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Abundance Estimate for Beluga (*Delphinapterus leucas)* in the Ungava Bay Area in Summer 2022

Caroline Sauvé, Anne P. St-Pierre, Mike O. Hammill, and Jean-François Gosselin

Maurice Lamontagne Institute
Fisheries and Oceans Canada
850 route de la Mer
Mont-Joli, Québec, G5H 3Z4

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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 line-transect and coastal surveys were flown August 1-16, 2022 to determine beluga abundance and distribution in Ungava and Diana Bays in northern Quebec (Nunavik). Ungava Bay was split into a high coverage stratum in the south (lines spaced 9.3 km apart) and a low coverage stratum located in the northern portion of the bay (lines spaced 18.5 km apart). Diana and Tasiujaq Bays were also covered using the high coverage systematic line spacing. The two strata in Ungava and Tasiujaq Bay were covered twice, while the Diana Bay stratum was flown once. Four groups of beluga (6 individuals total) were detected. There were too few observations to model a detection function. Instead, these observations were combined with 341 beluga group detections from aerial surveys of eastern Hudson Bay and James Bay flown in 2021 under similar conditions and using the same aircraft and methods to fit a gamma detection function. Beaufort sea state was selected as a covariate that improved detection function model fit and provided an average effective strip half-width of 763 m (CV = 6.8%). A single group of two beluga was detected over 1,918 km of survey lines during the first pass over the southern Ungava Bay stratum, while two individual beluga were detected over 2,469 km of survey lines in the northern Ungava Bay stratum. This yielded surface abundance indices of 11 (95% CI: 2-66) and 27 (95% CI: 7-111) beluga for the southern and northern Ungava Bay strata, respectively. No beluga were detected in Tasiujaq Bay over 76 and 72 km of survey lines for the first and second passes, respectively; nor during the second pass over Ungava Bay, which represented 1,962 and 2,330 km of survey lines for the southern and northern strata, respectively. When both passes were averaged, the southern and northern Ungava surface abundance estimates were 5 (95% CI: 1-29) and 14 (95% CI: 4-48), respectively. A group of two beluga was sighted on the 63 km of survey lines in Diana Bay, resulting in a surface abundance index of 10 (95% CI: 0-536) beluga. An availability bias estimate of 0.574 (CV = 8%) and a perception bias estimate of 0.497 (CV=17%) were applied to surface indices, resulting in a corrected abundance estimate of 19 (95% CI: 4-99) for the southern Ungava Bay stratum, 49 (95% CI: 14-172) for the northern Ungava Bay stratum, and 36 (95% CI: 6-223) for the Diana Bay stratum. When combining the southern and northern Ungava Bay strata, the resulting overall abundance estimate for Ungava Bay was 68 (95% CI: 23-202) beluga. The Potential Biological Removal for beluga summering in Ungava Bay calculated based on this mean survey estimate is zero whales.

INTRODUCTION

The beluga (*Delphinapterus leucas*) has a nearly circumpolar range in the Arctic and subarctic (Reeves and Mitchell 1989). In Canada, beluga stocks have been identified based primarily on the disjunct distribution of beluga summering aggregations (Sergeant 1973; Finley et al. 1982; Reeves and Mitchell 1987a; Richard 2010). For the most part, these stock separations have been supported by evidence for strong intra- and inter-annual site fidelity based on behavioural observations (Caron and Smith 1990), telemetry (Bailleul et al. 2012a), genetics (Brennin et al. 1997; Brown Gladden et al. 1997, 1999; de March et al. 2002, 2004; de March and Postma 2003; Postma et al. 2012; Colbeck et al. 2013; Turgeon et al. 2012; Parent et al. 2023), and stable isotopes and contaminant loads (Rioux et al. 2012). The social structure of beluga is quite complex; their strong philopatry to specific areas and migration routes are thought to be learned through the cultural transfer of information from females to calves (Colbeck et al. 2013; O'Corry-Crowe et al. 2020; Bonnell et al. 2022). These characteristics make beluga more vulnerable to local extinction and may reduce their ability to adapt to local changes and re-colonize areas where they are extirpated (Wade et al. 2012; O'Corry-Crowe et al. 2018, 2020).

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) identified eight beluga designatable units in Canada, with four units [Western Hudson Bay (WHB), Eastern Hudson Bay (EHB), James Bay (JB) and Ungava Bay (UB)] occurring in the waters adjacent to Nunavik (northern Quebec) at different periods throughout the year (COSEWIC 2016). In Nunavik, these four units are treated as management stocks, and harvest levels are co-managed by the Eeyou Marine Region Wildlife Board, the Nunavik Marine Region Wildlife Board, and DFO. A recent assessment identified that the EHB stock consists of at least two separate genetic populations: an Eastern Hudson Bay (EHB) and a Belcher Island (BEL) genetic population. However, these two groups overlap in their summer distribution and cannot be distinguished during aerial surveys to produce separate abundance estimates of beluga in the area. As a result, the two groups are managed together as an EHB-BEL management stock (St-Pierre et al. 2023a; Parent et al. 2023).

Historically abundant in Ungava Bay, beluga were traditionally hunted by Inuit along the shores of Ungava Bay, as well as in some of its estuaries (Reeves and Mitchell 1989). Commercial whaling operated by the Hudson Bay Company actively harvested beluga in Ungava Bay from 1867 to 1911, and is thought to have severely depleted the stock summering in the bay (Reeves and Mitchell 1987b). The UB summer stock is estimated to have numbered at least 1,914 whales in the late 1800s, with only a few hundred left by the 1960's and 1970's (DFO 2005). Unregulated subsistence hunting continued into the early 1980's, when both aerial and land-based surveys reported very low numbers that suggested overexploitation of the stock (Boulva 1981; Finley et al. 1982). Because of these low estimates, the Marralik (Mucalic in references) Estuary was closed to hunting and quotas were implemented in Ungava Bay in 1986 (Lesage et al. 2001). In 1988, COSEWIC designated the UB stock as "Endangered".

In 1982, 1985, 1993, 2001, and 2008, systematic surveys were flown over Ungava Bay. A few beluga were observed while in transit, but no animals were detected on transect lines during the systematic surveys (Smith and Hammill 1986; Kingsley 2000; Hammill et al. 2004; Gosselin et al. 2009). The absence of observations during the systematic surveys prevented the derivation of a meaningful population estimate using standard strip/line transect methods. A Bayesian approach that examined what the maximum population might be if no beluga were detected on-line over four successive surveys, provided an abundance estimate of 32 individuals (95% CI 0-94; Doniol-Valcroze and Hammill 2011). Continued occasional sightings and hunting indicate that beluga continue to frequent Ungava Bay (DFO 2005; Durkalec et al. 2020).

The current 5-year management plan for beluga in the Nunavik Marine Region was jointly developed by the Nunavik Marine Region Wildlife Board (NMRWB) and the Eeyou Marine Region Wildlife Board (EMRWB) in 2021, and is effective until January 31st, 2026. The management plan includes the closure of southern Ungava Bay, including the Marralik and Whale River (Ungunniavik) estuaries to harvesting (NMRWB and EMRWB 2020). This closure has been in effect since the initial management measures were implemented in Ungava Bay in 1986 (Lesage et al. 2001).

This study presents results from a systematic line-transect aerial survey flown during the summer of 2022 in Ungava Bay and Diana Bay to estimate the abundance of animals summering in these areas (Figure 1).

METHODS

STUDY AREA AND SURVEY DESIGN

Ungava Bay is a large (approximately 50,000 km^2) bay in northeastern Canada that is part of the Hudson Bay system, which is considered an inland sea of the Arctic Ocean (Carmack et al. 2015; Figure 1). Ungava Bay opens to the north into Hudson Strait. It is a plateau less than 150 m deep for the most part, except for a channel from the middle of the Bay to its northeastern limit towards Labrador Sea where depths greater than 300 m occur (Drinkwater 1986; NOAA 2022). The mouth of Leaf River, in Tasiujaq Bay, experiences a spring tidal range of more than 16 m, which represents, with the Bay of Fundy, one of the world's largest tides (O'Reilly et al. 2005).

The visual line-transect survey flown in August of 2022 covered most of Ungava Bay from the southern limits of the bay to 61°00' N, Tasiujaq Bay throughout its extent, and Diana Bay (west of Quaqtaq) from bottom to 61°05' N (Figure 2). Although Diana Bay is not located within Ungava Bay and was not covered in previous beluga surveys, it was surveyed because harvests and sightings were reported from the area during summers of the last decade by Uumajuit Wardens (DFO, unpublished data). At the request of the Local Nunavimmi Umajulirijiit Katujiqatigining (LNUK), survey aircrafts flew no closer than 27.8 km (15 nautical miles) of the community of Aupaluk.

The stratification in Ungava Bay in 2022 was the same as in previous surveys flown in 1993, 2001, and 2008 (Kingsley 2000; Hammill et al. 2004; Gosselin et al. 2009), with a high coverage area south of 59°30' N, and a low coverage area north of this latitude. The higher coverage in the southern portion and lower coverage in the northern portion of Ungava Bay aimed to ensure increased effort in areas of more frequent beluga sightings in summer, based on previous aerial surveys (Finley et al. 1982; Smith and Hammill 1986; Kingsley 2000) and Inuit Knowledge (Durkalec et al. 2020). Transect lines were oriented in an east-west direction in Ungava Bay (i.e., perpendicular to most of the coastline), and in a north-south direction in Tasiujaq and Diana bays to optimize the on-effort: line length ratio in these irregularly shaped areas in which no beluga density gradient was expected. There were 10 transect lines in the Ungava North stratum, 14 lines in the Ungava South stratum, 3 lines in the Diana Bay stratum, and 5 lines in the Tasiujaq Bay stratum. All strata except Diana Bay were surveyed twice, using two independent sets of transect lines with a random start (Figure 2). Lines in Ungava South, Tasiujaq Bay and Diana Bay were spaced 9.3 km (5 nautical miles) apart, whereas spacing in the low coverage strata was 18.5 km (10 nautical miles). The length of transect lines (measure of effort used to estimate density) were measured in R 4.1.0 (R Core Team 2021) based on the GPS locations corresponding to the moments observers came on effort at the start of the line and off effort at the end of the line, and excluding off effort portions while flying over islands. Line length for a given transect was defined as the average on-effort line length among primary observers on both sides of the plane. The area of each stratum (used to estimate abundance) was measured using the area surveyed over water in R using the ‘sp’ package (Bivand et al. 2013). An Azimuthal Equal Area projection was used for both line and area measures, with the central meridian at 67°15’ E and a reference latitude of 59°41’ N.

Additional surveys were flown along the coast to search for groups of belugas within estuaries and upriver until major obstacles (e.g., steep rapids) were encountered. The Abrat, Alluviaq, Barnoin, Baudan, Baudoncourt, False, Feuilles, George, Koksoak, Koroc, Marralik, Payne, Qurlutuq, Tutută uq, and Whale rivers were all covered twice, while Akpatok and Gesgier rivers were surveyed once (Figure 3). During coastal flights, planes flew within two hours of high tide at an offshore distance where observers were comfortable that they could detect all animals from the plane to the coast. The survey plan was presented to local and regional Nunavimmi Umajulirijiit Katujiqatigining (RNUK and LNUK; hunters organizations) to ensure complete coverage of important beluga aggregation sites.

DATA COLLECTION

Flights were conducted using a Cessna-337 Skymaster and a Partenavia P68C flying at a target altitude of 305 m (1000 feet) and a target speed of 185 km/h (100 knots). When both planes were flying on a same day, each plane flew every second line of the survey, while planes flew all lines when flying alone. Three observers were onboard each plane: one in the co-pilot seat (right front) and two in the rear seats (left rear and right rear). All observer stations were equipped with bubble windows, except for the co-pilot station in the Partenavia P68C which had a large window instead. As in previous surveys using Cessna-337 Skymasters, the observers in the right front and left rear positions were primary observers, while the observer in the right rear location was a secondary observer. For the Partenavia P68C, the two observers in the rear (left and right) of that aircraft were primary observers as their bubble windows were similar and provided a slightly better visibility near the track line than the right front window, where the observer was the secondary observer (as in prior surveys; St-Pierre et al. 2023a). Observations made by the primary observers in each plane were used to calculate beluga density and abundance (see next section). Primary observers were trained marine mammal observers (MMOs). The secondary observers were inexperienced observers and were onboard to learn aerial survey techniques. Their observations were not used to estimate density and abundance. Primary observers rotated between their two assigned positions each flight. There were some instances during the survey when only one primary observer was available in one of the planes, *i.e.*, only one side of the plane, or half of the field of view was surveyed. This was accounted for in the analyses by dividing the area surveyed (transect length) for these lines by two.

Observers measured the inclination angle to each sighting or to the center of groups of individuals, using clinometers (Suunto) when animals passed abeam. A group was defined as several individuals within a few body length of each other and swimming in the same general direction or showing similar behaviour. When groups were not detected abeam, 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 by Lerczak and Hobbs (1998). Observers were instructed to give priority to the estimation of group size and the time of observation, followed by inclination angle and other variables, including animal behaviour, if time permitted. Transects were generally flown in passing mode, but closing mode (interruption of the survey line to circle over sightings) also occurred when beluga were detected from the lines to accelerate trainee identification abilities, given the low number of sightings anticipated in Ungava Bay.

Weather and observation conditions were also recorded at the beginning of each transect 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 (glare), along with sun reflection intensity (4 levels: 1- intense, when animals were certainly missed in the center of reflection angle; 2- medium, when animals were likely missed in the center of reflection angle, 3- low, when animals were likely detected in center of reflection angle and 4- none, when there was no reflection). All the information was recorded on digital voice recorders by each observer.

DATA ANALYSIS

The density and abundance were estimated using the package 'mrds' (Laake et al. 2022) within the *R* environment. Analyses were based on the perpendicular distance to each observed beluga group, defined as a cluster of beluga within a few body lengths of each other. The number of beluga groups detected during the survey was insufficient to fit a detection curve (see Results). Instead, the effective strip half-width was estimated by combining the 2022 Ungava Bay sightings to the 341 perpendicular distances of beluga sightings from the 2021 James Bay and Belcher Islands-eastern Hudson Bay survey. Both surveys used the same planes and methods, crews with equal experience, and similar weather-related criteria to fly (see St-Pierre et al. 2023a).

The overall distribution of perpendicular distances was examined to determine if truncation was necessary to discard outliers at great distances from the track line. Rules of thumb for right truncation, including truncating when probability of detection [*g(w)*] = 0.15, or eliminating the furthest 5% of distance values were considered (Buckland et al. 2001). These candidate right truncation distances were tested 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* value of the W^2 statistic was retained and applied to further analyses. A Gamma distribution was fitted to the distribution of sighting distances as it allows for the maximal probability of detection to be away from the track line, without having to apply left truncation to the closest observations to account for the potential blind area underneath the aircraft.

We examined if AIC could be reduced by the use of adjustment terms (simple polynomial, hermite polynomial, or cosine) and then by the inclusion of covariates. Covariates that were considered included observer (ten levels), sea state (four levels), glare intensity (four levels), cloud cover (numeric), visibility (three levels), plane type (two levels; Cessna-337 Skymaster and Partenavia P68C) and cluster size to account for possible bias in detectability due to group size. Adjustment terms and covariates were considered to be significant and retained in the model if their inclusion resulted in a decrease in AIC of at least two points (ΔAIC >2; Arnold 2010).

The estimated indices of density ($\widehat{D}_i$) and abundance ($\widehat{N}_i$) of beluga at the surface during systematic survey of each stratum, *i*, were estimated in mrds using equations 1 and 2 (Buckland et al. 2001):

$$\widehat{D}_\iota = \frac{n_i \cdot \hat{E}_i(s)}{2L_i \cdot \widehat{ESHW_\iota}} \qquad (1)$$

$$\widehat{N}_i = \widehat{D}_i \cdot A_i \qquad (2)$$

where n_i is the number of groups detected, $\hat{E}_i(s)$ is the expected cluster size (average cluster size of detected groups was used), L_i is the sum of lengths of all transects, A_i is the area, and

$ESHW_i$ is the effective strip half-width of the stratum *i*. The $ESHW_i$ is defined as the distance at which the number of groups detected beyond $ESHW_i$ and missed within $ESHW_i$ is equal, such that:

$$\widehat{ESHW_i} = w \int_0^w \hat{g}(x)dx \qquad (3)$$

where *w* is the right truncation distance, and $\int_0^w \hat{g}(x)dx$ is the area under curve of the detection function $\hat{g}(x)$.

The associated variance in density and abundance of animals at the surface during the systematic survey was estimated by:

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

$$\widehat{var}(\hat{N}_i) = A_i^2 \cdot \widehat{var}(\hat{D}_i) \qquad (5)$$

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

$$(\hat{D}_i/C \,, \hat{D}_i \cdot C) \qquad (6)$$

where:

$$C = exp\left[z_\alpha \cdot \sqrt{var(\ln\ \hat{D}_i)}\right] \qquad (7)$$

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

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 strata covered twice (all strata except Diana Bay) was obtained by averaging the density and abundance estimates from the two passes (equations 9 to 15).

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

$$\hat{M}_i = (n/L)_i \cdot \hat{E}_i(s) \qquad (9)$$

The average density for strata covered twice ($\hat{D}$) was estimated as:

$$\hat{D} = \frac{\sum_i L_i \cdot \hat{D}_i}{L} \qquad (10)$$

$$L = \sum_i L_i \qquad (11)$$

where L_i is the total length of transects flown for each pass i.

The variance of $\hat{D}$ was estimated as follows:

$$\widehat{var}(\hat{D}) = \hat{D}^2 \cdot \left[\frac{\widehat{var}(\hat{M})}{\hat{M}^2} + \frac{\widehat{var}(\widehat{ESHW})}{\widehat{ESHW}^2}\right] \qquad (12)$$

where:

$$\hat{M} = \frac{\sum_i L_i \cdot \hat{M}_i}{L} \qquad (13)$$

$$\widehat{var}(\hat{M}) = \frac{\sum_i L_i^2 \cdot \widehat{var}(\hat{M}_i)}{L^2} \qquad (14)$$

$$\widehat{var}\left(\widehat{M}_i\right) = \widehat{M}_i^2 \cdot \left[\frac{\widehat{var}[(n/L)_i]}{(n/L)_i^2} + \frac{\widehat{var}[\hat{E}_i(s)]}{[\hat{E}_i(s)]^2}\right] \qquad (15)$$

The overall abundance in Ungava Bay was defined as the sum of abundance indices for the Ungava South, Ungava North, and Tasiujaq Bay strata, while the Diana Bay stratum was considered a separate area as the latter Bay is outside of Ungava Bay.

CORRECTIONS FOR AVAILABILITY AND PERCEPTION BIASES

Abundance estimates obtained using aerial surveys can be affected by two main sources of bias: 1) observers not detecting whales located within the area being surveyed because they are diving (availability bias), and 2) observers not detecting animals that are at or near the surface and 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). Availability and perception bias corrections were applied as detailed in St-Pierre et al. (2023a) and as described below.

Availability correction

The availability bias correction is based on beluga surface interval data from independent satellite telemetry projects and time-in-view from the aircraft based on flight characteristics. The availability correction factor is calculated using models describing the surface [*E(sf)*] and dive [*E(dv)*] intervals as a two-state, continuous-time Markov process (Laake et al. 1997). *E(sf)* and *E(dv)* represent the mean duration of surface and dive intervals, respectively, weighted by the number of dives recorded for each tagged individual. Time-depth data were obtained from nine beluga equipped with temperature depth-satellite relayed data loggers (TD-SRDLs; Sea Mammal Research Unit, St. Andrews, UK) in the eastern Hudson Bay arc in 2003 and 2004 (see Bailleul et al. 2012a for details regarding logger deployment and St-Pierre et al. (2023a) for data screening and analysis).

A dive was defined as an excursion below 4 m. This threshold was assumed to correspond to the depth beyond which beluga would become invisible to a passing aircraft, and is consistent with the 5 m depth at which models representing adult beluga could be detected and differentiated from narwhal models in the waters of Repulse Bay (Richard et al. 1994). Dive duration was calculated as the time elapsed until the animal came back above 4 m, and surface duration was the time between consecutive dives. Water was relatively clear in the area where beluga were detected in Ungava Bay. 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 flies overhead, and 2) the probability that an animal that is diving when the plane arrives overhead will surface within the observer's field of view while the plane passes overhead. The period during which a beluga is available for detection depends on the diving behaviour of the animal and on the time interval *w(x)* that a point at the surface of the water, located at a perpendicular distance *x* from the track line, remains in the field of view of the observers. The availability correction factor, or the estimated proportion of animals available at the surface, is therefore calculated using equation 4 in Laake et al. (1997):

$$a(x) = \frac{E(sf)}{E(sf)+E(dv)} + \frac{E(dv)\left[1-e^{-w(x)/E(dv)}\right]}{E(sf)+E(dv)} \qquad (16)$$

The time period *w(x)* depends on the aircraft speed, *v*, and on the searching pattern of the observers. Observers were assumed to have 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, thus *w(x)* was estimated using the following formula from Forcada et al. (2004), and Gómez de Segura et al. (2006):

$$w(x) = \frac{x}{v}\ [\cot(\emptyset_1) + \cot(\emptyset_2)] \qquad (17)$$

We used forward and backward viewing angles of 30° and 20°, based on measurements conducted from primary observer seats in both aircraft types used (Cessna-337 Skymaster and Partenavia P68C). Plane speed, *v*, was assumed to be constant at the target speed of 100 knots or 51.39 m/s. The availability correction factor, $\hat{a}$, was the average $a(x_j)$ of each observed group of beluga using:

$$\hat{a} = \frac{\sum_{j=1}^{n} a(x_j)}{n} \qquad (18)$$

where *n* is the number of groups detected for which the perpendicular distance, x_j, was within the right truncation distance from the aircraft. Similar to the calculation of the ESHW, all detections with measured perpendicular distances from the 2021 James Bay and EHB and the 2022 Ungava Bay beluga surveys were combined to compute a single overall availability correction factor.

The CV around the average availability correction factor was very low (≤ 1%) because it only accounted for the inter-individual variation between average surface (*E(sf)*) and dive (*E(dv)*) intervals among the 9 tagged beluga. However, there is intra-individual variation in surface and dive interval, which was unaccounted for in this study. Moreover, there is uncertainty associated with the reliability of the telemetry data (e.g., tag depth sensor precision) and depth to which beluga can be seen from an aircraft in Ungava Bay. Therefore, 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). The integration of the intra-individual variation in surface and dive intervals into the calculation of the variance of the availability correction factor should be revisited in future studies using such a correction factor.

Perception correction

Since there were no trained secondary observers onboard the planes during the current study, it was not possible to derive a survey-specific perception bias correction factor for Ungava Bay. Instead, a perception bias correction, *p(0)*, or the estimated proportion of animals at the surface of the water that are detected by observers, was derived from mark-recapture distance sampling (MRDS) using double platform data from the 2015 and 2021 surveys of James Bay and Belcher Islands-eastern Hudson Bay, which were conducted using the same survey platforms as in the present study (see St-Pierre et al. 2023a). During these surveys, two trained observers seated on the same (right) side of the plane, and searched the same area while visually and aurally isolated from each other. They could therefore be considered two independent platforms, and their observations were used to estimate perception bias correction factors via MRDS analyses (Laake and Borchers 2004). MRDS analyses consist of two functions: 1) a multiple covariate distance sampling detection function for detections pooled across the two right-side observers, and 2) a MRDS detection function to estimate *p(0)*, the probability of detection on the track line (Buckland et al. 2001, 2009). Estimates of *p(0)* for the primary observer are 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 sides of the aircraft.

Availability ($\hat{a}$) and perception ($\widehat{p(0)}$) bias correction factors were applied as sequential multipliers of surface abundance estimates ($\hat{N}$) to generate corrected abundance estimates ($\widehat{N_C}$). Variances of surface abundance estimates ($\widehat{var}(\hat{N})$) and correction factors [$\widehat{var}(\hat{a})$ and $\widehat{\mathrm{var}}(\widehat{\mathrm{p(0)}})$] were combined as follows:

$$\widehat{var}(\widehat{N_C}) = \widehat{N_c}^2 \cdot \left[\frac{\widehat{var}(\hat{N})}{\hat{N}^2} \cdot \frac{\widehat{var}(\hat{a})}{\hat{a}^2} \cdot \frac{\widehat{var}(\widehat{p(0)})}{\widehat{p(0)}^2}\right]^2 \qquad (19)$$

Coastal survey counts were added directly to the systematic offshore survey corrected abundance estimate. No correction for availability or perception biases were applied to the coastal counts as they were considered to be total counts.

Potential Biological Removal

The potential biological removal (PBR) level is a tool for quantifying the maximum annual number of animals that may be removed from a stock in addition to natural mortality while still allowing the target population to reach or maintain its optimum sustainable population size within 100 years (Wade 1998). The PBR therefore has an implicit management objective, which is to identify harvest levels that have a 95% probability of the population being above the Maximum Net Productivity Level, defined as 50% of the carrying capacity over a period of 100 years (Wade 1998). The PBR is calculated as:

$$PBR = 0.5\ R_{max}\ \times RF\ \times N_{min} \qquad (20)$$

Where R_{max} is the maximum rate of population increase (by default set to 4% for cetaceans), *RF* is a recovery factor ranging between 0.1 and 1, and N_{min} is the estimated population size using the 20th percentile of the assumed log-normal distribution around the abundance estimate (Wade 1998). Recovery factor values < 1 allocate a proportion of the expected net production to demographic growth, while accounting for uncertainties hindering population recovery (National Marine Mammals Service 2016). Default values of 0.1 are recommended for Endangered stocks, and was used for Ungava Bay beluga (Barlow et al. 1995; Wade 1998). The N_{min} is calculated as:

$$N_{min} = \frac{\widehat{N_C}}{\exp\left(z\sqrt{\ln\left(1+CV(\widehat{N_C})^2\right)}\right)} \qquad (21)$$

Where $\widehat{N_C}$ is the most recent population size estimate, *z* is the standard normal variate (0.824 for the 20th percentile), and $CV(\widehat{N_C})$ is the coefficient of variation for $\widehat{N_C}$.

RESULTS

SURVEY COMPLETION

The survey was conducted between August 1 and 16, 2022 (Table 1). The first pass over the Ungava South stratum was completed within two consecutive days, August 1-2. The second pass was initiated a week later on August 9, with a two day interruption on August 10 and 11 due to weather, and completed by August 14. The first pass over Ungava North was initiated immediately after the first pass over the south stratum and extended from August 3 to 13. However, there was a 4-day interruption between August 9 and 12 due to unfavourable weather conditions during which the second pass of the south stratum was started. The second pass over Ungava North was initiated after the second pass of the south stratum and was completed from August 14 to 16. The eastern end of the four northernmost lines of the second pass over Ungava North (latitude 60°30' N to 61°00' N) were never completed due to low ceilings north of Killiniq Island, i.e., 52 km, , 91 km, 131 km, and 139 km of four transect lines from 60º30' N to 61º00' N.

Tasiujaq Bay was surveyed on August 2, the last day of the first pass of stratum Ungava South and a second time on August 15 after completing the two passes over Ungava Bay. Diana Bay was surveyed only once during a single flight on August 8.

All rivers and estuaries targeted by the coastal survey (Figure 3) were flown between August 1 and 9, with a 4 day interruption due to weather from August 4 to 7. A second coastal survey also covering all rivers and estuaries was flown over three days, on August 9, 14, and 15.

Overall, survey conditions were similar between the 2021 James Bay and Belcher Islands-eastern Hudson Bay surveys and the 2022 Ungava Bay survey (Figure 4), with most marine mammal sightings (82% and 87% of sightings from the 2021 and 2022 surveys, respectively) associated with Beaufort sea states ranging between 1 and 3.

SIGHTINGS

Three groups of beluga, for a total of 4 individuals, were detected by the primary observers during surveys of Ungava Bay (Table 1). These groups were all observed during the first pass of the survey. One group of two beluga was sighted in the South Ungava stratum on August 1, while two singletons were observed during the first pass of the North Ungava stratum on August 3 (Table 1, Figure 2). In addition, one group of two beluga (one adult and one calf) was sighted in Diana Bay on August 8. The Beaufort sea state when sightings occurred ranged between 0 (n=2) and 2 (n=2). No beluga were detected in Tasiujaq Bay or in any of the rivers and estuaries surveyed. Closing mode when beluga groups were detected did not result in an increase in cluster size or in the detection of additional groups.

In addition to beluga, 13 minke whales, one bowhead whale, four bearded seals, 25 white-beaked dolphins, 13 killer whales, one walrus, > 630 harp seals, > 270 ringed seals and one polar bear were detected on transects during the survey.

DETECTION CURVE

All four beluga groups had perpendicular distance measurements. These sightings were added to the 341 detections with perpendicular distances from the 2021 James Bay and eastern Hudson Bay survey to fit a detection curve. The distribution of perpendicular distances from the track line showed an obvious gap between 1937 m and 3639 m, with three observations made between 3561 and 3639 m (Figure 5). These three observations were considered as outliers, leading to right-truncation of the distribution at 1938 m. All three outliers were observations from the 2021 survey, therefore right truncation did not further reduce the observation sample size from the present survey. Other right truncation rules of thumb suggested truncation distances of 1317 m (re. $g(x)$ = 0.15) and 1394 m (re. 5% of further sightings). However, the 1938 m truncation maximized the p value of the W^2 statistic of the Cramér-von Mises test, therefore no further right truncation was applied. The addition of adjustment terms was tested, but none improved the model. In contrast, two covariates, Beaufort sea state and cloud coverage, improved the model fit when added individually (Table 2). Attempting to include both covariates in the same model resulted in convergence issues, therefore the univariate model with the lowest AIC (*i.e.*, the model including Beaufort sea state as the sole covariate) was retained for further analyses. This generated four detection curves (one per Beaufort level; Figure 6) with an average (± SE) effective strip half-width (ESHW) of 763 ± 52 m.

Average cluster size without variance was used to estimate density and abundance per stratum as we only had one sighting of 2 individuals in the first pass of Ungava South, two singletons in the first pass of Ungava North, and a mother-calf pair in Diana Bay (Tables 1 and 3).

ENCOUNTER RATES

Three sightings of beluga detected over 4,381 km of transect during the first pass of Ungava Bay strata yielded encounter rates that were not significantly different for the high coverage South Ungava stratum (0.0005 groups per km; CV = 101%) and the low coverage North Ungava stratum (0.0008 groups per km; CV = 69%; Table 3). No whales were detected in either strata on the second pass. The mother-calf pair sighted over the lower effort of 63 km of transect line in Diana Bay resulted in an encounter rate 32 and 20 times higher than that of the Ungava Bay South and North strata, respectively. Note that all these comparisons are based on only four sightings.

DENSITY AND ABUNDANCE ESTIMATES

The surface abundance indices before correcting for availability and perception biases were 19 beluga (95% CI: 7-56) for Ungava Bay, and 10 beluga (95% CI: 0-536) for Diana Bay (Table 3). Surface densities were 0.0003 beluga per km^2 for both the Ungava South (CV = 101%) and the Ungava North (CV = 69%) (Table 3). In Diana Bay, surface density was 0.0175 beluga per km^2 (CV = 116%).

Availability bias was estimated at 0.574 for the present survey, with a fixed CV of 7.7%. The perception bias was set at 0.497 (CV = 18%), i.e., the average estimate from the 2015 and 2021 beluga surveys of James and eastern Hudson Bay (St-Pierre et al. 2023a).

Correcting the surface abundance indices from this survey considering the proportion of animals that are available at the surface and not submerged (availability bias) produced a partially corrected abundance index of 34 beluga for Ungava Bay (CV = 58%, 95% CI: 12-96) and 18 beluga for Diana Bay (CV = 117%, 95% CI: 3-109). Correcting further for the proportion of animals available at the surface that are detected by observers, i.e. perception bias, resulted in fully-corrected abundance estimates of 68 beluga for Ungava Bay (CV = 60%, 95% CI: 23-202) and 36 beluga for Diana Bay (CV = 118%, 95% CI: 6-223; Table 3).

POTENTIAL BIOLOGICAL REMOVAL

With a 2022 survey abundance estimate of 68, the Ungava Bay N_{min} estimate was 42. Using a recovery factor of 0.1, the PBR for the Ungava Bay beluga is 0.084 whales per year (i.e., 0 beluga).

DISCUSSION

The 2022 survey is the fifth of a series of systematic visual surveys flown since 1985 and covering nearshore and offshore areas of Ungava Bay (Smith and Hammill 1986; Kingsley 2000; Hammill et al. 2004; Gosselin et al. 2009). There were also coastal surveys conducted along the shores of Ungava Bay in 1980 and 1982 (Finley et al. 1982; Smith and Hammill 1986). Although based on a low number of sightings, the 2022 estimates are consistent with previous efforts and local knowledge that indicate that beluga do summer in Ungava Bay but that their numbers remain very small.

During the July 1980 aerial coastal surveys, 42 beluga were sighted, including a group of 24 in the Marralik River (Mucalic River in Finley et al. 1982). Surveys undertaken by Makivik Corporation in 1982 resulted in the detection of 11 beluga in southern Ungava Bay in July, and 12 in August (Smith and Hammill 1986). During the 1985 survey, no beluga were seen along transects, while daily counts from coastal surveys were < 10 individuals on any survey day (Smith and Hammill 1986). In 1993, although beluga were sighted in the Whale River estuary and in southern and western Ungava Bay, none were seen within the designed survey strip (Kingsley 2000). During this survey, the maximum daily count was 20 with most animals seen within or surrounding the Whale River estuary. Land-based surveys, also flown in 1993, detected a total of 36 beluga in southern Ungava Bay with eight animals seen off Kangirsuk (Doidge et al. 1994). No beluga were seen along transect lines or during coastal flights in 2001

(Hammill et al. 2004). Similarly, no beluga were seen in Ungava Bay in the summer of 2008, although no coastal flights were completed (Gosselin et al. 2009).

The 2022 survey did not cover Hopes Advance Bay, north of the community of Aupaluk. This area was excluded to respect a request to reduce disturbance near the community. However, it is unlikely that excluding this area would have substantially changed the abundance estimate from this study. Historically, Hopes Advance Bay was an important aggregation area for beluga, but several coastal and systematic surveys flown over this area since the 1980s have recorded very few animals to no animals (Reeves and Mitchell 1987b; Finley et al. 1982; Smith and Hammill 1986; Kingsley 2000; Hammill et al. 2004; Gosselin et al. 2009). Similarly, only sporadic beluga sightings have been reported in the summer by Uumajuit Wardens in the Aupaluk area (as recently as July 2020; DFO, unpublished data).

While the present study is the first to have detected beluga on transect lines in Ungava Bay, no beluga were seen in any river, estuary, or along the coast during the survey, resulting in a lower total number of individuals sighted (n = 6) than during the 1980, 1982, 1985, and 1993 surveys. The low number of beluga sightings raises concerns of whether observers may have missed animals due to a decline in focus or attention. However, during the survey over 535 marine mammal sightings of multiple species other than beluga were made, indicating that the low rate of beluga detections was not the result of observer inattention.

The number of beluga detections per stratum was low (n = 1 for both the South Ungava and Diana Bay strata, n = 2 in the North Ungava stratum) and resulted in no within-stratum variability in cluster size. Therefore, variance associated to cluster size was estimated as null for all strata.

In this study, no dive data were available from beluga in Ungava Bay to correct survey estimates for availability bias. Instead, dive data from beluga tagged in eastern Hudson Bay were used as a proxy to estimate the availability correction factor. There is uncertainty as to whether diving patterns and the proportion of time spent diving by beluga summering in Ungava Bay and eastern Hudson Bay are comparable, and the direction towards which the availability correction factor used in this study may be biased is unknown. Hudson Bay, with average and maximal depths of 100 and 257 m, respectively, is relatively shallow compared to Ungava Bay. In summer, beluga tagged in eastern Hudson Bay generally occur in shallow (< 100 m), coastal areas or in the shallow waters near offshore islands. In Ungava Bay, the beluga were detected in areas with water depths of 7, 224 and 360 m (NOAA 2022), which is deep compared to observations from eastern Hudson Bay. However, although there is considerable variability in diving behaviour among individuals, and summering animals do not systematically undertake deep dives to the sea floor (Bailleuil et al. 2012b). Moreover, the availability bias correction factor used in this study ($\hat{a}(x)$=0.574, CV=7.66%) is within the range of availability bias correction factors used in other beluga survey studies (0.314 – 0.775; Heide-Jørgensen and Acquarone 2002; Innes et al. 2002, Kingsley and Gauthier 2002; Heide-Jørgensen et al. 2010; Marcoux et al. 2016; Watt et al. 2021; St-Pierre et al. 2023a; Lesage et al. 2023).

The abundance estimate, corrected for both availability and perception bias, for the two passes of Ungava Bay is 68 individuals (CV=60.2%, 95% CI: 23-202). Considering only the first pass of the North and South strata, the corrected abundance estimate would be 133 (CV=60.4%; 95% CI: 45-397). The estimates from the first pass are much higher, but much less precise, than the combined estimates from the two surveys. Given the low number of sightings, and improvements in precision, the combined estimate is preferred. Doniol-Valcroze and Hammill (2011) estimated the Ungava Bay beluga population size at 32 (95% CI: 0-94) from four successive zero-count surveys conducted between 1985 and 2008. Because the latter estimate is derived from the integration of information from several surveys, it does not represent a point estimate usable in a time series. Moreover, Doniol-Valcroze and Hammill's (2011) estimate represents the maximal population that could yield four successive zero counts on the followed survey design, and is not directly comparable to estimates derived from distance sampling methods. Although based on a low number of sightings, our uncorrected surface estimate of 19 (95% CI: 7-56) and fully corrected abundance estimate of 68 (95%CI: 23-202) confirm that beluga are not abundant in Ungava Bay and suggest that there has been little change in abundance over the last decades. These results are in agreement with harvester observations of a lack of increase in beluga numbers in estuaries or in southern Ungava Bay (Durkalec et al. 2020). When calculated using the abundance estimate from the present survey, the PBR for beluga summering in Ungava Bay is zero, as in the previous assessment (Doniol-Valcroze and Hammill 2011).

Our estimate for Diana Bay of 10 individuals (95%CI: 0 – 536) at the surface, or 36 individuals (95% CI: 6 – 223) corrected for both availability and perception, were less precise than the Ungava Bay estimate because there was only three transects in this stratum. Diana Bay is located outside of Ungava Bay, west of Quaqtaq. Whether the individuals observed in this area are individuals from the Ungava Bay summering population or migrants from other populations is not known. The observers from the present survey were confident that the two beluga observed in Diana Bay were different from those observed 5-7 days earlier in Ungava Bay since all beluga sighted in Ungava Bay were adults, while the beluga sighted in Diana Bay were a mother-calf pair. Our abundance estimates confirm that the number of beluga summering in Ungava Bay is very low. This study did not attempt to determine the stock identity of these animals. To date, very few skin samples (n < 10) from southern Ungava Bay beluga have been obtained, preventing evaluation of the genetic structure of animals summering in the area. However, the persistence of beluga in southern Ungava Bay is not surprising, given the strong summer philopatry, and spatial structuring of beluga populations (Bonnell et al. 2022), which makes them more vulnerable to local extinction and may reduce their ability to adapt to local changes and colonize new areas (Wade et al. 2012; O'Corry-Crowe et al. 2018, 2020).

The stratification for this survey aimed to ensure increased effort in areas of most frequent beluga sightings in summer, and was based on the design used in previous surveys, with a higher coverage south of 59°30' N and a lower coverage north of this latitude. The northern limit of the high coverage stratum in southern Ungava Bay was based on observations during previous aerial surveys (Finley et al. 1982; Smith and Hammill 1986; Kingsley 2000), and Inuit Knowledge (Durkalec et al. 2020). Yet, these sources of information rely largely on coastal or nearshore observations. Two belugas were detected on lines in both the southern portion of the North stratum (2 sightings of a single individual each) and South stratum (one pair) of Ungava Bay, resulting in equal estimated densities (0.0003 beluga per km^2; Figure 2). Generally, geographic stratification in line transect surveys aims to produce estimates for delimited areas of interest or to reduce variance among transects by ensuring relatively homogeneous densities within strata when gradients in densities are expected or observed over a study area (Buckland et al. 2001). In light of our results, it might be reasonable in future surveys of Ungava Bay to consider moving the South/North Ungava delimitation 20 or 30 minutes to the North to cover the offshore area where sightings occurred during the present survey.

This survey is the first where the entire Ungava Bay systematic offshore strata and estuaries were flown twice (Smith and Hammill 1986; Kingsley 2000; Hammill et al. 2004; Gosselin et al. 2009). Our abundance estimates confirm that the number of beluga summering in Ungava Bay is very low. Interestingly, all beluga observations were made during the first pass, with no observations during the second pass (Table 3). Variability in abundance estimates derived from repeated visual aerial surveys of a same area have also been reported for other beluga populations, and are thought to result from the small size of the surveyed population, coupled with a non-random or contagious distribution of individuals that spend most of their time underwater (Kingsley and Gauthier 2002; Gosselin et al. 2007; Gosselin and Mosnier 2014; St-Pierre et al. 2023b). Conducting repeated surveys reduces the variability associated with the contagious distribution of beluga (e.g., Gosselin et al. 2007). In very low density areas, where sightings are sparse, repeated surveys may also reduce the chance of having only zero-counts as the sole available data, as well as the variance on estimates. Therefore, it is recommended that future surveys of Ungava Bay include several passes to increase the probability of obtaining detections on transect lines, and possibly construct a time series of non-zero abundance estimates for this small summering stock.

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TABLES

Table 1. Survey timing and effort, effective strip half-width (ESHW), and number of beluga groups and individuals detected in the different strata and passes during the visual line-transect survey of Ungava Bay and Diana Bay in the summer of 2022. The Ungava North stratum was surveyed with a low coverage (10 NM or 18.5 km spacing among transects), while other strata were surveyed with a high coverage (5 NM or 9.3 km spacing).

Area and stratum	Dates of completion (day/month)	Stratum area (km^2)	Nb lines	Total effort length (km)	Nb groups	Nb individuals	Groups (individuals) used for ESHW
Ungava Bay							
Ungava South, pass 1	08/01-08/02	18,762	14	1,918	1	2	1 (2)
Ungava South, pass 2	08/09-08/14	18,762	14	1,962	0	0	0
Ungava North, pass 1	08/03-08/13	46,664	10	2,469	2	2	2 (2)
Ungava North, pass 2	08/14-08/16	46,664	10	2,330	0	0	0
Tasiujaq Bay, pass 1	08/02	625	5	76	0	0	0
Tasiuaq Bay, pass 2	08/15	625	5	72	0	0	0
Diana Bay	08/08	582	3	63	1	2	1 (2)

Table 2. Selection of the detection function to estimate the effective strip half-width, ESHW in meters using a Gamma detection function with potential covariates fitted to 345 beluga observations recorded during the 2021 and 2022 line-transect surveys conducted in Nunavik. Perpendicular distances were right-truncated at 1938 meters.

Covariate	AIC	ΔAIC	Nb parameters	Effective strip half-width (*CV*)
Beaufort	**4938**	**0**	**5**	**739 (4.3%)**
Cloud cover	4942	4	3	749 (4.0%)
(None)	4957	19	2	773 (3.9%)
Cluster size	4957	19	3	770 (4.2%)
Platform type	4959	20	3	772 (3.4%)
Glare intensity	4960	22	5	768 (4.1%)
Visibility	4960	22	4	771 (3.9%)
Observer		*Did not converge*		

Table 3. Surface density and abundance indices for Ungava and Diana Bays in summer of 2022. These estimates consider the number of groups within the right truncation distance of 1938 m. Numbers in parentheses represent coefficients of variation and 95% CI. Density and abundance in strata covered twice (all strata except Diana Bay) were estimated as effort-weighted averages of strata-specific estimates. The Corrected abundance index represents the surface abundance index corrected for availability (correction factor 0.574, CV = 8%) and perception (correction factor 0.497, CV = 18%) biases.

Area and stratum	Nb groups	Expected group size	Encounter rate (groups/km)	Surface density (individuals/km2)	Surface abundance index	Corrected abundance
Ungava Bay	-	-	-	-	**19 (7– 56)**	**68 (23 – 202)**
Ungava south (combined)	-	-	-	0.0003 (100.7%)	5 (1 – 29)	19 (4 – 99)
Ungava south 1	1	2	0.0005 (100.6%)	*0.0006 (100.7%)*	*11 (2 – 66)*	*38 (6 – 263)*
Ungava south 2	0	-	-	*0*	*0*	0
Ungava North (combined)	-	-	-	0.0003 (68.8%)	14 (4 – 48)	49 (14 – 172)
Ungava North 1	2	1	0.0008 (68.8%)	*0.0006 (69.1%)*	*27 (7 – 111)*	*95 (18 – 513)*
Ungava North 2	0	-	-	*0*	*0*	0
Tasiujaq Bay (combined)	-	-	-	0	0	0
Tasiujaq Bay 1	0	-	-	*0*	*0*	*0*
Tasiujaq Bay 2	0	-	-	*0*	*0*	*0*
Diana Bay	1	2	0.0158 (116.2%)	0.0175 (116.3%)	**10 (0 – 536)**	**36 (6 – 223)**

FIGURES

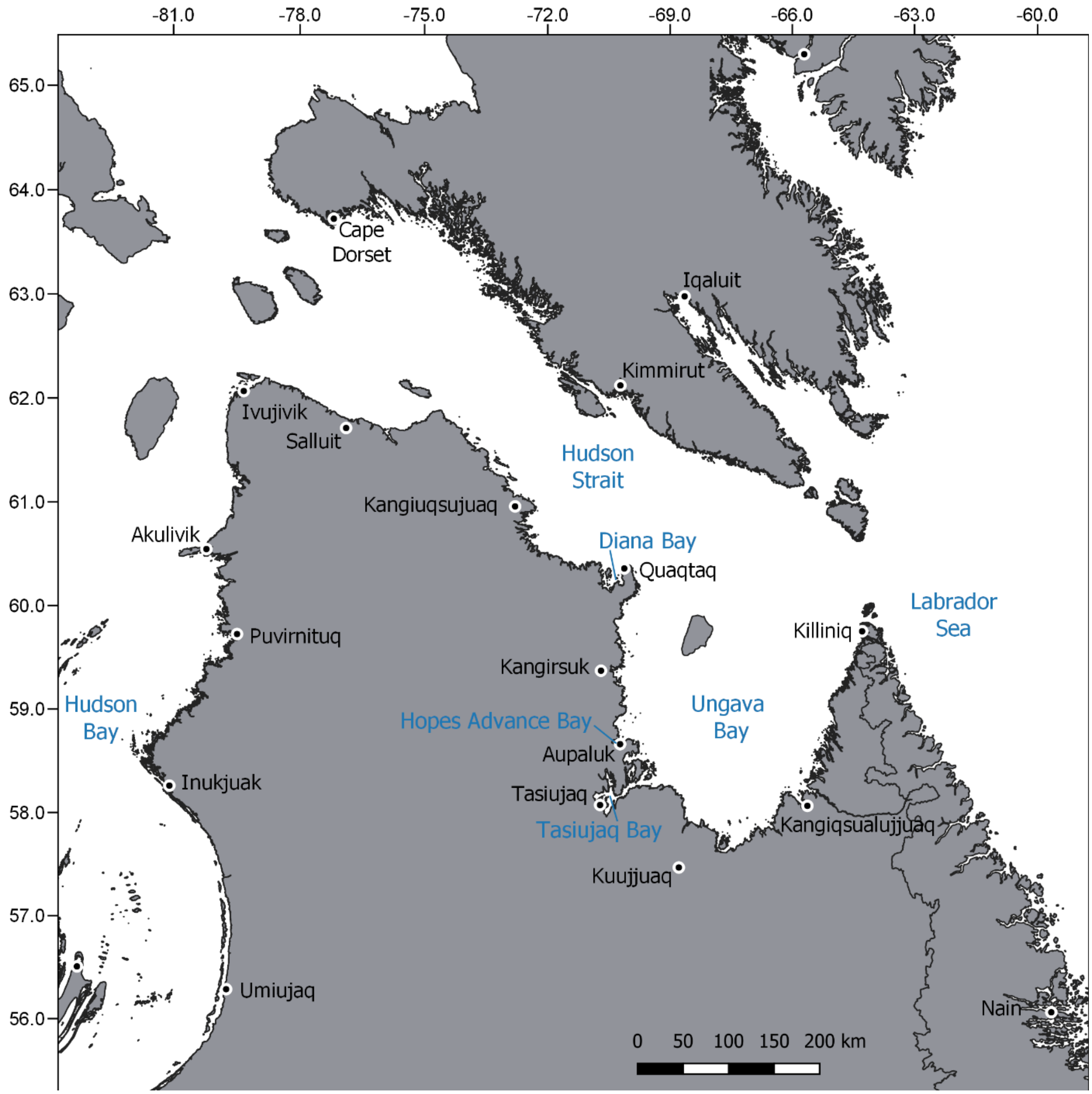

Figure 1. Ungava Bay, in northeastern Canada, opens to the North into Hudson Strait and to the Northeast into Labrador Sea.

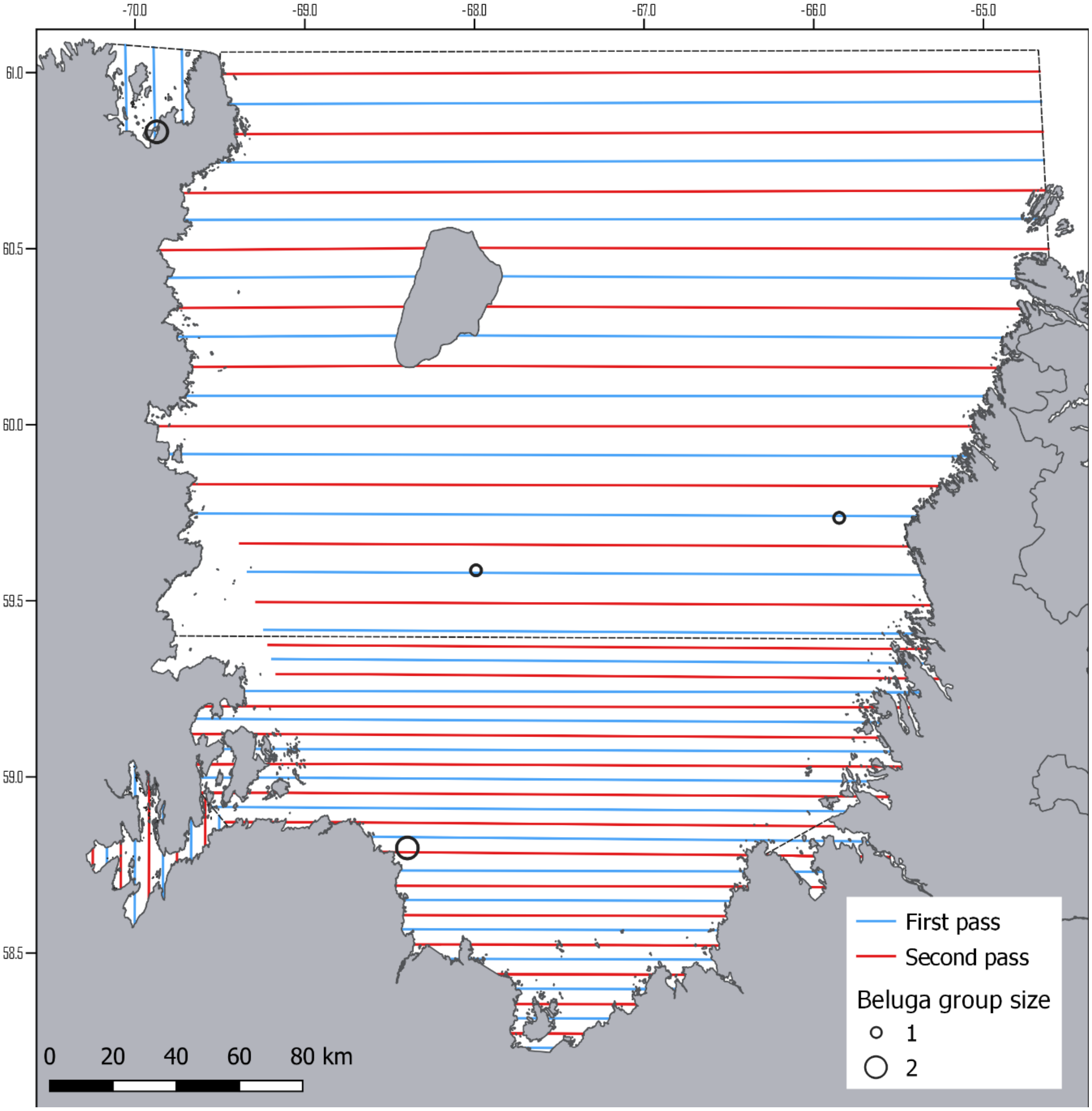

Figure 2. Transect lines (blue and red lines) planned and geographic distribution of detected beluga groups (black open circles) in Ungava and Diana bays during the systematic line-transect aerial beluga survey in the summer of 2022. Dashed lines delineate the Ungava South, Ungava North, Tasiujaq and Diana Bay strata. All strata except Diana Bay were covered twice, with different sets of lines corresponding to the first and second pass displayed by blue and red lines, respectively.

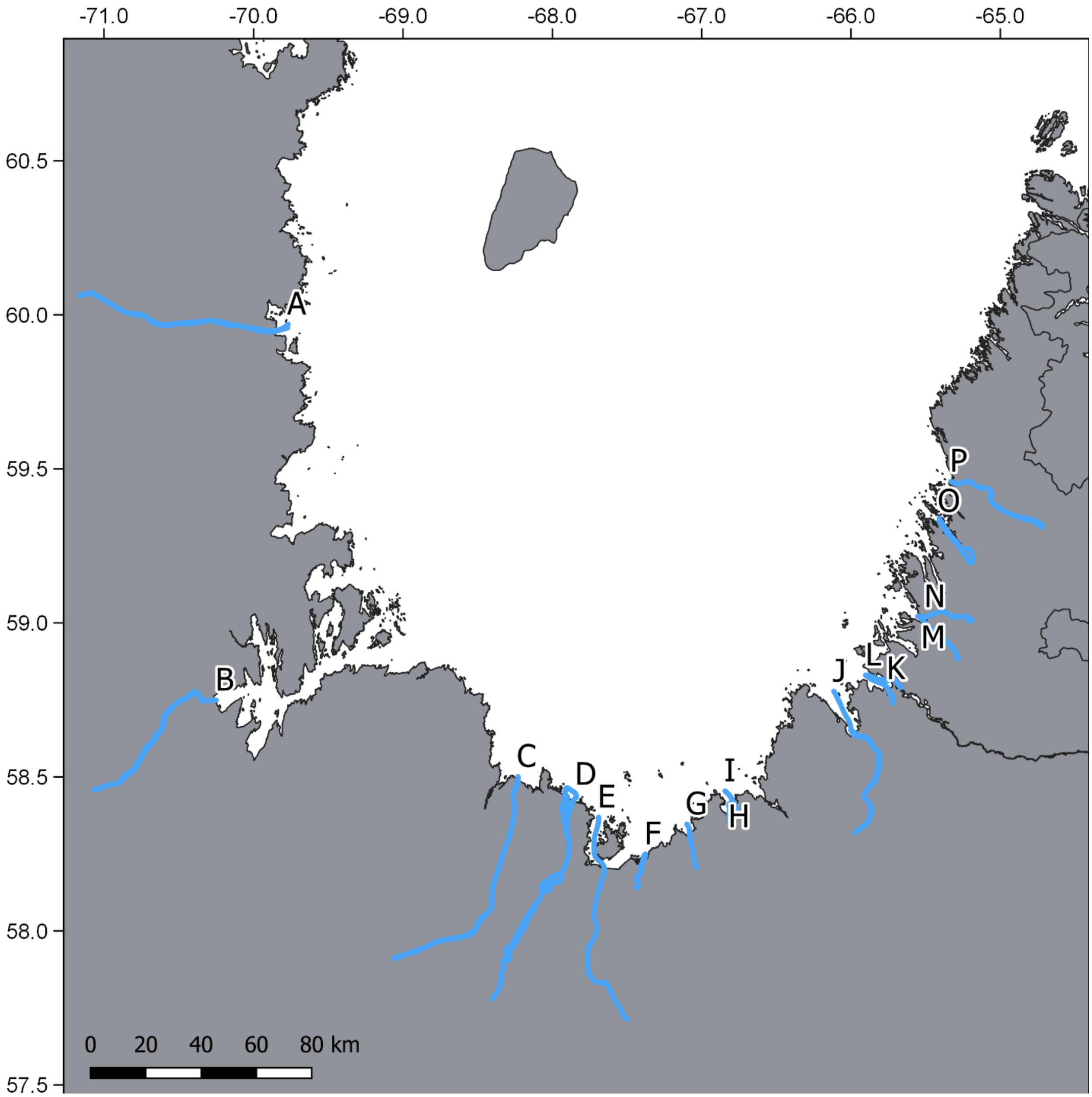

Figure 3. Coastal surveys (blue lines) conducted during August 2022 in major rivers and estuaries of the Ungava Bay A) Payne, B) Feuilles, C) Koksoak, D) False, E) Whale, F) Marralik, G) Tututtuq, H) Gesgier, I) Qurlutuq, J) George, K) Barnoin, L) Koroc, M) Baudan, N) Baudoncourt, O) Abrat, and P) Alluviaq rivers. A first pass was conducted between August 1st and 9th, with a 4 day interruption due to weather from August 4th-7th, and a second pass was done on August 9th, 14th and 15th. All rivers were surveyed twice within two hours of high tide, except for the Gesgier river which was only surveyed during the first pass.

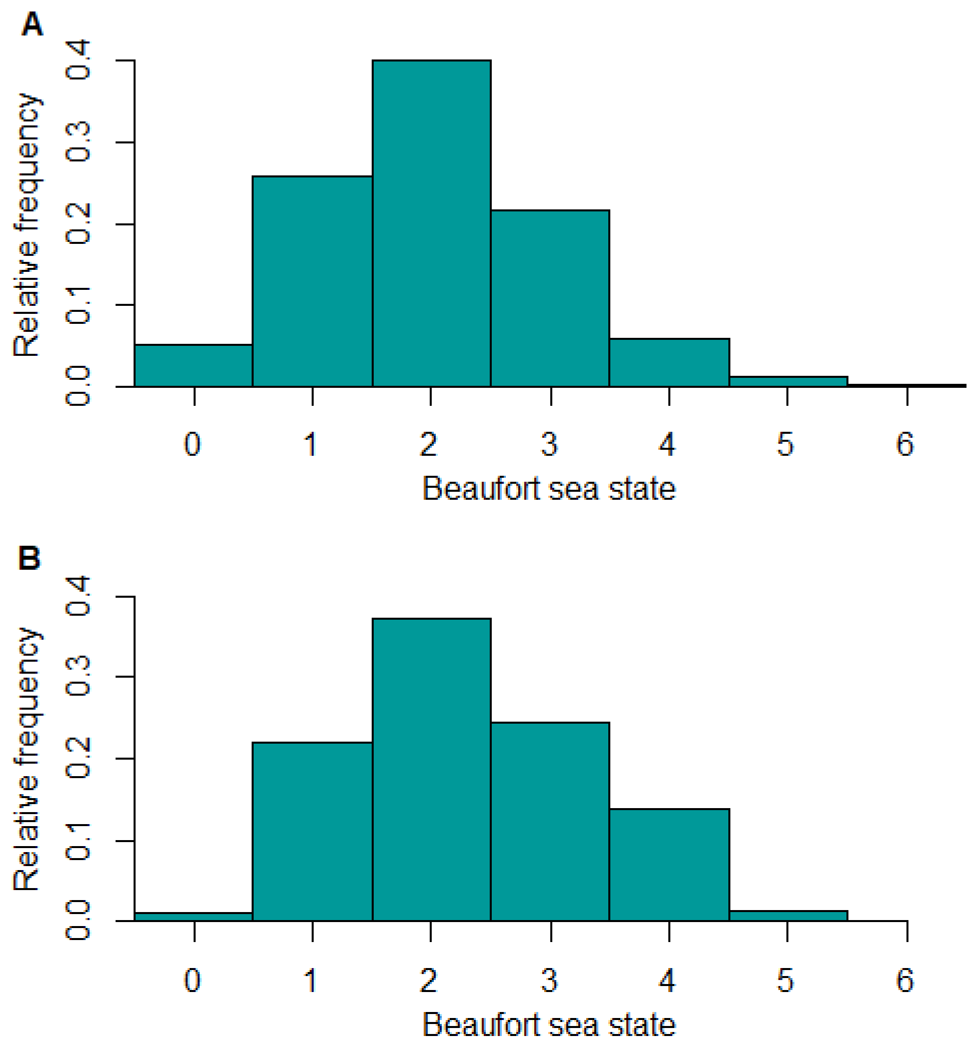

Figure 4. Distribution of Beaufort sea state conditions associated with marine mammal observations reported during A) the 2022 Ungava Bay (n = 3303), and B) the 2021 James Bay and eastern Hudson Bay aerial surveys (n= 8246).

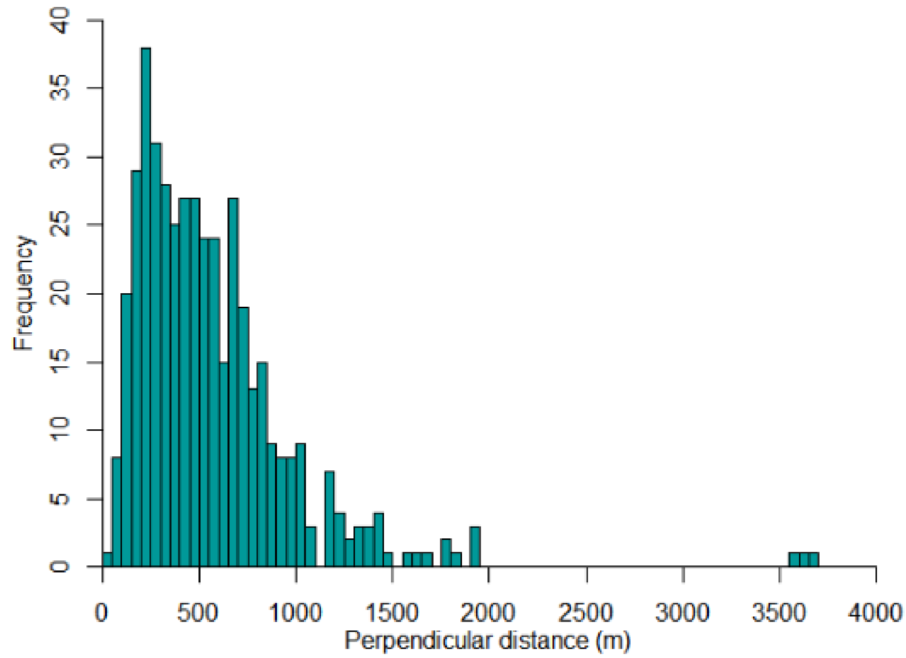

Figure 5. Distribution of perpendicular distances from the track line of 348 beluga groups detected during the aerial visual line transect surveys conducted in James Bay and Belcher Islands-eastern Hudson Bay in the summer of 2021, and in Ungava Bay and Diana Bay in the summer of 2022. The three observations considered outliers had perpendicular distances ranging between 3,561 and 3,654 m; their removal resulted in a maximal perpendicular distance of 1,937 m.

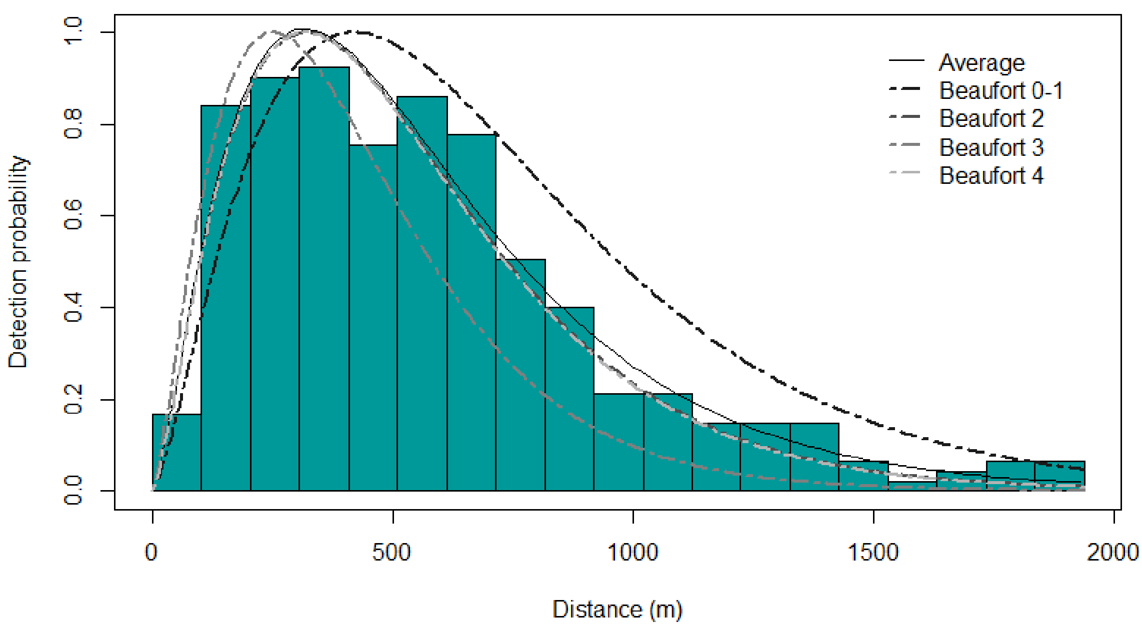

Figure 6. Distribution of perpendicular distances from the track line for 345 beluga groups detected from the track line during the aerial visual line transect surveys conducted in James Bay and Eastern Hudson Bay in the summer of 2021, and in Ungava Bay and Diana Bay in the summer of 2022. A gamma detection curve was fitted to ungrouped distances, with the Beaufort sea state as the sole covariate. The maximal perpendicular distance included in the data was 1,937 m. The black line displays the detection curve for the reference covariate level (Beaufort 0-1), while black circles illustrate predicted detection probabilities for Beaufort 2, 3, and 4 levels.