Fisheries and Oceans Canada
Ecosystems and Oceans Science

Pêches et Océans Canada
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Canadian Science Advisory Secretariat (CSAS)

Research Document 2023/040

Quebec Region

Abundance Estimates for Beluga (*Delphinapterus leucas*) in James Bay and the Belcher Islands-Eastern Hudson Bay Area in Summer 2021

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June 2024

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.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

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

ISSN 1919-5044
ISBN 978-0-660-71910-8 Cat. No. Fs70-5/2023-040E-PDF

Correct citation for this publication:

St-Pierre, A.P., Gosselin, J.-F., Mosnier, A., Sauvé, C. and Hammill, M.O. 2024. Abundance Estimates for Beluga (*Delphinapterus leucas*) in James Bay and the Belcher Islands-Eastern Hudson Bay Area in Summer 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/040. iv + 37 p.

Aussi disponible en français :

*St-Pierre, A.P., Gosselin, J.-F., Mosnier, A., Sauvé, C. et Hammill, M.O. 2024. Estimation de l'abondance du béluga (*Delphinapterus leucas*) dans la baie James et la région des îles Belcher-est de la baie d'Hudson à l'été 2021. Secr. can. des avis sci. du MPO. Doc. de rech. 2023/040. iv + 40 p.*

TABLE OF CONTENTS

ABSTRACT

Systematic line-transect surveys were flown in James Bay and the Belcher Islands-eastern Hudson Bay area from July 22 to August 23, 2021. A total of 357 groups of belugas were detected by primary observers, but only 330 groups remained after the left truncation of groups closer than 120 m from the track line to account for the reduction in detection probability near and underneath the plane. A single hazard-rate detection function was selected to model the probability of detection in both surveyed areas from the ungrouped distribution of perpendicular distances, which estimated an average effective strip half-width of 771 m (CV = 4%). A total of 249 groups with an average size of 1.78 (CV = 7%) animals were detected in James Bay over 4,272 km of survey lines, resulting in a surface abundance estimate of 5,043 (95% CI: 3,494–7,279) belugas. The Belcher Islands-eastern Hudson Bay area was split into a high coverage stratum, surveyed twice, and two low-coverage strata located to the north and in Richmond Gulf. On the first and second survey of the high coverage area, 72 and 35 groups with average sizes of 1.86 (CV = 12%) and 3.31 (CV = 26%) detected over 8,897 km and 8,828 km of transects, respectively. These produced respective surface abundance indices of 766 (95% CI: 413–1,423) and 669 (95% CI: 244–1,832). In the northern low-coverage stratum, only one individual was detected over 1,030 km of survey lines resulting in a surface abundance index of 12 (95% CI: 2–63). No beluga were observed in Richmond Gulf. New correction factors for availability and perception biases were calculated to account for the proportion of belugas visible at the surface and to account for animals at the surface but missed by observers. For the 2021 survey in James Bay, an availability correction factor of 0.590 (CV = 7.7%) and a perception bias correction factor of 0.601 (CV = 10.5%) resulted in a corrected abundance estimate of 14,213 (95% CI: 9,208–21,938). For the 2021 survey in Belcher Islands-eastern Hudson Bay, an availability correction factor of 0.549 (CV = 7.7%), a perception bias correction factor of 0.601 (CV = 10.5%), and the addition of 289 belugas observed in the Little Whale River Estuary, resulted in a corrected abundance index of 2501 (95% CI: 1,439–4,344). New correction factors were also estimated from and applied to the previous surveys (1985–2015) conducted in the James Bay and Belcher Islands-eastern Hudson Bay area.

INTRODUCTION

Beluga whales, *Delphinapterus leucas*, are distributed throughout the Arctic. In eastern Canada, beluga are observed during summer along the coasts of Hudson Bay, James Bay, and Ungava Bay. Different populations are recognized based on the discontinuity of their summer distribution, genetics, and movements inferred from satellite telemetry (Reeves and Mitchell 1989; Richard 1993; Brennin et al. 1997; Brown Gladden et al. 1997; DFO 2001; de March and Postma 2003; COSEWIC 2004; Richard 2010; Postma et al. 2012; Parent et al. 2023).

In previous assessments, four populations were recognized to inhabit or migrate along the Nunavik coasts: Ungava Bay, James Bay, and the Eastern and Western Hudson Bay populations (but see Parent et al. 2023). Genetic studies (Turgeon et al. 2012) and satellite telemetry (Bailleul et al. 2012a) have shown that the Eastern and Western Hudson Bay populations overwinter together in Hudson Strait, where they likely interbreed. Belugas in James Bay constitute a distinct breeding population and appear to undertake limited seasonal movements, remaining in the James Bay and southern Hudson Bay areas (Bailleul et al. 2012a; Postma et al. 2012). A fourth population was also identified in Ungava Bay (Smith and Hammill 1986; COSEWIC 2004; Richard 2010).

Commercial whaling during the 19th and early 20th centuries depleted the Ungava Bay and eastern Hudson Bay populations, and high subsistence harvests have likely limited their recovery (Finley et al. 1982). Beluga harvesting represents a traditional activity for Inuit living along the coasts of Nunavik. Based on low abundance estimates in eastern Hudson Bay and Ungava Bay, limits were placed on subsistence harvesting in 1986 (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 population was still decreasing over the period covered by the surveys (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 100 animals remained in this summering population (Doniol-Valcroze and Hammill 2012). Conservation concerns for beluga in eastern Hudson Bay and Ungava Bay led to their designation as “Threatened” and “Endangered”, respectively, by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2004, 2020). This led to more stringent management measures, including directing more of the harvest to Hudson Strait and complete hunting closures in eastern Hudson Bay and Ungava Bay in some years (Lesage et al. 2009). More recent surveys and modelling of the eastern Hudson Bay area indicated stabilization of the eastern Hudson Bay population size (Gosselin et al. 2009, 2013, 2017; Doniol-Valcroze et al. 2011; Hammill et al. 2017).

In a recent genetic study, Parent et al. (2023) identified a fifth group of belugas summering near the Belcher Islands as genetically distinct from the four previously known populations. Parent et al. (2023) concluded that grouping the Belcher Islands (BEL) and eastern Hudson Bay (EHB) beluga populations into one stock provides more robust genetic assignations since they share multiple haplotypes. In addition, telemetry data from belugas tagged in the eastern Hudson Bay arc, i.e., the Nunavik coast between Long Island and Cox Island, indicates that belugas from the arc (considered as belonging to the EHB population) move between the Nunavik coast and the Belcher Islands during summer, strongly suggesting that the BEL and EHB populations overlap spatially (Bailleul et al. 2012a, 2012b). Since animals from these populations cannot be distinguished during aerial surveys, Parent et al. (2023) proposed grouping animals into a single stock for management purposes, hereafter referred to as the BEL-EHB stock. In past documents (e.g., Gosselin et al. 2002, 2009, 2013, 2017; Gosselin 2005; Hammill et al. 2017, 2021), the term “EHB stock” was used to describe the very same animals, given their geographic location. The use of the term “BEL-EHB stock” now captures the change in the definition of the genetic composition of those animals, indicating the combination of two populations within the specific area of Belcher Islands and eastern Hudson Bay, during the summer period.

The signing of the Nunavik Inuit Land Claims Agreement (NILCA) transferred the responsibility of resource co-management to the Nunavik Marine Region Wildlife Board (NMRWB), which was established under the agreement. This responsibility is shared with the Eeyou Marine Region Wildlife Board (EMRWB) in the offshore overlap area, as established under the Eeyou Marine Region Land Claims Agreement and the Cree/Inuit Offshore Overlap Agreement. The current 5-year management plan was developed by the NMRWB and the EMRWB in 2021 and expires January 31, 2026. This management plan includes a combination of quota and non-quota limitation measures, and will be reviewed annually by the Boards. The management plan is based on the objective that the probability of a decline in abundance from the 3,400 animals estimated in eastern Hudson Bay (Hammill et al. 2017) must not exceed 50% during the next five years.

This study presents the abundance indices obtained from systematic line-transect aerial surveys conducted during summer 2021 in James Bay and the Belcher Islands-eastern Hudson Bay area. New correction factors for availability and perception biases were calculated using standardized methods and telemetry data (Marsh and Sinclair 1989). A new availability correction factor to account for animals that are diving while the plane passes overhead (based on diving data from satellite telemetry of eastern Hudson Bay and James Bay beluga) was used to replace the previous correction, which was based on St. Lawrence beluga diving behavior (Kingsley and Gauthier 2002). This is the first time that a perception bias correction factor was applied to eastern Hudson Bay abundance estimates to account for the proportion of belugas present at the surface but missed by observers on the aircraft. The new perception bias correction was estimated using double platform data from the 2015 and 2021 surveys. These correction factors were applied to indices from the 2021 survey, as well as to indices from previous surveys conducted since 1985 in the same geographical area to produce a time-series of fully corrected and comparable estimates. An adjustment was also applied to the 1985 strip-transect survey results prior to correction, to make it comparable to the line-transect survey design followed in later years.

METHODS

STUDY AREA AND SURVEY DESIGN

The visual line-transect survey flown in summer of 2021 covered all of James Bay and the eastern Hudson Bay arc from the coastline to longitude 81°W, which corresponds to 60 km west of the Belcher Islands (Figure 1). The stratification used in James Bay and the Belcher Island-eastern Hudson Bay area was similar to that of surveys conducted from 2004 to 2015 (Gosselin 2005; Gosselin et al. 2009, 2013, 2017). 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. 2012a), and traditional ecological knowledge (Lewis et al. 2009). Transect lines were oriented in an east-west direction. There were 24 lines in James Bay (JAM), 6 lines in the low-coverage stratum of eastern Hudson Bay (HN), and 5 lines in Richmond Gulf (RG; Table 1, Figure 1). The high-coverage strata of the Belcher Island-eastern Hudson Bay area (HC) was surveyed twice, using two independent sets of 36 lines represented as HC1 and HC2 in tables and figures (Table 1, Figure 1). While previous surveys had a low coverage stratum to the south of Belcher Islands-eastern Hudson Bay (referred to as “HS” in previous surveys), this small area was covered by the high coverage stratum which extended south to the limit of the James Bay stratum. The Belcher

Islands-eastern Hudson Bay area was formed by combining the HN, HC, and RG strata. Lines in James Bay and in the low coverage areas of Belcher Islands-eastern Hudson Bay were spaced 18.5 km (10 nautical miles) apart, whereas spacing in the high coverage strata was 9.3 km (5 nautical miles). The length of transect lines (used to estimate density) and the area of each stratum (used to estimate abundance) were both measured using line and area over water only, in R 3.6.1 (R Development Core Team 2018) with the package “sp” (Bivand et al. 2013) using the North Pole Lambert Azimuthal Equal Area (Canada) projection (ESPG 3573), with 80°W as the central meridian.

Coastal surveys were flown on three occasions (August 10, 16, and 20) to search for groups of belugas along the coastline and within estuaries. During coastal surveys, the planes flew offshore at a distance where observers determined that they could detect all animals between the plane and the coast. Digital photographs were taken when large numbers of belugas were detected (e.g., in river estuaries) and the animals were counted on adjacent pictures, using the maximum count of non-overlapping areas as the total number of animals observed for a given group. Because this count was performed using imagery, the availability and perception correction factors described below were not applied. The belugas observed in estuaries during coastal surveys were considered as a total count, although their numbers may have been underestimated given water turbidity in these areas. The highest number of belugas observed in each estuary during one visit (August 16) was then added to the corrected systematic survey estimate (see below). This assumes that there is little immigration or emigration from these estuaries to the offshore areas, and that belugas in estuaries have not been observed during the systematic survey. Although these assumptions are not fully representative of reality, the large group sizes observed in these estuaries are rarely seen in the systematic surveys and this method represents a means to include large estuary beluga counts in the abundance estimates. In the eastern Hudson Bay arc, the estuaries of the Little Whale River and the Nastapoka River were specifically targeted and visited every time a transit was passing by, weather permitting.

DATA COLLECTION

Flights were conducted using two Cessna-337 Skymasters and one Partenavia P68C flying at a target altitude of 305 m (1,000 feet) and a target speed of 185 km/h (100 knots). Each plane flew every third line of the survey, except for the first week when only the two Skymasters were available and each flew every second line of the survey. Three observers were onboard each plane at the following positions: 1) one on the right side of the plane in the co-pilot (right front) seat, 2) one on the left side of the plane behind the pilot (left rear), and 3) one on the right side of the plane behind the co-pilot (right rear). All observer stations were equipped with bubble windows, except for the co-pilot station in the Partenavia which had a large window instead. As in previous surveys using the Cessna-337 Skymasters, the observers in the front right and rear left positions were considered as primary observers, while the observer rear right location was considered a secondary observer. In the Partenavia P68C, the two observers in the rear (left and right) were considered primary observers as their bubble windows are similar and offer slightly better visibility near the plane than the right front window, and the right front observer was considered the secondary observer. Observations made by the primary observers in each plane were used to calculate beluga density and abundance (see next section) with equivalent effort on both sides of the plane. The observations by the secondary observer were used to calculate a perception bias correction factor (see section “Perception correction” below). In each plane, the observers rotated between the three positions each flight day.

Observers measured the inclination angle of each sighting using clinometers (Suunto) when animals passed abeam. When groups were detected away from the transect line, the relative bearing was also measured using an angle meter. Position and altitude of the plane were recorded every 2 seconds using a GPS (Garmin GPSMap 78s, Garmin GPSMap 64s, and/or BadElf Pro+). The perpendicular distance of the animals from the plane was obtained from the inclination angle and the altitude applied in the formula from Lerczak and Hobbs (1998). Observers were instructed to give priority to the estimation of group size and time of observation, followed by perpendicular distance and other variables, including animal behaviour, if time permitted.

Weather and observation conditions were also recorded at the beginning 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, low, null), cloud cover (percent), 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 FOR DENSITY AND ABUNDANCE ESTIMATES

Beluga density and abundance were estimated using the Distance software (Version 7.3, Release 1; Thomas et al. 2010). The analyses were completed using the ungrouped distances and clusters were defined as groups of beluga whales within a few body lengths of each other. For all analyses, the minimal statistical unit is an “observation” or “sighting”, which refers to a group of animals detected by an observer where group size is one individual or more.

The overall distribution of perpendicular distances was examined to determine if left and right truncations were necessary to discard outliers close to and far from the track line. Line transect surveys assume maximum probability of detection on the track line, but because there is a blind area underneath the plane, a left truncation was applied to discard the observations within the estimated maximum probability of detection. To that effect, the data were examined to identify the distance at which the number of observations increased regularly (a new sighting every few meters and then remained relatively constant). A range of potential left truncation distances were tested using both half-normal and hazard-rate detection functions to identify which improved the goodness of fit. The left truncation distance was selected by giving priority to observations near the track line (by maximizing the p-value of the C^2 statistic of the Cramér-von Mises test with cosine weighting), while maintaining good fit of the overall distribution by maximising the p value of the W^2 statistic of the Cramér-von Mises test with uniform weighting. The selected left truncation distance was then applied to further analyses by subtracting the left truncation distance to perpendicular distance of sightings to estimate the detection curve. Similarly, large gaps sometimes appeared among observations made at the greatest perpendicular distances. The distances of these gaps were tested as right truncations values to evaluate if they improved the fit of the detection function near the track line while maintaining good overall fit. The most distant right truncation distance that maximized the p-values of both the C^2 and the W^2 statistics was retained and applied to further analyses. An alternative to left truncation is to use a gamma distribution for the key function of the detection curve. This method was tested using the available coding functions from the package “mrds” (Laake et al. 2013) in R but could not be applied, as it generated errors which could not be resolved by the authors or by the package developer.

The survey was conducted with the same crew throughout, and the weather-related criteria to fly the survey remained the same from the first to the last day. Therefore, a single detection curve was used to estimate density and abundance in all strata. Model selection and inclusion of covariates followed the stepwise procedure detailed in Marques and Buckland (2003). In short, half-normal or hazard-rate models without adjustment terms were fit to the truncated distribution of ungrouped perpendicular distances of sightings, and the model with the lowest AIC was selected as the key function. Using the selected key function, we examined if AIC could be reduced further by the addition of one of the following covariates: observer (nine levels), sea state, glare intensity, cloud cover, and visibility, while avoiding to combine variables that are not independent. If AIC was significantly reduced by the addition of a covariate (ΔAIC > 2), the model with the covariate was retained. Models with additional covariates were selected in subsequent steps if the addition of another covariate further reduced the AIC.

To account for possible bias in detectability due to group size, we considered 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 in further analyses if significant at $\alpha = 0.15$, otherwise the mean cluster size was used (Buckland et al. 2001).

In some cases, observations lacked a perpendicular distance measurement. This usually occurred when high densities of beluga whales were encountered, during which observers did not have sufficient time to record detailed information about all groups and were instructed to prioritize recording group size. These observations were not used for the selection of the detection function, nor in the size-bias regression. Overall, 32 beluga groups recorded by primary observers lacked a distance measurement. However, observations without a recorded perpendicular distance measurement are assumed to be within truncation distances as it is expected that the effective searching width was narrowed at higher densities. If we assume that the observations without perpendicular distance follow the same distribution as the observations with distance measurements, and hence produce a similar proportion of sightings removed by truncation (3% of sightings), then truncation should remove less than one group without perpendicular distance. Hence, we consider that the potential bias caused by using sightings without perpendicular distances in the analysis is negligible. Therefore, these observations were included in the estimation of encounter rates and expected cluster size for the estimation of density and abundance. To that effect, all observations without perpendicular distances were added to the observations within truncation distances, and used with a uniform model with a multiplier, namely the inverse of the estimated probability of detection, $\hat{P}$ (with corresponding SE and degrees of freedom), which is associated with the estimation of the effective strip half-width (ESHW) from a single detection function estimated using the distribution of perpendicular distances of sightings from all strata combined.

The estimated indices 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 first expression of equation 1 below (equation 3.67 in Buckland et al. (2001)). When including sightings without perpendicular distance was required, the equation is replaced by the second expression of equation 1 and, to achieve this using Distance, the uniform model is used with $\hat{P}$ as divider of density.

$$\widehat{D}_i = \frac{n_i \cdot \hat{E}_i(s)}{2L_i \cdot \widehat{ESHW}} = \frac{n_i \cdot \hat{E}_i(s)}{2L_i \cdot Maximum\ perpendicular\ distance \cdot \hat{P}} \tag{1}$$

$$\widehat{N}_i = \widehat{D}_i \cdot A_i \tag{2}$$

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 associated variance of density and abundance of animals at the surface during the systematic survey is estimated by the following formula, where $\frac{\widehat{var}(\widehat{ESHW})}{(\widehat{ESHW})^2}$ is equal to $\frac{\widehat{var}(\hat{P})}{(\hat{P})^2}$:

$$\widehat{var}\left(\hat{D}_i\right) = \hat{D}_i^2 \cdot \left[\frac{\widehat{var}[(n/L)_i]}{(n/L)_i^2} + \frac{\widehat{var}(\widehat{ESHW})}{(\widehat{ESHW})^2} + \frac{\widehat{var}[\hat{E}_i(s)]}{[\hat{E}_i(s)]^2}\right] \tag{3}$$

$$\widehat{var}\left(\hat{N}_i\right) = A_i^2 \cdot \widehat{var}(\hat{D}_i) \tag{4}$$

The 95% confidence interval (CI) is estimated using the following formula, assuming the distribution of density is log-normally distributed, as suggested in Buckland et al. (2001):

$$(\hat{D}_i/C\ , \hat{D}_i \cdot C) \tag{5}$$

where:

$$C = exp\left[z_\alpha \cdot \sqrt{var(\ln\ \hat{D}_i)}\right] \tag{6}$$

$$var(\ln\ \hat{D}_i) = \ln\left[1 + \frac{\widehat{var}(\hat{D}_i)}{\hat{D}_i^2}\right] \tag{7}$$

and where z_α is the upper α point of the *N*(0,1) distribution (in this case, $z_\alpha = z_{0.025} = 1.96$ for a 95% CI).

The abundance index for Belcher Island-eastern Hudson Bay area was obtained by taking the average of the estimates of density and abundance from the two surveys flown in the high coverage stratum (HC1 and HC2) (equations 8 to 14) and adding in the abundance and density indices of the low coverage stratum (HN) and Richmond Gulf (RG; Figure 1, Table 2).

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

$$\hat{M}_i = (n/L)_i \cdot, \hat{E}_i(s) \tag{8}$$

The density of the high coverage stratum (HC) was estimated as:

$$\hat{D} = \frac{\sum_i L_i \cdot \hat{D}_i}{L} \tag{9}$$

$$L = \sum_i L_i \tag{10}$$

where L_i is the total length of transects flown for each pass *i*, and *L* is the total length of transect covered for the high coverage area. The variance of $\hat{D}$ is equal to:

$$\widehat{var}\left(\hat{D}\right) = \hat{D}^2 \cdot \left[\frac{\widehat{var}(\hat{M})}{\hat{M}^2} + \frac{\widehat{var}(\widehat{ESHW})}{\widehat{ESHW}^2}\right] \tag{11}$$

where:

$$\hat{M} = \frac{\sum_i L_i \cdot \hat{M}_i}{L} \tag{12}$$

$$\widehat{var}\left(\hat{M}\right) = \frac{\sum_i L_i^2 \cdot \widehat{var}(\hat{M}_i)}{L^2} \tag{13}$$

$$\widehat{var}\left(\hat{M}_i\right) = \hat{M}_i^2 \cdot \left[\frac{\widehat{var}[(n/L)_i]}{(n/L)_i^2} + \frac{\widehat{var}[\hat{E}_i(s)]}{[\hat{E}_i(s)]^2}\right] \tag{14}$$

The abundance and associated variance of the high coverage stratum were estimated using equations 3 and 5 above, with *A* being 78,459 km^2, the area of the high coverage stratum (HC).

The abundance indices for each stratum in Table 2 were not corrected for availability nor perception biases (see below), and thus represent the number of animals detected at the surface by the primary observers.

Adjustment of the 1985 strip-transect survey estimate

In the 1985 aerial surveys of beluga in James Bay and the Belcher Islands-eastern Hudson Bay area, the data were collected using a strip-transect design. Observers onboard the plane recorded all belugas within a 1,000 m-wide strip marked on the windows on each side of the aircraft (Smith and Hammill 1986). Analysis of strip transect surveys assumes that all animals within the strip have been recorded (Buckland et al. 2001); however, this assumption is often violated and can lead to negatively biased population estimates (Burnham and Anderson 1984).

To compare the 1985 strip-survey estimate with the subsequent line-transect estimates, the line-transect surveys flown between 1993 and 2021 were re-analyzed as strip-transects assuming a strip width of 1,000 m. For each survey, only belugas observed between a minimum distance of 53 m from the plane (i.e., the minimum perpendicular distance measured in all seven line-transect surveys, except for one outlier measured at 25 m which was deemed a measurement error given the field of view of the plane used that year) and a maximum distance of 1,053 m, were used in analysis to replicate a 1,000 m-wide strip. For each of the seven surveys, the ratio between the total surface abundance estimates from the strip-transect method and the line-transect method was calculated. The average ratio and corresponding variance was used to adjust the 1985 strip-transect survey estimate to be comparable with the line-transect estimates of subsequent years.

AVAILABILITY AND PERCEPTION BIASES CORRECTION FACTORS

Estimates of marine mammal abundance obtained using aerial surveys can be affected by two main sources of bias: 1) observers not detecting whales because the animals are diving, below the water's surface within the area being surveyed (availability bias), and 2) observers not detecting animals that are at or near the surface within the observer's field of view (perception bias; McLaren 1961, Marsh and Sinclair 1989, Laake *et al.* 1997, Fleming and Tracey 2008, Melville *et al.* 2008). In this study, two approaches were used to correct the abundance estimates for these sources of bias; 1) an availability bias correction based on beluga whales' surface intervals and the flight characteristics with respect to the period of time a surfaced beluga could be sighted, and 2) a perception bias correction based on mark-recapture distance sampling. Availability and perception bias correction factors were applied to the entire time-series of beluga surveys in James Bay and the Belcher Islands-eastern Hudson Bay area (1985 to 2021) as multipliers of the surface abundance estimates. In addition, belugas detected in estuaries were assumed to represent total counts and were added to the systematic line-transect estimates after correction for availability and perception biases.

Availability correction

The mean durations of surface and dive intervals needed to calculate an availability bias correction factor were obtained from temperature depth-satellite relayed data loggers (TD-SRDLs) from the Sea Mammal Research Unit (SMRU; St. Andrews, UK), which record the surface and dive duration for each dive. Loggers were installed on 9 belugas from the eastern Hudson Bay arc in 2003 and 2004. For details regarding logger deployment, see Bailleul et al. (2012a). For the present study, diving behaviour within 24 hours of tag deployment was omitted from the analysis because the whale's behaviour may have been altered as a result of the tagging process. Only data recorded in July and August during daytime (10:00 to 23:59 UTC) were used as it is representative of the time at which beluga aerial surveys take place, i.e., when belugas are in their summering areas and not migrating. Belugas were considered to be diving when recorded depth exceeded 4 m, otherwise they were considered to be at the surface. This is consistent with general depth of detection of a beluga whale from a plane calculated in the Canadian Arctic (Richard 1993; Marcoux et al. 2016).

The availability correction factor *a(x)* was based on a model developed by McLaren (1961) and improved by Laake et al. (1997). The latter model describes the surface intervals *E(s)* and dive intervals *E(d)* as a two-state continuous-time Markov process (Laake et al. 1997). *E(s)* and *E(d)* were obtained from the logger data, and correspond to the mean duration of surface intervals and dive intervals, respectively, weighed per individual based on the number of dives recorded. Preliminary analysis of the logger data showed no difference in surface and dive duration based on sex. Based on the model developed by Laake et al. (1997), the availability at a perpendicular distance *x* can be estimated by adding: 1) the probability that an animal is at the surface when a plane arrives overhead, estimated as the proportion of time an animal spends at the surface based on the mean surface and dive intervals, and 2) the probability that an animal is diving when the plane arrives overhead, but that it will become visible while its location remains within the area of the observer's visual search while the plane passes overhead. The period during which a beluga is available to be seen by the aerial observers depends on the diving behaviour of the animal and on *w(x)*, the time period a point at the surface of the ocean at a perpendicular distance *x* from the track line remains in the field of view of the observers. The availability correction factor is calculated as (equation 4 in Laake et al. 1997):

$$a(x) = \frac{E(s)}{E(s)+E(d)} + \frac{E(d)\left[1-e^{-w(x)/E(d)}\right]}{E(s)+E(d)} \tag{15}$$

The time period *w(x)* depends on the aircraft speed, *v*, and on the searching pattern of the observers. In this study, we assumed that the observers had a conical field of view on each side of the aircraft, limited horizontally forward by an angle Φ_1 and backward by an angle Φ_2. Hence, *w(x)* was estimated based on the formula from Forcada et al. (2004), and Gómez de Segura et al. (2006):

$$w(x) = \frac{x}{v}\left[\cot(\emptyset_1) + \cot(\emptyset_2)\right] \tag{16}$$

In the present study, the forward and backward viewing angles used were 30° and 20°, respectively, were measured from the observer seats, and were similar for both types of aircraft used (Cessna-337 Skymasters and one Partenavia P68C). Plane speed, *v*, was assumed to be constant at the target speed of 100 knots or 51.39 m/s.

For each of the seven surveys conducted from 1993 to 2021, an availability correction factor, $\hat{a}$, was calculated separately for James Bay and the Belcher Islands-eastern Hudson Bay area as the average $a(x_j)$ of each observed group of belugas using:

$$\hat{a} = \frac{\sum_{j=1}^{n} a(x_j)}{n} \quad (17)$$

where n is the number of groups detected for which the perpendicular distance, x_j, was estimated and was between the left and right truncation distances.

The 1985 survey was a 1,000 m strip-transect and the perpendicular distance of each sighting was not recorded, thus precluding the use of equations 15 to 17 to estimate availability. Instead, the availability correction factor applied to the 1985 survey was estimated using sightings from 53 m to 1,053 m from trackline for the seven surveys from 1993 to 2021 using equations 15–17 (see section “Adjustment of the 1985 strip-transect survey estimate” for details on the choice of 53 m and 1,053 m as limits).

For each year and stratum, the CV around the average availability correction factor was very low (≤ 1%). Because there is uncertainty associated with the reliability of the telemetry data (e.g., tag precision) and the depth to which belugas can be seen, the uncertainty around the availability bias correction factor was increased by fixing the CV at a value of 7.7% as reported by Kingsley and Gauthier (2002).

Perception correction

During the 2015 and 2021 surveys, the number and position of the observers onboard the planes made it possible to estimate a perception bias correction factor. Observers were considered to be primary or secondary observers based on their position within each plane (see DATA COLLECTION section). The data from the secondary observers during the 2015 survey was not used in previous assessment and therefore not mentioned in previous reports (Gosselin et al. 2017). In all aircraft, the two right-sided observers were seated approximately one meter apart and isolated from each other visually by an opaque curtain and aurally by headset intercom while searching the same area. Hence, the two observers on the right side of the aircraft were considered as two independent platforms and their observations were used to estimate perception bias correction factors via mark-recapture distance sampling (MRDS) analyses (Laake and Borchers 2004). All observations (i.e., sightings of groups of animals, where group size is one or more) made by observers on the right side of the plane while both observers were actively searching for animals (i.e., “on effort”) were used for this analysis. Observations made by the observer on the left side of the aircraft were not used for MRDS analyses. All MRDS analyses were performed in R 3.6.1 (R Development Core Team 2018) with the package “mrds” (Laake et al. 2013).

Prior to conducting MRDS analyses, duplicate sightings, i.e., groups of animals detected by both the primary and secondary observers, must be identified. Duplicate sightings were identified through coincidence in location based on the difference in time of recording, and the difference in clinometer measurement. Species identity was also used as a criterion in duplicate identification, meaning that both sightings needed to have the same species recorded to be considered duplicates. However, only beluga sightings were used for the MRDS model and calculation of the perception bias correction factor. In the primary literature, time thresholds used in surveys of cetacean species generally vary between 3 and 10 s, while clinometer thresholds generally range from 5 to 15° (e.g., Pike et al. 2008; Pike and Doniol-Valcroze 2015; Panigada et al. 2017; Lambert et al. 2019). In preliminary analyses for the present study, seven values of time thresholds (3, 5, 7, 10, 12, 15 and 20 s) were tested in conjunction with four clinometer thresholds (5, 10, 15, and 20°), using the 2015 and 2021 data separately. Based on the number of duplicates obtained with each combination of time and clinometer thresholds and expert opinion, thresholds of 10 s and 10° were selected for analyses for both the 2015 and 2021 survey data. These thresholds were considered as most likely to capture true duplicate sightings while minimizing the number of false duplicates. For observations with a missing inclinometer value (31 and 49 beluga observations in 2015 and 2021, respectively), only the time threshold was considered.

Because MRDS analyses require that perpendicular distances and covariate values be identical for a given pair of duplicate sightings, we attributed an average value (for continuous covariates, i.e., perpendicular distance, cluster size, cloud cover, and Beaufort) to these variables for the observations identified as duplicates if the two observers had recorded different values. The average perpendicular distance was used for distance analyses. For the categorical covariates (i.e., glare intensity and visibility), duplicates for which the two observers had recorded different values were attributed the value with the greatest negative effect on one's ability to observe animals (e.g., if one observer recorded visibility as good and the other recorded visibility as low, the latter value was attributed for this duplicate sighting).

MRDS analyses consist of two functions: 1) a multiple covariate distance sampling (MCDS) detection function for detections pooled across the two right-side observers, and 2) a MRDS detection function to estimate the probability of detection on the track line (Buckland et al. 2001, Buckland et al. 2009). Both functions used the same left and right truncation distances as those identified for the analysis of the single-platform dataset of their respective survey. For the MCDS function, AIC was used to select between half-normal and hazard-rate key functions and to examine if the addition of covariates (group size, observers, Beaufort state, glare intensity, cloud cover, and visibility) yielded a better fit following the procedure outlined in Marques and Buckland (2003). The key function and covariates yielding the lowest AIC in the MCDS detection function were used in the MRDS models. The latter were built with and without covariates and compared using AIC. A point independence configuration was applied in the MRDS models because detection probabilities may be correlated between observers even though the primary and secondary observers acted independently and were isolated from each other, for example due to factors like group size (i.e., both observers are more likely to detect larger groups than smaller groups as distance increases). This configuration assumes that platforms are symmetrical and that sightings are independent only on the track line, which is more robust then a configuration assuming independent detection at all perpendicular distances (Buckland et al. 2009, Burt et al. 2014). By definition, perpendicular distance is included as covariate in all point-independence MRDS models (Buckland et al. 2009). The best fitting MRDS model was selected and used to estimate the correction factor *p(0)* for each observer position. Estimates of *p(0)* for the primary observer were then used to correct the abundance estimates calculated using data from the primary observers, assuming that *p(0)* was the same for primary observers on the right and left side of the aircraft.

Perception bias correction factors were calculated separately for the 2015 and the 2021 surveys to yield a survey-specific value of *p(0)*. Because surveys prior to 2015 were flown as single platform, no survey-specific perception bias correction factor could be calculated for these surveys. Instead, the average *p(0)* from the 2015 and 2021 was applied to correct abundance estimates for surveys flown between 1985 and 2011.

RESULTS

SURVEY COMPLETION

The 24 lines planned in James Bay were completed in four days, from July 22 to July 26 with a one-day interruption (Figure 2). During the first survey of the Belcher Islands-eastern Hudson Bay area, 36 lines were flown in the high coverage stratum (HC1) and the 11 lines were flown in the low coverage strata (RG, HN). These strata were surveyed completely in five days during the first survey of the Belcher Islands-eastern Hudson Bay area, between July 26 to August 10, with one eight day interruption from July 28 to August 6 and a two-day interruption on August 8–9 (Figure 3). The second survey of the high coverage stratum (HC2) was completed in 5 days from August 14 to August 23, with several short interruptions on August 11–13, August 16, August 18–19 and August 21–22 (Figure 4).

BELUGA SIGHTINGS

A total of 357 groups of belugas, or 693 individuals, were detected by the primary observers during the surveys of James Bay and Belcher Island-eastern Hudson Bay (Table 1, Figures 2–4). On the first survey of the whole Belcher Island-eastern Hudson Bay strata (HC1, HN, RG; Figure 3), 135 beluga whales were detected, including only one in the northern low coverage stratum (HN; Table 1, Figure 3). No belugas were observed in Richmond Gulf. On the second survey of the high coverage strata (HC2), 116 belugas were detected (Table 1, Figure 4).

No belugas were sighted during the coastal survey from Cox Island to Nastapoka River on August 10 (Figure 5). During the coastal flight conducted on August 16 from the southern tip of Long Island to Little Whale River (LWR), three individual beluga whales were observed in the Long Island area and a group of 289 belugas was observed in the LWR Estuary (Figure 5). No belugas were sighted during the coastal survey flight from Nastapoka River to Richmond Gulf on August 20 (Figure 5). In addition, the Nastapoka River Estuary was visited twice during transits between survey lines (August 6 and 17) and no belugas were observed on any of these visits. The LWR Estuary was surveyed on five occasions during transits and the beluga count was highly variable, with no belugas sighted on three visits (July 27, August 6 and 17), while large groups of 257 and 203 beluga whales where observed on August 12 and 15, respectively. The maximum count of 289 beluga whales in LWR, observed during the dedicated coastal flight on August 16, was added to the systematic survey estimate (after correcting the survey estimate for availability and perception bias; see below). There was no clear relationship between the tide cycle and beluga presence in LWR Estuary.

DETECTION CURVE

The distribution of perpendicular distances from the track line showed 10 sightings within 106 m of the plane, beyond which distance the sightings became more frequent. This suggests potential left truncation distances of 106 m based on outliers only. Fitting a hazard-rate backwards on perpendicular distances of 500 to 0 m suggests that the detection probability was maximal beyond 252 m. A similar backward analysis from 300 to 0 m provided a better fit and suggested that the probability of detection increased rapidly and became maximal beyond 120 m. These three distances (106, 120, and 252 m) were tested as potential left truncation values. Left truncation distances of 120 m and 252 m had a better fit near the track line for the hazard-rate model (C^2 $p = 0.75$; W^2 $p = 0.85$), compared to the 106 m left truncation (C^2 $p = 0.45$; W^2 $p = 0.45$). The shape criterion was respected in all models (Buckland et al. 2001). For all left truncation distances tested, the fit of the half-normal model was not as good as that of the hazard-rate model, neither near the track line (C^2 $p = 0.13$ to 0.55) nor for the overall model (W^2 $p < 0.01$ to 0.75). Therefore, the hazard-rate model was used instead of the half-normal. Finally, a left truncation distance of 120 m was used because it maximized the number of sightings available for analysis and yielded a more efficient model (CV = 0.055) compared to a truncation distance of 252 m (CVs = 0.75).

Similarly, for the distant sightings, three observations beyond 1938 m could be identified as outliers. The probability of detection of the hazard-rate model became roughly 15% at a perpendicular distance of 1,372 m, which is a criterion for right truncation as suggested by Buckland et al. (2001). Another rule of thumb is to eliminate the last 5% or 10% of the data, which corresponded to truncation distances of 1,057 m and 1,329 m, respectively. Using 1,057 m, 1,329 m, or 1,372 m as right truncation distances did not improve the fit near the track line of the hazard-rate model for the left truncation of 120 m, compared to a model truncated at 1,938 m to remove outliers. Therefore, a right truncation of 1,938 m was used.

The hazard-rate (AIC = 4,693) was selected over half-normal (AIC = 4,701, ΔAIC = 8) when fitted to the 341 sightings left after the left truncation of 120 m. The addition of covariates was tested, and three of the covariates considered improved the model. Cloud cover was the covariate resulting in the better fit improvement (AIC = 4,682), followed by Beaufort (AIC = 4,684) and platform (AIC = 4,690). Multivariate models including cloud cover and either Beaufort or platform were fitted, but the inclusion of a second covariate did not improve model fit. Therefore, the hazard-rate model with cloud cover as sole covariate was retained which provided an effective strip half-width (ESHW) of 771 m (SE = 33, CV = 0.04, Figure 7). Given the left and right truncation distances applied, the adjustment to the uniform model to include observations without perpendicular distances was an estimated probability of detection, *P*, of 0.4241 (SE = 0.01018322, df = 327) based on the ESHW.

GROUP SIZE

The regression of the natural log of cluster size (ln*(s)*) against the probability of detection *g(x)* was not significant for the 341 groups with available perpendicular distance and within truncation distances (*p* >0.15) and, therefore, the average cluster size was used in all strata (Table 2). Across all strata, group size ranged from 1 to 30 belugas, with a global mean group size of 1.91 belugas (CV = 6%). The 249 groups detected in James Bay had a mean group size of 1.78 (CV = 6%, Table 2, Figures 2 and 7). In the high coverage stratum, the 72 groups detected during the first pass yielded a mean group size of 1.86 (CV = 12%) while the 35 groups detected during the second pass yielded a mean group size of 3.31 (CV = 26%; Table 2, Figures 3 and 4).

ENCOUNTER RATE

In James Bay, a high proportion of belugas were detected on the lines to the southeast of Akimiski Island and along the Ontario coast at the western ends of lines (Figure 2). The encounter rate in James Bay was 0.056 groups per km (CV = 16%) which is 7 to 14 times higher than the encounter rates in the high coverage stratum of eastern Hudson Bay (Table 2).

In the high coverage stratum of Belcher Islands-eastern Hudson Bay, the number of groups observed during the first survey (HC1, 72 groups) was twice the number of groups observed during the second survey (HC2, 35 groups), yielding encounter rates of 0.008 (CV = 29%) and 0.004 (CV = 47%) groups per km, respectively (Table 2, Figures 3 and 4). The encounter rate in the low coverage (HN) strata of eastern Hudson Bay was 0.001 (CV = 72%) based on only one observation (Table 2).

DENSITY AND ABUNDANCE ESTIMATES

Using the same detection curve adjusted for covariate values in each stratum and mean group sizes specific to each stratum resulted in abundance indices of 5,043 belugas (95% CI: 3,494–7,279) for James Bay and 730 belugas (95% CI: 407–1,307) for Belcher Islands-eastern Hudson Bay (Table 2). The density calculated was 0.064 individuals per km^2 (CV = 18%) in James Bay (Table 2). In the Belcher Islands-eastern Hudson Bay area, density was 0.009 individuals per km^2 (CV = 30%) in the high coverage strata (combined for HC1 and HC2; Table 2) and 0.001 individuals per km^2 (CV = 72%) in the low coverage strata (HN; Table 2). Hence, both the abundance and density calculated are about 7 times higher in James Bay compared to the Belcher Island-eastern Hudson Bay area (Table 2). These density and abundance indices represent the number of animals detected at the surface by the primary observers (i.e., initial values prior to availability and perception bias corrections, see below).

In James Bay, encounter rate, group size, and the detection function accounted respectively for 81.1%, 13.3%, and 5.6% of the variance of density. The same components accounted for respectively 83.1%, 15.0%, and 1.9% of the variance of density for the first survey of the high coverage stratum (HC1) in Belcher Islands-eastern Hudson Bay, and 76.1%, 23.2%, and 0.6% of the variance of density for the second survey of the high coverage stratum (HC2).

AVAILABILITY CORRECTION FACTORS

An availability bias correction factor was calculated for each of the seven surveys flown between 1993 and 2021 during which perpendicular distances were recorded, and separately for James Bay and the Belcher Islands-eastern Hudson Bay area. For the James Bay stratum, availability bias correction factors ranged from 0.574 to 0.624 (Table 3). For the Belcher Islands-eastern Hudson Bay area, availability bias correction factors ranged from 0.549 to 0.630 (Table 3). For the 1985 survey, an availability bias correction factor calculated from the perpendicular distances observed during the other seven surveys within the range of 53–1053 m yielded a correction of 0.567 for James Bay and 0.549 for eastern Hudson Bay (Table 3). The CVs of all availability correction factors were set to 7.7%based on Kingsley and Gauthier (2002).

PERCEPTION CORRECTION FACTORS

From the 2021 survey data, 162 unique beluga sightings were recorded by the observers positioned on the right side of the planes while both observers were on effort. Based on coincidence in location, using time and clinometer thresholds of 10 s and 10°, 63 sightings were identified as duplicates between the primary and secondary observers on the right side of the planes. The MRDS analysis used the same truncation distances as the detection curve for the 2021 survey (see above), and identified an MRDS model with a hazard-rate key and with Beaufort and group size as covariates as being the best fitting. This model yielded a primary *p(0)* of 0.601 (CV = 10.5%; Table 3).

From the 2015 survey data, 214 unique beluga sightings were recorded by the observers positioned on the right side of the planes while both observers were on effort. Based on coincidence in location, using time and clinometer thresholds of 10 s and 10°, 46 sightings were identified as duplicates between the primary and secondary observers. The MRDS analysis used a left truncation distance of 143 m and no right truncation (i.e., same as the detection curve for the 2015 survey; Gosselin et al. 2017), and identified an MRDS model with a hazard-rate key and Beaufort as covariate as being the best fitting. This model yielded a primary *p(0)* of 0.392 (CV = 15.9%; Table 3).

For surveys from 1985 to 2011 for which a double-platform configuration was not used, an average perception bias correction factor of 0.497 (CV = 17.9%) was applied (Table 3).

CORRECTED ABUNDANCE ESTIMATES

Correcting the surface abundance indices from the 2021 survey for the proportion of submerged animals that could not be detected from an aerial platform, using the availability bias correction factors described above, yielded abundance indices of 8,547 (CV = 19.8%, CI: 5,821–12,550; Table 3) for James Bay and 1,330 (CV = 30.7%, CI:738–2,397; Table 3) for the Belcher Islands-eastern Hudson Bay area.

Correcting the surface abundance estimate for both the availability and perception biases yielded an abundance estimate of 14,213 (CV = 22.4%, CI: 9,208–21,938; Table 3) for James Bay in 2021. Corrections for both availability and perception biases applied to the surface index in the Belcher Islands-eastern Hudson Bay area, to which we then added the count of 289 belugas observed in the Little Whale River Estuary, provided a fully corrected abundance estimate of 2,501 belugas (CV = 28.7%, CI: 1,439–4,344; Table 3) in 2021.

The corresponding availability and perception bias correction factors were also applied to survey results from 1993 to 2015 (Table 3). The availability estimates corrected for both biases varied from 12,811 to 39,152 in James Bay and from 4,163 to 7,841 in the Belcher Islands-eastern Hudson Bay area (Table 3).

For the 1985 survey, the original surface estimate from the strip-transect analysis (Smith and Hammill 1986) was first adjusted to be comparable to line-transect surveys. The average strip-to-line ratio calculated using the 1993 to 2021 survey data was of 1.511 (CV = 20.5%) and 1.792 (CV = 24.2%), for the James Bay strata and the Belcher Islands-eastern Hudson Bay area, respectively (Table 4). The 1985 strip-transect surface abundance indices for each strata were multiplied by the corresponding ratio, then corrected for availability and perception biases, to yield fully corrected estimates of 6,511 (CV = 28.3%, CI: 3,779–11,217) for James Bay and 6,711 (CV = 28.9%, CI: 3,855–11,682; Table 3) for the Belcher Islands-eastern Hudson Bay area.

DISCUSSION

In past surveys (e.g., Gosselin et al. 2009, 2013, 2017), the term “EHB stock” was used to describe the animals summering in the eastern portion of Hudson Bay that were counted during aerial surveys of this region. However, a genetic analysis by Parent et al. (2023) of skin samples provided by hunters from their catch has determined that two beluga populations summer in the area covered by the eastern Hudson Bay surveys: a Belcher Islands population and an eastern Hudson Bay population. The overlapping summer distribution of these two populations prevents differentiation of animals from these populations when counted from the air. Consequently, the two populations have been combined to form a single stock for management purposes, defined as the BEL-EHB stock.

The 2021 survey of James Bay and the Belcher Islands-eastern Hudson Bay area is the eighth of a series of systematic surveys flown since 1985 (Smith and Hammill 1986; Kingsley 2000; Gosselin et al. 2002, 2009, 2013, 2017; Gosselin 2005). However, three important changes were made in the analysis conducted in the present study, which affect the time series of abundance estimates. First, the 1985 strip-transect estimate of surface abundance was readjusted using a new strip-to-line transect ratio calculated based on all subsequent surveys. This new ratio lowered the James Bay surface estimate and increased that of the Belcher Islands-eastern Hudson Bay area surface estimate compared to earlier reports (Hammill et al. 2004; Gosselin 2005), and provided a measure of variance around the 1985 estimates. Secondly, new availability correction factors were calculated using tagging data from the region. This yielded partially corrected estimates (i.e., corrected for availability only) approximately 18%

lower than those calculated with the previously used availability correction factor (Kingsley and Gauthier 2002). Finally, applying a perception bias correction, which had not been used before in beluga surveys in Nunavik, had a strong impact on the abundance estimates in all years, on average increasing the surface abundance by a factor of two. Applying both the availability and the perception correction factors more than doubled the abundance estimates in all surveys.

ABUNDANCE ESTIMATES FROM THE 2021 SURVEY

James Bay population

With a value of 14,213 belugas, the corrected abundance estimate for the James Bay population calculated from the 2021 survey data is in the middle of the range of values observed for this stratum in surveys since 1985. The 2021 estimate is lower than that of the three most recent surveys (2008, 2011, and 2015) but higher than the corrected abundance estimates from 1985, 1993, and 2004. The 2021 estimate is ~21% lower than the last survey in 2015 (Gosselin et al. 2017). The CV of the 2021 estimate of 22.4% is lower than in previous surveys, which ranged from 27.9% to 69.7% (Table 3). The lower CV in 2021 comes from the absence of large groups (which yields a lower variance compared to previous surveys), and the slightly lower CV around the availability and perception correction factors specific to that survey (Table 3).

In the 2021 survey of James Bay, the majority of beluga sightings were divided between two zones: the area southeast of Akimiski Island, and the northwest coast of the bay (Figure 2). Similar spatial distributions between these two zones were observed in previous surveys of James Bay, with a large number of sightings to the southeast of Akimiski island, particularly during the 1985 and 2004 surveys, and a high proportion of sightings in the northwest portion of the bay in the 1993, 2001, 2008, 2011, and 2015 surveys (Smith and Hammill 1986; Kingsley 2000; Gosselin 2005; Gosselin et al. 2002, 2009, 2013, 2017). During the 2021 survey, ~60% of belugas sighted in James Bay were located in the southern half of the bay, and ~33% in the northwestern zone. In previous surveys, when low numbers were observed in the northwest portion of the bay (2004) or when this area could not be fully surveyed (1985, due to the presence of pack ice), it resulted in low abundance estimates for the James Bay area overall (Smith and Hammill 1986; Gosselin 2005). Beluga whales are also found along the Ontario coast of Hudson Bay (Richard 2005). The variability in sightings in the northwestern James Bay area may reflect movement between the two areas. Although belugas summering in James Bay are considered a distinct breeding population, telemetry and genetic information from this area are limited to the eastern portion of James Bay, and information about beluga summering along the Ontario coast of Hudson Bay is lacking (Bailleul et al. 2012a; Postma et al. 2012, Parent et al. 2023).

Belcher Islands-eastern Hudson Bay stock

The corrected abundance estimate obtained from the 2021 survey of Belcher Islands-eastern Hudson Bay is the lowest of the time series and is markedly lower than the estimates from the last two surveys which reached 5,001 and 7,841 belugas in 2011 and 2015, respectively, after correction for availability and perception biases. The CV measured for the 2021 BEL-EHB abundance estimate is also the lowest of the eight surveys.

Two common sources of uncertainty when conducting surveys of small populations with clumped distributions include the occurrence of a few large clusters (uneven distribution of group size among sightings) and variable encounter rates (uneven distribution of clusters among lines), which represent clumping at two different scales (Gosselin et al. 2007). Because average group size is a multiplier in the estimation of density, the occurrence of a few large beluga groups can rapidly increase both the abundance estimate itself and its variance, due to an increase in the variance component associated with the estimation of group size. This effect was observed in the three previous surveys (2008, 2011, and 2015) where a few large groups increased the mean cluster size by 50% to nearly 300%, resulting in higher abundance estimates and wider confidence intervals (Gosselin et al. 2009, 2013, 2017). In 2021, the only observation made during the systematic survey with a group size larger than 11 individuals was one group of 30 belugas sighted near the mouth of the Little Whale River Estuary.

At a broader spatial scale, the distribution of clusters among lines (i.e., the spatial distribution of beluga in the study area) may be influenced by a combination of foraging behaviour, social behaviour, and environmental conditions. Bailleul et al. (2012b) showed that sea surface temperature influences the dispersal of belugas equipped with satellite transmitters in Eastern Hudson Bay. Although the drivers of cluster distribution are still unclear, it is possible to adjust the survey methods to reduce its influence on the estimation of density and abundance. One way to reduce the effect of clumping is to increase effort, thus obtaining more observations to estimate the effective strip half-width, group size and encounter rate, and reducing the relative importance of each observation in the density and abundance indices. This approach was applied in eastern Hudson Bay in 2008 and 2015, and has been applied in the St. Lawrence Estuary (Gosselin et al. 2007, 2009, 2017). Two repeat surveys of the high coverage area of eastern Hudson Bay were flown during the 2021 survey. Three airplanes were used to ensure that both surveys were completed rapidly, despite weather-related delays. Having two surveys covering the entire high coverage area helps provide a more precise and accurate estimate of beluga abundance, but additional surveys of the same area would not be possible without increasing the number of planes as there is a limited time period available as animals start migration by late September (Kingsley et al. 2001; Lewis et al. 2009; Bailleul et al. 2012a). There is only limited room for further increasing effort through reduction in spacing between lines or to use adaptive sampling in future surveys given the 9.3 km (5 nautical miles) spacing in Belcher Islands-eastern Hudson Bay, which provides an estimated effective coverage of roughly 20% (Thompson and Seber 1996; Pollard and Buckland 2004). The latter approach may be useful in low coverage areas with line spacing of 18.5 km (10 nautical miles), although few beluga groups were detected in these areas in past surveys. Another solution to increase effort would be to reduce the number of years between surveys, which would also help with modeling efforts.

A second way to reduce the effect of clumping is to further stratify the survey design based on environmental variables affecting beluga behaviour. If this stratification is done based on a strong understanding of movements and habitat use within the summer season, it could result in an increase in the number of sightings during a survey. In the Belchers Islands-eastern Hudson Bay and James Bay regions, 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, 2009; Gosselin 2005), satellite telemetry data (Lewis et al. 2009, Bailleul et al. 2012a; 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 is limited.

Beluga whales are known to form summer aggregations in and around estuaries. In our surveys of the Belcher Islands-eastern Hudson Bay area, following the practice from previous surveys, we have excluded estuary counts from our transect estimates to add them in separately as total counts. During the 2021 survey, no belugas were detected in the Nastapoka River Estuary on four occasions and four different days. No belugas have been observed in this estuary during aerial surveys since 2004 (Gosselin 2005, Gosselin et al. 2009, 2013, 2017). The Little Whale River Estuary was visited on six occasions during the 2021 survey, including three when no belugas were observed in the estuary and three occasions when the beluga total count varied between 203 and 289 individuals. These beluga counts are consistent with the intra- and inter-annual variations in the number of animals observed in this estuary. In previous surveys, the daily maximum counts were 39, 354, and 167 belugas in 2001, 2011, and 2015, respectively. Conversely, no belugas were detected in the Little Whale River in 2004 and 2008 (Gosselin et al. 2002, 2009, 2013, 2017; Gosselin 2005). Further studies are needed to investigate the causes of daily variations in beluga presence in the Little Whale River Estuary. Tide is assumed to affect the number of belugas in estuaries, but so far no correlation with tidal cycles are apparent from the aerial survey data that remains limited to assess this potential effect.

Migration could bias systematic survey estimates. If a concentration of animals is migrating in the same direction as the survey lines are covered by the planes, this concentration of animals would then be oversampled, i.e., it would be counted on a higher number of transects than if it was not moving. Conversely, if the migration goes in a direction opposite to that of the survey plane, there would be a negative bias on the abundance estimate. The 2021 survey was conducted over a short time period using 3 planes, thus reducing this possible bias. We also assume that movement of BEL-EHB belugas was random and that there was no migration during the period of the survey, or between the first survey conducted from July 26 to August 10 and the second survey conducted from August 14 to August 23. This is supported by the movements from EHB beluga whales tagged with satellite transmitters in the Hudson Bay arc, which have shown a start of migration in late September and a peak of migration in October (Kingsley et al. 2001; Bailleul et al. 2012a). Assuming random movements, it can be expected that the number of groups recorded twice due to their movements from one line to the other as the lines are being surveyed would be cancelled out by the number of groups missed due to the same movement pattern in an opposite direction.

CORRECTION FACTORS APPLIED TO THE TIME SERIES OF SURVEYS

In the present study, the surface estimates from the 1985 strip-transect survey were adjusted to enable comparison with the subsequent line-transect surveys. Previously, the ratio used to adjust the surface estimate was 1.87, which had been calculated based only on data from the 1993 and 2001 surveys (Hammill et al. 2004; Gosselin 2005). Using data from six surveys (1993 to 2021) allowed calculation of ratios which better account for interannual variations in the distribution of sighting distances from the plane. This also allowed the variance around the average ratio to be calculated and to be carried forward to the adjusted estimate, while previous studies reported the adjusted surface estimate without variance (Hammill et al. 2004; Gosselin 2005). In addition, separate ratios were calculated for the James Bay and the Belcher Islands-eastern Hudson Bay stratum for more specificity. This led to a decrease in the adjusted surface estimate for James Bay (ratio of 1.511, surface estimate of 1,833) and an increase for the Belcher Islands-eastern Hudson Bay area (ratio of 1.792, surface estimate of 1,735 without estuary counts) compared to the values previously reported (2,256 and 1,820 for James Bay and Belcher Islands-eastern Hudson Bay area, respectively; Hammill et al. 2004; Gosselin 2005).

The surface abundances were then corrected to account for availability (animals underwater when the plane flies over) and perception (animals at the surface but missed by observers) biases (McLaren 1961; Marsh and Sinclair 1989; Laake and Borchers 2004). For previous surveys in James Bay and the Belcher Islands-eastern Hudson Bay area, surface estimates had been corrected using an availability correction factor developed to correct photographic surveys of St. Lawrence Estuary beluga, which estimated that the proportion of time animals were visible from a hovering aircraft was 0.478 (CV = 7.7%; Kingsley and Gauthier 2002). To obtain availability bias correction factors more representative of the Nunavik beluga populations, new correction factors were calculated using diving data from beluga tagged in eastern Hudson Bay area. Ideally, diving data from whales equipped with satellite transmitters during the period of the survey should be used to calculate the availability correction factor. Transmitters were not deployed during the 2021 survey, but it was assumed that beluga diving behaviour did not change over years and that the 9 belugas tagged in 2003–2004 were representative of populations in James Bay and eastern Hudson Bay. Because the observers have a few seconds to detect whales at the surface, the availability bias correction factors considered the time a beluga would be in view for the observer rather than an instantaneous correction such as those used in photographic surveys which may overestimate abundance when applied to a visual survey. The availability correction factors were calculated separately for each survey based on the perpendicular distances at which observations had been recorded, and separately for James Bay and the Belcher Islands-eastern Hudson Bay area, yielding correction factors ranging from 0.549 to 0.630 (CVs fixed at 7.7%; see section "Availability correction"). Overall, applying the new availability correction factors yielded estimates roughly 18% lower than when using the previous correction factor from Kingsley and Gauthier (2002). However, correction factors did not show any temporal trend and the differences between the two strata were not always the same, indicating that one stratum does not have a consistently higher correction factor than the other. The variability among years suggests potential differences in observer search patterns. Different observers may be focusing closer to or further from the plane, which could impact the distribution of perpendicular distances recorded and affect the availability bias correction factor calculated.

For other beluga populations in northern Canada, only instantaneous correction factors have been calculated based on the available data. For example, based on three 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 = 5%) and 0.485 (CV = 6%; Marcoux et al. 2016; Watt et al. 2021). Based on belugas tracked in the Canadian High Arctic, it was estimated that the proportion of time animals remained within 4 to 5 m from the surface was 0.430 (CV = 9%), which was used as an instantaneous correction for availability for populations in West Greenland (Heide-Jørgensen and Acquarone 2002; Innes et al. 2002; Heide-Jørgensen et al. 2010). As expected, such corrections tend to be slightly higher than those calculated for James Bay and the Belcher Islands-eastern Hudson Bay area, i.e., they provide a greater increase in abundance, because they don't take into account the fact that any given point at the surface of the water remains in the observer field of view for a variable amount of time as the plane flies overhead. In comparison, the proportion of time at the surface based on tag data from eastern Hudson Bay was 0.440.

During the two surveys conducted with double-platform configurations in 2015 and 2021, there were sufficient detections by primary and secondary observers to estimate perception bias correction factors for beluga whales. Prior to 2015, double-platform survey data were lacking and prevented the calculation of a perception bias correction factor. Thus, abundance estimates published so far were partially corrected (i.e., only for availability) and underestimated abundance with regards to this bias. Now that the corrected estimates take into account both the availability and perception bias corrections, they are expectedly higher. The correction factor for perception bias varied between the 2015 and 2021 surveys, with a *p(0)* of 0.392 and 0.601, respectively. This difference between years highlights the importance of measuring perception bias for each survey. A few factors could cause this difference, including: 1) differences in group size, since group size was generally smaller in 2021 compared to 2015; 2) varying environmental conditions, including the presence of ice in 2015 which could have influenced visibility; and 3) observer experience, given that the least experienced observer was always in the secondary observer position in 2015, while the observers in 2021 rotated their positions in the plane and had more similar levels of experience and more recent experience of visual surveys given that most observers had been involved in the large survey effort for North Atlantic right whale in the months prior to the survey in Nunavik. Further surveys using the double-platform configuration in the same area will be needed to investigate the causes of variability in perception bias correction factors. Until this information can be obtained, we can only assume that both the 2015 and 2021 perception bias correction factors are equally representative and apply the average *p(0)* from these two surveys to prior surveys where a double-platform configuration was not used. On average, applying only the perception correction factor to the surface abundance indices of the time series of surveys increased the abundance by a factor of two.

It is important to note that the perception bias correction factors calculated here are not comparable with those from surveys which had a double-platform configuration on both sides of the aircraft, as is often used in marine mammal surveys in the Canadian Arctic (Marcoux et al. 2016, Watt et al. 2021). In the surveys of James Bay and the Belcher Islands-eastern Hudson Bay area, the double-platform configuration was possible only on the right side of the plane and therefore the correction factors calculated (i.e., primary *p(0)*) are applicable only to the primary observers on each side of the plane, whose observations are used to calculate surface abundance estimates. In contrast, surveys conducted with a double-platform configuration on both sides of the aircraft generally calculate the surface abundance based on the total number of unique observations of both observers, *i.e.,* those seen only by the primary observer, those seen only by the secondary observer, and those seen by both observers. Because the surface estimate is already based on observations from two observers, the perception bias correction factor for the combined observers (combined *p(0)*) will always be higher, *i.e.*, will not increase the abundance as much, compared to the correction factor applicable to primary observers only (primary *p(0)*).

Across the eight surveys, the estimated abundances corrected for availability and perception biases were 2.8 to 4.5 times higher than the uncorrected surface estimates. These results highlight the importance of accounting for both sources of bias when analyzing aerial survey data. The uncertainty around the surface estimates, as well as the availability and perception correction factors, were combined to provide corrected abundance estimates combining variance from all these components. The 2021 BEL-EHB abundance estimate is the lowest of the time series of eight surveys since 1985. It was associated with the lowest combined correction for availability and perception of the time series, but even the surface abundance estimate before these corrections were applied was already the lowest of the time series. It followed the 2015 survey that was the highest corrected abundance estimate of the time series, as it was based on the third highest surface abundance estimate before corrections and the highest combined correction for availability and perception. All other surveys had intermediate combined corrections as an average perception correction was used. There is no reason to believe that there is a potential negative bias on the 2021 survey compared to the 2015 survey. The higher perception correction factor suggests that the observers were more efficient at detecting animals in 2021 than in 2015. Care should be taken when interpreting these survey abundance estimates, which are known to vary for beluga populations. The proper estimation of trends for the James Bay population and BEL-EHB beluga stock will be estimated through a population dynamic model (Hammill et al. 2023).

ACKNOWLEDGEMENTS

We are grateful for the participation of Solomon Masty and Johnny Mina as observers during the coastal surveys. Charlie Kumarluq was also available as observer for the coastal surveys. We thank Antoine Dispas, Sandrine Beaumont-Courteau, Serge Aucoin, Miranda Unger, Laurence Lévesque, and Camille Mancion who were observers for this survey. Special thanks to Pascale

Caissy and Talia Koll-Egyed, who were observers for this survey and greatly contributed to data validation and double-platform analyses. We thank Kerrith McKay for logistical support provided for this survey. Yves Labbé, from SASAIR, and Jean Gosselin, from Air Montmagny, provided support for deployment of the planes. We are thankful to Samuel Casaubon, Philippe Laurent, and Julien Provost for keeping the planes on lines and bringing us home safely. The survey was financially supported by the DFO National Survey Fund, the Implementation fund of the Nunavik Inuit Land Claims Agreement and the Nunavik Marine Region Wildlife Board.

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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 the Belcher Islands-eastern Hudson Bay area in summer 2021. The James Bay strata was surveyed with a low coverage (10 NM or 18.5 km spacing between transects). The survey of the Belcher Islands-eastern Hudson Bay area was stratified with a low coverage (10 NM or 18.5 km spacing) stratum in the north (HN), a central stratum which was surveyed twice with high coverage (5 NM or 9.3 km spacing, HC1 and HC2), and the Richmond Gulf (RG) stratum which was surveyed with a spacing of 5 NM or 9.3 km. The number of groups and individuals with perpendicular distance retained for effective strip half-width (ESHW) estimation after left truncation at 120 m and right truncation at 1,938 m are also provided.

Stratum	Dates of completion	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	Jul. 22–26	78,340	24	4,272	249	442	22 (28)	227 (414)
Belcher Islands-eastern Hudson Bay								
HC1	Jul. 26–Aug. 8	78,459	36	8,897	72	134	4 (4)	68 (130)
HC2	Aug. 14–23	78,459	36	8,828	35	116	1 (30)	34 (86)
HN	Aug. 6–8	18,918	6	1,030	1	1	0	1 (1)
RG	Jul. 27–Aug. 5	704	5	89	0	0	0	0

Table 2. Surface density and abundance indices for James Bay and the Belcher Islands-eastern Hudson Bay area in summer of 2021 showing the results of the strata within the Belcher Islands-eastern Hudson Bay area. These estimates consider the number of groups beyond the left truncation of 120 m but within the right truncation of 1,938 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 (in %) and 95% CI for abundance indices. The Belcher Islands-eastern Hudson Bay surface estimate is the sum of the HC, HN and RG areas (see Figure 1 for location of areas). Density in HC was estimated as the effort-weighted average of the density estimates of HC1 and HC2.

Area and stratum	Number of groups	Expected group size	Encounter rate (groups/km)	Surface density (groups/km^2)	Surface density (individuals/km^2)	Surface abundance index
James Bay	249	1.7751 (6.65)	0.0559 (16.41)	0.0363 (16.97)	0.0644 (18.23)	**5,043 (3,494–7,279)**
Belcher Islands-eastern Hudson Bay						**730 (407–1,307)**
HC (combined)	-	-	-	-	**0.0091 (30.24)**	**718 (397–1,297)**
HC1	*72*	*1.8611 (12.22)*	*0.0081 (28.76)*	*0.0052 (29.09)*	*0.0098 (31.55)*	*766 (413–1,423)*
HC2	*35*	*3.3143 (25.85)*	*0.0040 (46.80)*	*0.0026 (47.00)*	*0.0085 (56.64)*	*669 (244–1,832)*
HN	1	1	0.0010 (72.33)	0.0006 (72.46)	0.0006 (72.46)	12 (2–63)
RG	0	0	0	0	0	0

Table 3. Abundance estimates of beluga stocks in James Bay and Belcher Islands-eastern Hudson Bay estimated from eight systematic aerial surveys between 1985 and 2021. Abundance estimates have been corrected for availability bias, perception bias, and beluga whales counted in estuaries. Correction factors for the availability and perception biases are presented for each survey year. The 1985 survey data were collected using strip-transect techniques[a] *while the other seven surveys flew along similar lines, but data were collected using line-transect techniques*[b]*. Data from 1993 and 2021 were re-analyzed assuming a strip width of 1,000 m on each side of the aircraft to adjust the 1985 survey estimates by multiplying the strip-transect estimates by a strip-to-line ratio and then adding in estuary counts (see Table 4). Note that the CV of the availability correction factor was fixed at 7.7% based on Kingsley and Gauthier 2002 (see section "Availability correction").*

James Bay

Year	Surface abundance index	Availability correction factor (CV %)	Perception correction factor (CV %)	Estuary counts	Corrected abundance (CV %)
1985	1,833	0.567 (7.7)	0.497 (17.9)	0	6,511 (28.3)
1993	3,922	0.617 (7.7)	0.497 (17.9)	0	12,811 (27.9)
2001	8,262	0.589 (7.7)	0.497 (17.9)	5	28,242 (28.2)
2004	3,993	0.574 (7.7)	0.497 (17.9)	0	14,021 (33.3)
2008	9,196	0.624 (7.7)	0.497 (17.9)	0	39,152 (69.7)
2011	6,827	0.590 (7.7)	0.497 (17.9)	0	23,324 (33.3)
2015	5,024	0.587 (7.7)	0.392 (15.9)	0	21,860 (28.4)
2021	5,043	0.590 (7.7)	0.601 (10.5)	0	14,213 (22.4)

Belcher Islands-eastern Hudson Bay

Year	Surface abundance index	Availability correction factor (CV %)	Perception correction factor (CV %)	Estuary counts	Corrected abundance (CV %)
1985	1,735	0.560 (7.7)	0.497 (17.9)	474	6,711 (28.9)
1993	1,296	0.630 (7.7)	0.497 (17.9)	18	4,163 (42.3)
2001	1,379	0.613 (7.7)	0.497 (17.9)	39	4,570 (49.6)
2004	2,040	0.558 (7.7)	0.497 (17.9)	5	7,368 (39.3)
2008	1,394	0.589 (7.7)	0.497 (17.9)	0	4,764 (29.5)
2011	1,394	0.596 (7.7)	0.497 (17.9)	354	5,001 (47.0)
2015	1,742	0.579 (7.7)	0.392 (15.9)	167	7,841 (47.0)
2021	730	0.545 (7.7)	0.601 (10.5)	289	2,501 (28.7)

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[a] Smith and Hammill 1986

[b] Kingsley 2000; Gosselin et al. 2002, 2009, 2011, 2017; Gosselin 2005; this study

Table 4. Comparison of surface abundance indices for James Bay and eastern Hudson Bay in surveys from 1993 to 2021 when analyzed as strip-transect surveys versus line-transect surveys to generate a strip-to-line ratio. For each survey presented below, the strip-transect analysis used only data within a strip width of 1,000 m, i.e., observations recorded between the left truncation distance of 53 m and a limit of 1,053 m.

Year	**James Bay**			**Belcher Islands-eastern Hudson Bay**		
	Strip transect	**Line transect**	**Strip-to-line ratio**	**Strip transect**	**Line transect**	**Strip-to-line ratio**
1993	2,084	3,922	1.882	573	1,296	2.262
2001	4,113	8,262	2.009	537	1,379	2.009
2004	3,712	3,998	1.077	1,057	2,045	1.935
2008	6,866	9,196	1.339	938	1,394	1.486
2011	5,353	7,016	1.311	977	1,405	1.438
2015	3,360	5,024	1.495	1,297	1,742	1.343
2021	3,438	5,043	1.467	482	730	1.515
Mean (CV %)	-	-	**1.511 (20.5%)**	-	-	**1.792 (24.2%)**

FIGURES

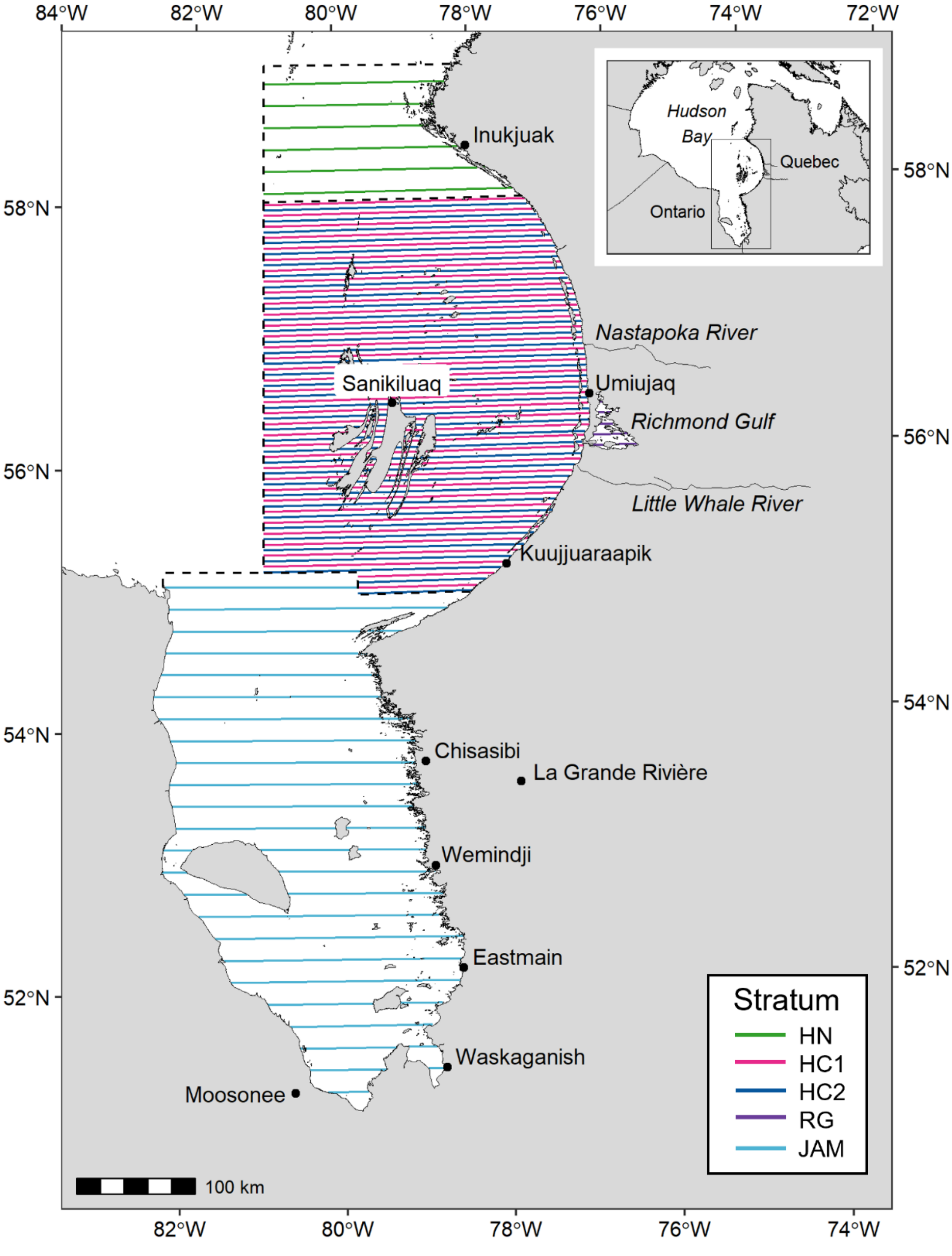

Figure 1. Transect lines planned in James Bay and the Belcher Islands-eastern Hudson Bay area for the systematic line-transect aerial beluga survey in summer 2021. The thin dashed lines show the limits of James Bay (JAM) and the low (HN) and high coverage (HC) strata in the Belcher Islands-eastern Hudson Bay area. Note that the HC stratum was covered twice (HC1 and HC2).

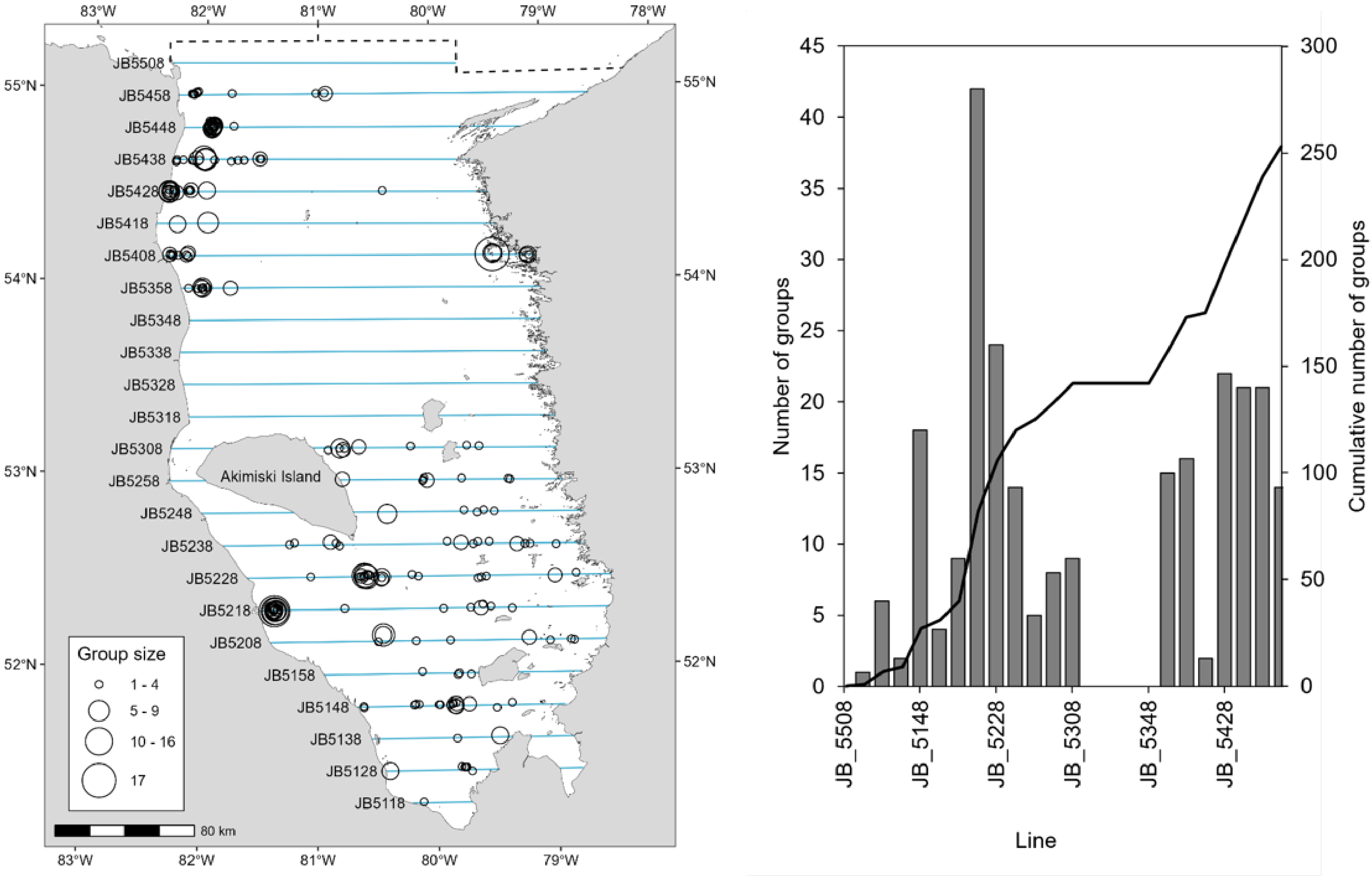

Figure 2. Left: Geographic distribution of detected beluga groups and lines surveyed in James Bay during the 2021 aerial survey. Right: Frequency of the number of groups detected per line and the cumulative number of groups from south to north.

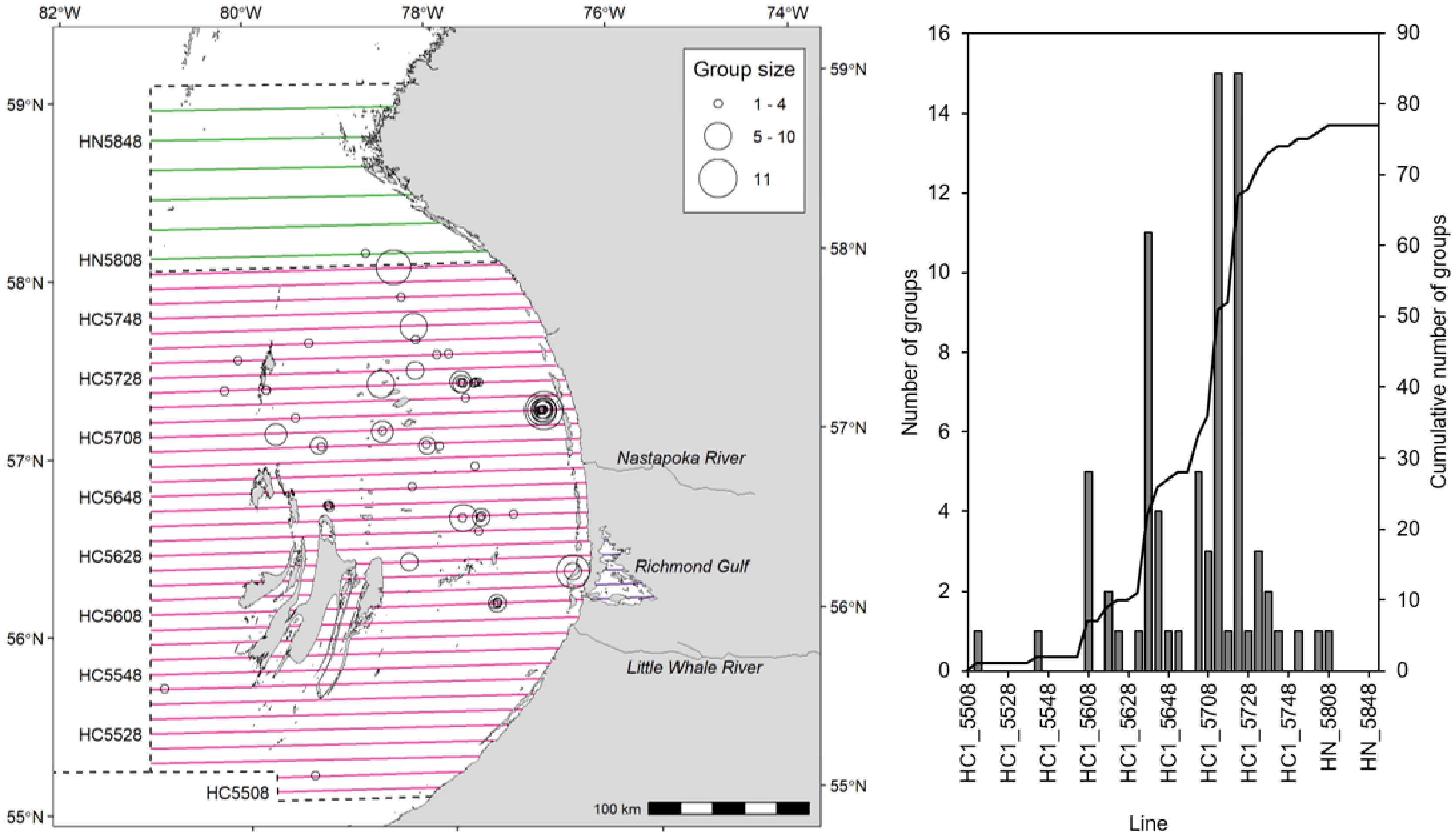

Figure 3. Left: Geographic distribution of detected beluga groups and lines surveyed on the first survey (pass) in the Belcher Islands-eastern Hudson Bay area during the 2021 aerial survey in the HC (pink lines), HN (green lines), and RG (purple lines) strata. Right: Frequency of the number of groups detected per line and the cumulative number of groups from south to north.

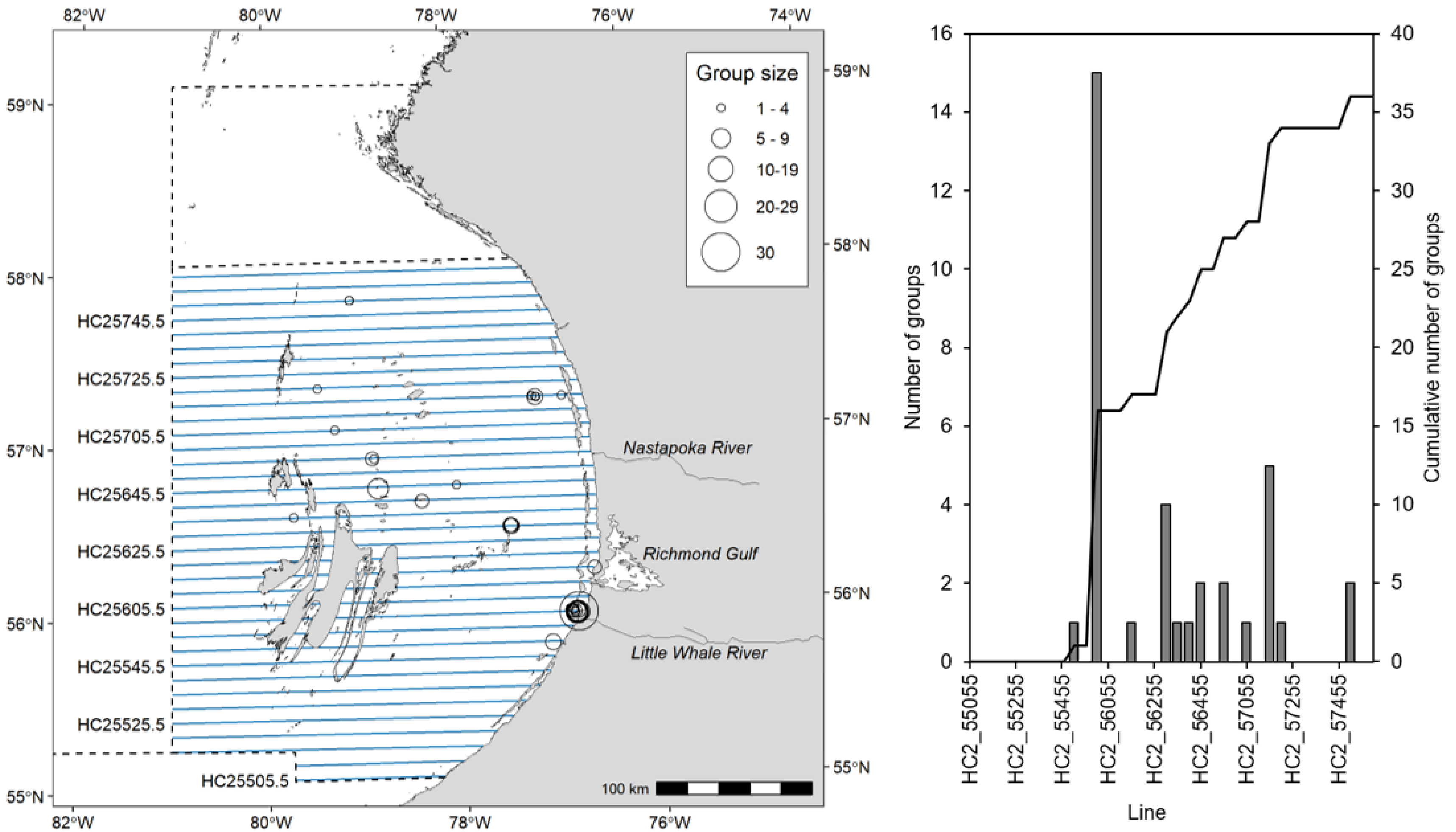

Figure 4. Left: Geographic distribution of detected beluga groups and lines surveyed on the second survey (pass) of the HC stratum in the Belcher Islands-eastern Hudson Bay area during the 2021 aerial survey. Right: Frequency of the number of groups detected per line and the cumulative number of groups from south to north.

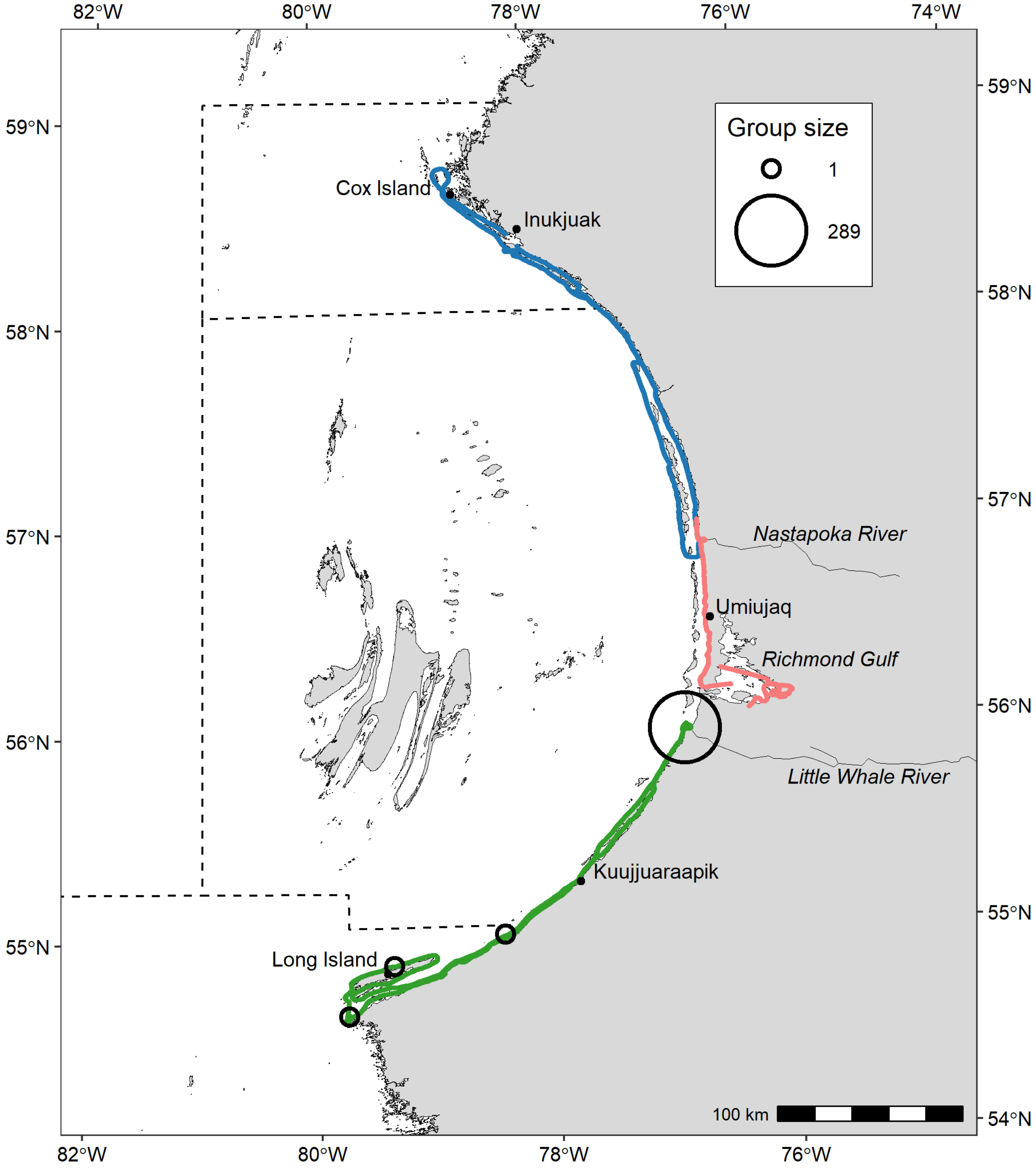

Figure 5. Distribution of the groups of belugas detected during the 2021 coastal surveys conducted from Cox Island to Nastapoka River on August 10 (blue track), and from Long Island to Little Whale River on August 16 (green track), and from Nastapoka River to Richmond Gulf on August 20 (red track).

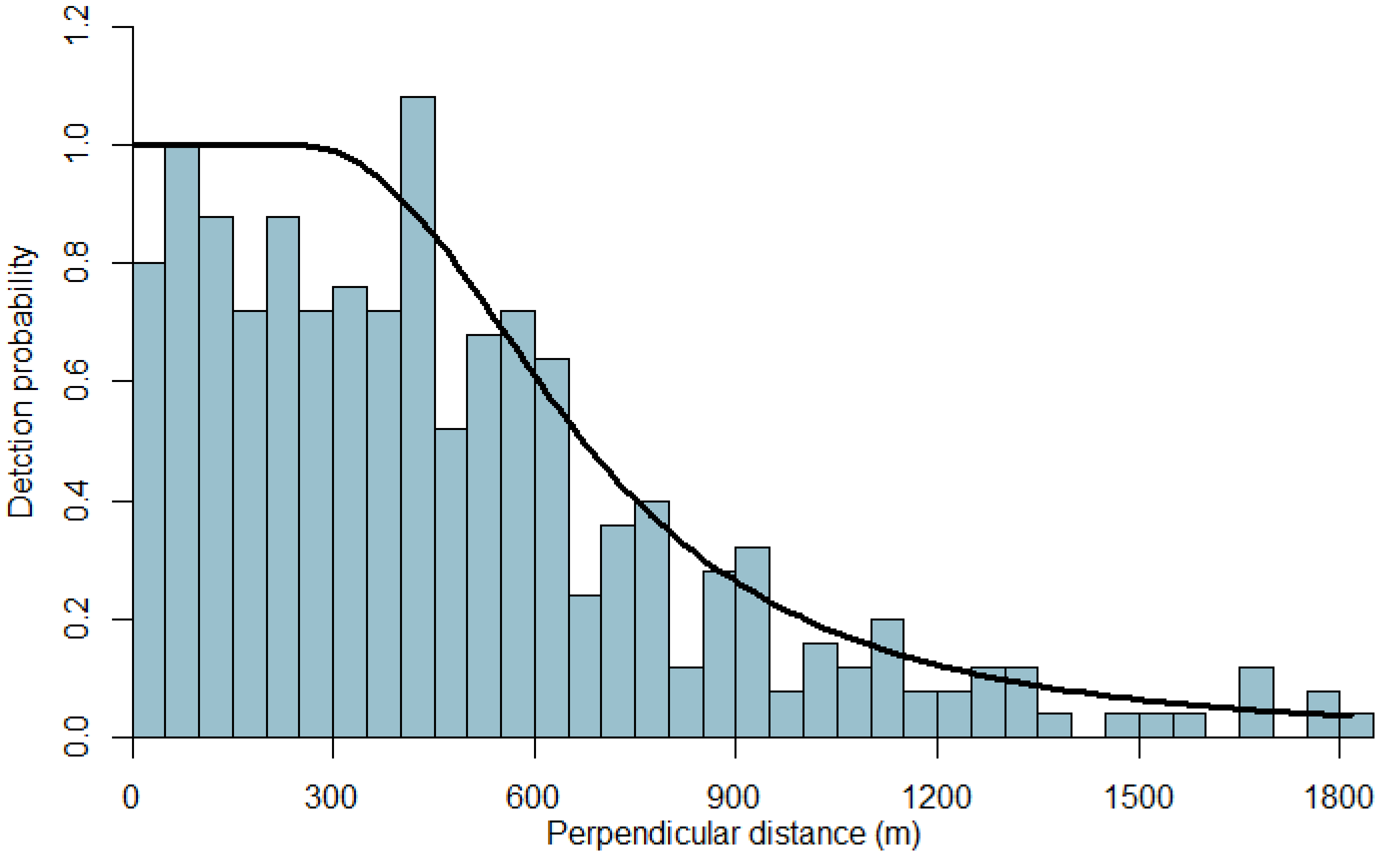

Figure 6. Distribution of perpendicular distances of 341 groups of beluga whales detected in James Bay and the Belcher Islands-eastern Hudson Bay area during the 2021 survey for which a perpendicular distance was recorded and the fitted hazard-rate detection function providing an effective strip half-width of 771 m. The perpendicular distances are grouped in 25 bins but the model was fitted to the ungrouped dataset from the left truncation of 120 m to right truncation distance of 1,938 m.

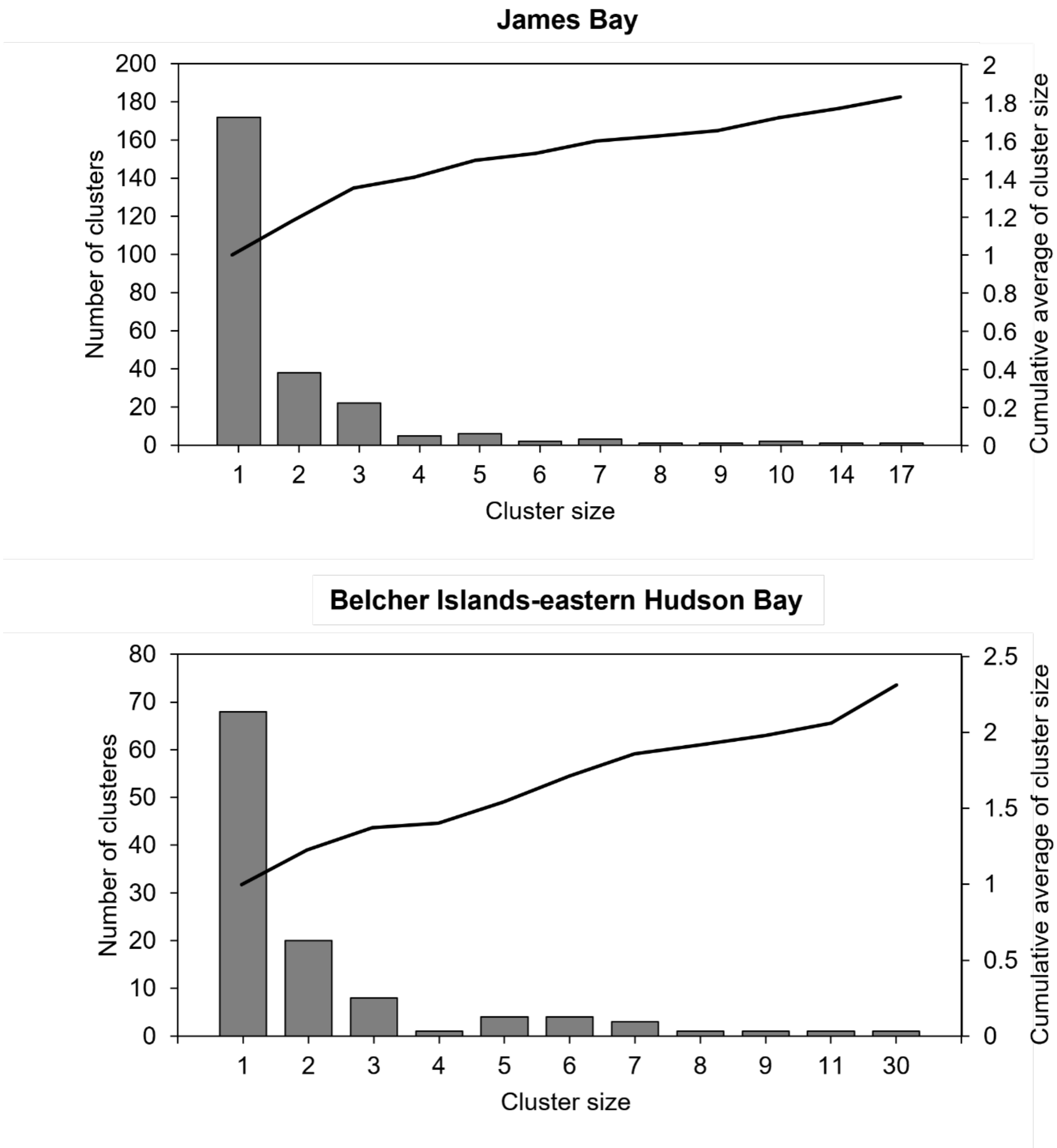

Figure 7. Frequency distribution of group sizes in James Bay and in the Belcher Islands-eastern Hudson Bay area during the 2021 survey. The cumulative average cluster size shows the effect of large clusters on the expected cluster size.

APPENDIX

Separate detection curves for the James Bay stratum and the Belcher Islands-eastern Hudson Bay stratum. Note that these curves were not used in analyses, since a single detection curve combining the observations from James Bay and the Belcher Islands-eastern Hudson Bay area was applied (see DATA ANALYSIS FOR DENSITY AND ABUNDANCE section).

JAMES BAY

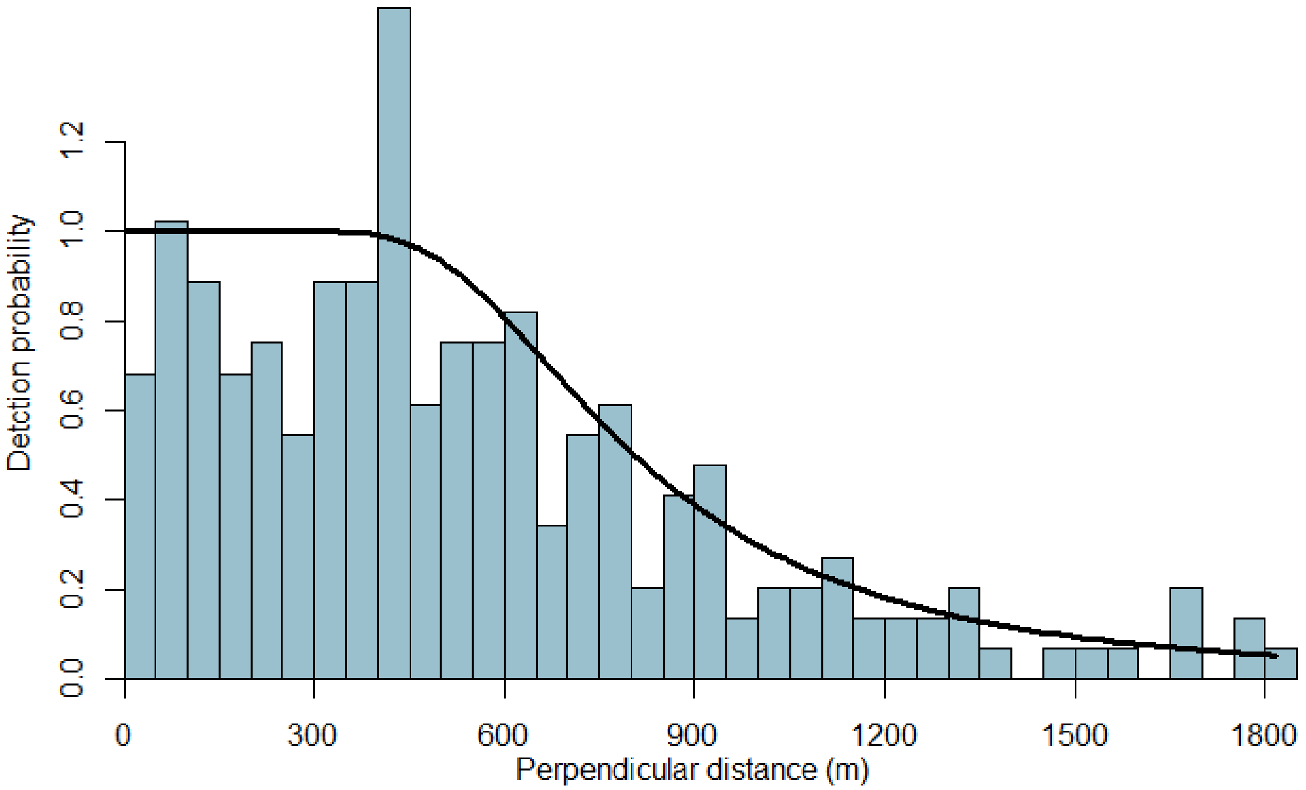

Figure A1. Distribution of perpendicular distances of 268 groups of beluga whales detected in James Bay for which a perpendicular distance was recorded and the fitted hazard-rate detection function providing an effective strip half-width of 888 m. The perpendicular distances are grouped in 25 bins but the model was fitted to the ungrouped dataset from the left truncation of 176 m to the right truncation of 3,000 m.

BELCHER ISLANDS-EASTERN HUDSON BAY

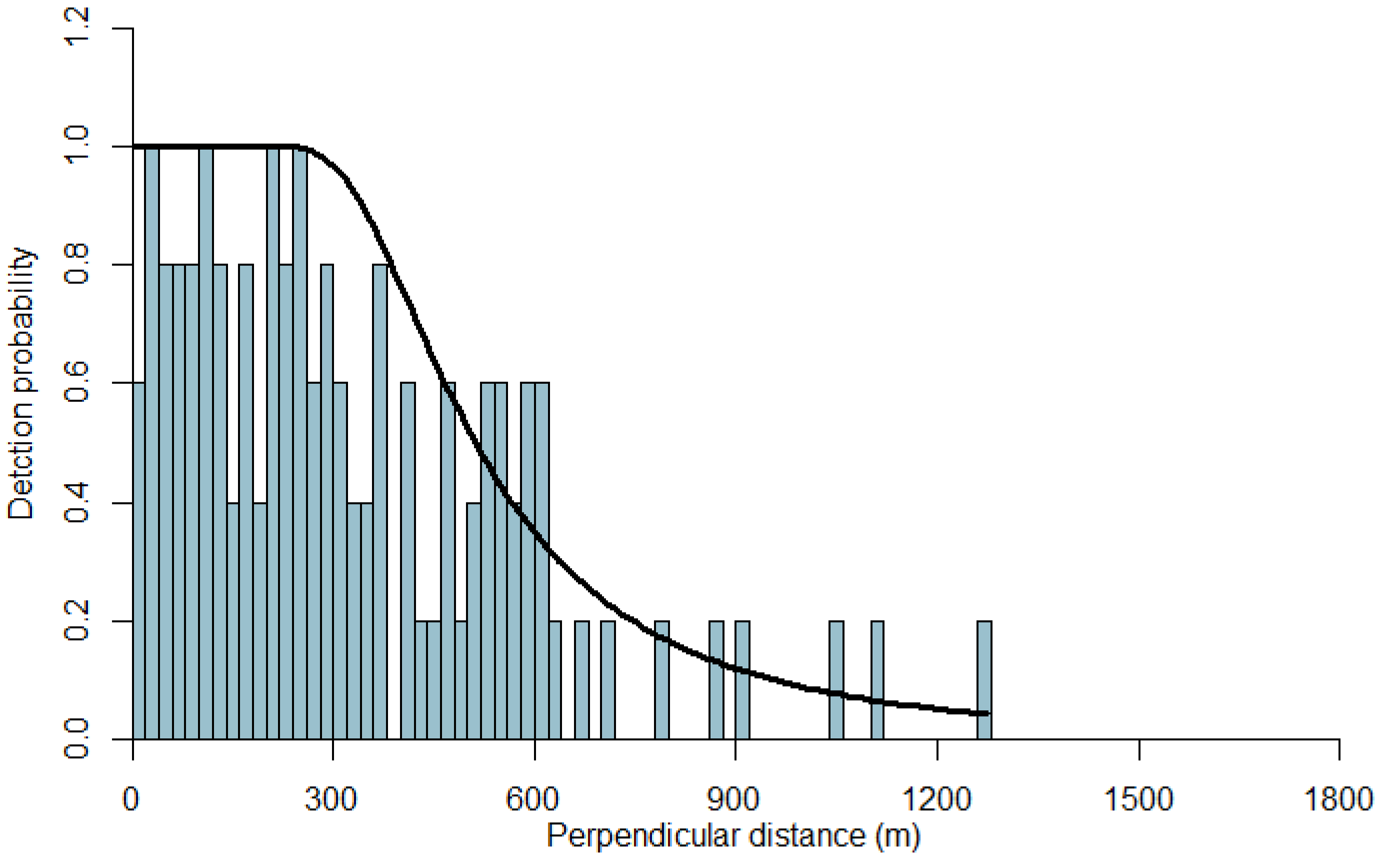

Figure A2. Distribution of perpendicular distances of 102 groups of beluga whales detected in Belcher Islands-eastern Hudson Bay for which a perpendicular distance was recorded and the fitted hazard-rate detection function providing an effective strip half-width of 1,288 m. The perpendicular distances are grouped in 25 bins but the model was fitted to the ungrouped dataset from the left truncation of 106 m to the maximum perpendicular distance measured of 1,395 m.