Fisheries and Oceans Canada — Pêches et Océans Canada
Science — Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2014/021

Quebec Region

Summer abundance indices of St. Lawrence Estuary beluga (*Delphinapterus leucas*) from a photographic survey in 2009 and 28 line transect surveys from 2001 to 2009

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May 2014

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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Published by:

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

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

ISSN 1919-5044

Correct citation for this publication:

Gosselin, J-F., Hammill, M.O. and Mosnier, A. 2014. Summer abundance indices of St. Lawrence Estuary beluga (*Delphinapterus leucas*) from a photographic survey in 2009 and 28 line transect surveys from 2001 to 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/021. iv + 51 p.

ABSTRACT

The abundance of beluga whales (*Delphinapterus leucas*) in the St. Lawrence Estuary was monitored by eight photographic aerial surveys conducted between 1988 and 2009, and twenty-eight visual line transect surveys conducted between 2001 and 2009. Overall, the surveys show no clear trend in abundance since 1988, although there are some indications that the population may have increased slightly from 1988 to 2003, and thereafter declined slightly since then. The 2009 photographic survey, corrected for animals not visible at the surface, resulted in a total abundance estimate of 676 whales (CV=0.16), the lowest result in the series since 1988. Six visual line transect surveys provide an average index of abundance of 979 whales (CV=0.14) in 2009. The visual estimates are negatively biased, not having been corrected for animals at the surface that are not detected by observers (perception bias). The coefficients of variation for the surveys are high due primarily to the highly clumped distribution of belugas. Photographic surveys also provide information on the proportion of calves in relation to the total number of belugas detected. This proportion was 15-18% for the period 1990 to 1997, but has since then declined to a range of 3-8% for the period 2000 to 2009.

Indices d'abondance d'été du béluga (*Delphinapterus leucas*) de l'estuaire du Saint-Laurent obtenus à partir d'un relevé photographique en 2009 et de 28 relevés en ligne de 2001 à 2009

RÉSUMÉ

L'abondance des bélugas (*Delphinapterus leucas*) dans l'estuaire du Saint-Laurent a été suivie par huit relevés aériens photographiques complétés entre 1988 et 2009 ainsi que par vingt-huit relevés visuels en ligne entre 2001 et 2009. Dans l'ensemble, les relevés ne montrent aucune tendance claire d'abondance depuis 1988, bien qu'il y ait des indications que la population ait augmenté légèrement de 1988 à 2003, puis aurait diminué légèrement par la suite. Le relevé photographique de 2009, corrigé pour les animaux non visibles à la surface, a produit une estimation d'abondance de 676 individus (CV=0,16), le plus bas indice de cette série depuis 1988. Six relevés visuels en ligne ont produit un indice d'abondance moyen de 979 individus (CV=0,14) en 2009. Les estimations obtenues par relevés visuels présentent un biais négatif car ils n'ont pas été corrigés pour les animaux en surface qui ne sont pas détectés par les observateurs (biais de perception). Les coefficients de variation des relevés sont élevés dû principalement à la distribution très agrégée des bélugas. Les relevés photographiques fournissent aussi de l'information sur la proportion de veaux sur le nombre de bélugas observés. Cette proportion était de 15 % à 18 % pour la période de 1990 à 1997, mais a diminué depuis pour atteindre une gamme de valeurs de 3 % à 8 % pour la période de 2000 à 2009.

INTRODUCTION

Beluga whales are gregarious marine mammals. The level of aggregation varies seasonally as animals concentrate during summer in coastal estuaries around the Arctic but disperse to offshore areas during the winter (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 (Boivin and Michaud 1990, Michaud 1993, Pippard and Malcolm 1978, Vladikov 1944).

Studies to evaluate SLE beluga abundance have used a variety of methods including total counts, visual and photographic surveys that used boats, helicopters and airplanes as platforms (Pippard and Malcolm 1978; Béland et al. 1987; Kingsley 2002, Sergeant and Hoek 1988). The early surveys suggested that St. Lawrence beluga numbers were quite low, but uncertainty in how some of the estimates were obtained as well as differences in methodology between these early efforts limited their value in the analysis of population trend over time (Michaud and Béland 2001). The 1995 SLE beluga recovery plan recommended that a standard method, systematic strip-transect photographic aerial surveys, be adopted to estimate abundance and improve the monitoring of the population (DFO and WWF 1995). Seven surveys following a standard protocol were carried out between 1988 and 2003 (Kingsley and Hammill 1991; Kingsley 1993, 1996, 1998, 1999, 2002, Gosselin et al. 2001, Gosselin et al. 2007). Considerable variability has been observed in the resulting survey indices. This variability is thought to result from challenges in trying to survey a small population with non-random or 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 capture the variability associated with the contagious distribution using repeated surveys. Line transect surveys are more efficient than strip transect surveys to estimate abundance of scarcely distributed animals over a large geographic area (Buckland et al. 2001). Furthermore, visual line transect surveys are generally less costly than large format photographic surveys making them more practical for repeated surveys. Five visual line transect surveys were conducted in the SLE in 2003 to evaluate the variability associated with clumping for this population. Since these visual surveys also overlapped with the 2003 aerial photographic survey, we were able to compare the index obtained from a strip-transect photographic survey with those obtained from visual line transect surveys. Another fourteen visual line transect surveys were conducted in 2005. The photographic survey and repeated visual surveys allowed us to examine some of the variability that can occur due to clumping between surveys, as well as comparing estimates obtained using visual and photographic survey methods (Gosselin et al. 2007).

Here, we present a new abundance index from a photographic survey conducted on 28 August 2009. We also present new abundance indices for the SLE beluga population from 8 visual line transect surveys conducted in 2001, 2008 and 2009, and revise the estimates of the visual line transect surveys conducted in 2003, 2005, and 2007 (Gosselin et al 2007, Lawson and Gosselin 2009).

MATERIAL

STUDY AREA

The survey design covers the major summer concentration of belugas in the SLE, which is centered at the confluence with the Saguenay River (Figure 1). The downstream portion of the study area from Tadoussac to Rimouski is characterized by the 300 m deep Laurentian Channel extending from the northeast limit of the Estuary along the north shore of the area to the confluence of the Saguenay River. The upstream portion of the study area from Tadoussac to Île-aux-Coudres is very shallow with 20 m deep channels and a series of small islands with wide tidal flats extending mostly along the south shore. These shallow waters are also associated with higher water turbidity that results 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.

PHOTOGRAPHIC SURVEY DESIGN

The photographic surveys followed a similar design from 1988 to 2009 (Figure 1). Although the designs were similar, coverage has changed over the years. In 1988 and 1990, there were 41 and 38 lines with 3.7 km (2 NM) spacing in an upstream stratum from Îles aux Loups Marins to Les Escoumins, and 12 and 13 lines with 11.1 km (6 NM) spacing in the downstream stratum from Les Escoumins to Pointe-des-Monts (Kingsley and Hammill 1991). Since 1992, the whole area from Île-aux-Coudres to Rimouski has been covered with a 3.7 km (2 NM) spacing design with 48 lines in 1992 and 49 lines in 1995 and 1997. The area was extended about 7.4 km (4 NM) in both directions in 2000 compared to the 1992 area, adding two lines at both the upstream and downstream ends so that the area upstream of Île-aux-Coudres to Rimouski was covered by 52 lines with 3.7 km (2 NM) spacing. A similar design with 53 lines over the same area was planned in 2003, but 51 lines were surveyed. This area was increased again in 2009, resulting in an extended area covered by 57 lines, one more line upstream and 3 more lines downstream of the 2003 survey, for a total stratum area of 5787 km^2.

PHOTOGRAPHIC SURVEY

In 2009, two planes flew a total of 57 transects perpendicular to the main axis of the Estuary (heading 320° and 140° true) with a spacing of 3.7 km (2 NM; Figure 1). The two planes started on adjacent transects in the center of the area to be surveyed, around Cacouna and flew subsequent transects in opposite directions. Aircraft were equipped with 9 inch x 9 inch mapping cameras (cameras and measured film widths: Zeiss Top 15, 230 cm x 230 cm; Wild RC 20, 229 cm x 229 cm) loaded with colour positive film (Agfa, Aviphot Chrome 200 PE1), fitted with calibrated lenses (152.930 mm and 153.091 mm), filters (A2 + 36%; Clair 420 nm 2X) and a forward motion compensation system. The target altitude was 1219 m (4000 ft) but the altitude from the GPS was recorded for each photograph. To assure complete coverage of each transect, camera speed was set to achieve a target overlap of 15% between consecutive photographs.

Surveys were conducted on days when preferred survey conditions were forecast, *i.e.* ceiling were above 1219 m, winds were less than 18.52 km/h (10 knots) and there was no fog over the survey area. It was timed so that the sun angle would be more than 30° above the horizon. The area photographed during the survey is approximately 50% of the total study area, but was estimated more precisely in the analyses.

The Saguenay River was surveyed visually with a helicopter (Bell 206 long-ranger) in 2001 and with a plane (high wing Cessna 337) in following years and timed to minimise the delay between photographic and visual surveys of adjacent areas. Two observers, one on each side of the plane, recorded the number and position of belugas on an upstream pass from Tadoussac to Saint-Fulgence and similarly on a downstream pass. Belugas moved between these two passes. Some belugas in a given location were counted twice, *i.e.* on the upstream pass and on the downstream pass, while others were only detected on one pass. Animals on the second pass were considered as being detected a second time if the difference in distance and time between the two passes corresponded to a swim speed of less than 10 knots. Animals that were only seen on one of the pass according to this criteria of maximum swim speed of 10 knots were added over the two 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. (2002). Frames were read 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 acetate overlay. 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 images were read by both readers. Once a first reading of all film was completed, each reader then re-read their first 100 frames a second time without consultation of their 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 15% between successive frames based on plane speed and shooting interval, the achieved overlap was estimated for each frame using immobile landmarks or ocean features as reference points during reading. Beluga images located within the overlap portion of a frame were compared with those observed on the previous frame to ensure that there were no duplicates or individuals that had gone undetected.

PHOTOGRAPHIC DATA ANALYSES

The analysis of the photographic survey was similar to that used in previous surveys (Gosselin et al. 2007). In 2009, additional information was available on altitude of the plane at the time that each image was taken. This allowed a slightly different estimation of overlap between consecutive photographs and the proportion of the transects masked by sun glare.

The image width on the ground, corresponding to the transect width W_j was calculated using the focal length of the lens, F_i (152.930 mm or 153.091 mm), and the width of the square images on the film, P_j (230 cm or 229 cm), and the average altitude, H_j, on the transect using:

$$W_j = H_j (P_j / F_j) \qquad [1]$$

The minimum number of photographs required to completely cover any transect without overlap, l_j, is estimated by:

$$l_j = L_j / W_j \qquad [2]$$

where L_j, is the total length of transect *j*. The target overlap between consecutive photographs was 15%. However, the achieved overlap could not be estimated on each frame as the smooth water surface seldom provided landmarks. Therefore, the achieved overlap on each transect, p_{gj} was estimated using the number of photographs taken on each transect, x_j, and the minimum number of photographs required to photograph all of the transect without overlap, l_j. This is expressed as:

$$p_{oj} = 1 - (l_j / x_j) \qquad [3]$$

The proportion of each transect masked by sun glare, p_{gi}, is:

$$p_{gj} = \frac{\sum_{i=1}^{x_j} p_{gi}}{(1 - p_{oj})} \qquad [4]$$

which, considering the equations above can be simplified as:

$$p_{gj} = \frac{\sum_{i=1}^{x_j} p_{gi}}{l_j} \qquad [5]$$

where p_{gi} is the proportion of each photograph hidden by sun glare and not included in the overlap with previous image. Taking into account the proportion of the transect where whales could not be detected due to glare, counts of belugas for each transect, n_i, were corrected as:

$$n_{rj} = n_j / (1 - p_{gi}) \qquad [6]$$

To account for the area of the Estuary not covered between transects, the count was multiplied by an expansion factor f estimated as:

$$f = S / W_j \qquad [7]$$

where *S* is transect spacing (3704 m = 2 NM). The number of belugas visible at the surface of the Estuary was then estimated as:

$$\hat{N} = f \sum_{j=1}^{k} n_{rj} \qquad [8]$$

where *k* represents the number of transects. The variance was estimated using the serial differences between transects including the finite population correction (Cochran 1977; Kingsley and Smith 1981) and estimated as:

$$V(\hat{N}) = \frac{f(f-1)k}{2(k-1)} \sum_{j=1}^{k-1} (n_j - n_{j+1})^2 \qquad [9]$$

PROPORTION OF CALVES

Readers were also instructed to record the number of calves on the photographs. Calves were defined as animals swimming alongside a large animal and being equal or less than half the body length of the adjacent animal. To reduce the inconsistency of calf identification among readers from 1990 to 2009, all photographs where belugas had been detected on previous surveys were re-read in 2009 by a single reader to determine the number of calves. The proportion of calves was determined for the whole survey as the number of calves divided by the total number of animals detected in the survey.

PHOTOGRAPHIC 1988

Some problems with the 1988 survey that could affect the abundance estimate were detected during a recent spatial analysis of the survey photographs. In Figure 1 of Kingsley and Hammill (1991), only lines 4 to 46 are shown, which corresponds to 43 lines, although 57 lines were flown according to photographic reading records. It became evident that the planned survey lines for the 1988 survey were, in fact, not followed by the planes (Figure 2). The actual tracks photographed were estimated by comparing the photographed coastline with the coastline from Toporama (Web Map Service, Natural resources Canada; in ArcGIS 9.2, add GIS Server) Photographs with coastline in them were used to provide an exact position of the center of the photograph and photographs without distinguishable coastlines were assumed to lie in a straight line between the photographs with corrected positions. Two pairs of adjacent lines actually crossed and showed a high proportion of overlap (Figure 2). The orientation also varied for each line; the lines were not perpendicular to the axis of the Estuary and were not parallel. Therefore, it is likely that the area covered by the survey was actually larger than if the survey design had been followed. A new abundance index based on the ratio of the whole area of the stratum divided by the area covered by the transects was estimated using the following formula from Buckland et al. (2001):

$$\hat{N} = \frac{1}{w} \times \frac{n}{L} \times A \qquad [10]$$

where *w* is the photograph width, *n* is the total count including animals in overlapping lines, *L* is the total length of all transects, including the overlapping transects and *A* is the area of the Estuary that was surveyed extending the geographic zone covered by the transect by half the spacing at each end and estimated on an Albers equal-area conic projection (spheroid WGS84; central meridian 68°45'W; standard parallel 1, 47°45'N; standard parallel 2, 48°45'N; latitude of origin, 48°15'N) in ArcView (3.2, ESRI). The variance was calculated as an encounter rate variance following the post-stratification scheme with overlapping strata with lines of different lengths of Fewster et al. (2009; equation 16) and considering the two pairs of overlapping lines as single lines with a length equal to the sum of both estimated lengths.

$$\mathrm{var}\left(\frac{n}{L}\right) = \frac{2k}{L(k-1)} \sum_{i=1}^{k-1} \frac{(l_i l_{i+1})^2}{(l_i + l_{i+1})^2} \left(\frac{n_i}{l_i} - \frac{n_{i+1}}{l_{i+1}}\right)^2 \qquad [11]$$

$$\mathrm{var}(\hat{N}) = \left(\frac{A}{w}\right)^2 \mathrm{var}\left(\frac{n}{L}\right) \qquad [12]$$

The abundance indices for the other photographic surveys were not revised.

VISUAL SURVEY DESIGN 2001-2009

The design of the visual survey was similar to the photographic survey in the same geographic area, but with a spacing twice as wide. This resulted in half the number of lines being flown in the same area of the Estuary so that each survey could be completed by one plane in a single day. Following observations of belugas in the downstream portion of the Estuary on 22 July 2007 (abundance presented here), we also surveyed the area from Rimouski to Pointe-des-Monts on the same day and over a period of a few days around the photographic survey date.

Therefore, in 2009, six systematic visual line transect surveys with 28 lines with 7.4 km (4 NM) spacing and random placement also covered the same area as the photographic survey (5787 km^2), and two visual line transect surveys with 16 lines covered the area downstream of the photographic survey extending to Pointe-des-Monts (6265 km^2) (Figure 3). The coverage in the Saguenay River extended to Saint-Fulgence and thus, was identical to the previous visual and photographic surveys.

All visual surveys were flown with a Cessna 337 equipped with bubble windows. A single plane with the same team was used within each year, except for 2007 and 2008 when two planes were used. On both of these years, it was planned that the two planes would fly the same lines with the second plane following the first plane a few minutes later to compare counts to assess g(0).

The visual surveys were flown at a target altitude of 457m (1,500 ft) in 2001 and 305m (1,000 ft) in 2003, 2008 and 2009. The 2005 surveys were planned to compare estimates between altitudes and therefore half the surveys were flown at 457m (1,500 ft) and the other half at 305m (1,000 ft). The 2007 survey was part of a multispecies survey on a wider geographic region that was flown at a target altitude of 198 m (650 ft). The target speed was 185 km/h (100 knots) for all surveys except for 241 km/h (130 knots) in 2001. Position and altitude were recorded every 2 or 10 seconds from a GPS (D-GPS in 2005) output into a laptop computer with mapping software (Garmin GPS76, GPS Map 60c; D-GPS antenna from Prairies Geomatics; Fugawi versions 3.0 and 4.0) except for 2001.

The observers received line transect sampling training on the ground prior to the surveys. The same team of observers completed all the surveys within each year, and some were part of the survey team over several years. All observers had previous aerial survey experience or field experience with marine mammals prior to their first survey. From 2001 to 2005, the observers used seats with bubble windows which were located in the back of the aircraft. From 2007 to 2009, the right hand observer moved to the front seat (i.e., co-pilot seat).

Observations of belugas were recorded as groups, which were defined as several animals within a few body length of each other and swimming in the same general direction or showing similar behaviour. For each group of beluga, observers were instructed to record in order of priority: the species, the estimated group size, the angle below the horizontal, the time when animals were passing abeam, reaction to plane and behaviour. Detection of belugas could be affected by their reaction to the plane, so observers were instructed to record behaviour and since 2007 they were specifically instructed to record reaction to plane, i.e. a change in behaviour assumed to be a reaction to the approaching plane. The perpendicular distance from the track line was estimated using the angle below the horizontal measured using an inclinometer (Suunto, PM 5/360 PC) and the planned altitude in 2001 or the GPS altitude output from 2003 to 2009 (D-GPS in 2005) using the formulae by Lerczak and Hobbs (1998) [note: the average difference between GPS altitude reading in the aircraft and actual airport elevation was estimated at 1.7 m (n=637, SD=7.4 m, max=36.7 m) in 2007]. The time when animals were passing abeam was synchronised with time from the GPS. The position of each observation was estimated using time and interpolation between adjacent GPS outputs.

Surveys were only initiated when sea conditions were Beaufort 3 or less, and when cloud cover was above the target altitude. Weather and observation conditions were also recorded at the beginning, end and at regular intervals along the lines or whenever changes in sighting conditions occurred. The conditions noted included sea state (Beaufort scale), subjective visibility (5 levels: 1- excellent; 2- good: some reduction of detection, 3- fair; 4- reduced: clearly missing sightings; 5- none: no visibility), 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), cloud cover percentage and water color (4 levels based on sediments in suspension: 1-dark: clear with no sediment in suspension, 2- green, 3- light green and 4- brown: high concentration of sediments). All the information was recorded on digital or analog mini-cassettes voice recorders by each observer.

LINE TRANSECT ANALYSES

Line transect analyses of observations of belugas recorded as groups were completed using Distance 6 (Thomas et al. 2009). Line transect sampling assumes that all animals on the track line (*i.e.* at perpendicular distance = 0 m) are detected and that the probability of detection decreases with increasing perpendicular distance from the track line. We know that for diving marine mammals, detection on the track line is not complete, as some animals are underwater when the plane is overhead (availability bias), and some animals that are at the surface are missed by the observers (perception bias). Details on the availability correction and possible perception bias are provided below (in the section Population Indices). Even if we know that detection is not perfect along the track line, density estimation assumes that the probability of detection is at its maximum on the track line and decreases with increasing distance from the aircraft. In aerial visual surveys, the probability of maximum detection actually occurs at some distance from the track line due to a blind area under the plane. This can be corrected by left truncation of the data (Thomas et al. 2009). The distribution of perpendicular distances was examined to detect differences in left and right truncation (*i.e.* close and distant truncation distances respectively). This was completed separately for each year and for each altitude in 2005 (Gosselin et al. 2007). The overall distribution of perpendicular distances was examined and the closest perpendicular distance showing a maximum frequency of detection that was maintained with increasing distance was chosen as the left truncation. We assumed maximum detection probability at the left truncation distance, and therefore, left truncation was applied by subtracting the left truncation distance to the perpendicular distance before further analyses. The left truncation distance will have an important influence on the estimation of density and once the detection function was selected (see below), the plot of the quantiles of the fitted cumulative distribution against the quantiles of the empirical distribution function (Qq-plot) was examined and the Cramér-von Mises test with cosine weighting function was used to verify that the model fitted the data, especially near the track line. Left truncation can be adjusted to improve the fit near the track line if the fit is poor. A method to identify truncation of distant sightings, or right truncation, suggested by Buckland et al. (2001) is to select between the hazard rate or half normal function on the overall distribution of sightings using the Akaike Information Criterion (AIC) and to truncate all sightings beyond the distance providing a model value probability of detection of 0.15. But this method cut out a large number of sightings and was not used. Instead, we only used a right truncation if distant outliers (a few inclinometer degrees away from the next shorter distance) were identified, and retained largest perpendicular distance as the right truncation.

Model selection and inclusion of covariates followed the stepwise procedure of Marques and Buckland (2003). The first step of this procedure is to select what we will refer to as the "key function" of the model. Half-normal or hazard-rate models without adjustment terms were fitted to the truncated distribution of ungrouped perpendicular distances of sightings and the model with the lowest AIC was selected as key function. Using the selected half-normal or hazard-rate as the key function, we examined, as the next step, if AIC could be reduced further by the addition of one of the following covariates: observers (2 or 4 levels each year), sea state (Beaufort = 0 to 4), glare intensity (4 levels: Intense, medium, low none), cloud percentage, water color (4 levels: 1-dark, 2-green, 3-light green, 4-brown) and visibility (5 levels: excellent, good, medium, reduced, none). The four variables for sea state, glare intensity, cloud percentage and visibility are correlated and therefore were never combined in the same model. For 2001 and 2003, glare intensity, cloud percentage, water color and visibility were not collected systematically. The covariates were also only included if they satisfied the following additional conditions after the reduction in AIC: if factor covariates only affected the scale and not the form of the detection function (*e.g.* covariate was not included if its addition created a new spike compared to key function or previous step model); if less than 5% of the estimated probabilities of detection of sightings were less than 0.2 and none were less than 0.1; if the Cramér-von Mises goodness of fit test, which puts more emphasis on the fit near the track line, estimated that the model fitted the data ($p > 0.05$). Models with additional covariates were selected in subsequent steps if the addition of a covariate further reduced AIC and if the conditions of estimated probabilities of detection of sightings were respected. During the first step of selection, when the half-normal and the hazard-rate functions had similar AIC scores, then the following steps were done with these two key functions. If half-normal and hazard-rate functions alone without covariates remained the best two models, or if these key functions with the same set of covariates had similar AIC scores, then model averaging was performed using bootstrap of lines (4999 resamples), and AIC for model selection for each resample.

Observations of belugas are recorded as groups and the estimation of density requires an estimation of the average group size in each stratum. There is a possible bias in the estimation of group size as larger groups of belugas may have a higher probability of being detected as perpendicular distance from the track line increases. To consider this potential bias, the expected group size of beluga observations in each geographic stratum was estimated using the size bias regression method of the natural logarithm of group size [*i.e.,* $\ln(s)$] against the detection function value [$g(x)$], or using the mean group size when the regression was not significant (p>0.15).

The encounter rate was estimated as the number of sightings along the total length of the surveyed lines and its variance was estimated using each line as a sampling unit and the formula for systematic design with overlapping strata of Fewster et al. (2009) implemented in Distance 6. In 2007 and 2008, the Estuary was surveyed on a single day with two planes following the same lines within minutes of each other. For these days, the two flights were considered as a single survey with twice the effort on each line. The encounter rate and its variance were estimated using the addition of the line counts of each plane and by doubling the length of each line to account for the doubled effort. This meant that the transect line, and not the passage of each plane, was the sampling unit.

The mean density of belugas in the Estuary within a year, or within a given altitude within a year (for the 305m and 457m altitude in 2005), was estimated as the mean density of surveys conducted on different days weighted by total effort on each day. One exception was 2007, when the different strata represented different geographic areas and the mean density was weighted by stratum area and the abundance indices of strata were added. In 2009, the Estuary surveys covering the area of the photographic survey between Îles aux Loups Marins and Rimouski were averaged following the approach described above for this area while the average of the surveys covering the area downstream of Rimouski were estimated separately. The variance of density for each year, or each altitude in 2005, was estimated empirically when only the half-normal or the hazard-rate without covariate were selected in the detection function model. When covariates were selected for the detection function model, the fitting of the model was made using all sightings for a given year, but a separate average probability density function was estimated for each day using the covariate values of that day. When covariates were included, the yearly density indices and their variance were estimated using bootstrapping resampling lines (4999 resamples) within each survey.

When sightings were detected, observers were instructed to give priority to the identification of species, followed by group size estimation, the angle below the horizontal measured using an inclinometer and the other variables described above if time permitted. Therefore, some observations were lacking perpendicular distance measurement (usually when high densities of beluga whales were encountered). These observations were discarded assuming that the lack of their detection away from the track line will reduce the effective strip width to compensate for not including them and the implied reduction in encounter rate. Some observations were lacking group size estimation, but these sightings were included in the estimation of the detection function and the encounter rate, but were not included in the estimation of expected group size.

SAGUENAY COUNTS

The Saguenay was surveyed as described for the photographic survey, but using the same Cessna 337 and observer team. Most of the time, it was completed following the Estuary survey. The number and position of belugas were recorded from Tadoussac to Saint-Fulgence and similarly on the way back. Sightings were seen in the same location on the upstream and downstream passes and the maximum count between the two passes was used as the total count for a given location. Sightings on the second pass that were not detected on the first pass and that could not be duplicates of sightings of the first pass according to the time lapse between the first and second pass and a maximum swimming velocity of 10 knots, were added.

POPULATION INDICES

Line transect sampling assumes that all animals on the track line are detected and that the probability of detection decreases with increasing perpendicular distance from the track line. As mentioned above, we know that for diving marine mammals the detection is not complete on the track line, as some animals are underwater when the plane is overhead (availability bias), and some animals that are at the surface are missed by the observers (perception bias). We did not estimate a perception bias correction factor which is usually done using double platform with independent observers during visual line transect surveys, although data from other studies suggest that this correction is small. The probability of detection of belugas during visual line transect surveys of the North Water Polynya has been estimated at 0.97 (CV 0.02) and 0.92 (CV 0.03) (Heide-Jorgensen et al. 2013). The correction for missed groups was estimated at 1.015 (CV 0.03) and 1.021 (CV 0.01) for surveys of Cook Inlet belugas during two different periods (Hobbs et al 2000). Corrections were applied for availability bias to account for diving animals by dividing the systematic density or abundance estimate by P_S = 0.478 (SE=0.0625, df=71) as the proportion of time beluga remained visible from an aerial survey platform estimated for belugas in the SLE. This has also been referred to as a multiplying factor of 2.09 (see below; Kingsley and Gauthier 2002).

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 behavior 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. Counts of whales in the Saguenay were not corrected 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 includes some availability correction because the area was surveyed during both the upstream and downstream flights.

The photographic survey series was included in an age-structured Bayesian population model to evaluate changes in abundance in the St. Lawrence beluga population (Mosnier et al. 2014). However, this model is not fitted to the line transect surveys series and changes in abundance indices from this series was estimated using simple linear regression.

RESULTS

PHOTOGRAPHIC SURVEY

The photographic survey was carried out on 28 August 2009 between 15h10 UTC and 22h06 UTC (11h10 and 18h06 local time) when sun elevation was 40° and 23° (*i.e.* just below the prescribed 30° at the end of the survey). The average hourly wind speed recorded at Rivière-du-Loup, in the center of the survey area, on that day from 11h00 to 18h00 was 5.4 km/h with a maximum of 9 km/h (Environment Canada, climate data online).

The survey was completed with minimal changes to the plan. The planes started on lines 27 and 28 within 24 minutes of each other, and the start of the Saguenay survey was flown within 28 minutes and 4 minutes from the passage of the planes in front of the entrance of the fjord (Figure 1). The average time lapse between adjacent lines was 5 minutes (range 3-19 minutes) if we exclude two interruptions of 1h40min between lines 6 and 7 and 1h46 min between lines 45 and 46. These longer breaks occurred at the end of the concentrations of belugas observed on the photographs. The downstream visual survey on 28 August started on line 29 adjacent to the photographic area and was started 5h30minutes before the closest photographic transect was completed.

FILM READING

A total of 1089 frames were read by both readers. A total of 152 belugas were counted by reader 1 and 149 by reader 2, but differences in interpretation actually occurred for 26 frames. After interpretation by the third reader and subsequent discussions, duplicates were removed and 154 images were accepted as belugas. No beluga was counted on the lines at the end of the surveyed area, with zero counts on the 6 lines at the downstream end and 11 lines at the upstream end (Figure 4, Table 1). Achieved overlap between adjacent frames was 17%, ranging from 14% to 18% between adjacent frames. Glare varied throughout the day with a mean glare correction of 2.9% (*i.e.* observed in the non-overlap portion of each frame). The proportion of a transect missed because of glare was on average 3.8% (range 0–9.8%) over all transects, and also averaged 4.7% (range 0.1 – 8.4%) on transects where beluga were seen (Table 1). This resulted in a reflection-corrected count of 161 belugas.

From equations 1 and 7, 50.6% of the Estuary was photographed. Applying the corresponding 1.976 expansion factor to the reflection-corrected count resulted in an estimated 319 (SE = 44) beluga present at the surface during the survey (Table 2). Ten belugas were seen at the mouth of the Saguenay River, near Tadoussac. The addition of these 10 animals to the photographic estimate, resulted in an estimated surface index of 329 (SE = 44) beluga whales in 2009. Applying the correction factor for availability of 2.09 based on the proportion of time of 0.478 (SE=0.0625, df=71) that St. Lawrence beluga have been estimated to be visible from an hovering aircraft to the 319 estimate of the systematic survey before adding the Saguenay fjord count provided an abundance index of 676 (SE=105, 95% CI: 490-906; Table 2, Figure 5).

The photographic surveys also provide information on population composition. Small animals were classified as calves if they were detected swimming alongside a large animal and were equal or less than half the body length of the adjacent animal. This category included newborn calves as well as yearlings still accompanied by a female. The final number of calves was 13 in 2009, for a proportion of calves of 8.4% (Table 2). Since the 1997 survey there has been a decline of the proportion of calves among the photographed animals. Between 1988 and 1997, calves comprised 15.1% to 17.8% of the photographed animals, but this proportion declined to a range of 3.2% to 8.4% in the 2000 to 2008 surveys (Table 2).

The 1988 survey was done over two strata, one upstream stratum extending from the Îles aux Loups Marins to Les Escoumins estimated at 3,189 km^2 and one downstream stratum extending from Les Escoumins to Pointe-des-Monts, which was estimated at 9,038 km^2 (Figure 2). As done by Kingsley and Hammill (1991), we divided the strata in the middle of the transect which was at the junction of the two strata and allocated half the count (five animals) and half the area of this transect to each stratum. A total of 149.5 belugas were counted in the upstream stratum and 2.5 belugas were counted in the downstream stratum. The width of the photographs at the surface of the water was 1.365 km and the total length of the transects was 882.8 km in the upstream stratum and 786.6 km in the downstream stratum. Including these values in equation [10] provided abundance indices of 396 (SE = 71, 95% CI: 279-562) for the upstream stratum and 21 (SE = 34; 95% CI: 2-194) for the downstream stratum. The overall abundance index at the surface for the Estuary was 417 (SE = 79, 95% CI: 293-607). The Saguenay fjord was not covered the day the survey was flown, but a count of 22 was added based on the average proportion of belugas detected in the Saguenay River (4.95%) during 8 aerial surveys that covered both the Estuary and the Saguenay from 1988 to 1992 (Michaud 1993). Applying the 2.09 correction factor for diving animals to the 417 surface index of the Estuary and adding 22 animals for the Saguenay, provided an abundance index in 1988 of 893 (SE = 177, 95% CI: 751-1,062; Table 2).

VISUAL SURVEYS

From 2001 to 2009, 28 visual line transect surveys of the Estuary between Rimouski and Île-aux-Coudres were completed between the end of July and early September (2001, n=1; 2003, n=5; 2005, n=14; 2007, n=1; 2008, n=1; 2009, n=6). Seventeen of the 28 surveys completed the systematic lines in the Estuary in a single flight starting from the downstream end to the upstream end. After refueling a second flight was done to cover the Saguenay river fjord. In 2003, 2007 and on August 20 and 23 in 2009, the surveys were interrupted for about an hour (45 to 71 minutes recorded) in the Saint-Irénée area for refueling, about 7 to 10 lines short of the upstream end. The second flights completed the remaining lines before the survey of the Saguenay fjord. In 2008, one of the two planes stopped twice, once in Rivière-du-Loup and once in Saint-Irénée. On 4 September 2009, to wait for fog to lift over the Estuary, the flights were done in opposite directions, starting with the Saguenay fjord and seven lines in the upstream portion before refueling in Saint-Irénée. GPS tracking was not used in 2001 and the GPS failed for the whole survey on one plane in 2008. On these two occasions, the target altitude was used and the position of the plane was interpolated from the time we flew over the position of the planned transect start and end points. The 2007 and 2008 surveys were planned so that the two planes would fly the same lines within a short period to assess g(0) but the results are not presented here. In 2007, the second plane followed the first plane by 0.5 to 7.8 km (9 sec to 2.4 min flying time). In 2008, logistical problems forced one plane to stop twice and only half the lines were completed with the planes within a short distance from each other. The spacing between lines was always 7.4 km (4 NM) for visual surveys, but the area covered extended over the years to consider the possible extension of summer range of belugas and therefore 24 lines were flown in 2001 while 28 were flown in 2009 (Table 3). Results of the 2003, 2005 and 2007 surveys have already been presented (Gosselin et al. 2007; Lawson and Gosselin 2009), but they have been reanalysed here, using covariates instead of post-stratification in the estimation of the detection function.

An average of 86 groups (193 individuals), with a wide range of 23 to 184 groups (45 to 426 individuals) were detected during the 28 surveys of the Estuary (Table 3, Figure 6). On 12 of the 28 surveys, groups were detected for which no distance measurements were recorded and therefore were not retained for the analyses. These groups without distance measurements occurred on 12 of the 28 surveys and their numbers ranged from 1 to 10 groups or 1 to 61 individuals (Table 3). In the most important cases this represented a reduction in the number of individuals observed of 19.6% on 24 August 2009, 11.9% on 10 September 2005, 10.3% on 17 July 2008 and 9.4% on 4 September 2009 (Table 3). Detection of belugas could be affected by their reaction to the plane and since 2007, observers were instructed to record reaction to plane, *i.e.* a change in behaviour estimated to be related to approaching plane. Reactions to plane were noted among 14 out of 203 groups (7%) in 2007, 5 out of 380 groups (1%) in 2009 and none of the 139 groups in 2008. The 2007 survey was flown lower (198 m, 650 feet) than the surveys in 2008 and 2009. This is likely a minimum number of reacting animals as reaction may not have been noted when high densities of animals were encountered.

TRUNCATION

All visual surveys used Cessna 337 equipped with bubble windows, but the depth of the bubble windows, the position or height of the seats relative to the window and the members of the team of observers changed between years which could influence the detection of belugas. The examination of the distributions of the perpendicular distances for each year and each altitude in 2005, showed that left truncation varied among years (Table 4). However, within years, the plane and team remained constant and consequently there was no logical reason to believe that detection near the track line might have changed. To avoid reducing the number of sightings which would have resulted from post-stratification, we chose to examine the influence of covariates instead and a different detection function was estimated separately for each year and in 2005 for each altitude. For most years, there was no evident distant outlier and there were sightings at almost every degree on the inclinometer almost all the way to the most distant point. Tests with right truncation reduced the number of sightings for the estimation of group size and encounter rate, but did not result in significant improvements in precision of the estimated effective strip width. Therefore, we did not use right truncation. An average of 2.4% (range 0 to 9.4%) of the sightings were discarded from the left truncation each year leaving 84 to 653 each year for the estimation of the detection function which is more than the minimum of 60-80 recommended by Buckland et al (2001) to produce a reliable estimate of the detection function (Table 4).

EFFECTIVE STRIP HALF WIDTH

We selected the covariates to incorporate in the model of the detection function using the method of Marques and Buckland (2003). The first step is to select the key function between the half-normal and the hazard-rate using AIC. There is usually less variability in the estimated effective strip width from different models when there is an evident shoulder in the distribution of the perpendicular distances and this is shown by a plateau of maximum probability of detection near the track line. The hazard-rate model tends to be selected more often when there is a sharp shoulder in the distribution of perpendicular distances. The hazard-rate model was selected over the half-normal model five times out of seven (Table 5, Figure 7). The two key functions had similar AIC (delta AIC < 2) during two years (2008 and 2009). In 2008, the key functions remained the best models after the evaluation of covariates and model averaging were used to estimate density.

Over all years, the selected models provided ESW that were on average within 4.6% (range:0 - 13.7%) of the key functions and retained models (Table 5). Although the estimated ESW was not used in the selection of the model it shows the extent of the possible effect of the choice of the model on the final abundance estimate. Covariates were selected over the key function on three occasions and provided ESW that were all lower than the estimated ESW of the best key function by 0.7% in 2003, 9.0% in 2007 and 12.1% in 2009 (Table 5). Therefore, using covariates in the model selection process increased the density and abundance estimates for those three years. The estimated ESW varied from 926 m to 1,596 m for an average of 1,179m with a CV of 0.18 indicating how detection of belugas varied among surveys, although it is accounted for in the estimation of density and abundance.

GROUP SIZE

The expected group size was estimated using the size bias regression method (ln of group size against the detection function value (ln(*s*) vs *g(x), p*<0.15, Buckland et al 2001). On 8 of 28 surveys, the regression estimate was used instead of the average group size. On these occasions, the expected group size was on average 0.8 times the average group size. The expected group size varied from 1.40 to 3.05 over the 28 surveys showing how variable the clumping at the individual scale can vary between surveys.

ENCOUNTER RATE

The total length of the surveys in the Estuary stratum (SLE stratum) between Rimouski and Ile-aux-Coudres increased by 27% from the 639 km flown in the 2001 survey to the maximum length of 804 km flown in 2009. But the distribution of recorded belugas remained within the central portion of the surveyed area with few sightings on lines at the extremities of the survey design. Therefore, the surveys captured most of the high summer density areas of the SLE belugas and the addition of several transects in consideration of an extended distribution did not introduce a bias in the abundance estimate. There is however one exception in 2007, when 17 groups of belugas (27 individuals) were detected in the Estuary downstream of Rimouski on 22 July and two belugas in the Gulf of St. Lawrence on the 25 July and 2 August (Figure 8). The variance of encounter rate reflects the variation in number of groups between adjacent transects when estimated empirically. High variance means that there was greater differences between adjacent transects and provides insight into the distribution or clumping at the scale of transects along the Estuary.

SAGUENAY COUNTS

The Saguenay count, considered as a total count, can represent up to 14% of the surface abundance index or up to 7% after we apply the 2.09 correction factor for availability. Although the Saguenay counts were higher in 2007, the number in the Saguenay can change from day to day as was seen in August 2005 (Table 6).

ABUNDANCE INDICES

The daily surface abundance indices in the Estuary between Rimouski and Île-aux-Coudres before correcting for diving animals and adding in the Saguenay count varied from 183 to 871 (Table 6). Even within years the variation among abundance estimates was important, varying by up to 225% on consecutive days as seen on 4 September and 5 September 2009. Animals are either missed during the survey, are clumped between lines or they move out of the area between Rimouski and Île-aux-Coudres. On 22 July 2007, 17 groups were detected downstream of Rimouski and west of Pointe-des-Monts (est stratum) and resulted in an abundance index of 425 (SE=168), representing 24% of the 2007 abundance index. There was only one animal detected in the downstream stratum (est09) in 2009, on 25 August. This observation resulted in an abundance index of 26 (SE=27) for that day, and an average of 12 (SE=26) if we take into account the absence of sightings on the 28 August 2009. However, for most of the daily surveys, the majority of sightings are detected on lines in the center of the Estuary stratum recognized as the summer range of SLE beluga (Figure 6). When several visual line transect surveys are conducted within a year, the yearly averages result in lower CVs (2003=14, 2005=9, 2009=14) than the daily CVs (Range of CVs for 2003: 24-36, 2005: 22-35 and 2009: 29-47; Table 6).

Changes in abundance in SLE beluga based upon the photographic abundance indices from 1988 to 2003 showed no significant trend (Hammill et al. 2007). More recently, an evaluation of changes in abundance in the St. Lawrence beluga has been carried out using an age-structured Bayesian population model that fitted the photographic survey time series (Mosnier et al. 2014). However, the abundances indices time series from the visual surveys was not fitted in this model. The visual survey abundance indices suggest a slight decline in abundance since 2001, but the linear regression of the daily surveys from year 2001 to 2009 showed a poor fit (adjusted $R^2 = 0.01$) and the slope was not significantly different from zero ($p = 0.27$, df=26, Figure 9).

DISCUSSION

The St. Lawrence beluga population, which was reduced by hunting that continued until the 1970’s, has not recovered since the end of the hunt. Early attempts to evaluate abundance concluded that the population may have been as low as 350 animals in 1980 (Pippard 1985). Between the early 1980s and 1988 a series of abundance indices confirmed that numbers were low (e.g. Béland et al. 1987; Sergeant and Hoek 1988). Beginning in 1988, a series of systematic photographic surveys were flown, and the 2009 survey represents the eighth in this series of surveys that has been conducted using similar methods. Kingsley (1998) examined some of the early surveys that had been used to evaluate the status of this population, combined them with the systematic photo surveys conducted between 1988 and 1997 and concluded that the population was likely increasing. However, this analysis was questioned because it was based on surveys that had used very different methods and in some cases there was limited information available concerning survey effort (Michaud and Béland 2001). Following the 2000 and 2003 surveys it was concluded that the population was probably stable at about 1,100 individuals (Hammill et al. 2007). The 2003 estimate was the largest of the time series, but with the second largest coefficient of variation. However, the high estimate obtained from the photographic survey in that year also coincides with a very high estimate obtained from the visual surveys conducted in the same year, suggesting that beluga numbers in that year were indeed high (Table 7). This contrasts with the 2009 photographic survey which is the lowest of the time series. The overall change in abundance from the photographic surveys, suggests that there might have been a population increase in the 1990’s which continued until 2003, followed by a decline to 2009 (Figure 5). However as previously mentioned, the increase from 1988 to 2003 was not significant (Hammill et al. 2007). The visual line transect surveys time series is not as long as the photographic series, but whereas the 2003 estimate is the highest among the five surveys, the 2009 estimate is also the lowest (979 animals), suggesting a slight, but not significant, decline in abundance since 2001. Concurrent with this slight change in abundance there also appears to have been a decline in herd productivity as shown by the lower proportion of calves in the herd.

Trend analyses of abundance will be affected by possible biases in the time series. Although the photographic surveys have followed the same basic design since they were first initiated in 1988, the target overlap between successive frames was 0% in 1988 and 1990, 30% from 1992 to 2003 and 15% in 2009. This double coverage assumes that animals that were photographed twice were recognised as duplicates and are only considered once in the count. However, other animals that have been diving and invisible when the first photograph was taken became visible on the second photograph and were added to the count. A 30% overlap means that 43% of the area along each transect is being photographed twice, while the remaining 57% of the area covered by the photographs is only captured once on film. By reducing the overlap to 15%, the total amount of the area along each transect that is photographed twice is reduced to 17.6%. This reduced the chances of detecting surfacing whales. The achieved estimated overlap of 16.8% in 2009 resulted in an increase of 3.4% of the number of belugas detected on photographs, *i.e.* 5 belugas invisible on a first photograph appeared on the second, increasing the count from 149 to 154 belugas. This however, is based on a small number of sightings and further analyses of photographs from previous photographic surveys, and information on diving behaviour of belugas in the SLE, should be examined to properly estimate this bias. Correction for this bias, however, will result in higher photographic abundance indices for 1988, 1990 and 2009, which would make the increase from 1988 to 2003 even less and would reduce the decrease from 2003 to 2009.

One difficulty associated with photographic surveys is detecting all animals on the imagery. Analyses of harp seal imagery has shown that correction factors for missed white pups on white ice can be large, and need to be considered (Stenson et al. 2002). Missing animals is less likely to be a problem when counting white beluga on a darker background, but grey and dark coloured neonates will be difficult to detect. For the early beluga surveys, each reader read a set of photos, and then readings were combined to obtain a final estimate. Some re-reading of photographs from early surveys indicated that inter-reader variability could be significant, with some counts differing by up to 10%. Beginning in 2003, the two readers read all of the imagery, and all images are compared and discussed to resolve discrepancies. For example, in 2009, the first counts by the two readers were 152 and 149, but inconsistencies were identified on 26 frames. A third reading led to a final count of 154, indicating that reader bias may be small on the order of 3%. Therefore, we are confident that reader bias had limited impact on our estimation of trend in abundance from the photographic time series and even on the estimation of proportion of calves.

The St. Lawrence beluga occupies a relatively small area making them easy to survey. To evaluate abundance, we have developed and maintained a time series of eight photographic surveys since 1988 to which 28 visual line transect surveys have been added since 2001. Each method has advantages as well as disadvantages. Advantages to photographic surveys include the fact that they provide a permanent record that can be re-analyzed if questions arise about the photograph counts and the imagery provides opportunities to collect other information such as the numbers of neonates in the population. However, photographs also require a considerable time commitment to examine the imagery, and they are expensive to fly requiring expensive equipment and trained operators in the case of large format cameras. In strip transect surveys, if animals are randomly distributed, then survey precision is expected to improve with the increase of the proportion of the area covered by the survey. In the St. Lawrence, the survey fraction at about 50% is already very high. In spite of the very high survey fraction, the coefficients of variation around the survey estimates are much higher than expected (14 to 50%). The survey fraction could only be increased slightly within the actual design with 2 NM spacing because of the potential for animals to move between lines while the surveys are being flown. To minimize this, the survey design has included two aircraft since 1988 to reduce time delays between adjacent lines. However, belugas are very social, and often travel in groups of variable size (Colbeck et al. 2013). Factors affecting group size are poorly understood, but their detection will have an important impact not only on the abundance estimate, but on survey precision as well. The challenge in estimating abundance of a population, particularly a small one, with an aggregated (clumped) distribution has been recognized in a number of marine mammal populations and some attempt has been made to take this clustering into account including repeating surveys (Gosselin et al. 2007; Kingsley et al. 1985; Smith et al. 1985). Visual surveys are less expensive to fly than photographic surveys meaning that several surveys can be completed for the cost of a single photographic survey. By combining the results of repeated survey improvements in survey precision can be achieved (Table 6). Therefore, repeating surveys is one approach to improve confidence in abundance estimate for clustered beluga populations.

There are other sources of uncertainty associated with the abundances indices of SLE beluga. One is the ability of animals to move in and out of the Estuary stratum recognised as the summer range (stratum SLE). In 2003, 2007 and 2009, we extended the area covered by the survey to minimize this possibility, but if animals move beyond the survey boundaries then survey estimates will be negatively biased. A better understanding of summer movements of belugas would be useful to evaluate this bias. The VHF tracking of 44 individuals tagged in the center of the recognised summer range from 2001 to 2005, and the visual tracking of 465 herds from 1989 to 2005, did not find movements outside of the recognised summer range (Lemieux-Lefebvre 2009). Therefore, there is no indication of movements outside of the summer range at a magnitude that could support changes in abundance in the order of 225% as observed between 4 and 5 September 2009. However, nineteen groups (29 individuals) were detected outside of the recognised summer range in July and August 2007 (Figure 8). Of these, 17 groups were detected between Rimouski and Pointe-des-Monts on 22 July which is roughly a month earlier than when photographic surveys have been conducted. Only one animal was detected during surveys flown on the 25 and 28 August 2009 suggesting few animals were outside the recognised summer area when the photographic survey was conducted that year. Maintaining coverage outside the recognised summer range during surveys and a better understanding of beluga movements in summer are two ways to evaluate this potential bias.

Another source of uncertainty related to beluga surveys is the variability associated with the correction factor applied to correct for animals under the water and non-visible to observers in the plane overhead. In the downstream portion of the study area, the water is quite clear and animals are visible to considerable depth, whereas upstream of the Saguenay River, there is much more sediment discharge and animals are much less visible below the surface. Kingsley and Gauthier (2002) examined changes in detectability throughout the recognised summer range of beluga, but more information on diving behaviour will be necessary to further improve this correction factor for photographic surveys and to adapt it to visual line transect surveys.

Trend analysis using the visual line transect surveys could also be influenced by the approach used to estimate the detection function and the effective strip width. The visual surveys in 2003 were flown to determine if visual surveys could produce results comparable to those obtained from photographic surveys, while those flown in 2005 examined the effects of flying at different altitudes on survey estimates for belugas. Results from these surveys presented here differ from those presented in Gosselin et al. (2007). In the 2007 analysis, the detection function was estimated following post-stratification, while in this study, covariates were used to consider the possible heterogeneity between days and we utilized the information from all surveys for a given year to estimate the daily detection function. When covariates were included in the estimation of the overall detection function, the stratum values were used to estimate the probability of detection on each daily survey where the three parameters were: the detection function, the expected group size and the encounter rate. A third approach to estimate the detection function is to assume that detection conditions did not change between days, and to fit a single detection function on the combined sighting of each year, and then daily variation in density would only vary according to the expected group size and encounter rate. However when a low number of sightings are detected, the approach used will have an impact. Here we used the covariate approach as it used more information to estimate the detection function for days when the number of sightings was lower.

Comparisons between photographic and visual surveys are difficult, in part because the clumped distribution of this small population of odontocetes means that the detection of groups in the survey can have a significant impact on survey estimates, as reflected in the variation between daily estimates in given years. In both approaches we have attempted to correct for availability bias by correcting survey estimates for animals not at the surface when the aircraft passed. However, the 2.09 correction factor used was developed for photographic surveys in the St. Lawrence and was based on the proportion of time belugas in the St. Lawrence remained in view of observers in hovering aircraft (0.478, CV 0.13; Kingsley and Gauthier 2002). This value is similar to the proportion of time belugas remained within 5m of the surface used for availability correction for belugas in North Water polynya surveys (0.43, CV=0.09, Heide-Jorgensen et al. 2013). This correction factor (2.09 = 1/0.478) falls within the range of corrections (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). More detailed information on diving behavior of belugas in the SLE will be required to further improve this correction factor to account for the fact that detection from visual line transect survey is not instantaneous, which will represent a lower correction for availability. Also, our visual estimates were not corrected for perception bias and consequently our final estimates will underestimate abundance by some unknown amount compared to the photographic surveys. However, perception bias corrections for belugas in North Water Polynya and in Cook Inlet were small, ranging from 1.015 to 1.087 (Heide-Jorgensen et al. 2013, Hobbs et al. 2000). Even though the correction may be small, adequate correction for perception bias will require the use of double platform in future surveys.

This study presented results from two series of aerial surveys conducted since the late 1980s. Overall, the surveys suggest that the population has been relatively stable over that time, with some indications of a slight increase up until 2003, followed by a slight decline since then (Figure 5; Mosnier et al. 2014). Simple linear analyses of these trends showed no significant change, although, there has been a decline in the proportion of calves in belugas detected in photographic surveys since the late 1990s. Other indices also point to changes occurring in the population since the late 1990s, including an increase in exposure to disturbance, changes in mortality patterns possibly associated with contaminants or toxic phytoplankton blooms and changes in trophic structure due either to natural variation in ecosystem conditions or resulting from longer term changes driven by climate change (Lair et al. 2014; Lebeuf et al. 2013; Lesage 2014; Ménard et al. 2014; Plourde et al. 2014; Scarratt et al. 2014). In recent years, there has been an increase in numbers of calves found stranded on the beach as well as additional unusual mortality which may further affect population trends (Lesage et al. 2014).

The aerial survey index is the only tool that has been used to estimate beluga abundance in the SLE. Further work is needed to identify ways of improving survey precision or at least to take into account, more formally, the variability associated with changes in clustering of animals. Furthermore, the photographic time series will need to take into account changes in technology as companies move from film to digital imagery. Effort should be directed at producing adequate correction factors to account for possible biases between photographic and visual line transect surveys to allow a better integration of both time series. The possible decrease in abundance in recent years is mainly based on the 2009 estimates and given the variability around estimates new surveys should be added soon to the time series to assess trends in this population.

ACKNOWLEDGEMENTS

Véronique Lesage provided support for the analyses and was involved in interpretation of the results. Cessna 337 were provided by Hicks and Lawrence in 2001, 2003 and 2005, and by SASAIR in 2007, 2008 and 2009. The Bell 206 long-ranger was provided by the Canadian Coast Guard for the Saguenay survey in 2001. Catherine Bajzak read the photos and highlighted the problem with the orientation of the transects in the 1988 photographic survey. Pierre Rivard also read the films in 2009. Visual survey observers that also helped with logistics were Pierre Carter, Virginie Chadenet, Thomas Doniol-Valcroze, Richard Labbé, Yves Morin, Samuel Turgeon. These surveys were funded by the Regional Fund and Interdepartmental Recovery Fund for Species at Risk, by large survey Fund from the Ecosystems Science Regional Initiative and by the Centre of Expertise on Marine Mammals (CEMAM).

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Table 1. Number of belugas counted on films on 28 August 2009 after removing the duplicates on overlap of adjacent photographs along transects. The glare corrected counts (n_{rj}) consider the proportion of a transect hidden by sun glare that was in areas outside of adjacent frame overlap. There were 57 transect lines flown, but only lines containing belugas are presented.

Line number	Count (n_j)	Glare %	Glare corrected count (n_{rj})
7	2	6.4	2.14
9	1	6.0	1.06
16	2	3.3	2.07
19	1	5.5	1.06
20	17	5.2	17.93
21	15	4.2	15.66
22	5	8.4	5.46
24	9	4.6	9.43
27	7	1.7	7.12
28	11	3.2	11.36
29	4	1.5	4.06
30	21	4.6	22.00
31	4	5.3	4.22
32	4	4.8	4.20
33	5	4.3	5.23
34	5	4.7	5.25
35	1	8.0	1.09
37	3	7.3	3.24
39	15	6.4	16.03
40	7	3.9	7.28
41	2	3.2	2.07
43	7	5.2	7.39
46	6	0.1	6.01
sum:	154		161.35

Table 2. Photographic survey abundance indices corrected for diving animals by multiplying the surface Estuary estimate by 2.09 (SE = 0.16; Kingsley and Gauthier 2002) before adding the Saguenay River counts. Surface abundance indices from 1990 to 2003 are the published indices (Kingsley and Hammill 1991, Kingsley 1993, 1996, 1999). The Saguenay was not covered in 1988 and 1990 and the number are based on the average percentage of 4.95% observed in the Saguenay during 8 complete aerial surveys from 1988 to 1992 (Michaud 1993). The 1988 surface index was corrected for realized overlapping of two pairs of planned survey lines. The proportion of calves, defined as animals equal or shorter than half the body length of an adjacent animal, is also provided and was estimated by re-analyses of the archived films by a 2009 reader.

Year	Surface abundance index in Estuary	Saguenay count	Corrected estimate	SE	Proportion of calves
1988	417	22	893	177	
1990	527	28	1129	567	0.168 (25/149)
1992	454	3	952	149	0.163 (37/227)
1995	568	52	1239	217	0.151 (43/284)
1997	575	20	1222	190	0.178 (51/287)
2000	453	6	953	134	0.078 (17/219)
2003	630	2	1319	263	0.032 (10/311)
2009	319	10	676	105	0.084 (13/154)

Table 3. Description of the survey design, the effort and number of groups and individual belugas detected during 28 line transect surveys of the St. Lawrence Estuary (SLE) and other areas in the eastern marine Estuary (est), the southern (g) and northeastern (esq) Gulf of St. Lawrence from late July to early September from 2001 to 2009.

Date (area other than SLE)	Stratum area (km^2)	Number of lines	Total track length (km)	Groups	Individuals	Groups (Individuals) without distance
2001-08-12	4531	24	639	88	177	
2003-08-20	5377	27	718	51	141	
2003-08-25	5377	26	686	80	179	1 (1)
2003-08-26	5377	27	718	77	195	4 (15)
2003-09-02	5377	26	686	99	309	3 (11)
2003-09-06	5377	27	718	43	130	3 (8)
2005-08-12	5377	27	734	105	245	
2005-08-14	5377	27	734	90	199	1 (10)
2005-08-15	5377	27	718	129	282	1 (5)
2005-08-18	5377	27	718	57	160	
2005-08-19	5377	27	734	121	260	
2005-08-25	5377	27	734	78	227	1 (1)
2005-08-26	5377	27	718	76	224	
2005-08-27	5377	27	718	98	249	1 (2)
2005-09-04	5377	27	734	70	98	
2005-09-05	5377	27	734	125	260	
2005-09-06	5377	27	718	81	118	
2005-09-08	5377	27	718	104	175	
2005-09-09	5377	27	734	98	175	
2005-09-10	5377	27	734	65	104	3 (14)

Table 3 cont'd.

Date (area other than SLE)	Stratum area (km^2)	Number of lines	Total track length (km)	Groups	Individuals	Groups (Individuals) without distance
2007-07-21	5231	27	1438 (2x734)	184	426	
2007-07-22 (est)	6840	7	365	17	27	
2007-07-25,26 (g)	72120	19	3883	1	1	
2007-08-02,06,07 (esq)	42,063	26	2244	1	1	
2008-07-17	5377	27	1437 (2x734)	140	350	10 (40)
2009-08-20	5787	28	788	66	130	
2009-08-23	5787	28	801	55	165	
2009-08-24	5787	28	804	93	250	4 (61)
2009-08-25 (est)	6265	16	783	1	1	
2009-08-28 (est)	6265	16	849	0	0	
2009-09-01	5787	28	785	23	45	
2009-09-04	5787	28	794	65	144	9 (15)
2009-09-05	5787	28	784	76	175	

Table 4. Number of groups with perpendicular distance measurements that were retained for line transect analysis and perpendicular distance from the track line that was used to truncate (left truncation) the area of reduced probability of detection under or close to the plane.

Year	Groups with distance	Left truncation (m)	Maximum perpendicular distance, *w* (m)	Groups retained after left truncation
2001	88	397	3204	84
2003	339	42	2906	339
2005-305m	635	129	4380	629
2005-457m	655	148	6587	653
2007	203	81	3476	203
2008	130	175	2207	127
2009	367	230	3093	336

Table 5. Model selection and inclusion of covariates following the stepwise procedure of Marques and Buckland (2003). Both key functions are shown first, followed by up to four models with covariates ordered by increasing AIC score. The model with lowest AIC (Delta AIC = 0) was selected unless indicated by asterisks as in case of model averaging.

Year Model	AIC	Delta AIC	Cramér-von Mises (cos) p	Effective Strip Width (m)	ESW cv
2001					
Hazard-rate(HR)	**1244.65**	**0.00**	**0.6**	**1126**	**0.09**
Half-normal(HN)	1247.20	2.55	0.7	1007	0.06
2003					
Half-normal(HN)	5030.31	2.03	0.10	1011	0.03
Hazard-rate(HR)	5032.87	4.59	0.50	978	0.06
HN+Beaufort	**5028.28**	**0.00**	**0.10**	**1003**	**0.04**
2005 - 305m					
Hazard-rate (HR)	**9610.39**	**0.00**	**0.5**	**1237**	**0.04**
Half-normal (HN)	9633.68	23.29	0.005	1282	0.02
2005 457m					
Hazard-rate (HR)	**10,141.64**	**0.00**	**0.5**	**1596**	**0.03**
Half-normal (HN)	10,149.75	8.11	0.15	1437	0.02
2007					
Half-normal (HN)	3136.37	24.76	0.15	1382	0.05
Hazard-rate (HR)	3141.15	29.54	0.8	1271	0.08
HN+Observer	**3111.61**	**0.00**	**0.9**	**1257**	**0.06**
HN+Observer+Visibility	3113.12	1.52	1.0	1245	0.06
HN+Observer+Beaufort	3113.32	1.71	0.9	1255	0.06
HN+Observer+Glare_int	3114.70	3.09	1.0	1245	0.06

Table 5 cont'd.

Year Model	AIC	Delta AIC	Cramér-von Mises (cos) p	Effective Strip Width (m)	ESW cv
2008					
Hazard-rate(HR)*	**1881.29**	**0.00**	**0.6**	**1048**	**0.07**
Half-normal (HN)*	**1881.85**	**0.56**	**0.9**	**1242**	**0.07**
2009					
Hazard-rate (HR)	4964.94	17.88	0.2	1053	0.05
Half-normal (HN)	4966.54	19.48	0.4	982	0.03
HN+Cloud percentage+Water color	**4947.06**	**0.00**	**0.8**	**926**	**0.05**
HN+Cloud percentage	4954.20	7.14	0.6	953	0.05
HN+Cloud percentage+Observer	4955.72	8.66	0.6	952	0.05
HN+Cloud percentage+Beaufort	4956.06	9.00	0.6	953	0.05

Table 6. Yearly, and daily, density and abundance indices of belugas in the St. Lawrence Estuary (SLE) from 28 line transect surveys conducted from late July to early September from 2001 to 2009. The density in the Estuary indices do not account for animals under water when the plane was overhead. The correction for availability of 2.09 (Kingsley and Gauthier 2002) was applied to the density in the Estuary before adding the Saguenay count to provide the abundance indices. The abundance indices are not corrected for animals missed by observers (perception bias). Estimated group size used in density estimation is obtained using the average ([a]) or the regression method ([r]), in which case average is provided in brackets. Coefficients of variation, in percent, are shown in parentheses. [b]Indicates that the estimates were obtained through bootstrap.

Year Survey	Effective strip width (m)	Estimated group size	Encounter rate (groups/km)	Density in the Estuary (Ind./km^2)	Surface abundance index in Estuary	Saguenay count	Abundance index	95% CI
2001								
2001-08-12	1126 (9)	2.00 (9)[a]	0.1315 (21)	0.1168 (25)	529	15	1122 (28)	555-1675
2003								
2003-08-20	998 (11)	2.84 (13)[a]	0.0798 (24)	0.1010 (30)	543	2	1138 (32)	614-2108
2003-08-25	918 (9)	2.34 (10)[a]	0.1152 (22)	0.1468 (25)	789	0	1651 (29)	953-2860
2003-08-26	1057 (9)	2.47 (11)[a]	0.1016 (15)	0.1186 (21)	637	0	1334 (24)	831-2141
2003-09-02	991 (8)	2.29 (9)[r] [3.1042]	0.1400 (26)	0.1620 (29)	871	7	1829 (32)	1001-3343
2003-09-06	1148 (12)	3.05 (21)[a]	0.0557 (25)	0.0740 (35)	398	25	857 (36)	430-1708
Bootstrap average weighted by effort for 2003:				**0.1224 (14)**	**658**	**7**	**1378 (14)**	**1039-1828**

Table 6 cont'd.

Year Survey	Effective strip width (m)	Estimated group size	Encounter rate (groups/km)	Density in the Estuary (Ind./km2)	Surface abundance index in Estuary	Saguenay count	Abundance index	95% CI
2005-305m								
2005-08-12	1237 (4)	1.99 (8)[r] [2.3333]	0.1431 (14)	0.1150 (17)	618	55	1349 (20)	907-2007
2005-08-15	"	2.00 (6)[r] [2.1641]	0.1782 (19)	0.1445 (21)	777	59	1684 (24)	1067-2657
2005-08-25	"	2.96 (24)[a]	0.1050 (22)	0.1257 (33)	676	24	1438 (35)	744-2780
2005-08-26	"	3.05 (19)[a]	0.1030 (16)	0.1272 (25)	684	35	1466 (28)	862-2494
2005-09-04	"	1.40 (7)[a]	0.0927 (31)	0.0524 (32)	282	28	617 (33)	323-1158
2005-09-06	"	1.45 (9)[a]	0.1114 (19)	0.0653 (21)	351	39	773 (24)	490-1219
2005-09-09	"	1.79 (9)[a]	0.1322 (22)	0.0959 (24)	516	18	1097 (27)	657-1831
Empirical average weighted by effort (2005-305m):				**0.1036 (13)**	**557**	**37**	**1203 (18)**	**850-1703**
2005-457								
2005-08-14	1596 (3)	2.12 (14)[a]	0.1213 (24)	0.0807 (27)	434	52	960 (29)	553-1668
2005-08-18	"	2.29 (11)[r] [2.8070]	0.0793 (18)	0.0569 (21)	306	0	640 (25)	396-1035

Table 6 cont'd.

Year **Survey**	Effective strip width (m)	Estimated group size	Encounter rate (groups/km)	Density in the Estuary (Ind./km2)	Surface abundance index in Estuary	Saguenay count	Abundance index	95% CI
2005-08-19	"	2.18 (11)[a]	0.1649 (22)	0.1124 (25)	604	12	1276 (28)	750-2170
2005-08-27	"	1.89 (8)[r] [2.5464]	0.1350 (22)	0.0802 (24)	431	73	976 (25)	602-1582
2005-09-05	"	2.08 (14)[a]	0.1704 (20)	0.1110 (25)	597	94	1343 (26)	810-2226
2005-09-08	"	1.68 (7)[a]	0.1434 (23)	0.0754 (24)	406	40	889 (26)	536-1473
2005-09-10	"	1.46 (8)[a]	0.0832 (17)	0.0380 (19)	204	19	447 (22)	291-686
Empirical average weighted by effort (2005-457m):				**0.0793 (13)**	**426**	**41**	**933 (18)**	**661-1318**
Empirical average weighted by effort for all of 2005:				**0.0915 (9)**	**492**	**39**	**1068 (9)**	**891-1280**
2007								
2007-07-21(SLE)	1257 (6)	2.32 (8)[a]	0.1280 (20)	0.1179 (22)	617	29	1319 (25)	810-2149
2007-07-22 (est)	1245 (20)	1.59 (13)[a]	0.0466 (28)	0.0297 (37)	203		425 (40)	192-942
2007-07-25_26 (g)	980	1	0.0003 (104)	0.0001 (135)	9		20 (135)	2-250
2007-08-02_07 (esq)	1944	1	0.0004 (105)	0.0001(124)	5		10 (124)	1-86
Bootstrap average weighted by stratum area for 2007:				**0.0065 (23)**	**822**	**29**	**1746 (23)**	**1047-2583**

Table 6 cont'd.

Year Survey	Effective strip width (m)	Estimated group size	Encounter rate (groups/km)	Density in the Estuary (Ind./km2)	Surface abundance index in Estuary	Saguenay count	Abundance index	95% CI
2008								
2008-07-17[b]	1051 (66)	2.38 (10)[b]	0.0889 (23)	0.0934 (26)	502	11	1053 (26)	636-1744
2009								
2009-08-20	859 (11)	1.97 (10)[a]	0.0799 (25)	0.0916 (29)	530	15	1124 (32)	615-2055
2009-08-23	831 (12)	2.21 (14)[r] [3.0400]	0.0624 (22)	0.0832 (29)	481	3	1010 (31)	553-1844
2009-08-24	1119 (9)	1.84 (8)[r] [2.0854]	0.1020 (27)	0.0838 (29)	485	11	1026 (32)	558-1885
2009-09-01	886 (18)	2.00 (11)[a]	0.0280 (43)	0.0317 (48)	183	22	405 (47)	169-972
2009-09-04	1069 (11)	1.77 (10)[r] [2.4038]	0.0655 (32)	0.0541 (36)	313	33	688 (36)	346-1367
2009-09-05	809 (11)	2.39 (12)[a]	0.0854 (21)	0.1260 (27)	729	20	1546 (29)	878-2722
Bootstrap average weighted by effort for 2009:				**0.0794 (14)**	**460**	**17**	**979 (14)**	**750-1277**

Table 7. Photographic and visual line transect survey abundance indices corrected for diving animals by multiplying the surface Estuary estimate by 2.09 (SE = 0.16; Kingsley and Gauthier 2002) before adding the Saguenay River counts. Surface abundance indices from 1990 to 2003 are the published indices (Kingsley and Hammill 1991, Kingsley 1993, 1996, 1999). The Saguenay was not covered in 1988 and 1990 and the number are based on the average percentage of 4.95% observed in the Saguenay during eight complete aerial surveys from 1988 to 1992 (Michaud 1993). The 1988 surface index was corrected for realized overlapping of two pairs of planned survey lines. The proportion of calves, defined as animals equal or shorter than half the body length of an adjacent animal, is also provided and was estimated by re-analyses of the archived films by a 2009 reader. The 2.09 correction factor was developed for the photographic surveys. Correction factors are still required to reduce the biases from the two survey methods to allow proper integration of the two time series.

Year	Method	Number of surveys	Surface abundance index in Estuary	Saguenay count	Corrected abundance index (CV)	95% CI
1988	Photo	1	417	22	893 (20)	751-1062
1990	Photo	1	527	28	1129 (50)	446-2860
1992	Photo	1	454	3	952 (16)	702-1291
1995	Photo	1	568	52	1239 (18)	881-1742
1997	Photo	1	575	20	1222 (16)	903-1654
2000	Photo	1	453	6	953 (14)	724-1254
2001	Visual	1	529	15	1122 (28)	555-1675
2003	Photo	1	630	2	1319 (20)	896-1942
2003	Visual	5	658	7	1378 (14)	1039-1828
2005	Visual	14	492	39	1068 (9)	891-1280
2007	Visual	1	822	29	1746 (23)	1047-2583
2008	Visual	1	502	11	1053 (26)	636-1744
2009	Photo	1	319	10	676 (16)	499-915
2009	Visual	6	460	17	979 (14)	750-1277

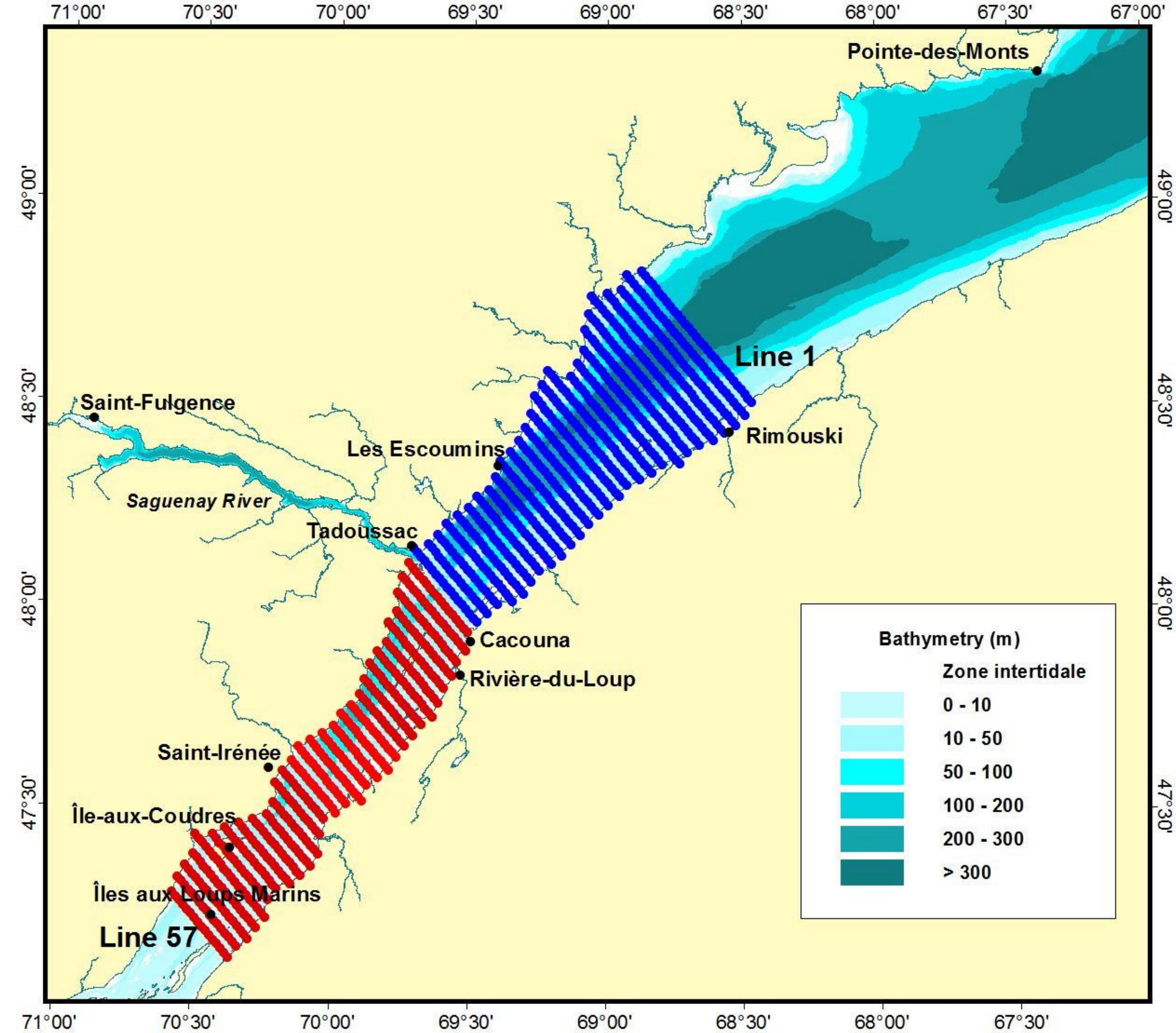


Figure 1. Design of the 2009 photographic survey to estimate abundance of St Lawrence beluga, showing the fifty-seven lines that were flown on 28 August. The lines flown by the two different planes are shown in red and blue.

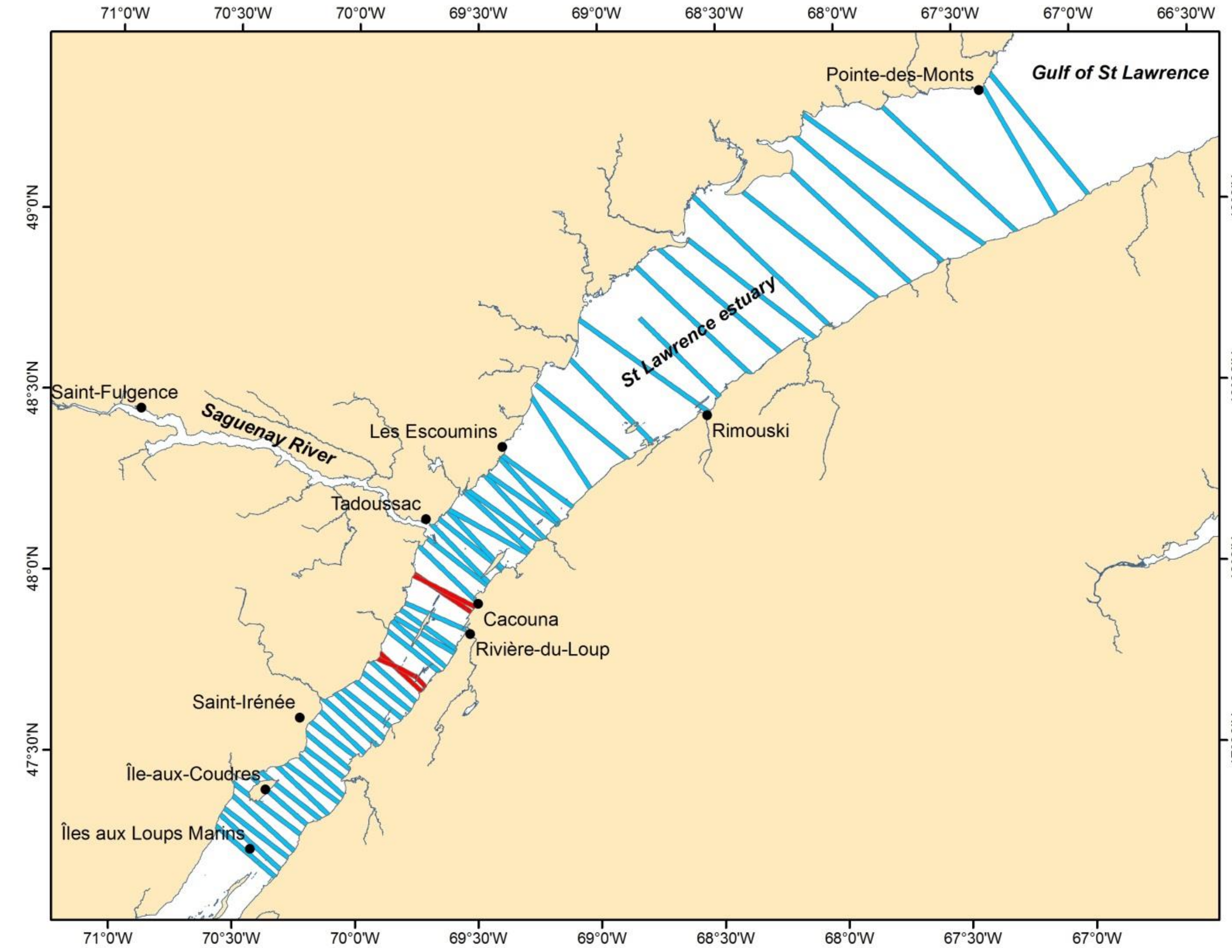


Figure 2. Position of the 57 lines surveyed during the photographic survey flown on 31 August 1988, showing in red two pairs of lines with extensive overlap that were considered as single lines in the revised analyses.

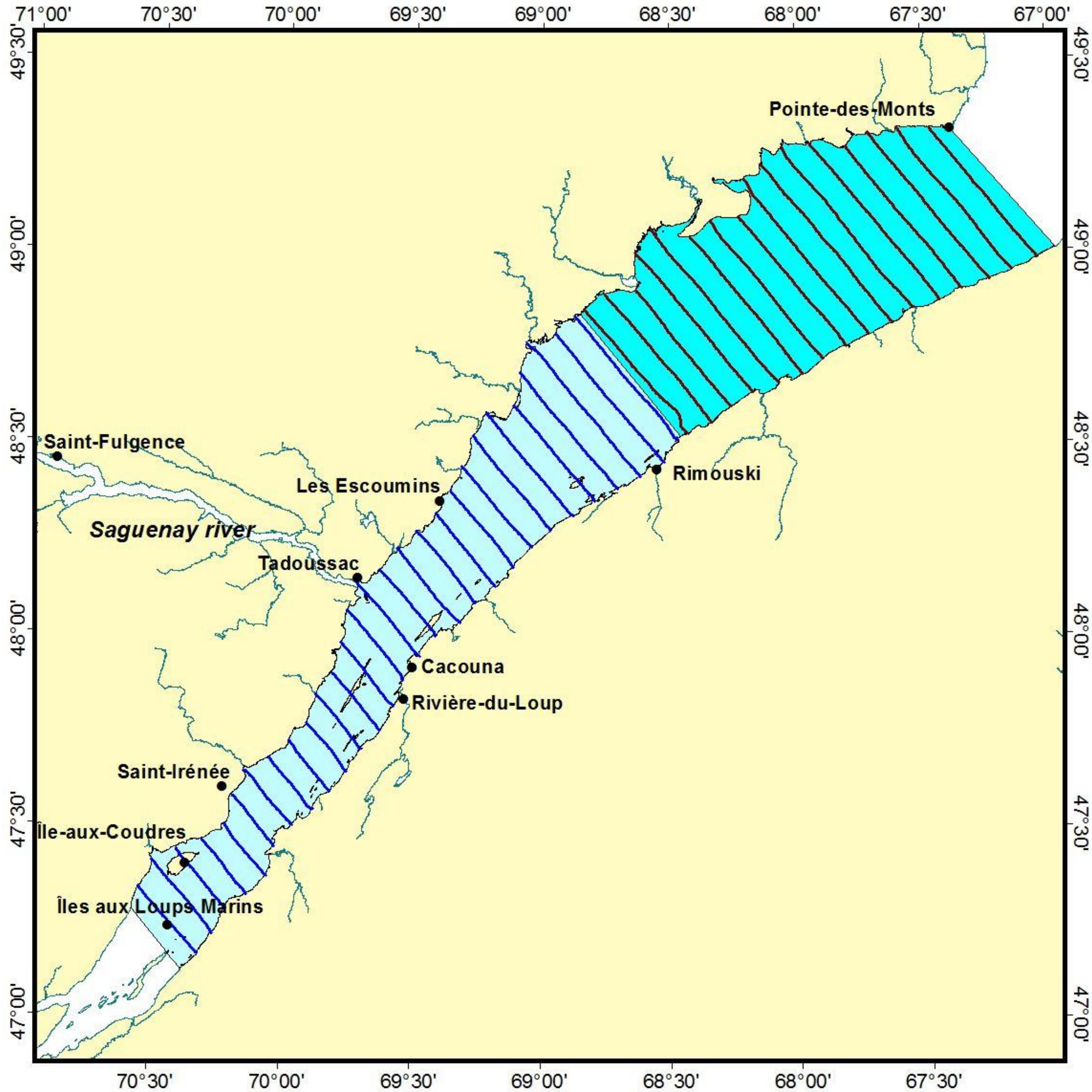


Figure 3. Systematic design of the 2009 visual line transect surveys, showing one set of 28 and 16 lines in the upstream and downstream strata respectively. The upstream stratum was surveyed six times and the downstream stratum was surveyed twice following systematic designs with 7.4 km (4 NM) spacing with random placement.

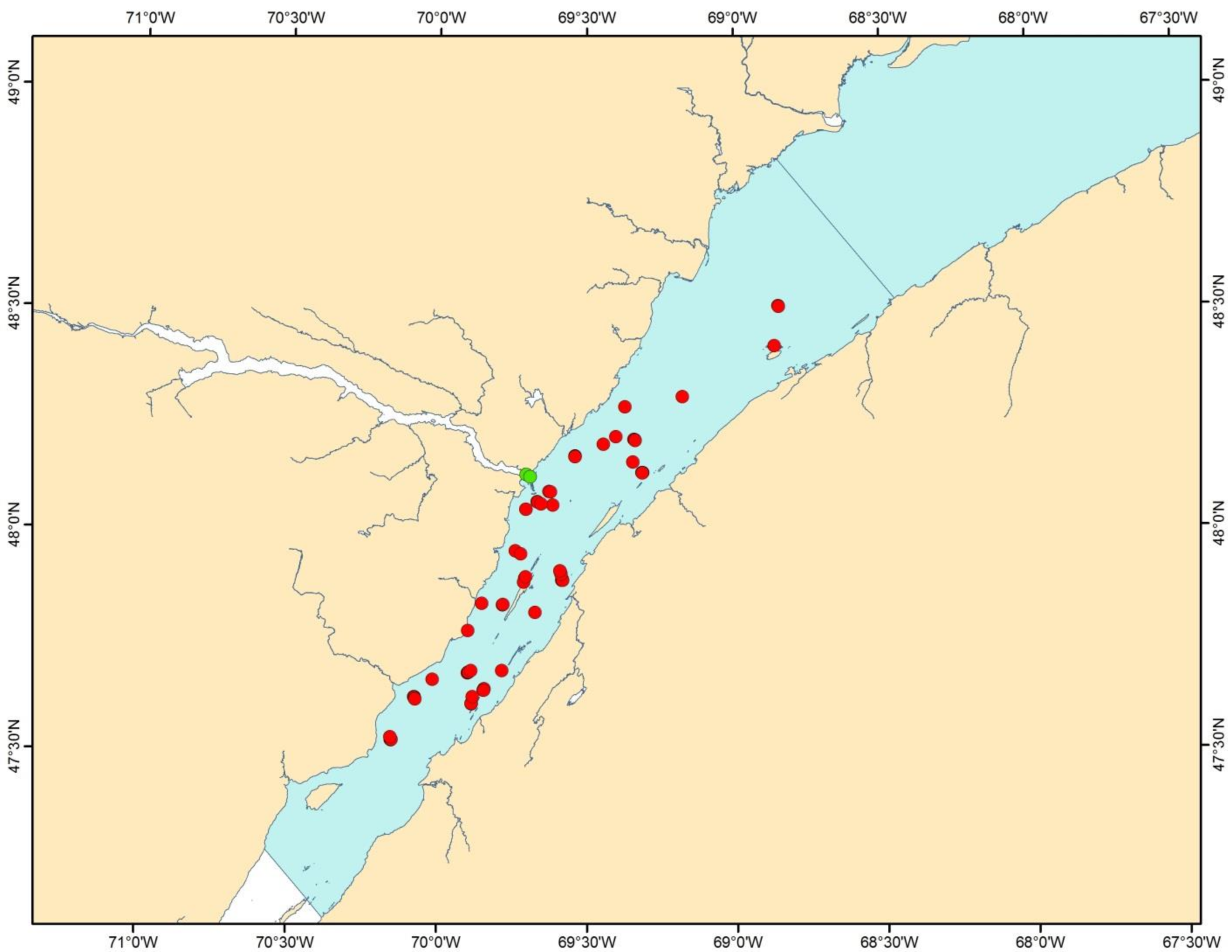


Figure 4. Distribution of belugas detected during the photographic aerial survey on 28 August 2009. Perpendicular lines to the axis of the Estuary show the limit of the area covered by the photographic survey.

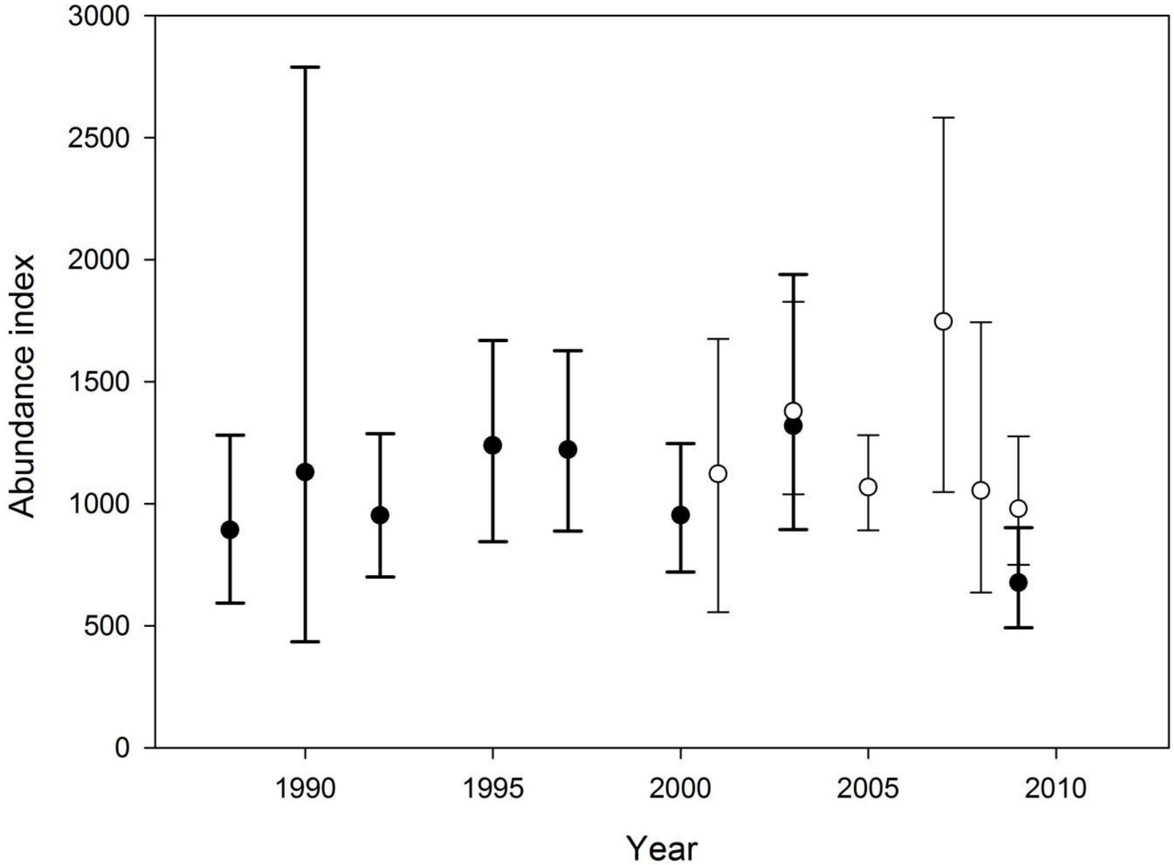


Figure 5. Abundance indices of St. Lawrence Estuary belugas from eight photographic surveys (close circles) and from the yearly average of 28 visual line transect surveys (open circles) from 1988 to 2009. The yearly average of visual line transect surveys were based on 1 survey in 2001, 5 in 2003, 14 in 2005, 1 in 2007, 1 in 2008 and 6 in 2009.

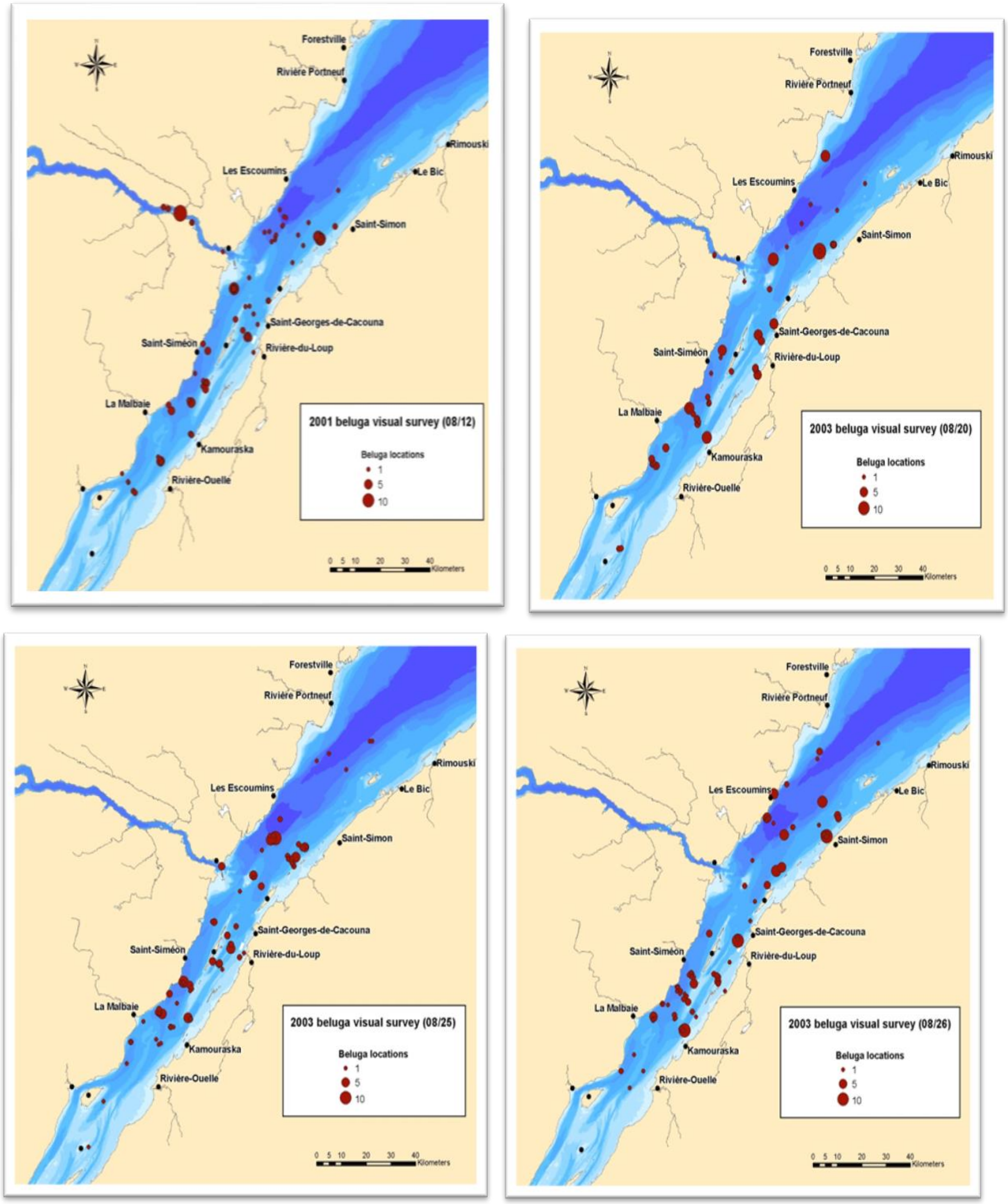


Figure 6. Locations and group sizes of beluga whales detected along transect lines flown on 12 August 2001 (top left), 20 August (top right), 25 August (bottom left) and 26 August 2003 (bottom right).

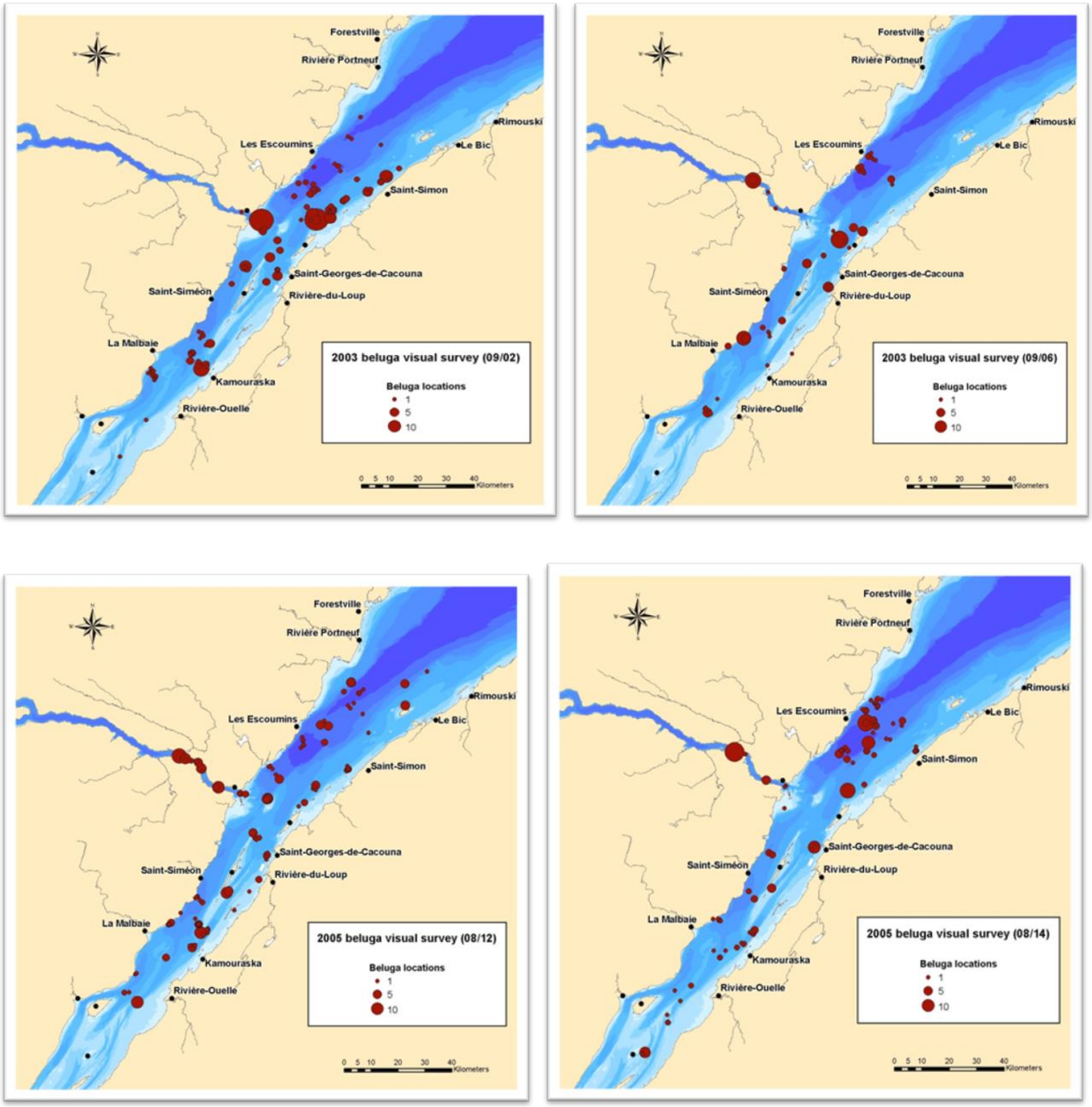


Figure 6 cont'd. Locations and group sizes of beluga whales detected along transect lines flown 2 September 2003 (top left), 6 September 2003 (top right), 12 August 2005 (bottom left) and 14 August 2005 (bottom right).

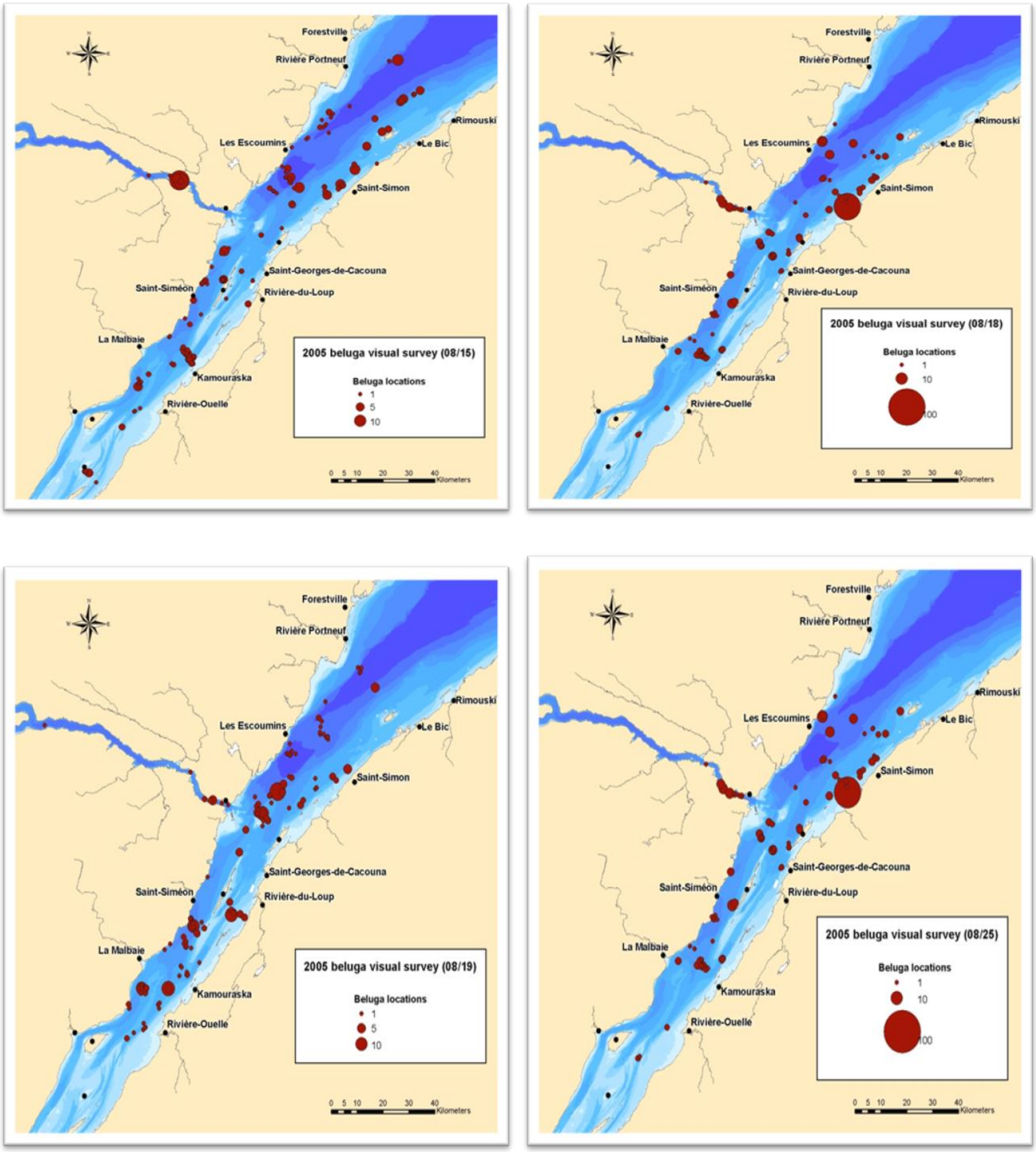


Figure 6 cont'd. Locations and group sizes of beluga whales detected along transect lines flown 15 August 2005 (top left), 18 August 2005 (top right), 19 August 2005 (bottom left) and 25 August 2005 (bottom right).

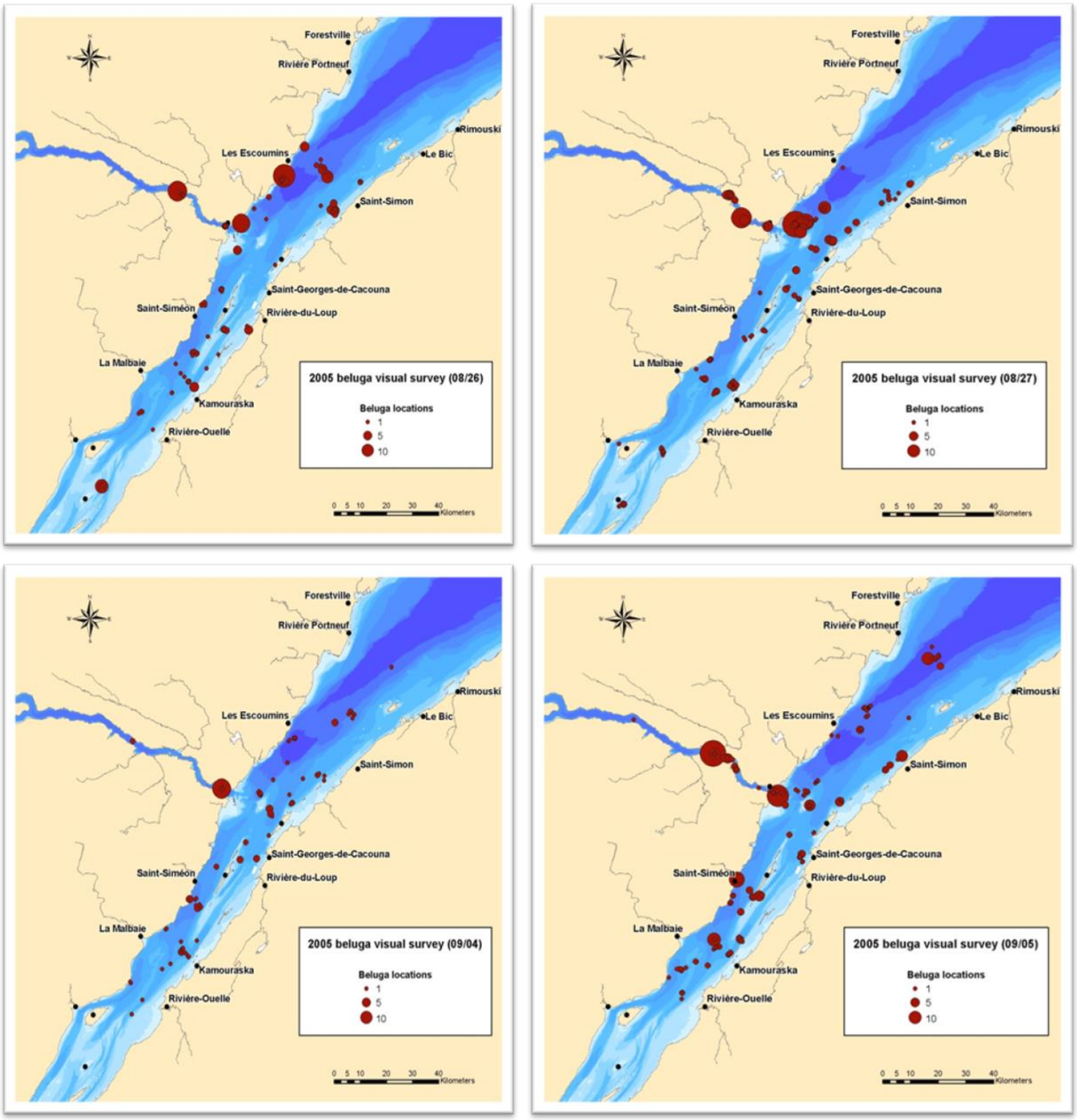


Figure 6 cont'd. Locations and group sizes of beluga whales detected along transect lines flown 26 August 2005 (top left), 27 August 2005 (top right), 4 September 2005 (bottom left) and 5 September 2005 (bottom right).

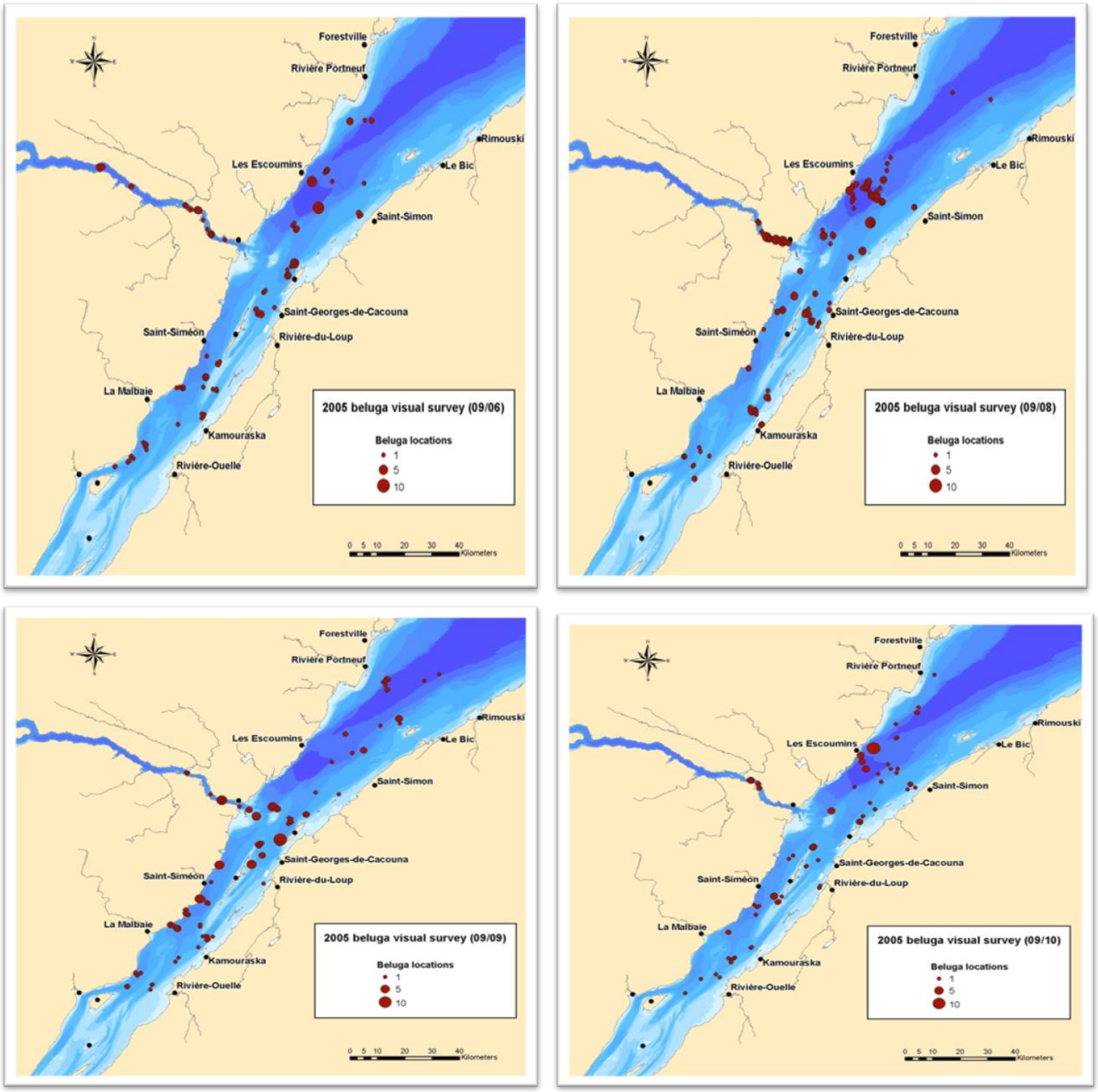


Figure 6 cont'd. Locations and group sizes of beluga whales detected along transect lines flown 6 September 2005 (top left), 8 September 2005 (top right), 9 September 2005 (bottom left) and 10 September 2005 (bottom right).

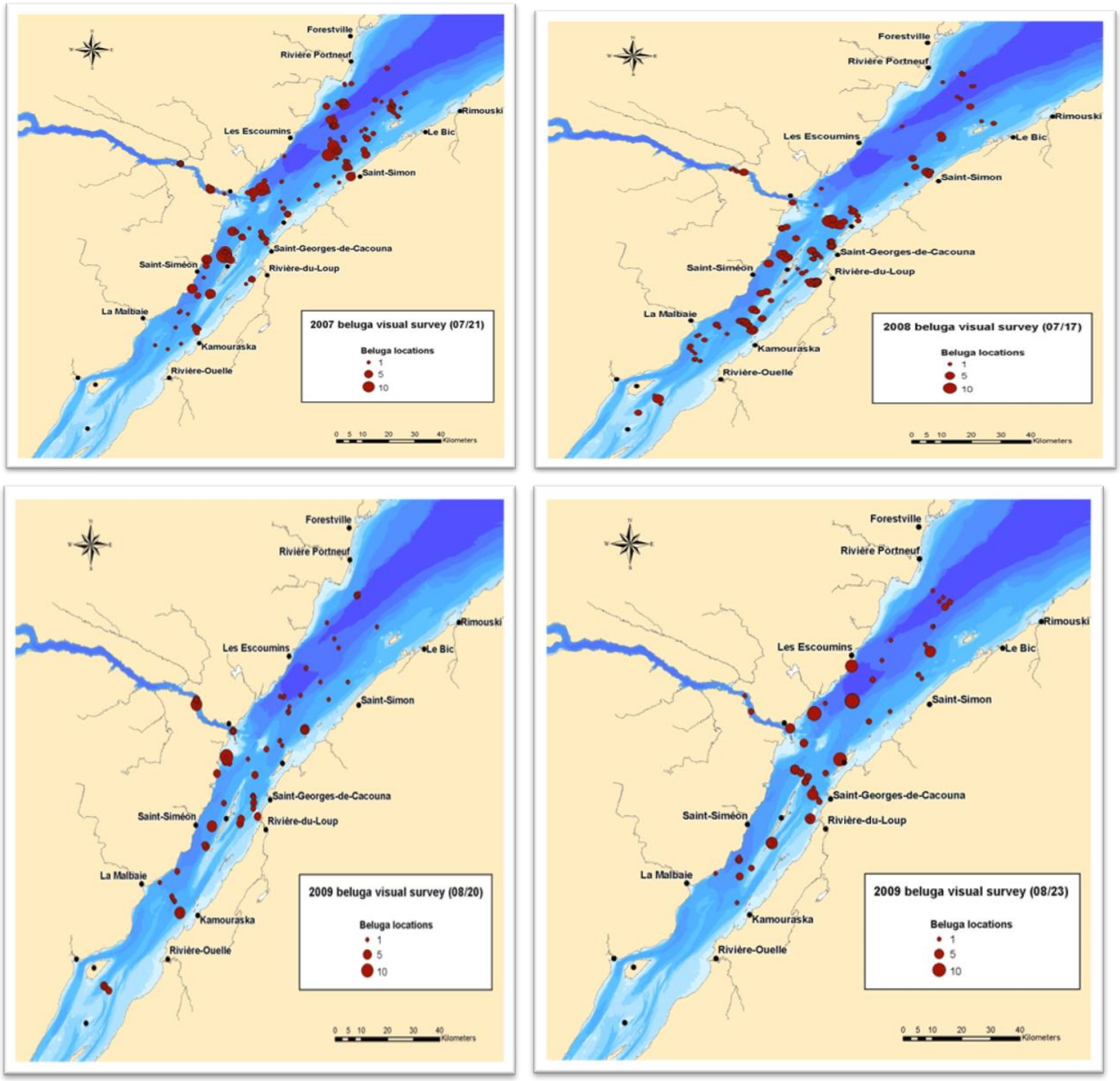


Figure 6 cont'd. Locations and group sizes of beluga whales detected along transect lines flown 21 July 2007 (top left), 17 July 2008 (top right), 20 August 2009 (bottom left) and 23 August 2009 (bottom right).

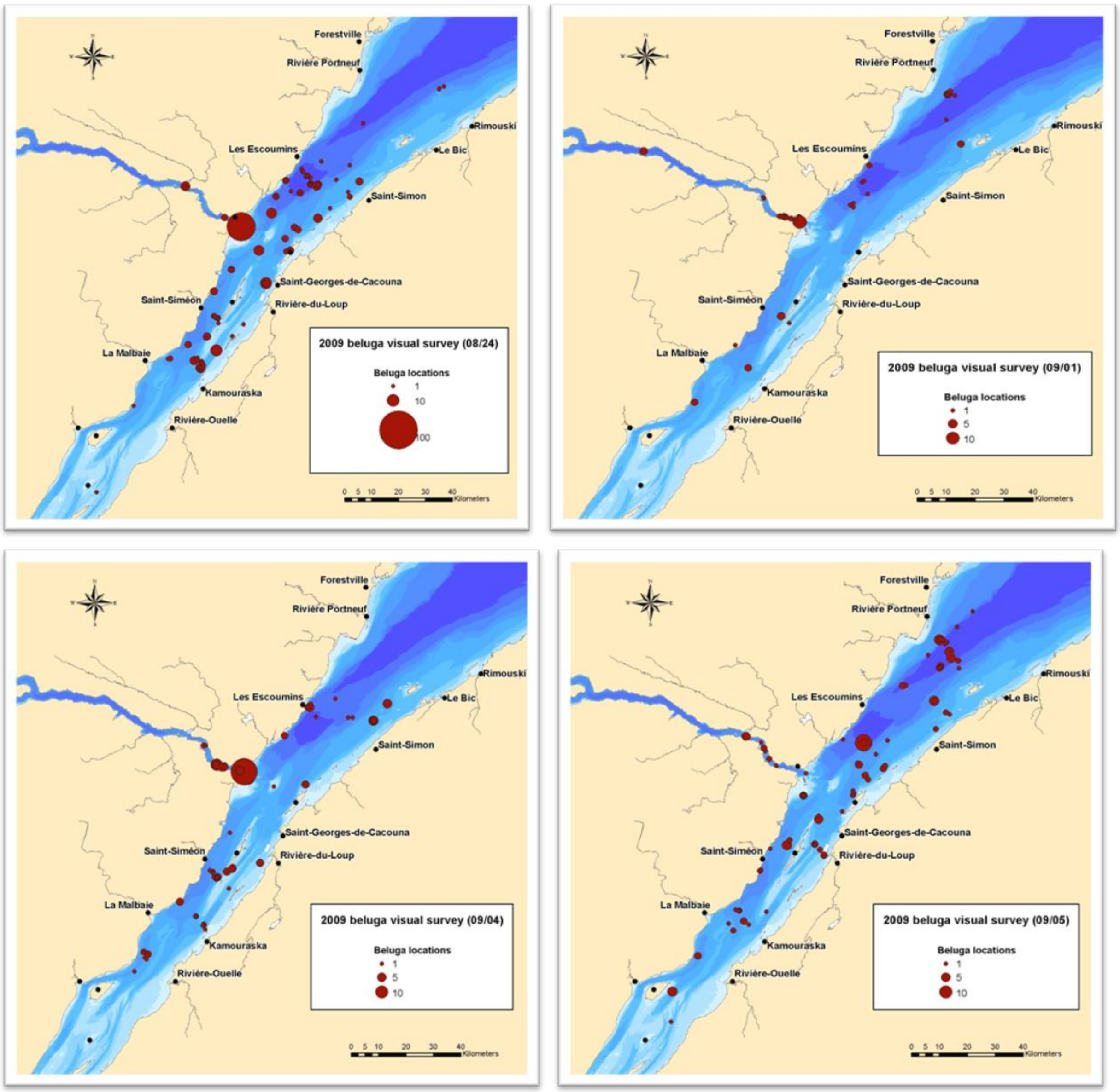


Figure 6 cont'd. Locations and group sizes of beluga whales detected along transect lines flown 24 August 2009 (top left), 1 September 2009 (top right), 4 September 2009 (bottom left) and 5 September 2009 (bottom right).

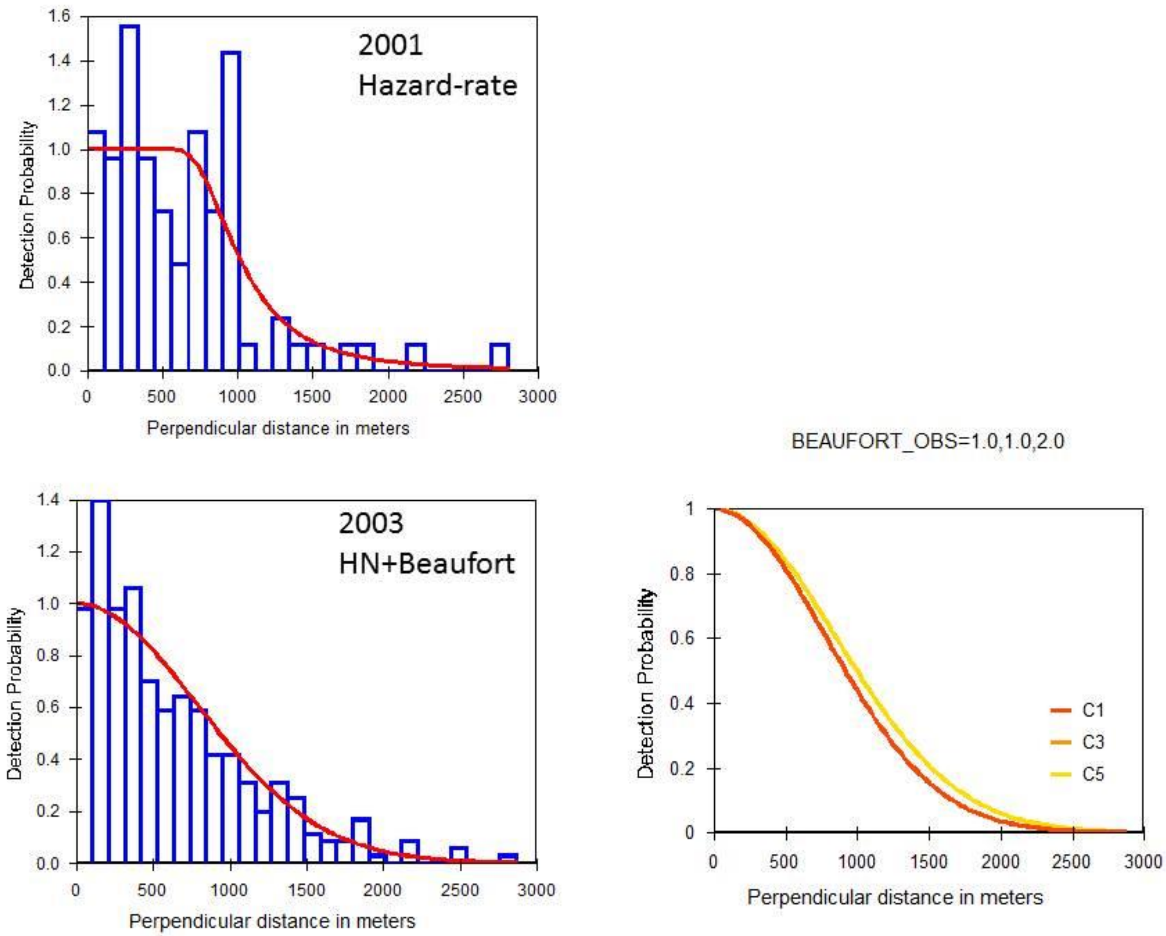


Figure 7. Distribution of perpendicular distances of groups of belugas and the detection function from the selected models for each year and each altitude in 2005 that were used in the estimation of density and abundance. Graphs show perpendicular distances grouped in bins but the models were fitted to the ungrouped distances.

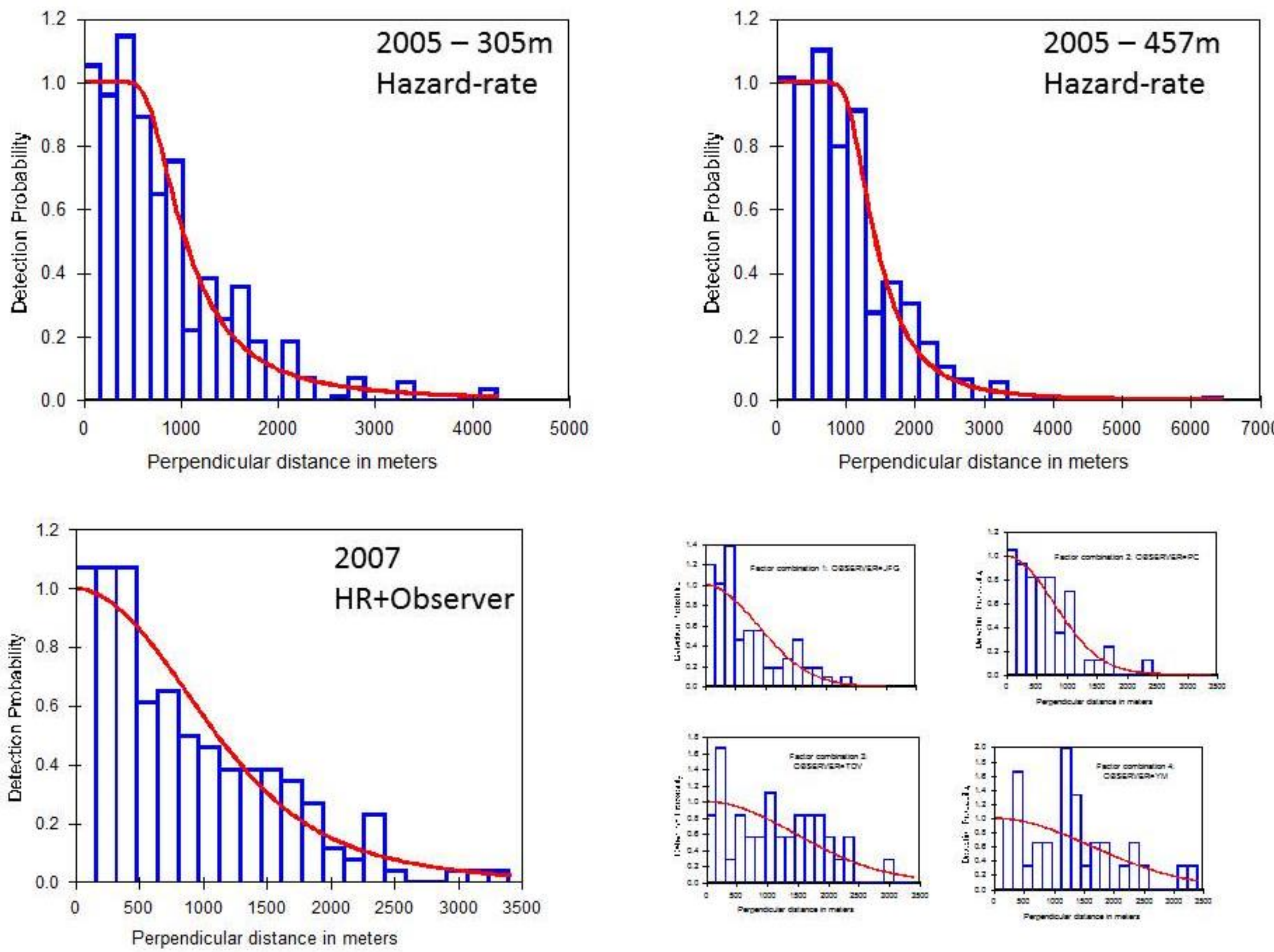
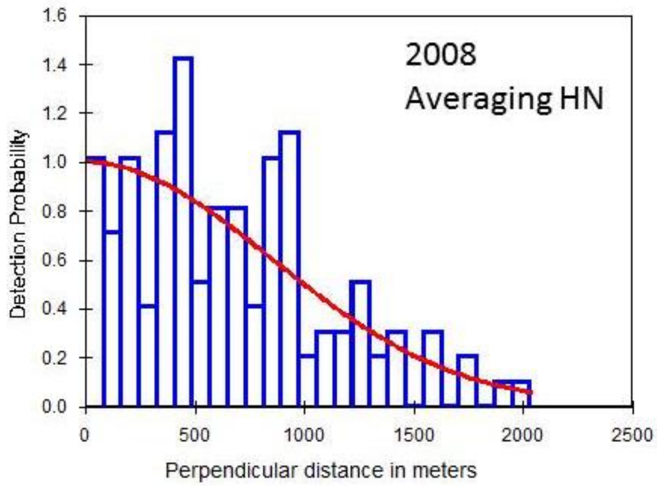


Figure 7 cont'd. Distribution of perpendicular distances of groups of belugas and the detection function from the selected models for each year and each altitude in 2005 that were used in the estimation of density and abundance. Graphs show perpendicular distances grouped in bins but the models were fitted to the ungrouped distances.



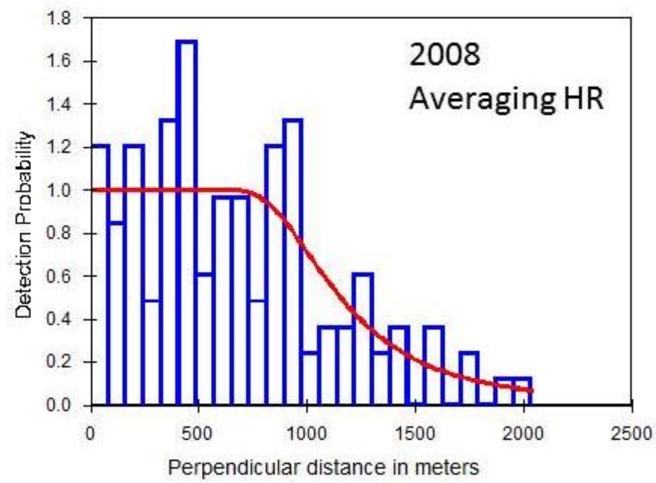


Figure 7 cont'd. Distribution of perpendicular distances of groups of belugas and the detection function from the selected models for each year and each altitude in 2005 that were used in the estimation of density and abundance. Graphs show perpendicular distances grouped in bins but the models were fitted to the ungrouped distances.

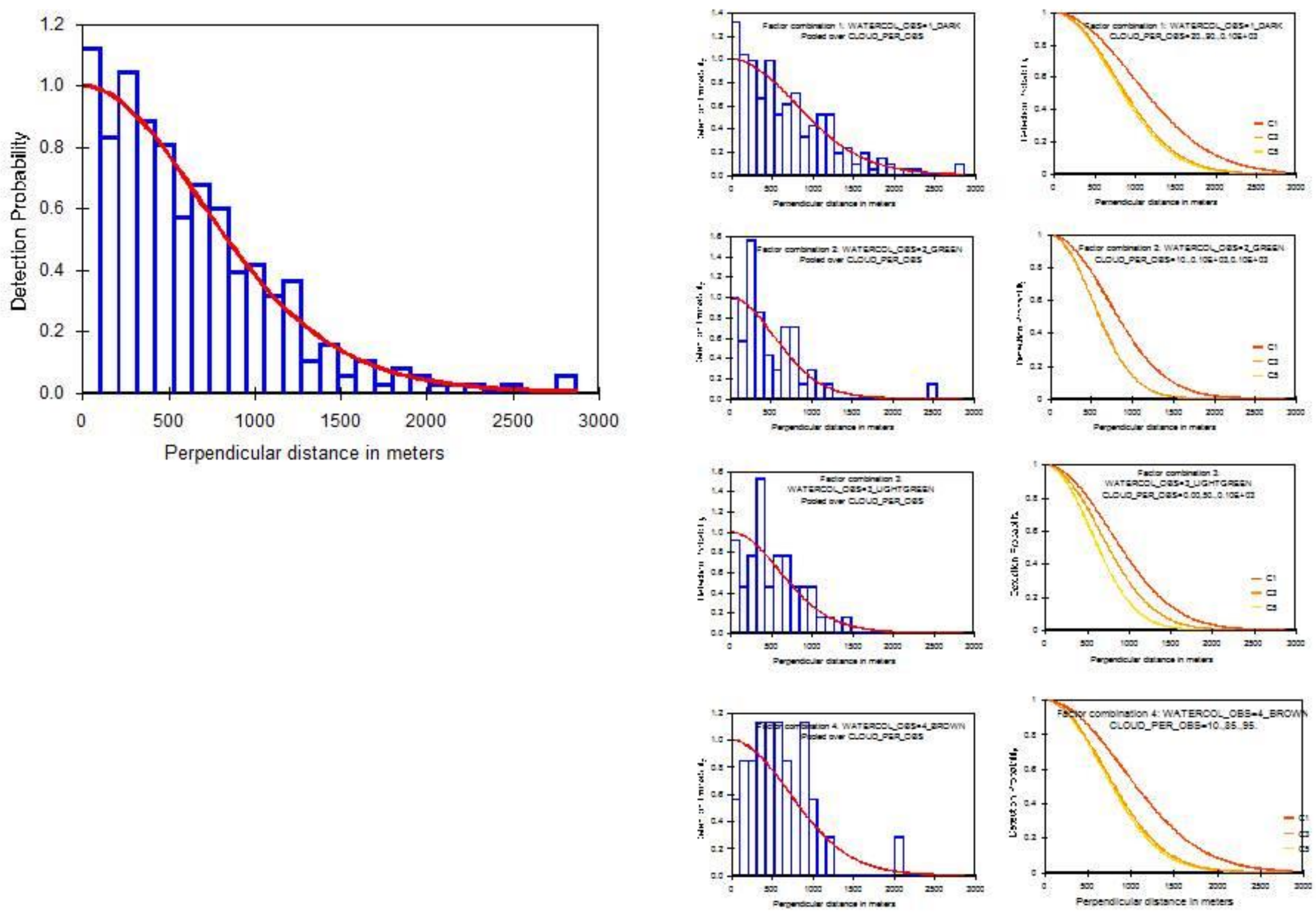


Figure 7 cont'd. Distribution of perpendicular distances of groups of belugas and the detection function from the selected models for each year and each altitude in 2005 that were used in the estimation of density and abundance. Graphs show perpendicular distances grouped in bins but the models were fitted to the ungrouped distances.

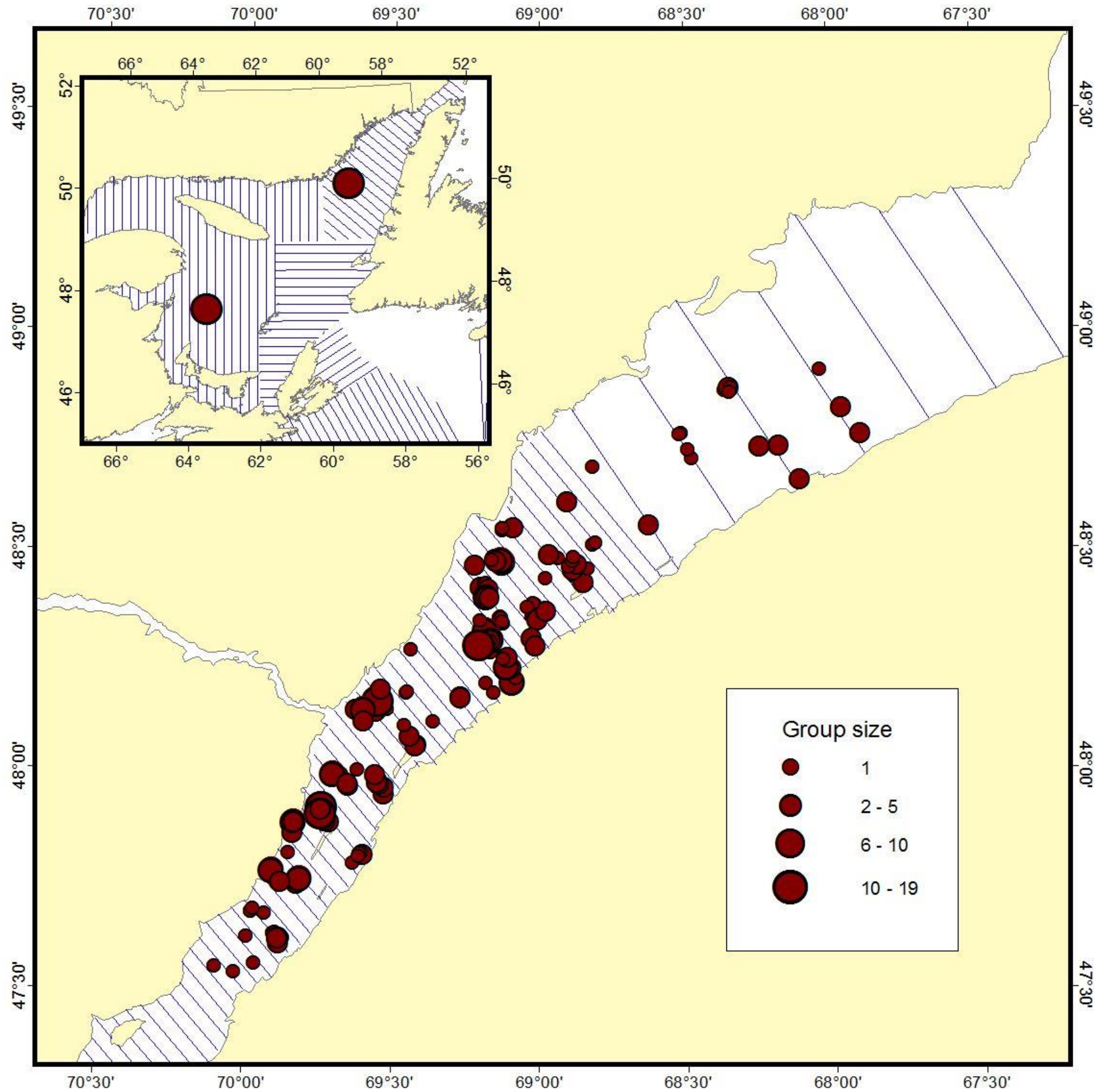


Figure 8. Location and group size of beluga whales detected in the Estuary and the Gulf of St. Lawrence from 21 July to 2 August 2007. The sightings in the Gulf were single individuals.

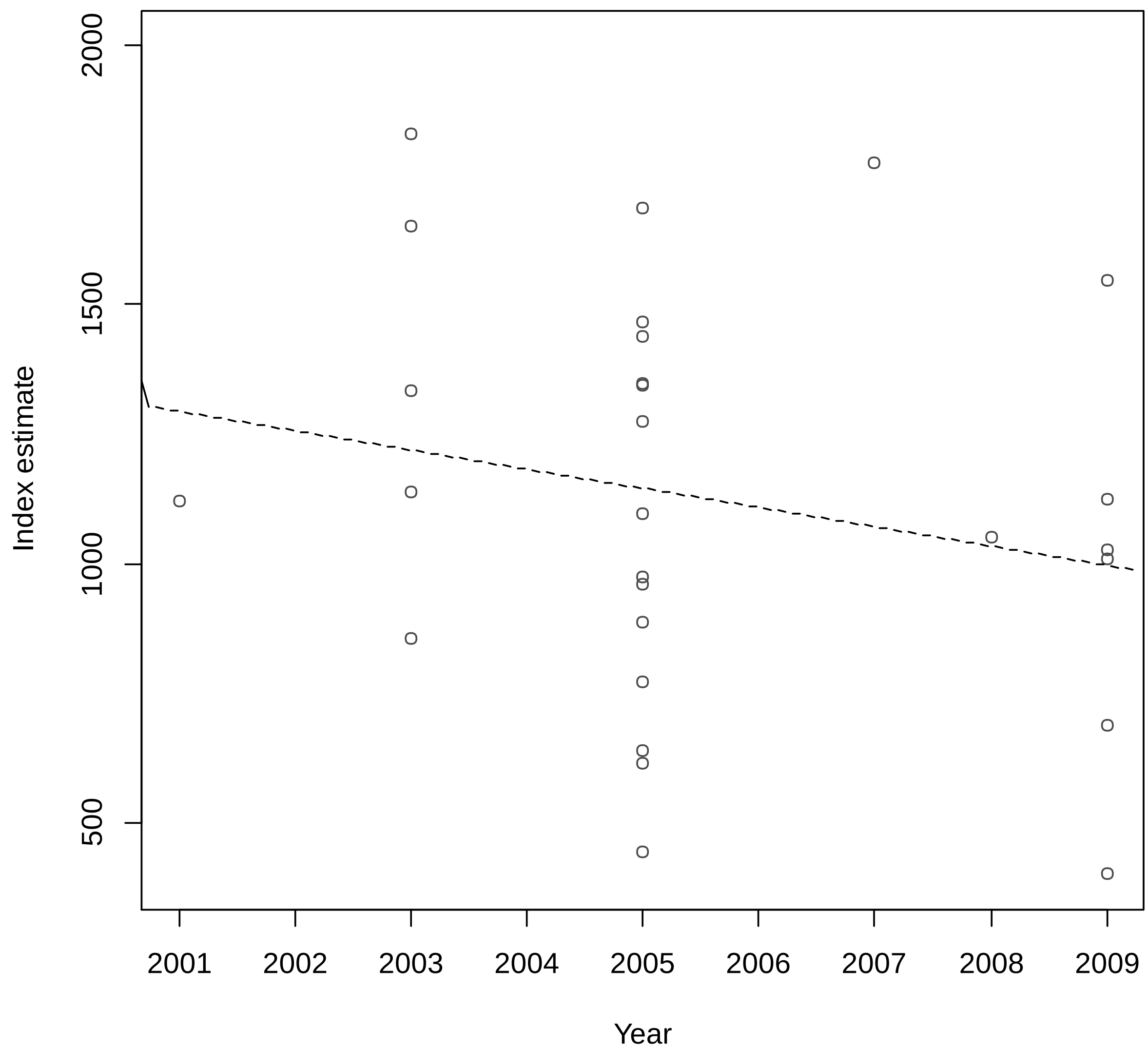


Figure 9. Regression of the 28 line transect survey abundance indices corrected for diving animals in the Estuary (availability factor 2.09) and including the Saguenay count from 2001 to 2009. The regression showed a poor fit (adjusted R^2 = 0.01) and the slope was not significantly different from zero (p = 0.27, df=26).