therefore, the use of bubble windows and change in altitude both seem to have an impact on the left truncation and the detection of belugas near the track line. It was estimated that the change in altitude from 457 m to 305 m had no effect on the estimation of abundance of belugas from a series of 14 surveys conducted at both altitude in the St Lawrence estuary in 2005 (Gosselin et al. 2007). The use of bubble windows may affect the left truncation, but after using different left and right truncations, the resulting estimated ESHW were identical in 2011 (765 m, CV = 0.07) and 2015 (764 m, CV = 0.05) supporting little effect of bubble windows on the abundance indices and consistency between the detection due to observer teams and weather conditions for the last two surveys.

The estimated ESHW in James Bay and eastern Hudson Bay is about twice as wide as the ESHW estimated for the western Hudson Bay survey in 2015 (764 m vs 382 m) (Matthews et al. 2016). Surveys in eastern Hudson Bay and James Bay and the Ontario coast have been flown using a Cessna 337. Surveys of the western Hudson Bay coast have been flown using a deHavilland Twin Otter. The ESHW between surveys in James Bay and eastern Hudson Bay from 1993 to 2015 ranged from 554 m to 839 m with an average of 721 m (Gosselin 2005, Gosselin et al. 2002, 2009, 2013; Kingsley 2000). Therefore, the ESHW in James Bay and eastern Hudson Bay in 2015, is close to the average for the series of surveys in this area. During surveys conducted in 2004 in western Hudson Bay, the ESHW for different strata ranged from 361 m to 634 m with an average of 477 m (Richard 2005). The ESHW of 382 m in western Hudson Bay in 2015 falls within the lower range estimated in 2004. In 2004, after the survey of the western Hudson Bay and the Ontario coast was completed, the same two aircraft (Cessna 337s) and two observers continued to complete the survey of James Bay and eastern Hudson

Bay where different ESHW of 817 m and 622 m respectively were estimated (Gosselin 2005). Considering all surveys, and the differences in abundance between western Hudson Bay and James and eastern Hudson Bay observers might concentrate search effort closer to the aircraft at higher densities, although the trend does not appear to be linear (r^2 =0.11). Differences do not appear to be due to aircraft type. Both the Twin Otter and the Cessna have high wing configuration with limited visual obstruction that could reduce detection away from the track line and the planes are flying at the same altitude (305 m) and same speed (185 km/h). A narwhal survey conducted using Twin Otters in the Arctic in 2013 provided an ESHW of 481 m. This is higher than 2015 western Hudson Bay ESHW, in the range of the 2004 WHB survey and lower than the 2015 ESHW of James Bay and eastern Hudson Bay survey. Sighting conditions and observer searching patterns most likely contributed to the difference in ESHW between the areas in 2015.

JAMES BAY

The abundance index in James Bay in 2015 at 10,615, represents the median value of the seven surveys flown since 1985. Its CV of 0.25 is comparable to four of the previous survey CV that varied from 0.24 to 0.30. The two exceptions were the higher CV of 0.66 in 2008 which was associated with the highest estimate and the lower CV of 0.13 in 1985 which was a strip transect estimate and for which the equivalent line-transect variance could not be estimated.

Again in 2015, a high proportion of animals were detected in the northwest portion of the bay (Figure 2). This has been reported in the previous surveys of 1993, 2001, 2008 and 2011, but not in 1985 and 2004 (Smith and Hammill 1986, Kingsley 2000, Gosselin 2005, Gosselin et al. 2002, 2009 and 2013). The 1985 and 2004 surveys provided the two lowest abundance indices of the time series for James Bay (Table 3). The northwestern area of James Bay was not surveyed in 1985 due to the presence of heavy consolidated ice which was assumed to contain few belugas (Smith and Hammill 1986). In 2004, a low proportion of sightings was detected in the northwest James Bay from 7 to 24 August and provided an abundance index of 8,364 (CV = 0.30) (Gosselin 2005). Only a few days before the James Bay survey, the coast of Ontario and the eastern part of the Manitoba coast were surveyed from 2-6 August and provided an abundance index of 14,799 (CV = 0.39) after applying the same correction for submerged animals of Kingsley and Gauthier (2002) (Richard 2005). In 2015, numerous belugas were also detected in transit between lines along the Ontario coast with at least 124 belugas between northernmost lines JB5441 to JB5511. Genetic data and the limited satellite telemetry suggest that James Bay animals form a distinct breeding population and stock (Postma et al. 2012; Bailleul et al. 2012). However, this information comes from the eastern side of the bay. Better information is required from the Ontario coasts of northwest James Bay and Hudson Bay to evaluate the potential movement of belugas between these areas in summer.

EASTERN HUDSON BAY

The 2015 abundance index of eastern Hudson Bay was similar in both value and CV to the previous abundance index of 2011. As reported before, the ESHW were also identical in 2011 and 2015. There were however important differences between the two surveys, the major one being the fact that only one survey of the high coverage area was completed in 2011, while two surveys were done in 2015.

Only two groups of belugas larger than 20 individuals were detected during the systematic survey of eastern Hudson Bay and both were detected and counted on 9 August. A group of 177 belugas detected at 16h58 on line HC5616 and a group of 68 belugas detected on line HC5626 at 19h18 and they were at 73 km and 51 km from the Little Whale River estuary respectively. Beluga were detected in the Little Whale River estuary before and after that line was surveyed with counts of 79, 15 and 74 at 12h04, 14h33 and 19h47 respectively. The groups of 177 and 68 individuals are unusually large compared to group sizes from previous systematic surveys conducted in eastern Hudson Bay but the presence of large numbers of animals throughout that same day in the vicinity of Little Whale River estuary does not support the idea of excluding these observations from the systematic survey.

In 2011, the Little Whale River estuary was surveyed on two days that provided counts of 354 and 330 individuals that were higher than the 2015 daily maximum count of 167 individuals showing that more animals may frequent the estuary on some occasions. In 2008, the Little Whale River estuary was visited eight times and no beluga were detected in the estuary per se. No belugas were detected in the Little Whale River in 2004 and 39 animals were detected on 28 August 2001.

No belugas were detected in the Nastapoka River estuary on 4 occasions and 4 different days in 2015, on 10 occasions and 3 different days in 2011, on 5 occasions and 5 different days in 2008 and one day, 28 August, in 2001. However, 26 belugas were counted on 29 August 2004.

The aggregations of belugas in estuaries may remain together outside of estuaries and may form the large groups observed in the systematic surveys. The single group of 177 individuals detected on the 9 August almost doubled the average group size (189%) and combined with the group of 68 individuals it almost tripled (288%) the average group size (Figure 7). Group size being a multiplier in the estimation of density, the effect was similar on the density and abundance indices of the first survey of eastern Hudson Bay. These few large groups also increased the variance associated with the estimation of group size which was carried on to a higher variance in density and abundance. This situation has been encountered in previous surveys. In 2011, a group of 75 individuals increased the average group size by 53% (2.11 to 3.23 beluga/group) and in 2001 a group of 52 individuals increased the average group size by 47% (1.7 to 2.5 beluga/group). As recommended after the 2011 survey, cameras proved to be very useful in 2015 for the estimation of the size of the two large groups.

The second survey of the high coverage area of eastern Hudson Bay provided lower density and abundance estimates than the first survey. This reduction is mainly due to the detection of the two large groups and some other larger groups on the first pass, as the encounter rate on the second survey was higher than on the first survey. The higher encounter rate compensated for the smaller group size as the abundance index of the first survey was only 2.4 times higher than the index of the second survey.

The segments of lines that were not surveyed during the second survey were in an area where there were only two sightings during the first survey. We could expect that truncating sections of lines with expected low numbers of sightings might have increased our encounter rate on the second survey. However, during the second surveys there were six sightings west of the Belchers Islands compared to only one sighting for the first survey, even though the effort west of the Belchers was about half of what it was on the first survey. Assuming that the movement west of the Belcher Islands was similar in the northern portion as it was in the southern portion of the stratum where lines were completed, we decided to use the whole area of the stratum to estimate the abundance index, *i.e.,* not cutting the area not covered by transect.

We have no reason to believe that migration of EHB beluga might explain the difference in abundance between the first survey conducted from 8 to 20 August and the second survey conducted from the 24 August to 3 September. 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). 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.

The differences in the two surveys of the high coverage area is another example of how clumping in beluga distribution may influence the estimation of density and abundance. Increasing effort to obtain more observations to estimate the effective strip half width, group size and encounter rate will reduce the relative importance of each observation in the density and abundance indices. One way of increasing effort is to repeat surveys as was done in eastern Hudson Bay in 2008 and in the St. Lawrence estuary (Gosselin et al. 2007, 2009). There is however a limited period each summer to repeat surveys in eastern Hudson Bay as animals start migration by late September (Kingsley et al. 2001; Lewis et al. 2009; Bailleul et al. 2012). One solution, would be to increase the number of planes, but this would also increase the need for experienced observers. Another solution to increase effort would be to reduce the number of years between surveys, which would also help with modeling efforts.

Adaptive sampling is another solution to increase the number of detected groups in areas of encountered high density (Pollard and Buckland 2004; Thompson and Seber 1996). However, the current spacing of 9.26 km (5 NM) in the high coverage area and the effective strip half width ranging from 554 m to 839 m from line-transect surveys since 1993 already represent survey coverage of 12% to 18%. With sightings regularly detected as far as 2000 m from the track line, extending to 43% of the area, this leaves little room for the additional lines required by adaptive sampling before running into the potential problem of double counting. Furthermore, with the lines in the high coverage area of eastern Hudson Bay being 280 km (150 NM) long and the round trip to the airport being more than half the capacity of the Cessna 337s, it would be more practical to reduce the spacing than to use adaptive sampling.

The survey design could be stratified to increase the numbers of observations and improve the precision of the estimation of the three component of density estimation. This could be done using recent information on habitat use in James Bay and eastern Hudson Bay from past surveys (Smith and Hammill 1986; Kingsley 2000; Gosselin 2005; Gosselin et al. 2002, 2009), satellite telemetry (Lewis et al. 2009; Bailleul et al. 2012), and spatial representation of traditional ecological knowledge (Lewis et al. 2009). However, complex stratification of survey design could be counterproductive if based on a wrong habitat use model. The variability observed in the limited information available from the sources cited above may preclude this approach at the moment.

The systematic visual surveys produce density and abundance indices of belugas at the surface, but to estimate abundance these indices 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 availability bias correction factor used for the survey in James Bay and eastern Hudson Bay in 2015 was developed to correct photographic surveys of St Lawrence estuary beluga and estimated that the proportion of time animals were visible from a hovering aircraft was 0.478 (CV = 0.16; Kingsley and Gauthier 2002). It has been applied to all abundance indices of the time series since 1985 to evaluate population size and trend (Hammill et al. 2017). The availability correction factors used for the survey of western Hudson Bay were lower and based on the estimation that belugas can be detected to depths of 2 m in murky water and 5 m in clear water (Richard 2013; Richard et al. 1994). The proportion of time that animal remained within 2 m from the surface in the murky waters of the Churchill River estuary was estimated at 0.583 (CV = 0.06) from satellite linked time depth recorders deployed on eight belugas near Churchill in July 2015 (Matthews et al. 2017). The proportion of time these same animals remained above 5 m outside of the Churchill River estuary was estimated at 0.809 (CV = 0.04). Using the same approach for three female belugas tagged in Cumberland Sound in 2006 and 2007, it was estimated that the proportion of time animals remained within 5 m and 2 m from the surface was 0.394 (CV = 0.05) and 0.485 (CV = 0.06; Marcoux et al. 2016). An instantaneous correction for availability was used to correct abundance of belugas in West Greenland based on the proportion of time of 0.43 (CV = 0.09) that belugas tracked in the Canadian High Arctic remained within 4 to 5 m from the surface (Heide-Jorgensen and Acquarone 2002; Heide-Jorgensen et al. 2010; Inness et al. 2002). The limited diving behaviour analyses for belugas marked in eastern Hudson Bay and James Bay suggest that the proportion of time within 4 m from the surface (used as a threshold to consider a dive) was highly variable in summer, but likely closer to 0.50 (Bailleul et al. 2012). Therefore, the proportion of 0.478 used in the past for the time series was kept as the basis for availability correction until more specific analyses are completed.

All these availability correction factors assume 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 bias for surveys in James and Hudson Bays, more detailed information on diving behaviour of belugas in these areas is needed and must be acquired from telemetry projects that are independent from surveys. To estimate perception bias, double platform sampling should be implemented for visual surveys in the future to estimate a correction factor. This method should be applied to several surveys to estimate its associated variance between surveys, which would allow us to apply a perception correction and associated variance to the complete time series of surveys.

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TABLES

Table 1. Survey effort and number of belugas detected in the different strata and sub-strata during the visual line-transect survey of James Bay and eastern Hudson Bay in summer 2015. Eastern Hudson Bay survey plan was stratified with low coverage (10 NM spacing) areas in the south (HS) and north (HN). A central region of eastern Hudson Bay was planned to be surveyed twice with high coverage (5 NM spacing). The first survey (HC1) and a northern portion of the second survey (HC2North) were covered as planned. Delays due to weather forced resulted in lower coverage in the southern region of the second survey (HC2South). The Richmond Gulf was surveyed with a spacing of 5 NM. The numbers with perpendicular distance retained for effective strip half width estimation after left truncation at 143 m are also provided.

Stratum sub-stratum	Dates of completion (day/month)	Stratum area (km^2)	Number of lines	Total track length (km)	Number of groups	Number of individuals	Groups (individuals) without distance	Groups (individuals) used for ESHW
James Bay	29/07 - 8/08	78,272	24	4251	202	432	10 (28)	187 (368)
Eastern Hudson Bay								
HS	8/08	5,867	2	321	0	0	0	0
HC1	8/08 - 16/08	72,273	32	7,834	58	368	0	58 (368)
HC2South	24/08 - 3/09	51,836	12	2,867	45	64	0	43 (61)
HC2North	24/08	20,437	9	1,788	18	25	0	18 (25)
HN	16/08 -20/08	18,893	6	975	1	1	0	1 (1)
Richmond Gulf	31/08	705	5	62	0	0	0	0

Table 2. Surface density and abundance indices for James Bay and eastern Hudson Bay in summer of 2015 showing the results of the sub-strata of eastern Hudson Bay. These estimates consider the number of groups beyond the left truncation of 143 m and the number of groups that were detected without perpendicular distances but that were assumed to be beyond left truncation. Parentheses show coefficient of variation and 95% CI for abundance indices. The eastern Hudson Bay surface estimate is the sum of the HS, HC, HN and Richmond Gulf areas (see Figure 1 for location of areas). Density in HC2 was estimated as the area-weighted average of density estimates for HC2North and HC2South. Density in HC was then estimated as the effort-weighted average of the density estimates of HC1 and HC2.

Stratum	Number of groups	Expected group size	Encounter rate (groups/km)	Density (Groups/km^2)	Density (Individuals/km^2)	Abundance index
James Bay	197	2.14 (0.10)	0.0463 (0.18)	0.0303 (0.18)	0.0648 (0.21)	5,074 (3,354-7,676)
Eastern Hudson Bay						**1,746 (760-4,009)**
HS	0	0	0	0	0	0
HC	**-**	**-**	**-**	**-**	**0.0240 (0.44)**	**1,733 (750-4,001)**
HC1	*58*	*6.34 (0.51)*	*0.0074 (0.17)*	*0.0048 (0.17)*	*0.0307 (0.54)*	*2,222 (816-6,053)*
HC2	**-**	**-**	**-**	***0.0089 (0.19)***	***0.0126 (0.23)***	***909 (568-1,454)***
HC2South	*43*	*1.42 (0.17)*	*0.0150 (0.22)*	*0.0098 (0.22)*	*0.0139 (0.28)*	*722 (411-1,267)*
HC2North	*18*	*1.39 (0.18)*	*0.0101 (0.24)*	*0.0066 (0.25)*	*0.0092 (0.30)*	*187 (101-348)*
HN	1	1	0.0010 (1.11)	0.0007 (1.11)	0.0007 (1.11)	13 (1-127)
Richmond Gulf	0	0	0	0	0	0

Table 3. Abundance estimates of beluga populations in James Bay and eastern Hudson Bay (EHB) estimated from seven 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*	*0.13*
	1993	*8,205*	*0.24*
	2001	*17,285*	*0.24*
	2004	*8,364*	*0.30*
	2008	*19,439*	*0.66*
	2011	*14,967*	*0.30*
	2015	*10,615*	*0.25*
Eastern Hudson Bay	*1985*	*4,282*	*0.13*
	1993	*2,729*	*0.40*
	2001	*2,924*	*0.48*
	2004	*4,274*	*0.37*
	2008	*2,646*	*0.47*
	2011	*3,351*	*0.49*
	2015	*3,819*	*0.43*

FIGURES

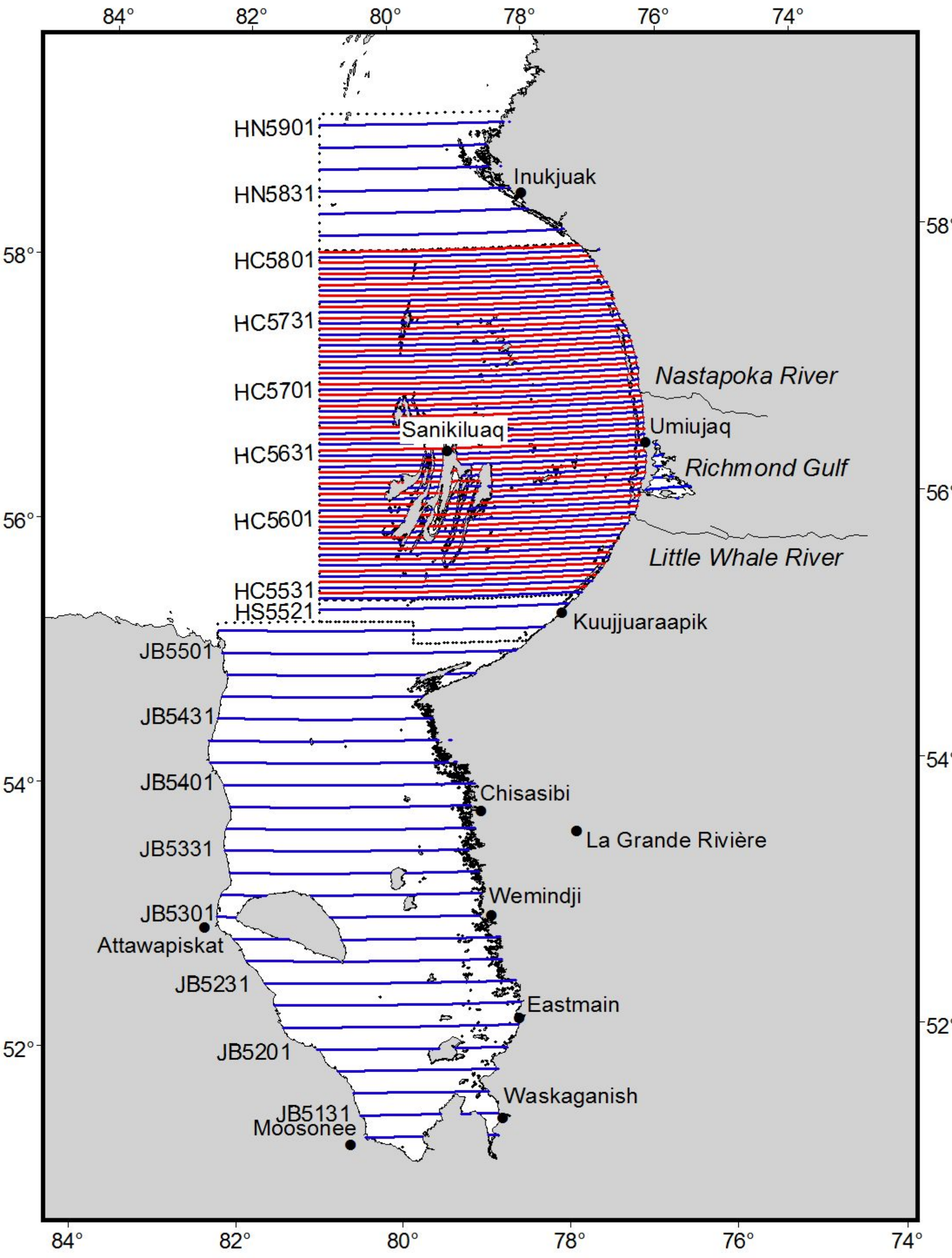

Figure 1. Transect lines planned in James Bay and eastern Hudson Bay for the aerial survey in summer 2015. The thin dotted lines show the limits of James Bay (JB) and the low (HS and HN) and high coverage (HC) strata in eastern Hudson Bay. The red lines show the plan for the second pass in the high coverage area (referred to as HC2).

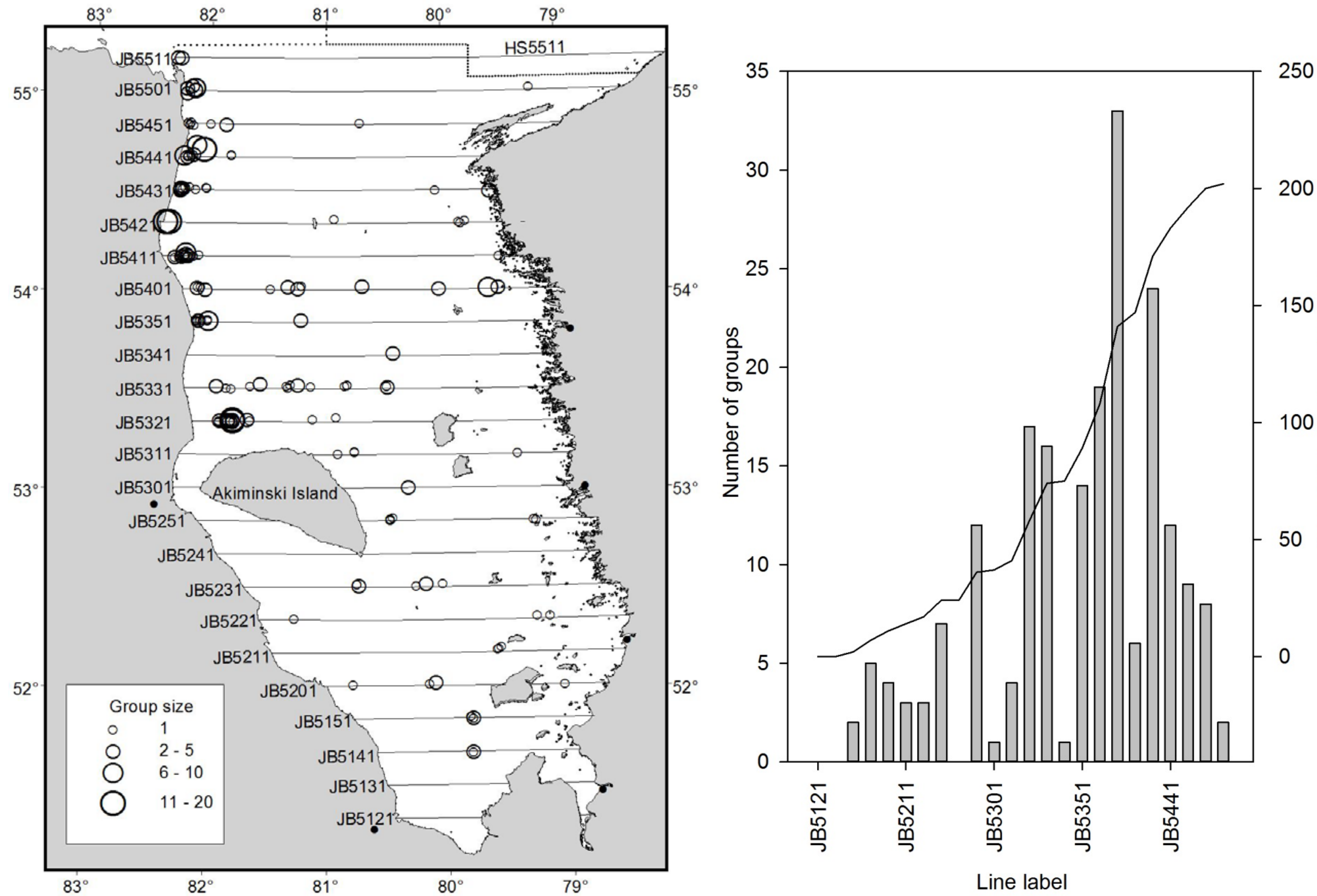

Figure 2. Left: Geographic distribution of detected groups and lines surveyed in James Bay. Right: Frequency of the number of groups detected per line and the cumulative number of groups from south to north.

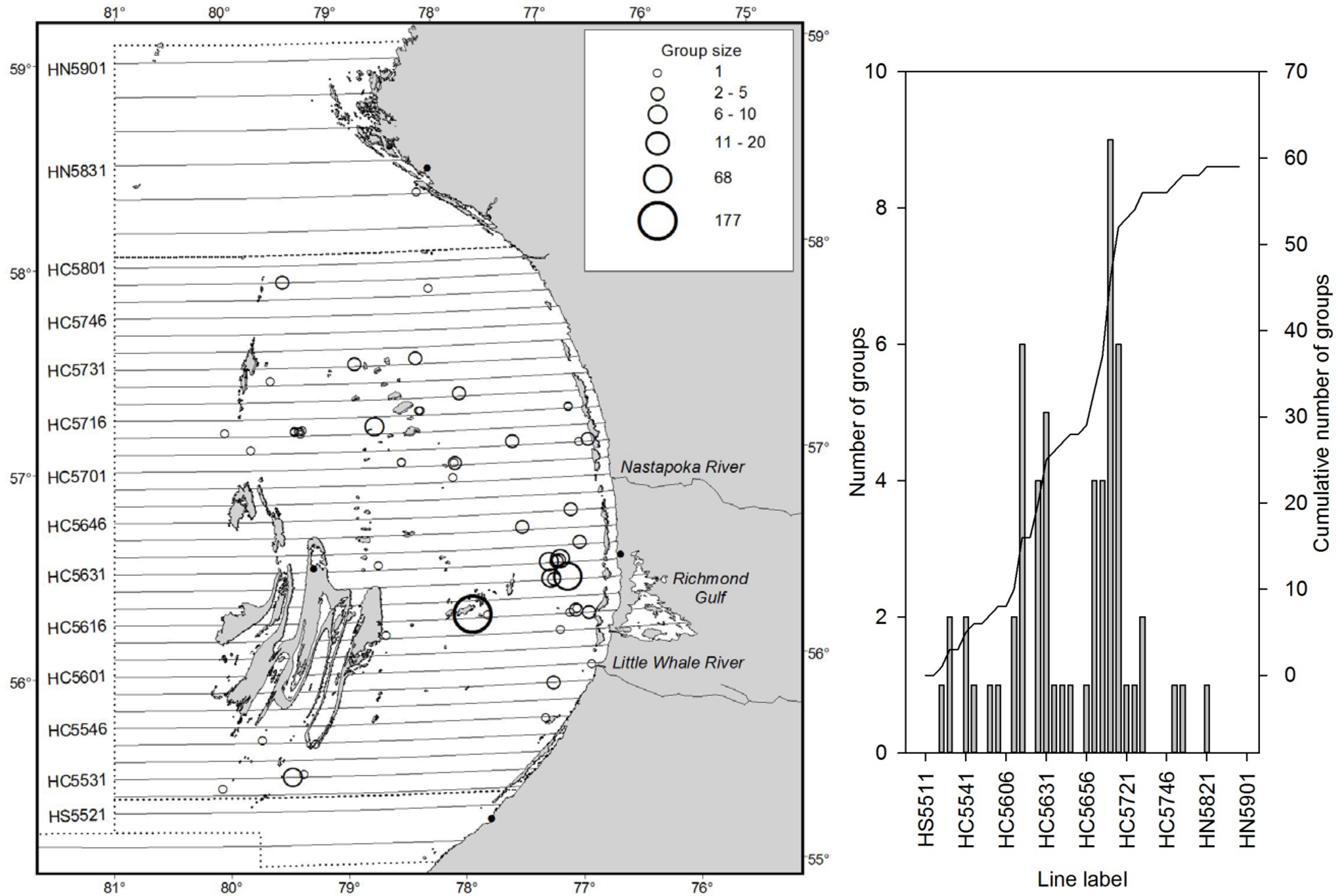

Figure 3. Left: Geographic distribution of detected groups and lines surveyed on the first survey (pass) in eastern Hudson Bay. Right: Frequency of the number of groups detected per line and the cumulative number of groups from south to north.

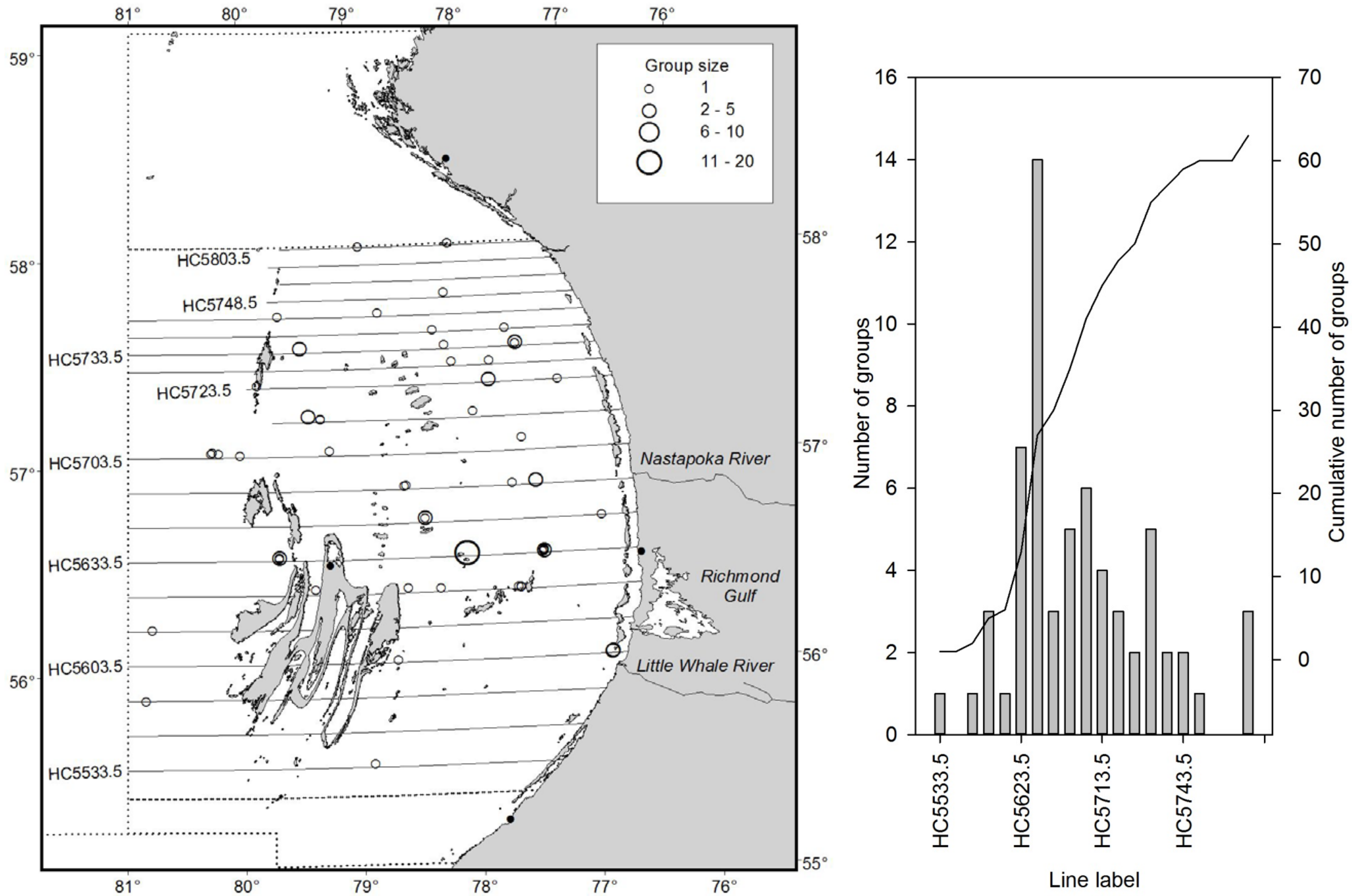

Figure 4. Left: Geographic distribution of detected groups and lines surveyed on the second survey (pass) in eastern Hudson Bay. Right: Frequency of the number of groups detected per line and the cumulative number of groups from south to north.

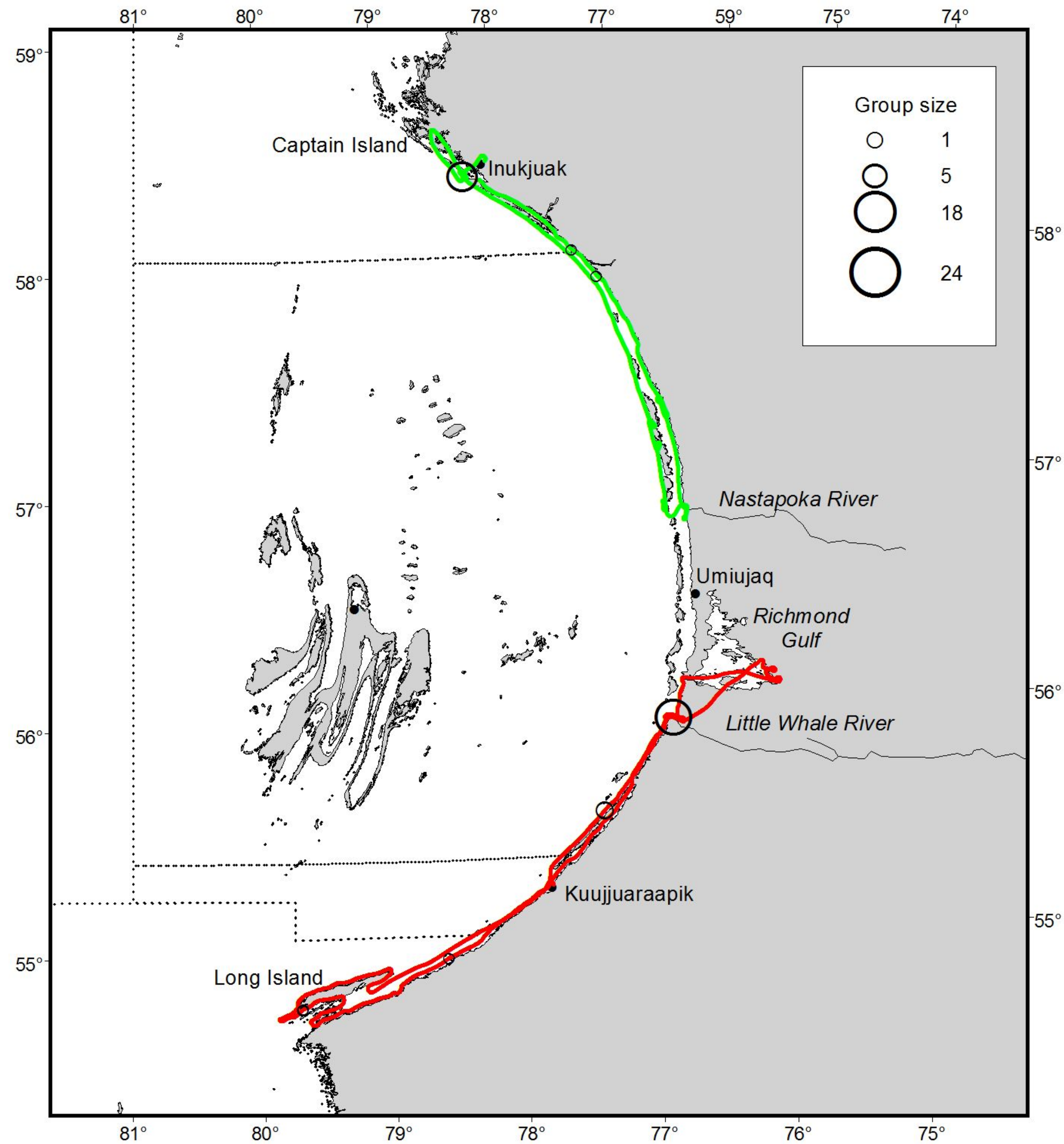

Figure 5. Distribution of the groups of belugas detected during the coastal surveys conducted from Inukjuak on 24 August 2015 (green track) and from Kuujjuaraapik on the 2 September 2015 (red track).

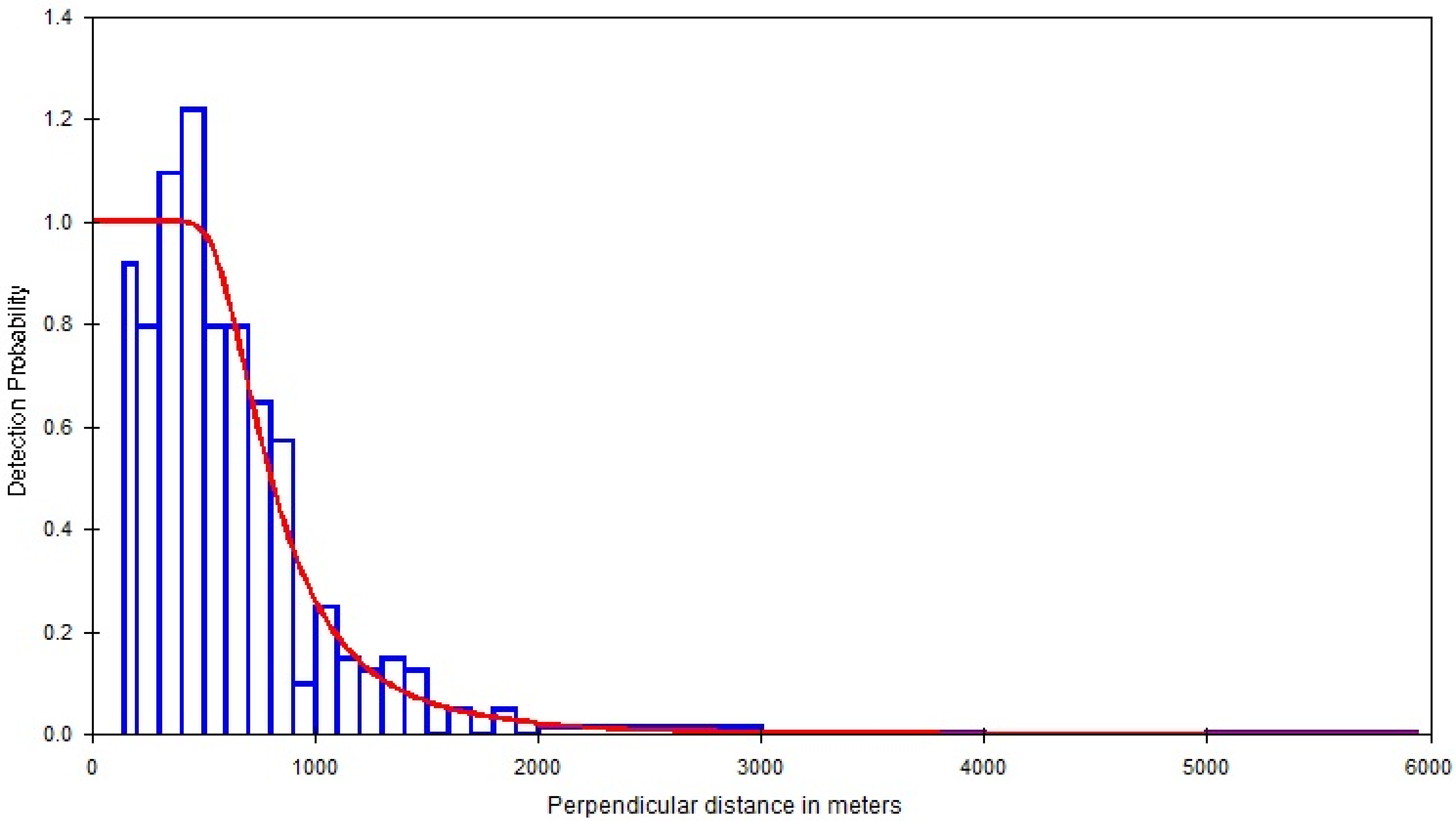

Figure 6. Distribution of perpendicular distances of 307 groups of beluga whales detected in James Bay and eastern Hudson Bay and the fitted hazard rate detection function providing an effective strip half width of 764 m. The perpendicular distances are grouped in 23 bins but the model was fitted to the ungrouped dataset from the left truncation of 143 m to the maximum perpendicular distance of 5,938 m.

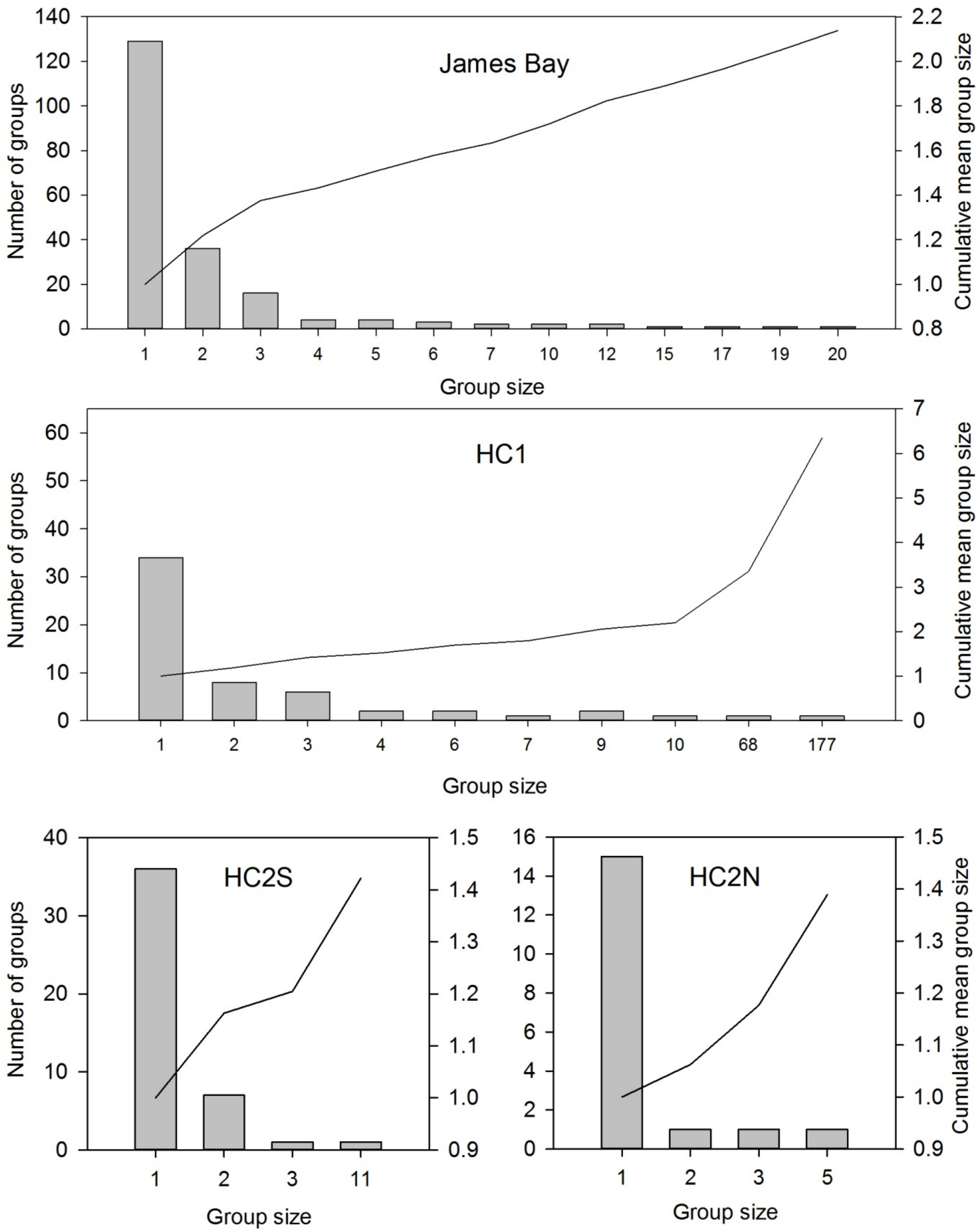

Figure 7. Frequency distribution of group sizes in James Bay and in eastern Hudson Bay. The cumulative average cluster size shows the effect of large clusters on the expected cluster size for each stratum and sub-stratum.