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Comparison of photographic and visual abundance indices of belugas in the St. Lawrence Estuary in 2003 and 2005

Comparaison des indices d'abondance photographique et visuels des bélugas de l'estuaire du Saint-Laurent en 2003 et 2005

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ABSTRACT

Beluga abundance in the St. Lawrence estuary and Saguenay River was estimated using photographic and visual aerial surveys from the middle of August to early September in 2003 and 2005. Transects covered an area of 5377 km^2 in the estuary which corresponds to the main summer concentration of animals. A total of 311 belugas were counted on 1108 photographs taken on 2 September 2003. This count was increased to 312 animals after taking into account that 0.2% of the area photographed was masked by glare from the sun. This count was also multiplied by an expansion factor of 2.021, to account for the 49.5% photo coverage of the estuary. Two animals observed in the Saguenay River were added to the final estimate resulting in a surface abundance index of 632 (SE = 116) beluga for the photographic survey in 2003. Systematic visual line transect surveys were completed along every second line of the photographic survey design in order for the whole area to be covered in a single day. Five visual surveys were flown at an altitude of 305 m in 2003, and another 14 surveys completed in 2005, alternated between altitudes of 305 m and 457 m. Distance analyses were done on the truncated distribution of perpendicular distances from the transect line to account for the areas of lower detectability of animals under (*re.* left truncation) and away (*re.* right truncation) from the plane. The perpendicular distance distribution was left-truncated at 99 m and right–truncated at 1569 m in 2003. Left and right truncations were 155 m and 2172 m respectively for the 305 m altitude, and 213 m and 2355 m respectively at the 457 m altitude in 2005. The combined abundance index of 934 (SE = 105) belugas from the visual line transect surveys in 2003 was 48% higher than the index from the photographic survey. In 2005, the combined abundance index of 675 (SE = 101) for the lower altitude (305 m) was not significantly different ($F = 1.79$, $p = 0.21$) than the combined index of 531 (SE = 62) at the higher altitude (457 m). The altitude did not have a significant effect on effective strip half width, estimated cluster size nor encounter rate. Belugas were more frequent and generally more abundant in the Saguenay River in 2005 than in 2003. Animals were detected in the fjord on 13 of the 14 surveys completed with an average of 39 individuals in 2005, compared to 3 out of 6 surveys with an average of 6 individuals in 2003. Although abundance indices from the visual and photographic methods were not significantly different, additional comparisons should be completed to ensure calibration of these two techniques.

RÉSUMÉ

L'abondance des bélugas dans l'estuaire du Saint-Laurent et la rivière Saguenay a été estimée par des relevés aériens photographique et visuels de la mi-août au début septembre en 2003 et 2005. Les transects ont couvert une région de 5377 km^2 de l'estuaire qui correspond à la principale concentration d'animaux en été. Un total de 311 bélugas ont été comptés sur 1108 photographies captées le 2 septembre 2003. Ce compte a été augmenté à 312 animaux en considérant que 0.2% de la région photographiée était masquée par la réflexion solaire. Ce compte a été multiplié par un facteur d'expansion de 2.021, pour tenir compte de la couverture photographique de 49.5% de l'estuaire. Deux animaux observés dans la rivière Saguenay ont été additionnés à l'estimation finale produisant un indice d'abondance en surface de 632 (erreur-type = 116) bélugas pour le relevé photographique de 2003. Les relevés systématiques visuels par échantillonnage en ligne ont été complétés en suivant une ligne sur deux du plan de relevé photographique afin de couvrir toute la région en une journée. Cinq relevés visuels ont été complétés à une altitude de 305 m en 2003 et 14 relevés additionnels ont été complétés en 2005, en alternant entre les altitudes de 305 m et 457 m. Les analyses de distance ont été faites sur la distribution tronquée des distances perpendiculaires à la ligne de transect pour tenir compte des zones de plus faible détectabilité des animaux sous (*re.* troncature à droite) et loin (*re.* troncature à gauche) de l'avion. La distribution des distances perpendiculaires a été tronquée à gauche à 99 m et tronquée à droite à 1569 m en 2003. Les troncatures à droite et à gauche étaient respectivement à 155 m et 2172 m pour l'altitude de 305 m et à 213 m et 2355 m pour l'altitude de 457 m en 2005. L'indice combiné d'abondance de 934 (erreur-type = 105) bélugas des relevés visuels par échantillonnage en ligne en 2003 était de 48% plus élevé que l'indice du relevé photographique. En 2005, l'indice combiné d'abondance de 675 (erreur-type = 101) pour l'altitude inférieur (305 m) n'était pas significativement différent (F = 1.79, p = 0.21) de l'indice combiné de 531 (erreur-type = 62) pour l'altitude supérieur (457 m). L'altitude n'a pas eu d'effet significatif sur la demi-largeur de bande efficace, sur la taille estimée de groupe, ni sur la fréquence des détections. Les bélugas étaient plus fréquents et généralement plus abondants dans la rivière Saguenay en 2005 qu'en 2003. Des animaux ont été détectés dans le fjord lors de 13 des 14 relevés complétés avec une moyenne de 39 individus en 2005, comparativement à des détections lors de 3 des 6 relevés avec une moyenne de 6 individus en 2003. Bien que les indices d'abondance des méthodes visuelle et photographique ne soient pas significativement différents, des comparaisons supplémentaires devraient être complétées afin de garantir la calibration de ces deux méthodes.

INTRODUCTION

Beluga are gregarious marine mammals. The level of aggregation varies seasonally as animals concentrate during summer in coastal estuaries around the Arctic but disperse to more offshore areas during the winter months (Finley et al 1982, Richard et al 1990, Richard 1991). A similar seasonal pattern is observed in the St Lawrence estuary (SLE), where animals concentrate in a relatively small geographic area from Ile-aux-Coudres to Rimouski and in the Saguenay River during summer, but disperse towards the Gulf of St Lawrence in winter (Michaud 1993, Michaud et al 1990, Pippard and Malcolm 1978, Vladikov 1944).

Surveys to evaluate St Lawrence beluga abundance have used a variety of methods including boats, helicopters, airplanes, visual and photographic surveys, and have been considered as samples or total counts (Pippard and Malcolm 1978; Béland et al. 1987; Kingsley 2002, Sergeant and Hoek 1988). The early surveys indicated that St Lawrence beluga numbers were quite low, but differences in methodology in these early efforts weakened comparisons. The 1995 St Lawrence beluga recovery plan recommended that a standard method, the systematic strip-transect photographic aerial survey design, be adopted to estimate abundance and improve the monitoring of the population. Six surveys following this protocol have been completed from 1988 to 2000 (Kingsley and Hammill 1991; Kingsley 1993, 1996, 1998, 1999, 2002, Gosselin et al. 2001). Considerable variability has been observed between survey indices. This variability is thought to result from challenges in trying to survey a small population with contagious distribution that spends much of its time below the surface (Gosselin et al 2001, Kingsley and Gauthier 2002).

A possible solution to this problem is to repeat surveys to capture the variability associated with the contagious distribution. Beluga abundance is also estimated in eastern Hudson, James and Ungava Bays, using visual line transect techniques (Hammill et al. 2004). The visual line transect method lacks some of the advantages associated with the permanent records of photographs, but its lower cost make it more efficient than photographic strip transect method for surveys of scarcely distributed animals over a large geographic area (Buckland et al 2001). Five visual line transect surveys were conducted in the St Lawrence estuary in 2003 to evaluate the variability associated with clumping for this population. Since these visual surveys overlapped with the aerial photographic surveys flown to estimate SLE beluga abundance we were able to compare indices obtained from a strip-transect photographic survey with those obtained from visual line transect surveys.

Following recommendations from the National Marine Mammal Review Committee (DFO 2002), the 2004 survey of the Eastern Hudson Bay population was flown at a lower altitude of 305 m rather than the 457 m of previous surveys of 1993 and 2001 (Gosselin 2005). Unfortunately, inclement weather in 2004 prevented between altitude comparisons of the survey results. In 2005, a study was carried out in the St Lawrence estuary to evaluate the effects of this change in altitude on visual line transect survey indices. It was more efficient to conduct this experiment in the higher and more predictable density of beluga of the St Lawrence and the repeated surveys also provided further evaluation of the problem of clumping with this population.

Here, we present new abundance indices of the St Lawrence beluga population from 19 visual line transect surveys, from one photographic strip transect survey and a comparison of indices obtained from the two different survey approaches.

METHODS

Study area

The survey design covers the major summer concentration of belugas in the St Lawrence estuary, which is centered at the confluence with the Saguenay River (Figure 1). That portion of the estuary is characterised by the 300 m deep waters of the Laurentian channel extending from the northeast limit along the north shore of the area to rise at the confluence of the Saguenay River. The upstream portion of the estuary is very shallow with 20 m deep channels and a series of small islands extending mostly along the south shore which shows wide tidal flats. These shallow waters are also associated with higher water turbidity that result in a general gradient of increasing detectability from shallow to deeper water and from upstream to downstream sections of the estuary. The section of the Saguenay River covered by the survey is a 270 m deep fjord bordered by steep cliffs (up to 300 m) creating wind channels and local variations in sea state and detection conditions. The 2003 photographic survey was intended as an extension of the time series of systematic surveys of St Lawrence beluga and thus, covered the same area as the six surveys flown since 1988. However, in order to account for a possible extension of beluga distribution in the Estuary, the study area for the 2003 and 2005 surveys was extended four nautical miles (NM) (2 transects) in both the upstream and downstream directions (Figure 1). The coverage in the Saguenay River extended to La Baie and Saint-Fulgence and thus, was identical to the previous surveys.

Survey design

The surveys followed a similar design to the one used for the systematic photographic surveys flown since 1988. A series of transects perpendicular to the main axis of the St Lawrence estuary were covered either photographically or visually (Figure 1). To obtain an abundance index from the visual line transect density index, an area of 5377 km^2 was used, which corresponds to the area of the estuary systematically covered by transects extended by 1 NM from both upstream and downstream transects.

Photographic survey

Two Piper Aztec aircraft flew a total of 51 transects spaced 2 nautical miles (3.704 km) apart, crossing the estuary on headings of 320° and 140° true. The two aircraft were flown in opposite directions from a starting point, in Cacouna, chosen so as to ensure the completion of the survey by both aircrafts without refuelling. Aircraft were equipped with 229 x 229 mm (*i.e.* 9 inch x 9 inch) format mapping cameras (Wild-Leitz RC-20) loaded with colour positive aerial survey film (Kodak, 2427-0061-014), and fitted with calibrated lenses (152.898 mm and 151.720mm), filters (CLAIR A/V 124354; Clair 420 NM), and a motion compensation system. The target altitude was 1219 m (*i.e.* 4000 feet). This was controlled by a certified pressure altimeter and satellite-linked Global Positioning System. Camera shooting speed was adjusted automatically with the aircraft speed and altitude to allow a 30% forward overlap between frames.

The preferred survey conditions required a ceiling of at least 1219 m, sun angles of more than 30° above the horizon, winds less than 18.52 km/h (*i.e.* 10 kt), and no fog over the study area during the survey in order to insure good quality images.

The Saguenay River was surveyed visually by helicopter (Bell 206 Long Ranger) at 457 m (*i.e.* 1500 feet) while the photographic survey was being conducted in the Estuary. Two observers, one on each side in rear seats covered the full width of the fjord which varies from 1 to 3 km across, and noted the number of beluga whales and their positions on both the upstream and downstream passes.

Film interpretation

Frames were examined for beluga images, using a light table, and a dissecting microscope. The film was read using the approach outlined by Stenson et al. (2000). Complete reading of frames was assured by superimposing a transparent grid of 10 rows and 10 columns on each frame and the exact location of beluga images was recorded on an overlaid acetate. Both main readers involved in the interpretation of beluga images had no previous experience in reading marine mammal aerial photographs. Before starting to record any sightings, frames with beluga were examined so that readers could familiarize themselves with the shape and size of the target images. The films were not read in the same chronological order by the two readers, but all the films were read by both readers. Once a first reading of all films was completed, each reader then re-read their first 100 frames a second time without consultation of previous results. All frames for which the first and second reading counts or counts by the two readers differed were read by both readers an additional time. If disagreement still occurred between readers, a third reader experienced in looking at marine mammal aerial photographs examined the imagery, and a consensus was agreed upon by the three readers.

Although the target overlap was 30% between successive frames from plane speed and shooting interval, the achieved overlap was estimated for each frame using immobile landmarks or ocean features as reference points. Beluga images located within the overlap portion of a frame were compared with those observed on the previous frame to identify duplicates or individuals that had gone undetected.

Photographic data analysis

Data were analysed using the methods developed for previous photographic surveys flown (Kingsley and Hammill 1991; Kingsley 1993; 1996; 1998; 1999, Gosselin et al. 2001). Beluga counts were corrected to account for animals that went undetected due to sun glare (Kingsley 1996). The proportion of a frame omitted due to sun glare, p_g, was calculated as

$$p_g = p_{-og} / (1-p_o) \qquad [1]$$

where p_{-og} is the glare portion of a frame that is not included in the overlap, and p_o is the portion of frame in the overlap. Since glare conditions were affected by time of day (sun height), wind, and cloud cover, the correction was applied on a transect basis. Reflection-corrected counts of beluga for the i^{th} transect was estimated by:

$$n_{ri} = n_i / (1-p_{gi}) \qquad [2]$$

where n_i is the beluga count and p_{gi} is the average proportion of frames omitted due to glare.
In order to obtain an index for the Estuary and to compensate for the gaps between transects, the sum of reflection-corrected counts on transects was multiplied by an expansion factor, f, defined as

$$f = S/W = S/(H \cdot B/L) = 2.0210 \qquad [3]$$

where : S = transect spacing (3704 m)

W = transect width

H = flying height (1219 m)

B = photo frame breadth (230 mm and 228 mm: 0.229 m)

L = lens focal length (152.898 mm and 151.720 mm: 0.152309 m)

An estimate of the number of visible beluga in the estuary, $\hat{N}$, is then given by

$$\hat{N} = f \sum_{i=1}^{k} n_{ri} \qquad [4]$$

where k represents the number of transects.

The estimation of variance, $V(\hat{N})$, is based on serial differences between transects including the finite population correction (Cochran 1977; Kingsley and Smith 1981) and was calculated as

$$V(\hat{N}) = \frac{f(f-1)k}{2(k-1)} \sum_{i=1}^{k-1} (n_i - n_{i+1})^2 \qquad [5]$$

Visual survey design

Systematic visual surveys were completed along every second line of the photographic survey design to allow the whole area to be covered by a single plane in a single day. These two sets of lines were completed alternatively in 2003, whereas they alternated after completion of pairs of surveys at the two altitudes in 2005. The Saguenay survey was completed on the same day as the visual survey of the Estuary using the same plane flying at the same altitude and speed, and using the same team of observers.

Five visual surveys were conducted from 20 August to 6 September 2003 and 14 surveys were conducted from 12 August to 10 September 2005. The same fixed high winged aircraft (Cessna 337, Skymaster) with bubble windows was used for both years, with a target airspeed of 185 km/h (100 kt) and a target altitude of 305 m (1000 feet) in 2003 and alternating target altitudes of 305 m (1000 feet) and 457 m (1500 feet) in 2005. Position and altitude were recorded continuously by D-GPS output into a laptop computer with mapping software (2 or 10 seconds intervals; Prairies Geomatics D-GPS coupled with Garmin GPS76; Fugawi mapping softwares).

A team composed of the same two observers completed all surveys within each year, and one observer was the same for both 2003 and 2005. The two observers in the back recorded meteorological conditions and beluga sightings. Line transect sampling training was done on the ground before the first survey each year, even if all observers already had prior experience with aerial surveys. For each group of beluga, estimated group size, the angle below the horizontal measured using an inclinometer (Suunto, PM 5/360 PC) when animals were passing abeam, and time synchronised with the D-GPS were recorded on micro-cassettes. Position of each observation was estimated using time and interpolation between adjacent D-GPS outputs.

Flights were only initiated when sea conditions were Beaufort 3 or less. Sea condition (Beaufort), intensity of reflection (absent, low, medium or high) and cloud cover (in eighths) were recorded at the beginning and the end of each transect and when noticeable visibility changes were detected.

Line transect analysis

Abundance was estimated using line transect method using the software Distance (Buckland et al. 2001, Hammill et al. 2004, Thomas et al. 2003).

A different priority was given to different parameters recorded to maintain minimum data quality in areas of high densities. Priority was given first to the number of animals in the group and then to the perpendicular distance, which resulted in some observations lacking distance measurements. The detection function was estimated using all observations with recorded distance. Size bias with distance was assessed using observations that had both distance and group size. As missing distance recordings only occurred in high density areas, we assumed that all groups detected were within the truncation distances, and therefore all sightings were added for estimation of encountering rate (*n/L*), density ($\hat{D}$) and abundance ($\hat{N}$) in each stratum.

The effective strip half width (*ESHW*) was estimated from ungrouped perpendicular distances estimated using the inclinometer angle under the horizon and formulae in Lerczak and Hobbs (1998). The detection function model, uniform, half-normal or hazard-rate was selected according to the minimum Akaike's Information Criteria (AIC). The overall distribution of perpendicular distances was examined and all observations from the transect line to maximum detectability were truncated (*i.e.* left-truncation). Distant outliers and observations further than the preliminary detection probability of 15 % (i.e., $g(x) = 0.15$) were also truncated (*i.e.* right-truncation). Post stratified model by date or by altitude were selected when the sum of their AIC values was lower than the AIC value for the model over the pooled dataset.

Group size, $\hat{E}(s)$, was estimated for each date using the size bias regression method (ln of cluster size (s_i) against the detection function value [$g(x)$] ($p < 0.15$)) (Buckland et al. 2001). Assuming that groups without distance measurements in high density areas were within truncation distances, group size for the stratum was estimated as the weighed average of mean group size of observations without distance and estimated group size at maximum detectability of observations with distance. If the size bias regression method showed no significance (p > 0.15), the overall average group size was used.

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

$$\hat{D} = \frac{n \cdot \hat{E}(s)}{2L \cdot ESHW} \quad [6]$$

$$\hat{N} = \hat{D} \cdot A \quad [7]$$

where n is the number of groups detected, $\hat{E}(s)$ is the expected cluster size, L is the sum of lengths of all transects and A is the area of the study area considered as the summer range of belugas in the St Lawrence estuary, considered to be 5377 km^2 for all visual surveys (*i,e.* extension of 1 NM of the portion of the Estuary covered by 2005 transects). The associated variance of density and abundance of animals at the surface during systematic survey is estimated by:

$$\mathrm{var}(\hat{D}) = \hat{D}^2 \cdot \left[\frac{\mathrm{var}(n)}{n^2} + \frac{\mathrm{var}(ESHW)}{[ESHW]^2} + \frac{\mathrm{var}(E(s))}{[E(s)]^2} \right] \quad [8]$$

The distribution of density is positively skewed, and assuming it is log-normally distributed the 95% CI was estimated using:

$$\left(\hat{D}/C, \hat{D} \cdot C\right) \quad [9]$$

where

$$C = \exp\left[t_{df}(\alpha) \cdot \sqrt{\mathrm{var}(\ln \hat{D})} \right], \quad [10]$$

$$\mathrm{var}(\ln D) = \ln\left[1 + \frac{\mathrm{var}(\hat{D})}{\hat{D}^2} \right] \quad [11]$$

and where $t_{df}(\alpha)$ is the critical value of Student's t-distribution at α= 0.05. To consider the few degrees of freedom of some components of the variance, the degrees of freedom were computed according to the Satterthwaite (1946) method adapted by Buckland et al (2001):

$$df = \frac{\left[\sum_q [cv_q]^2\right]^2}{\sum_q [cv_q]^4 / df_q}$$ [12]

where the coefficient of variation and degrees of freedom are estimated for each of the *q* components of the estimation of density, which are: *n, ESHW* and *E(s)*.

The daily estimates of abundance, N_j (*i.e.* $\hat{N}$ in formula 7) were combined to provide abundance, N_s, for each year and for each altitude in 2005. Average abundance was weighed by effort (*i.e.* total length of transects on day $j = L_j$) with the variance calculated using the variation in abundance between dates (modified from equations 3.84-3.87 in Buckland et al 2001, treating the stratum as a sample):

$$N_s = \frac{\sum_{j=1}^{d} L_j N_j}{L_s}$$ [13]

$$\mathrm{var}(N_s) = \frac{\sum_{j=1}^{d} [L_j (N_j - N_s)^2]}{L_s (d-1)}$$ [14]

where L_s is the total length of transects for the year or altitude and *d* is the number of daily indices combined.

The possible effect of altitude was examined using an ANOVA that compared the seven daily abundance, ESHW, cluster size and encounter rate estimates (PROC GLM, SAS v.8).

Saguenay counts

Beluga counts obtained during the upstream and downstream passes in the Saguenay River in 2003 were compared for location and number of individuals in groups to identify and eliminate possible duplicate observations. Higher counts in 2005 did not allow identification of duplicates between upstream and downstream passes, therefore the highest count was used.

Population indices

Population indices consider availability bias (*i.e.* for animals diving when the aircraft passed overhead) by applying a 2.09 correction factor to the systematic photographic or visual survey index of the Estuary, to which the Saguenay count is added with no correction. The availability correction factor was specifically developed for the photographic survey method used in the St Lawrence since 1988 (Kingsley and Gauthier 2002). It is based on the proportion of time belugas were visible from a hovering helicopter during experiments conducted in different portions of the Estuary to take into account diving behaviour and water turbidity. It is further adjusted to consider a 30% overlap on adjacent frames (Kingsley and Gauthier 2002). This correction factor falls within the range of correction (1.66 to 2.90) suggested from time spent at surface from telemetric studies on belugas in the Arctic (Heide-Jorgensen et al. 1998, Martin et al 1994, Martin and Smith 1992, Frost et al 1985). For comparison purposes, the 2.09 correction was also applied to the visual line transect survey index of the Estuary. Although the correction would likely be lower than in the estuary, a proper availability correction should be estimated for the Saguenay. But here these counts were added with no correction, because the narrow searching area and curves in plane trajectory allowed observers to scan forward and backward increasing searching time on any given location, water turbidity is lower than in most of the estuary, and the count already included some availability correction as no duplicates are added or the highest of the upstream and downstream counts was retained.

RESULTS

Photographic survey and film interpretation

The photographic survey was flown on 2 September 2003, between 9h10 and 16h27 (local time) when the sun angle above the horizon in the centre of the geographic area was 27° and 28° respectively, close to the prescribed minimum of 30°. The weather was good for surveys with the recorded hourly wind speed at Rivière-du-Loup varying from 4 km/h to 6 km/h from 9h00 to 17h00 (Environment Canada, climate data online[1]).

The survey was executed with a few changes to its planned design. Starting on transects 2115 and 2105, the two planes proceeded as planned in opposite directions, but transects 1315 and 1325 that were planned at the north-eastern extreme of the study area were not surveyed (Figure 1). The average time lapse between the start of a transect and the end of an adjacent transect ranged from 9 min:13 s to 29 min:26 s. Longer time lapses to complete adjacent transects were observed on three occasions because of camera problems, *i.e.* between transects 1605 and 1615 (13h11 to 14h58 local = 1:46:37), between transects 2025 and 2105 (9h20 to 10h41 local = 1:20:56) and transects 2325 and 2405 (10h18 to 13h20 local = 3:02:39). These longer time lapses represented breaks in the regular systematic coverage of the estuary. The 1605-1615 and 2325-2405 breaks occurred in areas where few belugas were counted during the visual survey conducted the same day, but the 2025-2105 break occurred in the middle of the main beluga concentration detected during the visual survey that day. The visual survey of the Saguenay River was completed between 10h30 and 11h50 (local time).

A total of 1108 frames were read by both readers. A total of 315 belugas were counted by reader 1 and 310 by reader 2, but differences in interpretation actually occurred for 28 beluga images. After interpretation by the third reader and discussions, 311 images were accepted as belugas after excluding images identified as duplicates from the overlap of adjacent frames. Achieved overlap between adjacent frames was 33%, ranging from 28% to 41% for given transects. Glare generally increased at the end of the day but also varied along transects due to local wave conditions. Maximum glare observed in the non-overlap portion of a frame was 4.5%. The proportion of a transect missed because of glare was on average 0.2% (range 0–1.6%) over all transects, and also averaged 0.2% (range 0–0.8%) on transects where beluga were seen. This resulted in a reflection-corrected count of 312 belugas.

From equations 4 and 5, 49.5% of the Estuary was photographed. Applying the corresponding 2.021 expansion factor to the reflection-corrected count resulted in an estimated 630 (SE = 116) beluga present at the surface during the survey. Two single belugas were seen in the Saguenay River, 7 km and 62 km upstream of Tadoussac (Figure 2). The addition of these 2 animals to the photographic estimate, resulted in an estimated surface index of 632 (SE = 116) beluga whales in 2003

Visual surveys

For the five visual surveys in 2003, transects were surveyed from the northeast to the southwest with a break of 45 to 71 min for refuelling between lines 2625 and 2715 (20 August, 26 August and 6 September) or between lines 2705 and 2725 (25 August and 2 September). The remaining lines and the Saguenay River were surveyed on a second flight. The systematic survey covered either 27 lines, from 1315 to 3025, for a daily effort of 718 km, or 26 lines, from 1325 to 3015, for a daily effort of 686 km. The daily average Beaufort conditions ranged from 0.8 on 25 August to 3.1 on 6 September in 2003 (Table 1).

[1] **www.climate.weatheroffice.ec.gc.ca/climateData/canada_f.html**

In 2005, 12 of the 14 surveys were completed through a single flight from the northeast to the southwest, and the Saguenay was surveyed on a second flight. Lines were flown in the inverse order after surveying the Saguenay on 18 August. Local fog conditions resulted in a delay of 91 minutes between lines 1905 and 1925, at which time the Saguenay was flown, and in a delay of 46 minutes between lines 2215 and 2305 for refueling. The daily average Beaufort conditions ranged from 0.9 on the 15 August to 2.6 on the 18 August in 2005 (Table 1).

A total of 351 groups of belugas were detected as far as 2.9 km from the transect line over the five surveys of 2003. Over 14 surveys in 2005, 635 groups were detected as far as 4.4 km from the transect line at the altitude of 305 m, and 659 groups were detected as far as 6.6 km at the altitude of 457 m.

Truncations

The overall distributions of perpendicular distances revealed that the width of the area missed under the plane varied between years and altitudes, which were therefore treated separately. Maximum detectability used as left truncation (*i.e.* close truncation) distance was attained by 99 m from the transect line (inclinometer angle = 72°) in 2003, and by 155 m (inclinometer angle = 63°) and 213 m (inclinometer angle = 65°) for respective altitudes of 305 m and 457 m in 2005. The half-normal model (AIC = 5130) provided the best fit to 344 groups with distance measurements in 2003 and a detectability value below 0.15 by 1570 m from the transect line [$g(x)$ = 0.17 at inclinometer angle = 11°, 1569 m rounded to higher integer value] which was used as right truncation (*i.e.* far truncation). For seven surveys conducted at each altitude in 2005, the hazard-rate model provided the best fit on the overall distribution of 635 groups detected at 305 m (AIC = 9821) and the 655 groups detected at 457 m (AIC = 10 284). Data were right truncated at the measured distance where the pooled probability of detection, g(x), fell below 0.15, which was 2172 m [g(x) = 0.11, inclinometer angle = 8°] at 305 m and 2355 m [g(x) = 0.14, inclinometer angle = 11°] at 457 m.

Effective strip half width

The hazard-rate was the best model (lowest AIC: 4421) for the 309 observations detected between the right and left-truncation distances of 99 m and 1570 m in 2003. Post-stratification by day further improved the fit (sum of AICs = 4415) and these curves provided ESHW ranging from 481 m to 1170 m (Figure 3, Table 2). The use of daily ESHW increased the variance on daily indices of density and abundance, but it reduced the variance on the combined density index for 2003. The hazard-rate model (AIC = 8949) performed better than the half-normal model (AIC = 8958) for 601 observations within truncation distances during the seven surveys flown at 305 m in 2005. It was further improved from daily post-stratification (sum of daily AICs = 8934; Figure 4). However, the model produced a spurious spike near the transect line with the 9 September data and was therefore replaced by the half-normal for that day. ESHW at 305 m in 2005 ranged from 896 m to 1382 m (Table 2). For the surveys flown at 457 m, the hazard-rate model also provided a better fit (AIC = 9257) of the 613 observations than the half-normal model (AIC = 9262), but post-stratification by date did not improve the fit (sum of daily AICs = 9259). Therefore, the hazard-rate model fitted to the pooled dataset at 457 m was used in the estimation of density and abundance and provided an effective strip half width of 1338 m (Figure 5, Table 2).

Cluster size

Average cluster size was used for all dates but three. The regression of ln of cluster size increased as the detection function value decreased, or as the distance from the transect line increased on 2 September 2003 (p = 0.06), 12 August 2005 at 305 m (p = 0.11) and 27 August 2005 at 457 m (p = 0.05). The regression of 78 groups recorded with distance measurements on the 2 September 2003 survey provided an estimated cluster size at maximum detectability of 2.32 (CV = 10.7%), and three groups for which distance was not measured, had an average group size of 3.67 (CV = 72.7%). The weighed average of these values provided an expected cluster size of 2.37 (CV = 20.7%) (Table 2). On 12 August 2005, the 101 groups were all recorded with distance and provided an estimated cluster size at maximum detectability of 2.07 (CV = 8.1%). On 27 August 2005, 93 groups recorded with distance provided an estimated group size at maximum detectability of 1.81 (CV = 7.4%), which remained 1.81 (CV = 7.3%) after considering the only group of 2 animals recorded without distance.

Encounter rate

Encountering rate was generally the most important contributor to the total variance of abundance indices with CV ranging from 23.1% to 35.7%. Consistency between surveys comes from the fact that variance for this component is estimated from a constant number of transects, either 26 or 27, and because the general distribution of beluga groups throughout their summer range is somewhat similar between days (Figures 6 to 8).

Saguenay counts

Belugas were more frequent in the Saguenay River in 2005 than in 2003. Animals were detected in the fjord on 13 of the 14 surveys completed in 2005, compared to 3 out of 6 surveys in 2003. The Saguenay count never exceeded 2.6% of the daily Estuary index in 2003, while it averaged 7.2% of the Estuary index, and as much as 15.3% of the corresponding daily estuary abundance index in 2005 (Table 2). Beluga groups were also more frequently detected further upstream in 2005 than in 2003 (Figures 6 to 8).

Abundance indices

The daily index of abundance declined with increasing Beaufort conditions. These lower estimated values were associated with a reduction in encounter rate with higher Beaufort conditions, as the effective half-strip width did not vary as much and the cluster size increased with higher Beaufort conditions in 2003.

Most of the CVs of daily abundance ranged between 26.7% and 53.9%, with an extreme exception on 6 September 2003 with a CV = 145.9%, when the survey was flown under conditions with an average sea state of Beaufort 3.1. The combination of daily indices provided global abundance indices with reduced CVs.

The combined abundance indices of 675 (SE = 101) for the lower altitude (305 m) was 27% higher than the index of 531 (SE = 62) at the higher altitude (457 m), but the daily indices were variable and the difference was not significant (F = 1.79, p = 0.21). Specifically, there was no significant difference in any of the three estimated components used in estimating densities [effective strip half width (F = 2.16, p = 0.17), estimated cluster size (F = 0.11, p = 0.74) and encounter rate (F = 1.79, p = 0.21)].

For 2003, the visual line transect abundance index of 934 (SE = 105) beluga for the five surveys combined was 48% higher than the index of 632 (SE = 116) beluga from the photographic survey (Table 2). Curiously, over the 5 daily visual surveys conducted that year, the one conducted on the same day as the photographic survey (2 September) provided the closest index, which was only higher by 4% (26 animals).

DISCUSSION

This work added 19 visual and 1 photographic surveys to the existing time series of six surveys completed using a similar protocol. Sea state on 2 September 2003 averaged 1.5 on the Beaufort scale according to the visual survey observers. This resulted in little glare on the images and as a result the area photographed and read was only reduced by 0.2%, which means that 48.5% of the estuary between the extreme transects was actually photographed. The counts of each reader before verification (310 and 315) were very close to the accepted final count of 311 and we therefore feel that they were both properly trained and that observer experience did not represent a concern. The major concern with the photographic survey in 2003 comes from the three long delays between adjacent transects, principally for the one between transects 2025 and 2105 that represent an important area of concentration. It is not possible to evaluate the real impact of these delays. However, a visual survey was also conducted that same day (2 September) and the similarity in both the general distribution of detected groups in the vicinity of transects where delays occurred, and the abundance indices of the two methods, suggest that the problem might have been limited.

This photographic index is the highest of the series of seven since 1988, but it also showed the second largest CV (18.3%)(Kingsley and Hammill 1991; Kingsley 1993; 1996; 1998; 1999, Gosselin et al. 2001). The photographic survey design provides a coverage of 49% of the recognised summer range of beluga in the St Lawrence. It is logistically difficult to further increase this coverage, without increasing the chance of movement of animals between transects unless we have instantaneous coverage. This may be possible through satellite imagery, and this may become available in the near future, but the precision of the technology publicly available is not adequate at this time.

The visual surveys provided a total of 5 indices in 2003 and 14 in 2005. Visual indices from 2003 were higher than those obtained from photographs, but the differences were not significant. Indices obtained from the 2005 surveys were lower and closer to the values of photographic indices. It would appear that visual surveys provide similar counts to the photographic approach and offer an alternative to the expensive photographic design. Although, there is little difference in the mean indices, the methods used here to estimate survey variance were different. The photographic technique estimated the variance using a serial difference estimation (Cochran 1977; Kingsley and Smith 1981), while the visual line transect analyses used an estimation more appropriate for a random design. The latter produces a greater variance when a systematic gradient exists between transects. The combination of multiple visual surveys provided a more precise index than the photographic index or than any of the daily visual surveys, and the weighing by survey effort did not consider the way the daily survey variance was estimated..

The main advantage of photographic surveys over visual surveys is that they provide a permanent record, which allows training of inexperienced readers and allows them to compare and validate their counts with experienced or previous readers when interested in trend analyses. They provide a permanent record of whale counts, their distribution and herd composition, which can provide additional information to be used in any retrospective analysis of abundance, spatial distribution or demographic analyses. Archived images also eliminate the components of variance associated with estimating the effective strip width and cluster size for the line transect method, and reduces the variance of abundance index to the sampling variance estimated from counts between transects, *i.e.* the sampling units. Besides problems due to maintaining altitude during flights, which could introduce bias, the strip width is fixed, and the assumption that observers detect all animals available, *i.e.* at the surface, within that strip is satisfied or can be verified (*re.* perception bias). The variance associated with estimation of group size is eliminated as individuals and not groups are counted on photos. If the above perception problems (not detecting animals at the surface) are reduced in photographic surveys, the method does not eliminate the availability problem (*i.e.* animals diving below detectable depth) and the method still requires a $g(0)$ correction factor, although its estimation may be simplified compared to the correction for visual surveys.

Photographic surveys have many benefits, but there are also many challenges associated with this approach. Photographic surveys are expensive to fly because of the need to contract for specialized equipment, and because of time required to read the films. Time required for film development and reading, usually make results available after the prime survey season has passed, preventing any correction in the field. As an alternative to the photographic approach, a single visual survey is less expensive to complete. For a comparison, the 14 surveys in 2005 were completed and analysed for a costs similar to the 2003 photographic survey. Thus multiple surveys can be completed in a single season and analyses can also be completed more quickly. The analysis of the different components of estimation of abundance through repeated surveys also provides information related to clumping at different scales of space and time. The large CVs associated with estimation of cluster size, such as 24.7% on 25 August 2005, are associated with the detection of a few very large groups, and so could be use as a measure of clumping at the individual or social group level. The large CVs of encountering rate, reveal that numbers detected on each transect are more variable and in the case of the actual visual design, it could serve as a measure of clumping at a scale of 4 NM along the axis of the estuary. The repeated surveys also allow monitoring of how this clumping behaviour changes through time.

One of the challenges in surveying beluga populations is that animals are quite clumped. For the photographic surveys from 1992 to 2003, 50% of belugas were detected on only 10 to 14 frames out of totals 832 to 1144 frames. Therefore, the detection or failure to detect significant groups has a significant impact on survey indices. In 2003, a single frame with 48 individuals accounted for 15 % of the total count of 311 and by itself accounted for the difference observed with the indices for the estuary in 1995 and 1997. In the case of photographic surveys with only a single survey in one season, this results in considerable variability in indices between surveys. If multiple surveys can be completed in a short period of time, then this variability might be reduced through averaging of multiple surveys as shown in 2005. Alternatively, if we improved our knowledge of beluga social behaviour along with summer habitat use, it might be possible to improve survey indices by timing these surveys with periods when animals are more dispersed, rather than clumped.

Another solution to improve survey design would be to stratify the survey design. However this could not be applied before we improve our understanding of beluga distribution, as surveys show that distribution of animals is variable. Early surveys considered that few belugas used the Saguenay River regions. However in 2005, the average number of belugas occupying this area was 39, almost 3 times greater than the average of 13 reported from 18 surveys conducted from 1988 to 2003 (Kingsley and Hammill 1991; Kingsley 1993; 1996; 1998; 1999, Gosselin et al. 2001).

Abundance estimation tends to be lower as Beaufort increases. The lower estimates are driven by a reduction in encounter rate associated with increasing average daily Beaufort condition. Intuitively, this reduction in encounter rate might be associated with an increase in cluster size with increasing Beaufort, as larger groups may have higher detectability than smaller groups. This increase was not observed for the daily expected cluster size in 2005 when Beaufort did not exceed 2.6, but it was observed in 2003 with a higher cluster size at Beaufort 3.1. Another effect that might intuitively be expected with increasing Beaufort is a reduction in ESHW as whales may not be visible as far away from the plane in bad sea conditions. This would have a compensatory effect to the reduction in encounter rate on the abundance estimate. Looking at the distributions of perpendicular distances and maximum distances of detection each day, the right truncations of 1570 m in 2003, and those of 2172 m and 2355 m in 2005 were adequate for most days, with the possible exception of the 26 September and 4 September 2005, when a slightly shorter truncation could have been more appropriate. Overall, groups were recorded as far away in higher sea states within the limits of sea states surveyed. The few daily estimations of ESHW did suggest a slight reduction with increasing Beaufort, but this reduction did not completely compensate for the reduction in encounter rate, and therefore abundance indices were lower. DeMaster et al. (2001) examined the effect of Beaufort sea state on estimation of beluga density in more detail and they observed similar effects. The authors could not investigate the effect of Beaufort index on cluster size. They estimated densities at Beaufort sea state 1, that were about three times higher than at Beaufort sea states of 2, 3 and 4. They also reported a similar difference in encounter rates between the same sea states values. Although limiting surveys to the very best conditions (Beaufort sea state=1) might be possible for the relatively small St Lawrence Estuary region, it is often impractical to obtain these conditions throughout larger regions such as eastern Hudson Bay. Further investigations on the precise effect of Beaufort on density estimation and on the production of correction factors are needed.

From the 2005 results, the change in altitude from 457 m to 305 m in the latter 2004 survey of belugas in James Bay and eastern Hudson Bay may not have had a significant impact on survey indices. No significant differences were observed between the two altitudes for ESHW, cluster size, encounter rate, and for abundance indices. The observed 44% increase in abundance index in eastern Hudson Bay from 2001 to 2004, and the 30% increase from the 457 m to the 305 m combined St Lawrence indices of 2005, are both well below the 202% and 152% maximum increase recorded between extreme daily values for each altitude. The potential effect of altitude on estimation of beluga density should not be neglected, but it seems that efforts should rather be directed at: improving survey designs through adaptive sampling or stratification to increase the number of detections, the evaluation of the potential effects of factors such as sea state (Beaufort), and mostly at an evaluation of a proper *g(0)* correction factor including both the availability (*re.* animal diving behaviour) and perception (*i.e.* animals at the surface not detected) biases.

In conclusion, the index of 632 (se = 116) beluga whales obtained from the 2003 photographic survey represents an adequate addition to the series of six photographic survey indices obtained since 1988. The specific correction factor of 109% (SE = 16%) for animals that were not visible at the surface from photographs with 30% overlap provides the most reliable true population index available (Kingsley and Gauthier 2002). This correction applied to the systematic photographic index and then adding the 2 animals detected in the Saguenay without correction, provides a total population index for 2003 of 1318 (se = 262) belugas for the St Lawrence Estuary population. While photographic surveys provide a vertical snapshot of whales at the surface, visual surveys rely on different cues that are available to observers for longer periods of time. Therefore, although visual and photographic indices were not significantly different, additional comparisons and calibration of the two techniques are needed before indices from these two methods could be reliably combined for trend analyses.

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REFERENCES

Béland, P., Michaud, R., and Martineau, D. 1987. Recensements de la population de bélugas (*Delphinapterus leucas*) du Saint-Laurent par embarcations en 1985. Rapport Technique Canadien des Sciences Halieutiques et Aquatiques 1545: 21p.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. Introduction to distance sampling, Estimating abundance of biological populations. Oxford University Press, New York. 432 p.

Cochran, W.G. 1977. Sampling Techniques, 3rd edition. John Wiley and Sons. New York. 428 p.

DeMaster, D.P., Lowry, L.F., Frost, K.J. and Bengston, R.A.. 2001. The effect of sea state on estimates of abundance for beluga whales (*Delphinapterus leucas*) in Norton Sound, Alaska. Fish. Bull. 99:197-201.

DFO 2002. Proceedings of the National Marine Mammal Peer Review Committee. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2002/012.

Finley, K.J., Miller, G.W., Allard, M., Davis, R.A. and Evans, C.R. 1982. The belugas (*Delphinapterus leucas*) of northern Quebec: distribution, abundance, stock identity, catch history and management. Can. Tech, Rep. Fish. Aquat. Sci. 1132, 57 p.

Frost, K.J., Lowry, L.F. and Nelson, R.R. 1985. Radio-tagging studies of Belukha whales (*Delphinapterus leucas*) in Bristol Bay, Alaska. Mar. Mamm. Sci. 1: 191-202.

Gosselin, J-F. 2005. Abundance indices of belugas in James Bay and eastern Hudson Bay in summer 2004. Canadian Science Advisory Secretariat, Ottawa. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/011. 22 p.

Gosselin, J.-F., Lesage, V. and Robillard, A. 2001. Population index estimate for the beluga of the St Lawrence estuary in 2000. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/049. 21 p.

Hammill, M.O., Lesage, V., Gosselin, J.-F., Bourdages, H., de March, B.G.E. and Kingsley, M.C.S. 2004. Evidence for a decline in northern Quebec (Nunavik) belugas. Arctic 57(2): 183-195.

Heide-Jorgensen, M.P., Richard, P., and Rosing-Asvid, A. 1998. Dive patterns of belugas (*Delphinapterus leucas*) in waters near eastern Devon Island. Arctic 51: 17-26.

Kingsley, M.C.S. 1993. Census, trend, and status of the St Lawrence beluga population in 1992. Canadian Technical Report of Fisheries and Aquatic Sciences 1938: vi + 17 p.

Kingsley, M.C.S. 1996. Population index estimate for the belugas of the St Lawrence in 1995. Canadian Technical Report of Fisheries and Aquatic Sciences 2117: vi + 38 p.

Kingsley, M.C.S. 1998. Population index estimates for the St. Lawrence belugas, 1973–1995. Marine Mammal Science 14: 508-530.

Kingsley, M.C.S. 1999. Population indices and estimates for the belugas of the St Lawrence Estuary. Canadian Technical Report of Fisheries and Aquatic Sciences 2266: vii+ 27 p.

Kingsley, M.C.S. 2002. Status of the belugas of the St Lawrence estuary, Canada. NAMMCO Sci. Publ. 4: 239-257.

Kingsley, M.C.S. and Gauthier, I. 2002. Visibility of St Lawrence belugas to aerial photography, estimated by direct observation. NAMMCO Sci. Publ. 4: 259-270.

Kingsley, M.C.S., and Hammill, M.O. 1991. Photographic census surveys of the St. Lawrence beluga population, 1988 and 1990. Canadian Technical Report of Fisheries and Aquatic Sciences 1776: v + 19 p.

Kingsley, M.C.S., and Smith, G.E.J. 1981. Analysis of data arising from systematic transect surveys, p.40-48. *In* F.L. Miller and A. Gunn (eds), Proc. Symp. Census and Inventory Methods for Populations and Habitats, Banff, April 1980. Contribution # 217, Forest, Wildlife and Range Experiment Station, U. of Idaho, Moscow, Idaho.

Lerczak, J.A. and Hobbs, R.C. 1998. Calculating sighting distances from angular readings during shipboard, aerial, and shore-based marine mammal surveys. Marine Mammal Science 14 (3): 590-599.

Martin, A.R. and Smith, T.G. 1992. Deep diving in wild, free-ranging beluga whales, *Delphinapterus leucas*. Can. J. Fish. Aquat. Sci. 49: 462-466.

Martin, A.R., Kingsley, M.C.S. and Ramsay, M.A. 1994. Diving behaviour of narwhals (*Monodon monoceros*) on their summer grounds. Can. J. Zool. 72: 137-147.

Michaud, R. 1993. Distribution estivale du béluga du Saint-Laurent; synthèse 1986 à 1992. Rapport Technique Canadien des Sciences Halieutiques et Aquatiques 1906: vi + 28 p.

Michaud, R., Vézina, A., Rondeau, N., and Vigneault, Y. 1990. Distribution annuelle et caractérisation préliminaire des habitats du béluga (*Delphinapterus leucas*) du Saint-Laurent. Rapport Technique Canadien des Sciences Halieutiques et Aquatiques 1757: 27 p.

Pippard, L., and Malcolm, H. 1978. White whales (*Delphinapterus leucas*). Observations on their distribution, population and critical habitats in the St. Lawrence and Saguenay rivers. Unpublished report prepared for Department of Indian and Northern Affairs, Parks Canada, Ottawa, Ontario. 161 p.

Richard, P.R., Orr, J.R. and Barber, D.G. 1990. The distribution and abundance of belugas, *Delphinapterus leucas*, in eastern Canadian waters: a review and update. Pages 23-28 In T.G. Smith, D.J. St. aubin and J.R. Geraci (eds). Advances in research on the beluga whale, *Delphinapterus leucas*. Can. Bull. Fish. Aquat. Sci. 224 p.

Richard, P.R. 1991. Status of the belugas, *Delphinapterus leucas*, of Southeast Baffin Island, Northwest Territories. Canadian Field-Naturalist 105: 206-214.

Satterthwaite , F.E. 1946. An approximate distribution of estimates of variance components. Biometric Bulletin 2: 110-114.

Sergeant, D.E., and Hoek, W. 1988. An update of the status of white whales *Delphinapterus leucas* in the St. Lawrence Estuary, Canada. Biological Conservation 45: 287-302.

Stenson, G.B., Hammill, M.O., Gosselin, J.-F., and Sjare, B. 2000. 1999 pup production of harp seals, *Phoca groenlandica*, in the Northwest Atlantic. DFO Can. Stock Assess. Res. Doc. 2000/080. 35 p.

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H. and Bishop, J.R.B. 2003. Distance 4.1 Release 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http/www.ruwpa.st-and.ac.uk/distance/

Vladykov, V.D. 1944. Étude sur les mammifères aquatiques. III. Chasse, biologie et valeur économique du marsouin blanc ou béluga (*Delphinapterus leucas*) du fleuve et du golfe Saint-Laurent. Département des Pêcheries, Québec. 129 p.

Table 1. Summary of sea conditions and number of groups of belugas detected during a photographic survey conducted on 2 September 2003, and 19 visual line transect surveys flown at altitudes of 305 m or 457 m in summers of 2003 and 2005.

	Effort (km)	Beaufort (Mean recorded value)	Groups detected	Groups with distance
Year 2003				
Photographic survey	**1306**	**1.5**	***311 individuals***	**n/a**
Visual surveys 305 m			**355**	**344**
20 August	718	1.7	51	51
25 August	686	0.8	80	79
26 August	718	1.9	82	78
2 September	686	1.5	99	96
6 September	718	3.1	43	40
Year 2005			**1297**	**1290**
Visual surveys 305 m			**637**	**635**
12 August	734	1.4	105	105
15 August	718	0.9	129	128
25 August	734	1.5	78	77
26 August	718	2.3	76	76
4 September	734	2.1	70	70
6 September	718	2.5	81	81
9 September	734	2.0	98	98
Visual surveys 457 m			**660**	**655**
14 August	734	1.5	90	89
18 August	718	2.6	57	57
19 August	734	1.9	121	121
27 August	718	1.9	98	97
5 September	734	1.3	125	125
8 September	718	1.2	104	104
10 September	734	2.1	62	62

Table 2. Density and abundance indices of belugas at the surface during systematic photographic and visual line transect surveys flown in the St Lawrence estuary in 2003 and 2005. Saguenay counts were added to the estuary indices estimated from density and a total area of 5377 km^2. Coefficient of variance of components are shown in brackets. The standard errors tabled with abundance indices also apply to density indices.

Stratum	Effective strip width (m)	Group size	Encounter rate (group/km)	Density in estuary	Abundance in estuary	Saguenay count	Abundance (est.+Sag.) (SE)	95% CI
2003								
Photographic					**630 (116)**	**2**	**632 (116)**	**442 - 903**
Combined visual				**0.1725 [11.4]**	**927 (106)**		**934 (105)**	**749 – 1165**
20 August	660 [16.2]	2.84 [13.2]	0.0696 [32.5]	0.1496 [38.7]	805 (311)	2	807	
25 August	489 [29.5]	2.25 [10.6]	0.1050 [28.4]	0.2415 [42.3]	1298 (549)	0	1298	
26 August	780 [15.8]	2.46 [11.1]	0.1100 [25.8]	0.1730 [32.2]	930 (300)	0	930	
2 September	1170 [24.7]	2.37 [20.7]	0.1182 [29.3]	0.1211 [43.4]	651 (283)	7	658	
6 September	481 [140.6]	3.23 [21.0]	0.0529 [32.6]	0.1780 [145.9]	957 (1396)	25	982	
2005								
Combined visual				**0.1049 [10.3]**	**564 (58)**		**603 (61)**	**496 – 734**
Combined 305m				**0.1188 [15.4]**	**639 (99)**		**675 (101)**	**504 - 904**
12 August	1382 [12.2]	2.07 [8.1]	0.1377 [23.5]	0.1029 [27.7]	553 (154)	55	608	
15 August	960 [12.3]	2.19 [7.4]	0.1726 [23.6]	0.1964 [27.6]	1056 (292)	59	1115	
25 august	1273 [32.8]	3.01 [24.7]	0.0995 [28.1]	0.1178 [49.8]	633 (315)	24	657	
26 August	896 [10.3]	3.11 [19.4]	0.0988 [23.4]	0.1716 [32.0]	923 (296)	35	958	
4 September	988 [12.7]	1.40 [6.8]	0.0913 [35.7]	0.0648 [38.5]	349 (134)	28	377	
6 September	970 [46.4]	1.38 [7.5]	0.1030 [26.4]	0.0732 [53.9]	393 (212)	39	432	
9 September	1056 [8.0]	1.79 [9.3]	0.1254 [29.8]	0.1065 [32.3]	573 (185)	18	591	
Combined 457m				**0.0910 [11.2]**	**489 (55)**		**531 (62)**	**422 - 668**
14 August	1338 [4.9]	2.12 [13.6]	0.1172 [29.1]	0.0927 [32.5]	499 (162)	52	551	
18 August	"	2.80 [15.6]	0.0710 [30.0]	0.0744 [34.2]	400 (137)	0	400	
19 August	"	2.13 [11.5]	0.1500 [26.3]	0.1192 [29.1]	641 (186)	12	653	
27 August	"	1.81 [7.3]	0.1308 [29.2]	0.0885 [30.5]	476 (145)	73	549	
5 September	"	2.11 [14.2]	0.1663 [23.9]	0.1309 [28.2]	704 (199)	94	798	
8 September	"	1.64 [6.6]	0.1281 [28.9]	0.0786 [30.1]	422 (127)	40	462	
10 September	"	1.62 [12.5]	0.0859 [23.1]	0.0520 [26.7]	279 (75)	19	298	

Table 3. Seven photographic indices and the 2005 visual line transect survey indices corrected for diving animals by multiplying the estuary systematic index by 2.09 and adding in the uncorrected Saguenay River counts.

Year	Surface index	Saguenay	Corrected index	SE
1988	427	5	898	144
1990	527	5	1106	567
1992	454	3	952	149
1995	568	52	1239	217
1997	575	20	1222	190
2000	453	6	953	134
2003	630	2	1319	263
2005	*564*	*39*	*1218*	*151*

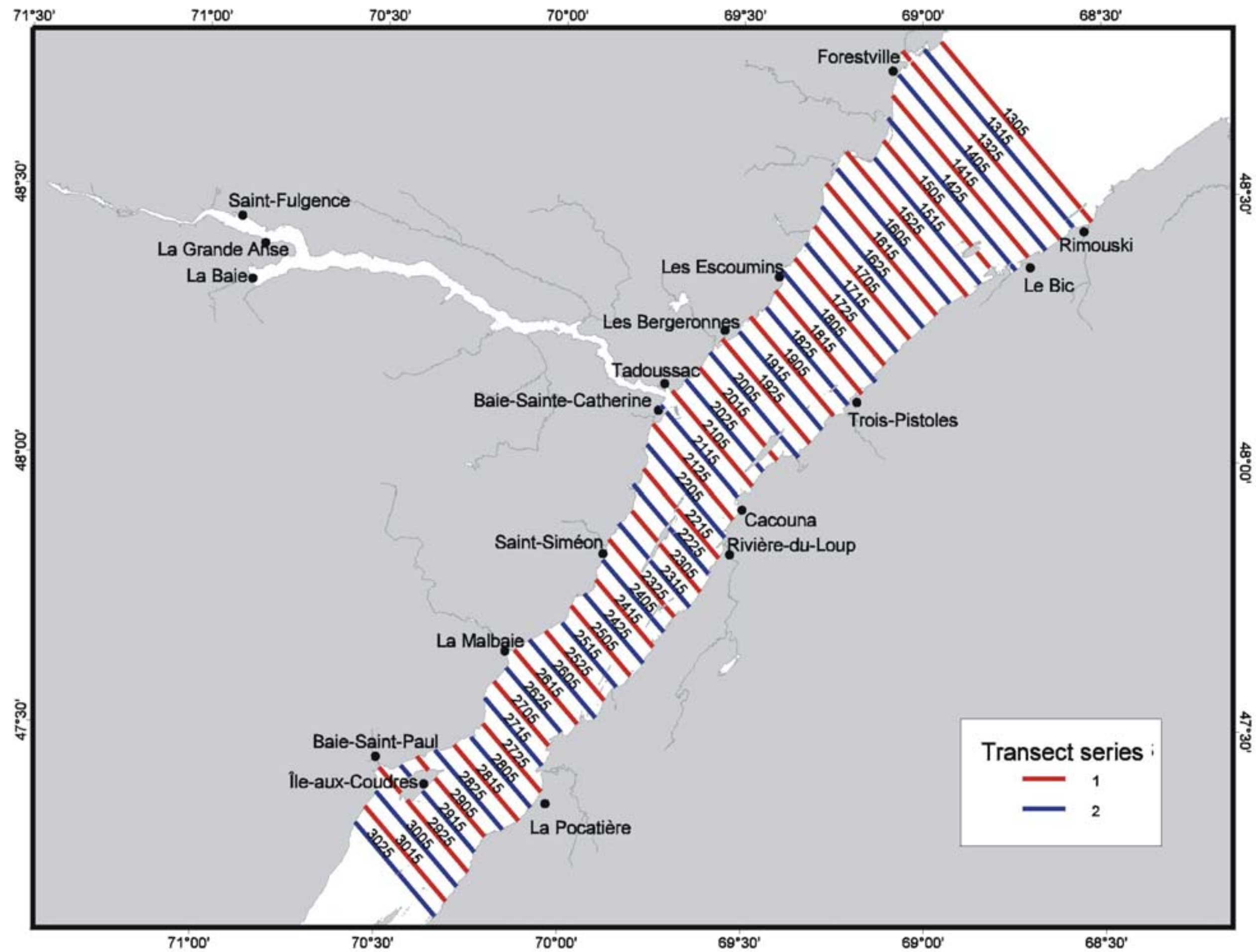

Figure 1. Transects flown during a systematic photographic survey in 2003 (lines 1405 to 3025), five visual line transects conducted at an altitude of 305 m in 2003 (lines 1315 to 3025), and 14 visual line transect surveys conducted at altitudes of 305m and 457 m in 2005 (lines 1305 to 3025). Daily visual surveys followed one of the two series of transects.

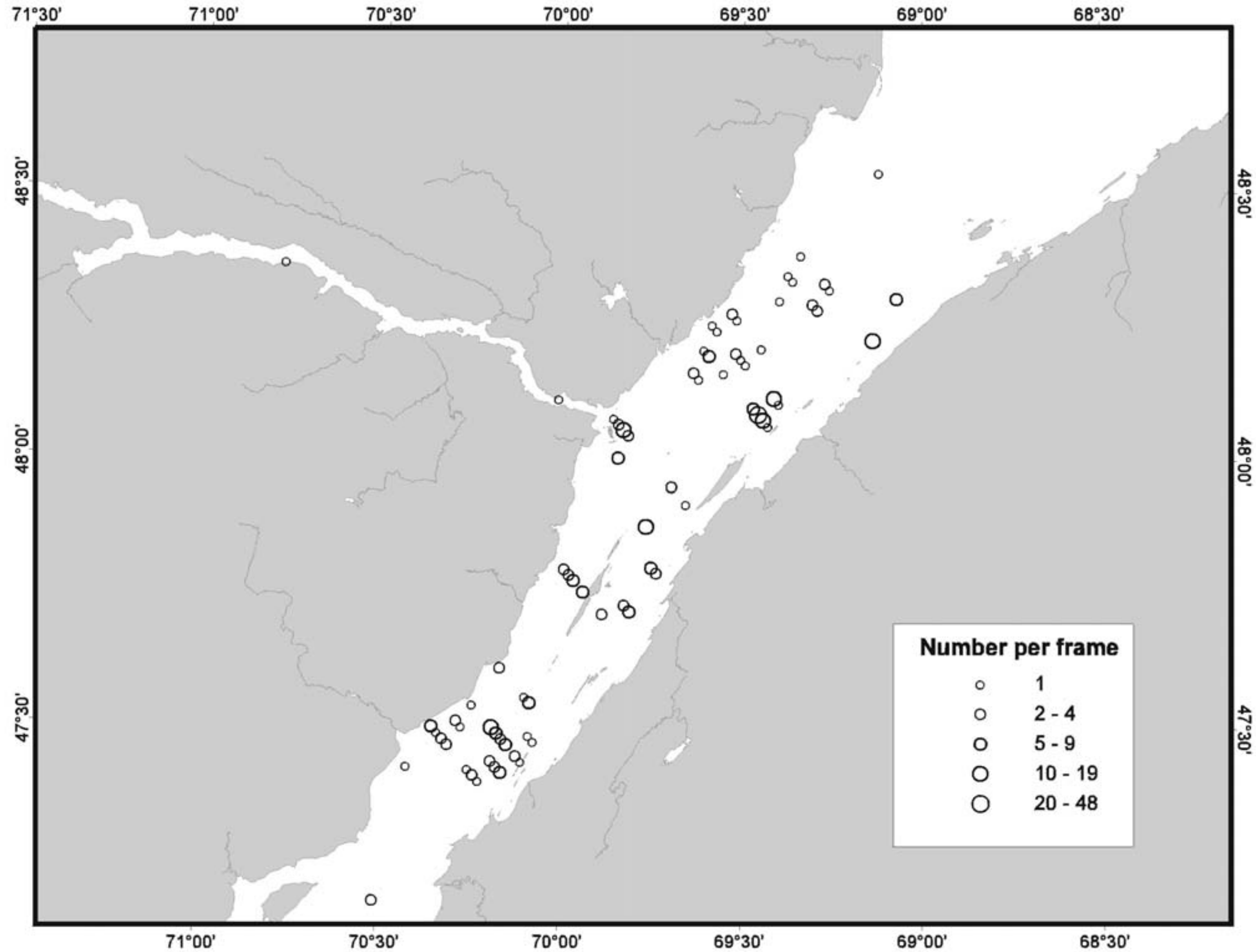

Figure 2. Distribution of belugas detected on images taken along the 51 transects covered during the photographic survey and 2 belugas detected during the visual survey of the Saguenay on 2 September 2003.

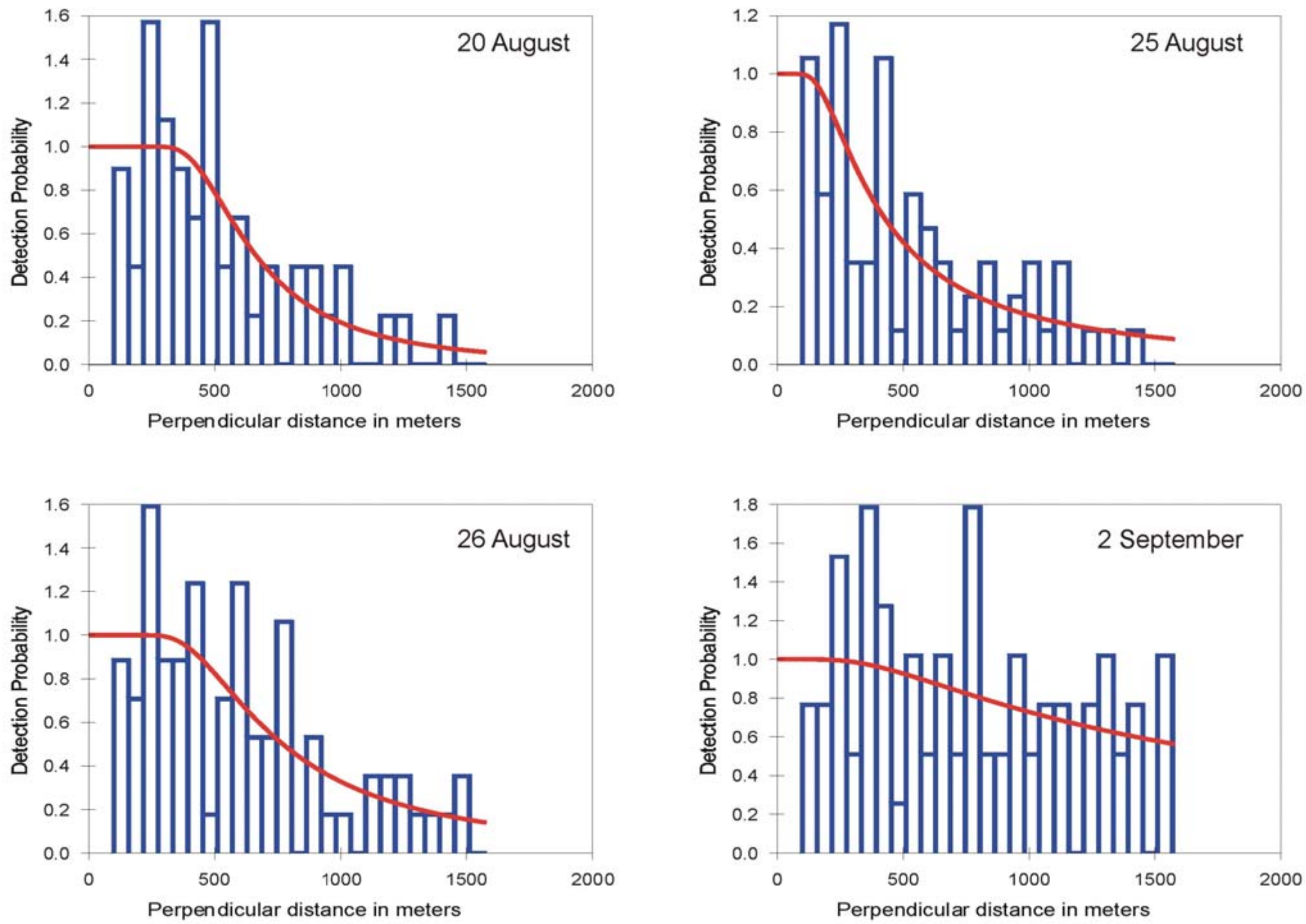

Figure 3a. Distribution of perpendicular distances of groups of belugas detected and the fitted hazard-rate models for five visual line transect surveys conducted in 2003. Graphs show perpendicular distances grouped in bins, but the models were fitted to the ungrouped datasets.

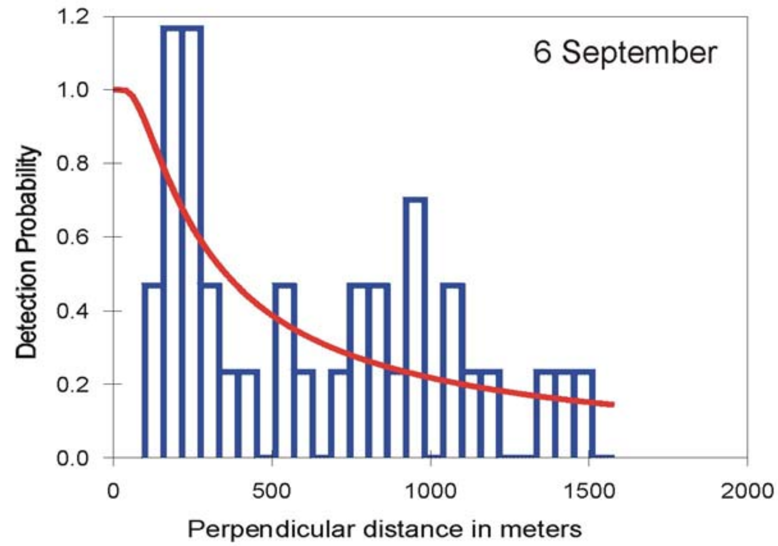

Figure 3b. Distribution of perpendicular distances of groups of belugas detected and the fitted hazard-rate models for five visual line transect surveys conducted in 2003. Graphs show perpendicular distances grouped in bins, but the models were fitted to the ungrouped datasets.

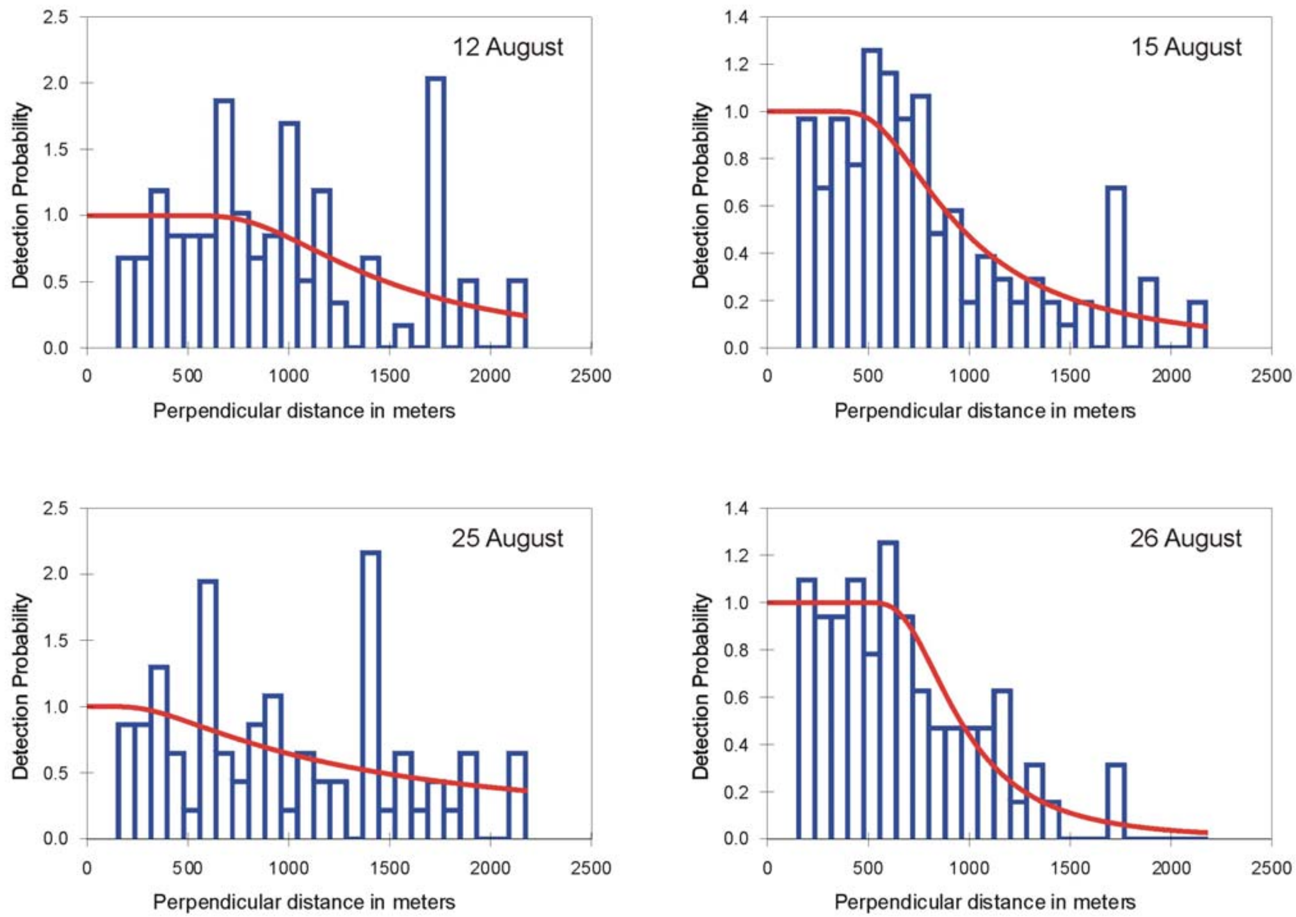

Figure 4a. Distribution of perpendicular distances of groups of belugas and the fitted hazard-rate models for seven visual line transect surveys conducted at an altitude of 305 m in 2005. Half-normal model was used on 9 September. Graphs show perpendicular distances in bins, but the models were fitted to the ungrouped datasets.

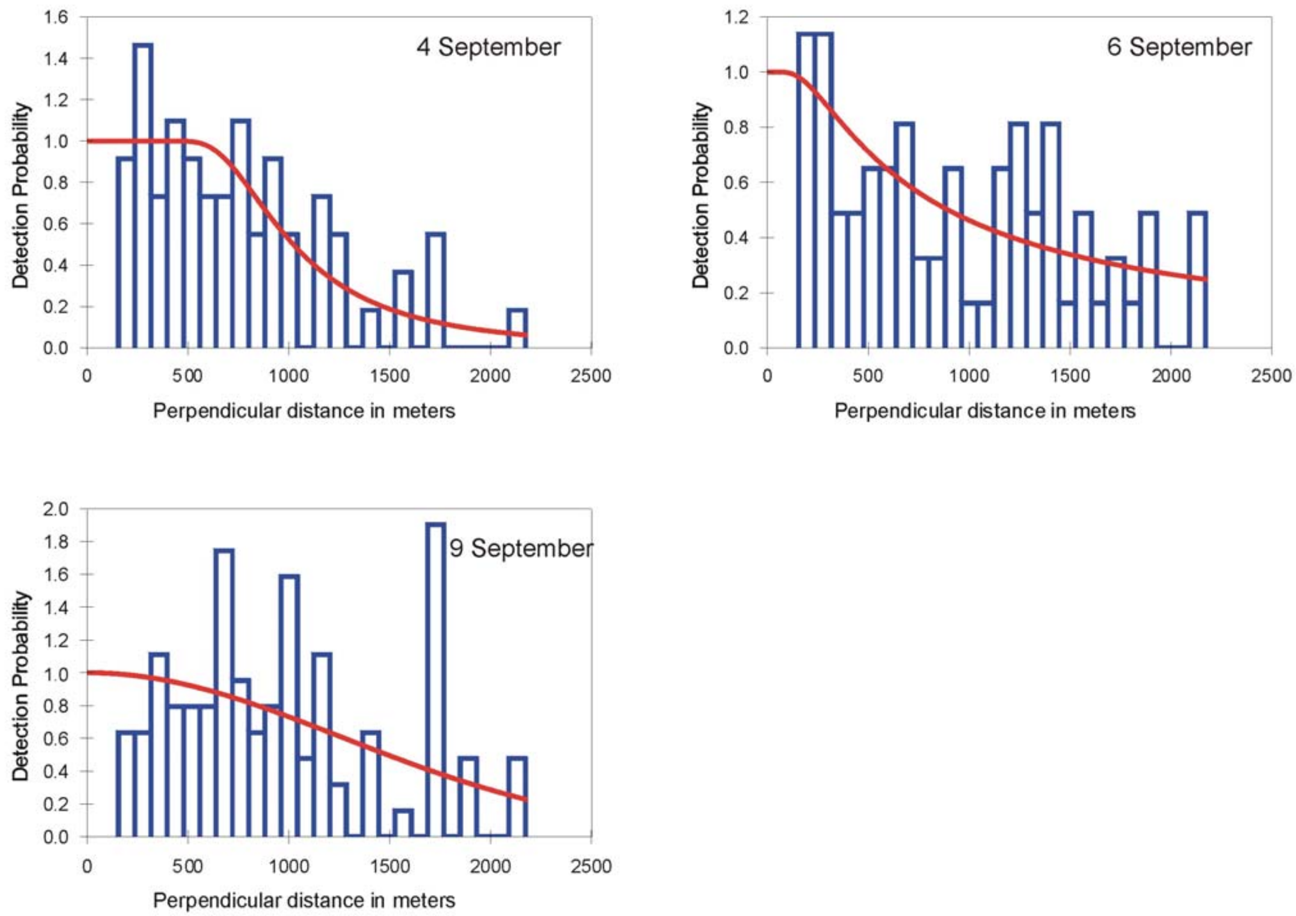

Figure 4b. Distribution of perpendicular distances of groups of belugas and the fitted hazard-rate models for seven visual line transect surveys conducted at an altitude of 305 m in 2005. Half-normal model was used on 9 September. Graphs show perpendicular distances in bins, but the models were fitted to the ungrouped datasets.

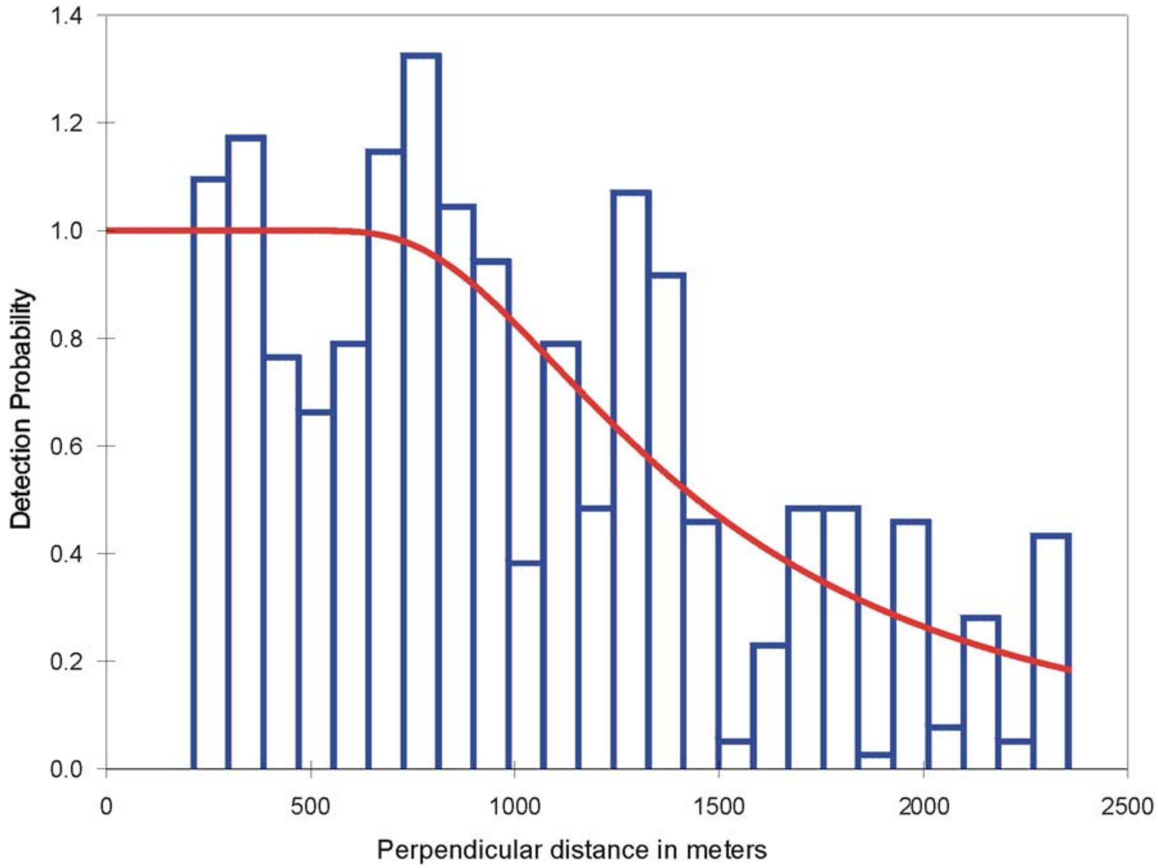

Figure 5. Distribution of the pooled perpendicular distances of groups of belugas detected during seven visual line transect surveys conducted at an altitude of 457 m in 2005, and the unique hazard-rate model used for density and abundance estimation. Perpendicular distances are presented in bins, but the model was fitted to the ungrouped dataset.

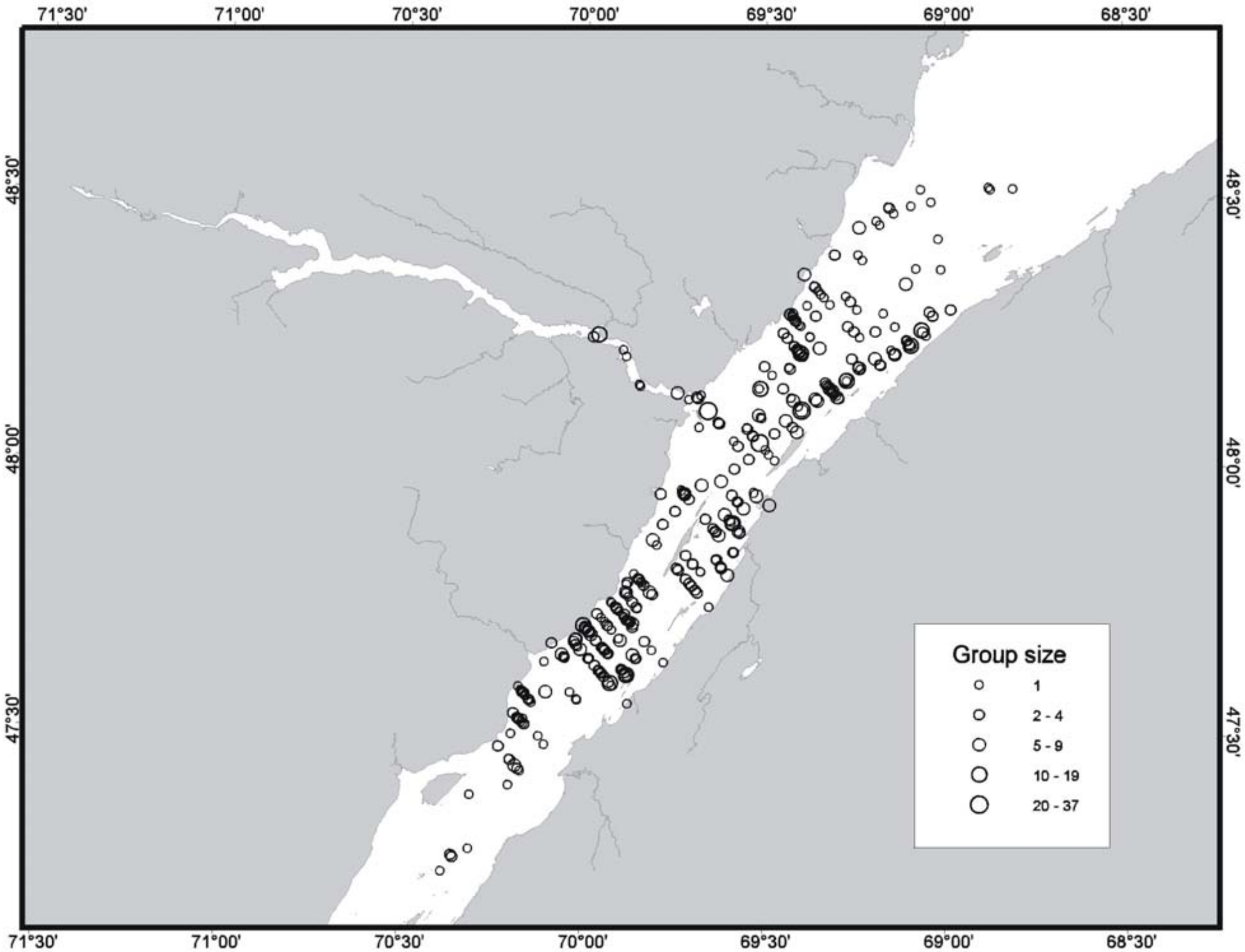

Figure 6. Distribution of belugas detected during five visual line transect surveys conducted at an altitude of 305 m from 20 August to 6 September 2003.

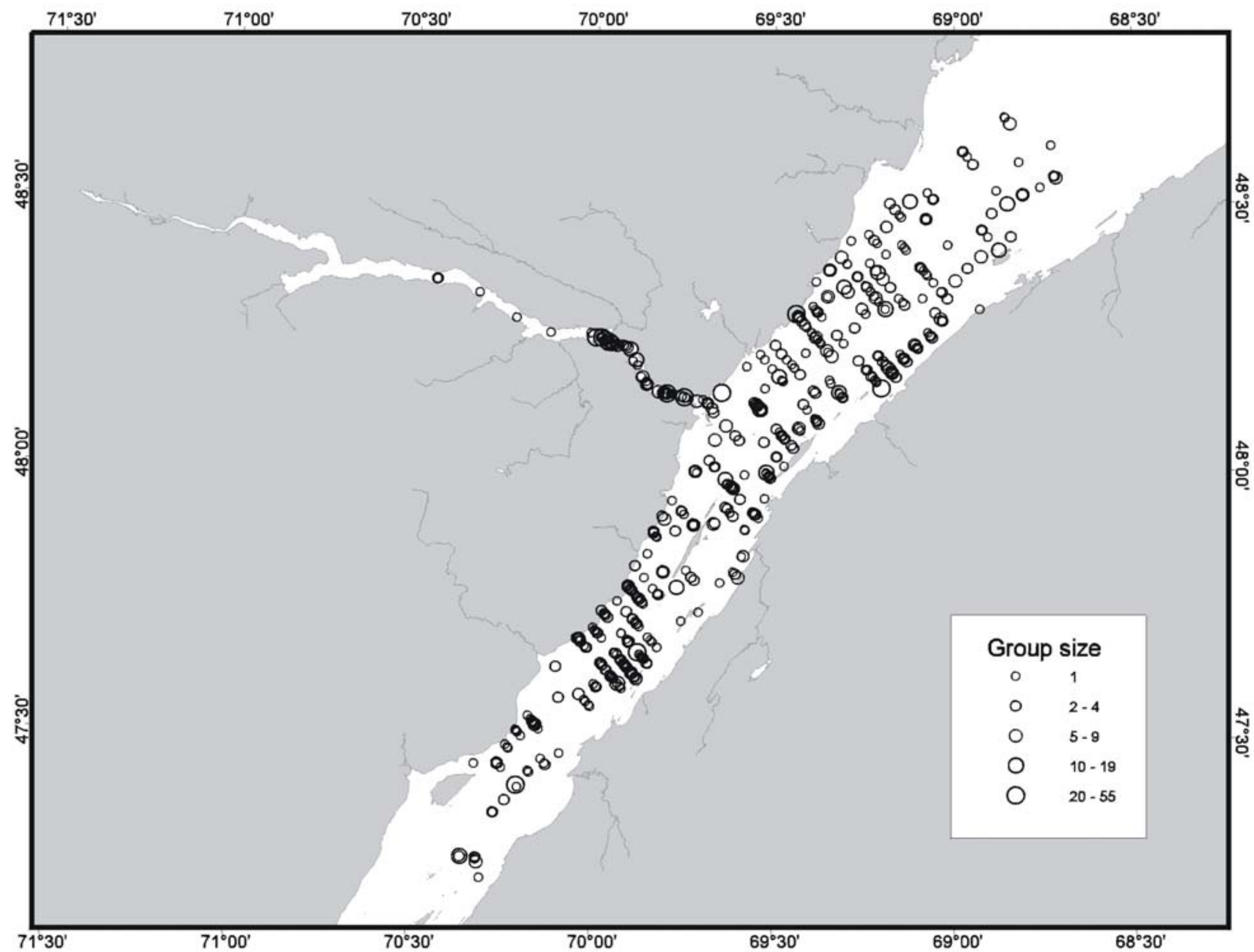

Figure 7. Distribution of belugas detected during seven visual line transect surveys conducted at an altitude of 305 m from 12 August to 9 September 2005.

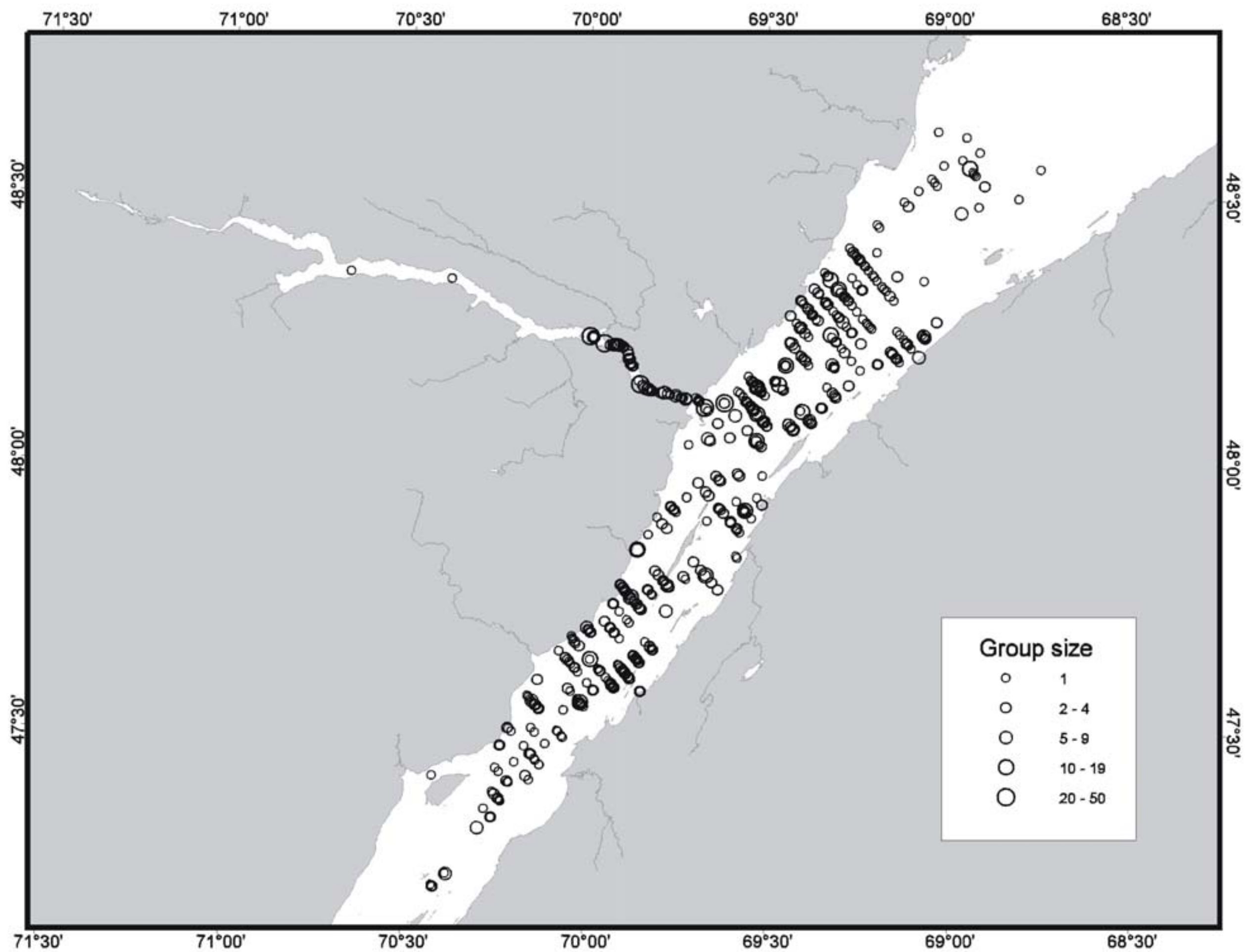

Figure 8. Distribution of belugas detected during seven visual line transect surveys conducted at an altitude of 457 m from 14 August to 10 September 2005.