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Seasonal Variation in Distribution and Habitat Use of St. Lawrence Estuary Beluga (*Delphinapterus leucas*) Estimated from Systematic Photographic and Visual Line-transect Aerial Surveys

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Foreword

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

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ABSTRACT

Observations from 64 systematic photographic and visual aerial surveys conducted during the summers of 1990 – 2022, and 34 visual surveys conducted in fall, winter and spring of 2012 – 2023 were used to update and quantify the seasonal distribution of St. Lawrence Estuary (SLE) beluga, and to identify their areas of concentration. Kernel density analyses indicate that a large portion of the population (43 – 55%) is present year-round between Kamouraska/La Malbaie and Rimouski/Colombier. A seasonal shift in distribution is observed during the fall and winter, with an easterly movement from the Upper SLE to the Lower SLE and northwestern Gulf of St. Lawrence (nwGSL), followed by a reversed, westerly movement in the spring. In summer, the 50% and 95% kernel contours show that beluga occupy the entire SLE between Battures aux Loups Marins and Rimouski/Colombier. However, an increased use of the Lower SLE habitats between Saint-Simon/Les Escoumins and Rimouski/Forestville has been observed in recent year (2014 – 2022) compared to the earlier period (1990 – 2009). In the fall, distribution generally extends from La Malbaie in the Upper SLE, to the nwGSL, with most of the population occupying the Lower SLE between the mouth of the Saguenay River and Rimouski/Colombier. During winter, only a small portion (5%) of the population appears to remain in the Upper SLE; most of the population (63% on average) occupy the Lower SLE, with approximately one-third (32%) moving into the nwGSL. The beluga range is at its smallest during spring, although the number of spring surveys is small. High concentrations of beluga were observed in the most upstream part of the Upper SLE. Beluga are present in the Saguenay River year-round, mainly downstream of Ile Saint-Louis/Baie-Sainte-Marguerite in summer, and downstream of Cap de la Boule in fall, winter, and spring. Core areas of use (50% kernel) were identified throughout a wide extent of the SLE and nwGSL, and were characterized by a high degree of interconnection (75% kernel). Identifying the vital functions associated with these core areas might help mitigate potential threats, and improve our understanding of the drivers influencing the seasonal movements and distribution of this population.

INTRODUCTION

Beluga (*Dephinapterus leucas*) are social and gregarious marine mammals, which have a discontinuous circumpolar distribution in the Arctic and Subarctic regions. Within their range, populations exhibit movements between habitats according to seasons and biological requirements, with high site fidelity during summer (Caron and Smith 1990, Turgeon et al. 2012, O'Corry-Crowe et al. 2018, Bonnell et al. 2022). Based on summer ranges, genetics, and movements, eight designatable units (DU) have been identified in Canadian waters (COSEWIC 2016). The St. Lawrence Estuary beluga (SLE) is genetically distinct from other DUs (Montana et al. 2024), and is located at the southern limit of the species' global distribution (Figure 1; Stewart and Stewart 1989).

The SLE beluga population is a relic from the Wisconsin glaciation, which likely became established in the SLE approximately 10,000—12,000 years ago when the Champlain Sea covered most of the St. Lawrence Lowland (Harington 2008). While its historical abundance was estimated at several thousands of individuals, intensive commercial hunting from the 18th to the 20th centuries severely reduced the size of the population to only a few hundred individuals by the late 1970's (Pippard 1985). Despite the ban on commercial hunting in 1979 and the multiple management measures put forward over time (Lesage 2017, DFO 2022), the population has failed to recover (Tinker et al. 2024). Several factors potentially limiting their recovery have been identified, including habitat loss and degradation (DFO 2012; COSEWIC 2014; Lesage et al. 2024a). Moreover, SLE beluga live downstream of highly industrialized and urbanized regions, and along a major international seaway.

The SLE DU is currently listed as 'Endangered' under the Canada's *Species at Risk Act* (SARA), which requires that a Recovery Strategy be developed, and that Critical Habitat be identified, to the extent possible, using the best available information. In 2012, a first Recovery Strategy under the SARA was developed for SLE beluga, which identified Critical Habitat (DFO 2012). This assessment was based on distribution information from coastal observations, historical hunting data, opportunistic sightings, and non-systematic vessel-based and aerial surveys, as well as more systematic aerial surveys conducted since 1988 (reviewed in Mosnier et al. 2010). These data suggested that by 2010, the range of the population had been reduced to approximately 65% of its historical range, with an annual core distribution being at the lower limit of the size of the area of occupancy described for any beluga population (Figure 2; Mosnier et al. 2010; COSEWIC 2014). Based on historical data, and information available when Critical Habitat was assessed (Vladykov 1944, Mosnier et al. 2010, DFO 2012), the population was thought to undertake only limited seasonal movements, with part of the population moving into the northwestern Gulf of St. Lawrence (nwGSL) during winter. The paucity of information outside the period extending from June to October led to a Critical Habitat designation that relied primarily on information obtained during those months (DFO 2012). Briefly, the summer distribution, centered at the confluence of the Saguenay River, was described as extending from the Battures aux Loups Marins to Rivière-Portneuf /Rimouski, including the Saguenay River up to Saint-Fulgence, with only occasional sightings outside these limits (Figure 3). Within the summer range, multiple areas of intensive use or of consistent aggregation, connected by an extensive network of transit corridors, have been identified (Pippard and Malcolm 1978, Boivin and INESL 1990, Michaud 1993, Lemieux-Lefebvre et al. 2012, Mosnier et al. 2016, Ouellet et al. 2021).

Until recently, information outside the summer period was limited to a few and often non-systematic studies (reviewed in Mosnier et al. 2010). However, passive acoustic monitoring has since enhanced our understanding of SLE beluga seasonal distribution by providing year-round coverage (Simard et al. 2023). These studies confirmed that there is a downstream movement in the fall, with beluga extending their range into the Lower SLE and nwGSL (Figure 2; Vladykov 1944, Sears et Williamson 1982, Boivin et INESL 1990, Michaud et al. 1990, Lesage et al. 2007, Simard et al. 2023). In spring, beluga remain present along the Gaspé Peninsula and nwGSL, but concentrate in the Upper SLE, leading to a maximum extent of the population range at that time of year (Michaud and Chadenet 1990). An estimated 40% to 60% of the population would use the Lower SLE during summer (Michaud 1993, Mosnier et al. 2016, Simard et al. 2023). However, uncertainty remains regarding the proportion of the population using the SLE and nwGSL, and how individuals distribute within these regions during other seasons.

To fill these knowledge gaps, visual aerial surveys following a systematic design were conducted seasonally from 2012 to 2023, across what is thought to be the fall, winter and spring ranges of the population. The current study provides an estimate of the beluga distribution and habitat use for these three seasons, and an update of the summer distribution using data acquired since 2014. While the abundance and trends of the SLE beluga population are estimated using summer surveys when their distribution is the most constrained, we present abundance estimates for all four seasons to validate the assumption that the seasonal surveys covered the entire range of the population. In revisiting data from previous surveys, some inconsistencies were noted in the spatial boundaries of the Saguenay River, and the methodology applied to identify duplicate sightings in this sector. To that end, an objective and reproducible method based on a spatiotemporal clustering approach was developed, and retrospectively applied to previously analyzed surveys, including the most recent summer abondance estimates (St-Pierre et al. 2024a).

MATERIALS AND METHODS

STUDY AREA

Aerial surveys covered the SLE, part of the GSL and the Saguenay River (Figure 4). The latter is a deep fjord reaching depths of 270 m, bounded by steep cliffs up to 300 m high. The Upper SLE, located upstream of the Saguenay River, is characterized by a channel with depths varying from 40 to 140 m in the northern half, and a narrow channel 40 m deep with banks along the coast and several islands in the southern half (Figure 1). The Upper SLE is also characterized by a water turbidity gradient, with more turbid waters at the upstream end than at the downstream end. The SLE downstream of the Saguenay River, referred here as the Lower SLE, is characterized in the northern half by the 300 m deep Laurentian Channel, which rises to 40 m at the confluence of the Saguenay River, and in the southern half by a shelf less than 40 m deep and a few islands. East of Pointe-des-Monts/Les Méchins, the SLE widens into the GSL. This enclosed sea is connected to the Atlantic Ocean by the Cabot Strait and the Strait of Belle-Isle, and is characterized by deep channels (300-540 m) bounded by shallow shelfs 100 m deep or less. The SLE and GSL are typically ice-covered in winter. Sea ice usually begins to form in the SLE in December, with melting in early April. Sea ice starts to form slightly later (January) in the GSL, with isolated patches of ice usually present until about mid-May (Galbraith et al. 2022). There are also areas of open water year-round near the Saguenay River mouth and in the Lower SLE as a result of strong upwelling and sea ice shifting with wind direction.

SYSTEMATIC LINE-TRANSECT AERIAL SURVEYS

Summer surveys were limited to the SLE, where the entire beluga population is considered to concentrate (St-Pierre et al. 2024a; Lesage et al. 2024a). This area was divided into two strata, the upstream stratum (hereafter “Main stratum”) from Battures aux Loups Marins to Rimouski/Colombier, and the Downstream stratum, which extended east to Pointe-des-

Monts/Les Méchins (Figure 4a). The Main stratum covered the area recognized as the main summer range of SLE beluga (Figure 3; Mosnier et al. 2010). The Downstream stratum is thought to be used by beluga mainly outside of summer, however, it has been consistently surveyed in summer since 2007 to detect any possible range extension of the population (Gosselin et al. 2017). To assess the seasonal distribution of beluga, surveys outside of summer were extended to cover different sectors of the northern GSL (strata 2 to 8 in Figure 4). For these surveys, Stratum 1 combined the Main and Downstream summer strata and thus, represented the entire SLE downstream of Battures aux Loups Marins. Based on the annual extent of the range observed during surveys conducted in 1989-1990, and on opportunistic beluga sightings (Boivin and INESL 1990, Michaud et al. 1990), higher priority was given to the Main stratum in summer, and to Stratum 1, 2, 3, and 5 in other seasons. The Saguenay River from Tadoussac to Saint-Fulgence, including La Baie des Ha! Ha! (Figure 5), was surveyed once or twice during all summer surveys of the Main Stratum, except for three visual surveys conducted in 2014, 2015 and 2016. In other seasons, the Saguenay River from Tadoussac to Baie-Sainte-Marguerite was also covered each time Stratum 1 was surveyed, except during one survey conducted in winter 2014.

Survey period and coverage

Summer surveys were flown between early-July and mid-September, a period when beluga are concentrated in the SLE (Appendix 1; St-Pierre et al. 2024a). The fall surveys targeted the late November to December period, when some potential prey (e.g., herring (*Clupea harengus*) and American eel (*Anguilla rostrata*) are thought to leave the SLE or move into deeper waters (Vladykov 1944, 1946, Bérubé and Lambert 1999, de Lafontaine et al. 2010). This period also precedes the ice formation in the SLE (Galbraith et al. 2022), which may trigger the fall migration, as observed in Arctic beluga (Bailleul et al. 2012, Hauser et al. 2017, Niemi et al. 2019). Winter surveys were flown from January to March, but mostly from mid-February to March, the period of maximum sea-ice extent in the SLE and nwGSL (Galbraith et al. 2022). Spring surveys were flown from late-April to early May, which may coincide with the return of some forage species such as Atlantic herring and rainbow smelt (*Osmerus mordax)* (Vladykov 1946, Bailey et al. 1977, Greendale and Powles 1980, Fortier and Gagné 1990, Bérubé and Lambert 1997, Bérubé and Lambert 1999).

Survey design

The survey design over the SLE and the GSL was systematic with random placement of parallel transects oriented perpendicular to the main axis of each stratum or bathymetric contours. In summer, line spacing was generally 3.7 km (2 NM) for photographic surveys and 7.4 km (4 NM) for visual surveys (see Table A1 in Appendix 1 for details). Exceptions were: 1) the four surveys conducted in 2019 which were flown simultaneously as a visual and photographic survey and thus, necessitated a line spacing of 4 NM to ensure that the same individuals were not recorded repeatedly on successive transects by the observers and; 2) one survey of Stratum 1 in 2020 and three surveys of Stratum 2 in 2008, 2016 and 2020, which were flown with a line spacing of 18.5 km (10 NM). The area covered over the Main stratum increased over the years at both extremities to consider the possible expansion of beluga summer range (Figure 4; see St-Pierre et al. 2024a). In seasons other than summer, line spacing was 13 km (7 NM) for all surveys and strata (Table 2). The number of transects covering each stratum varied slightly among surveys depending on placement of lines and strata's extent (see Table A1 and Table A1.2 in Appendix 1).

Visual surveys

Different aircraft were used for the surveys (see Tables A1.1 and A1.2 in Appendix 1), although all were equipped with bubble windows at the observer seats, except for the co-pilot seat in the Partenavia which had a large standard (flat) window. The visual surveys were generally flown at a target speed of 185 km/h (100 knots) and a target altitude of 305 m (1000 ft), except for a few surveys (see Table A1.1 and Table A1.2 in Appendix 1). Each survey was completed with either one or two aircrafts covering over different transect lines.

During each survey, a primary observer was seated on each side of the aircraft. When available, a third observer was seated on the right side of the plane, and was considered to be a secondary observer. All observers had aerial survey experience or received aerial survey training before surveys, and were isolated from each other visually and aurally.

Observers recorded beluga sightings as groups, defined as individuals within 2-3 body lengths of each other. The bearing relative to the track line was recorded using an angle meter. Observers also measured the inclination angle to the centre of each group using clinometers (Suunto, PM 5/360 PC), and recorded the time (synchronised with the GPS) when animals were detected. The perpendicular distance of the animals from the plane were triangulated from the inclination angle and the altitude of the aircraft. Observers were instructed to give priority to the estimation of group size and time of observation, followed by inclination angle, and then other variables, including animal behaviour and any behavioural changes assumed to be a reaction to the approaching plane, if time permitted. When two observers were seated on the same side of the plane, groups of animals detected by both observers were identified (St-Pierre et al. 2024a, 2024b). Groups and group sizes detected by the primary observer were retained for the abundance analysis, while the highest of both counts was used for spatial analyses.

Weather and observation conditions were recorded at the beginning of each transect, at regular intervals along the transect, and whenever observation conditions changed. The information recorded included sea state (Beaufort scale), cloud cover (percent), angle of searching area affected by sun reflection, along with sun reflection intensity, ice cover and a subjective measure of detectability (visibility). Surveys were only initiated when sea conditions were Beaufort 3 or less, and when cloud cover was above the target flight altitude, and ideally when the weather forecast predicted suitable conditions over the entire area for the whole day.

Each survey was flown with the aim of covering the area as rapidly as possible, over the course of a few days. However, weather did not always allow complete coverage of a specific stratum or of all strata during a single survey or season, resulting in varying coverage (see Table A1.1 and Table A1.2 in Appendix 1). It was assumed that the distribution of animals did not change significantly over the time period needed to complete a survey, even when more than one day was required to survey an entire stratum.

Photographic surveys

Photographic surveys were only conducted during summer and over the Main stratum. From 1990 to 2009, they were completed in one day using two aircraft flying simultaneously at a target altitude of 1,219 m. In 2019, photographic surveys were still completed in one day but using a single plane flying at an altitude of 305 m to allow simultaneous visual surveys. Details on the type of cameras and lenses used, photo coverage overlap and other methodological details can be found in St-Pierre et al. (2024a) and in Table A1.1 (Appendix 1). All photographs obtained from those surveys were examined for beluga by at least two independent readers. Animals ≤ 0.5 the length of other beluga, and within one body length from another animal were considered to be calves. This category included both newborns and one-year-old animals, as they could not be reliably distinguished from aerial photos. Given that the area covered by visual surveys was wider than for photographic surveys, spatial analyses of the 2019 survey data were conducted using only visual survey detections.

Saguenay River counts

The number and position of beluga were recorded by observers or determined from aerial imagery on both upstream and downstream surveys of the Saguenay River (Figure 2), except prior to 2001 (n = 5 surveys) when this information was unavailable (see Table A1.1 in Appendix 1). Only the 51 surveys with location data were included in the analyses presented in this manuscript. A spatiotemporal clustering approach was first applied to remove duplicate sightings between the upstream and downstream surveys. Specifically, sighting locations were filtered by longitude, keeping only sightings located west of -69.7165 degrees, which corresponds to a line crossing the Saguenay River between Pointe de l'Islet and Pointe-Noire (Figure 5). Then, using the distance between each pair of observations and time of each observation, the displacement speed required for beluga located at observation site 1 to reach observation site 2 was calculated. This information was then used in a cluster analysis (function "hclust" from the R package "stats") to regroup the observations that were "closer" (i.e., which required the lowest speed to correspond to the same animal or group of animals). A threshold of 10 knots (maximum swimming speed of a beluga, Lemieux Lefebvre et al. 2012) was used to divide the cluster tree and identify observations or group of observations that were independent from others. Due to the speed of the plane, successive observations made during a given survey were highly likely to be independent; as a result, the cluster analysis mainly served to match observations from the upstream survey with those of the downstream survey based on the probability that these observations corresponded to the same animals. For each beluga group, the maximum number of beluga observed either during the upstream or downstream survey was retained, to which were added non-duplicate observations from the opposite survey to obtain the total (maximum) number of beluga observed during the Saguenay River survey. Counts in the Saguenay River were not corrected for availability nor perception biases because of the narrow searching area, the curves in the plane trajectory which allowed observers to spend more time searching any given location and impeded inclination angle measurement, as well as the replicate passes (upstream and downstream). The total count of beluga seen in the Saguenay River (or average of total counts in seasons when the Saguenay River was flown multiple times) was added to the average fully-corrected abundance estimate of the Main stratum (summer) or Stratum 1 (other seasons). Summer abundances presented in St-Pierre et al. (2024a) were updated using this new method for estimating Saguenay counts (See Appendix 1).

ABUNDANCE ESTIMATION

The analytical approach to abundance estimation from visual and photographic surveys is presented in St-Pierre et al. (2024a) for summer surveys (both visual and photographic surveys). Analyses for fall, winter and spring surveys (all visual) followed the methodology outlined in St-Pierre et al. (2024a), although with a slight variant for estimating availability bias given the absence of tag data for periods outside of summer (see below).

Briefly, the sum of the lengths of transects flown and the area of each stratum were used to estimate abundance per survey and stratum using distance sampling and the package "mrds" (Laake et al. 2013) in R 4.3.0 (R Development Core Team 2018). The need for right truncating the distribution of perpendicular distances was examined, with the most appropriate right-truncation distance being assessed based on four different approaches (see St-Pierre et al. 2024a). The selection of the detection function best fitting the data, and appropriateness of including covariates followed the stepwise procedure detailed in Marques and Buckland (2003), and outlined in details in St-Pierre et al. 2024a. Potential covariates considered were group size, sea state, glare intensity, cloud cover, ice cover, airplane type (when a survey was flown using different aircrafts, i.e., Cessna vs Partenavia), and season. A bootstrap procedure was used to include observations without perpendicular distances in the estimation of density and abundance (details in St-Pierre et al. 2024a). The surface abundance index and associated variance for a given stratum and season were obtained by taking the average of surface abundance indices from all passes of the stratum, with combined variance calculated via the delta method (Seber 1982, Powell 2007). Total surface abundance index and its variance for a given season and survey was calculated as the sum of the average surface abundance indices from the different strata.

An availability bias correction was applied to summer surface abundance indices to account for animals missed by observers because they were diving (see St-Pierre et al. 2024a for details). While the method for estimating availability bias in that study accounts for environmental factors, behaviour and sector used by SLE beluga, it is based on archival tag data collected exclusively during summer (Lesage et al. 2024b). In absence of data outside of summer, and to acknowledge that behaviour may vary among seasons, the mean duration of dives [*E(d)* = 155 seconds (s)] and surface intervals [*E(s)* = 78 s] from these 27 summer deployments were used to calculate availability bias for each beluga group observed using equations 1 and 2 in Lesage et al. (2024b). An availability bias, *â*, was calculated for each survey and stratum, and for each season, using the average availability, $a(x_j)$ of each of the *n* detected group of beluga given their perpendicular distance, x_j, as follows:

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

For each survey and stratum, the calculated CV around the average availability bias was very low (≤ 1%) because it was computed to only account for inter-individual variation between average surface (E(sf)) and dive (E(dv)) intervals among the tagged beluga. However, other sources of variability affect the availability bias. To account for the fact that the depth to which beluga can be detected by observers can be variable, the uncertainty around the availability bias was increased by fixing the CV at a value of 7.7% as reported by Kingsley and Gauthier (2002).

A correction also needed to be developed for the perception bias, i.e., for observers missing animals that were available to be counted at the surface. Surveys conducted in the fall of 2012, 2019, 2020, winter of 2013, 2015, 2020-2023, and spring of 2018 were flown in a double-platform configuration, on the right side of the plane. Perception bias was calculated using all double-platform survey data combined into a single MRDS analysis (see method in St-Pierre et al. 2024a; 2024b) to yield a global value of primary *p(0)*. This value was then used to correct all survey results, including single-platform surveys.

The following formula was used to correct abundance indices for availability (*â*) and perception [*p(0)*] for each survey and stratum, assuming that *p(0)* was the same for primary observers on the right and left side of the aircraft:

$$fully\ corrected\ abundance = abundance_i \cdot \frac{1}{\hat{a}} \cdot \frac{1}{p(0)} \quad \text{[Eq. 2]}$$

SPATIAL ANALYSES

Proportion of the population in different areas

Changes in overall distribution between seasons were estimated using proportions of the population observed in various sectors of the SLE, GSL, and Saguenay River. To allow direct comparisons of estimated proportions with Mosnier et al. (2016) and Simard et al. (2023), the SLE was divided into three and five sectors, respectively (Figure 1). The proportion of beluga that were observed in each sector was calculated for each survey in a given season, and then weighted by the stratum-specific average abundance estimate derived from all surveys in that season. This led to each sector's contribution being adjusted for the mean proportion of the total population occurring in that stratum. In summer, only surveys covering the Main stratum, the Downstream stratum, and the Saguenay River were included in this calculation, whereas for other seasons, only surveys covering strata 1, 2, 3, 5, and the Saguenay River were considered. The four photographic surveys conducted in 2019 were discarded from these and all other spatial analyses, unless otherwise specified, to avoid considering the same individuals twice, since the visual and photographic surveys were carried out simultaneously.

Summer distribution was estimated using all survey years from 1990 – 2022. However we also estimated distribution separately for surveys from 1990 – 2009 and from 2014 – 2022 to examine potential long-term changes in distribution. These two periods contrasted in beluga population dynamics and SLE environmental conditions (Plourde et al. 2014; Tinker et al. 2024). Starting in 2010, a significant change in calf mortality and adult female survival was noted, leading to a slowing of population growth and possible decline after 2018 (Tinker et al. 2024). These changes in population dynamics coincided with an increase in water temperatures, a reduction in sea-ice indices, and a decrease in biomass of some prey (Plourde et al. 2014). Although environmental conditions started to shift in the late 1990's to reach the extremes observed in the 2010's and 2020's (see Plourde et al. 2014; Galbraith et al. 2022), the low number of surveys conducted before 2000 (n = 4, all photographic surveys) prevented us from examining beluga distribution separately for this decade.

Seasonal 2D kernel density analyses in the SLE and GSL

The seasonal density distribution of beluga was evaluated by a combination of two-dimensional spatial kernel density estimates following Mosnier et al. (2016). This approach allowed the detection of areas of higher beluga density and recurrent use over the study period. While analyses by Mosnier et al. (2016) were restricted to the main summering area (i.e., Main stratum), those presented in this report included other strata, while accounting for variable survey effort within season (i.e., line spacing or partial coverage of a stratum) and across seasons.

Seasonal maps of distribution and habitat use were produced using a grid of 1 km by 1 km cells (similar to Mosnier et al. 2016; see Appendix 2), and a four steps approach (Figure 6). First, one kernel was produced for each stratum and replicate survey in a given year (referred to as survey-stratum kernel). As coverage of a stratum was sometimes partial due to bad weather, a mask was applied to limit calculation of densities only to grid cells covered during the survey.

In a second step, seasonal-stratum kernels were produced for each stratum and survey year, using the weighted mean of the survey-stratum kernels from step 1. Each survey-stratum kernel was weighted by: 1) the area of its corresponding survey effort to account for variability in coverage among surveys (i.e., different spacing between adjacent transects or incomplete coverage due to weather conditions), and 2) the total number of individuals counted in each survey, assuming that a survey with a larger number of animals sighted provided a more accurate representation of SLE beluga distribution.

In a third step, seasonal-stratum kernels were mapped for each season and year, by weighting seasonal-stratum kernels for each survey year by the median proportion of the observations observed across survey years in each stratum during that season, yielding the final seasonal kernels (Step 4). The median was used instead of the mean as it likely represents a more conservative way of summarizing the distribution considering the large variability observed among surveys. For summer, this median proportion was calculated by only considering surveys that covered both the Main and Downstream strata. For spring and autumn, only surveys covering strata 1, 2, 3, and 5 were used for the calculation, whereas in winter, stratum 7 was added to these 4 strata as this stratum was covered twice in winter (2013 and 2014).

The kernel calculation method used here does not take into account the barrier effect resulting from islands. As a result, two groups of animals located on opposite sides of an island would be combined when estimating densities even though these counts should be treated as independent. While methods exist to address this issue (Benhamou and Cornelis 2010), they could not be applied in this case: barriers used in these methods need to be represented by polygons composed of segments at least three times the length of the smoothing factor (i.e., 3 x 926 m, or 3 x 1,563 m in our case, depending on the season considered, see Appendix 2). Such large distances would have prevented an accurate representation of the SLE islands. Instead, masks were applied to exclude areas on land and islands of the kernel calculation. The resulting values were then normalized to obtain kernel densities estimations within the surveyed areas (strata). Final outputs included a grid of 1 km by 1 km cells containing the kernel value, and contour lines containing 50%, 75%, and 95% of the population. The same method was used to represent the summer distribution of beluga calves (0-1 year-old animals combined). However, only observations from photographic surveys (including the 2019 surveys) were used in this case, as detection and identification of beluga calves during visual surveys were largely unreliable.

As for overall distribution, a seasonal home range was calculated using either the entire time series (summer: 1990 – 2022; other seasons: 2012 – 2023), or, for summer surveys only, separately for 1990 – 2009 and 2014 – 2022. Surveys conducted in 1990 – 2009 mainly took place from mid-August to mid-September, whereas those conducted in 2014 – 2022 were sometimes initiated in July. To examine the potential effect of survey timing on distribution estimates, summer kernel densities including 2014 – 2022 data were generated for both the July – August and August – September periods.

Seasonal 1D kernel density analyses in the Saguenay River

Due to the different survey design used in the Saguenay River (two surveys and no distance sampling), an alternative approach was required to estimate densities in this region. The distribution of the observations was thus considered as a relative density of sightings along a single axis (one dimension; 1D) representing the distance from the Saguenay River mouth, defined as sightings located west of -69.7165 degrees, corresponding to a line crossing the Saguenay river between Pointe de l'Islet and Pointe-Noire to either Saint-Fulgence or Baie-Ste-Marguerite depending on the seasonal survey coverage (see section “Saguenay River counts” above). The relative density distribution was obtained for each survey and then combined for each season as a weighted average, taking into account the number of animal seen in the Saguenay during the surveys. The summer density distribution was obtained only for the period 2001 – 2022 as the position of belugas observed in the Saguenay during surveys conducted before 2001 were unavailable. Again to assess potential change in usage of the Saguenay River over the study period, the summer spatial density was estimated separately for the periods 2001 – 2009 and 2014 – 2022. For spring, fall, and winter, spatial density analyses were limited to the 2012 – 2022 period, since surveys were not conducted in these seasons before 2012. All spatial analyses were conducted using QGIS (QGIS Development Team 2021) and R 4.3.0 (R Development Core Team 2018) using the Quebec Lambert projection. For convenience, the figures presented in this document were not projected.

RESULTS

SURVEY EFFORT

Summer surveys

A total of 64 summer aerial surveys, including 11 photographic and 53 visual surveys, were conducted since 1990 and were available for this analysis (Figure 4; Table A1.1 in Appendix 1). Photographic surveys were flown from mid-August to early September. From 1990 to 2009, they were completed once every two to four years. This was followed by a ten-year gap, after which four consecutive photographic surveys were completed in 2019.

The visual survey time series was initiated in 2001, with surveys flown annually or biennially, except for four years in 2010 – 2013 when no survey was conducted. The visual surveys were generally conducted between mid-August and early September, although some surveys were flown in mid-July or, in more recent years, in early July. Several surveys were flown in some years, resulting in the Main stratum being surveyed 53 times over 11 survey years, and the Downstream stratum being surveyed 15 times over 8 survey years (Figure 4; Appendix 1). The Main and Downstream stratum were generally completed within a day. However, in 2016, the Downstream stratum took two days to be covered, and in 2022, two weeks were needed to meet suitable weather conditions to complete surveys of the two strata.

Fall, winter, spring surveys

Seven surveys (all visuals) were flown in the fall (November 18 – December 20), 21 in the winter (January 18 – March 29), and six in the spring (May 2 – May 16) between 2012 and 2023. Stratum 1 (the entire SLE) was covered in each of the 34 surveys (Figure 4, Table A1.2 in Appendix 1), while strata 2, 3, and 5 were surveyed 27, 24, and 18 times, respectively (Appendix 2). In contrast, strata 4 and 7 were surveyed only twice (in the winters of 2013 and 2014), while strata 6 and 8 were surveyed only once (in winter 2014; Figure 4; Table A1.2 in Appendix 1). Outside of summer, a given stratum was generally covered within 1 to 18 days depending on weather conditions, but in 71% of cases, complete coverage was achieved in three days or less (Table A1.2 in Appendix 1).

BELUGA COUNTS

Summer

Beluga counts varied over the study period and within survey years (St-Pierre et al. 2024a). Considering adjustment of counts for the Saguenay River, photographic surveys provided an average of 233 individuals (range: 149–311), and visual surveys an average of 234 individuals (range: 44–471) for spatial analyses (see Figure A3.1 in Appendix 3). Overall, fewer surveys were conducted in the Main Stratum during the 1990 – 2009 period compared to 2014 – 2022, resulting in fewer groups and individuals detected in this stratum during the earlier period (Table 1). In contrast, the Downstream Stratum showed the opposite trend, as survey coverage in this area only began in 2007. Notably, the average group size (i.e., the average number of individuals per group) was larger in the 2014 – 2022 period than in 1990 – 2009 for both strata (Table 1). On average, 29 beluga were counted in the Saguenay River when present, with a maximum count of 158 individuals (2022 survey). Beluga were absent from the Saguenay on seven occasions. Applying the new method to identify duplicated observations during Saguenay River surveys resulted in an update of counts from the previous stock assessment in 17 cases, with modifications varying from the removal of 12 individuals to the addition of 38 individuals to the Saguenay counts (see St-Pierre et al. 2024a and Table A1.1 in Appendix 1).

Fall, winter and spring

The number of sightings and group sizes were on average lower during fall surveys than winter or spring surveys (Table 1, see Table A1.2, Figure A3.3, A3.4 and A3.5 in Appendix 3). Most detections in all three seasons occurred in Stratum 1. Beluga were detected in fall and winter in Stratum 2, but rarely in the spring (Figure A4.4 in Appendix 4); they were observed only once in Stratum 3 (fall 2019) and Stratum 7 (winter 2013), and were absent from other strata (see Table A1.2 in Appendix 1 and Figure A4.4 in Appendix 4).

Beluga were detected in the Saguenay River during three of the seven surveys conducted in the fall, four of the 21 surveys conducted in winter, and two of the six surveys carried out in the spring. The highest number of individuals observed in this area during a survey was 18 in the fall, 4 in winter and 3 in the spring (Figure 5; see also Table A2.d.1).

ABUNDANCE ESTIMATES

Summer

Correcting counts from the Saguenay River for duplicate sightings had little impact on the summer abundance estimates, which remained similar to those reported in St-Pierre et al. (2024a) (see Table A1.1 in Appendix 1).

Fall, winter and spring

A total of 1,145 beluga sightings made during fall, winter and spring surveys, and with associated perpendicular distances were used to fit the detection curve for the abundance estimation analysis. The best fit of the detection function was obtained with a right truncation at 1,437 m, which retained 1,029 of the original sightings. The gamma key function had a higher AIC than the half normal and hazard-rate key functions, but was selected nevertheless, as the latter two functions did not meet the goodness of fit criterion (*p* value of the Cramér-von Mises test was < 0.05). Including season as a covariate reduced the model AIC (AIC = 592.97, compared to 619.02 for the model without covariates), while maintaining adequate goodness of fit. The addition of Beaufort further improved the model (AIC = 584.97). The addition of group size did not improve model fit (AIC = 619.38), nor did any additional covariates. After including observations with missing perpendicular distances via bootstrapping (see "Calculation of abundance estimates" section), the gamma detection function yielded an overall effective strip half-width of 770 m (95% CI: 765 – 777 m) and an average probability of detection of 0.536 (95% CI: 0.532 – 0.541) (see Figure A3.1 in Appendix 3). Based on bootstrap results, the average expected group size varied from 1.00 to 11.00 during fall surveys, from 1.35 to 5.31 during winter surveys, and from 1.00 to 5.46 during spring surveys. The availability bias ranged from 0.380 to 0.686 between survey and strata, with an average value of 0.497 (see Table A4.1).

In total, 392 unique beluga sightings were recorded on-effort by the two observers positioned on the right side of the plane. Of those sightings, 112 were identified as duplicates between the primary and secondary observers on the right side of the plane, for a total of 352 unique sightings remaining for analysis after right truncation. The two components of the MRDS model were a conventional distance sampling detection function with a gamma key function and percent ice cover as a covariate, and an MRDS detection function with no added covariates. This model yielded a primary p(0) of 0.557 (CV = 0.093).

Abundance estimates for a given stratum and season were highly variable (see Table A5.1 in Appendix 5). In stratum 1, surface abundance indices not corrected for availability and perception biases ranged from 79 (2013, survey 1) to 1,283 animals (2020, survey 1) during fall surveys, from 37 (2019, survey 1) to 1,533 animals (2021, survey 2) during winter surveys, and from 145 (2015, survey 1) to 1,151 animals (2018, survey 2) during spring surveys. Correcting the surface abundance indices for both availability and perception biases increased these values by a factor of 3.64 on average. Fully corrected abundance estimates combining all strata surveyed in a given season and year ranged from 263 (2013) to 4,593 animals (2012) for fall surveys, from 1,452 (2013) to 4,311 animals (2021) for winter surveys, and from 518 (2015) to 3,667 animals (2014) for spring surveys.

The mean abundance estimates averaged over the 2012 – 2022 for spring, fall, and winter overlapped with the mean summer estimate (2,883 ind., CV = 0.523) for the 1990 – 2022 period. This suggested that most of the population was likely surveyed in all seasons in most years (Figure 7).

SEASONAL DISTRIBUTION AND HABITAT USE

Summer

The estimated 95% kernel density contour for the summer distribution covered almost the entire SLE from Battures aux Loups Marins to Rimouski/Colombier, with some extension east to Matane/Baie-Comeau (Figure 8). This general distribution pattern also persisted when the study period was split into the earlier (1990 – 2009) and more recent (2014-2022) period (Figure 9). Overall, a similar proportion of the population occupied the Lower SLE compared to the Upper SLE (45% vs 47%), with approximately 2% of the individuals seen in the Saguenay River (Table 2a). However, a decrease in use of the Upper SLE was noted in 2014 – 2022 compared to the 1990 – 2009 period (Table 2a, 2b).

A visual inspection of the final mean interannual kernel density estimates indicates a high degree of similarity in aggregation areas when comparing the two periods (Figure 9). Most of the high-use areas (50% and 75% kernel contours) identified in the Upper SLE and Lower SLE between the Saguenay River mouth and Saint-Simon/Les Escoumins were similar in both 1990 – 2009 and 2014 – 2022 (Figure 10). However, during the most recent period, higher densities of beluga were observed in the downstream portion of the summer range off Les Escoumins, throughout the Laurentian Channel, and in mid-SLE between Le Bic and Rimouski (Figures 10 and 11). This pattern was detected regardless of whether the most recent surveys that were conducted in July were included or not in the analysis (Figure 11). Herds of adult females with calves were partly responsible for this recent redistribution of animals within the summer range (Figure 12). It is not known if there has been an increase in the use of the Lower SLE east of Rimouski/Colombier given the limited survey effort for this sector during the 1990 – 2009 period (Table 2).

Most of the sightings in the Saguenay River were recorded in the vicinity or downstream of Baie-Sainte-Marguerite (94.8%), with observations becoming more scattered upstream of Ile St-Louis. The highest relative densities of beluga were located near Baie-Sainte-Marguerite, where 25% of all observations in the Saguenay River were made during summer. Further downstream, beluga were observed all along the Saguenay River, but several small peaks in density were noted at Cap de la Boule and Anse Saint-Étienne and slightly upstream of the Baie Sainte-Catherine/Tadoussac ferry crossing (Figure 5). No significant difference in summer distribution was observed between the periods 2001 – 2009 and 2014 – 2022.

Overall, calves were scattered throughout the SLE, except the Laurentian Channel (Figure 12). However, a greater proportion of them were observed in the Upper SLE. Specifically, 221 newborn or one-year-old calves detected during the 11 photographic surveys were observed in shallow waters (< 200 m depth), mostly (84%) between La Malbaie/Kamouraska and Les Bergeronnes/Trois-Pistoles, and east of Ile aux Coudres. Eight of the 10 calves detected downstream of Les Escoumins/Trois-Pistoles were observed during the 2019 surveys (see Figure A4.2). While newborn and one-year-old calves were also detected in the Saguenay River during the 2019 photographic survey, their distribution in this sector over the study period could not be assessed given all other surveys were only visually flown.

Fall, Winter and Spring

In fall and winter, the beluga distribution shifted east in the SLE, with an extension into the nwGSL (Figure 8). While sample size for fall surveys was small compared to winter surveys (n = 7 vs 21, respectively), available data indicated a range extent that was similar in both seasons. Observations spanned the Upper SLE from east of Ile aux Coudres to western Anticosti Island in the nwGSL. Within this range, however, differences were noted in core densities between the two seasons. While the average proportion of individuals occupying the Lower SLE was similar between in fall and winter (64 vs 63%), a marked decrease was observed in use of the Upper SLE compared to summer (44%), with 21% of the individuals being found in the Upper SLE in the fall, and 5% in winter. Kernel density estimates suggested that this decline was associated to a reduced use of habitats located west of La Malbaie. In contrast, an increase in use was noted for habitats downstream of the summer range, i.e., east of Colombier/Rimouski. The proportion of the population using the latter sector increased from 10 to 21% from fall to winter, and from 14 to 32% for the nwGSL (Table 3). During winter, a continuum of 50% kernel densities was observed throughout the Lower SLE, with additional aggregations in the nwGSL west of Sept-Iles/Rivière-à-Claude (Figure 8).

In spring, there was a westward shift in beluga distribution, with an average of 36% of the population returning to the Upper SLE, and 17% of the population remaining east of the summer range, including 2% in the nwGSL (Table 3). Survey data suggest that beluga distribution is most concentrated at that time of year, however, the small sample size for spring surveys (n = 6) calls for caution when interpreting these results and kernel densities. In the spring, 50% kernel density contours were scattered, and indicated aggregation areas between Battures aux Loups Marins and Kamouraska in the Upper SLE, off the mouth of the Saguenay River, west of Ile Verte, and in the Laurentian Channel between Les Escoumins and Rivière-aux-Outardes (Figure 8).

In the Saguenay River, beluga densities generally peaked near Baie-Sainte-Marguerite and near or downstream of Cap de la Boule in all seasons, except during winter when beluga were seen only in the latter area (Figure 5).

Overall, the spatial analysis of beluga densities indicates that the core of the SLE beluga distribution remains within the SLE boundaries year-round, and that beluga also use the downstream part of the Saguenay River in all seasons.

DISCUSSION

This study examined the seasonal distribution and habitat use of SLE beluga using data obtained from systematic visual and photographic line-transect aerial surveys collected over a period of 35 years. The spatiotemporal extent of this dataset enabled us to investigate how summer distribution has changed over the past few decades. This also provided a year-round understanding of the population’s distribution patterns across its entire range, allowing us to better quantify potential seasonal shifts towards the Lower SLE and nwGSL outside summer months, and to assess the importance of different parts of the St. Lawrence ecosystem for this population throughout the year.

Aerial survey coverage was designed to encompass the full extent of the SLE beluga's assumed seasonal range, as identified from historical records and more recent observations. Coverage of summer surveys was limited to the SLE where the population is known to concentrate at that time of year. Opportunistic beluga sightings have been rare outside the SLE, and only a few individuals have been detected despite the intensive survey effort recently deployed in eastern Canada, particularly in the GSL (Lawson and Gosselin 2009, Lesage et al. 2024a, St-Pierre et al. 2024c), suggesting our survey coverage for this season was adequate.

In fall, winter, and spring, our survey coverage was expanded to the GSL. Since the population's range outside of summer was not well known, we aimed to extend survey efforts across the entire northern GSL in winters of 2013 and 2014. However, unfavorable weather conditions and logistical constraints prevented full coverage of this area, leading us to prioritize areas where belugas have been reported in the past. Except for six additional surveys conducted over the SLE in winter 2014, all surveys conducted in fall, winter and spring covered the SLE and, at least partially, the nwGSL. These surveys also encompassed parts of the population's historical range, focusing primarily on offshore areas near the Gaspé Peninsula and Chaleur Bay, although less effort was dedicated to Chaleur Bay in the fall. The northeastern GSL was also partially surveyed twice, in the winters 2013 and 2014.

Beluga were detected in the SLE in every survey and were regularly observed in the nwGSL, especially during winter. Sightings were rare in the stratum just off Gaspé, with beluga recorded in only one fall survey, and absent from Chaleur Bay. Despite limited coverage of the Honguedo Strait, just south of Anticosti, beluga were regularly observed in this area at least during winter (not surveyed in other seasons). Uneven survey effort and gaps in coverage introduce uncertainties in our understanding of the fine-scale seasonal distribution patterns of the population. Nevertheless, repeated coverage of the SLE and nwGSL, along with enhanced effort in the SLE during winter 2014, provides robust data for understanding the winter distribution of the population. However, the limited number of surveys conducted in fall (n = 7) and spring (n = 6) call for caution when interpreting results of both the abundance and spatial analyses related to these seasons.

Although opportunistic sightings outside our survey areas were few (Lesage et al. 2024a), they indicate that a portion of the population might not have been captured by our fall, winter, and spring surveys. However, if any part was missed, this portion is likely small, as suggested by, the comparison of seasonal abundance estimates. Although correcting for availability bias improved our abundance estimates, the absence of dive data specific to the environmental conditions and behaviour of beluga prevailing during the fall, winter and spring remains a caveat to our study. Beluga diving behaviour can vary with seafloor depth (Lesage et al. 2024b) and seasonal habitats and their characteristics (Bailleul et al. 2012, Citta et al. 2013, Storrie et al. 2022). Understanding the seasonal diving behaviour of beluga in various parts of their annual habitat and its effects on availability would help better estimate the seasonal abundance of the population in various sectors, hence the spatial distribution of the population (see Lesage et al. 2024b).

Another source of bias in our estimate of habitat use comes from the Saguenay counts. The approach we proposed to estimate the number of beluga in the Saguenay River provided a systematic and reproducible methodology. However, it only applied a minimum correction for availability, in estimating the largest number of unique animals observed during two successive surveys (up and down the River). This correction assumed that all beluga present were seen on one of these two surveys, which is unlikely to be the case due to the depth of the River. A more thorough analysis of the Saguenay River counts, including the development of availability bias corrections specific to this sector, might be warranted in the future to better assess the seasonal significance of this area for SLE beluga.

Kernel density estimation helps define both the distribution and the density of a species across its range (Worton 1995). Combining data from different surveys in a single analysis, however, generally requires that survey effort be consistent across the entire study area. Unfortunately, in the case of the SLE beluga, spatial coverage varied between surveys and seasons. To overcome this problem and avoid loss of information, we developed an approach that weights spatial distribution according to both the temporal and spatial coverage of the area. Overlaying kernel density maps allowed us to identify areas that were repeatedly used across surveys, both within and between seasons and to characterize seasonal distribution patterns of the SLE beluga. The analysis delimited regions of various importance where 50% kernels contours highlighted areas where beluga were consistently observed year after year, 75% kernels contours represented areas used on a more occasional basis or for shorter periods (transit behaviour for instance), or by lesser densities of animals, while the 95% kernel contour likely delineate the home range, or the seasonal extent, of the population.

The visual inspection of the resulting maps suggested that the seasonal distribution patterns observed in the SLE and GSL were largely consistent with previous knowledge of SLE beluga distribution throughout their annual range. As documented in earlier studies, beluga were observed almost continuously in the SLE in summer from Battures aux Loups Marins to Colombier/Rimouski, with a distribution centered on the Saguenay River, and to Baie-Ste-Marguerite or slightly upstream (Ile St-Louis) in the Saguenay River (Michaud 1993, Mosnier et al. 2016, Simard et al. 2023). The extent of the summer habitat remained unchanged over the period 1990 – 2022. Furthermore, most of the areas intensively used in summer (50% population kernel contours) between 1990 and 2009 continued to be used between 2014 and 2022, indicating strong site fidelity to these areas, which are likely of high importance for maintaining the population. This relative stability in summer distribution over decades has also been supported by acoustic data (Simard et al. 2023). However, our analyses also revealed that distribution of SLE beluga within their summer range has shifted over the past decade, with a noticeable decline in the use of habitats located at the western end of their range, and a concomitant increase in the use of habitats located further downstream in the Lower SLE, between Saint-Simon/Les Escoumins and Colombier/Rimouski. Although some recent surveys were conducted earlier than in the previous period (end of July vs August-early September), this difference in timing did not explain the observed shift as the latter remained visible when the July surveys were removed from the analysis. Evidence for this shift is also supported by dietary studies, indicating a greater reliance on prey from the Lower SLE in recent years (Rioux et al. 2023; Cabrol et al. 2025). Photographic surveys, which allow the identification of 0-1 year-old calves, indicate that females with calves do contribute to the observed shift in distribution. Reasons behind these observations are unclear. Environmental conditions have considerably changed in the SLE and GSLwith unusually warm water temperatures noted since 2010 (Plourde et al. 2014; Galbraith et al. 2022). Whether these warmer conditions during summer have affected prey availability in the Upper SLE where water depths are particularly shallow, or whether they might cause physiological discomfort for beluga, an Arctic species, is unknown.

Beluga used the SLE year-round, and used the SLE from Kamouraska/Saint-Fidèle to Colombier/Rimouski, and the sector downstream of Cap de La Boule in the Saguenay River as their core area. Seasonal movements were observed, that align with historical data as well as more recent observations obtained from visual land-based and passive acoustic monitoring (Vladykov 1944, Pippard et Malcom 1978, Michaud and Chadenet 1990, Michaud 1992, Chadenet 1997, Conversano et al. 2017, Simard et al. 2023). Our systematic coverage of the Lower SLE and nwGSL also support historical observations suggesting that beluga distribution extends beyond coastal areas (Vladykov 1944; DFO 2012). During fall and winter, beluga were detected in offshore areas of the Lower SLE and nwGSL. In addition, sightings recorded during spring surveys in the northern GSL in 2014 and 2018, suggested that part of the population occasionally remained or moved through this region during this season. Beluga made a regular use of the Upper SLE during winter in our study, suggesting that a larger proportion of the population than previously thought may use this area during winter. Similarly, Simard et al. (2023) reported an increase of vocalizations in this area in March, possibly reflecting a return of beluga in this area. Opportunistic sightings reported in the most upstream part of the Upper SLE throughout the year also support the use of this area year-round (Lesage et al. 2024a). Whether the use of the Upper SLE during winter is a population trait or whether it results from the recent change in sea-ice coverage in the area is unknown given that our time series was initiated in 2012 and thus, after the general warming of the ecosystem. Ice cover is thought to be a key factor driving the seasonal movements of beluga (Barber et al. 2001). Warming trend of the water temperature in the St. Lawrence ecosystem observed over the last decades has resulted in delayed sea-ice formation and reduced sea-ice extent (Galbraith et al. 2022), factors that may have contributed to the increased use of the Upper SLE during winter. The timing of surveys may have contributed to these observations, as most winter sightings in the Upper SLE occurred in March, i.e. closer to spring. Visual examination of ice charts suggested that beluga sightings in the Upper SLE during fall and winter corresponded with areas of low ice coverage. Further research is needed to assess how environmental factors such as sea-ice influence the seasonal distribution of SLE beluga.

In a previous study, kernel densities obtained from aerial surveys conducted prior to 2010 were used in a spatial modelling exercise in an attempt to link SLE beluga distribution to environmental variables (Mosnier et al. 2016). However, no significant relationship was found, possibly due to the resolution of the environmental data available for the SLE, which was probably too low to accurately represent the highly dynamic and heterogeneous ecosystem, and the variety of habitats that beluga use. Additionally, information on prey distribution was either lacking or did not align with the spatial and temporal coverage of the study area. Since data availability has not improved in this area, we did not attempt to replicate that study. Comparison with other data sources can, however, provide insights into the ecological functions of areas used by the SLE beluga. Many of the areas revealed by the kernel maps of our study as intensively used by beluga in summer likely serve for foraging or transiting, as they align with high-residency areas (i.e. a geographic zone where individuals or herds spend a disproportionately large amount of time, as indicated by fine-scale tracking or movement data) and travel corridors identified through behavioural studies conducted between 1989 and 2016 (Figure 13 and Figure 14; Lemieux-Lefebvre et al. 2012, Ouellet et al. 2021; Barreau et al. accepted). These areas should thus be considered as important habitat for the population. To further improve our knowledge, it would be important to assess the habitat characteristics of the core areas identified in this study as it could help estimate the quality and availability of resources necessary to support specific life processes of SLE beluga. Moreover, more recent telemetry data would help quantify the change in beluga habitat use in the SLE in recent years, and determine the functions of the different areas we have identified as important in other seasons. As a species listed under the Canadian *Species at Risk Act*, the SLE beluga benefits from legal protection of its Critical Habitat. Maps presented here are based on systematic surveys that covered a region encompassing the range of the population in all seasons. This is the most precise and extensive representation of the SLE beluga distribution currently available, and a critical source of information for the development of efficient conservation measures.

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TABLES

Table 1. Survey effort and number of beluga or beluga groups detected in each stratum during systematic photographic and visual aerial line-transect surveys conducted in the Estuary and Gulf of St. Lawrence during summer (1990 – 2022, 1990 – 2009, and 2014 – 2022) and in other seasons (2012–2023). Numbers in parentheses indicate the minimum and maximum values recorded for each period, while bolded numbers represent the overall statistic for each period.

Season	Stratum	Numbers of Survey	Groups		Individuals	
			Number	Average	Number	Average
Summer						
1990 – 2022	1	60	6032	101 (23 – 287)	13720	229 (44 – 471)
	2	15	58	3 (0 – 24)	313	20 (0 – 140)
	-	**60**	**6990**	**102 (23 – 287)**	**14033**	**234 (44 – 471)**
1990 – 2009	1	35	3536	101 (23 – 287)	6936	198 (44 – 311)
	2	3	17	6 (0 – 17)	27	9 (0 – 27)
		35	**3553**	**102 (23 – 287)**	**6963**	**199 (44 – 311)**
2014 – 2022	1	25	2496	100 (34 – 185)	6784	271 (58 – 471)
	2	12	41	3 (0 – 24)	286	24 (0 – 140)
	-	**25**	**2537**	**101 (36 – 185)**	**7070**	**283 (60 – 471)**
Fall	1	7	224	32 (6 – 67)	551	79 (9 – 184)
	2	7	14	2 (0 – 8)	49	7 (0 – 26)
	3	6	3	1 (0 – 3)	4	1 (0 – 4)
	5	6	0	0 (0 – 0)	0	0 (0 – 0)
	-	**7**	**241**	**34 (6 – 68)**	**604**	**86 (9 – 202)**
Winter	1	21	653	(–)	1752	(–)
	2	14	122	(–)	382	(–)
	3	13	0	0 (0 – 0)	0	0 (0 – 0)
	4	2	0	0 (0 – 0)	0	0 (0 – 0)
	5	10	0	0 (0 – 0)	0	0 (0 – 0)
	6	1	0	0 (0 – 0)	0	0 (0 – 0)
	7	2	2	1 (0 – 2)	9	5 (0 – 9)
	8	1	0	0 (0 – 0)	0	0 (0 – 0)
	-	**21**	**777**	**37 (8 – 69)**	**2143**	**102 (20 – 242)**
Spring	1	6	260	43 (11 – 99)	621	103 (27 – 190)
	2	6	4	1 (0 – 3)	17	3 (0 – 16)
	3	5	0	0 (0 – 0)	0	0 (0 – 0)
	5	5	0	0 (0 – 0)	0	0 (0 – 0)
	-	**6**	**264**	**44 (11 – 102)**	**638**	**106 (27 – 203)**

Table 2. Fully-corrected abundance estimates for St. Lawrence Estuary beluga, presented per survey year for fall, winter and spring.

Year	Season	Covered strata	Abundance estimate (95% CI)	CV
2012	Fall	1, 2, 3	4,593 (1,652 – 1,277)	0.56
2013	Winter	1, 2, 3, 4, 5, 7	1,529 (670 – 3,490)	0.44
	Spring	1, 2	1,689 (478 – 5,971)	0.78
	Fall	1, 2, 3	263 (83 – 833)	0.64
2014	Winter	1, 2, 3, 4, 5, 6, 7, 8	1,452 (1,028 – 2,050)	0.18
	Spring	1, 2, 3, 5	3,667 (1,886 – 7,130)	0.35
	Fall	1, 2, 3	3,287 (1,474 – 7,334)	0.43
2015	Winter	1, 2, 3, 5	2,571 (1,163 – 5,683)	0.42
	Spring	1, 2, 3, 5	518 (156 – 1,713)	0.67
2018	Winter	1, 2	3,292 (1,709 – 6,340)	0.34
	Spring	1, 2, 3, 5	2,924 (1,688 – 5,068)	0.29
	Fall	1, 2	746 (308 – 1,802)	0.47
2019	Winter	1, 2, 3, 5	2,388 (1,508 – 3,783)	0.24
	Spring	1, 2, 3, 5	877 (414 – 1,856)	0.40
	Fall	1, 2, 3, 5	1,124 (371 – 3,408)	0.61
2020	Winter	1, 2, 3, 5	3,122 (1,484 – 6,567)	0.39
	Fall	1, 2, 3, 5	3,122 (1,707 – 5,711)	0.32
2021	Winter	1, 2, 3, 5	4,311 (2,826 – 6,575)	0.22
2022	Winter	1, 2, 3, 5	2,222 (1,314 – 3,758)	0.27
2023	Winter	1, 2, 3, 5	2,932 (1,702 – 5,051)	0.28

Table 3. Average proportion (in %, ± standard deviation) of the St. Lawrence Estuary beluga population detected in different parts of the St. Lawrence ecosystem during systematic photographic and visual aerial line-transect surveys conducted in summer of 1990 – 2022, 1990 – 2009 and 2014 – 2022, and in other seasons during 2012 – 2023 . Sectors are as defined by a) Mosnier et al. (2016) and b) Simard et al. (2023), including the Saguenay River (Figure 1).

a)

Season	Upper SLE	Saguenay River to Colombier/Rimouski	Colombier/Rimouski to Pointe-des-Monts/Les Méchins	Northwestern Gulf	Saguenay River
Summer					
1990 – 2022	44.8 ± 12.8	46.7 ± 12.7	7.1 ± 11.3	-	1.7 ± 0.6
1990 – 2009	46.4 ± 10.6	45.9 ± 10.6	6.5 ± 11.0	-	1.2 ± 0.8
2014 – 2022	42.3 ± 15.6	48.1 ± 15.6	7.2 ± 11.9	-	2.4 ± 3.4
Fall	21.3 ± 19.5	53.9 ± 17.4	10.3 ± 14.5	14.4 ± 16.7	0.0 ± 0.0
Winter	5.0 ± 6.1	41.8 ± 16.1	21.4 ± 13.7	31.8 ± 28.4	0.0 ± 0.0
Spring	35.5 ± 23.9	45.4 ± 12.3	16.9 ± 15.5	2.1 ± 4.7	0.1 ± 0.2

b)

Season	Upstream	Center	Donwstream	Le Bic/Portneuf -sur-Mer to Colombier/ Rimouski	Colombier/Rimouski to Pointe-des-Monts/Les Méchins	Northwestern Gulf	Saguenay River
Summer							
1990 – 2022	35.4 ± 12.7	37.1 ± 14.3	13.7 ± 11.1	4.5 ± 8.0	7.1 ± 11.3	-	1.7 ± 0.6
1990 – 2009	37.4 ± 9.4	38.4 ± 12.9	12.7 ± 9.2	3.8 ± 8.2	6.5 ± 11.0	-	1.2 ± 0.8
2014 – 2022	32.9 ± 16.8	36.0 ± 16.8	15.5 ± 13.7	5.9 ± 7.8	7.2 ± 11.9	-	2.4 ± 3.4
Fall	20.5 ± 19.8	20.9 ± 19.1	24.9 ± 14.8	9.1 ± 10.1	10.3 ± 14.5	14.4 ± 16.7	0.0 ± 0.0
Winter	3.7 ± 4.3	13.3 ± 11.9	17.1 ± 14.1	12.6 ± 9.4	21.4 ± 13.7	31.8 ± 28.4	0.0 ± 0.0
Spring	33.2 ± 24.1	9.4 ± 10.6	21.5 ± 17.0	16.7 ± 18.6	16.9 ± 15.5	2.1 ± 4.7	0.1 ± 0.2

FIGURES

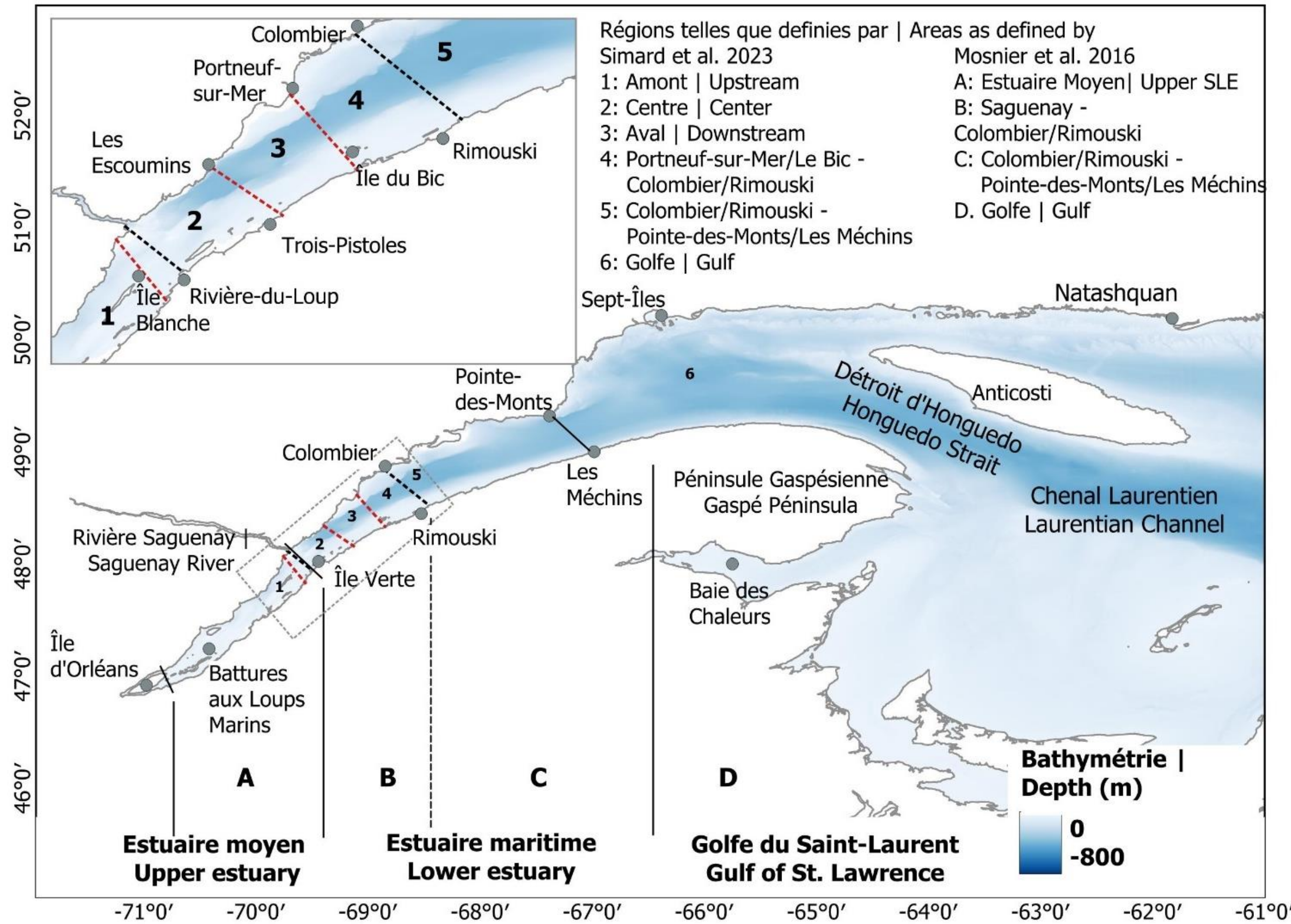

Figure 1. Study area, with bathymetry, showing the separation (solid lines) between the Upper and the Lower Estuary and the Gulf of St. Lawrence. The black and the red dashed lines referred respectively to the zones following the delimitation used by Mosnier et al. (2010) and Simard et al. (2023).

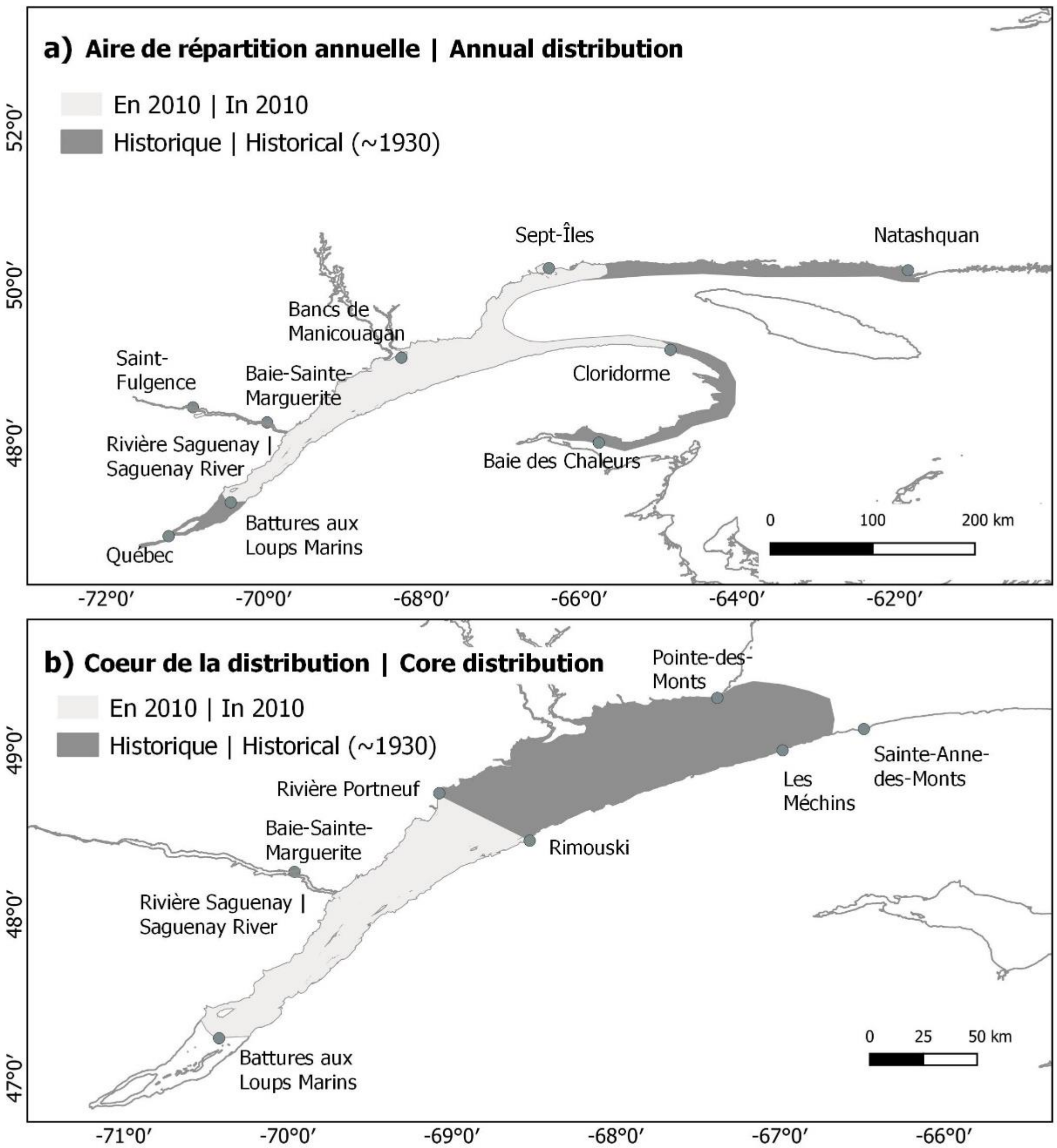

Figure 2. Total (a) and core area (b) of the annual distribution of St. Lawrence Estuary beluga as assess historically (1930s; Vladykov 1944) and in 2010 (Mosnier et al. 2010).

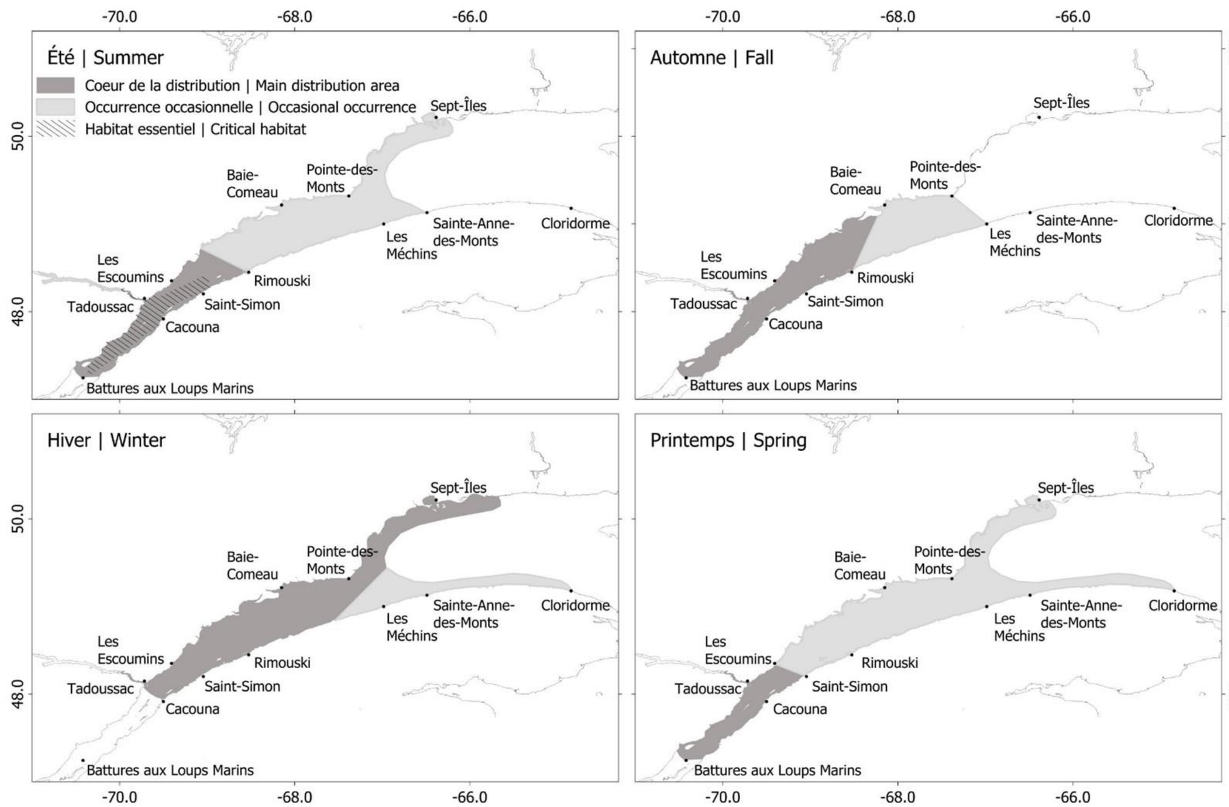

Figure 3. Seasonal variation in the distribution of St. Lawrence Estuary beluga, as reported in 2012 (Mosnier et al. 2010; DFO 2012).

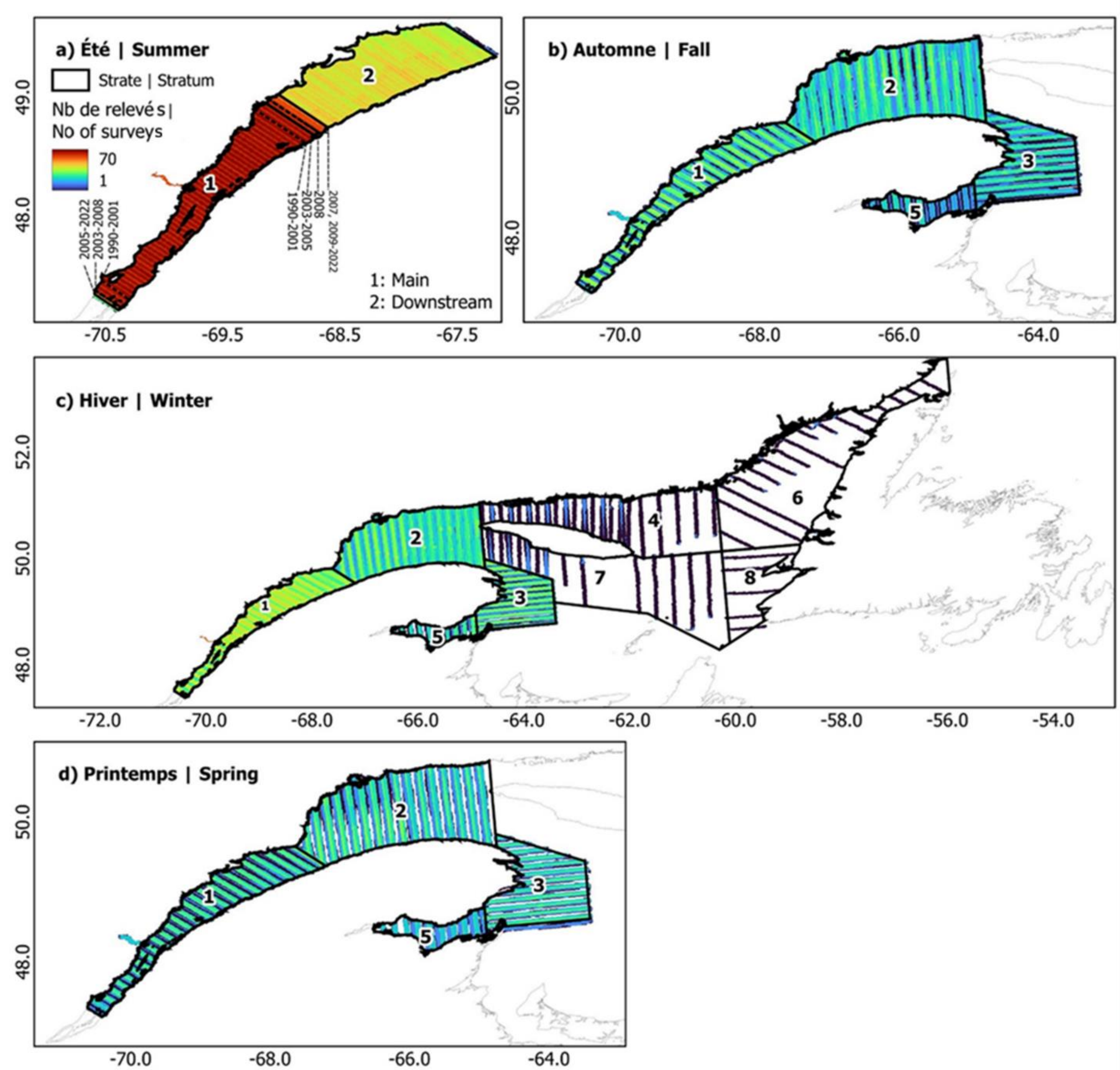

Figure 4. Number of systematic line-transect aerial surveys covering the strata over the Estuary and Gulf of St. Lawrence in (a) summer of 1990 – 2022, and in the (b) fall, (c) winter and (d) spring of 2012 – 2023. Dotted lines in panel a) indicate the limits of the Main stratum according to years. All panels are displayed using the same color scale to facilitate direct comparison.

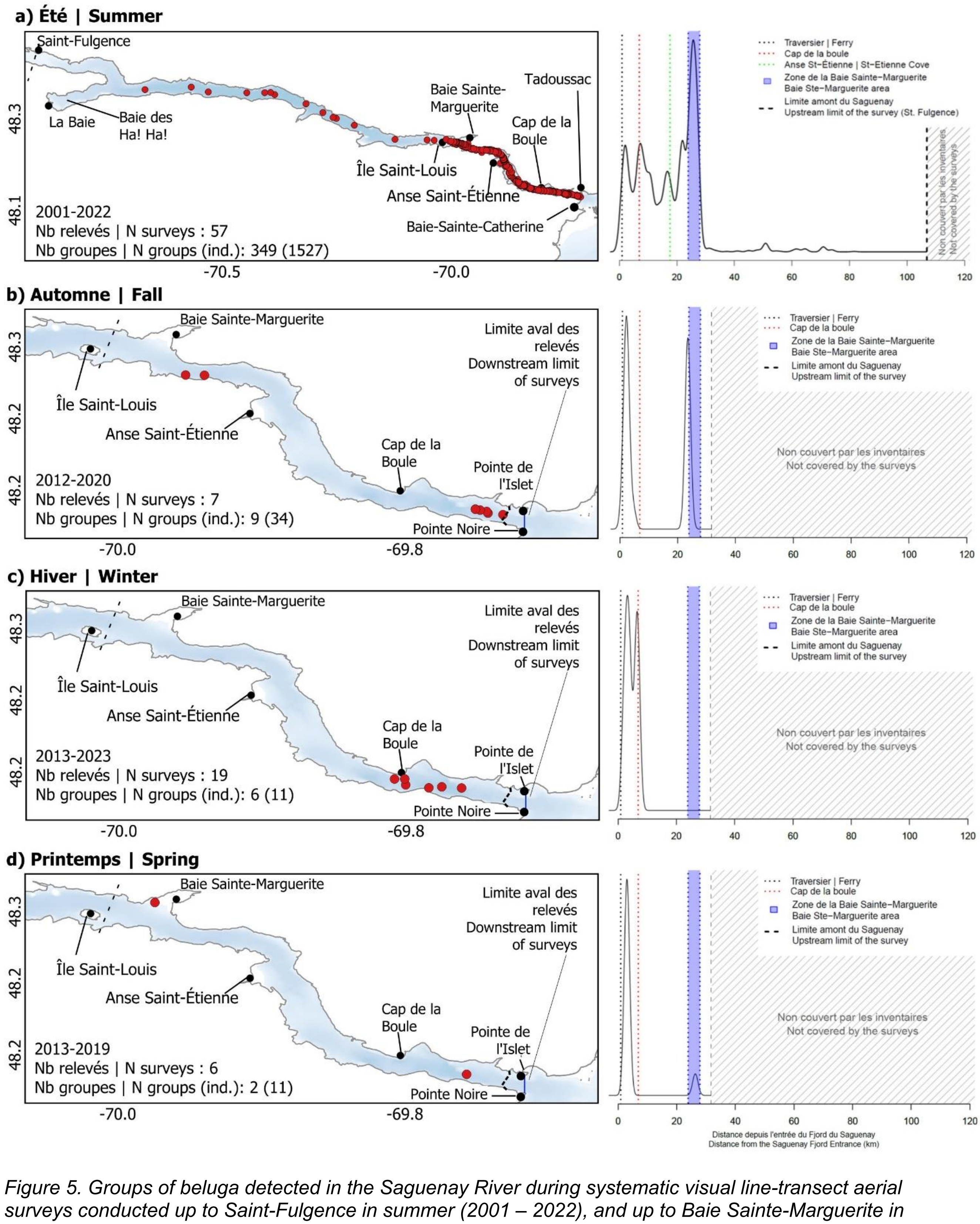

Figure 5. Groups of beluga detected in the Saguenay River during systematic visual line-transect aerial surveys conducted up to Saint-Fulgence in summer (2001 – 2022), and up to Baie Sainte-Marguerite in fall (2012 – 2020), winter (2013 – 2023) and spring (2013 – 2019). Relative beluga densities along the main axis of the Saguenay River are also presented (right panels).

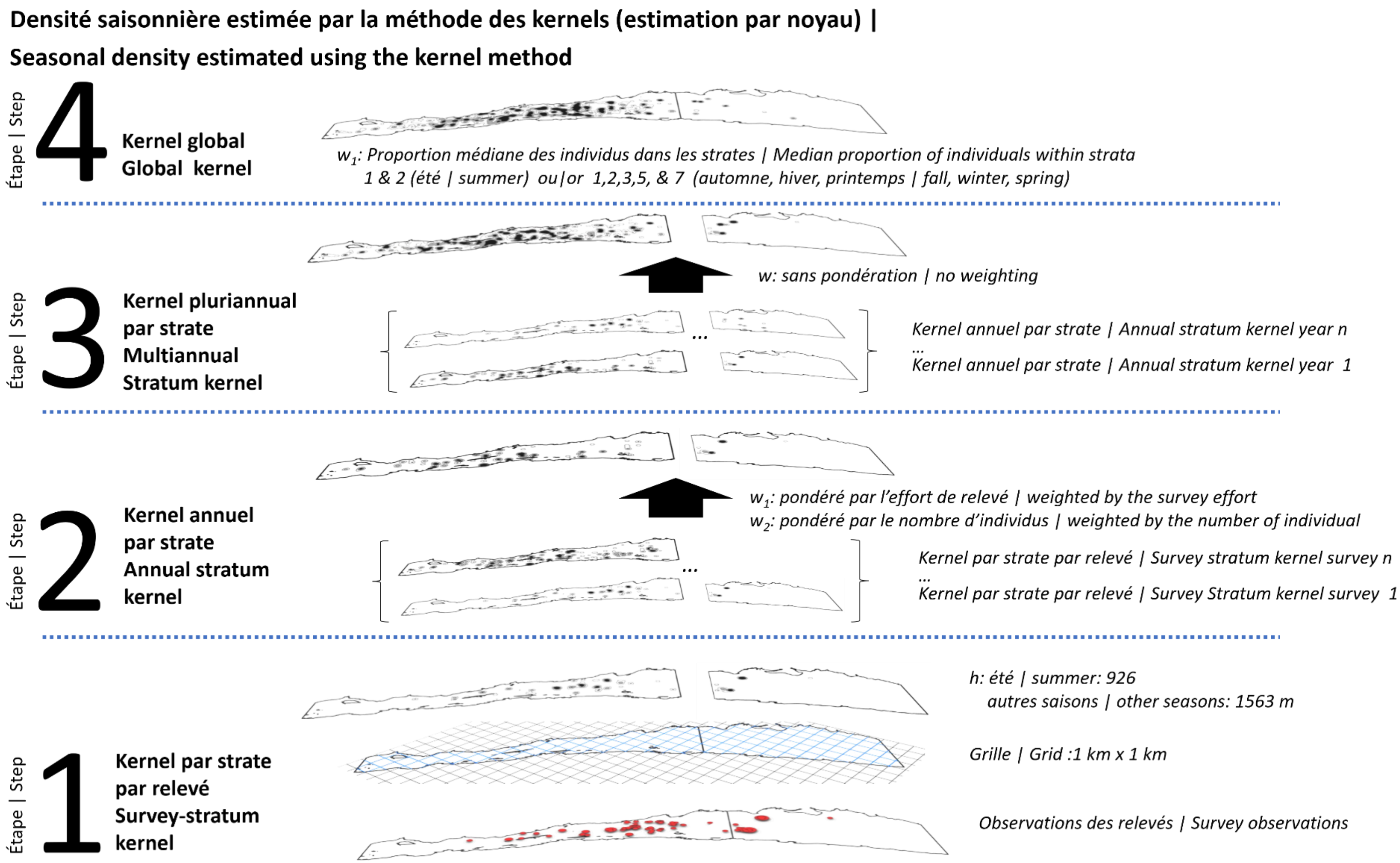

Figure 6. Schematic representation of the different steps of the method used to estimate the seasonal density of St. Lawrence Estuary beluga population using two-dimension kernel analyses.

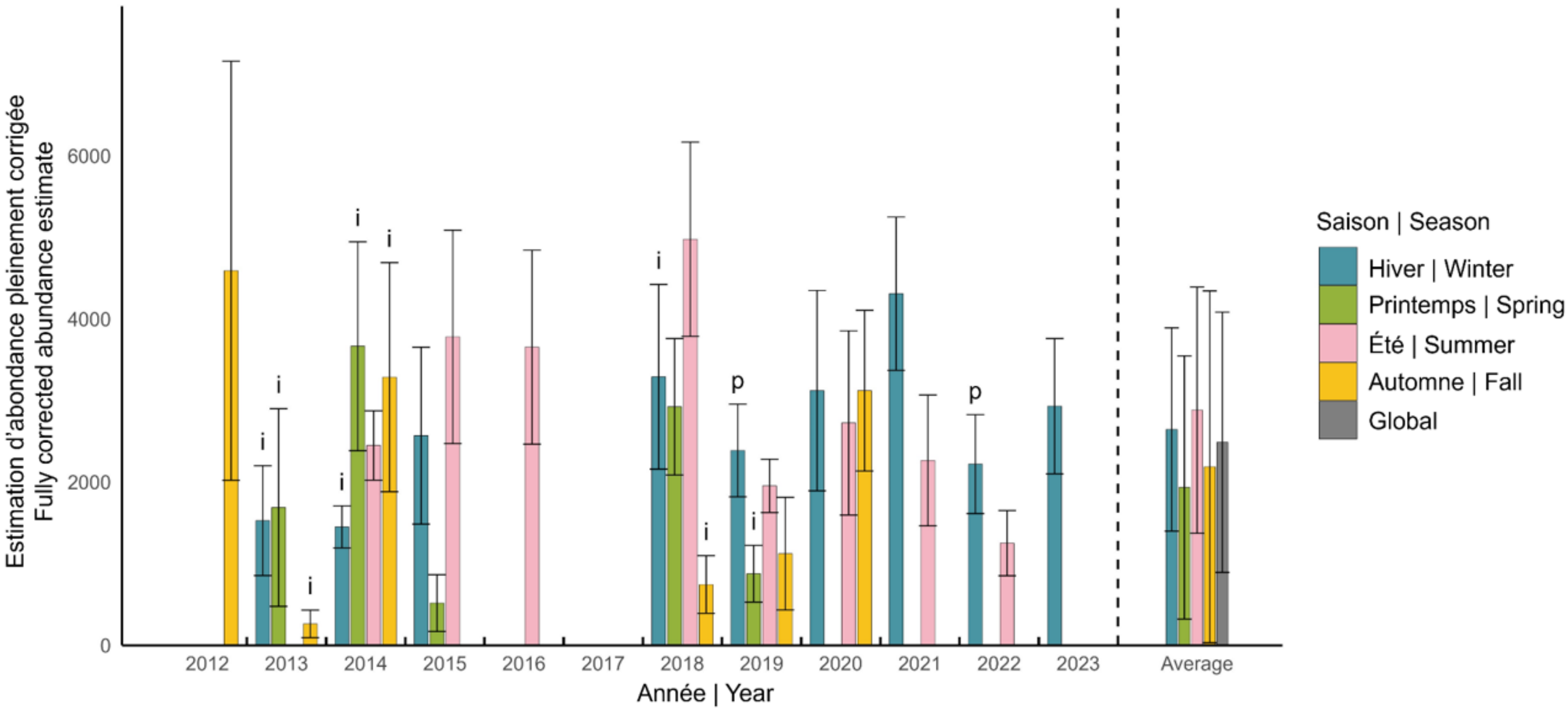

Figure 7. Fully corrected abundance estimates (and SEs) from systematic line-transect visual aerial surveys conducted in the Estuary and Gulf of St. Lawrence in the fall, winter, and spring during the period 2012 –2023. Summer abundance estimates are also included for comparative purposes. Bars from fall, winter, and spring surveys identified with "i" indicate that although strata 1, 2, 3, and 5 were surveyed, coverage of at least one of these strata was incomplete (i.e., no survey provided complete coverage). Similarly, bars identified with a "p" indicate a partial survey coverage of strata 1, 2, 3, and 5 (i.e.,. at least one survey was fully completed but some were not). The gray bar represents the global average (i.e., all seasons averaged).

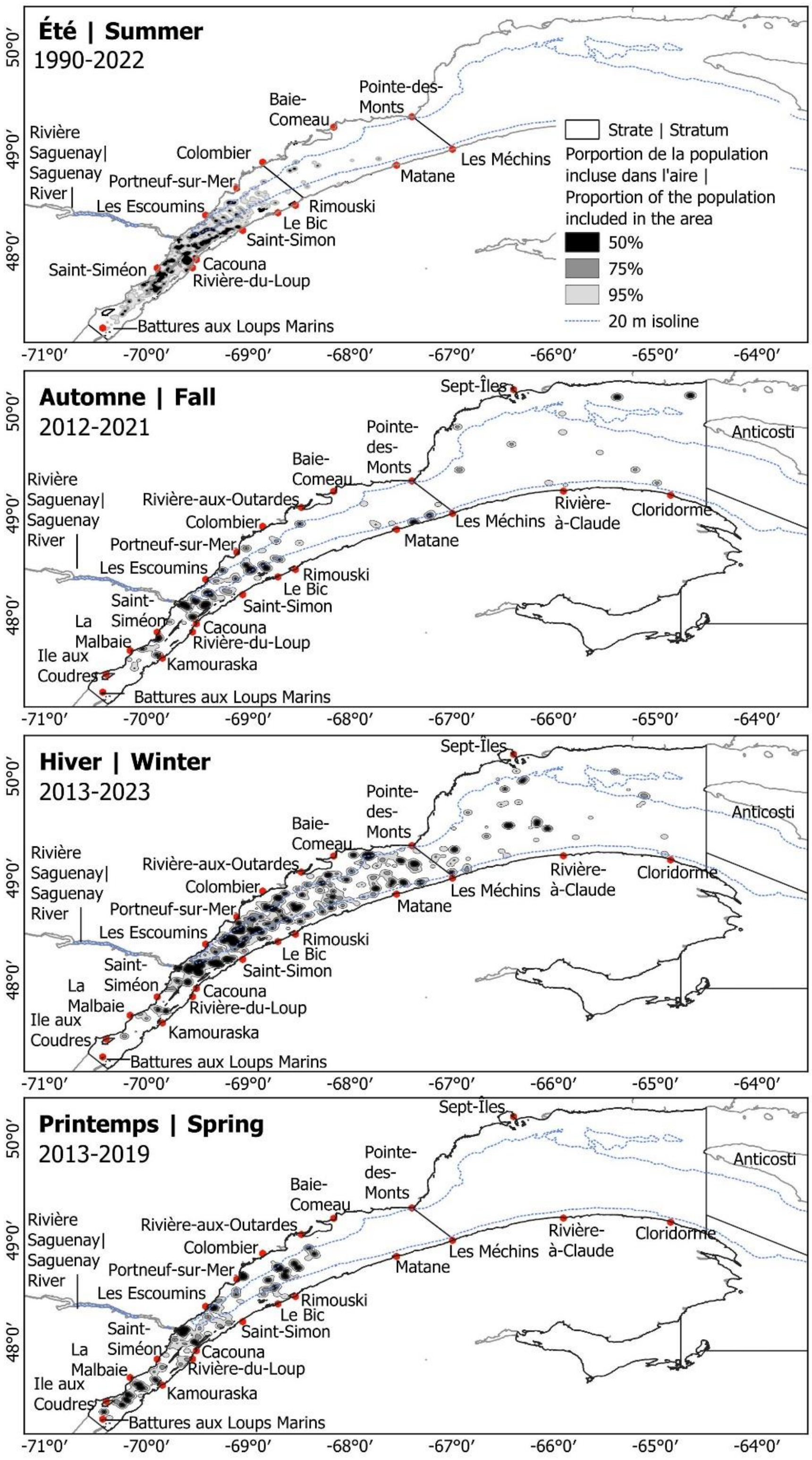

Figure 8. Areas including 50, 75 and 95% of the St. Lawrence Estuary beluga population obtained by the two-dimensional kernel method using detections from systematic photographic and visual line-transect aerial surveys conducted over the Estuary and the Gulf of St. Lawrence in summer (1990 – 2022), fall (2013 – 2020), winter (2013 – 2023) and spring (2013 – 2019).

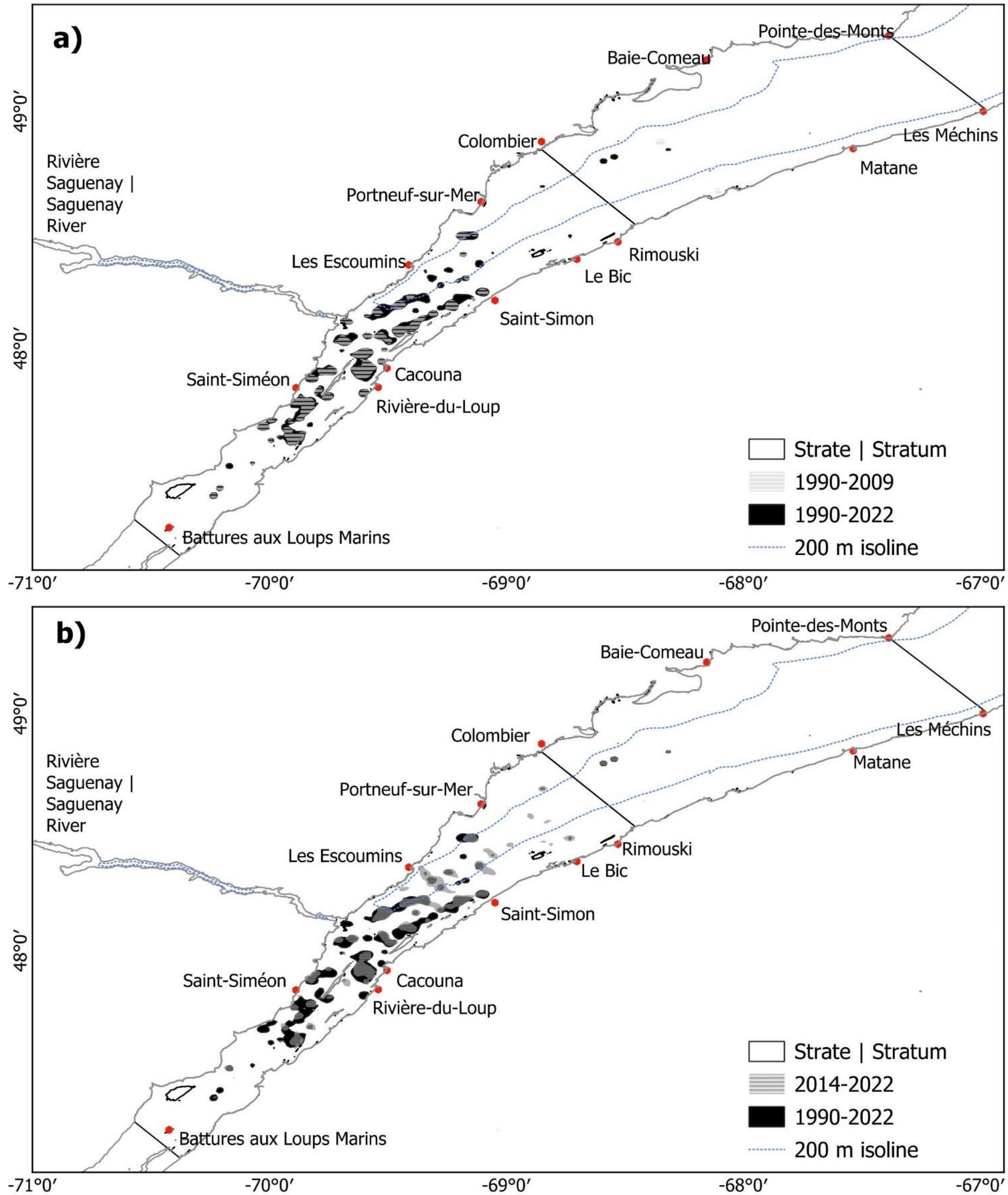

Figure 9. Overlap of areas including 50% of the St. Lawrence Estuary beluga population obtained by the two-dimensional kernel method using detections from systematic photographic and visual line-transect aerial surveys conducted in summer over the St. Lawrence Estuary in 1990-2022 compared to the kernels from a) 1990 – 2009 and b) 2014 – 2022.

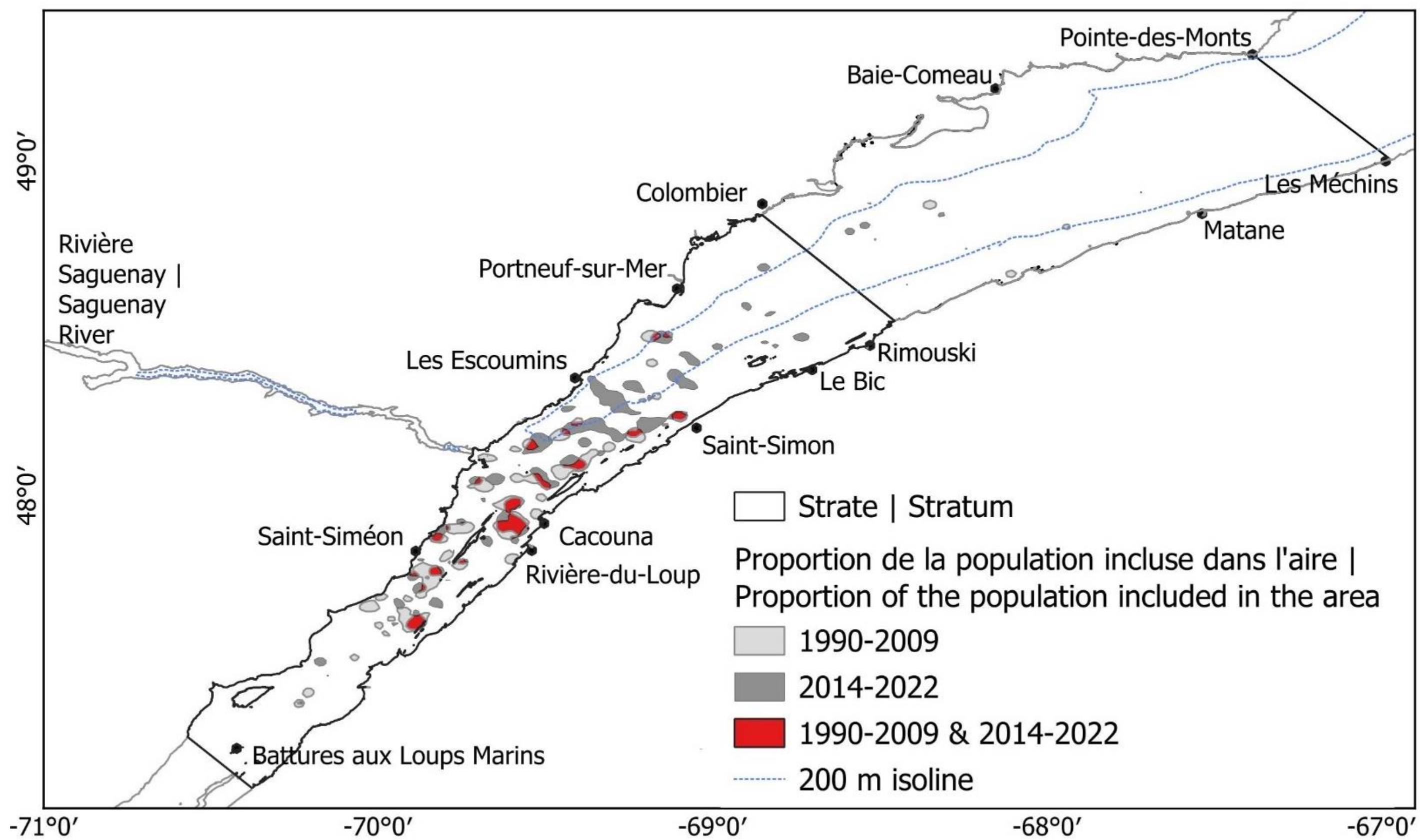

Figure 10. Overlap of areas including 50% of the St. Lawrence estuary beluga population obtained by the two-dimensional kernel method from beluga detected during systematic photographic and visual line-transect aerial surveys conducted in summer 1990 – 2009 and 2014 – 2022.

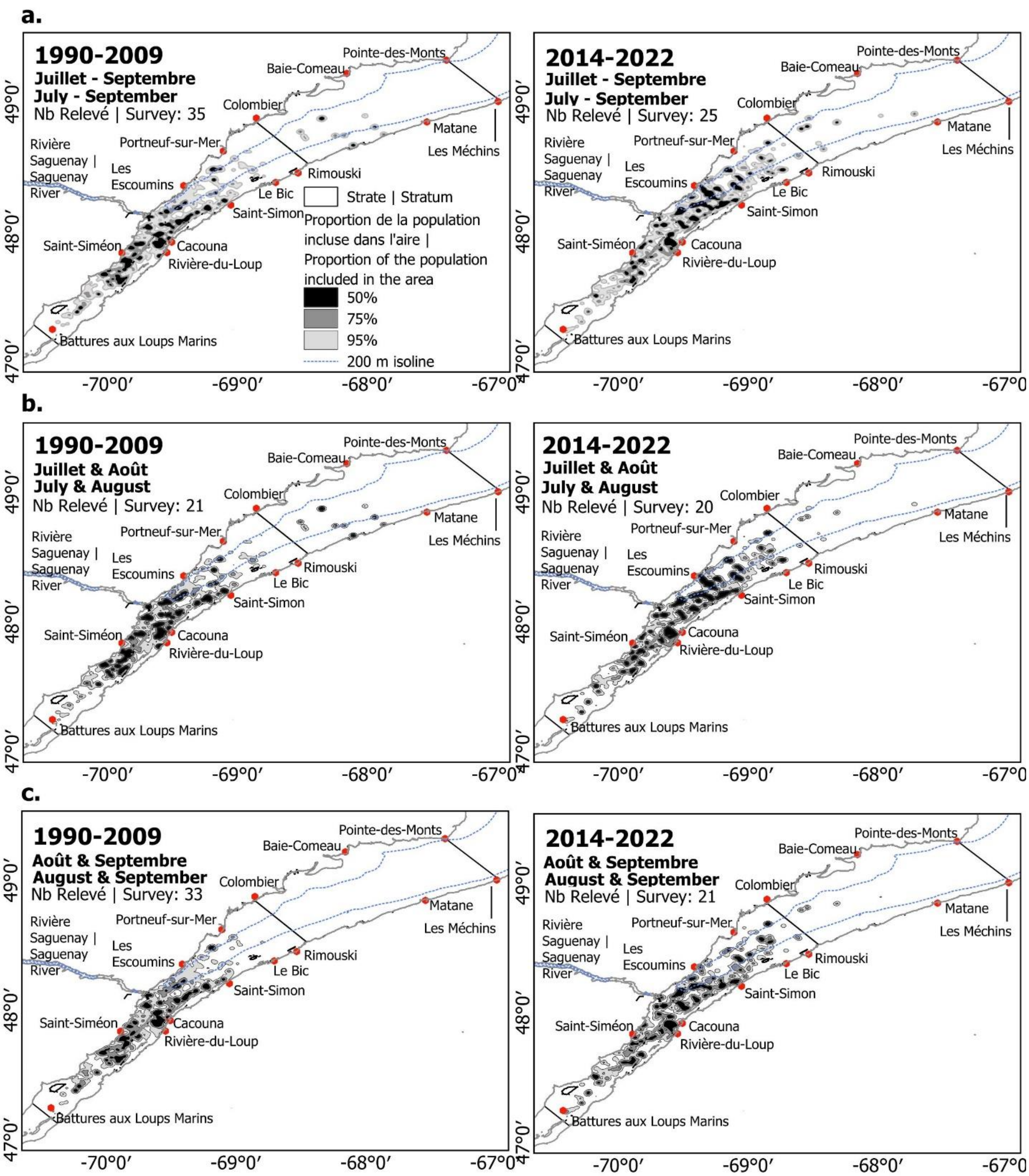

Figure 11. Areas including 50, 75 and 95% of the St. Lawrence estuary beluga population obtained by the two-dimensional kernel method using detections from systematic photographic and visual line-transect aerial surveys conducted in 1990 – 2009 (left panels) and 2014 – 2022 (right panels), using a) all summer surveys (July, August and September), b) only July and August surveys, and c) only August and September surveys. Strata delimitation is also presented. No survey was conducted over the Downstream stratum in August and September between 1990 and 2009.

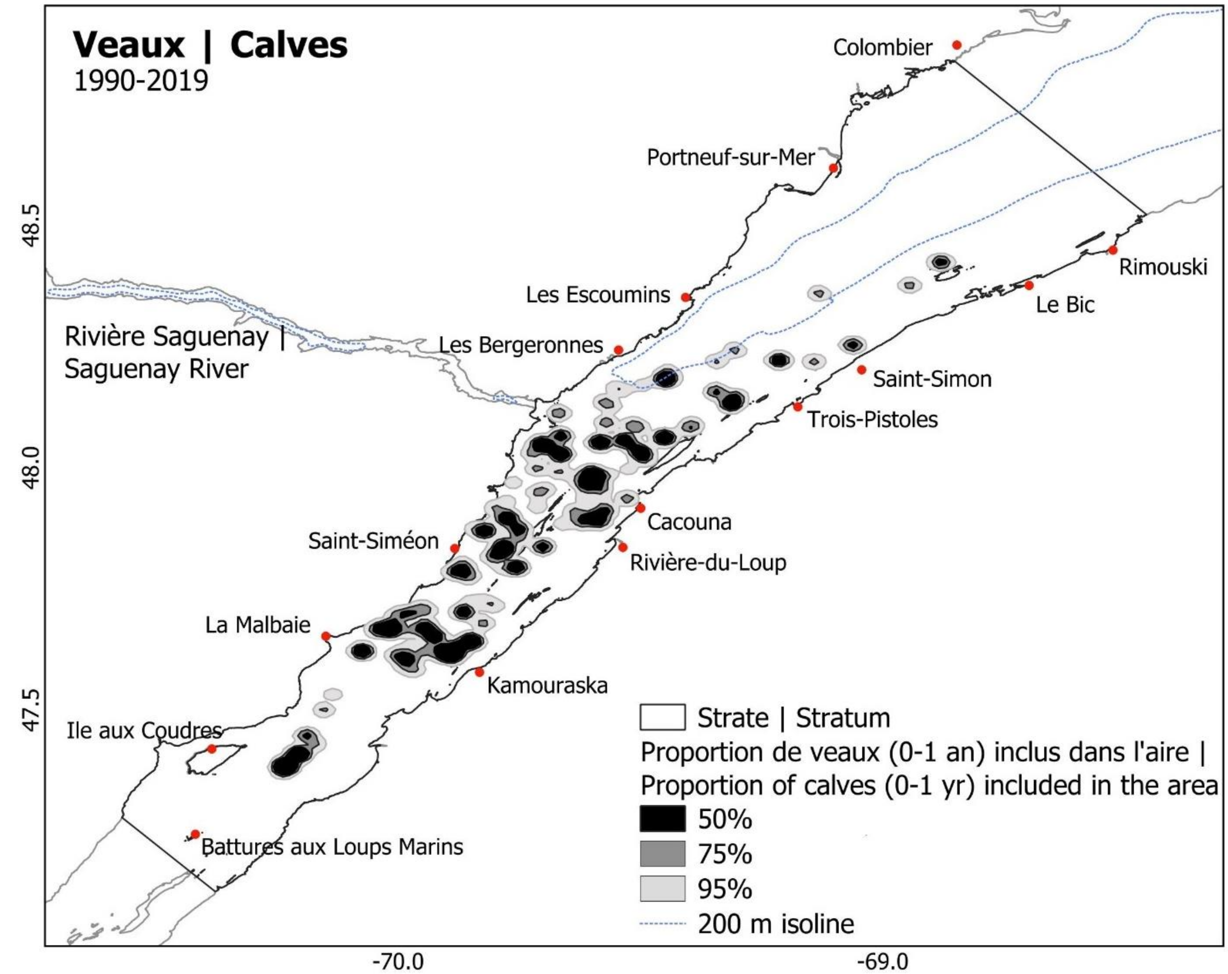

Figure 12. Areas including 50, 75 and 95% of the St. Lawrence estuary beluga calves (0 and 1 year-olds) population obtained by the two-dimensional kernel method using detections from systematic photographic line-transect aerial surveys conducted in summer over the Main stratum in 1990 – 2019.

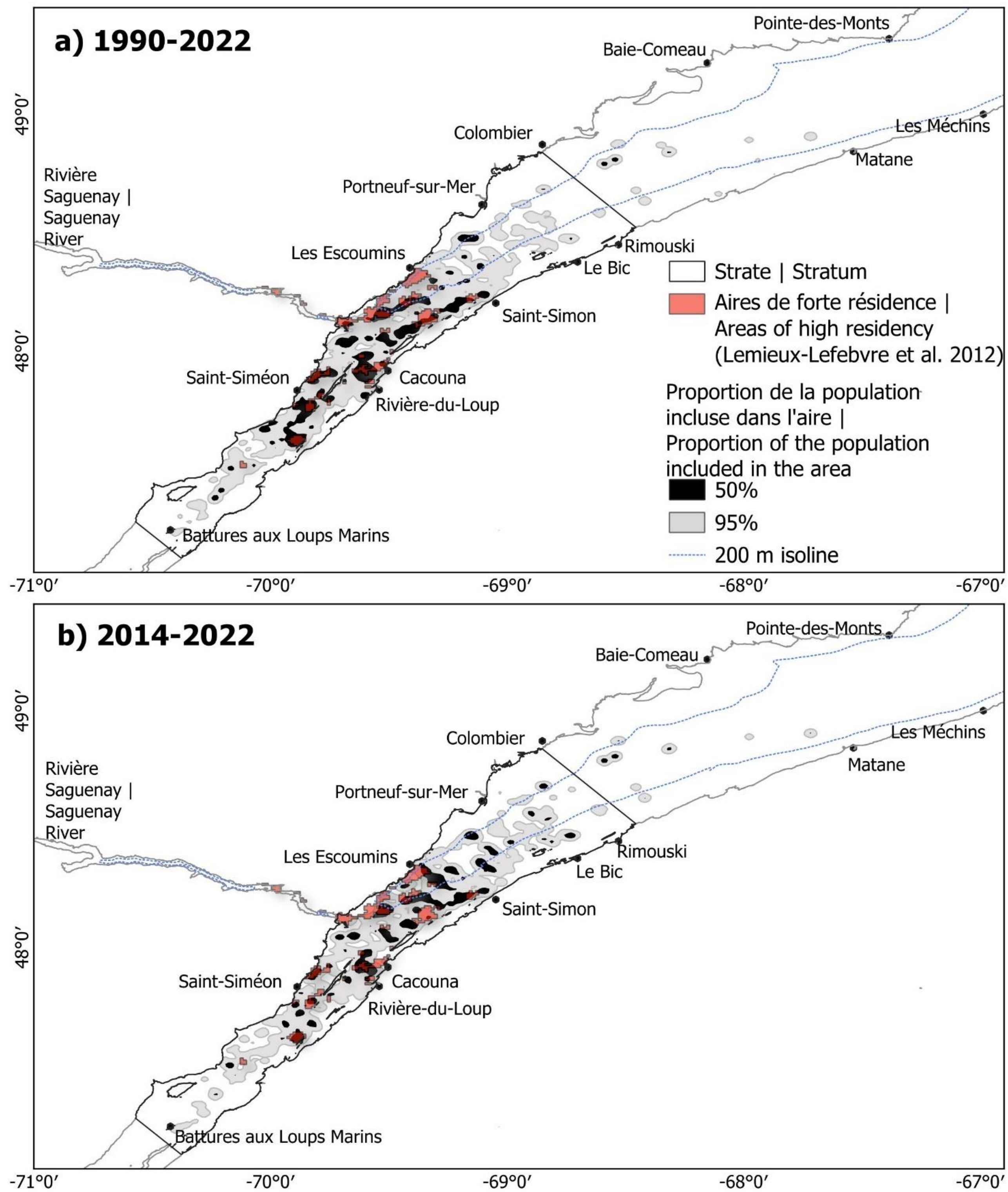

Figure 13. Comparison between areas including 50 and 95% of the St. Lawrence estuary beluga population obtained by the kernel method from systematic photographic line-transect aerial surveys conducted in summer over the St. Lawrence Estuary between a) 1990 and 2022 and b) 2014 and 2022 and areas of high residency described by Lemieux Lefebvre et al. (2012).

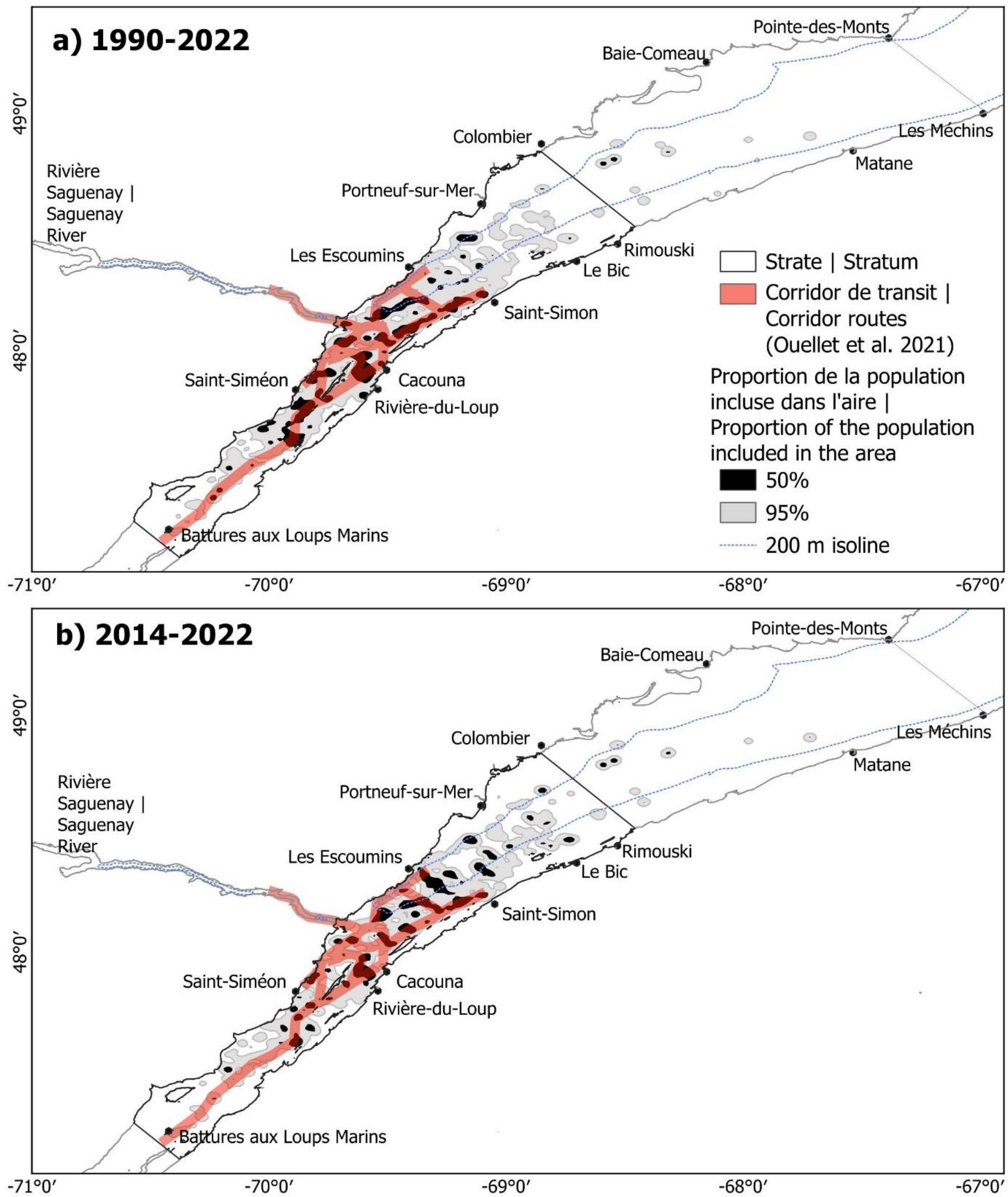

Figure 14. Comparison between areas including 50 and 95% of the St. Lawrence estuary beluga population obtained by the kernel method from systematic photographic line-transect aerial surveys conducted in summer over the St. Lawrence Estuary between a) 1990 and 2022 and b) 2014 and 2022 and the network of corridor routes described by Ouellet et al. (2021).

APPENDICES

APPENDIX 1. DETAILED SURVEY DESIGN FOR PHOTOGRAPHIC AND VISUAL SURVEYS

Table A1.1 Description of survey design and effort and number of groups and individuals detected during systematic photographic and visual aerial line transect surveys conducted in the St. Lawrence Estuary and Saguenay River from early July to mid-September, 1990 and 2022. Survey platforms were either a Rockwell Aero Commander ("A"), Piper Aztec ("PA"), Cessna 337 Skymaster ("C"), Partenavia P68C ("P"), or Twin Otter ("TO"). Abundance estimates and Saguenay counts were recalculated using the methodology described in the current manuscript for assessing Saguenay counts, and thus, may not match those reported in St-Pierre et al. (2024). Survey names in this paper differ from those in St-Pierre et al. (2024a). Abundance was not estimated for survey V2020s02r01. Saguenay counts rolling into abundance estimates from photographic surveys, but that are not used in the spatial analysis are indicated with an asterisk. A hyphen means that the stratum was not surveyed (e.g., Saguenay count for stratum 2) or the data exists but was not used (e.g., detections during photographic surveys in years when visual surveys were also conducted).

Year	Survey	Type Survey	Date Survey (mm/dd)	Stratum	Spacing (km)	Target altitude (m)	Platform	Number of transects flown	Total track length (km)	No Group (No Ind) for spatial analyses	Saguenay Count	Abundance corrected for availability and perception
1990	P1990s01r01	P	09/12	1	3.7	1219	C & PA	38	-	94 (149)	28	1,516 (815 – 2,822)
1992	P1992s01r01	P	09/12	1	3.7	1219	A & PA	48	-	227 (227)	3	1,432 (1,079 – 1,902)
1995	P1995s01r01	P	08/28	1	3.7	1219	A	49	-	264 (284)	52	1,634 (1,225 – 2,179)
1997	P1997s01r01	P	08/26	1	3.7	1219	NA	49	-	287 (287)	20	1,685 (1,290 – 2,201)
2000	P2000s01r01	P	08/28	1	3.7	1219	PA	52	-	124 (219)	6	1,326 (1,043 – 1,686)
2001	V2001s01r01	V	08/12	1	7.4	457	C	24	639	88 (177)	16	3,043 (1,420 – 6,520)
2003	P2003s01r01	P	09/02	1	3.7	1219	PA	51	639	161 (311)	2	1,759 (1,260 – 2,455)
	V2003s01r01	V	08/20	1	7.4	305	C	27	718	51 (143)	1	2,415 (1,071 – 5,446)
	V2003s02r01	V	08/25	1	7.4	305	C	26	686	80 (182)	0	3,239 (1,482 – 7,080)
	V2003s03r01	V	08/26	1	7.4	305	C	27	718	77 (195)	0	3,129 (1,527 – 6,408)
	V2003s04r01	V	09/02	1	7.4	305	C	26	686	99 (309)	7	4,484 (2,089 – 9,623)
	V2003s05r01	V	09/06	1	7.4	305	C	27	718	43 (127)	18	2,255 (977 – 5,207)
2005	V2005s01r01	V	08/12	1	7.4	305	C	27	734	105 (243)	55	2,367 (1,217 – 4,605)
	V2005s02r01	V	08/14	1	7.4	457	C	27	734	90 (198)	52	1,760 (781 – 3,966)
	V2005s03r01	V	08/15	1	7.4	305	C	27	718	129 (282)	59	3,294 (1,687 – 6,433)
	V2005s04r01	V	08/18	1	7.4	457	C	27	718	57 (155)	0	1,085 (437 – 2,694)
	V2005s05r01	V	08/19	1	7.4	457	C	27	718	121 (260)	12	2,193 (947 – 5,077)
	V2005s06r01	V	08/25	1	7.4	305	C	27	734	78 (224)	24	2,371 (1,092 – 5,148)

Year	Survey	Type Survey	Date Survey (mm/dd)	Stratum	Spacing (km)	Target altitude (m)	Platform	Number of transects flown	Total track length (km)	No Group (No Ind) for spatial analyses	Saguenay Count	Abundance corrected for availability and perception
	V2005s07r01	V	08/26	1	7.4	305	C	27	718	76 (226)	30	2,278 (1,108 – 4,686)
	V2005s08r01	V	08/27	1	7.4	457	C	27	718	98 (249)	73	1,705 (706 – 4,117)
	V2005s09r01	V	09/04	1	7.4	305	C	27	734	70 (93)	30	1,287 (577 – 2,868)
	V2005s10r01	V	09/05	1	7.4	457	C	27	734	125 (260)	73	2,143 (961 – 4,778)
	V2005s11r01	V	09/06	1	7.4	305	C	27	718	81 (118)	94	1,271 (631 – 2,561)
	V2005s12r01	V	09/08	1	7.4	457	C	27	718	104 (175)	42	1,480 (625 – 3,506)
	V2005s13r01	V	09/09	1	7.4	305	C	27	718	98 (173)	18	2,034 (975 – 4,241)
	V2005s14r01	V	09/10	1	7.4	457	C	27	734	65 (104)	19	934 (384 – 2,275)
2007	V2007s01r01	V	07/21	1	7.4	198	C	27	734	100 (255)	29	2,115 (1,018 – 4,396)
	V2007s01r01	V	07/22	2	18.52	198	C	7	365	17 (27)	-	504 (189 – 1,340)
2008	V2008s01r01	V	07/17	1	7.4	305	C	27	734	93 (258)	11	1,890 (889 – 4,019)
2009	P2009s01r01	P	08/28	1	3.7	1,219	PA	57	849	73 (154)	0	949 (744 – 1,212)
	V2009s01r01	V	08/20	1	7.4	305	C	28	788	66 (126)	15	1,361 (634 – 2,925)
	V2009s02r01	V	08/23	1	7.4	305	C	28	801	55 (165)	3	1,640 (772 – 3,483)
	V2009s03r01	V	08/24	1	7.4	305	C	28	804	93 (245)	11	2,870 (1,273 – 6,469)
	V2009s03r01	V	08/25	2	7.4	305	C	28	804	0	-	8 (1 – 40)
	V2009s04r01	V	09/01	1	7.4	305	C	28	785	23 (44)	11	545 (202 – 1,472)
	V2009s04r01	V	09/01	2	7.4	305	C	28	785	0	-	0 (0 – 0)
	V2009s05r01	V	09/04	1	7.4	305	C	28	794	65 (144)	33	1,678 (705 – 3,996)
	V2009s06r01	V	09/05	1	7.4	305	C	28	784	76 (175)	18	2,112 (1,044 – 4,275)
2014	V2014s01r01	V	08/19	1	7.4	305	P	29	802	114 (273)	-	2,568 (1,177 – 5,603)
	V2014s02r01	V	08/20	1	7.4	305	P	28	779	162 (434)	17	3,529 (1,688 – 7,379)
	V2014s03r01	V	08/21	1	7.4	305	P	29	775	55 (147)	48	1,636 (731 – 3,662)
	V2014s04r01	V	08/24	1	7.4	305	P	29	801	78 (194)	38	1,841 (616 – 5,501)
	V2014s04r01	V	08/24	2	7.4	305	P	29	801	0	-	0 (0 – 0)
	V2014s05r01	V	08/29	1	7.4	305	P	16	830	185 (462)	26	3,134 (1,283 – 7,658)
	V2014s06r01	V	09/03	1	7.4	305	P	16	830	90 (220)	49	1,154 (429 – 3,108)
	V2014s07r01	V	09/08	1	7.4	305	P	16	830	141 (369)	22	2,756 (1,241 – 6,121)

Year	Survey	Type Survey	Date Survey (mm/dd)	Stratum	Spacing (km)	Target altitude (m)	Platform	Number of transects flown	Total track length (km)	No Group (No Ind) for spatial analyses	Saguenay Count	Abundance corrected for availability and perception
	V2014s07r01	V	09/08	2	7.4	305	P	16	830	0	-	0 (0 – 0)
	V2014s08r01	V	09/10	1	7.4	305	P	16	851	147 (432)	0	2,952 (1,050 – 8,296)
2015	V2015s01r01	V	07/16	1	7.4	305	C	28	767	144 (471)	10	5,717 (2,493 – 13,112)
	V2015s02r01	V	07/16	1	7.4	305	C	29	808	132 (245)	-	1,836 (935 – 3,604)
2016	V2016s01r01	V	08/02	1	7.4	183	C	29	791	96 (223)	38	2,993 (1,269 – 7,057)
	V2016s01r01	V	08/04	2	18.52	183	C	29	791	0	-	0 (0 – 0)
	V2016s02r01	V	08/02	1	7.4	183	C	29	791	104 (243)	-	4,279 (1,833 – 9,990)
2018	V2018s01r01	V	08/16	1	7.4	305	P	28	778	43 (251)	51	4,497 (2,653 – 7,622)
	V2018s01r01	V	08/17	2	7.4	305	P	28	778	0	-	0 (0-0)
	V2018s02r01	V	08/20	1	7.4	305	P	28	760	69 (304)	22	5,251 (2,366 – 11,651)
	V2018s02r01	V	08/21	2	7.4	305	P	28	760	6 (140)	-	2,727 (528 – 14,093)
	V2018s03r01	V	08/30	1	7.4	305	P	28	769	63 (196)	25	3,346 (1,603 – 6,985)
	V2018s03r01	V	08/31	2	7.4	305	P	15	804	2 (3)	-	24 (0 – 8,961)
	V2018s04r01	V	09/04	1	7.4	305	P	15	804	56 (261)	88	3,275 (1,386 – 7,734)
	V2018s04r01	V	09/05	2	7.4	305	P	15	805	3 (39)	-	125 (27 – 578)
	V2018s05r01	V	09/06	1	7.4	305	P	15	805	50 (272)	0	4,932 (2,170 – 11,209)
2019	P2019s01r01	P	08/13	1	7.4	305	TO	28	777	-*	15*	1,037 (752 – 1,430)
	V2019s01r01	V	08/13	1	7.4	305	TO	28	777	86 (222)	15	1,525 (810 – 2,874)
	P2019s02r01	P	08/14	1	7.4	305	TO	28	776	-*	45*	2,846 (1,752 – 4,622)
	V2019s02r01	V	08/14	1	7.4	305	TO	28	776	135 (388)	45	2,248 (1,174 – 4,302)
	P2019s03r01	P	08/15	1	7.4	305	TO	16	839	-*	15*	2,142 (1,491 – 3,076)
	V2019s03r01	V	08/15	1	7.4	305	TO	29	801	143 (376)	15	1,814 (1,055 – 3,119)
	V2019s03r01	V	08/15	2	7.4	305	P	16	801	0	-	0 (0 – 0)
	P2019s04r01	P	08/16	1	7.4	305	TO	16	802	-*	74*	2,446 (1,442 – 4,150)
	V2019s04r01	V	08/16	1	7.4	305	TO	29	802	102 (273)	74	2,169 (1,099 – 4,281)
	V2019s04r01	V	08/21	2	7.4	305	P	16	811	1 (6)	-	28 (5 – 159)
2020	V2020s01r01	V	07/22	1	7.4	243	C	28	767	101 (220)	37	2,726 (1,250 – 5,947)
	V2020s02r01	V	07/21	1	18.52	243	C	9	NA	34 (58)	0	-

Year	Survey	Type Survey	Date Survey (mm/dd)	Stratum	Spacing (km)	Target altitude (m)	Platform	Number of transects flown	Total track length (km)	No Group (No Ind) for spatial analyses	Saguenay Count	Abundance corrected for availability and perception
	V2020s02r01	V	07/23	2	18.52	243	C	5	NA	2 (2)	-	-
2021	V2021s01r01	V	07/03	1	7.4	305	C & P	16	854	100 (146)	26	1,740 (806 – 3,755)
	V2021s01r01	V	07/03	2	7.4	305	C & P	16	854	24 (79)	-	527 (152 – 1,832)
2022	V2022s01r01	V	08/20 & 09/04	1	7.4	305	C	28	764	66 (104)	158	1,049 (565 – 1,950)
	V2022s01r01	V	08/25 & 09/04	2	7.4	305	C	16	851	3 (17)	-	203 (38 – 1,083)

Table A1.2. Description of the survey design, effort, and number of beluga or beluga groups detected by the primary observers during systematic line transect aerial surveys conducted in the St. Lawrence Estuary, the Gulf of St. Lawrence and Saguenay River in fall (mid-November to mid-December), winter (mid-January to the end of March) and spring (early to mid-May) of 2012 – 2023. For platform, "C" indicates a Cessna 337 Skymaster, "P" indicates a Partenavia P68C, and "I" represents an Islander. NA indicates the Saguenay was not flown.

Year	Season	Survey	Start date	End date	Stratum	Stratum area (km^2)	Platform	Number of transects	Total track length (km)	Number of groups (individuals)	Saguenay count	Number of groups (individuals) detected by primary observers only	Groups (individuals) without distance
2012	Fall	Fa2012s01r01	20/11	27/11	1	12,052	C	27	987	67 (176)	18	49 (130)	3 (9)
		Fa2012s01r01	20/11	20/11	2	22,348	C & P	16	1,718	1 (26)	-	1 (11)	0 (0)
		Fa2012s01r01	20/11	21/11	3	11,062	P	11	855	0 (0)	-	0 (0)	0 (0)
2013	Winter	Wi2013s01r01	23/02	25/02	1	12,052	C	26	961	34 (63)	3	27 (54)	0 (0)
		Wi2013s01r01	22/02	23/02	2	22,348	C & P	16	1,775	3 (3)	-	2 (2)	0 (0)
		Wi2013s01r01	23/02	23/02	3	11,062	P	12	885	0 (0)	-	0 (0)	0 (0)
		Wi2013s01r01	24/02	25/02	4	14,232	P	17	1,052	0 (0)	-	0 (0)	0 (0)
		Wi2013s01r01	23/02	23/02	5	1,464	P	3	107	0 (0)	-	0 (0)	0 (0)
		Wi2013s01r01	24/02	24/02	7	6,398	P	7	455	2 (9)	-	2 (9)	0 (0)
	Spring	Sp2013s01r01	14/05	15/05	1	12052	C	26	961	22 (71)	0	22 (71)	0 (0)
		Sp2013s01r01	14/05	14/05	2	11,067	C	8	825	0 (0)	-	0 (0)	0 (0)
	Fall	Fa2013s01r01	21/11	22/11	1	12,052	C	26	961	6 (9)	1	6 (9)	0 (0)
		Fa2013s01r01	22/11	22/11	2	22,348	C & P	17	1,833	0 (0)	-	0 (0)	0 (0)
		Fa2013s01r01	22/11	22/11	3	2,298	P	4	137	0 (0)	-	0 (0)	0 (0)
2014	Winter	Wi2014s01r01	26/02	27/02	1	12,052	C	24	902	10 (22)	NA	10 (22)	0 (0)
		Wi2014s01r01	01/03	02/03	2	22,348	C & I	16	1,761	0 (0)	-	0 (0)	0 (0)
		Wi2014s01r01	03/03	03/03	3	11,062	I	12	843	0 (0)	-	0 (0)	0 (0)
		Wi2014s01r01	02/03	06/03	4	26,923	C & I	13	1,085	0 (0)	-	0 (0)	0 (0)
		Wi2014s01r01	03/03	03/03	5	1,640	I	3	80	0 (0)	-	0 (0)	0 (0)
		Wi2014s01r01	05/03	06/03	6	27,652	P	17	1,104	0 (0)	-	0 (0)	0 (0)
		Wi2014s01r01	02/03	07/03	7	29,342	C & I & P	11	1,149	0 (0)	-	0 (0)	0 (0)
		Wi2014s01r01	06/03	06/03	8	8,824	P	5	350	0 (0)	-	0 (0)	0 (0)

Year	Season	Survey	Start date	End date	Stratum	Stratum area (km^2)	Platform	Number of transects	Total track length (km)	Number of groups (individuals)	Saguenay count	Number of groups (individuals) detected by primary observers only	Groups (individuals) without distance
		Wi2014s01r02	18/03	18/03	1	10,623	C	24	840	12 (52)	0	12 (52)	0 (0)
		Wi2014s01r03	19/03	19/03	1	10,623	C	24	843	15 (39)	0	15 (39)	1 (2)
		Wi2014s01r04	26/03	26/03	1	12,052	C & P	26	1,404	35 (142)	4	35 (142)	2 (7)
		Wi2014s01r05	29/03	29/03	1	12,052	C	26	954	28 (67)	0	28 (67)	0 (0)
		Wi2014s01r06	29/03	29/03	1	12,052	P	26	936	22 (39)	0	22 (39)	1 (1)
	Spring	Sp2014s01r01	06/05	07/05	1	12,052	P	26	945	99 (187)	0	99 (187)	1 (1)
		Sp2014s01r01	06/05	06/05	2	22,348	C & P	16	1,723	3 (16)	-	3 (16)	0 (0)
		Sp2014s01r01	06/05	07/05	3	11,062	C	12	907	0 (0)	-	0 (0)	0 (0)
		Sp2014s01r01	07/05	07/05	5	3,187	C	7	252	0 (0)	-	0 (0)	0 (0)
	Fall	Fa2014s01r01	16/12	20/12	1	12,052	C & P	26	943	40 (97)	15	40 (97)	0 (0)
		Fa2014s01r01	15/12	15/12	2	22,348	C & P	16	1,736	0 (0)	-	0 (0)	0 (0)
		Fa2014s01r01	16/12	16/12	3	10,149	P	10	744	0 (0)	-	0 (0)	0 (0)
2015	Winter	Wi2015s01r01	24/03	28/03	1	12,052	C	26	978	42 (131)	0	37 (118)	0 (0)
		Wi2015s01r01	24/03	25/03	2	22,348	C & P	17	1,821	4 (4)	-	4 (4)	1 (1)
		Wi2015s01r01	24/03	25/03	3	11,062	P	12	896	0 (0)	-	0 (0)	0 (0)
		Wi2015s01r01	25/03	25/03	5	3,689	P	9	242	0 (0)	-	0 (0)	0 (0)
	Spring	Sp2015s01r01	01/05	02/05	1	12,052	C	25	945	11 (27)	0	12 (28)	0 (0)
		Sp2015s01r01	01/05	01/05	2	22,348	C & P	17	1,756	0 (0)	-	0 (0)	0 (0)
		Sp2015s01r01	01/05	02/05	3	11,062	P	12	867	0 (0)	-	0 (0)	0 (0)
		Sp2015s01r01	02/05	02/05	5	3,689	P	9	277	0 (0)	-	0 (0)	0 (0)
2018	Winter	Wi2018s01r01	21/03	23/03	1	9,519	C	17	781	29 (156)	0	29 (156)	0 (0)
		Wi2018s01r01	21/03	21/03	2	10,438	C	8	807	8 (15)	-	8 (15)	0 (0)
	Spring	Sp2018s01r01	07/05	09/05	1	12,052	C	27	991	34 (92)	10	34 (92)	1 (1)
		Sp2018s01r01	03/05	09/05	2	22,348	C & P	17	1,749	1 (1)	-	1 (1)	0 (0)
		Sp2018s01r01	03/05	06/05	3	11,062	P	12	870	0 (0)	-	0 (0)	0 (0)

Year	Season	Survey	Start date	End date	Stratum	Stratum area (km²)	Platform	Number of transects	Total track length (km)	Number of groups (individuals)	Saguenay count	Number of groups (individuals) detected by primary observers only	Groups (individuals) without distance
		Sp2018s01r01	06/05	06/05	5	3,689	P	9	256	0 (0)	-	0 (0)	0 (0)
		Sp2018s01r02	10/05	16/05	1	12,052	C & P	27	968	56 (190)	1	56 (190)	1 (3)
		Sp2018s01r02	09/05	16/05	2	22,348	C & P	16	1,747	0 (0)	-	0 (0)	0 (0)
		Sp2018s01r02	13/05	16/05	3	11,062	P	12	869	0 (0)	-	0 (0)	0 (0)
		Sp2018s01r02	10/05	13/05	5	3,689	P	10	313	0 (0)	-	0 (0)	0 (0)
	Fall	Fa2018s01r01	26/11	26/11	1	12,052	P	25	882	10 (19)	0	10 (19)	0 (0)
		Fa2018s01r01	25/11	26/11	2	10,468	P	8	917	1 (1)	-	1 (1)	0 (0)
2019	Winter	Wi2019s01r01	06/02	06/02	1	9,317	P	22	741	2 (4)	0	2 (4)	0 (0)
		Wi2019s01r01	13/03	14/03	3	11,062	C & P	12	895	0 (0)	-	0 (0)	0 (0)
		Wi2019s01r01	02/03	13/03	2	22,348	P	17	1,752	6 (16)	-	6 (16)	0 (0)
		Wi2019s01r01	13/03	13/03	5	3,689	C	9	285	0 (0)	-	0 (0)	0 (0)
		Wi2019s01r02	02/03	03/03	1	12,052	P	27	992	9 (29)	0	9 (29)	0 (0)
		Wi2019s01r02	14/03	19/03	2	22,348	C & P	16	1,770	17 (94)	-	17 (94)	1 (12)
		Wi2019s01r02	14/03	14/03	3	7,900	P	9	627	0 (0)	-	0 (0)	0 (0)
		Wi2019s01r03	19/03	19/03	1	12,052	C & P	26	960	22 (69)	0	22 (69)	0 (0)
	Spring	Sp2019s01r01	02/05	03/05	1	12,052	P	26	971	38 (54)	0	38 (54)	0 (0)
		Sp2019s01r01	03/05	03/05	2	22,348	C & P	16	1,722	0 (0)	-	0 (0)	0 (0)
		Sp2019s01r01	03/05	05/05	3	11,062	C	12	920	0 (0)	-	0 (0)	0 (0)
		Sp2019s01r01	04/05	04/05	5	3,015	C	7	255	0 (0)	-	0 (0)	0 (0)
	Fall	Fa2019s01r01	18/11	20/11	1	12,052	P	29	959	13 (30)	0	13 (30)	0 (0)
		Fa2019s01r01	18/11	18/11	2	22,348	C & P	17	1,791	4 (4)	-	2 (2)	0 (0)
		Fa2019s01r01	24/11	02/12	3	11,062	C & P	13	901	3 (4)	-	1 (1)	0 (0)
		Fa2019s01r01	02/12	02/12	5	3,689	P	9	274	0 (0)	-	0 (0)	0 (0)
2020	Winter	Wi2020s19r01	18/01	24/01	1	12,052	C & P	29	981	12 (48)	0	12 (48)	0 (0)
		Wi2020s19r01	13/01	24/01	2	22,348	C & P	17	1,791	12 (82)	-	12 (80)	0 (0)

Year	Season	Survey	Start date	End date	Stratum	Stratum area (km^2)	Platform	Number of transects	Total track length (km)	Number of groups (individuals)	Saguenay count	Number of groups (individuals) detected by primary observers only	Groups (individuals) without distance
		Wi2020s19r01	22/01	23/01	3	11,062	C & P	14	866	0 (0)	-	0 (0)	0 (0)
		Wi2020s19r01	23/01	23/01	5	3,689	C	10	304	0 (0)	-	0 (0)	0 (0)
		Wi2020s01r01	16/03	16/03	1	12,052	C & P	27	954	79 (172)	0	61 (144)	1 (2)
		Wi2020s01r01	12/03	16/03	2	22,348	P	17	1,777	5 (8)	-	4 (7)	0 (0)
		Wi2020s01r01	12/03	12/03	3	11,062	C	11	837	0 (0)	-	0 (0)	0 (0)
	Fall	Fa2020s01r01	04/12	08/12	1	12,052	C	28	985	67 (184)	0	54 (150)	6 (6)
		Fa2020s01r01	05/12	17/12	2	22,348	C	17	1,795	0 (0)	-	0 (0)	0 (0)
		Fa2020s01r01	04/12	05/12	3	11,062	C	14	865	0 (0)	-	0 (0)	0 (0)
		Fa2020s01r01	04/12	05/12	5	3,689	C	10	304	0 (0)	-	0 (0)	0 (0)
		Fa2020s02r01	08/12	17/12	1	12,052	C	27	951	21 (36)	0	17 (28)	0 (0)
		Fa2020s02r01	09/12	19/12	2	22,348	C	17	1,839	8 (18)	-	6 (14)	0 (0)
		Fa2020s02r01	09/12	19/12	3	11,062	C	13	895	0 (0)	-	0 (0)	0 (0)
		Fa2020s02r01	09/12	17/12	5	3,689	C	9	277	0 (0)	-	0 (0)	0 (0)
2021	Winter	Wi2021s01r01	18/02	19/02	1	12,052	C	27	940	49 (113)	0	46 (106)	0 (0)
		Wi2021s01r01	19/02	27/02	2	22,348	C	13	1,823	6 (23)	-	5 (22)	0 (0)
		Wi2021s01r01	19/02	20/02	3	11,062	C	13	921	0 (0)	-	0 (0)	0 (0)
		Wi2021s01r01	19/02	19/02	5	3,689	C	10	305	0 (0)	-	0 (0)	0 (0)
		Wi2021s02r01	16/03	16/03	1	12,052	C	27	962	88 (241)	0	80 (203)	0 (0)
		Wi2021s02r01	16/03	24/03	2	22,348	C	17	1,783	1 (1)	-	1 (1)	0 (0)
		Wi2021s02r01	17/03	24/03	3	11,062	C	13	876	0 (0)	-	0 (0)	0 (0)
		Wi2021s02r01	17/03	17/03	5	3,689	C	10	306	0 (0)	-	0 (0)	0 (0)
2022	Winter	Wi2022s01r01	13/02	14/02	1	12,052	C	26	963	19 (39)	0	18 (38)	0 (0)
		Wi2022s01r01	14/02	03/03	2	22,348	C	17	1,812	14 (45)	-	8 (24)	0 (0)
		Wi2022s01r01	03/03	03/03	3	11,062	C	13	862	0 (0)	-	0 (0)	0 (0)
		Wi2022s01r01	03/03	03/03	5	3,689	C	9	268	0 (0)	-	0 (0)	0 (0)

Year	Season	Survey	Start date	End date	Stratum	Stratum area (km^2)	Platform	Number of transects	Total track length (km)	Number of groups (individuals)	Saguenay count	Number of groups (individuals) detected by primary observers only	Groups (individuals) without distance
		Wi2022s02r01	09/03	11/03	1	12,052	C	26	980	18 (49)	0	14 (44)	0 (0)
		Wi2022s02r01	09/03	09/03	2	9,681	C	9	893	11 (41)	-	8 (36)	0 (0)
		Wi2022s02r01	11/03	11/03	3	11,062	C	14	878	0 (0)	-	0 (0)	0 (0)
		Wi2022s02r01	11/03	11/03	5	3,689	C	9	284	0 (0)	-	0 (0)	0 (0)
		Wi2022s03r01	15/03	18/03	1	12,052	C	26	944	53 (131)	0	48 (122)	0 (0)
		Wi2022s03r01	18/03	24/03	2	22,348	C	17	1,771	10 (16)	-	10 (14)	0 (0)
		Wi2022s03r01	24/03	24/03	3	3,499	C	6	276	0 (0)	-	0 (0)	0 (0)
2023	Winter	Wi2023s01r01	25/01	07/02	1	12,052	C	26	941	53 (91)	3	46 (76)	1 (4)
		Wi2023s02r01	09/02	15/02	1	12,052	C	26	922	22 (55)	1	18 (46)	1 (7)
		Wi2023s02r01	15/02	15/02	2	22,348	C	16	1,741	25 (34)	-	23 (32)	0 (0)
		Wi2023s02r01	28/02	04/03	3	11,062	C	13	872	0 (0)	-	0 (0)	0 (0)
		Wi2023s02r01	15/02	15/02	5	3,689	C	9	286	0 (0)	-	0 (0)	0 (0)

APPENDIX 2. METHODOLOGICAL APPROACH FOR ESTIMATION OF KERNEL DENSITIES (FROM MOSNIER ET AL. 2016)

We used the fixed kernel method (Worton 1989) in our analyses. This choice is commonly favored in wildlife space use studies as it generally performs better than the adaptive kernel approach (Terrell and Scott 1992, Seaman and Powell 1996, Seaman et al. 1999, Kernohan et al. 2001). The kernel density estimator is highly sensitive to the bandwidth value used (Silverman 1986). We decided to apply an arbitrary fixed value based on the sampling design of the surveys. As we used a bivariate normal kernel, the bandwidth (h) has the same properties as the standard deviation (σ) on a normal curve. Since 99.99% of the values in a normal distribution fall within four standard deviations of the mean, 99.99% of the density in a kernel density estimate centered at a given location is contained within a circle of radius 4h around that location, where h is the bandwidth. Considering that observations on transects were representative of the real distribution of individuals, we wanted to extend this information to the space not covered between sighting ranges. However, we wanted to limit the influence of information obtained on a given transect to the space between the previous transect and the next one. Given the systematic survey sampling plan, we chose h = 926 m (0.5 nautical miles) (Figure A2.1) for both photographic and visual surveys conducted in summer. Using different h values (e.g. a smaller h for photographic surveys than for visual surveys) would have resulted in beluga locations having a different spatial influence depending on whether they were noted during a visual or a photographic survey. Moreover, sighting range during photographic surveys was limited (1990 – 2009) or inferior (2019) to ~910 m on each side of the transect (footprint of the photos the at water's surface). The influence range of an observation on the border of a frame is thus negligible outside the space between two transects (Figure A2.1), satisfying our wish to limit the influence of the interpolation to the space between two successive transect. For the kernel analyses conducted in other seasons, as the spacing between adjacent transects is wider than in summer, we chose h = 1,563 m (0.84 nautical miles).

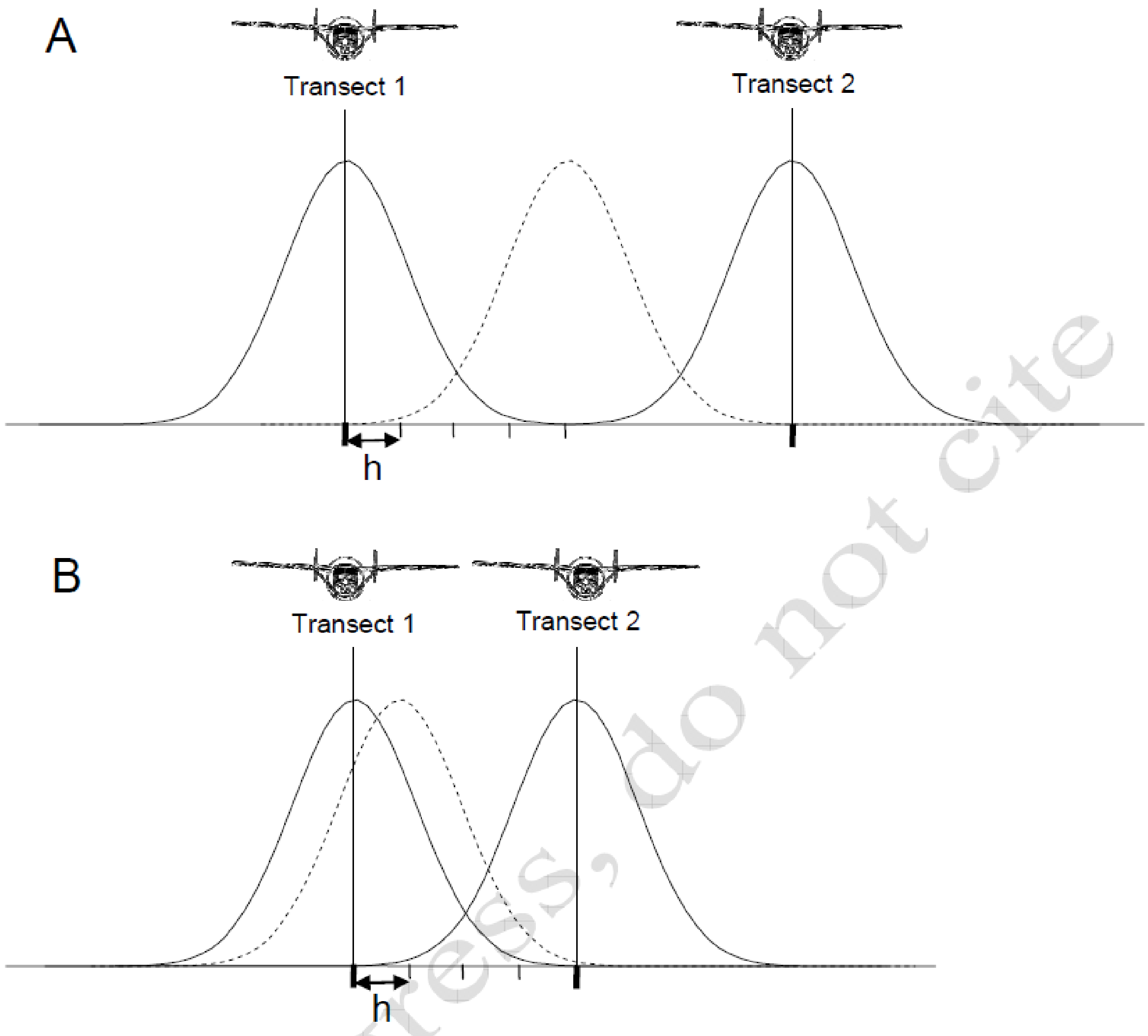

Figure A2.1. Two-dimensional representation of kernel smoothing of values obtained on transects of aerial surveys. Solid lines corresponds to influence range of one location on each transect. Dotted lines show that influence does not extend beyond the other transect even if (A) the observation is located mid-way (i.e. 2 nautical miles) from the two transects in visual surveys or (B) on the border of a frame (i.e.: ~0.5 nautical mile) in photographic surveys.

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APPENDIX 3. DETECTION FUNCTION FOR FALL, WINTER AND SPRING SURVEYS

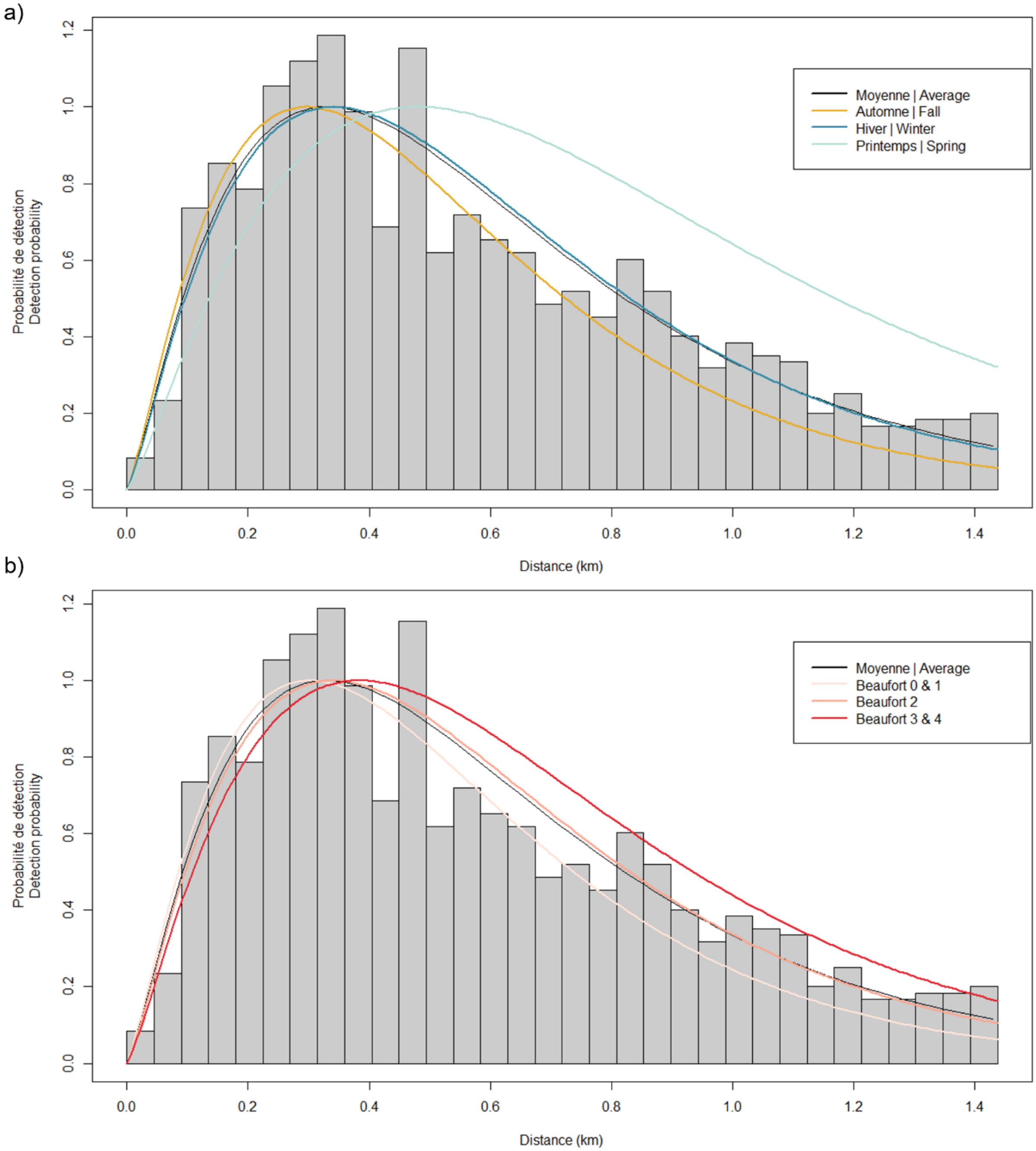

Figure A3.1. Histograms of observed perpendicular distance and fitted Gamma key detection function according to a) season and b) Beaufort for beluga observed during systematic visual line-transect aerial surveys conducted in the Estuary and Gulf of St. Lawrence in fall, spring, and winter of 2012 – 2023. This analysis used a right truncation distance of 1,437 m, and Gamma key function with season and Beaufort as covariate. The number of sightings used in the detection curve was 1029, and the effective strip half-width (ESHW) was 770 m.

APPENDIX 4. LOCATIONS AND GROUP SIZES OF SLE BELUGA DETECTED DURING AERIAL SURVEYS

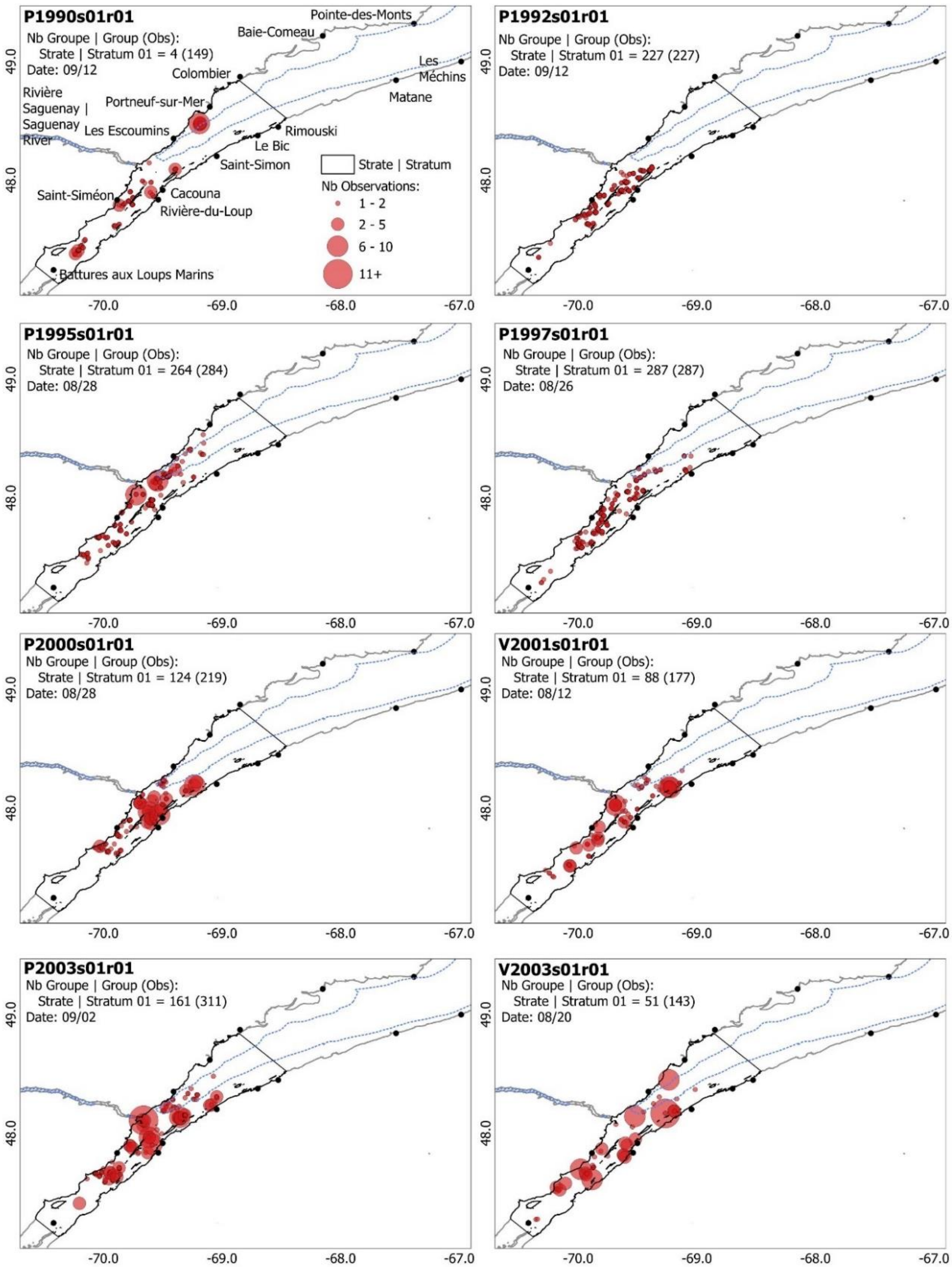

Figure A4.1. Area covered, locations and group sizes of beluga detected by 60 systematic photographic and visual line-transect aerial surveys conducted over the St. Lawrence Estuary during summer (early July to mid-September) from 1990 to 2022. The first letter of panel labels indicates the type of survey (P=photographic, V=visual).

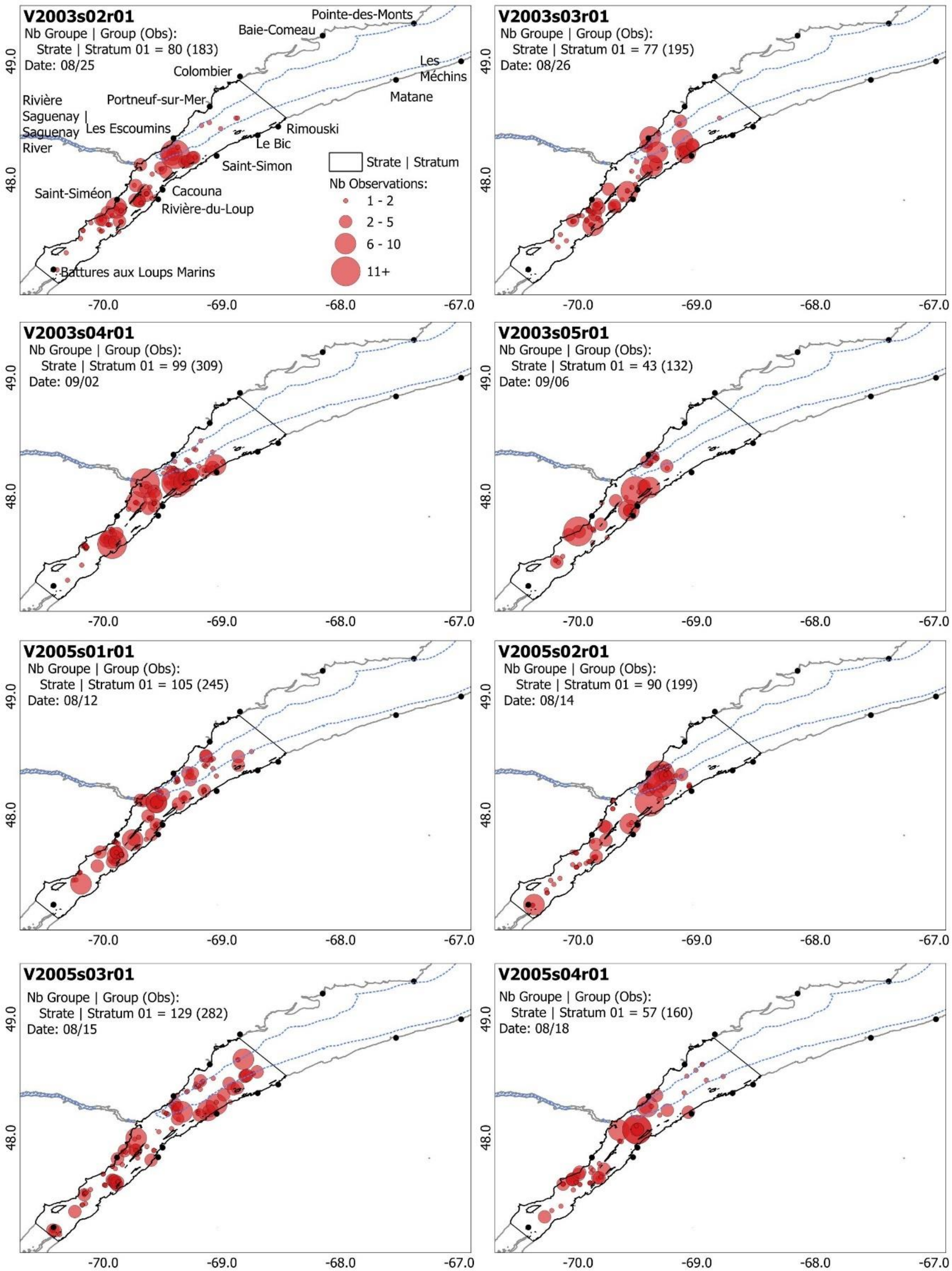

Figure A4.1. Continued.

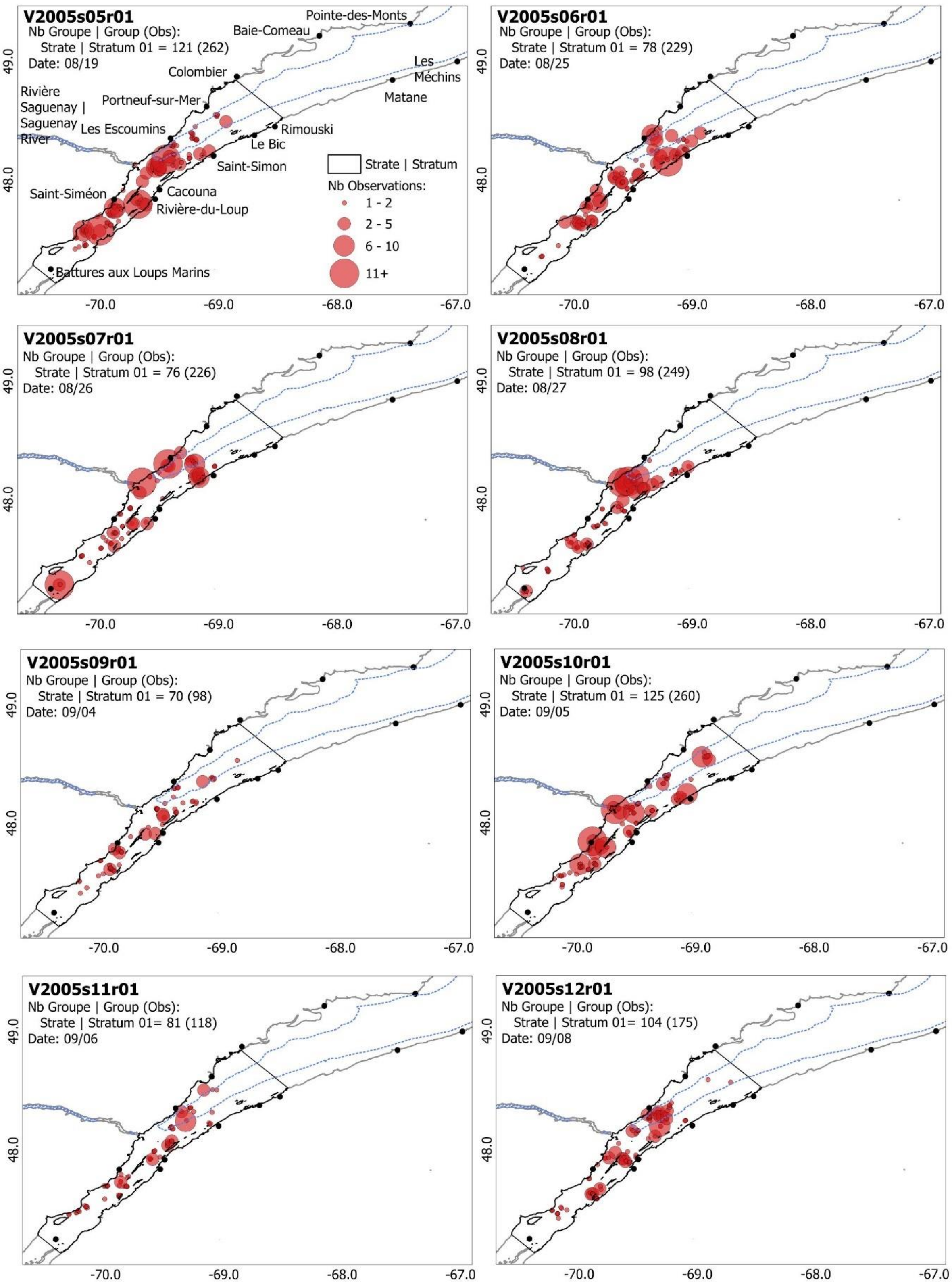

Figure A4.1. Continued.

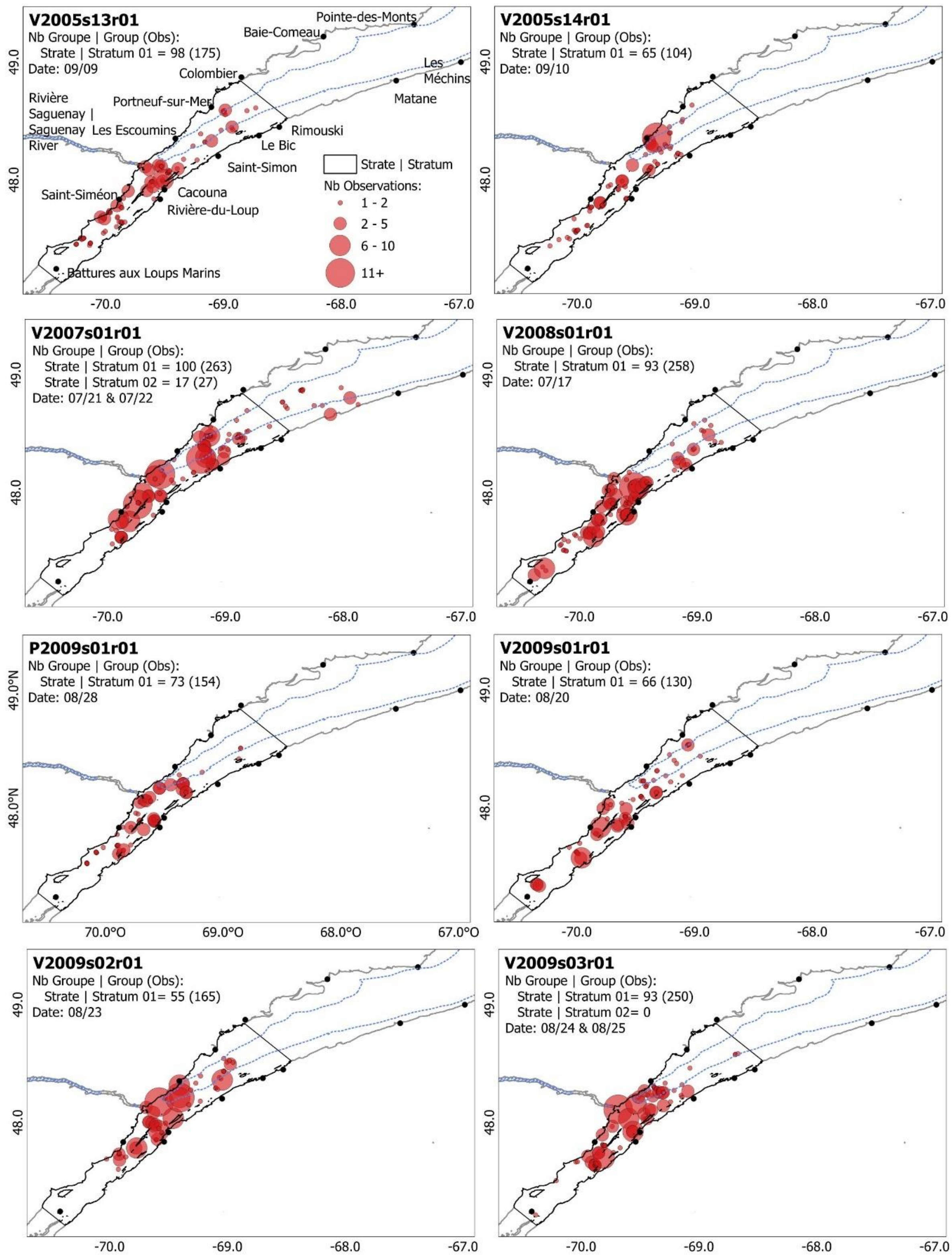

Figure A4.1. Continued.

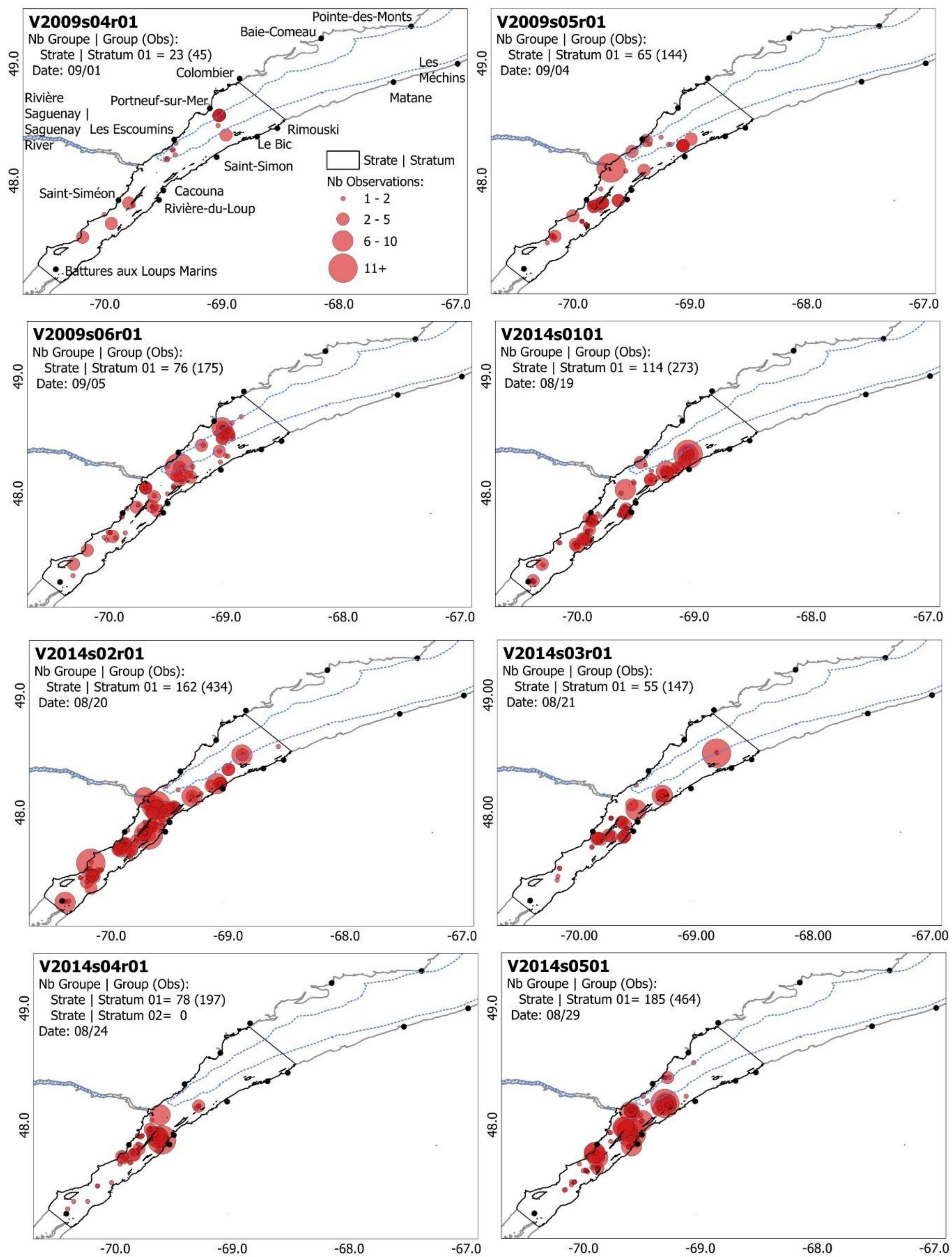

Figure A4.1. Continued.

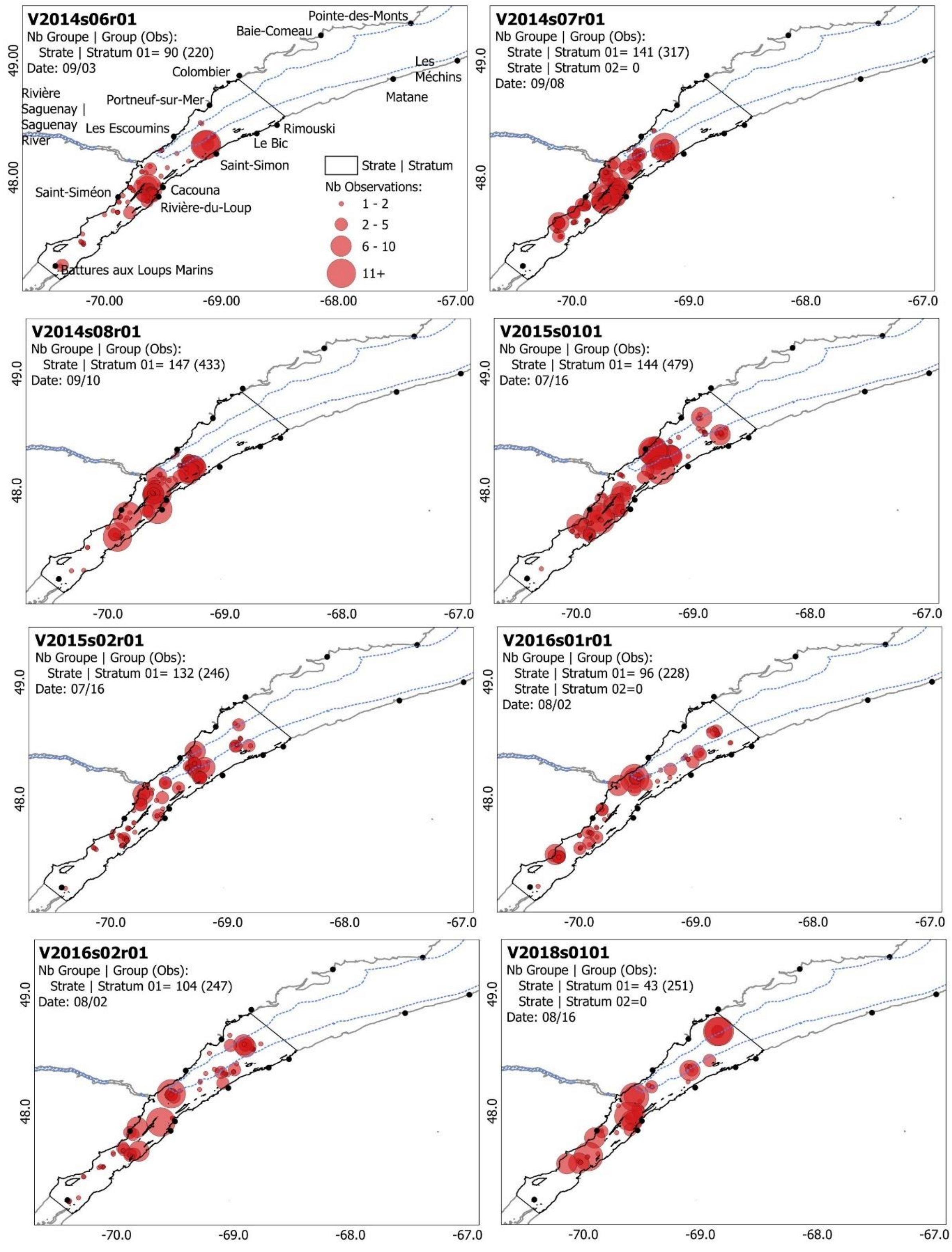

Figure A4.1. Continued.

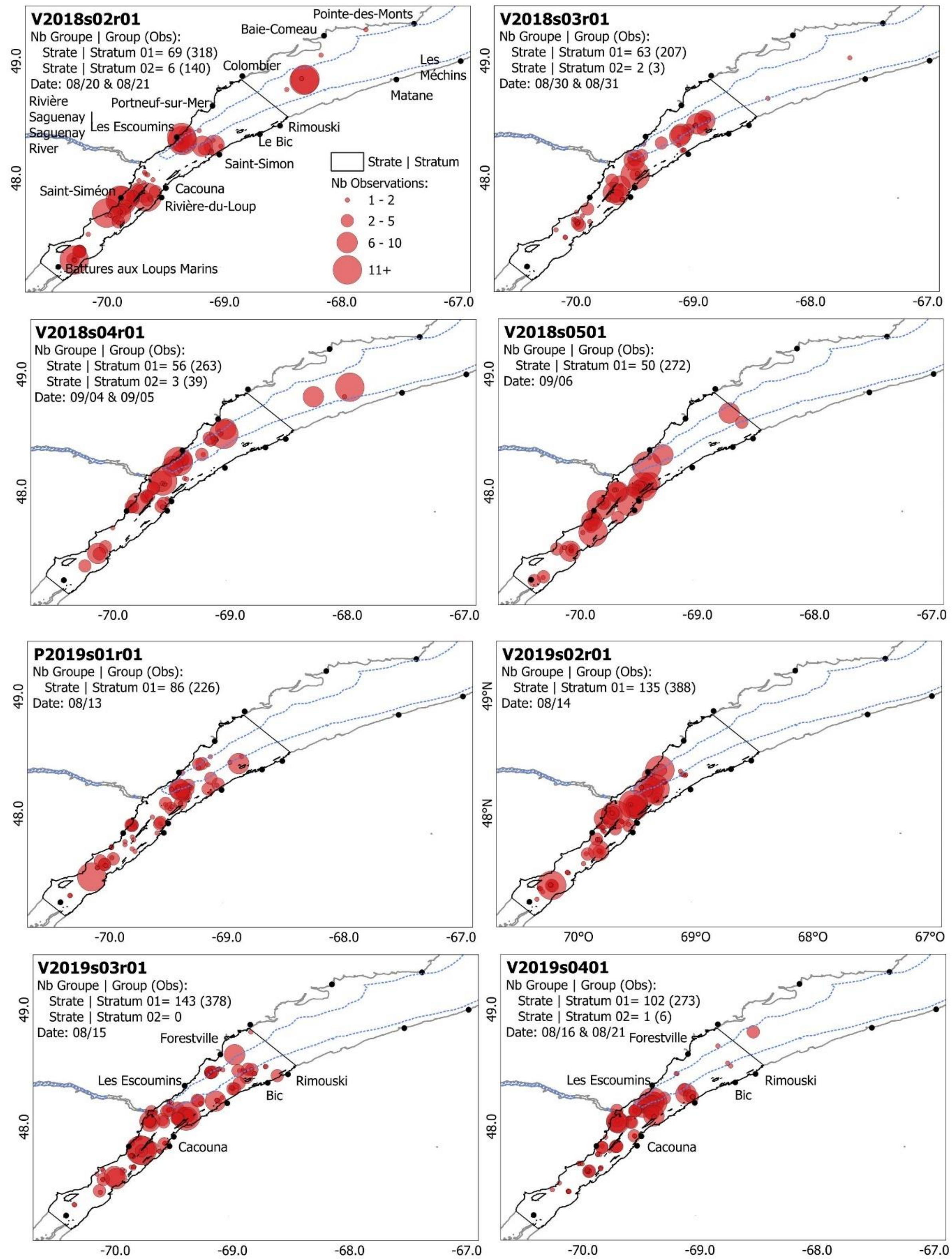

Figure A4.1. Continued.

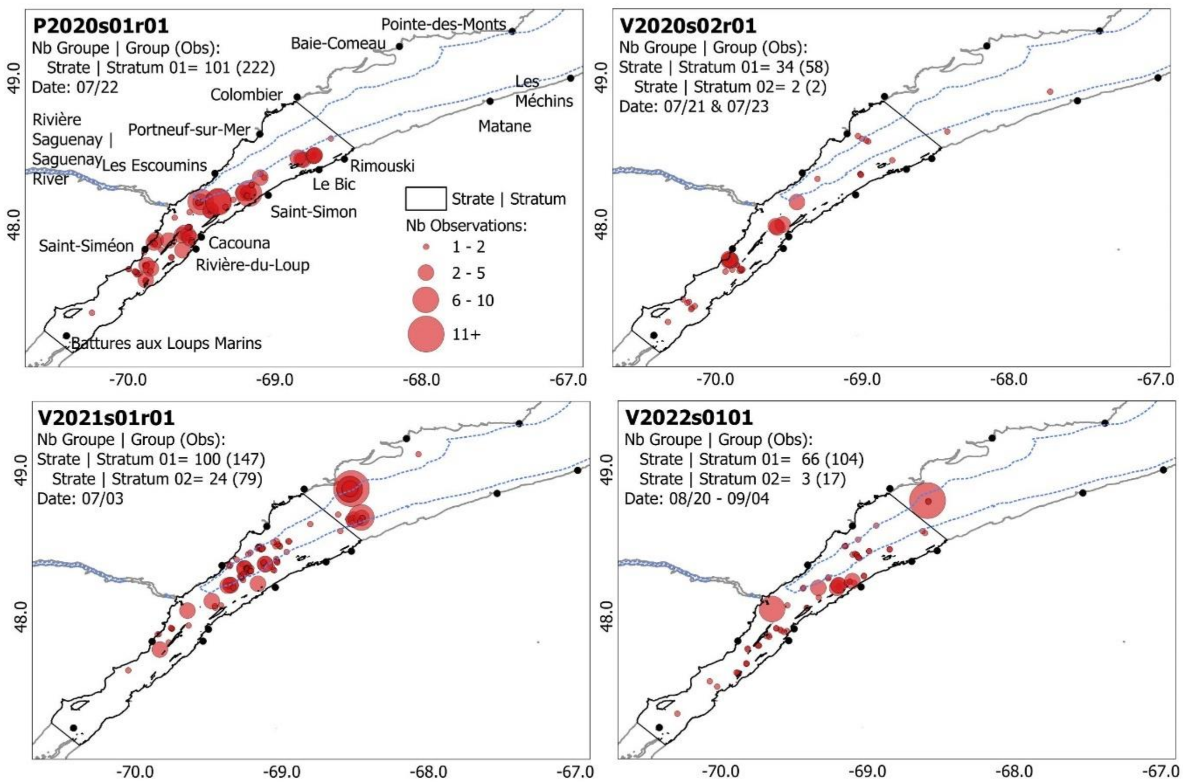

Figure A4.1. Continued.

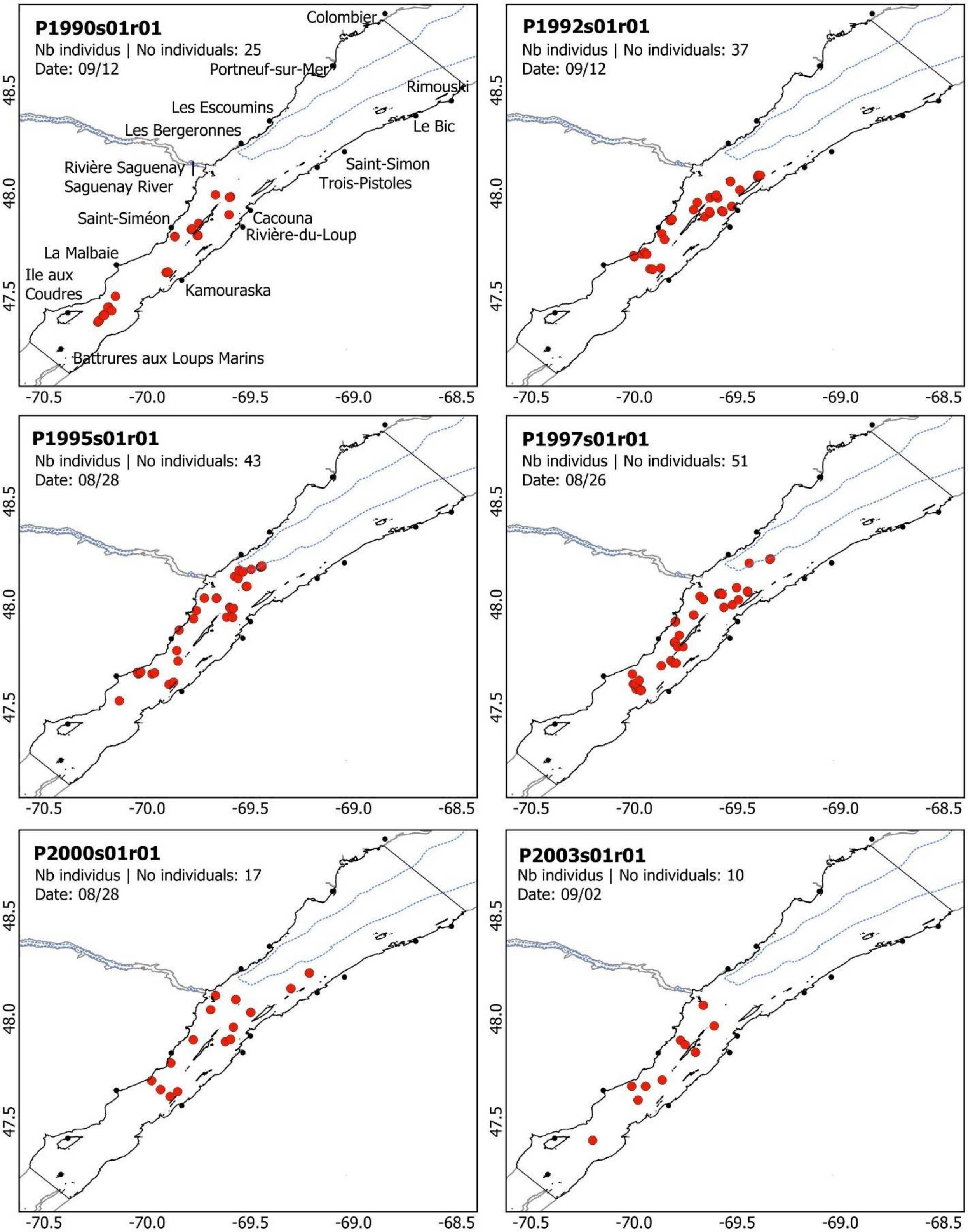

Figure A4.2. Area surveyed, locations of beluga calves detected during eleven systematic photographic aerial surveys conducted over St. Lawrence Estuary in summer (mid-August to mid-September) from 1990 to 2019. Each red dot represent a single calf.

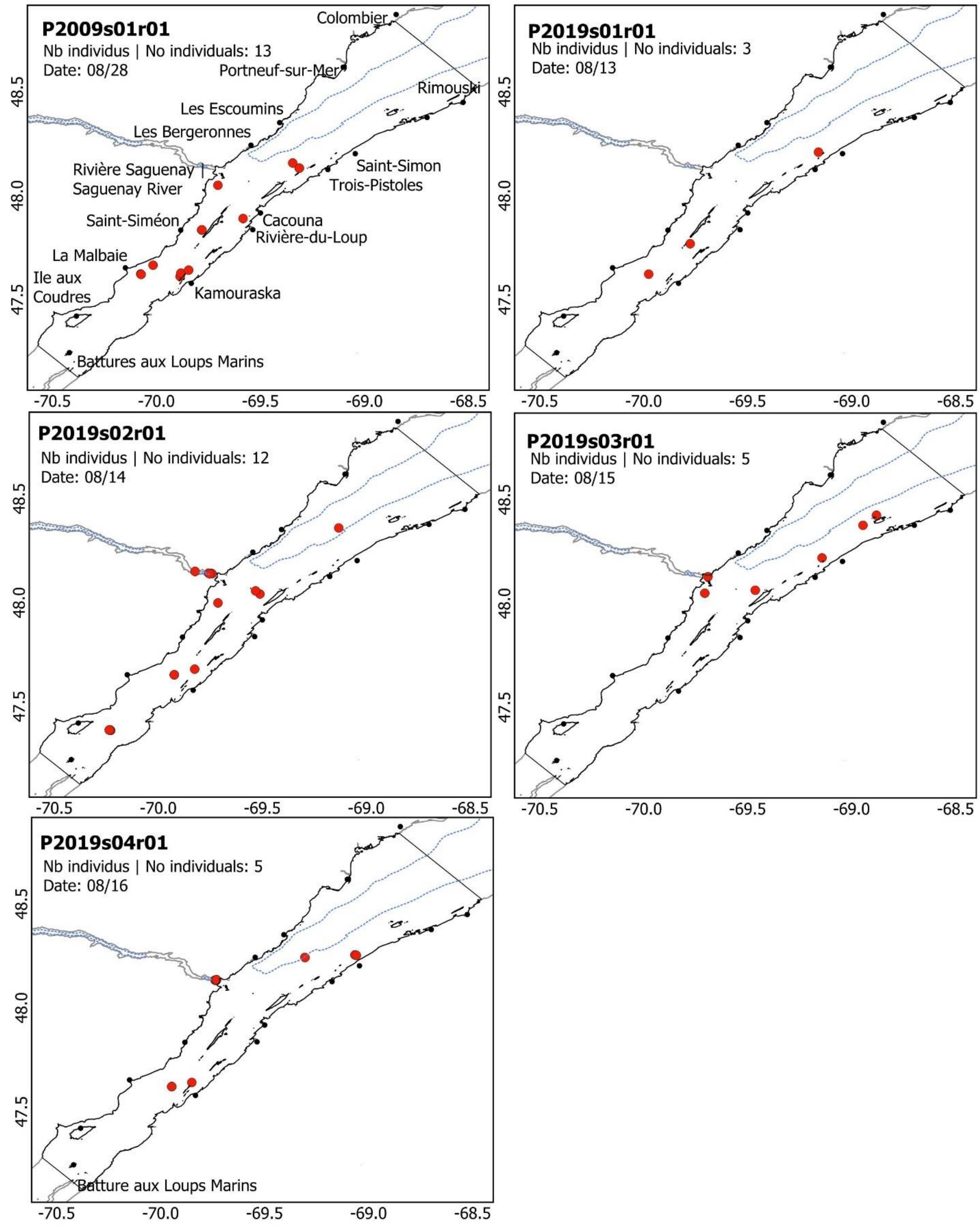

Figure A4.2. Continued.

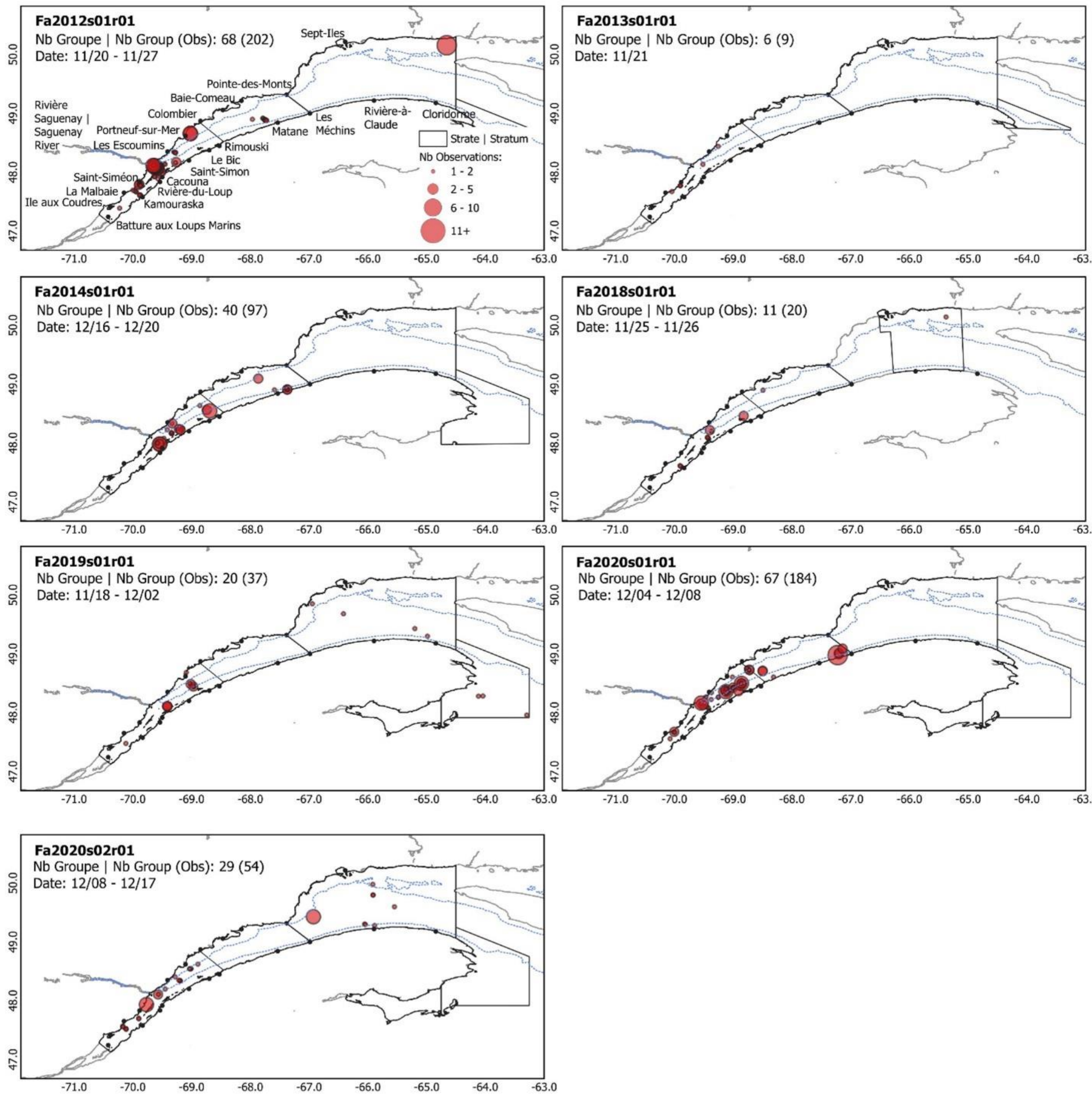

Figure A4.3. Area surveyed, locations and group sizes of beluga whales detected during seven systematic visual line-transect aerial surveys conducted over the Estuary and the Gulf of St. Lawrence during fall (mid-November to mid-December) from 2012 to 2020.

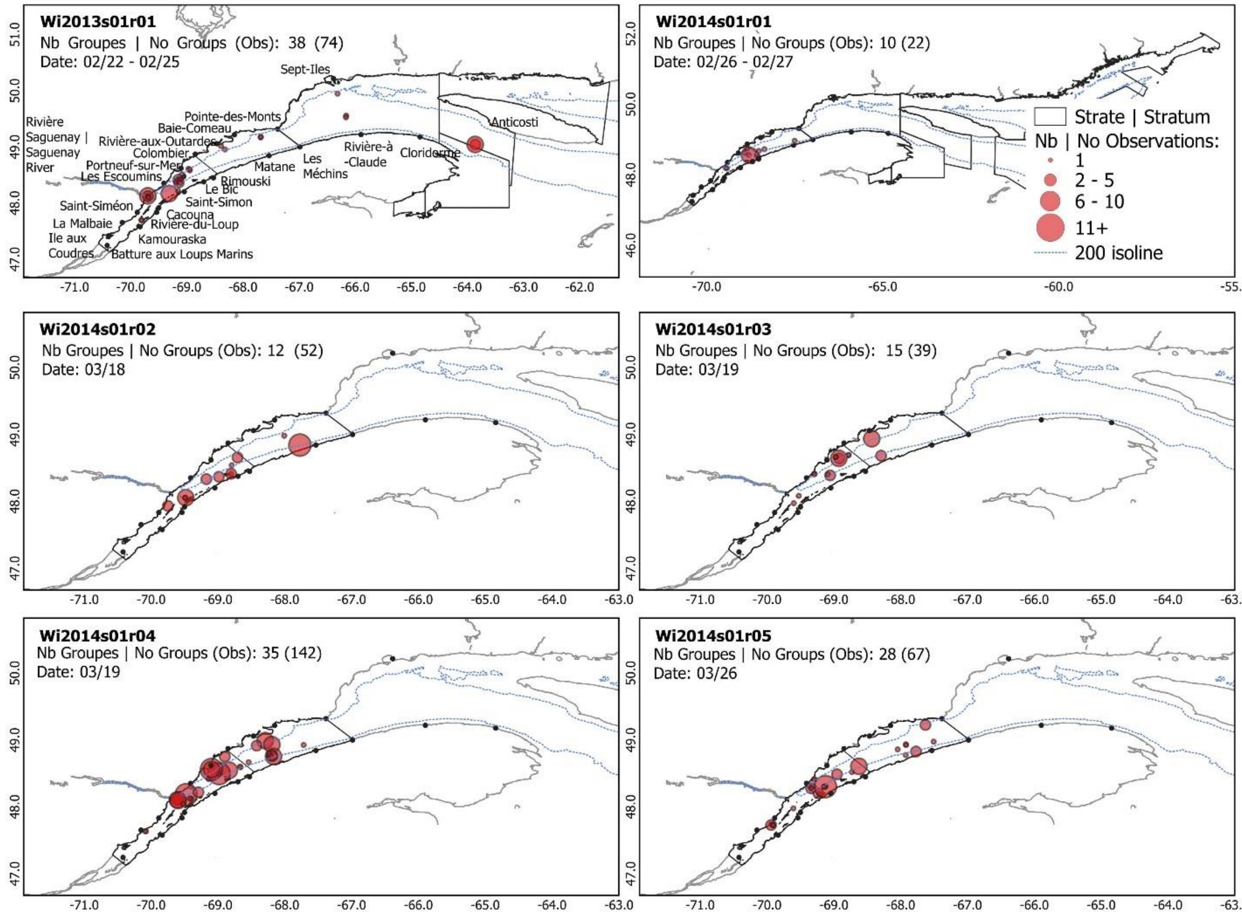

Figure A4.4. Area surveyed, locations and group sizes of beluga detected during 21 systematic visual line-transect aerial surveys conducted over the Estuary and Gulf of St. Lawrence during winter (mid-January to the end of March) from 2013 to 2023.

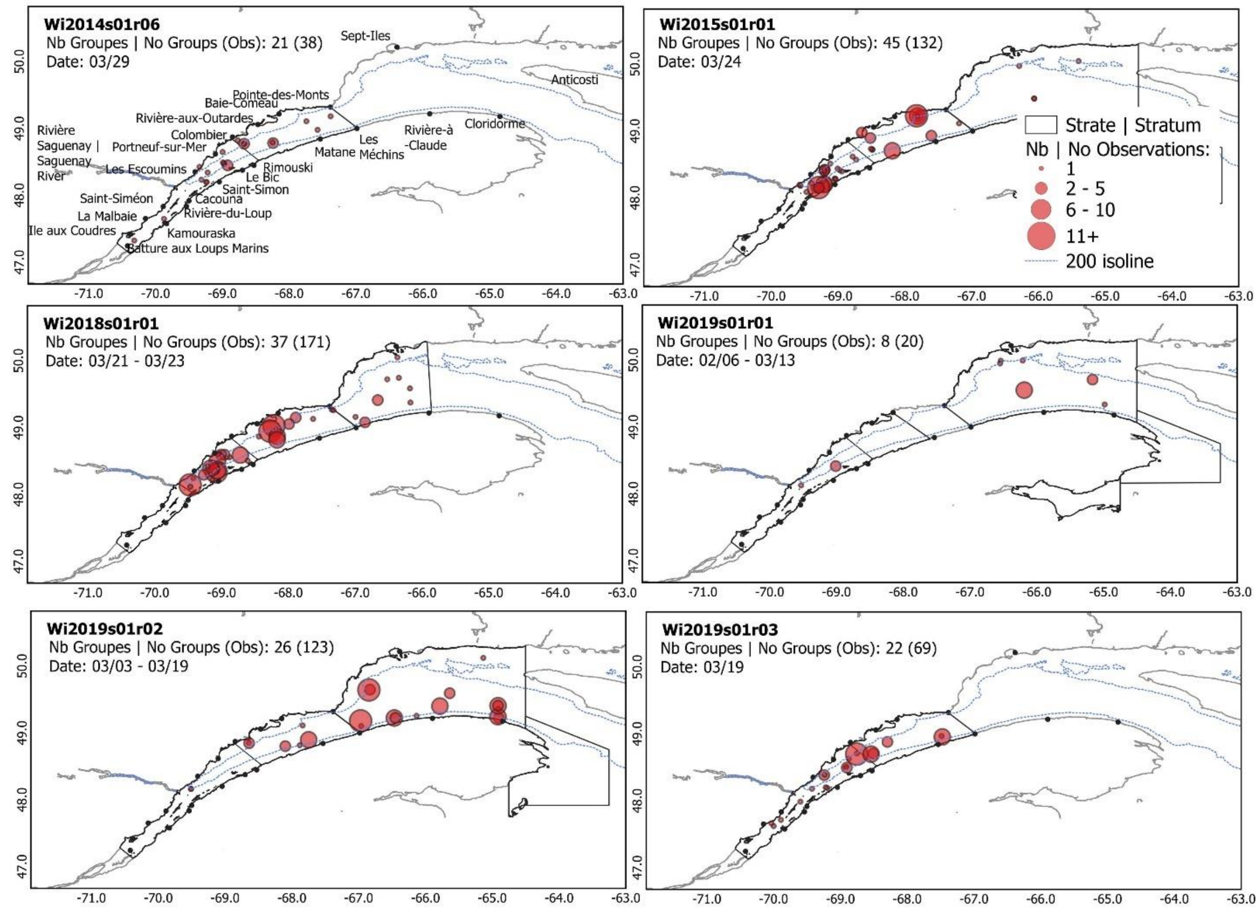

Figure A4.4. Continued.

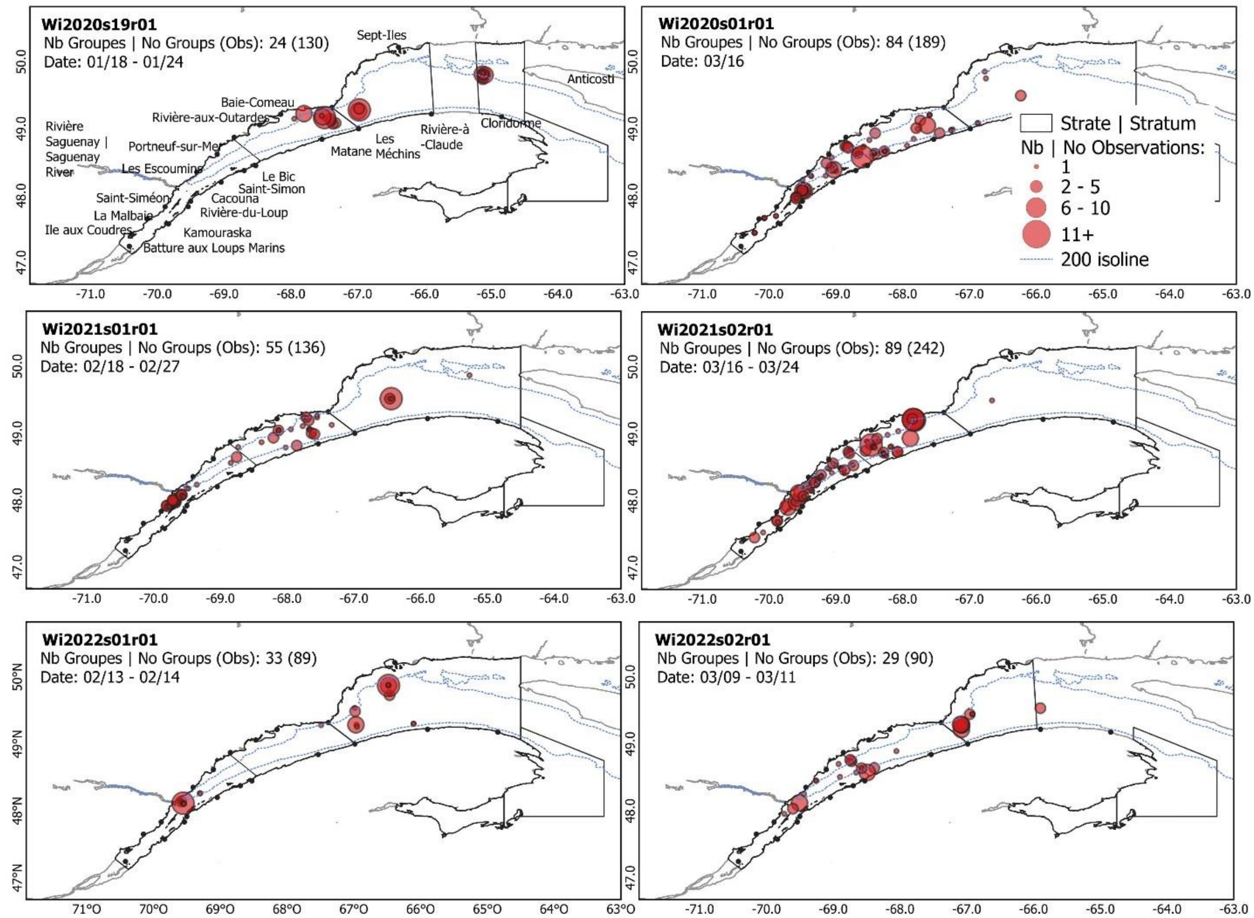

Figure A4.4. Continued.

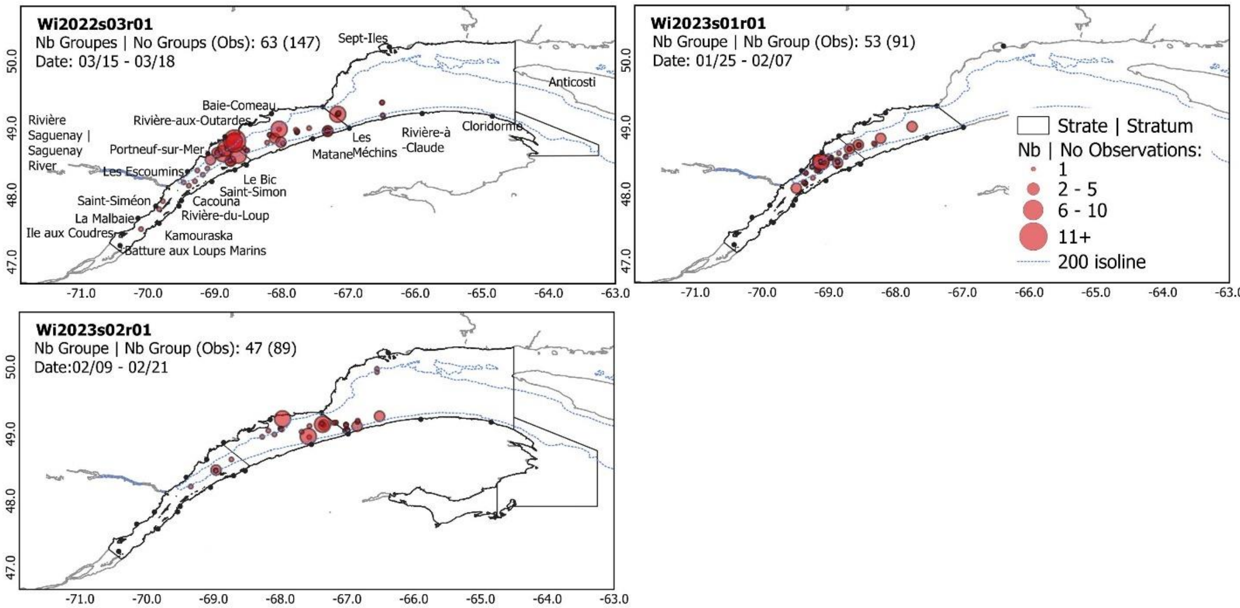

Figure A4.4. Continued.

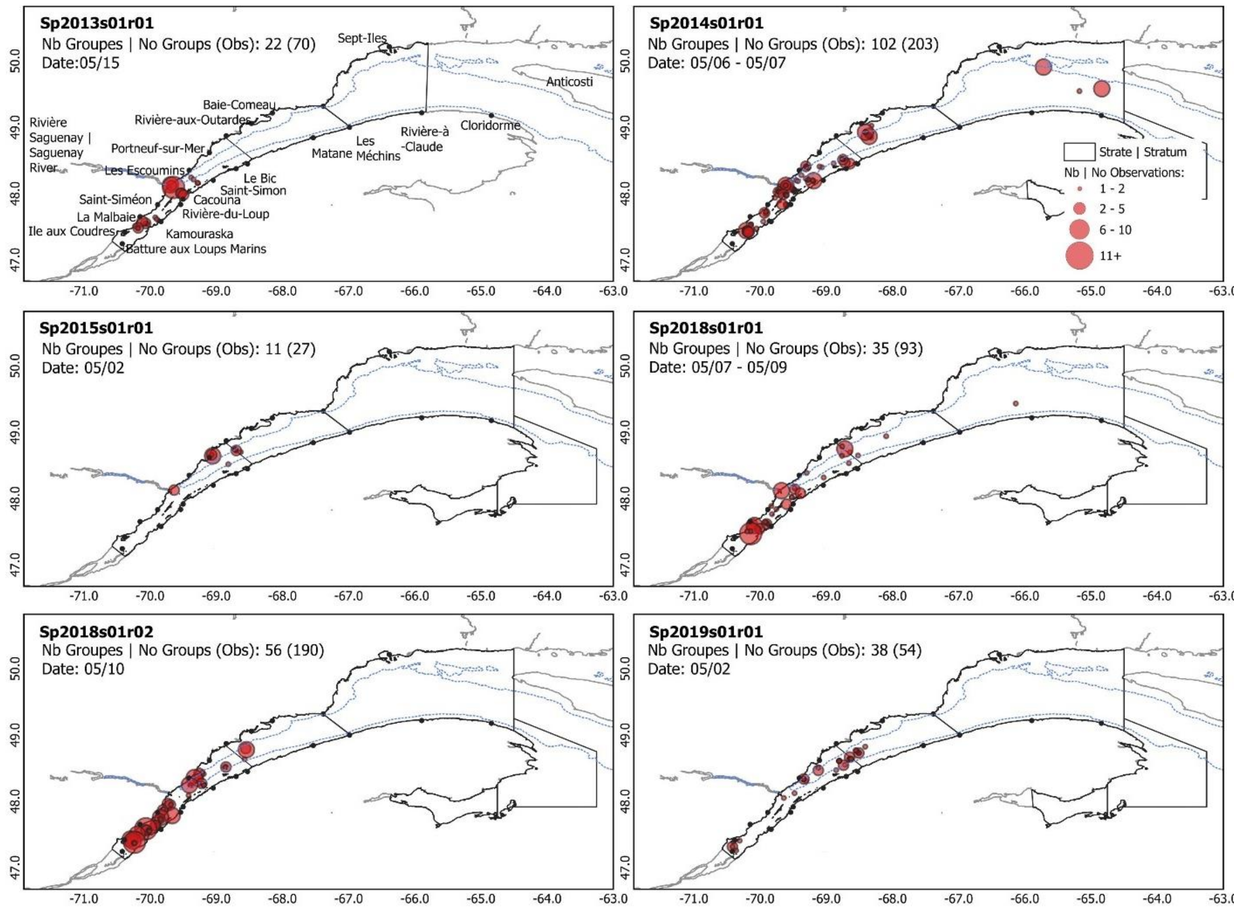

Figure A4.5. Area surveyed, locations and group sizes of beluga detected during six systematic visual line-transect aerial surveys conducted over the Estuary and Gulf of St. Lawrence in spring (early to mid-May) from 2013 to 2019.

APPENDIX 5.

Table A5.1 Mean individual density, encounter rate, expected group size of beluga for all strata of the Estuary and Gulf of St. Lawrence covered during systematic line-transect aerial surveys conducted in fall, winter and spring between 2012 and 2023, based on results from the bootstrapping procedure (see Methods). Numbers in parentheses represent 95% confidence interval for each value.

Year	Season	Survey	Stratum	Average density	Average encounter rate	Average expected group size
2012	Fall	Fa2012s01r01	1	0.096 (0.096 - 0.093)	0.132 (0.132 - 0.132)	2.619 (2.615 - 2.622)
			2	0.005 (0.005 - 0.004)	0.006 (0.006 - 0.006)	11 (11 - 11)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2013	Winter	Wi2013s01r01	1	0.034 (0.034 - 0.033)	0.053 (0.053 - 0.053)	2.126 (2.123 - 2.127)
			2	0.001 (0.001 - 0.001)	0.001 (0.001 - 0.001)	1 (1 - 1)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			4	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			7	0.005 (0.005 - 0.005)	0.007 (0.007 - 0.007)	3 (3 - 3)
2013	Spring	Sp2103s01r01	1	0.039 (0.039 - 0.039)	0.071 (0.071 - 0.071)	3.476 (3.469 - 3.482)
			2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2013	Fall	Fa2013s01r01	1	0.007 (0.007 - 0.006)	0.009 (0.009 - 0.009)	1.502 (1.5 - 1.503)
			2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2014	Winter	Wi2014s01r01	1	0.016 (0.016 - 0.015)	0.024 (0.024 - 0.024)	2.183 (2.177 - 2.189)
			2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			4	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			6	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			7	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			8	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
		Wi2014s01r02	1	0.024 (0.024 - 0.024)	0.039 (0.039 - 0.039)	3.3 (3.299 - 3.3)
		Wi2014s01r03	1	0.032 (0.032 - 0.032)	0.046 (0.046 - 0.046)	2.596 (2.596 - 2.596)
		Wi2014s01r04	1	0.063 (0.063 - 0.062)	0.101 (0.101 - 0.101)	4.039 (4.036 - 4.042)
		Wi2014s01r05	1	0.044 (0.044 - 0.043)	0.07 (0.07 - 0.07)	2.39 (2.388 - 2.393)
		Wi2014s01r06	1	0.027 (0.027 - 0.027)	0.042 (0.042 - 0.042)	1.758 (1.757 - 1.759)
2014	Spring	Sp2014s01r01	1	0.085 (0.085 - 0.084)	0.16 (0.16 - 0.161)	1.965 (1.961 - 1.975)
			2	0.005 (0.005 - 0.005)	0.009 (0.009 - 0.009)	5.333 (5.333 - 5.333)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2014	Fall	Fa2014s01r01	1	0.075 (0.075 - 0.073)	0.101 (0.101 - 0.101)	2.349 (2.342 - 2.356)
			2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2015	Winter	Wi2015s01r01	1	0.058 (0.058 - 0.057)	0.093 (0.093 - 0.093)	2.94 (2.936 - 2.943)
			2	0.001 (0.001 - 0.001)	0.002 (0.002 - 0.002)	1 (1 - 1)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)

Year	Season	Survey	Stratum	Average density	Average encounter rate	Average expected group size
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2015	Spring	Sp2015s01r01	1	0.012 (0.012 - 0.012)	0.023 (0.023 - 0.023)	2.195 (2.193 - 2.196)
			2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			1	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2018	Winter	Wi2018s01r01	2	0.095 (0.095 - 0.094)	0.15 (0.15 - 0.15)	4.921 (4.909 - 4.934)
			3	0.009 (0.009 - 0.009)	0.015 (0.015 - 0.015)	1.72 (1.719 - 1.721)
2018	Spring	Sp2018s01r01	1	0.045 (0.045 - 0.045)	0.082 (0.082 - 0.083)	2.917 (2.901 - 2.975)
			2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
		Sp2018s01r02	1	0.095 (0.095 - 0.094)	0.177 (0.174 - 0.178)	3.513 (3.511 - 3.521)
			2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2018	Fall	Fa2018s01r01	1	0.015 (0.015 - 0.015)	0.022 (0.022 - 0.022)	1.863 (1.859 - 1.867)
			2	0.001 (0.001 - 0.001)	0.001 (0.001 - 0.001)	1 (1 - 1)
2019	Winter	Wi2019s01r01	1	0.004 (0.004 - 0.004)	0.005 (0.005 - 0.005)	2 (2 - 2)
			2	0.007 (0.007 - 0.006)	0.009 (0.009 - 0.009)	2.749 (2.742 - 2.756)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
		Wi2019s01r02	1	0.021 (0.021 - 0.021)	0.029 (0.029 - 0.029)	3.222 (3.222 - 3.222)
			2	0.034 (0.034 - 0.034)	0.053 (0.053 - 0.053)	5.547 (5.544 - 5.55)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
		Wi2019s01r03	1	0.037 (0.037 - 0.037)	0.054 (0.054 - 0.054)	2.778 (2.773 - 2.783)
2019	Spring	Sp2019s01r01	1	0.022 (0.022 - 0.022)	0.043 (0.043 - 0.043)	1.354 (1.354 - 1.354)
			2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2019	Fall	Fa2019s0r01	1	0.022 (0.022 - 0.021)	0.031 (0.031 - 0.031)	2.285 (2.281 - 2.289)
			2	0.001 (0.001 - 0.001)	0.001 (0.001 - 0.001)	1 (1 - 1)
			3	0.001 (0.001 - 0.001)	0.001 (0.001 - 0.001)	1 (1 - 1)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2020	Winter	Wi2020s19r01	1	0.027 (0.027 - 0.027)	0.038 (0.038 - 0.038)	4.571 (4.567 - 4.576)
			2	0.034 (0.034 - 0.033)	0.045 (0.045 - 0.045)	6.429 (6.404 - 6.455)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
		Wi2020s01r01	1	0.096 (0.096 - 0.095)	0.141 (0.139 - 0.141)	2.34 (2.339 - 2.345)
			2	0.003 (0.003 - 0.003)	0.004 (0.004 - 0.004)	1.78 (1.778 - 1.782)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2020	Fall	Fa2020s01r01	1	0.106 (0.106 - 0.104)	0.141 (0.14 - 0.142)	2.92 (2.893 - 2.982)
			2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)

Year	Season	Survey	Stratum	Average density	Average encounter rate	Average expected group size
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
		Fa2020s02r01	1	0.021 (0.021 - 0.02)	0.029 (0.029 - 0.029)	1.643 (1.64 - 1.647)
			2	0.005 (0.005 - 0.005)	0.008 (0.008 - 0.008)	2.339 (2.334 - 2.344)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2021	Winter	Wi2021s01r01	1	0.061 (0.061 - 0.061)	0.091 (0.091 - 0.091)	2.464 (2.463 - 2.465)
			2	0.007 (0.007 - 0.007)	0.011 (0.011 - 0.011)	5 (5 - 5)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
		Wi2021s02r01	1	0.127 (0.127 - 0.126)	0.193 (0.193 - 0.193)	2.488 (2.486 - 2.49)
			2	0 (0 - 0)	0.001 (0.001 - 0.001)	1 (1 - 1)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2022	Winter	Wi2022s01r01	1	0.029 (0.029 - 0.028)	0.039 (0.039 - 0.039)	2.111 (2.111 - 2.111)
			2	0.013 (0.013 - 0.012)	0.02 (0.02 - 0.02)	2.494 (2.489 - 2.499)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
		Wi2022s02r01	1	0.01 (0.01 - 0.01)	0.013 (0.013 - 0.013)	3 (3 - 3)
			2	0.022 (0.022 - 0.022)	0.031 (0.031 - 0.031)	4.084 (4.077 - 4.091)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
		Wi2022s03r01	1	0.065 (0.065 - 0.064)	0.101 (0.101 - 0.101)	2.208 (2.203 - 2.213)
			2	0.005 (0.005 - 0.005)	0.007 (0.007 - 0.007)	1.474 (1.472 - 1.477)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
2023	Winter	Wi2023s01r01	1	0.054 (0.054 - 0.054)	0.079 (0.079 - 0.079)	1.689 (1.685 - 1.694)
		Wi2023s02r01	1	0.034 (0.034 - 0.029)	0.047 (0.04 - 0.048)	2.59 (2.327 - 2.608)
			2	0.011 (0.011 - 0.011)	0.017 (0.017 - 0.017)	1.443 (1.442 - 1.445)
			3	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
			5	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)

APPENDIX 6.

Table A6.1. Abundance indices obtained from the bootstrap procedure for all strata of the Estuary and the Gulf of St. Lawrence covered during systematic visual line-transect aerial surveys conducted in fall, winter, and spring between 2012 and 2023. Perception correction factor use for all surveys is 0.554 (CV=0.093). Abundances per stratum represent the mean of all survey for a given stratum, while the total abundance is the sum of strata mean. Final CV is related to the fully corrected abundance.

Year	Season	Survey	Stratum	Surface abundance index (variance)	Availability bias	Abundance (variance) corrected for both availability and perception	Saguenay count	Fully corrected abundance (95% CI) (including Saguenay count)	Final CV
2012	Fall	Fa2012s01r01	1	1,153 (485,557)	0.506 (0.002)	4,097 (6,372,657)	18	4,115 (1,359-12,458)	0.613
			2	101 (9,969)	0.38 (0.001)	477 (226,595)	-	477 (94-2,433)	0.997
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2013	Winter	Wi2013s01r01	1	405 (35,354)	0.524 (0.002)	1,390 (443,851)	3	1,393 (572-3,390)	0.478
			2	16 (242)	0.502 (0.001)	56 (3,148)	-	56 (11-287)	1.01
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			4	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			7	31 (925)	0.686 (0.003)	81 (6,444)	-	81 (16-410)	0.996
2013	Spring	Sp2103s01r01	1	469 (109,924)	0.499 (0.001)	1,689 (1,467,840)	0	1,689 (478-5,971)	0.717
			2	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2013	Fall	Fa2013s01r01	1	79 (2,528)	0.543 (0.002)	262 (28,617)	1	263 (83-833)	0.642
			2	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2014	Winter	Wi2014s01r01	1	188 (12,107)	0.487 (0.001)	692 (171,515)	NA	692 (234-2,047)	0.599
			2	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			4	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0

Year	Season	Survey	Stratum	Surface abundance index (variance)	Availability bias	Abundance (variance) corrected for both availability and perception	Saguenay count	Fully corrected abundance (95% CI) (including Saguenay count)	Final CV
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			6	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			7	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			8	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
		Wi2014s01r02	1	259 (10,705)	0.522 (0.002)	890 (138,243)	0	890 (406-1,954)	0.418
		Wi2014s01r03	1	338 (18,251)	0.469 (0.001)	1,293 (292,017)	0	1,293 (589-2,839)	0.418
		Wi2014s01r04	1	756 (67,149)	0.48 (0.001)	2,827 (1,056,201)	4	2,831 (1,421-5,642)	0.363
		Wi2014s01r05	1	528 (40,639)	0.509 (0.002)	1,862 (556,413)	0	1,862 (875-3,967)	0.401
		Wi2014s01r06	1	322 (12,535)	0.507 (0.002)	1,141 (176,123)	0	1,141 (568-2,294)	0.368
2014	Spring	Sp2014s01r01	1	1,027 (139,169)	0.563 (0.002)	3,280 (1,575,135)	0	3,280 (1,589-6,769)	0.383
			2	104 (4,556)	0.483 (0.001)	387 (65,067)	-	387 (119-1,256)	0.659
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2014	Fall	Fa2014s01r01	1	908 (139,688)	0.498 (0.001)	3,272 (1,971,988)	15	3,287 (1,474-7,334)	0.427
			2	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2015	Winter	Wi2015s01r01	1	700 (88,237)	0.513 (0.002)	2,452 (1,171,213)	0	2,452 (1,073-5,606)	0.441
			2	33 (372)	0.503 (0.002)	119 (4,943)	-	119 (40-348)	0.593
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0

Year	Season	Survey	Stratum	Surface abundance index (variance)	Availability bias	Abundance (variance) corrected for both availability and perception	Saguenay count	Fully corrected abundance (95% CI) (including Saguenay count)	Final CV
2015	Spring	Sp2015s01r01	1	145 (9,203)	0.504 (0.002)	518 (121,001)	0	518 (156-1,713)	0.672
			2	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2018	Winter	Wi2018s01r01	1	905 (106,379)	0.549 (0.002)	2,963 (1,268,530)	0	2,963 (1,442-6,088)	0.38
			2	99 (1,105)	0.54 (0.002)	328 (13,814)	-	328 (166-648)	0.358
2018	Spring	Sp2018s01r01	1	546 (47,142)	0.518 (0.002)	1,894 (619,844)	10	1,904 (874-4,148)	0.413
			2	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
		Sp2018s01r02	1	1,151 (166,377)	0.524 (0.002)	3,944 (2,181,135)	1	3,945 (1,940-8,022)	0.374
			2	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2018	Fall	Fa2018s01r01	1	185 (7,808)	0.465 (0.001)	714 (123,997)	0	714 (286-1,782)	0.493
			2	8 (65)	0.457 (0.001)	32 (1,011)	-	32 (6-163)	1.005
2019	Winter	Wi2019s01r01	1	37 (822)	0.427 (0.001)	154 (14,869)	0	154 (39-604)	0.791
			2	146 (6,929)	0.513 (0.002)	512 (88,919)	-	512 (178-1,477)	0.582
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
		Wi2019s01r02	1	257 (12,797)	0.457 (0.001)	1,009 (212,103)	0	1,009 (430-2,367)	0.457
			2	760 (86,828)	0.562 (0.002)	2,431 (974,564)	-	2,431 (1,130-5,228)	0.406

Year	Season	Survey	Stratum	Surface abundance index (variance)	Availability bias	Abundance (variance) corrected for both availability and perception	Saguenay count	Fully corrected abundance (95% CI) (including Saguenay count)	Final CV
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
		Wi2019s01r03	1	446 (19,651)	0.505 (0.002)	1,587 (285,308)	0	1,587 (835-3,016)	0.337
2019	Spring	Sp2019s01r01	1	262 (9,831)	0.537 (0.002)	877 (121,138)	0	877 (414-1,856)	0.397
			2	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2019	Fall	Fa2019s0r01	1	264 (31,422)	0.471 (0.001)	1,007 (472,456)	0	1,007 (300-3,384)	0.683
			2	21 (201)	0.463 (0.001)	80 (3,111)	-	80 (24-275)	0.693
			3	9 (69)	0.426 (0.001)	36 (1,249)	-	36 (7-180)	0.969
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2020	Winter	Wi2020s19r01	1	326 (64,075)	0.529 (0.002)	1,108 (756,855)	0	1,108 (285-4,310)	0.785
			2	759 (274,210)	0.52 (0.002)	2,622 (3,371,066)	-	2,622 (760-9,043)	0.7
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
		Wi2020s01r01	1	1,161 (105,138)	0.52 (0.002)	4,013 (1,491,874)	0	4,013 (2,239-7,192)	0.304
			2	63 (1,223)	0.496 (0.001)	227 (16,795)	-	227 (80-643)	0.57
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2020	Fall	Fa2020s01r01	1	1,283 (231,917)	0.479 (0.001)	4,806 (3,591,731)	0	4,806 (2,281-10,125)	0.394
			2	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0

Year	Season	Survey	Stratum	Surface abundance index (variance)	Availability bias	Abundance (variance) corrected for both availability and perception	Saguenay count	Fully corrected abundance (95% CI) (including Saguenay count)	Final CV
		Fa2020s02r01	1	247 (12,811)	0.459 (0.001)	968 (209,837)	0	968 (401-2,336)	0.473
			2	119 (4,921)	0.455 (0.001)	471 (79,931)	-	471 (158-1,397)	0.601
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2021	Winter	Wi2021s01r01	1	739 (67,192)	0.498 (0.001)	2,668 (978,919)	0	2,668 (1,320-5,392)	0.371
			2	154 (23,378)	0.526 (0.002)	524 (276,555)	-	524 (102-2,690)	1.003
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
		Wi2021s02r01	1	1,533 (149,257)	0.51 (0.002)	5,396 (2,274,275)	0	5,396 (3,153-9,237)	0.279
			2	8 (62)	0.433 (0.001)	33 (1,073)	-	33 (6-168)	1.006
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2022	Winter	Wi2022s01r01	1	347 (94,519)	0.441 (0.001)	1,413 (1,598,216)	0	1,413 (314-6,352)	0.895
			2	216 (31,822)	0.456 (0.001)	850 (504,325)	-	850 (204-3,538)	0.835
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
		Wi2022s02r01	1	152 (4,925)	0.498 (0.001)	547 (68,423)	0	547 (225-1,331)	0.478
			2	217 (36,924)	0.49 (0.001)	795 (504,542)	-	795 (177-3,568)	0.894
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
		Wi2022s03r01	1	779 (36,774)	0.529 (0.002)	2,646 (526,918)	0	2,646 (1,560-4,486)	0.274
			2	114 (8,125)	0.496 (0.001)	415 (109,219)	-	415 (105-1,639)	0.797

Year	Season	Survey	Stratum	Surface abundance index (variance)	Availability bias	Abundance (variance) corrected for both availability and perception	Saguenay count	Fully corrected abundance (95% CI) (including Saguenay count)	Final CV
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
2023	Winter	Wi2023s01r01	1	657 (60,269)	0.47 (0.001)	2,510 (971,513)	3	2,513 (1,197-5,274)	0.392
		Wi2023s02r01	1	415 (35,829)	0.445 (0.001)	1,676 (624,374)	1	1,677 (697-4,033)	0.471
			2	242 (23,328)	0.519 (0.002)	837 (289,225)	-	837 (265-2,649)	0.642
			3	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0
			5	0 (0)	0 (0)	0 (0)	-	0 (0-0)	0

APPENDIX 7. SEASONAL KERNEL DENSITIES PER SURVEY YEAR

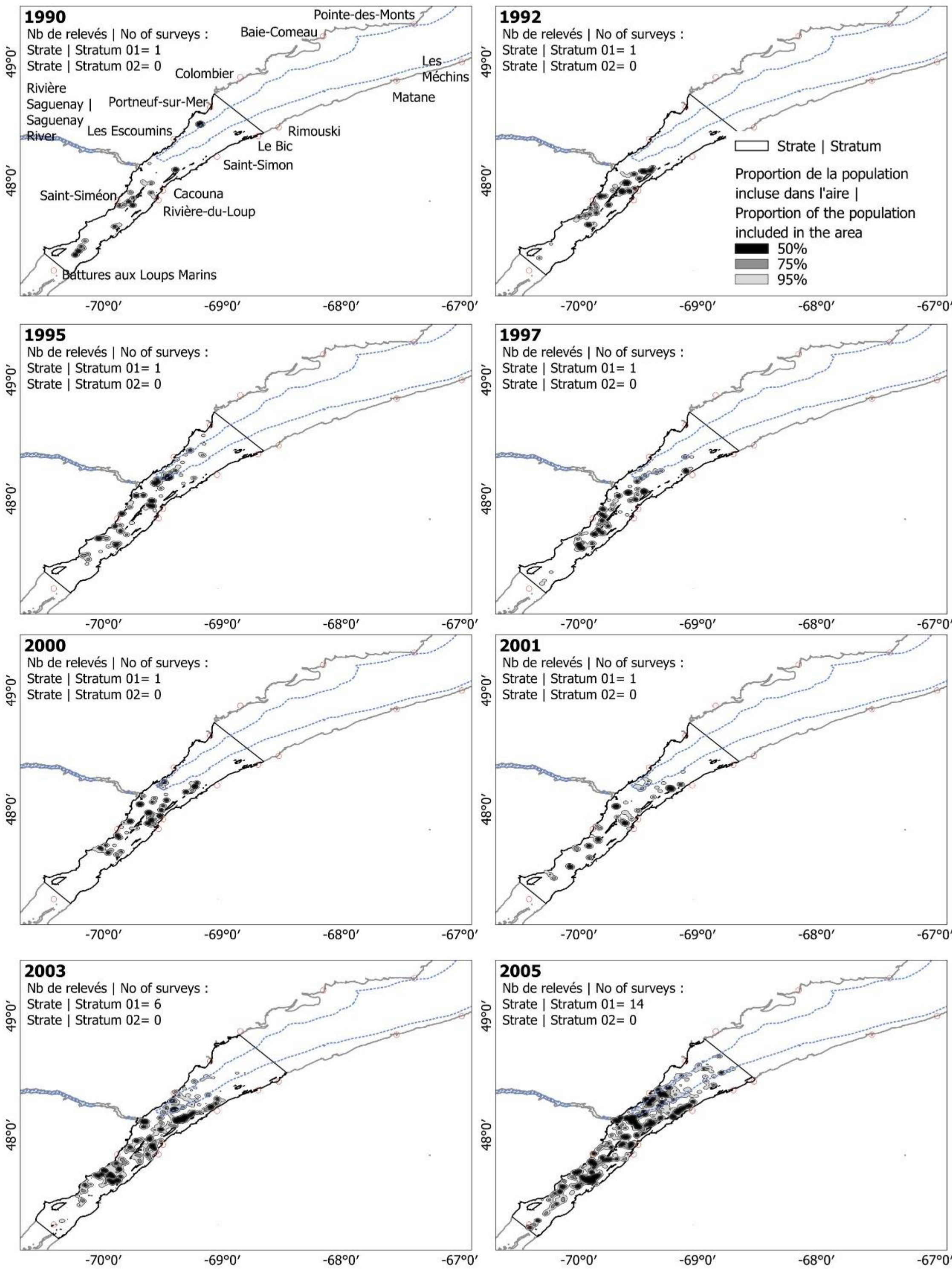

Figure A7.1. Areas including 95%, 75% and 50% of the St. Lawrence estuary beluga population estimated from a mean annual kernel calculated from detections during systematic photographic and visual line-transect aerial surveys conducted over the St Lawrence Estuary in summer (from early July to mid-September) of 1990 – 2022.

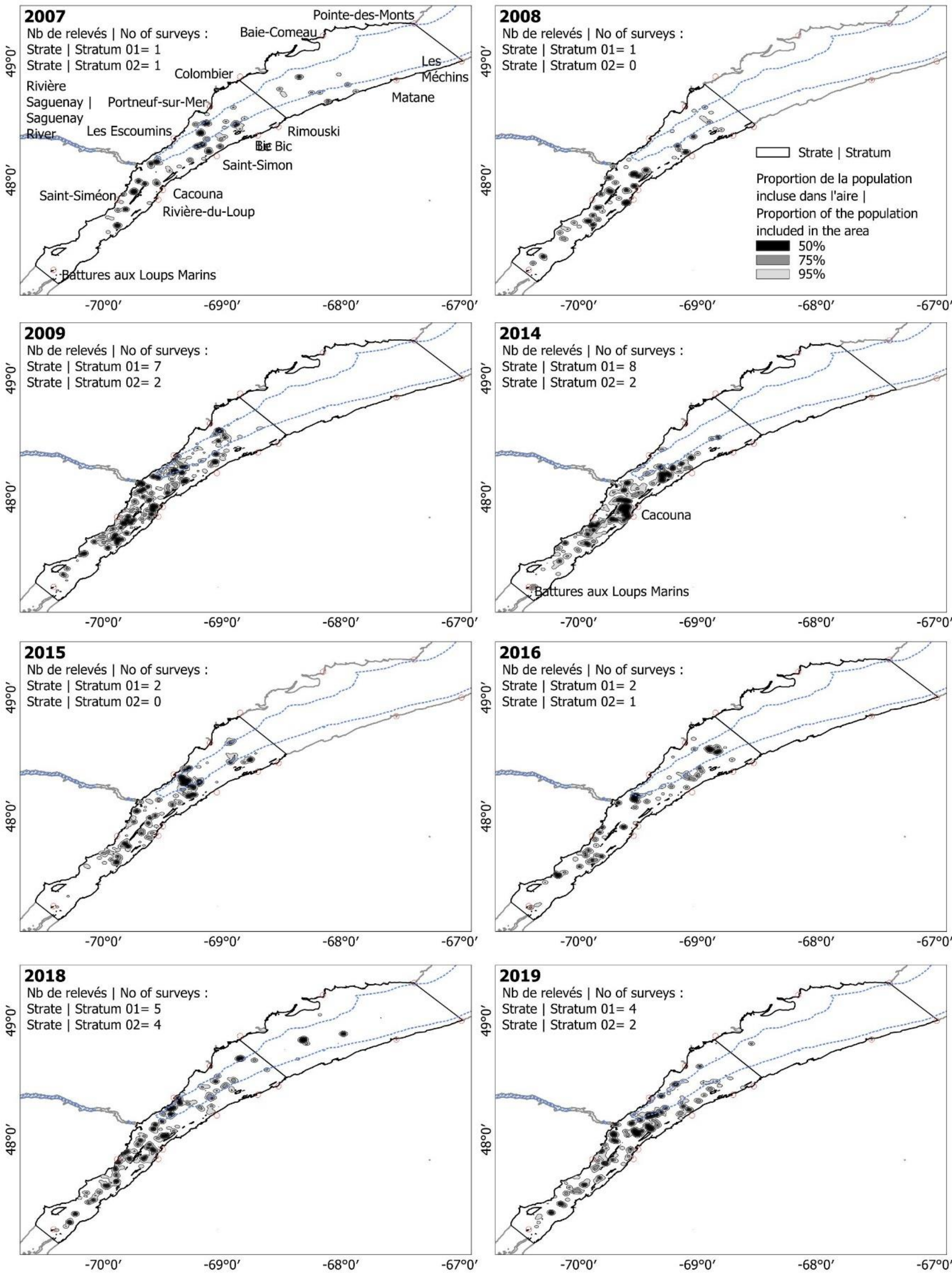

Figure A7.1. Continued.

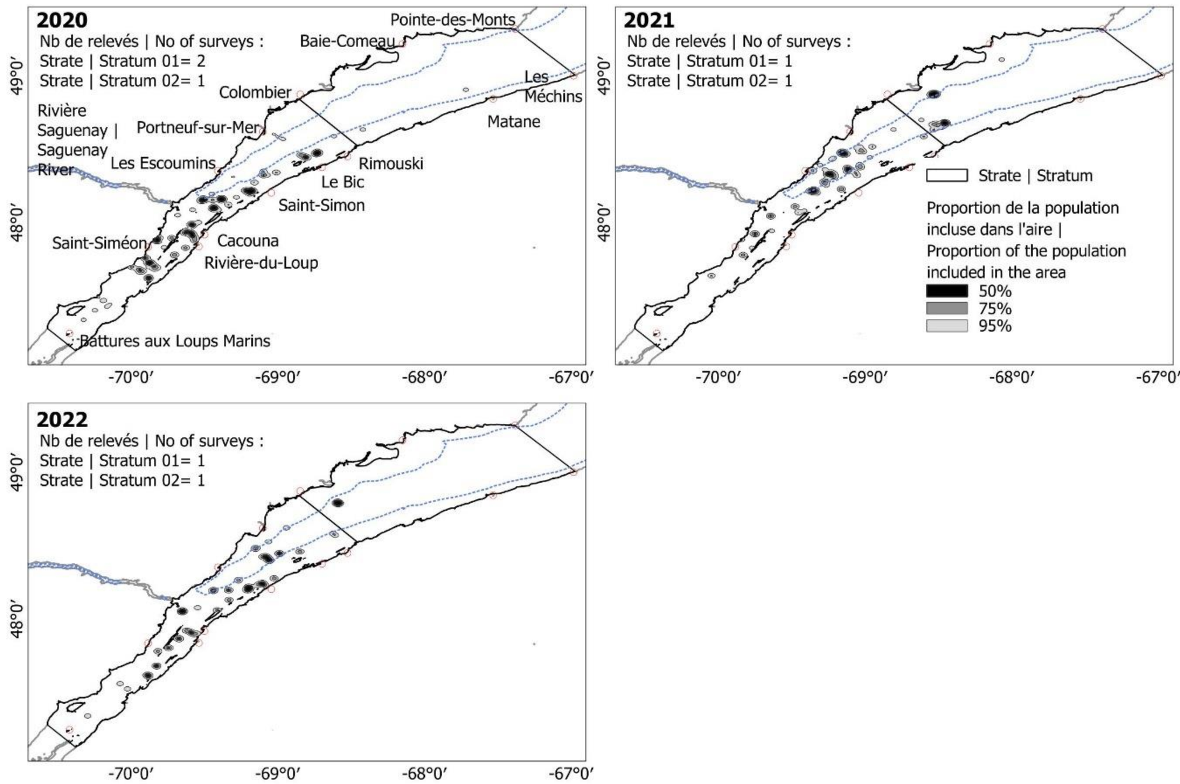

Figure A7.1. Continued.

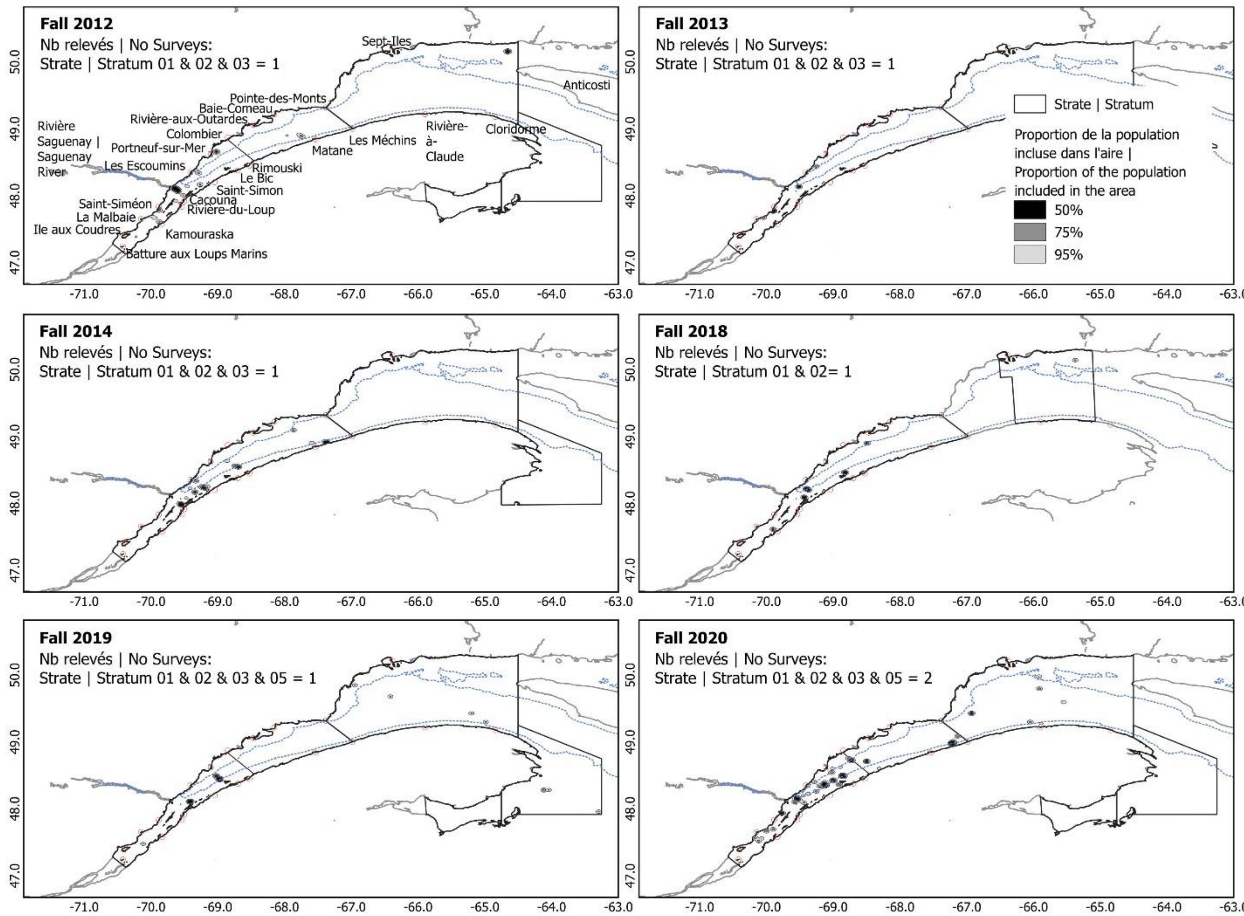

Figure A7.2. Areas including 50, 75 and 95% of the St. Lawrence estuary beluga population estimated from a mean annual kernel calculated from detections during systematic visual line-transect aerial surveys conducted over the Estuary and the Gulf of St. Lawrence in Fall (mid-November to mid-December) from 2012 to 2020.

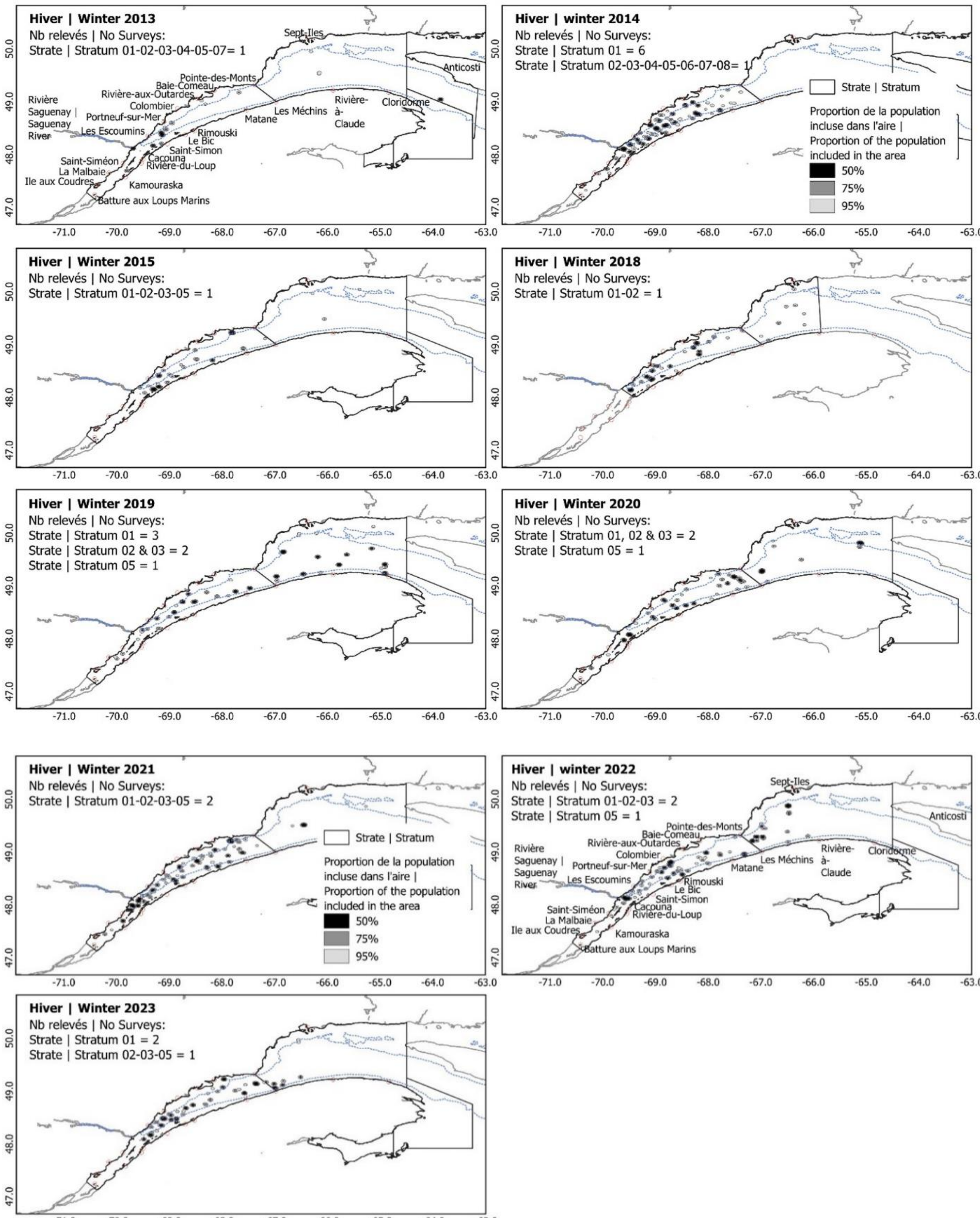

Figure A7.3. Areas including 50, 75 and 95% of the St. Lawrence estuary beluga population estimated from a mean annual kernel calculated from detections during systematic visual line-transect aerial surveys conducted over the Estuary and the Gulf of St. Lawrence during winter (mid-January to the end of March) from 2013 to 2023.

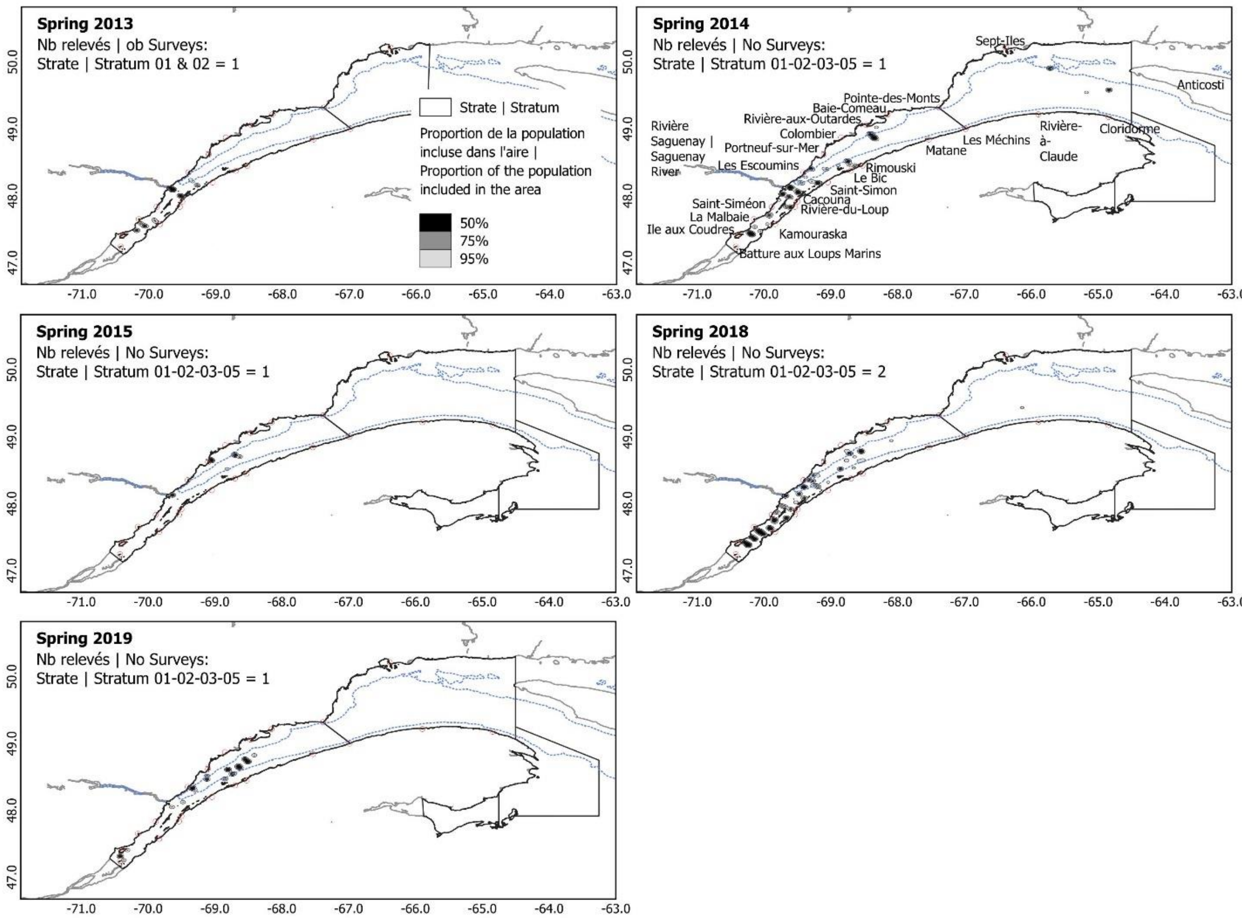

Figure A7.4. Areas including 50, 75 and 95% of the beluga population estimated from a mean annual kernel calculated from detections during systematic visual line-transect aerial surveys conducted over the Estuary and the Gulf of St. Lawrence conducted during spring (early to mid-May) between 2013 and 2019.