Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2024/062

Quebec Region

Recovery Potential Assessment for the St. Lawrence Estuary Beluga (*Delphinapterus leucas*) Population

Véronique Lesage[1], Valérie Harvey[1], M. Tim Tinker[2], Anne P. St-Pierre[1], Florian Aulanier[1], Stéphane Lair[3], Mike Hammill[1], Yvan Simard[1], Tanya Brown[4], Arnaud Mosnier[1], Ève Rioux[1], Jory Cabrol[1], Jean-François Gosselin[1]

[1]Fisheries and Oceans Canada
Maurice Lamontagne Institute
Box 1000, 850 Route de la Mer
Mont-Joli, QC G5H 3Z4

[2]Nhydra Ecological Consulting
11 Parklea Drive
Head of St. Margarets Bay NS B3Z 2G6

[3]Centre québécois sur la santé des animaux sauvages / Canadian Wildlife Health Cooperative
Faculté de médecine vétérinaire
Université de Montréal
3200 rue Sicotte
St. Hyacinthe, QC J2S 2M2

[4]Fisheries and Oceans Canada
Pacific Science Enterprise Centre
4160 Marine Drive
West Vancouver, BC V7V 1H2

September 2024

Canada

Foreword

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

Published by:

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

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

ISSN 1919-5044
ISBN 978-0-660-73124-7 Cat. No. Fs70-5/2024-062E-PDF

Correct citation for this publication:

Lesage, V., Harvey, V., Tinker, M.T., St-Pierre, A.P., Aulanier, F., Lair, S., Hammill, M., Simard, Y., Brown, T., Mosnier, A., Rioux, È., Cabrol, J., Gosselin, J.-F. 2024. Recovery Potential Assessment for the St. Lawrence Estuary Beluga (*Delphinapterus leucas*) Population. DFO Can. Sci. Advis. Sec. Res. Doc. 2024/062. iv + 63 p.

Aussi disponible en français :

*Lesage, V., Harvey, V., Tinker, M.T., St-Pierre, A.P., Aulanier, F., Lair, S., Hammill, M., Simard, Y., Brown, T., Mosnier, A., Rioux, È., Cabrol, J., Gosselin, J.-F. 2024. Évaluation du potentiel de rétablissement du béluga (*Delphinapterus leucas*) de l'estuaire du Saint-Laurent. Secr. can. des avis sci. du MPO. Doc. de rech. 2024/062. iv + 69 p.*

TABLE OF CONTENTS

ABSTRACT

The St. Lawrence Estuary (SLE) beluga (*Delphinapterus leucas*) population occurs at the southernmost limit of the species' distribution, and is a relict from the Wisconsin glaciation. While the historical abundance of this population is highly uncertain, it was most likely above 10,000 individuals. However, the effective carrying capacity for SLE beluga has fundamentally changed from historical levels, and is estimated under current conditions at 6,700 beluga (95% credible interval, CI95 = 4,300 – 10,400). Abundance in 2022 was estimated to be most likely (95% CI) between 1,500 and 2,200 individuals, with a point estimate of 1850 beluga, putting the population in the Cautious Zone according to the DFO Precautionary Framework.

Average temperatures in the Gulf of St. Lawrence over the period 2010 – 2022 have increased by three quarters of a degree Celsius relative to the average for 1970 – 2009. Assuming an additional warming of Gulf temperatures by 0.5 Celsius over the next 100 years, and continuation of natural variation without changes (positive or negative) in other mortality factors, projections indicate a low (0.3%) risk of quasi-extinction (i.e., of being reduced to ≤ 50 individuals), a 13% probability for the population reaching the Healthy Zone (i.e., at least 3,219 beluga) over the next 100 years, and a 61% probability of falling into the Critical Zone (i.e., below 1,609 beluga). These results suggest that recovery is theoretically feasible, and is even more so if some of the current threats to the population, such as factors leading to increased pregnancy-related and calf mortality, can be mitigated. Allowable harm from human-related stressors is estimated at 3.4 beluga per year using the Potential Biological Removal approach.

Both historical and contemporary data indicate that SLE beluga distribution is the most constrained during summer, and the most extensive in the spring, when a portion of the population is still present in the northwestern Gulf of St. Lawrence, but that the core of the distribution remains within the SLE year-round. Data was sufficient to identify important habitat for both summer (June-October) and winter (Jan-March) for the population; data was insufficient for spring and autumn. Functions could not be attributed to specific locations within the seasonal distribution range, and for most features, there are also insufficient data to support quantitative attributes.

INTRODUCTION

The St. Lawrence Estuary (SLE) beluga (*Delphinapterus leucas*) population occurs at the southernmost limit of the species' distribution (O'Corry-Crowe 2018), and represents a relict from the Wisconsin glaciation (Harington 2008). Centuries of intense exploitation reduced the population to an estimated few hundred individuals by the late 1970's (Pippard and Malcolm 1978, Sergeant and Hoek 1988, Kingsley 1998). Based on this information, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated SLE beluga as 'Endangered' in 1983 (Pippard 1985). Concerns over population decline triggered the implementation of a series of programs, that have been rigorously maintained over time, to monitor the health, demography, and dynamics of the population (reviewed in Lesage et al. 2014a; Lair et al. 2015, 2016; Mosnier et al. 2015; St-Pierre et al. 2024; Tinker et al. 2024). This multi-faceted dataset is among the longest for a cetacean, making SLE beluga the best monitored beluga population (Norman et al. 2022), and one of the best monitored cetacean populations worldwide.

The SLE beluga population has been re-assessed multiple times by COSEWIC since 1983. While the 'Endangered' status from 1983 was reaffirmed in 1997 (Lesage and Kingsley 1998), new listing criteria led to a change in population status to 'Threatened' in 2004 (COSEWIC 2004). However, following a documented decline in abundance in the 2000's, accompanied by high calf mortality, the COSEWIC reverted the population's status back to 'Endangered' in 2014 (COSEWIC 2014).

Typically, once COSEWIC assesses a species as Threatened, Endangered or Extirpated, Fisheries and Oceans Canada (DFO) undertakes a number of actions that require scientific information on the current status of the population, threats to its survival and recovery, and the feasibility of recovery. This information is typically summarized in a Recovery Potential Assessment (RPA), which is conducted shortly after the COSEWIC assessment.

A RPA was conducted in 2005 following the 2004 COSEWIC assessment, which set recovery targets for population size and distribution (Lawson et al. 2006). Recovery objectives were to reach 7,070 individuals or 70% of historical population size (i.e., 10,000 individuals), and to have the population reoccupy the full range of habitat described by Vladykov (1944) in the SLE and northern Gulf of St. Lawrence (GSL). However, in a recent analysis the population size recovery target of 7,070 individuals was deemed unrealistic.(Williams et al. 2021). Moreover, while Critical Habitat was defined in 2012 as part of the SLE Beluga Recovery Strategy, the boundaries were based on data acquired from June to October and, thus, came largely from summer months.

DFO Science has been asked to undertake a new RPA given the change in population status since the 2005 RPA, and the acquisition of recent information on population abundance and trends, threats, and habitat use outside of summer. The current RPA has been developed following the national RPA Guidance (DFO 2007; 2014a; ECCC 2020; 2022), and will form the basis for updating the SLE beluga Recovery Strategy, which is due for renewal. While the national RPA Guidance includes 22 elements (DFO 2014a), elements 1, 7, 18, 21 will not be addressed as part of the RPA process:

- **Element 1** on the biology and ecology of the species: up-to-date information is already available from the literature (e.g., COSEWIC 2014; Lesage 2021).
- **Element 7** on identification and description of residence: this concept does not apply to cetaceans.

- **Element 18** on feasibility of habitat restoration: this element is not required for SLE beluga recovery planning purposes.
- **Element 21** on parameter values for assessing economic, social and cultural impacts in support of the listing process: this element is not required for SLE beluga recovery planning purposes.

ASSESSMENT

ELEMENTS 2 AND 3: POPULATION ABUNDANCE AND LIFE HISTORY PARAMETERS

Population dynamics, abundance, and trends of the SLE beluga population were assessed using an integrated model fitted to abundance estimates and multiple other sources of information spanning 30 to 40 years (see Tinker et al. 2024 for details). Main data sources included historical harvest records, abundance estimates from photographic and visual aerial surveys, age- or stage-structure data from aerial and skiff surveys, age-at-death data from carcass stranding records, cause-of-death data from necropsied carcasses, and environmental correlates of calf survival. This comprehensive population model allowed several processes underlying SLE beluga population trends to be highlighted, and provided a more realistic measure of the level of uncertainty associated with population dynamics.

Pre-1980s

The model indicated that historical abundance, using 1865 as the reference year, was likely between 12,400 – 17,400 beluga. Abundance, however, declined drastically over the following century to an estimated 1,500 – 1,600 individuals at the end of the 1970's. Increased harvest mortality was the main driver of the observed decline (Reeves and Mitchell 1984). However, other contributing factors included density-dependent reductions in reproduction and increases in calf mortality, likely associated with habitat degradation, as well as density-independent increases in adult mortality reflecting increased pollution and other environmental impacts. These factors were likely responsible for the lack of population recovery after the ban on harvest in the late 1970's.

Post-1980s

A fluctuating but generally stable population trend was estimated for the period 1980 – 2000, likely as a result of variable survival rates of all age/sex classes. Similar to the population assessment from 2012 (DFO 2014b), the current model indicates that survival rates became even more variable after 2000, with several downward spikes in survival (especially for calves and yearlings) causing a decline in abundance through 2007. An increase in the survival of older adults, resulting at least in part from a reduction in the rate of cancers, led to a slight population increase between 2010 and 2018. However, the continued lower calf survival since 2010, combined with a higher mortality of adult females resulting from an increased occurrence of pregnancy-related mortality, have impacted recruitment in recent years. These sources of mortality will likely continue to limit population recovery in the future. Although there is always greater uncertainty near the end of a time series, the continued decline in the survival of calves and pregnant females, combined with a more recent uptick in mortality of all adult age classes after 2018, appears to have caused abundance trends to level off since approximately 2018 (Figure 1). Additional aerial survey and other data will be needed to clarify recent trends.

The model estimated the abundance to be most likely (95% credible interval, rounded to the nearest 100) between 1,500 and 2,200 individuals in 2022, with a point estimate of 1,850 beluga. A sensitivity analysis indicates that the datasets with the most influence on model results are the age structure data from the carcass monitoring program, the proportion of 0-1 year-old calves on aerial photographs, and the photographic survey abundance estimates. The large variance associated with visual surveys limited the influence of this time series on model results. A refinement of abundance estimate calculations might help clarify population trends.

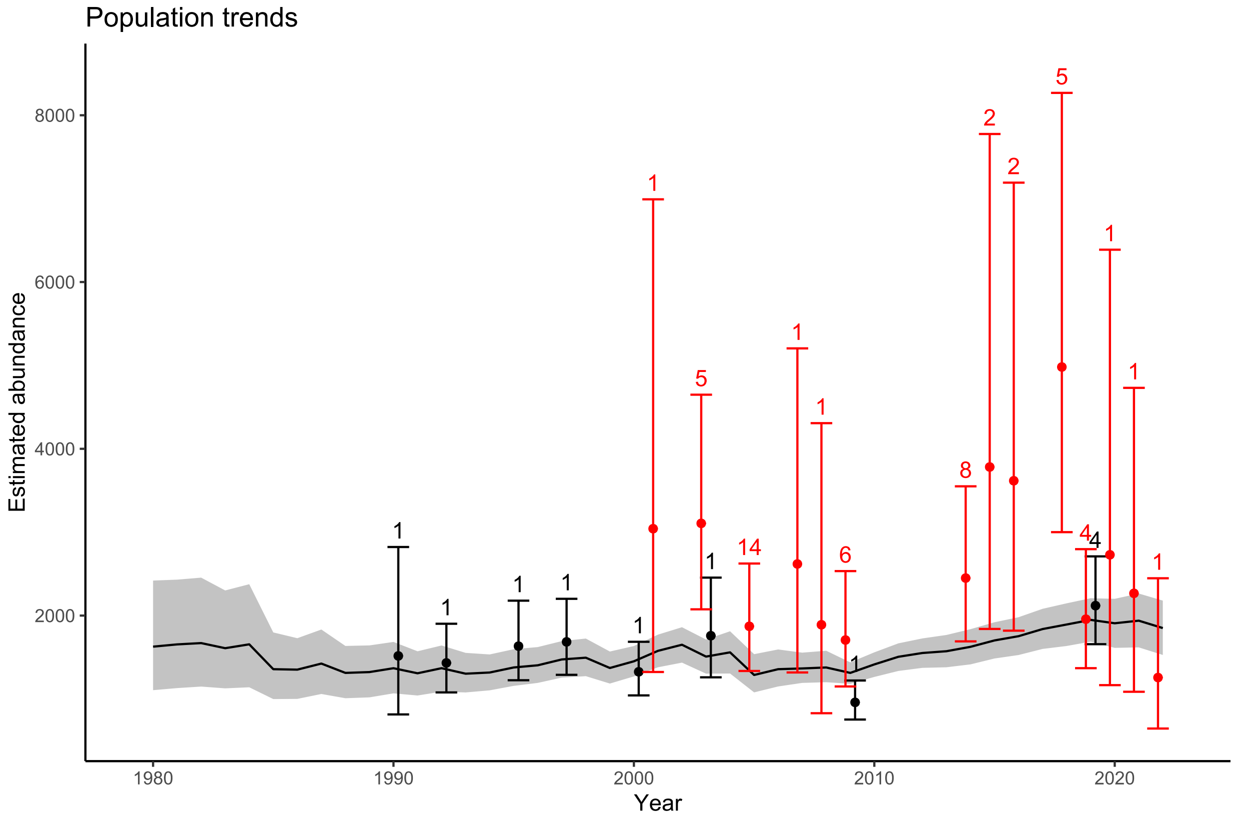


Figure 1. Estimated trends in abundance from an Integrated Population Model fit to the St. Lawrence Estuary beluga population data (Tinker et al. 2024). The solid line shows the mean annual abundance estimated by the model, while the shaded band shows the uncertainty (95% credible interval) around these estimates. The points represent survey-based estimates of abundance from aerial photo-based surveys (in black) and aerial visual surveys (in red), and the associated error bars represent the 95% credible interval around each point estimate. The number of times surveys were repeated in a year is indicated above the error bars.

ELEMENTS 4, 5 AND 6: DISTRIBUTION, IMPORTANT HABITAT, AND PROPERTIES

Information on the historical and recent distribution of SLE beluga, along with important habitat and its properties have been reviewed in detail (Mosnier et al. 2010) in the context of the 2012 Recovery Strategy (DFO 2012). While information was deemed sufficient to proceed with a partial identification of SLE beluga Critical Habitat as part of the Recovery Strategy, the latter was based on data acquired from June to October and thus, largely from summer months. Functions for the Critical Habitat, as well as their features and attributes were also only defined in general terms in the Recovery Strategy, as they were based on fragmentary information (see Mosnier et al. 2010). The following section provides an update on the seasonal distribution of SLE beluga and habitats that are considered important for this population, including the functions, features and attributes of these habitats. This assessment was made by incorporating recently-acquired information, including for periods outside summer.

Overall distribution

During the 1930’s, beluga were reported as far west as upstream of Quebec City, up to Chicoutimi in the Saguenay River (14 km west of St-Fulgence), and in the GSL at least as far east as Natashquan (Lower North Shore) and Baie des Chaleurs (Vladykov 1944; Figure 2). Over the past few decades, beluga have been observed only rarely in the fluvial portion of the St. Lawrence River or upstream of St-Fulgence. Their distribution is now considered to be restricted to waters downstream of the Battures aux Loups Marins in the SLE, and downstream of St-Fulgence in the Saguenay River (Gosselin et al. 2017; St-Pierre et al. 2024; Harvey et al. in prep.[1]).

The eastern limit of the SLE beluga distribution has been, and remains, challenging to define, although all records agree that it extends into the GSL. More specifically, assessments in both the 1930’s and in 2010 indicated a distribution extending seasonally outside of the SLE into the northern GSL (Figure 2a; Vladykov 1944; Mosnier et al. 2010). However, the distribution in the GSL has been described as highly coastal and continuous along the Quebec north shore and Gaspé peninsula (Cloridorme to Baie des Chaleurs), with an apparent absence of beluga in offshore waters (Figure 2a; Mosnier et al. 2010). This conclusion likely arose from: 1) the lack of historical or contemporary systematic survey effort in offshore waters of the northern GSL outside of summer (Mosnier et al. 2010); and 2) the fact that historical information was also highly coastally-biased as it was based on knowledge of mariners, catch data, and visits to communities in the SLE and northern GSL (Vladykov 1944). Since 2012, however, systematic line-transect surveys have been conducted repeatedly throughout the northwestern GSL, including offshore waters, during spring, fall and winter. These surveys, combined with anecdotal sighting reports from various sources (Figure 3), have confirmed the occurrence of beluga throughout the northwestern GSL in spring, fall and winter. An acoustic recorder installed along the Quebec north shore near Sept-Iles (see Figure 2) also supports this conclusion, having detected beluga calls in this area from mid-fall to early spring in recent years (Simard et al. 2023). Given that a species’ range would be expected to decrease and not increase as a result of a reduction of population size, it is likely that beluga also occurred throughout this area historically, and not just coastally, as reported previously (Vladykov 1944).

Anecdotal sighting reports available from the literature, and from more contemporary sources, do not support a regular occurrence of substantial numbers of beluga in other parts of the GSL in any season (Figure 3; Vladykov 1944; Sergeant and Brodie 1969; Sergeant et al. 1970; Reeves and Katona 1980; Curren and Lien 1998; Reeves and Mitchell 1984; Pippard 1985; Michaud et al. 1990). These anecdotal reports are, however, incomplete (e.g., very low coverage during winter and in the eastern Gulf) and are not effort-corrected and thus, must be interpreted with caution.

[1] Harvey, V., Mosnier, A., St-Pierre, A.P. Lesage, V. Gosselin, J.-F. In preparation. Seasonal Variation in Distribution and Abundance of St Lawrence Estuary Beluga (*Delphinapterus leucas*) Within the Assumed Annual Range. DFO Can. Sci. Advis. Sec. Res. Doc.

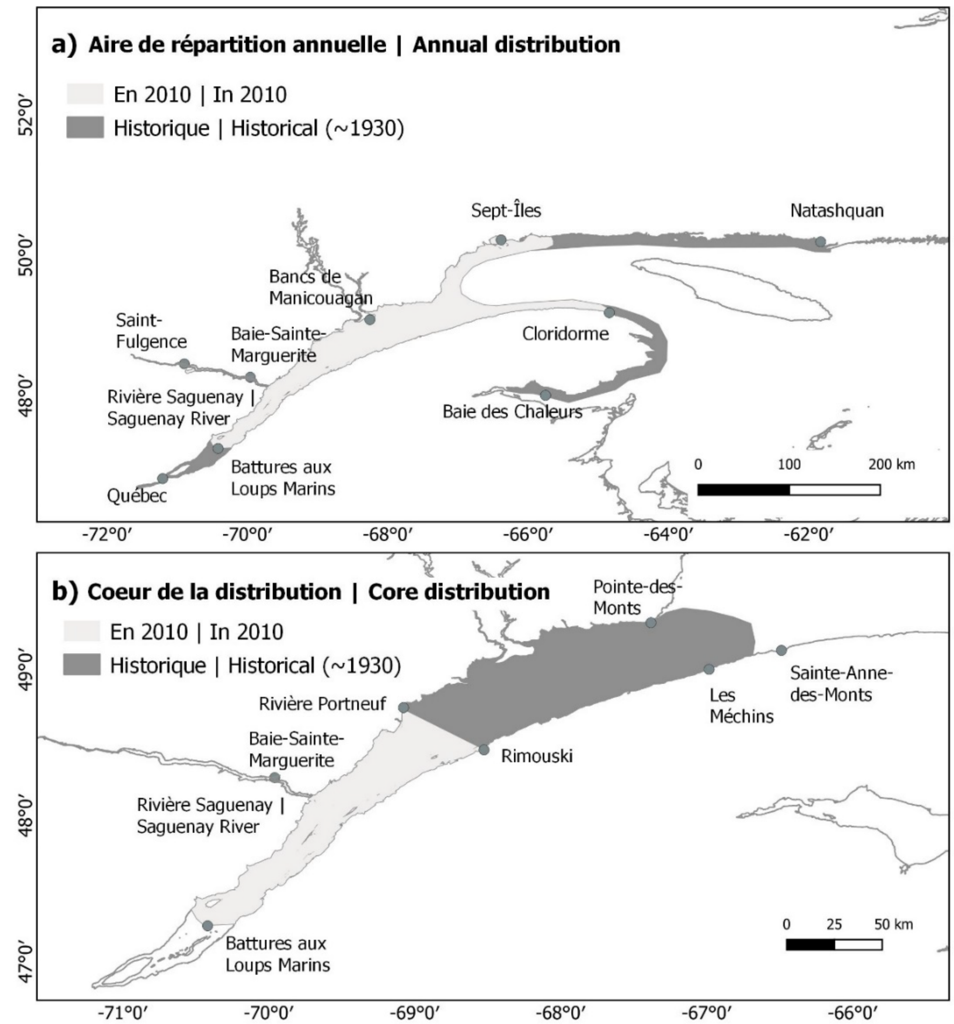


Figure 2. Annual and core distributions of SLE beluga. The historical distribution for the 1930's is taken from Vladykov (1944). The distribution in 2010 was defined based on the information available when important habitat for this population was last assessed (Mosnier et al. 2010).

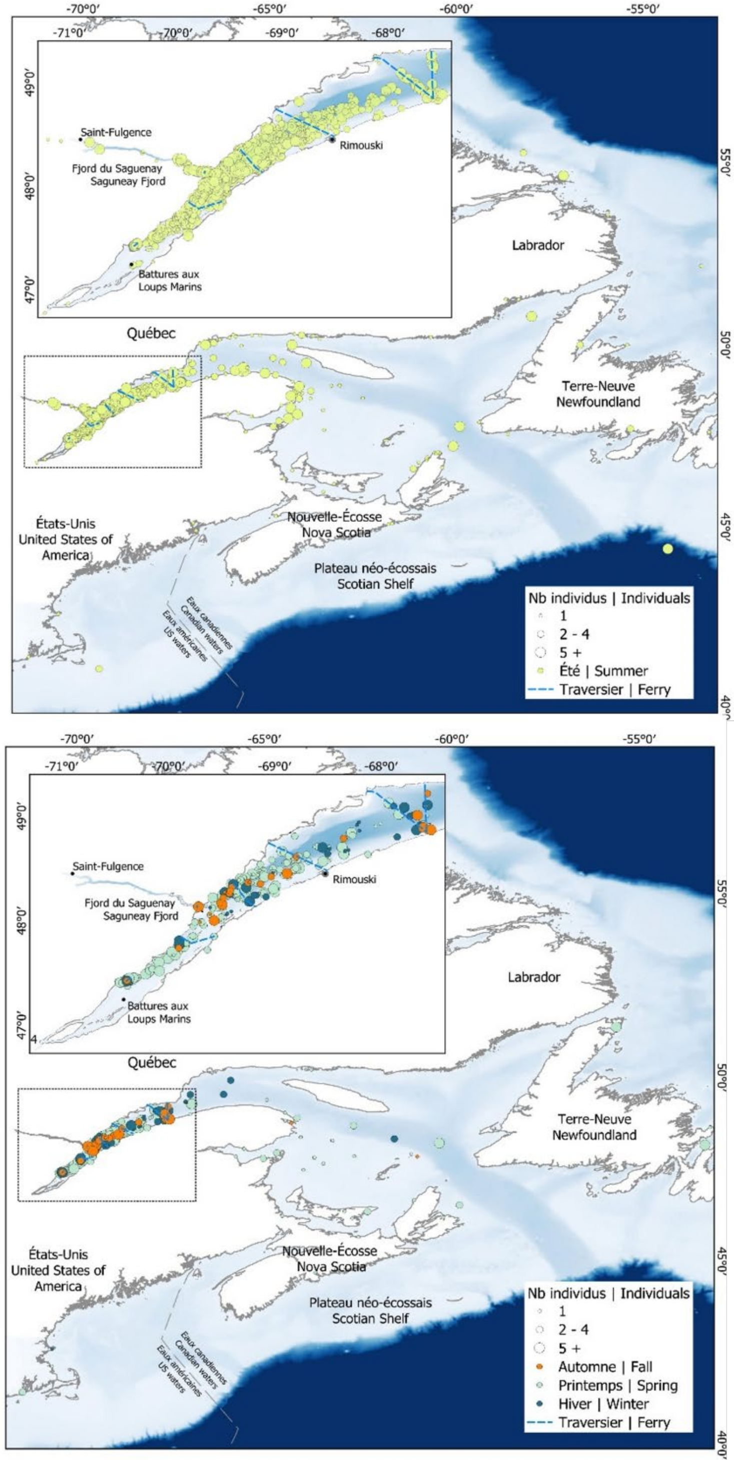


Figure 3. Opportunistic sightings from aerial and boat-based DFO surveys and other sources compiled mostly from 2013 – 2023 by the ROMM, GREMM, MARS (see acknowledgement section for acronyms), and DFO, for the periods of June – October (top panel), and for spring, fall and winter (lower panel): April – May (pale blue), November – December (orange), and January – March (dark blue). Not all possible data sources were included here; therefore, this representation is incomplete.

Beluga have historically been, and continue to be reported in Newfoundland and Labrador waters (Curren and Lien 1998; J. Lawson, DFO, Unpublished data). They are also reported occasionally outside the GSL, in Nova Scotia and eastern U.S. waters (Figure 3; see also Reeves and Katona 1980; Michaud et al. 1990; R. Michaud GREMM, Unpublished data). Given that some of the northern beluga populations winter in southern Labrador (Bailleul et al. 2012), sporadic influxes of individuals from the Arctic into Newfoundland waters and the GSL are highly probable, and have been suspected at times (see e.g., Vladykov 1944). However, the particularly low haplotype diversity documented in SLE beluga suggests that immigration by Arctic whales has remained uncommon (COSEWIC 2016; Postma 2017). Recent genetic, contaminant, and photo-identification analyses indicate that beluga observed in the eastern GSL, and Newfoundland and Labrador waters are more likely to be from the Arctic; beluga seen in the southern GSL, Nova Scotia, and eastern U.S. waters would more likely be wandering SLE beluga, possibly having followed the Gaspé and Labrador currents (Sergeant and Brodie 1969; R. Michaud, T. Frasier, and V. Lesage, Unpublished data; Béland et al. 1990a).

Seasonal movements and distribution

The extent of seasonal movements varies considerably among beluga populations worldwide, with some populations migrating over more than a thousand kilometres seasonally, and others showing only limited movements (Suydam et al. 2001, Hobbs et al. 2005; Richard and Stewart 2008; Lewis et al. 2009). These differences are likely driven by ice cover, prey availability, and predation risk. Given climate variability and global warming, some interannual variability and long-term trends in migratory patterns might be expected for a given beluga population. There is also indications that an increase in sea surface temperature may impact beluga spatio-behavioural dynamics by reducing the frequency of beluga aggregations (Rivas et al. 2024).

Table 1. Relative proportion of beluga (in %) using different sectors of the St. Lawrence Estuary and Gulf of St. Lawrence, including the Saguenay River, as estimated from seasonal aerial surveys. Sectors are as defined in Simard et al. (2023), and Harvey et al. (in prep.[1]): Upstream (Batture aux Loups Marins to Ile Blanche), Center (Ile Blanche to Les Escoumins / Saint-Simon), Downstream (Saint-Simon / Les Escoumins to Bic / Portneuf-sur-Mer), Northwestern Gulf (East of Pointe-des-Monts / Les Méchins), Saguenay River (the River excluding the Saguenay River mouth). Seasons correspond to mid July – early September (Summer), mid November – mid December (Fall), mid January – March (Winter), and early May (Spring).

Season	Upstream	Center	Dowstream	Bic/Portneuf to Colombier/ Rimouski	Colombier/ Rimouski to Point-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 ± 0.3	-	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

The SLE beluga population undertakes only limited seasonal movements, with a general movement eastward observed in the fall, and a movement westward observed in the spring. Long-term monitoring of beluga distribution using aerial surveys conducted mainly from mid-July to early September, as well as year-long passive acoustic monitoring, both confirm that the distribution during summer is centered on the Saguenay River (Figure 2 and 4; Gosselin et al. 2014; Simard et al. 2023; Harvey et al. in prep.[1]). Historically, large numbers of beluga used waters offshore of Manicouagan and the nearby Betsiamites river and thus, contributed to an extended summer range (Figure 2; Vladykov 1944). Recent survey data indicate that beluga still occur in this region, although on a more occasional basis (Harvey et al. in prep.[1]). Overall, these observations make the current core summer distribution smaller than it was historically (Figure 2b).

Acoustics data suggest that during summer, the majority of the population (i.e., 55 – 57%) is found in the central portion of the SLE (Ile Blanche to Saint-Simon / Les Escoumins*)*, with approximately 18% occupying the Upstream sector (up to Battures aux Loups Marins), and 25% being found in the Downstream sector located between St-Simon / Les Escoumins and Bic / Portneuf (Simard et al. 2023; see Figure 4 for place names). Note that the acoustic study does not account for the proportion of whales using the Saguenay River. Compared to the acoustics data, aerial surveys estimate that a lower proportion of the population (i.e., ~ 37%) uses the central portion of the SLE, with 35% of the beluga using the Upstream sector, and 14% using the Downstream sector (25% if including the eastern sector of the SLE, not covered by Simard et al. 2023; Table 1). Aerial surveys estimate that approximately 2% of the beluga are using the Saguenay River during summer. However, aerial surveys provide an instantaneous view of the distribution, and thus, tend to underestimate habitat use as they do not account for the turnover of users in a given sector. Habitat use estimations based on a long-term observational dataset suggest that the Saguenay River may in fact be used, on a more or less regular basis, by at least 37% of the population (Ouellet et al. 2021; Bonnell et al. 2024).

Beluga occur in the Saguenay River throughout the year. Survey data, land-based observations, and passive acoustics data indicate a slow rise in beluga presence in the vicinity of Baie-Sainte-Marguerite starting in June, with a decline in October (Figure 5; Harvey et al. in prep.[1]; Conversano et al. 2017; Simard et al. 2023). These observations suggest that the use of the upper Saguenay (past Cap de la Boule) peaks during summer. While beluga continue to be visually and acoustically detected occasionally in the upper Saguenay between November and May, most detections during the fall, winter and spring surveys occur in the lower Saguenay (downstream of Cap de la Boule) (aerial surveys only, as there was no acoustic recorder in that sector; Figure 5). Ice conditions are not as severe in the lower Saguenay as they are in the upper Saguenay, which might explain the continued use of this area by beluga across seasons, apparently partly for foraging purposes. Beluga presence in the lower Saguenay is also consistent with historical and recent reports of their regular occurrence at, and near, the Saguenay River mouth during winter (Vladykov 1944; Boivin and INESL 1990; Michaud et al. 1990; Harvey et al. in prep.[1]).

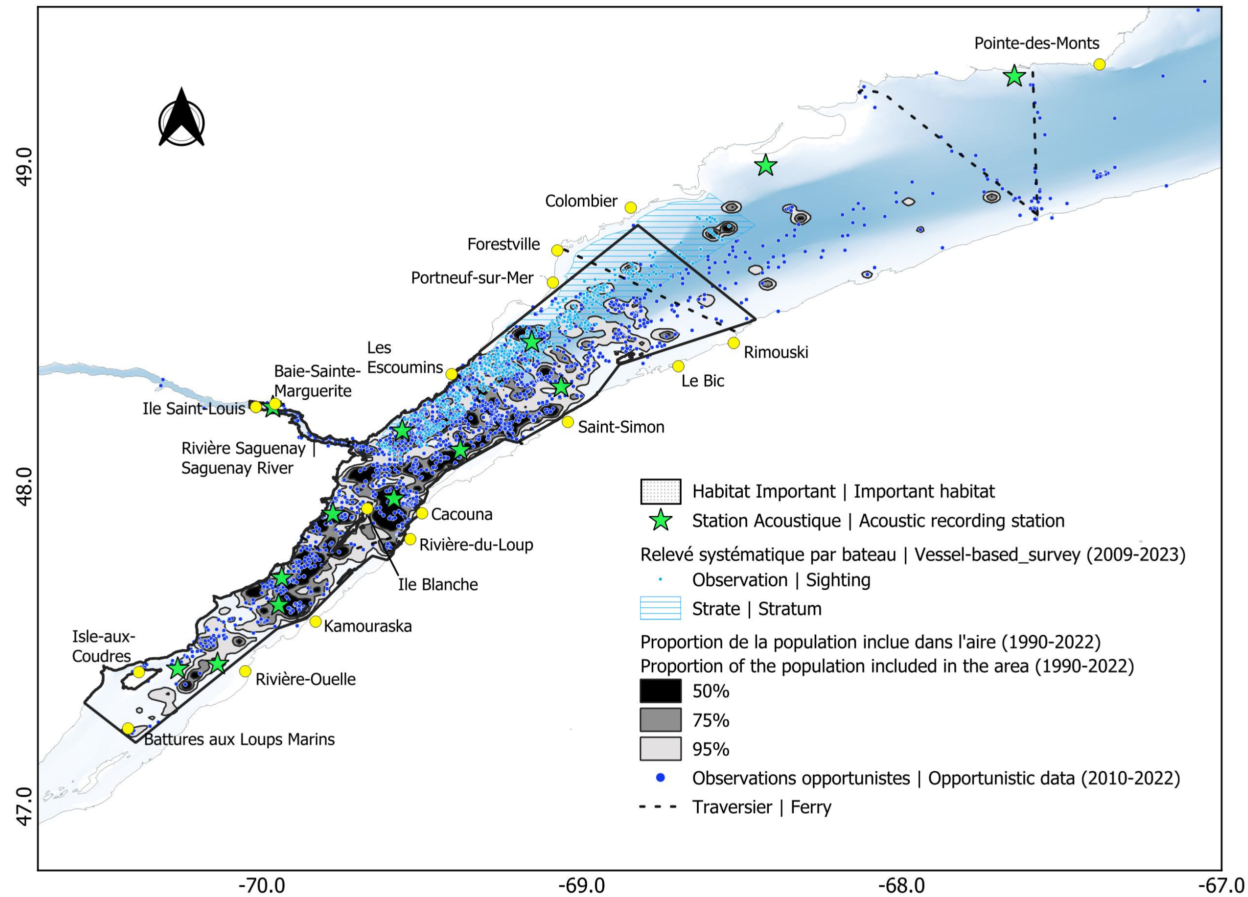


Figure 4. Important habitat for SLE beluga for the period June – October (black contour). Identification is based on the best available information, including a kernel analysis of 64 systematic aerial surveys (1990 – 2022; Harvey et al. in prep.[1]), DFO systematic skiff surveys (2010 – 2023; see e.g., Mosnier et al. 2022), opportunistic sightings from various sources (see Fig. 3 for list), and passive acoustic monitoring stations (Simard et al. 2023). See text for other sources of information. Seasonal use of the Saguenay River is presented in Figure 5.

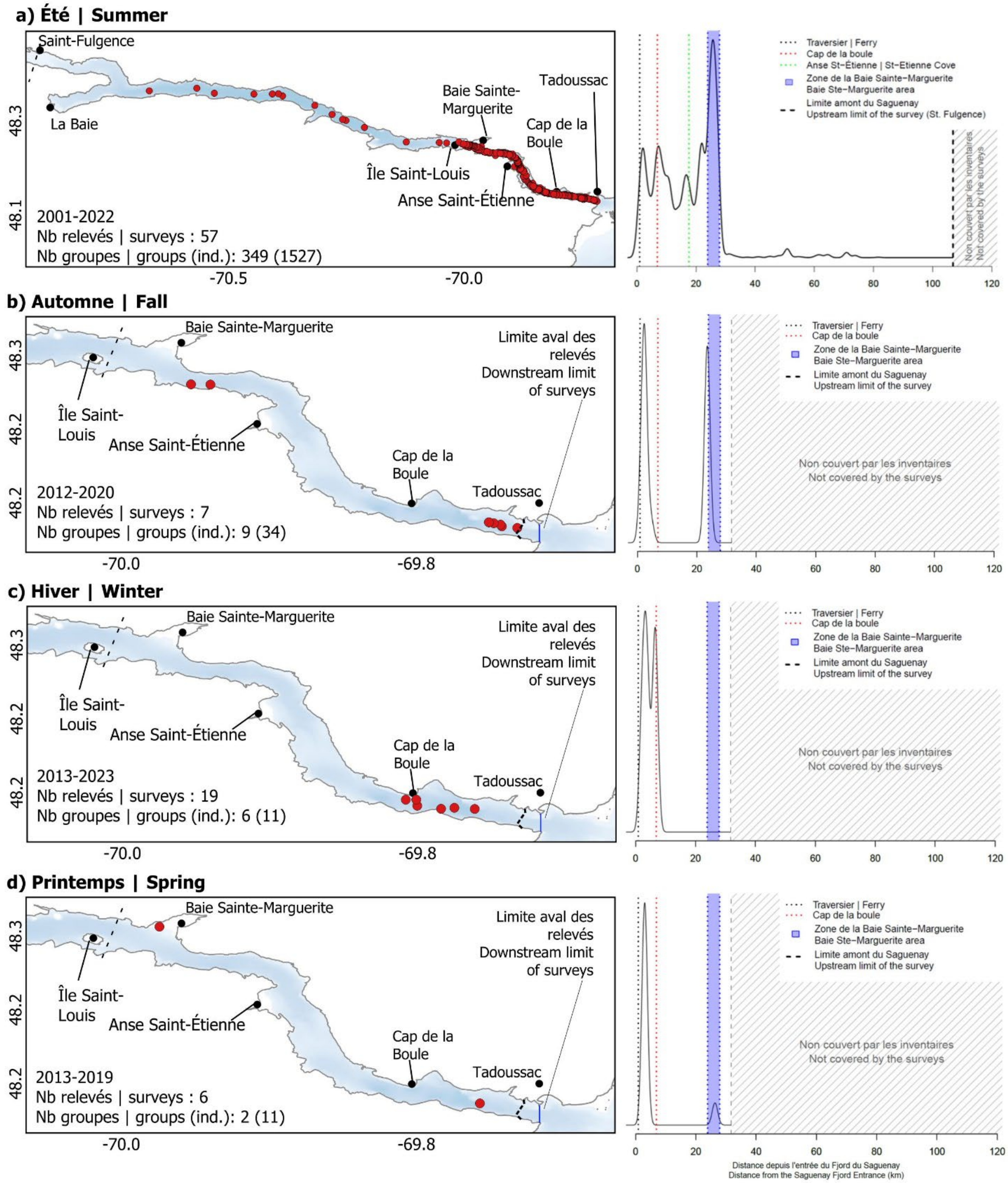


Figure 5. Seasonal occurrence of SLE beluga in the Saguenay River, based on DFO visual and photographic surveys (Harvey et al. in prep.[1]). Data are represented as sightings (left panels; can be more than one individual per sighting) and as relative densities according to distance from the Saguenay River mouth (right panel). Note that due to the narrowness of the Saguenay River, dots represent the position of the survey plane and not the position of the beluga.

The comparison of summer distributions from the 1990 – 2009 and 2014 – 2022 periods indicates a recent increase of about 6% in the use of the sector of the SLE located downstream of the Saguenay River mouth, i.e., the Lower Estuary, and more specifically, of the habitats located downstream of Les Escoumins / Saint-Simon (Harvey et al. in prep.[1]; Table 1). Herds of adult females with calves appear to be at least partly responsible for this recent redistribution of the animals within the summer range (see Harvey et al. in prep.[1]). Overall, however, the extent of the summer distribution remains unchanged compared to the last assessment: the distribution is still centered on the Saguenay River, with beluga continuing to use habitats in the upstream portion of their range, although now more intensively exploiting habitats from the downstream portion of their summer range (Figure 5).

Fall movements are generally easterly-oriented, although historically, some movements were documented in the opposite direction and up the Saguenay River, possibly in response to American eel (*Anguilla rostrata*) migrations (Vladykov 1944). No such movements have been reported recently. Studies from the 1980's, acoustic monitoring, and the most recent seasonal surveys suggest an initiation of this easterly movement sometime in October. By November, both acoustic and survey data indicate that the majority of beluga have moved out of the Upper Estuary, i.e., the sector of the SLE west of the Saguenay River mouth (Figures 6 and 7; Harvey et al. in prep.[1]; Simard et al. 2023), an area where ice cover can be almost complete during cold winters (Sears and Williamson 1982; Boivin and INESL 1990). Nonetheless, recent data indicate that beluga persist in using the Upper Estuary both during the fall and throughout winter (Figure 8; Harvey et al. in prep.[1]; Simard et al. 2023). Whether this persistence is made possible by the recent decrease in ice cover associated with warming temperatures or is a historical trait of the population, irrespective of climate, cannot be verified. The fall movement toward the east results in the majority of the population (64%) occupying the Lower Estuary, i.e., between the Saguenay River mouth and Pointe-des-Monts / Sainte-Anne des Monts (Figures 2 and 6), with an increase noted in the use of the portion of the Lower Estuary located downstream of the summer range (Harvey et al. in prep.[1]). This movement is also confirmed by passive acoustic monitoring data (station A; see Simard et al. 2023). In autumn, an average 14% of the population occupies the northwestern GSL (Table 1).

Distribution during winter is relatively similar to that observed in the fall, although beluga are observed in fewer numbers (5% of the population) in the Upper Estuary than during the summer or fall, and occupy mainly the lower portion of this sector. Similar to the fall season, most beluga (63%) are observed in the Lower Estuary during winter, but with a larger proportion of the population (32%) occupying the northwestern GSL (Figure 8).

Acoustic monitoring indicates that beluga return to the Upper Estuary habitats starting in March (Simard et al. 2023). At that time of year, beluga still occur in substantial numbers (36%) in the portion of the Lower Estuary downstream of the summer range, and in the northwestern GSL (Figures 3, 6 and 7; see also Michaud et al. 1990). The Upper Estuary appears to be of particular importance for beluga in April – May, with 36 – 50% of the population being found there depending on the data source (Simard et al. 2023; Harvey et al. in prep.[1]).

Considering all sources of information available (systematic and non-systematic aerial and boat surveys, passive acoustic monitoring, anecdotal reports), both historical and contemporary data indicate that SLE beluga distribution is the most constrained during summer (Figure 4; Vladykov 1944; Michaud and Chadenet 1990; Mosnier et al. 2010; Simard et al. 2023; Harvey et al. in prep.[1]). Available data also confirm that distribution is the most extensive in the spring, when a portion of the population still occurs in the northwestern GSL, while some individuals start returning to habitats of the most upstream portion of the SLE (Figures 6 and 7). Together, the results presented on seasonal movements and degree of occupancy of the various sectors indicate that the core of the SLE beluga distribution remains within the boundaries of the St.

Lawrence Estuary year-round. Again, whether the fraction of the population moving into the northern GSL is higher when ice coverage is more extensive, as in years prior to the late 1990’s, cannot be ascertained. While uncertainty persists as to the eastern limit of the annual distribution, the reduction of the SLE beluga range to the west in the SLE and into the Saguenay River, combined with the decline in use of the Manicouagan area, suggests that the current area of occupancy is reduced compared to the historical range.

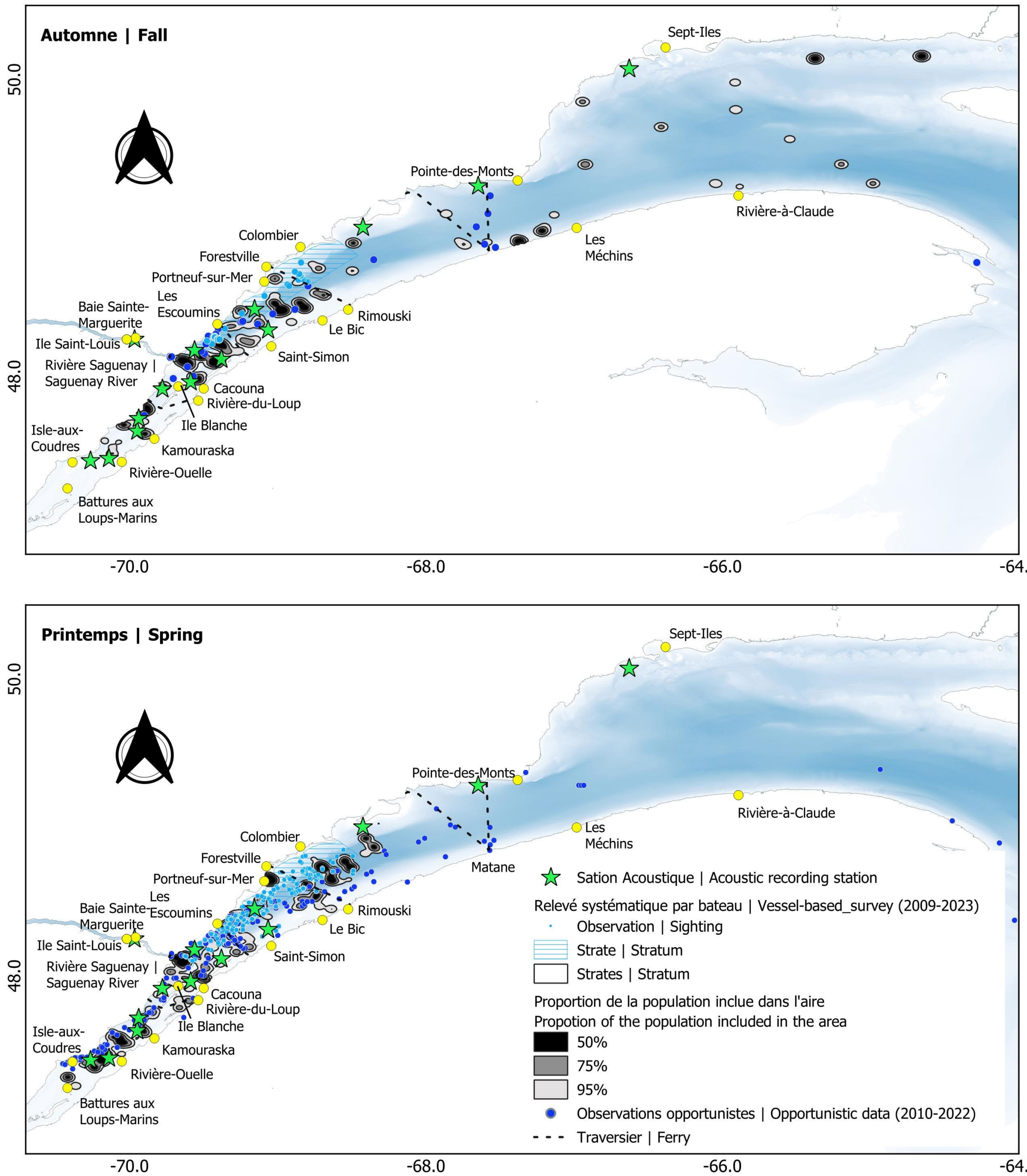


Figure 6. Fall (November – December) and spring (early May) distribution of the SLE beluga population, based on the best available information, including a kernel analysis of systematic aerial surveys (2013 – 2022; Harvey et al. in prep.1), DFO systematic skiff surveys (2010 – 2023, see e.g., Mosnier et al. 2022), opportunistic sightings from various sources (see Fig.3 for list), and passive acoustic monitoring (Simard et al. 2023). See text for other sources of information. Seasonal use of the Saguenay River is presented in Figure 5.

When last assessed, area of occupancy of SLE beluga was estimated at 20,628 km^2 or 65% of the distribution defined in the late 1930's (Mosnier et al. 2010; COSEWIC 2014). However, the information presented here indicates that the area of occupancy was underestimated both in the 1930's and in the 2010 assessment due to not including the offshore waters of the northwestern GSL, making the estimations of percent reduction in area of occupancy unreliable.

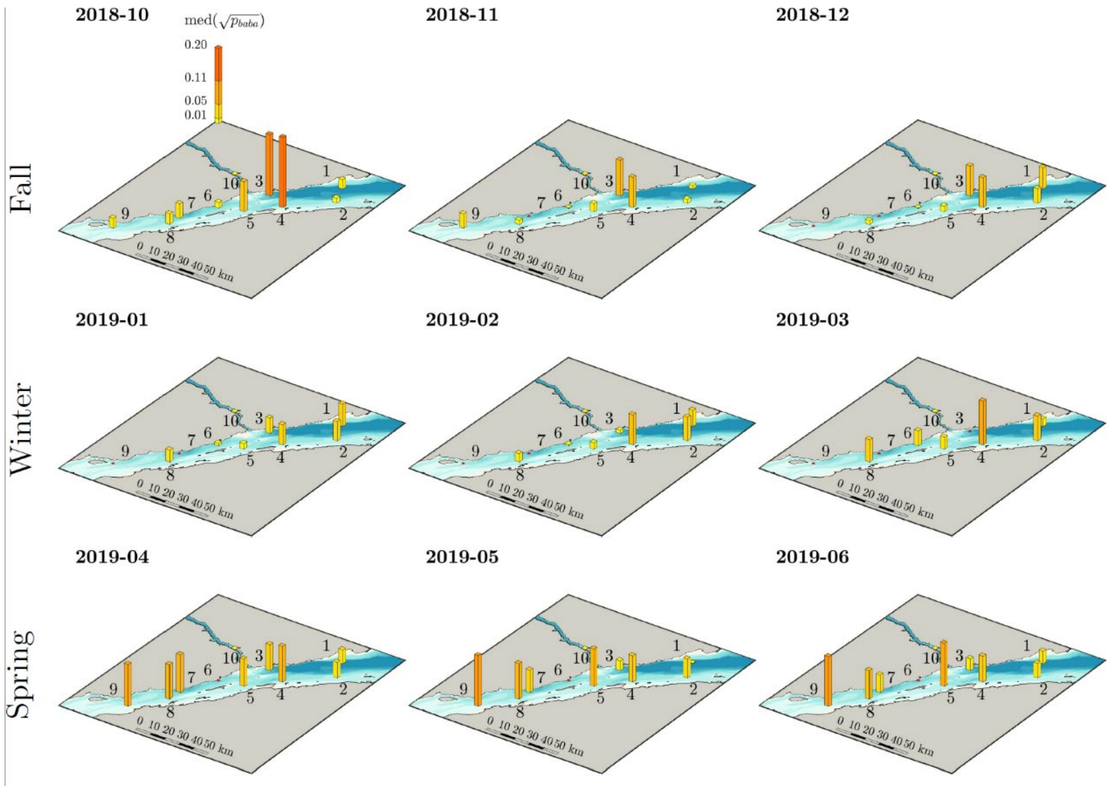


Figure 7. Acoustic evidence (monthly median hourly call occurrence index) for seasonally important habitat in the fall, winter and spring (October – June). From Simard et al. (2023).

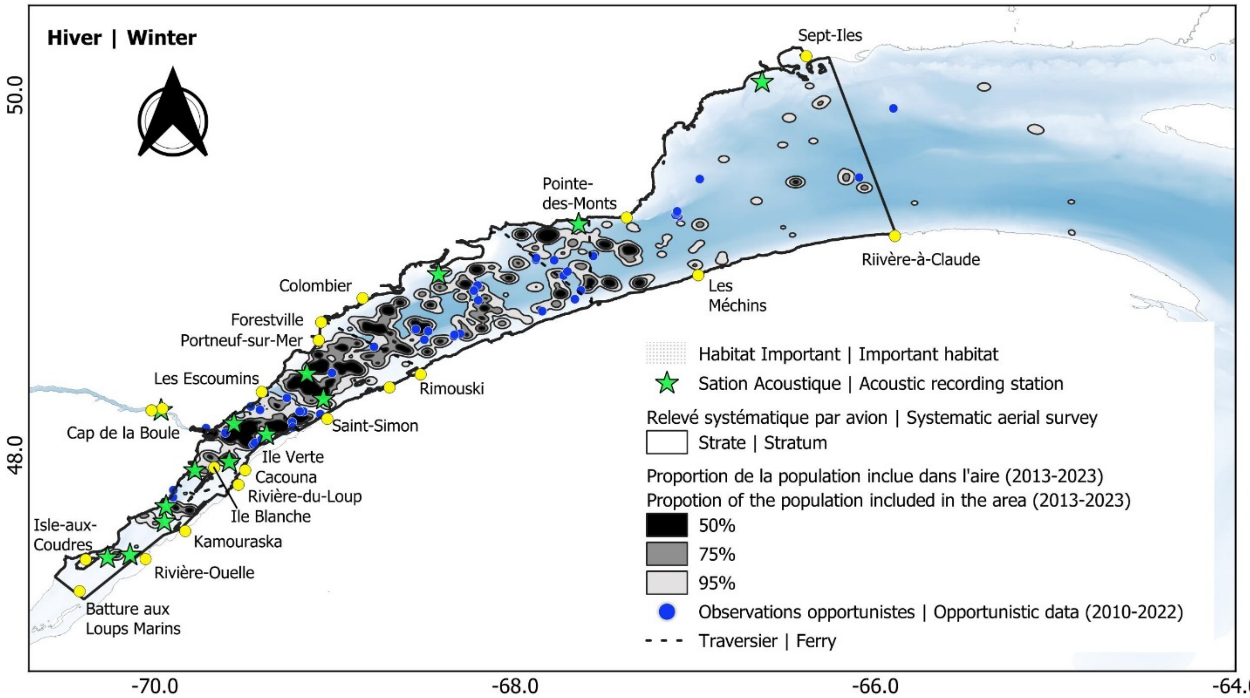


Figure 8. Important habitat for SLE beluga for the period January – March (black contour). In the St. Lawrence Estuary, the important habitat contour corresponds to the main stratum covered by systematic aerial surveys. See figure 5 for important habitat versus surveyed area in the Saguenay River. Identification is based on the best available information, including a kernel analysis of 21 systematic aerial surveys, 2013 – 2023; Harvey et al. in prep.[1]), opportunistic sightings from various sources (see Fig. 3 for list), and passive acoustic monitoring (Simard et al. 2023). See text for other sources of information.

Habitat requirements

The species

The beluga is a species which is highly adapted to cold and ice-infested environments where cover during winter may reach 70%, and sometimes exceed 90% (Barber et al. 2001; Suydam et al. 2001). While ice is a feature of beluga habitat, at least seasonally, the specific function of ice in their life cycle is uncertain. Sea ice might serve as a shelter against storms or predators (e.g., Matthews et al. 2020), and may provide food resources given the processes occurring at ice edges. Ice may also limit habitat occupancy by potential competitors such as seabirds or other marine mammal species, at least seasonally. Whether beluga would survive and reproduce successfully in an ice-free environment, assuming it remains cold, is unknown. A coarse-scale habitat model inferring habitat quality across the beluga range indicates that some beluga populations will have lost suitable winter habitat by year 2100 (Skovrind et al. 2021).

Beluga use a variety of habitats seasonally, and can routinely dive to 500 – 600 m, and down to 1400 m or more in some regions (e.g., Storrie et al. 2022). During summer, estuaries or river mouths are an important feature of their habitat, as individuals from several populations aggregate near this feature type, sometimes in large numbers (e.g., Sergeant and Brodie 1975; reviewed in Mosnier et al. 2010; see also Whalen et al. 2020). The purpose of aggregating in estuaries remains unclear, and may not be unique or constant among sites (reviewed in Mosnier et al. 2010). Potential functions include a thermal advantage for calves, feeding, moulting, and predation avoidance (Kleinenberg et al. 1964; Tomilin 1967; Sergeant 1973; Fraker et al. 1979; Finley 1982; St. Aubin et al. 1990; Frost and Lowry 1990; Watts et al. 1991;

Boily 1995; Richard et al. 2001; but see Doidge 1990). The species shows sex- and age-segregation during summer, with females and juveniles typically using warmer, shallower or more sheltered waters than adult males (reviewed in Michaud 2005; see also Loseto et al. 2006). Whether this segregation extends to seasons other than summer is currently unknown (see Colbeck et al. 2013).

An important aspect of the species that has an impact on habitat requirements is the strong philopatry and site fidelity that beluga show to natal locations or specific summering areas (Caron and Smith 1990; Smith et al. 1994; Turgeon et al. 2012; O'Corry-Crowe et al. 2018; Bonnell et al. 2022; 2024). Migratory routes appear to be transmitted culturally from older to younger individuals (Brown Gladden et al. 1997; Palsbøll et al. 2002; Turgeon et al. 2012; Colbeck et al. 2013; O'Corry-Crowe et al. 2018; 2020). Therefore, habitats with similar characteristics are not necessarily used or known to all individuals in a population. In other words, deterioration or destruction of a habitat may not be compensated by colonization of a similar or new habitat elsewhere, even if it is available (see Wade et al. 2012).

Beluga have a varied diet consisting of both fish and invertebrate species that may be benthic or pelagic (e.g., Kleinenberg et al. 1964; Seaman et al. 1982; Heide-Jorgensen and Teilmann 1994; Quakenbush et al. 2015). The species is considered to be opportunistic; several species are often found simultaneously in their digestive tracts. However, the species that are important in the beluga diet vary among populations and seasonally. It is also noteworthy that the period most important for feeding and fattening also varies among populations, likely as a result of local prey availability. Given that prey are not all of similar nutritional quality (see Rosen 2009), a few key prey might be crucial for fattening and providing the necessary energy to give birth and successfully wean a calf (see e.g., section on Threats).

Beluga are called sea canaries, as they have a highly varied vocal repertoire (Sjare and Smith 1986a; Faucher 1988). They use calls such as whistles or pulsed sounds to communicate with each other, and clicks emitted at higher frequencies to navigate and forage (Sjare and Smith 1986b). Therefore, an acoustic environment which allows signals to not only be detected, but also to be discriminated and recognized, and which allows for comfortable communication is needed (Erbe et al. 2016). Beluga are also suspected of using passive listening to locate conspecifics and to navigate through their habitat. Studies providing a definition of what constitutes an adequate acoustic environment, or providing thresholds above which noise exposure results in deleterious effects, are generally lacking for marine mammals, and even for humans (e.g., Chen and Ma 2020; Southall et al. 2021). While there is a wealth of studies about potential impacts of high ambient sound levels on marine mammal behaviour, studies demonstrating such impacts or identifying noise levels where impacts occur are scarcer, and inconsistent in their findings (Richardson et al. 1995; Southall et al. 2021). Behavioural responses are often context-specific, leading to difficulties of interpretation or generalization (Hatch et al. 2012; Gomez et al. 2016; Southall et al. 2021). Transposing individual behavioural responses into empirically measurable impacts, or even into modelled predictions of impacts, on foraging efficiency, health or reproduction, at the individual or population level, is even more challenging (but see Pirotta et al. 2021; 2022; 2023; New et al. 2014). Thresholds above which noise can cause hearing damage, either temporarily or permanently, are better documented, although not for all species and circumstances (see Southall et al. 2007; 2019).

The SLE beluga population

The SLE, especially the Lower Estuary (which extends from the Saguenay River mouth east to Ste-Anne-des-Monts/Les Méchins), and the northwestern GSL, are highly productive areas, and offer a generally cold environment year-round to SLE beluga due to local oceanographic processes and inputs from cold, nutrient-rich waters (Saucier et al. 2009). The Upper Estuary offers particularly warm, shallow, and brackish waters to SLE beluga (Vladykov 1944; d'Anglejan and Smith 1973). The SLE and GSL are seasonally ice-covered, which may affect the movements of species that are prey to beluga and thus, might regulate their availability to beluga (reviewed in Mosnier et al. 2010). Nonetheless, the occurrence of large numbers of harp seals (*Pagophilus groenlandicus*) in the Lower Estuary during winter (Bailey et al. 1977; Anderson and Gagnon 1980; Murie and Lavigne 1991; Sergeant 1991) suggests that some prey such as capelin remain abundant in the region throughout this season (see Hammill et al. 2005).

In the SLE and northwestern GSL, seafloor depth does not exceed 400 m. As a result SLE beluga can easily reach the bottom and its associated prey. Their historical diet was described extensively in the 1930's from stomach contents obtained as part of the beluga harvest (Vladykov 1946). However, their contemporary diet remains difficult to tackle using currently available tools (reviewed in Lesage 2014; Lesage et al. 2020). Generally, small pelagic fish such as capelin and sandlance, and also likely herring and smelt, may be seasonally important for SLE beluga. Demersal fish species such as cod, hake, and more recently redfish, are likely also important prey at least during late summer and fall (see Vladykov 1946; Lesage 2014; Lesage et al. 2020). While data remain scarce, several lines of evidence from historical records, and the timing of calving suggest that spring feeding might be crucial for the SLE population (reviewed in Mosnier et al. 2010; Lesage et al. 2020; Lesage 2021). At that time of year, species such as capelin and herring are spawning and may represent key prey for SLE beluga (see e.g., Lesage and Kingsley 1995; reviewed in Lesage et al. 2020). Currently, there is little information documenting feeding patterns in SLE beluga. Feeding probably occurs throughout the year, but further research is needed to understand age-specific seasonal patterns of feeding and fattening in SLE beluga.

Breeding is suspected to occur in late winter / early spring in SLE beluga based on the duration of gestation (approximately 14.5 mo) and peak calving period (late June to mid-August) (Sergeant 1986; Michaud 2007; Hill et al. 2024). Observations of breeding or parturition in wild beluga are extremely scarce (Hill et al. 2024); for SLE beluga, a single instance of what appears to be a female giving birth has been reported (Béland et al. 1990b). As a result, there is no clear breeding or calving habitat, or characteristics of habitats associated with these activities that can be identified. In the last assessment, the calving habitat was taken as equivalent to the range where females and calves can be seen during summer, which was then identified as the Critical Habitat for the population (DFO 2012).

Given that the current distribution of SLE beluga varies seasonally but is mostly constrained to the estuarine portion of the St. Lawrence system, we can ascertain that beluga use this region to carry out all their important vital functions such as breeding, calving, resting, and foraging. Within this larger habitat, the sex- and age-segregation typical of the species has been documented for SLE beluga during summer: females with juveniles and calves use mainly the Upper Estuary, southern portion of the Lower Estuary, and Saguenay River, whereas adult males use mainly the entire Lower Estuary and Saguenay River (Michaud 1993; Ouellet et al. 2021). A recent study based on an extensive data set of beluga herd follows (1989 – 2016) confirmed the age- and sex-class segregation within the summer range of the population during June-October (Ouellet et al. 2021), which was originally established based on a reduced data set from the 1980's and early 1990's (Michaud 1993). Some site fidelity within these sex- or age-specific habitats has also been documented recently (Bonnell et al. 2022; 2024), making the habitat available to specific segments of the population potentially smaller than expected based on the overall distribution alone.

SLE beluga do not use the habitats available within their distribution range equally. Areas of consistent aggregation in July – September (Figure 4; Harvey et al. in prep.[1]), and areas of high residency from June – October (Lemieux Lefebvre et al. 2012) have been identified for SLE beluga. Areas identified from these two data sources are highly consistent spatially (see Mosnier et al. 2010), and are connected by corridor routes (Ouellet et al. 2021). Habitat modelling using long-term distribution information and environmental characteristics has failed to identify habitat features that can explain beluga occurrence patterns or their greater use of some sectors (Mosnier et al. 2016). Bathymetric changes and oceanographic features such as water masses, fronts, 3D tidal currents, up- and downwelling, and eddies are likely important for the aggregation of some beluga prey such as pelagic fish (Marchand et al. 1999; Simard et al. 2002), or when transiting between habitats (Ouellet et al. 2021). However, the diversity of prey that may be important to beluga (see above), and the substantial heterogeneity in habitat characteristics associated with beluga aggregations, make the lack of overarching patterns in habitat features characterizing their use unsurprising. A major caveat to the understanding of habitat use, and the functions, features and attributes of important habitat for SLE beluga is the near-absence of data on prey abundance or changes in availability (see Mosnier et al. 2016).

Several of the areas of high residency or consistent aggregation are located within the SLE and northwestern GSL where there exists no clear barrier to movements. However, some areas of high residency are located in the Saguenay River (Michaud et al. 1990; Lemieux Lefebvre et al. 2012). Although there is no evidence that the multiple ferries operating around the clock at the mouth of the Saguenay River represent a full barrier to beluga movements up and down the Saguenay River, there is also no evidence that their operation has no measurable effect on the use of this portion of their habitat.

The SLE beluga acoustic environment is far from pristine, as it is subject to recurrent, and at times and in specific locations, heavy marine traffic (Simard et al. 2010; Aulanier et al. 2016; Chion et al. 2017; 2021; Chaire de recherche du MPO à l'ISMER-UQAR en acoustique marine appliquée à la recherche sur l'écosystème et les mammifères marins 2021). The acoustic environment of SLE beluga is also heterogeneous, with generally quieter habitats found along the south shore than along the north shore, where most of the vessel traffic is concentrated (e.g., McQuinn et al. 2011; Lesage et al. 2014b). At the confluence of the Saguenay River, where three ferries sometimes operate simultaneously, natural ambient noise levels (which were defined as being equivalent to 96.1 dB re 1 μPa for the 1—20 kHz frequency band) prevailed < 10% of the time in the spring and early summer (Gervaise et al. 2012). In this area, the potential communication range of beluga was also reduced to one-third of the range available in natural conditions at least half of the time. While the Saguenay River mouth is the noisiest sector of the beluga habitat (McQuinn et al. 2011), there are several other sectors within the SLE beluga seasonal habitat where their potential communication range can be reduced substantially (see Figure 9; Simard et al. 2022). Although noise from ships and other vessels is generally the most intense at low frequencies, it can also affect the echolocation band used by SLE beluga when foraging (Gervaise et al. 2012).

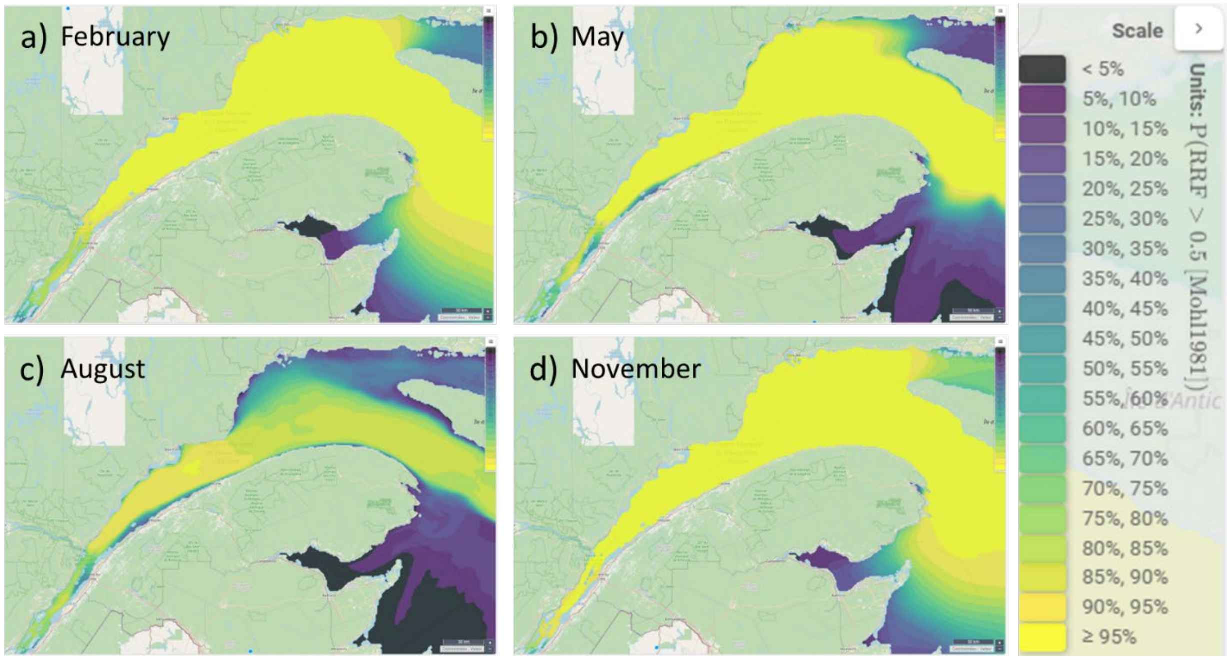


Figure 9. Monthly probability for shipping noise to reduce the acoustic detection and communication range by half at 2 kHz in a) February; b) May; c) August and d) November. The value of 2 kHz is the frequency within the communication band for beluga (i.e., 200 Hz – 20 kHz) where the range reduction factor was the most important.

Spatial extent of important habitat

As part of the 2012 Recovery Strategy, SLE beluga Critical Habitat was defined as the habitat where adult females accompanied by juveniles and calves were found during June to October (DFO 2012; see Figure 4 black contour). This habitat comprised waters from the Saguenay River up to l'Île Saint-Louis, the entire Upper Estuary east of Battures aux Loups Marins, and the southern portion of the Lower Estuary east to approximately Saint-Fabien-sur-Mer (just west of St-Simon) and Portneuf. Because data on habitat use outside this period were insufficient, Critical Habitat could not be partitioned by season, and was considered minimal pending additional data collection (DFO 2012).

In the last assessment (Mosnier et al. 2010), the upstream limit of important habitat in the Saguenay River was established based on a combination of aerial and boat-based surveys; the latter indicated some area-restricted search patterns typical of foraging behaviour occurring in the vicinity of Île Saint-Louis (see Figure 4 black contour). There is no additional information suggesting that this limit should be changed (Figure 4). Similarly, only slight changes to the limit of important habitat in the Upper Estuary were deemed warranted to account for repeated opportunistic observations of beluga in the channel to the north of L'Isle-aux-Coudres (Figure 4). Summer aerial surveys suggest that habitats located in the downstream portion of the summer range may be more intensively used in recent years (see previous section; Harvey et al. in prep.[1]). This extension in habitat use applies to females and calves (Harvey et al. in prep.[1]), and possibly to other segments of the population and thus, warrants an extension of the SLE beluga important habitat along the south shore to include habitats of the Lower Estuary to at least Rimouski / Colombier, and possibly further east (Figure 4). Data is sufficient also to exclude from summer important habitat, the shallow waters along the north and south shores of the Lower Estuary (see Figure 4). Important habitat for adult males overlaps little with that of females in the deeper waters of the Laurentian Channel (Ouellet et al. 2021). This nearlyexclusive habitat for adult males is considered important habitat for the population (Figure 4), as it provides access to additional foraging habitat and prey species in a context where food resources might be limited. Males, while in this habitat, also have little opportunity for aggressing females and their calves, a behaviour documented in other sectors of the summer range (R. Michaud, GREMM, Unpublished data).

Considerable amounts of new data have been acquired for the fall, winter, and spring. Habitat that might be important for SLE beluga are presented below for all three seasons. However, data was deemed sufficient to characterize this habitat spatially only for winter, although not sufficiently to be specific to particular age- or sex-classes (see Figure 8). Generally, seasonal aerial surveys highlighted the continued use of the Lower Saguenay (up to Cap de la Boule) during at least the fall and winter months (Figure 5). While beluga were detected both in the lower and the upper Saguenay during spring surveys, more data are needed for a full assessment of the importance of the Saguenay for SLE beluga at that time of year.

Sometime in October (Figure 7) or at least by November / December (Figure 6), the importance of habitats from the Upper Estuary diminishes in favour of habitats located in the Lower Estuary. However, beluga continue to use habitats in the Upper Estuary to the east of La Malbaie / Kamouraska, although they concentrate mainly in the Lower Estuary down to at least Pointe-à-Michel / Les Méchins in autumn, with some occurrence also noted in the northwestern GSL (Table 1).

During winter, the Lower Estuary continues to represent the most important habitat for SLE beluga, but their distribution extends to and beyond its eastern limit into the northwestern GSL to at least Sept-Îles / Rivière-à-Claude (Figures 7 and 8; Table 1; Harvey et al. in prep.[1]). For the winter, information was deemed insufficient to exclude shallow waters of the Lower Estuary from important habitat for SLE beluga. The Saguenay River up to Cap de la Boule is also considered part of important habitat given this area likely continues to serve foraging purposes. As during the fall, habitats from the Upper Estuary continue to be used by a portion of the population during winter, especially those located to the east of La Malbaie / Kamouraska, although beluga continue to be reported up to L'Isle-aux-Coudres at that time of year (Figure 8; Harvey et al. in prep.[1]). The upstream limit of the important habitat was therefore unaltered for the winter season. An increase in winter survey effort may help to identify consistency in habitat use both in the upstream sector of the Upper Estuary and within the northwestern GSL.

In the spring, starting likely around March based on acoustic data (Figure 7; Simard et al. 2023), the Upper Estuary from Battures aux Loups Marins appears to be of particular importance for the population (Harvey et al. in prep.[1]; Simard et al. 2023). The westernmost portion of the Upper Estuary is where multiple areas of high density and the highest call occurrences are documented at that time of year (Figures 6 and 7; Simard et al. 2023; Harvey et al. in prep.[1]). This is consistent with historical data suggesting an increased presence of beluga at Rivière-Ouelle and near L'Isle-aux-Coudres, likely as a result of capelin and smelt spawning in these sectors, providing beluga hunting opportunities (Casgrain 1873; Vladykov 1944). Nonetheless, the Lower Estuary east to at least Pointe-à-Michel / Le Bic continues also to be used by a non-negligeable portion of the population, with a small part of the population still being found in the northwestern GSL (Figure 6).

Functions, features and attributes of important habitat

According to the "Guidelines for the Identification of Critical Habitat for Aquatic Species at Risk", (DFO 2015) a ***function*** is a life-cycle process taking place in critical habitat (e.g., nursery, rearing, feeding and migration). Every function is the result of a single or multiple ***feature(s)***, which are the structural components of the critical habitat. Features are usually comprised of more than one part, or attribute. ***Attribute(s)*** are measurable properties or characteristics of a feature. Together, the attributes allow the feature to support the function.

Various behaviours or important activities such as foraging, socializing, resting, calving, nursing and movement / navigation are documented, or are suspected to occur, during summer in SLE beluga. These activities, except calving, are likely maintained during the fall, winter, and spring. Mating likely occurs in March-April in SLE beluga (Hill et al. 2024) and thus, might occur anywhere within the winter / spring range of the population.

The functions, features, and attributes of important habitat were defined in general terms as part of the Critical Habitat identification exercise in 2012 (DFO 2012). Area-restricted search behaviour has been documented in various sectors of the SLE beluga summer distribution, including the Saguenay River (Lemieux Lefebvre et al. 2012). Area-restricted search is often indicative of foraging (Fauchald and Tveraa 2003), although it may be also associated with other behaviours such as socialization, calving, etc. Little additional information has been acquired to refine habitat characterization, or to confirm the functions linked to the observed area-restricted search behaviours, either for the June-October period, or for other seasons (see Table 2). For instance, beluga can experience water temperatures ranging from the freezing point to more than 16 degrees Celsius in the North (Leatherwood et al. 1988; Smith et al. 1994), but their tolerance for prolonged stays in warm waters is unknown. Beluga can also withstand ice concentrations up to 10/10 (Barber et al. 2001; Suydam et al. 2001), but whether or not they could persist in an environment becoming totally ice-free over the long-term is unknown. The only additional information now available is related to the identification of corridor routes allowing connectivity among highly-used summer habitats (Ouellet et al. 2021). As a result, the list of features and attributes (Table 2) is likely incomplete, and for most of the features, there are also insufficient data to support definition of quantitative attributes.

Table 2. Functions, features and attributes of the habitat important to St. Lawrence Estuary beluga.

Season	Location	Functions	Features	Attributes
June-October	Upper Estuary (from Battures aux Loups Marins), Saguenay River (up to Ile St-Louis), Lower Estuary (east to Rimouski / Colombier)	Calving, nursing, foraging, rearing of the young, resting, socialization, habitat connectivity, communication, navigation	Warm, relatively shallow and sheltered waters Suitable water temperature range	Depth < 100 m From freezing point to 16 degrees Celsius (at least for short periods of time)
January-March	Upper Estuary (from Battures aux Loups Marins), Saguenay River (up to Cap de la Boule), Lower Estuary (east to Sept-Iles / Rivière-à-Claude)	Mating, nursing, foraging, rearing of the young, resting, socialization, habitat connectivity, communication, navigation	Suitable ice cover Suitable water temperature range	Minimum unknown; can occur in waters with sea ice concentrations up to 10/10 From freezing point to 16 degrees Celsius (at least for short periods of time)
Year-round	-	-	Food supply Water quality Suitable acoustic environment Physical space including the entire water column Refuge from predators Oceanographic processes leading to mineral-rich and highly productive cold water upwelling, including fronts that concentrate prey	Quality and quantity of prey (e.g., capelin, Atlantic herring, sandlance, rainbow smelt, redfish, cod, hake) Chemical contaminant levels in sediments, prey and beluga that are below threshold for health effects Natural ambient sound levels ensuring integrity of acoustic space

ELEMENTS 8, 9, 10 AND 11: THREATS AND LIMITING FACTORS

SLE beluga are exposed to multiple anthropogenic threats, which are described at length in recent reports (DFO 2012; 2020; in prep.[2]; COSEWIC 2014; Lesage 2018; 2021). A detailed list of potential sources for the various threats identified was also produced as part of a threat assessment conducted by the COSEWIC following the 2014 review and report (available directly from COSEWIC). A brief overview of each threat, including sources of uncertainty, is presented below.

The threats identified as part of the very first recovery strategy for SLE beluga, published in 1995 (Bailey and Zinger 1995), have changed little over time, although the evaluation of their severity has been updated with the acquisition of new scientific information. In the most recent reviews, including the last COSEWIC assessment (2014), the following threats were those of highest concern: 1) chronic exposure to high levels of toxic substances; 2) disturbance of beluga activity and deterioration of the acoustic environment associated with marine development projects and vessel traffic; 3) reduced abundance, quality and availability of food resources caused by fisheries, climate change, or increased competition; and 4) other habitat loss or degradation (e.g., from development of coastal or marine infrastructures, dredging operations, introduction of exotic species). Harvesting, which was a threat historically, is not considered further in this document, as this activity was banned in 1979 under the Canadian *Fisheries Act*. Risks posed by each of these threats are assessed (Table 3); main anthropogenic sources for these threats are also presented (Table 4).

The 2013 SLE beluga status review (DFO 2014b) documented a sudden increase in pregnancy-related mortality of females, and in newborn calf mortality starting in 2010 (Lesage et al. 2014a; Lair et al. 2014). At the time, this pattern had been attributed to three potential causes (see Lesage 2021 for a full review). First, the polybrominated dichloroethane (PBDEs), a toxic substance potentially causing complications at parturition in adult females (see Lair et al. 2014 and references therein), had increased exponentially in beluga and their environment in the 1990's, and was since at historical maxima in beluga tissues (Lebeuf et al. 2014; Simond et al. 2017). Starting around year 2000, an increase had also been noted in ecotourism activities targeting beluga directly within their Critical Habitat, with potential disrupting effects on parturition and nursing (Ménard et al. 2014; Lair et al. 2016). Finally, a change in ecosystem structure as a result of the collapse of groundfish stocks in the 1990's, and of the unusual ecosystem warming starting around 2000, was suspected to have affected the SLE beluga's food supply (Plourde et al. 2014; Lesage 2021). Warming waters and the persistent reduction in seasonal ice cover associated with this environmental change, especially since 2010, have likely made the St. Lawrence ecosystem less suitable for an Arctic species such as the beluga (Plourde et al. 2014; Galbraith et al. 2023).

The most recent (in 2023) status review indicates that the increased mortality of parturient females and newborn calves, noted since 2010, has continued through to at least 2022 (Lesage 2021; Tinker et al. 2024; Larrat et al. in review[3]). The extremely warm conditions noted since 2010 have also persisted (Galbraith et al. 2023). The coincidence in dates, and concurrent

[2] DFO. 2024. Action plan for the Beluga Whale (*Delphinapterus leucas*), St. Lawrence Estuary population in Canada. Species at Risk Act Action Plan series. Fisheries and Oceans Canada, Ottawa. In preparation.

[3] Larrat. S, Lesage, V., Lair, S., Michaud, R. 2024. Relationship Between Nutritional Condition and Causes of Death in Beluga Whales (*Delphinapterus leucas*) from the St. Lawrence Estuary, Quebec, Canada. Submitted for publication.

persistence of the two phenomena, point to the unprecedented extremes in environmental conditions documented since 2010 as a probable cause for the increased mortalities in adult females and calves. However, the mechanisms leading to the observed high mortalities in females and calves are not fully understood, and could be indirect, e.g., through effects on adult female body condition and reproductive success (Lair et al. 2016; Lesage 2021). A study examining fat stores of SLE beluga suggested a decrease in body condition of SLE beluga between 1998 and 2016 (Bernier-Graveline et al. 2021), accompanied by a change in diet composition (Lesage 2014). In other mammals, such as cows, nutritional stress during the last semester of pregnancy increases the risk of parturition-associated complications (Gruner 1973). However, the existence of a nutritional stress in late pregnancy, or of a link between a potential deteriorating body condition in pregnant females and the observed increase in calf mortality and pregnancy-related complications in females, remains to be established (Lair et al. 2016).

Poorer body condition could arise from a change in food supply. Some prey species and feeding periods are suspected to be critical for pregnant and lactating females (Lockyer 1986; Jönsson 1997; Miller et al. 2011). In captive beluga for instance, food intake increases 1.5 to 4-fold over the normal intake during late pregnancy and the first months of lactation (Kastelein et al. 1994). Given that the birth period extends from late June to August in SLE beluga (Sergeant 1986; Michaud 2007), spring would correspond to late pregnancy. Reports from the 1800's describe SLE beluga as rapidly accumulating fat during spring (Casgrain 1873; Vladykov 1944). These observations are consistent with spring being a critical feeding period for this population, and emphasize the importance of an adequate food supply at that time of year, and through to August – September (see Lesage et al. 2020; Lesage 2021). A better understanding of SLE beluga energetics and seasonal diet, and of prey availability and quality in their habitat, would help identify species that are seasonally key to SLE beluga, and verify the hypothesis of a food supply shortage.

Poorer body condition can also arise solely from an increase in energy output, and thus, not necessarily from a reduced energy intake or shortage of food supply. For instance, nutritional deficiency can result from repeated avoidance responses to vessel proximity or from a noise-mediated reduction in foraging efficiency (Lusseau and Bejder 2007; Christiansen et al. 2015; Pirotta et al. 2015; Senigaglia et al. 2016; John et al. 2024). In food-limited conditions or for females with a dependent calf, the ability of an individual to cope with these stressors might be reduced further (e.g., Williams and Loren 2009; Senigaglia et al. 2016). Therefore, while a food-mediated effect represents a highly plausible explanation for the poorer body condition (Bernier-Graveline et al. 2021) and current demographic situation of SLE beluga, other stressors may also contribute to the challenges this population is facing in their changing environment (Lesage 2021).

Recently, a competing hypothesis for the increased pregnancy-related mortality in females (and newborn calves) has emerged (C. Sauvé, DFO, pers. comm.), and will merit careful investigation. The SLE ecosystem has experienced singularly warm conditions since 2010. Beluga are likely better adapted for coping with a cold environment than with an extremely warm environment. Therefore, it cannot be excluded that some females having particularly intense or prolonged labor, may have died from exertional rhabdomyolysis or other physiological conditions caused by thermoregulation failure during parturition.

Threats

Pollutants (air, water, sediment, prey) – The SLE beluga population lives downstream of the Great Lakes and other highly industrialized areas. While some beluga prey species migrate from these areas, and thus, likely act as vectors of contamination, pollutants generally enter the beluga habitat via water and sediments transported from upstream habitats, and the beluga themselves via ingestion of prey.

The SLE beluga Recovery Strategy from 2012 presents a highly comprehensive review of the main types of contaminants to which SLE beluga are, or have been, exposed to over the past several decades (see Appendix 2 in DFO 2012). Among these compounds are several persistent organic pollutants of high concern for SLE beluga, such as polychrorinated biphenyls (PCBs), polycyclic aromatic hydrocarbon (PAH), and PBDEs, as well as some metals such as mercury (Hg), lead (Pb) and cadmium (Cd). While PAH and PCBs were regulated before concerns were raised about their potential effects on SLE beluga, other toxic compounds have been introduced in the environment over recent decades. Some of these compounds, such as PBDEs and chlorinated paraffins, have since been regulated. Others, however, such as substitutes to PBDEs, industrial antioxidants and UV absorbents, and several classes of per- and polyfluoroalkyl substances (PFASs), remain largely unregulated, and were found at concerning levels in SLE beluga (Simond et al. 2017; 2023; Barrett et al. 2021; Blouin et al. 2022). While long-term trend data exist for some of these chemical compounds in SLE beluga or their habitat (e.g., PCBs and PBDEs), such information is a lot more scarce for PAH and most metals.

Many of these chemical substances have been found to have deleterious effects on reproduction and development, and on the endocrine and nervous systems of a range of species (e.g., Costa et al., 2014; Yu et al., 2015), or may cause a change in skin microbiome (Jia et al. 2022). Metals such as Hg, Cd and Pb can be particularly harmful as they can adversely affect immune function (Wong et al. 1992; Bernier et al. 1995; De Guise et al. 1996). In general, however, information for numerous chemical substances is largely lacking for the levels at which deleterious effects are observed in beluga or other cetaceans. Concentrations for some toxic contaminants of concern (i.e., PCBs and PBDEs) in SLE beluga, however, approach or exceed marine mammal health effects thresholds (Noël and Brown 2021). Further, levels of PCBs, PBDEs, organochlorine pesticides and their by-products, and of some emerging halogenated flame retardants have been correlated with hormone levels or thyroid- and steroid-related gene expression, with some also affecting lipid metabolism (Simond et al. 2019; 2020; 2022; Jolicoeur et al. 2024). Some are also suspected of inducing immunosuppression, and of being responsible for the severity, high prevalence, and diversity of lesions observed in SLE beluga (De Guise et al. 1994; 1995; 1996; Martineau et al. 1994; De Guise 1998; Lair et al. 2016). PAHs, in particular, originating from aluminum smelters, were suspected to be responsible for the high rates of cancer documented in the SLE beluga population (Martineau et al. 2002). A recent study examining PAH–DNA adducts in beluga intestine lent support to this hypothesis (Poirier et al. 2019). The observed decrease in the incidence of neoplasia in SLE beluga born after 1971 (Lair et al. 2016), with no cases reported since 2011 (S. Lair, pers. comm.), in parallel to the cessation of PAH emissions in 1976, strongly advocate for such a relationship. The ban on PCBs in 1979, which reduced PCB loads in beluga over time (Lebeuf et al. 2014), may also have contributed to the observed disappearance of some neoplastic diseases (Martineau et al. 2002; Lair et al. 2016). Overall, these results indicate that regulatory actions to reduce toxic substance discharge and beluga exposure to these substances can have measurable effects on beluga health.

Acoustic and physical disturbance – The potential effects of a chronic exposure to elevated noise levels and repeated disruption of normal activities of marine mammals is a concern worldwide (Clark et al. 2009; Boyd et al. 2011; Williams et al. 2015). Interference with normal activities can arise through the masking of vocalizations and important acoustic signals, a reduction in acoustic space, diverting attention, disrupting natural behaviour, habituation (i.e., learned deafness), and chronic stress (Clark et al. 2009; Erbe et al. 2016; 2019). This may limit the energy and time allocated to critical activities like foraging, or can impair social interactions (Tyack and Clark 2000). A variety of anthropogenic sources can result in such effects including shipping, ferry operations, whale-watching, recreational boating (either motorized or non-motorized), research activities, and marine development projects. Recent studies indicate that the interference is not only related to noise emitted, but can also result from the physical presence of these sources (Pirotta et al. 2015). The threats posed by noise and physical disturbance to SLE beluga are reviewed at length elsewhere (DFO 2018; 2020; Lesage 2021), and are only briefly summarized here. In general, however, the pathways of effects from noise exposure towards measurable impacts on health, reproductive output or survival remain poorly understood. There are many challenges associated with the assessment of long-term effects from (often) short-term measurements on species subject to multiple stressors (but see Pirotta et al. 2015; 2019; 2022; 2023; Williams et al. 2006).

Vessel traffic and other nautical activities or infrastructures have demonstrated effects on SLE beluga. High levels of noise have been shown to reduce the acoustic space of SLE beluga or mask their calls in sectors such as the Laurentian Channel, the Saguenay River mouth or habitat therein (e.g., Figure 8; Gervaise et al. 2012; Vergara et al. 2021). For instance, in a key habitat for SLE Beluga (Baie Sainte-Marguerite in the Saguenay River), vessel noise was found to reduce the communication range of adults and subadults from a median of 6.7 km to 2.9 km, and that of newborn calves from a median of 360 m to 170 m (Vergara et al. 2021). Similar findings indicating the partial or complete masking of common communication calls have also been documented for Cook Inlet beluga exposed to commercial ships (Brewer et al. 2023). Vessel traffic, including whale-watching activities, has also been shown to alter the vocal behaviour and diving patterns of SLE beluga (Blane and Jaackson 1994; Lesage et al. 1999; Scheifele et al. 2005), with high speed responses to disturbance markedly reducing the whale's capacity for prolonged submergence (John et al. 2024). While chronic disturbance may have impact on habitat use, this is not as frequently observed. However, the abandonment of Tadoussac Bay by SLE beluga following the establishment of a marina, is highly suspected to be the consequence of disturbance from increased vessel traffic and noise exposure (Pippard 1985).

The St. Lawrence River represents the main seaway to interior North America, with several thousands of ships transiting through the SLE beluga habitat each year (Simard et al. 2010). This traffic, combined with multiple ferries and the multi-million dollar whale-watching industry also operating year-round or seasonally in this area, chronically elevate ambient noise levels in the SLE beluga habitat (Simard et al. 2010; McQuinn et al. 2011; Simard et al. 2014; Gervaise et al. 2015). Beluga exposure to these activities, and the noise they generate, varies seasonally and among habitats. Vessel traffic and beluga-oriented ecotourism activities (even if the latter is prohibited) peak in July–August, when SLE beluga give birth (Sergeant 1986). Noise levels and vessel traffic are currently the highest near the shipping lane and at the Saguenay River mouth, where a marina and most of the whale-watching companies are based (McQuinn et al. 2011). Noise exposure is the lowest in habitats located along the south shore, where traffic of all sources is currently light (McQuinn et al. 2011; Lesage et al. 2014b; Roy and Simard 2015). However, nature-watching companies specifically targeting beluga and recreational activities have increased in SLE beluga Critical Habitat along the Upper Estuary south shore (Ménard et al. 2014), with some beluga-vessel interactions leading to legal actions by DFO. Initiatives such as the Maritime Strategy of the Quebec Government (now Avantage Saint-Laurent: Avantage Saint-Laurent – Transports et Mobilité durable Québec (gouv.qc.ca)) or mine exploitation in the upper Saguenay River (e.g., DFO 2018) are likely to add to the current traffic with new port developments, and to increase in ambient noise levels in these quieter sectors of the SLE beluga Critical Habitat.

Disruption or destruction of habitat – The Tadoussac Bay abandonment following the marina establishment is an example of potential habitat destruction. The damming of the Manicouagan River for hydroelectricity exploitation, and the associated alteration of the physicochemical and biological characteristics of the area, may also have caused beluga abandonment of the area, although overharvesting could not be ruled out as a cause for the latter phenomenon (Pippard 1985).

While these two examples are extreme, various other human activities have the potential to destroy or disrupt the SLE beluga habitat, either physically or acoustically, as outlined above. Those potentially affecting the habitat physically include fisheries, and activities related to coastal and offshore development projects. Any fisheries operating within or outside the SLE beluga habitat and targeting beluga prey, disturbing the benthos or removing directly or indirectly species important for the beluga or their prey, has the potential to disrupt foraging habitat, affect food supply or reduce foraging success. Development projects that involve excavation, dredging, addition of material or structures in the water can reduce access to habitat or alter its physicochemical characteristics, with impacts on nutrient availability and food supply.

Reduction in food supply – The collapse of several commercially exploited fish stocks in the 1990's (Worm and Myers 2003; Savenkoff et al. 2007; Cairns et al. 2014) and the population increase of potential competitors, such as grey (*Halichoerus grypus*), harp (*Pagophilus groenlandicus*), and harbour (*Phoca vitulina*) seals (Hammill et al. 2015; Stenson et al. 2020; Mosnier et al. 2023), or the striped bass (*Morone saxatilis*; Valiquette et al. 2017) have modified ecosystem trophodynamics (Savenkoff et al. 2007) with potential consequences on the food supply of SLE beluga and other species. Climate warming since the turn of the 21th century has reduced ice cover and altered water mass characteristics, stratification, and circulation (Jutras et al. 2020; Galbraith et al. 2023), with measurable effects on the biomass and energy contents of various components of the St. Lawrence ecosystem including forage species (e.g., Helenius et al 2023). These conditions have reached extremes almost every year since 2010 (Galbraith et al. 2023).

Beluga in the SLE have a varied diet, composed of fish and invertebrates generally < 30 cm in length (Vladykov 1946; Lesage et al. 2020). Diet composition differs between adult males and females, as anticipated from the sex segregation observed at least during summer (Lesage 2014; Lesage et al. 2020). Stable isotope analyses have estimated a change in SLE beluga diet since the early 2000's, although the species responsible for this change remains to be identified (Lesage 2014). A change toward a diversification of food resources has been observed in fin whales (*Balaenoptera physalus*) sampled in the SLE around the same period (Cabrol et al. 2021). These changes coincided with warming of the system starting around 2000 (Plourde et al. 2014). Meanwhile, there has been a decline in essential fatty acid concentration in SLE beluga blubber between 1998 and 2016, suggesting a decline in body condition (Bernier-Graveline et al. 2021). Whether the observed change in beluga diet has resulted from a reduction in energy intake or food supply due to intraspecific or interspecific competition, a reduction in overall prey abundance, an increase in energy output or a combination of these factors, is uncertain (Bolnick et al. 2003; Svanbäck and Bolnick 2007; Araújo et al. 2011).

Extremely warm conditions since 2010 may have exacerbated effects on the various ecosystem components, bringing the SLE to a point where impacts have become measurable on adult female reproduction and calf survival (Tinker et al. 2024). These changes in SLE beluga reproductive success echo changes observed in the population dynamics and distribution of other cetaceans using the St. Lawrence ecosystem, including fin whales, humpback whales (*Megaptera novaeangliae*), and North Atlantic right whales (*Eubalanea glacialis*), also pointing toward a change in trophodynamics and food supply (Meyer-Gutbrod et al. 2015; Schleimer et al. 2019; Kershaw et al. 2020).

Toxic spills – There were very few major toxic spills in the St. Lawrence prior to 2000, with most having occurred in ports (Villeneuve and Quilliam 1999); data post-2000 are available via the Transportation Safety Board of Canada website but have not been compiled in a usable form (but see Ryan et al. 2019). The occurrence of strong tides and currents, seasonal ice cover, and frequent fog in the SLE and GSL increase the risk of toxic spills. The St. Lawrence River and GSL are among the zones where the probability of a large spill occurring is the highest in Canada (WSP Canada Inc. 2014). Because the area occupied by SLE beluga is limited, a large proportion of the population and their habitat could be exposed to a toxic spill (Peterson et al. 2003; Desjardins et al. 2018). So while the likelihood of a large spill occurring may be small, impacts could be substantial.

The consequences on beluga health and habitat, however, depends largely on the type of pollutant, volume and spatial extent of the spill, and on weather or environmental conditions during the spill. Impacts on beluga can occur through direct contact with the skin, or via inhalation, or ingestion of either the pollutant or of contaminated prey (e.g., Loughlin 1994; Matkin et al. 2008). Some pollutants may sink to the bottom, and become a persistent source of contamination for beluga, which are known consumers of benthic prey (Vladykov 1946; Lesage et al. 2020).

Entanglement – Beluga lack a dorsal fin, which likely reduces their vulnerability to entanglements. However, the main factor limiting this threat for SLE beluga is the paucity of fishing activity within their habitat. While fishing is extensive in the GSL, most of this activity either occurs downstream of the beluga habitat during summer, or is reduced to a low level or is absent during periods when SLE beluga extend their distribution into the eastern SLE and northwestern GSL.

The deaths of only two beluga out of 291 carcasses examined (i.e., 0.7%) between 1983 and 2022 was attributed to fishing activity (Lair et al. 2014; Larrat et al. in review[3]). A calf drowned after being entangled in a herring net, and an adult died from being entangled by the fluke in a longline. Long-term photo-identification of free-swimming beluga has not identified interactions with fishing gear, although an inspection of the full body and appendages of beluga would be needed to confirm this (Le Net et al. 2021).

Vessel collision – The beluga is a small cetacean with high maneuverability, highly directional hearing, and sophisticated sonar (Turl et al. 1987; Castellote et al. 2014; Zahn et al. 2021). As a result, they are not vulnerable to colliding with vessels moving in a straight line or at relatively slow speeds, such as merchant ships. However, they may be more susceptible to collision with vessels showing erratic movement patterns and/or high displacement speeds.

Between 1983 and 2022, vessel collisions are suspected to have been the primary cause of death for nine out of 291 beluga examined (3.1%; Lair et al. 2016; S. Lair, unpublished data). Whether this percentage is negatively-biased is unknown; there is no evidence that victims of vessel collisions had a lower probability of being recovered via the carcass program than whales dying from other causes. There seems to be an increased risk of injury from curiosity toward propellers in solitary young belugas wandering outside their traditional habitat, and showing social behavior towards humans (Le Net et al. 2021). These individuals are not part of the statistics presented above.

Toxic algal blooms – The SLE is well-known for the high abundance of cysts from the harmful dinoflagellate *Alexandrium tamarense*, and for the recurrence of blooms of this major source of paralytic shellfish toxins (Therriault et al. 1985; Laroque and Cembella 1990; Gracia et al. 2013). Over the past three decades, at least three major red tides have been documented in the SLE, including one (in 2008) which was associated with an unusual mortality event involving several marine species, including SLE beluga (Scarratt et al. 2014; Starr et al. 2017). Factors such as eutrophication (oxygen depletion caused by an increase in nutrients and plant growth, and leading to death of fish or mollusks), climate warming, and changes in rainfall patterns may increase event frequency and severity (Van Dolah 2000; Anderson et al. 2012). Given its relatively small size and current trends, the SLE beluga population could be significantly affected by a single exposure to toxins (Scarratt et al. 2014).

Epizootic diseases – Infectious disease outbreaks have generally increased in frequency over recent decades in marine mammals (Gulland and Hall 2007; Harvell et al. 1999; Simeone et al. 2015), possibly as a result of climate change (Sanderson and Alexander 2020). So far, no epizootic diseases have been documented in SLE beluga. However, papillomavirus and herpesvirus, the primary cause for these epidemic events, have been reported in SLE beluga (Martineau et al. 1988; De Guise et al. 1994; Lair et al. 2014) and other beluga populations, with possible congenital effects on calves (Burek-Huntington et al. 2023; see also Nielsen et al. 2017). Other pathogens, such as the cetacean morbillivirus (CeMV), pose a high risk to SLE beluga because the population apparently has not been previously exposed to these pathogens (Mikaelian et al. 1999; Nielsen et al. 2000). Beluga could become exposed via the range expansion of exotic infected marine mammal species as a result of climate change, or via biological contamination from municipal sewage, waste and ballast waters, and coastal runoff discharged into the St. Lawrence ecosystem. The small size of the SLE beluga population, their gregariousness, potentially weakened immune systems from chronic exposure to contaminants (e.g., De Guise et al. 1995), and low genetic diversity make them vulnerable to epizootic diseases.

More recently, severe outbreaks of the avian influenza virus A(H5N1) have been documented, causing unprecedented mortality of birds in Europe, but also in eastern Canada and U.S. including the SLE and GSL (Harvey et al. 2023). Infections and mortality were thought to be limited to pinniped species within marine mammals, with documented cases in the SLE (Canadian Wildlife Health Cooperative database). However, recent reports of a dead bottlenose dolphin, a harbour porpoise, and a white-sided dolphin infected with A(H5N1) indicate that this virus can also affect cetaceans (Leguia et al. 2023; Thorsson et al. 2023; Canadian Wildlife Health Cooperative database, unpublished data). Whether climate change, population increase or densification of haul-out sites for pinnipeds are at play in the observed outbreaks is unknown (e.g., Lavigne and Scmitz 1990; Marcogliese et al. 1996).

An intracellular protozoan, a parasite called *Toxoplasma goodii*, is highly prevalent (44%) in SLE beluga (Iqbal et al. 2018). This parasite can cause various diseases, and can lead to fetal death, abortion or neonatal death if infection occurs early in gestation (see Iqbal et al. 2018 for details). While *Toxoplasmosis* was the primary cause of death for only 2% of the SLE beluga examined (Lair et al. 2016), further investigation of the effect of this parasitic pathogen is likely warranted.

Research activities – Research on SLE beluga has occurred seasonally since the late 1970’s. While research efforts in the field remained limited to one or two organizations up until about 2015, research programs have expanded in recent years to collect data for a larger range of purposes and organizations. Some research activities that require close or repeated vessel or aircraft approach, or to collect biopsies, deploy archival tags or track the animals, have the potential to disturb individual behaviour, or to inflict wounds or result in infections (Giménez et al. 2001; Charlton et al. 2023). These more invasive activities are scrutinized by the Canadian Council on Animal Care to ensure they are conducted in an ethical and responsible manner, while Fisheries and Oceans Canada and Parks Canada are responsible for issuing research licenses, and for ensuring that all proposed research activities meet the purposes and pre-conditions of applicable Canadian Acts and Regulations that are under their governance.

Table 3. Population-level threat assessment for the St. Lawrence Estuary beluga in Canada; H: Historical, C: Current, A: Anticipatory (see DFO 2014a for category definitions). Population-level threat risk is a combination of likelihood of occurrence and level of impact, with causal certainty in parenthesis.

Threat	Likelihood of occurrence	Level of impact	Causal certainty (Rank)	Population-level threat risk	Population-level threat occurrence	Population-level threat frequency	Population-level threat extent
Pollutants	Known	High	High (2)	High (2)	H, C, A	Continuous	Extensive
Toxic spills	Likely	High	Medium (3)	High (3)	H, C, A	Continuous	Broad
Acoustic and physical disturbance	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Extensive
Disruption or destruction of habitat	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Broad
Reduction in food supply	Likely	Medium	Medium (3)	Medium (3)	H, C, A	Continuous	Extensive
Toxic algal blooms	Known	Medium	Medium (3)	Medium (3)	H, C, A	Recurrent	Extensive
Epizootic diseases	Likely	Medium	High (2)	Medium (2)	A	Recurrent	Extensive
Vessel collisions	Known	Low	Low (4)	Low (4)	H, C, A	Continuous	Extensive
Entanglement	Known	Low	Very low (5)	Low (5)	H, C, A	Recurrent	Narrow
Scientific research	Known	Low	Very low (5)	Low (5)	H, C, A	Recurrent	Broad
Hunt	Remote	High	Very high (1)	Low (1)	H	Recurrent	Extensive

Table 4. Current threats identified for SLE beluga and main anthropogenic sources for these threats. An exhaustive list of actions, including achievements so far and performance indicators, are available in Lesage (2018) and in DFO (2020; 2022).

Threat	Source of threat (non-exhaustive)
Pollutants (air, water, sediment, prey)	Industry (any), municipalities, agriculture, vessels
Acoustic and physical disturbance	Shipping, ferries and other vessels (whale-watching, recreational, fishery, search and rescue, research), industry (coastal and offshore development including construction-related sources and operations), echosounders, multibeam and other commercial or military sonars, seismic surveys and other geophysical sources
Disruption or destruction of habitat	Vessel traffic, fishery, industry (coastal and offshore development, energy production (including river damming)
Reduction in food supply	Fishery
Toxic spills	Vessels, ports, marina, industry, municipalities
Entanglement	Fishery (fishing gear)
Vessel collision	Fast or erratically moving vessels
Toxic algal blooms	Agriculture and any activity leading to eutrophication
Epizootic diseases	Exotic species
Research activities	Vessels, sampling procedures

Limiting factors

The beluga is an Arctic species adapted to a cold environment with, typically, an important seasonal ice cover (Barber et al. 2001). A coarse-scale habitat model based on predicted or observed water depth and temperature and sea ice cover estimated that no suitable winter habitat would remain for beluga in the St. Lawrence system by year 2100 (Skovrind et al. 2021). Warming conditions and reduction in sea ice cover might limit SLE beluga population growth through various mechanisms. Ice cover, which normally offers shelter to beluga against storms and predators, may increase beluga mortality if reduced. Warming conditions may affect prey quality and quantity or allow potential competitors to persist in beluga habitat, potentially reducing energy intake. Warming conditions are also favourable to toxic algal bloom events (e.g., Klemm et al. 2022). Beluga can experience water temperatures ranging from freezing or near-freezing waters to more than 16 degrees Celsius in estuaries (Leatherwood et al. 1988; Smith et al. 1994). The unusually high water temperatures recorded lately in the St. Lawrence system might lead to additional stress for parturient females going through particularly intense labour, potentially resulting in death of the female, the calf, or both.

Beluga are long-lived and have a low fecundity (a single calf every 2 to 3 years) (Sergeant 1973; Ferguson et al. 2020). While these characteristics make the species resilient to environmental perturbation, they also limit population growth rate compared to species with a shorter generation time.

The highly social nature of beluga (Michaud 2005) may also limit recovery and potential to adapt to a changing habitat. Indeed, the species is highly philopatric to specific summering areas, migratory routes are culturally learnt, and there is evidence for substructure in habitat use during summer including in the SLE (Bonnell et al. 2022). These factors may limit dispersion, and the potential for recolonizing formerly exploited habitat, or for colonizing new habitat (Wade et al. 2012).

Low genetic diversity has been identified as a potential threat to SLE beluga in past recovery strategies (Bailey and Zinger 1995; DFO 2012). A recent study confirms that the population presents the lowest level of haplotype diversity of all beluga populations in Canada (Postma 2017). A loss of diversity may reflect a demographic bottleneck as a result of a severe reduction in population size (Postma 2017), although this seems unlikely given historical, recent, and current estimates of population size (see Tinker et al. 2024). Alternatively, low levels of genetic diversity can occur as a result of more recent and prolonged isolation of a population, a random allelic loss (genetic drift), or reproduction between related animals. Whether this population is subject to an Allee effect depressing its reproduction rate and potential for recovery is unknown. Genetic rescue from neighbouring beluga populations is considered unlikely given the strong philopatry observed in beluga, the precarious status of most of the neighbouring populations, and the low genetic diversity observed in SLE beluga (COSEWIC 2016; Bonnell et al. 2022).

Vagrant individuals are reported each summer in Newfoundland waters, the northwestern and southern GSL, Scotian Shelf or eastern U.S. (Curren and Lien 1998; R. Michaud, unpublished data). While some of the animals from the northwestern GSL and Newfoundland waters have been identified genetically or from their contaminant loads as coming from the Arctic, animals found south of the SLE were likely emigrants from the SLE population. Given current population size, the emigration of only a few individuals per year may limit population growth.

The beluga is an Arctic species, known to occupy areas with variable but sometimes high ice cover (Barber et al. 2001). While the warming conditions are likely to reduce ice cover and the period with icy conditions, they may also result in ice more easily shifting with winds. Whether these changes in ice cover will reduce or increase risks of entrapment for SLE beluga is unknown.

Historically, beluga in the SLE have been subject to predation from killer whales (Vladykov 1944; Mitchell and Reeves 1988). Reports of killer whales have been rare in the St. Lawrence system over the past few decades, except in the eastern GSL where they are reported on a regular basis (Lawson and Stevens 2014). As a result, SLE beluga are considered to be predator-free (Mosnier et al. 2010). In recent years, grey seal abundance has increased substantially in the SLE (Mosnier et al. 2023). Grey seals are known predators of harbour porpoises in the SLE and elsewhere (Stringel et al. 2015; van Neer et al. 2020; GREMM, unpublished data; R. Pintiaux, pers. obs.). Harbour porpoises are the size of a beluga calf. Whether grey seals may start preying on SLE beluga calves is unknown but cannot be excluded; beluga calves may benefit from increased protection against predators as a result of the presence of their mother.

Threats to co-occurring species

If threats to the SLE beluga are abated, there might be benefits for co-occurring species (e.g., DFO 2020). The SLE beluga share their habitat with several other marine mammals, including species with a healthy status (e.g., several pinniped populations), and other populations considered as Special Concern, Threatened or Endangered under the *Species at Risk Act*: the blue whale (Northwest Atlantic population), fin whale (Atlantic population), North Atlantic right whale, and harbour porpoise (Northwest Atlantic population). Except for beluga and harbour seals, these populations are all seasonal visitors to the SLE and northern GSL, seeking these productive waters mainly to feed from spring to fall/early winter (Lesage et al. 2018; Roy et al. 2018; Simard et al. 2019; COSEWIC 2022). At-risk species and some of the healthy populations are impacted by most of the threats listed above, although to variable extents. Among at-risk species, the three larger species for instance (blue whales, fin whales, and right whales), have a higher risk of colliding with vessels given their poorer maneuverability and directional hearing compared to SLE beluga, and their occupancy of the Laurentian Channel where most of the shipping traffic is concentrated (Chion et al. 2021). In contrast, these three species are also less likely to accumulate high levels of bio-magnified contaminants given that they occupy lower trophic levels (Lesage et al. 2001; Gavrilchuk et al. 2014; Cabrol et al. 2021). Harbour porpoises are also less vulnerable to contaminants given their diet is composed mainly of forage fish (Fontaine et al. 1994). All four species, but especially harbour porpoises and right whales, can be vulnerable to entanglement in fishing gear (Lesage et al. 2006; Knowlton et al. 2022). All species are subject to potential effects from noise exposure, especially given they occur largely in the Laurentian Channel where traffic is intense (Simard et al. 2010; McQuinn et al. 2011). Habitat improvements that are beneficial to an already healthy population might further increase threats to SLE beluga via increased competition. For instance, an increase in food supply might become deleterious to beluga if it is shared with species, which have a naturally higher fecundity and potential for population growth such as pinnipeds, voracious fish like striped bass, or other small cetaceans like harbour porpoises.

Threat abatement actions are generally beneficial to co-occurring species, but not always. For instance, deviations of the shipping lanes in the Lower Estuary were proposed in the early 2010’s to reduce collision risk with blue and fin whales, and with smaller vessels. However, an analysis of the various scenarios proposed identified that all would have resulted in a substantial increase in the exposure of SLE beluga to noise (Lesage et al. 2014b). This example underscores the importance of examining management actions under various angles to capture all positive and negative effects on the various species of concerns.

ELEMENTS 12, 13, 14 AND 15: RECOVERY OBJECTIVES AND TIME FRAME FOR RECOVERY

Historical abundance and carrying capacity (*K*)

While beluga presence in the SLE was noted by seventeenth-century European visitors, their historical abundance is unknown. At least 1,000 beluga, and likely several thousands, were taken during the 18th century. However, harvest records, sometimes solely in the form of oil yields, are only available since 1866 (see Reeves and Mitchell 1984). Retrospective estimates based on these historical harvest records suggest that SLE beluga probably numbered around 6,000 – 9,000 at the end of the 19th century (Tinker et al. 2024). This analysis assumed that the population was at or near its historical carrying capacity in the mid-1800s, which the model estimated at 13,558 beluga (CI95 = 12,428 – 17,432; scenario Historical *K* in Tables 5 and 6). The high degree of uncertainty around historical harvest levels and new insights into past dynamics, however, caution against using estimates of historical carrying capacity as management benchmarks (Tinker et al. 2024). Alternative approaches which recognize that the effective carrying capacity for SLE beluga has fundamentally changed from historical levels, and which are more relevant to current dynamics, estimate the carrying capacity under current conditions (as defined in Tinker et al. 2024; see Table 5) at 6,706 beluga (CI95 = 4,309 – 10,435; scenario Current *K* in Table 6). Carrying capacity *K,* corresponds to the maximum population size that could be sustained in the SLE without anthropogenic sources of mortality.

Population projections

Two reference points can be set based on the point estimate of *K*, and the precautionary assumption that Maximum Net Productivity Level (MNPL) would occur at approximately 60% of *K* (which was validated by numerical simulations, see Tinker et al. 2024): the Precautionary Reference Level (PRL) and the Limit Reference Level (LRL). Under the Precautionary Framework, any population with population size above the PRL is considered to be in the Healthy Zone, whereas a population below the LRL is considered to be in the Critical Zone (DFO 2013; Hammill et al. 2017). The space between the LRL and the PRL provides a buffer zone, referred to as the Cautious Zone. Following the DFO guidelines, the PRL was set at 80% of MNPL (i.e., 3,219 beluga), or 48% of estimated *K*, and the LRL to 40% of MNPL (i.e., 1,609 beluga), or 24% of *K* (Hammill et al. 2017).

Using these reference points, the mean abundance estimate for 2022 falls below the PRL and above the LRL and thus, puts the current population in the Cautious Zone (Tinker et al. 2024). Assuming continuation of recent (2010 – 2022) environmental conditions and natural variation without aggravation, as well as no reductions in other mortality factors (Scenario 0; Tables 5 & 6), there is a 78% probability that the population will remain below the PRL (i.e., 22% probability of reaching the Healthy Zone), a 41% probability of it falling into the Critical Zone (i.e., below the LRL), and a 0.06% probability of quasi-extinction (i.e., a population with 50 individuals or less) over the next 100 years (Table 6).

These results are not as pessimistic as those estimated using a previous population viability analysis and a reduced set of variables (Scenario 'Present' in Williams et al. 2021), and are considered more accurate. They indicate that while the probability of the population reaching the Healthy Zone within the next 100 years is low under current or predicted conditions, this probability exists and makes the recovery of the SLE beluga population theoretically feasible, and even more so if some of the current threats to the population can be mitigated (see below).

However, Gulf temperatures are expected to continue to increase according to climate model predictions and annual observations (Lavoie et al. 2020; Galbraith et al. 2023). This model relies on several assumptions about warming of the Gulf Stream and inputs from the Labrador Current. It predicts that Gulf temperatures at a depth of 200 m are highly likely to increase by at least 0.5 degree Celsius over the next 100 years, and that a 1 degree Celsius increase is also possible. If water temperature increases by an additional 0.5 and 1.0 degree Celsius over the next 100 years (noted in Figure 10 as 10% and 20% increases, respectively), the probability for the population reaching the Healthy Zone within that period decreases to 13 and 8%, respectively; the probability of falling into the Critical Zone within that time frame increases to 61 and 73%, with the risk of quasi-extinction increasing to a probability of 0.3 and 1.4%, respectively (Table 6). For reference, average Gulf temperatures over the period 2010 – 2022 have already increased by three quarters of a degree Celsius relative to the average for 1970 – 2009.

Table 5. Description of Scenarios evaluated using forward projections of the best-fit model, with modifications to parameters as described. All model projections were run for 100 years and replicated 10,000 times to capture parameter uncertainty and sampling variance.

Scenario	Description	Explanation
Scenario 0	Base model	Project model with no management action or expected change in conditions: parameters drawn from estimated joint posterior distribution, and environmental variables and random effects drawn from observed distributions over the most recent 12 years (2010-2022)
Scenario 1	10% incr. Temp.	Same as base, but Gulf water temperature increases by 10% over 100 years (i.e., one half degree Celsius higher than 2010-2022 values)
Scenario 2	20% incr. Temp.	Same as base, but Gulf water temperature increases by 20% over 100 years (i.e., one degree Celsius higher than 2010-2022 values)
Scenario 3	25% reduced Base Hz.	Same as base, but reduce baseline hazards by 25%
Scenario 4	25% increased Base Hz.	Same as base, but increase baseline hazards by 25%
Scenario 5	25% reduced DyPP Hz.	Same as base, but reduce dystocia/postpartum hazards by 25%
Scenario 6	25% increased DyPP Hz.	Same as base, but increase dystocia/postpartum hazards by 25%

Table 6. Summary of results from future simulations generated using an integrated population model for St. Lawrence Estuary beluga. The historical carrying capacity (Pre-harvest est. K) and functional carrying capacity under current conditions (Model est. K) are also presented. Model projections were run for 100 years and replicated 10,000 times to capture parameter uncertainty and sampling variance (refer to Table 4 for details of each simulation). The distributions of simulation results were then compared to target thresholds, including 60% K or the Maximum Net Productivity Level (MNPL) = 4,024 beluga, Precautionary Reference Level (PRL) = 3,219 beluga, Limit Reference Level (LRL) = 1,609 beluga, and Quasi-Extinction (QE) defined as 50 individuals. The probability of the mean instantaneous rate of growth (r) over a single generation (28 years) exceeding 1% or of being less than -1% is also shown.*

Scenario	Description	Mean N	CI95_lo	CI95_hi	Min_N	% Change vs Base	Prob. >60%K	Prob. >PRL	Prob. >LRL	Prob. <QE	Prob. r > 1%	Prob. r < -1%
Historical K	Pre-harvest est. K	13,558	12,428	17,432	-	-	-	-	-	-	-	-
Current K	Model est. K	6,706	4,309	10,435	-	-	-	-	-	-	-	-
Scenario 0	Base model	2,285	338	6,289	1,235	-	0.1308	0.2230	0.5944	0.0006	0.181%	0.2592
Scenario 1	10% incr. Temp.	1,687	155	5,503	1,043	-26.2	0.0710	0.1264	0.3918	0.0030	0.069%	0.2312
Scenario 2	20% incr. Temp.	1,272	67	4,949	842	-44.3	0.0476	0.0830	0.2660	0.0144	-0.044%	0.2056
Scenario 3	25% redc. Base Hz.	5,335	1,352	11,721	1,674	133.5	0.6418	0.7728	0.9582	0.0000	1.419%	0.6798
Scenario 4	25% incr. Base Hz.	945	84	3,148	686	-58.6	0.0098	0.0224	0.1600	0.0098	-0.926%	0.0602
Scenario 5	25% redc. DyPP Hz.	2,484	376	6,738	1,280	8.7	0.1618	0.2570	0.6450	0.0000	0.279%	0.286
Scenario 6	25% incr. DyPP Hz.	2,099	306	5,861	1,191	-8.1	0.1022	0.1864	0.5380	0.0004	0.087%	0.2304

Proposed abundance and distribution objectives

A long-term (100 year) recovery target could be to maintain the population abundance above the Limit Reference Level, with a goal of eventually exceeding 2,500 mature individuals and the Precautionary Reference Level of 3,219 total individuals in the population. While this objective is unlikely to be reached within the next century (Figure 10A, scenario 'Base'), decreasing the baseline hazards or pregnancy-related mortality could allow this objective to be reached sooner (see Figure 10C and 10E).

More proximate objectives could be to achieve, over the next 28 years (one generation), (1) an average annual growth rate of at least 1%, (2) a 25% decrease in calf mortality and pregnancy-related female mortality, and (3) an overall reduction of annual anthropogenic mortality below PBR (see next section for estimate), including interactions with fishing gear and vessels (DFO 2023).

As the population increases, it is expected that the population range will also expand to some extent. This hypothesis is supported by the reverse observation from Cook Inlet beluga, where a reduction in population size has resulted in a reduction in distribution (Hobbs et al. 2000). While our understanding of SLE beluga historical range is limited by the highly coastal nature of the data sources outside the summer months, an extension of the summer range to the east, with new and recurrently used areas of concentration would be a sign of such an expansion as a result of population increase. The recently observed expansion of the summer distribution to the east (Harvey et al. in prep.[1]) may not result from population increase however, as it seems to be associated with a diminished use of the Upper Estuary habitats (Simard et al. 2023).

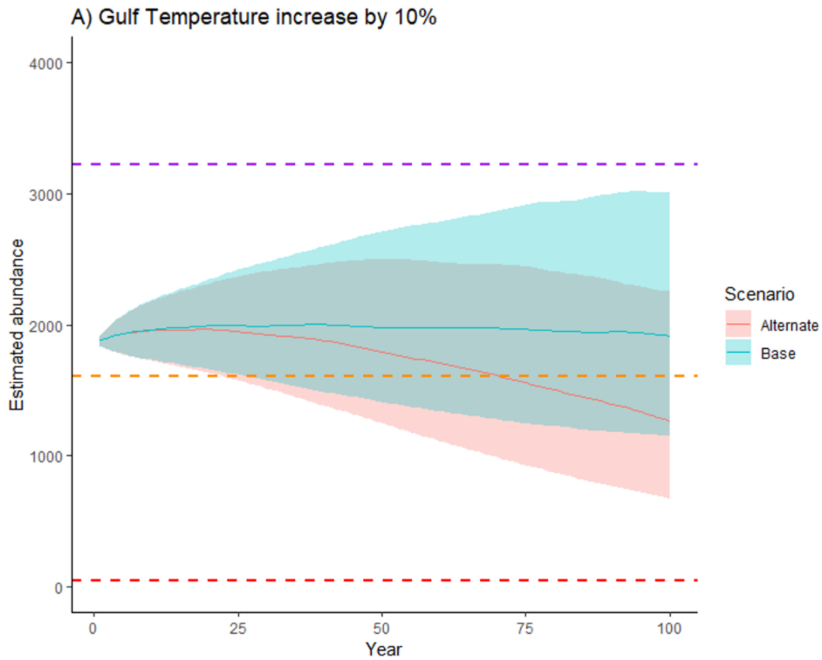
ELEMENTS 16, 17, 19, 20 AND 21: SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

Actions that have been undertaken or proposed to reduce threats to SLE beluga, including achievements and performance indicators, have been recently reviewed (Lesage 2018; DFO 2022). A current list of potential actions to reduce threats to SLEB and their habitat is also presented in two recent Action Plans addressing noise-related threats (DFO 2020) and all other threats (DFO 2022; DFO in prep.[2]). Generally, continued actions to reduce outputs of toxic substances into the air and water, including sewage, agricultural and ballast waters, might eliminate or reduce certain causes of mortality such as infections, epizootic diseases, and cancers, and can help reduce the risk of toxic algal blooms, with likely beneficial effects on the overall health of SLE beluga. An ecosystem approach to fisheries management, and limitation of vessel interactions with beluga during the calving period or crucial feeding periods, may help reduce pregnancy-related mortality, and increase calf survival. Actions to limit fisheries and vessel speeds within the SLE beluga seasonal distribution range can help eliminate direct human-caused mortality. Actions leading to quieting or a reduced disruption of beluga important habitat are also likely to improve the population's potential for recovery by increasing foraging efficiency, reducing call masking, or disruption of calving or other important behaviours of this highly social species (Michaud 2005).

Different scenarios of future ecological change and threat mitigation have been evaluated for their effects on population dynamics (Williams et al. 2021; Tinker et al. 2024). However, the pathways of effects, and actions that may lead to biologically and ecologically significant reductions in specific threats are not fully understood (Lesage 2021). Noise or contaminant levels causing significant biological impacts on SLE beluga are context- and substance-specific (e.g., Gomez et al. 2016; Hall et al. 2018). As a result, threat mitigation actions were not explicitly stated in the population model, and were instead introduced as percent reductions in specific threats, regardless of the means to achieve the specified percent reduction.

CLIMATE EFFECTS – The model indicates that if the relationship between calf mortality and warming conditions persists, and if water temperature continues to increase, then the population is expected to decline. Even a 10% additional increase in average Gulf temperatures over the next century (an increase of 0.5 degree Celsius) could lead to a 26% reduction in projected abundance relative to the base model (Scenario 0), with associated increases in the probabilities of falling below management thresholds (Figure 10A, scenario ‘Alternate’; Table 6). For reference, average Gulf temperatures over the period 2010-2022 have already increased by three quarters of a degree Celsius relative to the average for 1970-2009 (Lavoie et al. 2020). A 20% increase in Gulf temperatures (i.e., an increase of 1 degree Celsius) would be expected to have even more dire consequences (a 44% reduction in projected abundance), and would increase quasi-extinction probability to 1.4% (Figure 10B, scenario ‘Alternate’; Table 6). A study examining environmental predictors of beluga habitat using a coarse-scale model, suggests that no suitable habitat may remain for SLE beluga by 2100 (Skovrind et al. 2021).

THREAT REDUCTION – If conservation efforts could reduce density-independent hazards (such as those associated with pollution impacts, toxic algal blooms or disease outbreaks) by 25%, this could increase projected abundance by 34% relative to the baseline scenario and reduce the probability of being below the PRL to 23% (Figure 10C, scenario ‘Alternate’; Table 6). Similar though less drastic improvements could be achieved by reducing dystocia/postpartum mortality (Figure 10E, scenario ‘Alternate’; Table 6). Concrete actions to reduce density-independent hazards are provided in DFO Action Plans for noise and other threats (DFO 2020; in prep.[2]), and as part of the science-based review of the effectiveness of past recovery actions (Lesage 2018).



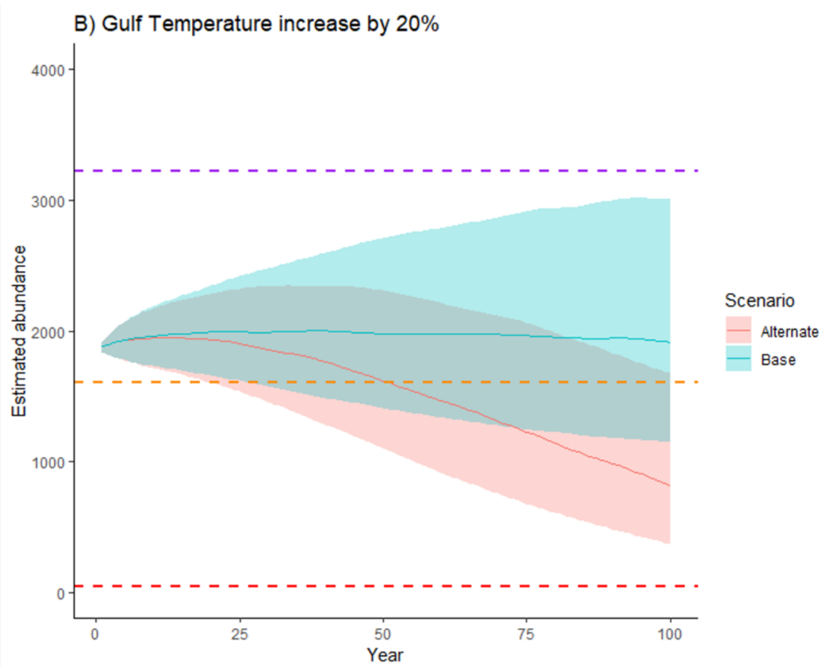
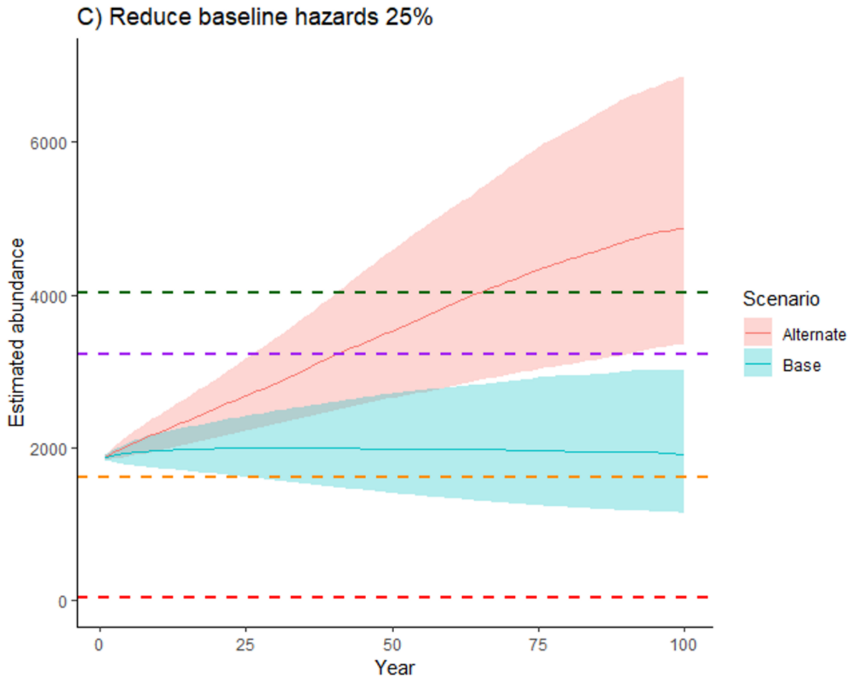


Figure 10. Results from model projections of future population dynamics for St. Lawrence Estuary beluga. Plots A – F show simulated population dynamics for alternative scenarios of future conditions or management effects (light red) as compared to baseline scenario (light blue) (refer to Table 5 for details). Dashed lines show possible management thresholds: Maximum Net Productivity Level (green), Precautionary Reference Level (purple), Limit Reference Level (orange) and Quasi-extinction threshold (QE; red). Solid lines show mean of iterated simulations and shaded bands show the inter-quartile range (Tinker et al. 2024).



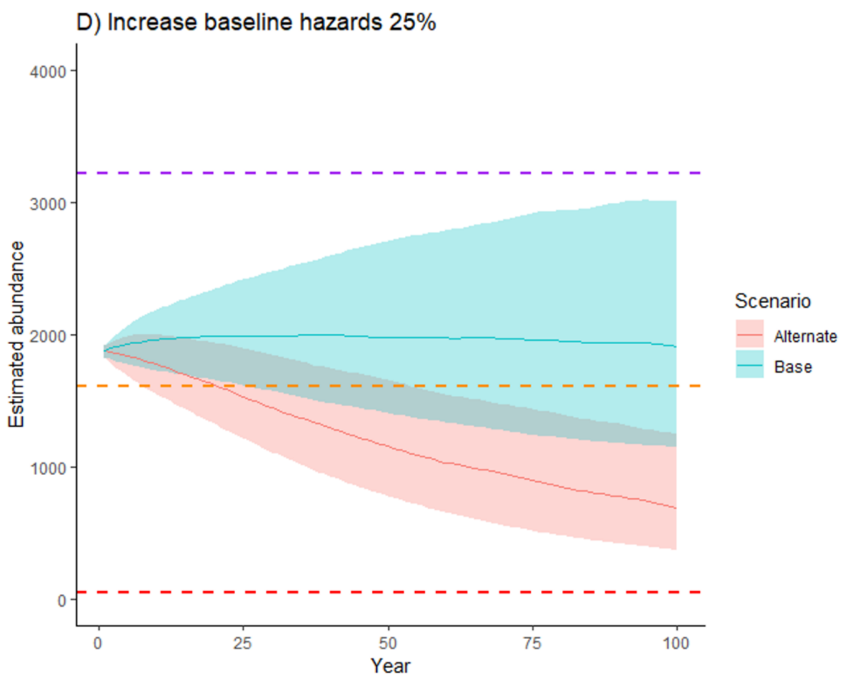
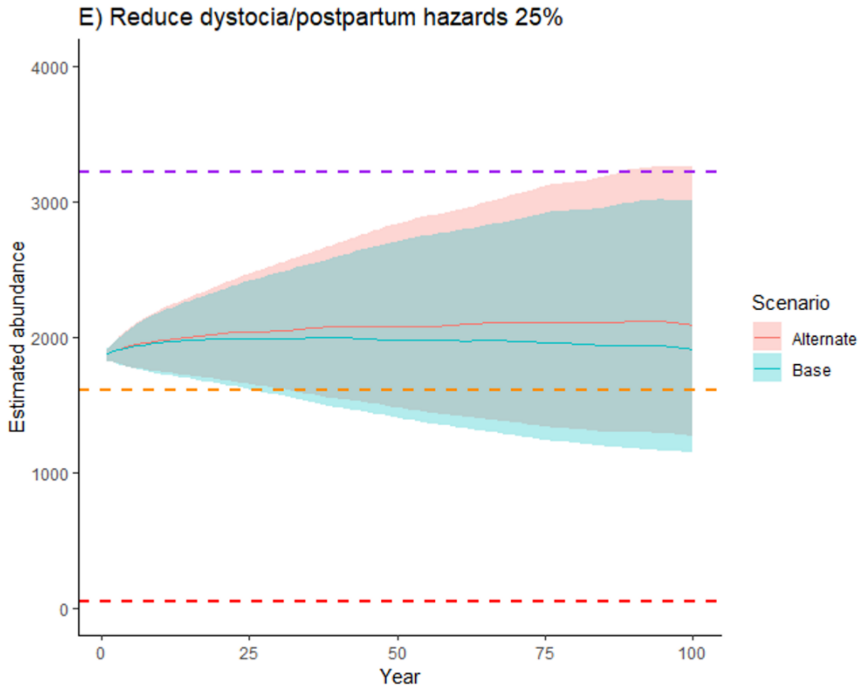


Figure 10. Continued.



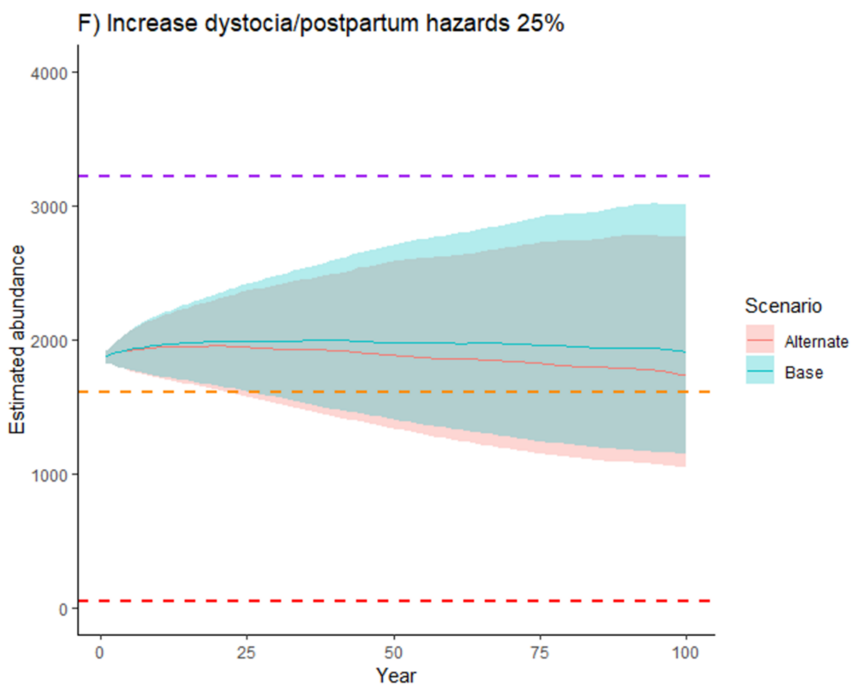


Figure 10. Continued.

Additional scenarios for threat mitigation were examined as part of an earlier modelling exercise using a less exhaustive population model with a time series ending in 2012 (Williams et al. 2021). In the absence of information on the mechanisms linking noise effects to foraging energetics, noise impacts on SLE beluga were estimated in the model as a percent reduction in access to available prey biomass (mainly spring herring and demersal fish). Similarly, given the lack of information on the dose-effect relationship for contaminants in cetaceans, impacts were estimated using mink as an animal model for cetaceans, PCBs as a surrogate for all contaminants, and the probability of calf survival as the only possible pathway for effects on the SLE beluga population. Acknowledging these caveats, model results suggest that actions supporting an increase in calf survival, restoring prey biomass, increasing feeding efficiency via reductions in noise disturbance, and removing PCBs from the environment would all be required to build the population's resilience and allow it to persist long enough for global actions mitigating climate change to take effect (Figure 11).

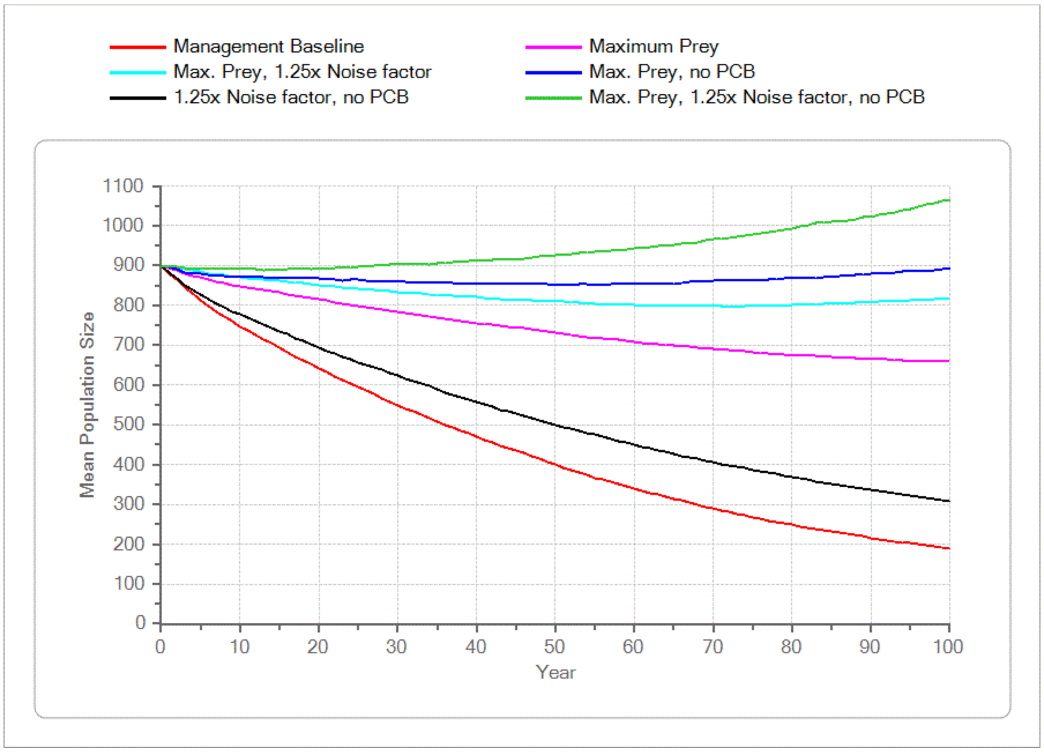


Figure 11. Mean population sizes projected if the current environmental conditions (period 2008-2012) and recent prey biomasses (2000-2012) persist ("Management baseline"), both spring herring and demersal prey biomasses are restored to the highest levels observed in recent decades ("Maximum prey"), prey are restored to the highest levels observed and noise is reduced so that prey availability is increased 1.25x ("Max. prey, 1.25x noise factor"), noise is reduced and PCB contaminants in the system are eliminated ("1.25x noise factor, no PCB"), prey are restored to the highest levels observed and PCB contaminants are eliminated ("Max. prey, no PCB"), or all threat reductions are achieved so that prey availability is increased 1.25x, the highest levels of prey are restored, and PCB contaminants are eliminated ("Max. prey, 1.25x noise factor, no PCB").

ELEMENT 22: ALLOWABLE HARM ASSESSMENT

Maximum human-induced mortality for SLE beluga was estimated using the Potential Biological Removal (PBR) method following standard procedures for cetaceans (Wade 1998). This method provides an estimation of the maximum number of non-natural deaths that can occur each year without preventing the population from reaching or maintaining an optimum sustainable population size within 100 years. PBR therefore has a built-in management objective that differs from the recovery targets presented above and estimated using the population dynamics model. Based on the model estimated abundance for 2022 and associated uncertainty, and using a recovery factor of 0.1 to account for population status (Hammill et al. 2017), PBR for SLE beluga was estimated at 3.4 individuals in 2022 (details in Tinker et al. 2024).

The maximum habitat destruction that the SLE beluga population can sustain without jeopardizing its survival or recovery is unknown, but likely limited. The area of occupancy for SLE beluga is one of the smallest described for the species. The recent description of structuring in habitat use within the SLE beluga population, where clusters of individuals each preferentially use restricted areas within their summer range (Ouellet et al. 2021; Bonnell et al. 2022; 2024), suggests that effects from habitat destruction might be underestimated if they do not account for this partitioning of habitat. In addition, if habitat destruction were to occur, it might affect some segments of the population disproportionally. For instance, destruction of a habitat heavily used by females and calves would be likely to have a larger impact on population abundance and recovery than if it affected adult males alone.

ACKNOWLEDGEMENTS

We thank Sarah Corbett and Stéphanie Ratelle, the Réseau d'Observation des Mammifères Marins (ROMM), the Groupe of Research and Education on Marine Mammals (GREMM), and the Marine Animal Response Society (MARS) for kindly sharing their opportunistic sightings databases.

REFERENCES CITED

Anderson, A., Gagnon, M. 1980. Les ressources halieutiques de l'estuaire du Saint-Laurent. Rapp. Can. Ind. Sci. Halieut. Aquat. 119: 1–56.

Anderson, D.M., Cembella, A.D., Hallegraeff, G.M. 2012. Progress in understanding harmful algal blooms: paradigm shifts and new technologies for research, monitoring, and management. Ann. Rev. Mar. Sci. 4: 143–176.

Araújo, M.S., Bolnick, D.I., Layman, C.A. 2011. The ecological cause of individual specialisation. Ecol. Lett. 14: 948–958.

Aulanier, F., Simard, Y., Roy N., Gervaise, C., and Bandet, M. 2016. Spatial-temporal exposure of blue whale habitats to shipping noise in St. Lawrence system. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/090: vi + 26 p.

Bailey, R.J.F., Able, K., Leggett, W.C. 1977. Seasonal and vertical distribution and growth of juvenile and adult capelin (*Mallotus villosus*) in the St Lawrence Estuary and western Gulf of St Lawrence. J. Fish. Res. Brd Can. 34: 2030–2040.

Bailey, R., Zinger, N. 1995. St Lawrence beluga recovery plan. World Wildlife Fund, Toronto and Department of Fisheries and Oceans, Mont-Joli, Québec. 73 p.

Bailleul, F., Lesage, V., Power, M., Doidge, D.W., Hammill, M.O. 2012. Differences in diving and movement patterns of two groups of beluga whales in a changing Arctic environment reveal discrete populations. Endang. Species Res. 17: 27–41.

Barber, D.G., Saczuk, E., Richard, P.R. 2001. Examination of beluga-habitat relationships through the use of telemetry and a Geographic Information System. Arctic 54: 305–316.

Barrett, H., Du, X., Houde, M., Lair, S., Verreault, J., Peng, H. 2021. Suspect and nontarget screening revealed class-specific temporal trends (2000–2017) of poly- and perfluoroalkyl substances in St Lawrence beluga whales. Environ. Sci. Technol. 55: 1659–1671.

Béland, P., De Guise, S., Plante, R. 1990a. Mortalité de mammifères marins dans le fleuve, l'estuaire et le golfe du Saint-Laurent québécois en 1989. Prepared by the INESL. 41 p. Available via DFO library, Dartmouth, Halifax, NS.

Béland, P., Faucher, A., Corbeil, P. 1990b. Observations on the birth of a beluga whale (*Delphinapterus leucas*) in the St. Lawrence Estuary, Quebec, Canada. Can. J. Zool. 68: 1327–1329.

Bernier, J., Brousseau, P., Krzystyniak, K., Tryphonas, H., Fournier, M. 1995. Immunotoxicity of heavy metals in relation to Great Lakes. Environ. Health Perspect. 103, Suppl. 9: 23–34.

Bernier-Graveline, A., Lesage, V., Cabrol, J., Lair, S., Michaud, R., Rosabal, M., Verreault, J. 2021. Lipid metabolites as predictors of energy reserves in highly contaminant-exposed belugas from the endangered St. Lawrence Estuary population. Environ. Res. 192: 110272.

Blane, J., Jaakson, R. 1994. The impact of ecotourism boats on the St. Lawrence beluga whales. Environ. Conserv. 21: 267–269.

Blouin, K, Malaisé, F., Verreault, J., Lair, S., Lu, Z. 2022. Occurrence and temporal trends of industrial antioxidants and UV absorbents in the endangered St. Lawrence Estuary beluga whale (*Delphinapterus leucas*). Sci. Total. Environ. 842: 156635.

Boily, P. 1995. Theoretical heat flux in water and habitat selection of phocid seals and beluga whales during the annual molt. J. Theor. Biol. 172: 235–244.

Boivin, Y., INESL. 1990. Survols aériens pour l'estimation de la distribution saisonnière et des déplacements des bélugas, INESL, Montréal, Québec. 91 p. Disponible de Institut National d'Écotoxicologie du Saint-Laurent, 5040 Mentana, Montreal, QC, CAN. H2J 3C3

Bolnick, D.I., Svanbäck, R., Fordyce, J.A., Yang, L.H., Davis, J.M., Hulsey, C.D., Forister, M.L. 2003. The ecology of individuals: incidence and implications of individual specialization. The Am. Nat. 161: 1–28.

Bonnell, T.R., Michaud, R., Dupuch, A., Lesage, V., Chion, C. 2022. Extracting spatial networks from capture-recapture data reveals individual site fidelity patterns within a marine mammal's spatial range. Ecol. Evol. 12: e8616.

Bonnell, T.R., Michaud, R., Dupuch, A., Lesage, V., Chion, C. 2024. Detecting spatial mixing within populations from the mismatch between local individual diversity and abundance: a case study using beluga from the St. Lawrence Estuary, Canada. Mar. Mamm. Sci. e13162.

Boyd, I.L., Frisk, G., Urban, E., Tyack, P., Ausubel, J., Seeyave, S., Cato, D., Southall, B., Weise, M., Andrew, R. 2011. An international quiet oceans experiment. Oceanography 24: 174e181.

Brewer, A.M., Castellote, M., Van Cise, A.M., Gage, T., Berdahl, A. 2023. Communication in Cook Inlet beluga whales: Describing the vocal repertoire and masking of calls by commercial ship noise. J. Acoust. Soc. Am. 154: 3487-3505.

Brown Gladden, J.G., Ferguson, M.M., Clayton, J.W. 1997. Matriarchal genetic population structure of North American beluga whales (*Delphinapterus leucas*). Mol. Ecol. 6: 1033–1046.

Burek-Huntington, K.A., Shelden, K.E.W., Andrews, R.D., Goertz, C.E.C., McGuire, T.L., Dennison, S. 2023. Postmortem pathology investigation of the wounds from invasive tagging in belugas (*Delphinapterus leucas*) from Cook Inlet and Bristol Bay, Alaska. Mar. Mamm. Sci. 39: 492–514.

Cabrol, J., Lesage, V., Leclerc, A., Giard, J., Iverson, S., Bérubé, M., Michaud, R., Nozais, C. 2021. Decline in individual- and population-level specialization of the fin whale (*Balaenoptera physalus*) during a period of ecosystem shift. Sci. Rep. 11: 17181.

Cairns, D.K., Chaput, G., Poirier, L.A., Avery, T.S., Castonguay, M., Mathers, A., Casselman, J.M., Bradford, R.G., Pratt, T., Verreault, G., Clarke, K., Veinott, G., Bernatchez, L. 2014. Recovery potential assessment for the American eel (*Anguilla rostrata*) for eastern Canada: life history, distribution, reported landings, status indicators, and demographic parameters. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/134.

Caron, L.M.J., Smith, T.G. 1990. Philopatry and site tenacity of belugas, *Delphinapterus leucas*, hunted by the Inuit at the Nastapoka estuary, eastern Hudson Bay. Can. Bull. Fish. Aquat. Sci. 224 : 69–79.

Casgrain, Abbé. 1873. La pêche aux marsouins dans le fleuve Saint-Laurent. 16 p. Montréal. Published without author name. Accessed 28 February 2020.

Castellote, M., Mooney, T.A., Quakenbush, L., Hobbs, R., Goertz, C., Gaglione, E. 2014. Baseline hearing abilities and variability in wild beluga whales (*Delphinapterus leucas*). J. Exp. Biol. 217 : 1682–1691.

Chaire de recherche du MPO à l'ISMER-UQAR en acoustique marine appliquée à la recherche sur l'écosystème et les mammifères marins. 2021. Atlas des paysages acoustiques océaniques.

Charlton, C., Christiansen, F., Ward, R., Mackay, A.I., Andrews-Goff, V., Zerbini, A.N., Childerhouse, S. Guggenheimer, S., O'Shannessy, B., Brownell Jr., R.L. 2023. Evaluating short to medium term effects of implantable satellite tags on southern right whales. Dis. Aquat. Org. 155 : 125–140.

Chen, J., Ma, H. 2020. A conceptual model of the healthy acoustic environment – elements framework and definition. Front. Psychol. 11 : 554285.

Chion, C., Lagrois, D., Dupras, J., Turgeon, S., McQuinn, I.H., Michaud, R., Ménard, N., Parrott, L. 2017. Underwater acoustic impacts of shipping management measures: results from a social-ecological model of boat and whale movements in the St. Lawrence River Estuary (Canada). Ecol. Modell. 354: 72–87.

Chion, C., Bonnell, T., Lagrois, D., Michaud, R., Lesage, V., Dupuch, A., McQuinn, I., Turgeon, S. 2021. Agent-based modelling reveals a disproportionate exposure of females and calves to a local increase in shipping and associated noise in an endangered beluga population. Mar. Pollut. Bull. 173 : 112977.

Christiansen, F., Bertulli, C.G., Rasmussen, M.H., Lusseau, D. 2015. Estimating cumulative exposure of wildlife to non-lethal disturbance using spatially explicit capture recapture models. J. Wildl. Manage. 79: 311–324.

Clark, C.W., Ellison, W.T., Southall, B.L., Hatch, L., Van Parijs, S.M., Frankel, A., Ponirakis, D. 2009. Acoustic masking in marine ecosystem: intuitions, analysis, and implication. Mar. Ecol. Prog. Ser. 395: 201–222.

Colbeck, G.J., Duchesne, P.D., Postma, L., Lesage, V., Hammill, M.O., Turgeon, J. 2013. Groups of related belugas (*Delphinapterus leucas*) travel together during their seasonal migrations in and around Hudson Bay. Proc. R. Soc. Lond. B 280 : 20122552.

Conversano, M., S. Turgeon et N. Ménard. 2017. Caractérisation de l'utilisation de l'embouchure du Saguenay et de la baie Sainte-Marguerite par le béluga du Saint-Laurent et par le trafic maritime entre 2003 et 2016. Analyse des données d'observation terrestre et recommandations sur des mesures de gestion visant à réduire le dérangement dans les aires de haute résidence du béluga dans le parc marin du Saguenay−Saint-Laurent. Parcs Canada, Tadoussac, Québec. 122 p. Accédé en ligne, 30 Sep. 2023.

COSEWIC. 2004. COSEWIC 2004. COSEWIC assessment and update status report on the beluga whale *Delphinapterus leucas* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 70 p.

COSEWIC. 2014. COSEWIC assessment and status report on the Beluga Whale *Delphinapterus leucas*, St. Lawrence Estuary population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 64 p.

COSEWIC. 2016. Designatable Units for beluga whales (*Delphinapterus leucas*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 73 p.

COSEWIC. 2022. COSEWIC assessment and status report on the Harbour Porpoise *Phocoena phocoena*, Northwest Atlantic population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 46 p.

Costa, L.G., de Laat, R., Tagliaferri, S., Pellacani, C. 2014. A mechanistic view of polybrominated diphenyl ether (PBDE) developmental neurotoxicity. Toxicol. Lett. 230: 282–294.

Curren, K., Lien, J. 1998. Observations of white whales, *Delphinapterus leucas*, in waters off Newfoundland and Labrador and in the Gulf of St. Lawrence, 1979-1991. Can. Fld-Nat. 112: 28–31.

d'Anglejan, B.F., Smith, E.C. 1973. Distribution, transport and composition of suspended matter in the St Lawrence Estuary. Can. J. Earth Sci. 10: 1380–1396.

De Guise, S. 1998. Effects of in vitro exposure of beluga whale leukocytes to selected organochlorines. J. Toxicol. Environ. Health Part A 55: 479–493.

De Guise, S., Lagacé, A., Béland, P. 1994. Gastric papillomas in eight St. Lawrence beluga whales (*Delphinapterus leucas*). J. Vet. Diag. Invest. 6: 385–388.

De Guise, S., Martineau, D., Béland, P, and Fournier, M. 1995. Possible mechanisms of action of environmental contaminants on St. Lawrence beluga whales (*Delphinapterus leucas*). Environ. Health Perspect. 103, Suppl. 4: 73–77.

De Guise, S., Bernier, J., Martineau, D., Béland, P., Fournier, M. 1996. Effects of in vitro exposure of beluga whale splenocytes and thymocytes to heavy metals. Environ. Toxicol. Chem. 15 : 1357–1364.

Desjardins, C., Hamel, D., Landry, L., Scallon-Chouinard, P.-M. et Chalut, K. 2018. Évaluation de la vulnérabilité de composantes biologiques du Saint-Laurent aux déversements d'hydrocarbures provenant de navires. Secr. can. de consult. sci. du MPO. Doc. de rech. 2018/003: ix + 280 p.

DFO. 2007. Revised Protocol for Conducting Recovery Potential Assessments. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/039.

DFO. 2012. Recovery Strategy for the beluga whale (*Delphinapterus leucas*) St. Lawrence Estuary population in Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. x + 88 p.

DFO. 2013. Proceedings of the national workshop for Technical Expertise in Stock Assessment (TESA): Maximum Sustainable Yield (MSY) reference points and the Precautionary Approach when productivity varies; December 13–15, 2011. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2012/055.

DFO. 2014a. Guidance on Assessing Threats, Ecological Risk and Ecological Impacts for Species at Risk. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/013. (Erratum: June 2016).

DFO. 2014b. Status of beluga (*Delphinapterus leucas*) in the St. Lawrence River estuary. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/076.

DFO. 2015. Fisheries and Oceans Canada, Species at Risk Act. Directive on identifying critical habitat for aquatic species at risk – Canada.ca

DFO. 2018. Potential effects of the construction of marine terminals in the Saguenay fjord on St. Lawrence beluga and its habitat. DFO Can. Sci. Advis. Sec. Sci. Resp. 2018/025.

DFO 2020. Action Plan to reduce the impact of noise on the beluga whale and other marine mammals at risk in the St. Lawrence Estuary. Species at Risk Act action plan Series. Fisheries and Oceans Canada, Ottawa, iv + 31 p.

DFO. 2022. Report on the progress of Recovery Strategy implementation for the Beluga Whale (*Delphinapterus leucas*), St. Lawrence Estuary Population in Canada, for the period 2012 to 2019. Species at Risk Act Recovery Strategy Report series. Fisheries and Oceans Canada, Ottawa. iv + 66 pp.

DFO. 2023. Abundance and population trajectory of St. Lawrence Estuary beluga. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/024.

Doidge, D.W. 1990. Integumentary heat loss and blubber distribution in the beluga, *Delphinapterus leucas,* with comparisons to the narwhal, *Monodon monoceros*. Can. Bull. Fish. Aquat. Sci. 224: 129–140.

Environnement et Changement climatique Canada (ECCC). 2020. Politique relative au rétablissement et à la survie en vertu de la *Loi sur les espèces en péril*, *Loi sur les espèces en péril* : Série de Politiques et de Lignes directrices. Accédé en ligne 30 sept. 2023.

Environment and Climate Change Canada (ECCC). 2022. Species at Risk Act Implementation Guidance for Recovery Practitioners, Guidelines on Characterizing Recovery and Developing Population and Distribution Objectives. Developed by Environment and Climate Change Canada and the Canadian Wildlife Service.

Erbe, C., Reichmuth, C. Cunningham, K. Lucke, K., Dooling, R. 2016. Communication masking in marine mammals: A review and research strategy. Mar. Pollut. Bull. 103: 15-38.

Erbe, C., Marley, S. A., Schoeman, R. P., Smith, J. N., Trigg, L.E., Embling, C.B. 2019. The effects of ship noise on marine mammals—A review. Front. Mar. Sci. 6: 606.

Fauchald, P., Tveraa, T. 2003. Using first-passage time in the analysis of area-restricted search and habitat selection. Ecology 84: 282–288.

Faucher, A. 1988. The vocal repertoire of the St. Lawrence estuary population of beluga whale (*Delphinapterus leucas*) and its behavioral, social and environmental contexts. M.Sc. thesis. Dalhousie University, Halifax. NS, CAN

Ferguson, S.H., Willing, C., Kelley, T.C., Boguski, D.A., Yurkowski, D.J., Watt, C.A. 2020. Reproductive parameters for female beluga whales (*Delphinapterus leucas*) of Baffin Bay and Hudson Bay, Canada. Arctic 73: 405–420.

Finley, K.J. 1982. The estuarine habit of the beluga or white whale *Delphinapterus leucas*. Cetus 4: 4–5.

Fontaine, P.-M., Hammill, M.O., Barrette, C., Kingsley, M.S.C. 1994. Summer diet of harbour porpoise (*Phocoena phocoena*) in the Estuary and northern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 51: 172–178.

Fraker, M.A., Gordon, C.D., McDonald, J., Ford, J., Cambers, G. 1979. The distribution of white whales in the Mackenzie estuary in relation to physical and chemical factors. Can. Fish. Mar. Serv. Tech. Rep. 863: 56 p.

Frost, K.J., Lowry, L.F. 1990. Distribution, abundance, and movements of beluga whales, *Delphinapterus leucas*, in coastal waters of western Alaska. pp. 39–57 In Smith, T.G., St. Aubin, D.J., Geraci, J.R. (eds). *Advances in research on the beluga whale,* Delphinapterus leucas. Can. Bull. Fish. Aquat. Sci. 224.

Galbraith, P.S., Chassé, J., Shaw, J.-L., Dumas, J. Lefaivre, D. and Bourassa, M.-N. 2023. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2022. Can. Tech. Rep. Hydrogr. Ocean Sci. 354: v + 88 p.

Gavrilchuk, K., Lesage, V., Ramp, C., Sears, R., Bearhop, S., Beauplet, G. 2014. Trophic niche partitioning among sympatric baleen whale species during the period following the collapse of groundfish stocks in the Northwest Atlantic. Mar. Ecol. Prog. Ser. 497: 285–301.

Gervaise, C., Simard, Y., Roy, N., Kinda, B., Ménard, N. 2012. Shipping noise in whale habitat: Characteristics, sources, budget, and impact on belugas in Saguenay–St. Lawrence Marine Park hub. J. Acoust. Soc. Am. 132: 76–89.

Gervaise, C., Aulanier, F., Roy, N., Simard, Y. 2015. Mapping probability of shipping sound exposure level. J. Acoust. Soc. Am. 137: EL429–435.

Giménez, J., De Stephanis, R., Gauffier, P., Esteban, R., Verborgh, P. 2001. Biopsy wound healing in long-finned pilot whales *Globicephala melas*. Vet. Rec. 168: 101.

Gomez, C., Lawson, J.W., Wright, A.W., Buren, A., Tollit, D., Lesage, V. 2016. Behavioural responses of marine mammals to man-made sounds and recommendations for the future. Can. J. Zool. 94: 801–819.

Gosselin, J.-F., Hammill, M.O., Mosnier, A. 2014. Summer abundance indices of St. Lawrence Estuary beluga (*Delphinapterus leucas*) from a photographic survey in 2009 and 28 line transect surveys from 2001 and 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/021: iv + 52 p.

Gosselin, J.-F., Hammill, M.O., Mosnier, A., Lesage, V. 2017. Abundance index of St. Lawrence Estuary beluga, *Delphinapterus leucas*, from aerial visual surveys flown in August 2014 and an update on reported deaths. DFO Can Sci. Advis. Sec. Res. Doc. 2017/019. V + 28 p.

Gracia, S., Roy, S., Starr, M. 2013. Spatial distribution and viability of *Alexandrium tamarense* resting cysts in surface sediments from the St. Lawrence Estuary, Eastern Canada. Estuar. Coast. Shelf Sci. 121–122: 20–32.

Gruner, E. 1973. Clinical aspects of the nutritional status of the dam and parturition: calving problems and early viability of the calf. Curr. Top. Vet. Med. Anim. Sci. 4: 468–477.

Gulland, F.M.D., Hall, A.J. 2007. Is marine mammal health deteriorating? Trends in the global reporting of marine mammal disease. Ecohealth 4: 145–150.

Hall, A.J., McConnell, B.J., Schwacke, L.H., Ylitalo, G.M., Williams, R., Rowles, T.K. 2018 Predicting the effects of PCBs on cetacean populations through impacts on immunity and calf survival. Environ. Pollut. 233: 407–418.

Hammill, M.O., Lesage, V., Carter, P. 2005. What do harp seals eat? Comparing diet reconstructions from different compartments of the digestive tract with diets estimated from stable isotope ratios. Can. J. Zool. 83: 1365–1372.

Hammill, M.O., Stenson, G.B., Doniol-Valcroze, T., Mosnier, A. 2015. Conservation of Northwest Atlantic harp seals: Past success, future uncertainty? Biol. Conserv. 192: 181–191.

Hammill, M.O., Stenson, G.B., Doniol-Valcroze, T. 2017. A management framework for Nunavik beluga. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/060: v + 34 p.

Harington, C.R. 2008. The evolution of Arctic marine mammals. Ecol. Appl. 18: S23–S40.

Hatch, L.T., Clark, C.W., Van Parijs, S.M., Frankel, A.S., Ponirakis, D.W. 2012. Quantifying loss of acoustic communication space for right whales in and around a U.S. national marine sanctuary. Conserv. Biol. 26: 983-994.

Harvell, C.D., Kim, K., Burkholder, J.M., Colwell, R.R., Epstein, P.R., Grimes, D.J., Hofmann, E.E., Lipp, E.K., Osterhaus, A.D., Overstreet, R.M., Porter, J.W., Smith, G.W., Vasta, G.R. 1999. Emerging marine diseases-climate links and anthropogenic factors. Science 285: 1505–1510.

Harvey, J.A., Mullinax, J.M., Runge, M.C., Prosser, D.J. 2023. The changing dynamics of highly pathogenic avian influenza H5Z1: Next steps for management and science in North America. Biol. Conserv. 282: 110041.

Heide-Jørgensen, M.P., Teilmann, J. 1994. Growth, reproduction, age structure and feeding habits of white whales (*Delphinapterus leucas*) in West Greenland waters. Meddel. Grøenland Biosci. 39: 195–212.

Helenius, L., Head, E., Jekielek, P., Orphanides, C.D., Pepin, P., Perrin, G., Plourde, S., Ringuette, M., Runge, J., Walsh, H., Johnson, C. 2023. Spatial variability in size and lipid content of the marine copepod *Calanus finmarchicus* across the Northwest Atlantic continental shelves: implications for North Atlantic right whale prey quality. J. Plankton Res. 00: 1-16.

Hill, H.M.M., Lilley, M.K., Ham, J.R., Robeck, T. 2024. A review of beluga sexual behavior and reproductive physiology leading to conception. Theriogenology 4: 100071.

Hobbs, R.C., Laidre, K.L., Vos, D.J., Mahoney, B.A., Eagleton, M. 2005. Movements and area use of belugas, *Delphinapterus leucas*, in a Subarctic Alaskan Estuary. Arctic 58: 331-440.

Hobbs, R.C., Waite, J.M., Rugh, D.J. 2000. Beluga, *Delphinapterus leucas*, group sizes in Cook Inlet, Alaska, based on observer counts and aerial video. Mar. Fish. Rev. 62: 46-59.

Iqbal, A., Measures, L., Lair, S., Dixon, B. 2018. Toxoplasma gondii infection in stranded St. Lawrence Estuary beluga *Delphinapterus leucas* in Quebec, Canada. Dis. Aquat. Org. 130: 165–175.

Jia, B., Garlock, E., Allison, M.J., Michaud, R., Lo, R., Round, J.M., Helbing, C.C., Verreault, J., Brinkman, F.S.L. 2022. Investigating the relationship between the skin microbiome and flame retardant exposure of St Lawrence Estuary beluga. Front. Environ. Sci. 10: 954060.

Jolicoeur, V., Houde, M, Loseto, L., Michaud, R., Verreault, J. 2024. Variations in thyroid hormone levels in endangered St. Lawrence Estuary belugas: Potential linkage with stress and organohalogen contaminant exposure. Environ. Int. 186: 108647.

John, J.S., Christen, D.R., Flammer, K.L., Kendall, T.L., Nazario, E.C., Richter, B.P., Gill, V., Williams, T.M. 2024. Conservation energetics of beluga whales: using resting and swimming metabolism to understand threats to an endangered population. J. Exp. Biol. 227: jeb246899.

Jönsson, K.I. 1997. Capital and income breeding as alternative tactics of resource use in reproduction. Oikos 78: 57–66.

Jutras, M., Dufour, C. O., Mucci, A., Cyr, F., and Gilbert, D. 2020. Temporal changes in the causes of the observed oxygen decline in the St. Lawrence Estuary. J. Geophys. Res. Oceans 125: e2020JC016577.

Kastelein, R.A., Ford, J., Berghout, E., Wiepkema, P.R., van Boxsel, M. 1994. Food consumption, growth and reproduction of belugas (*Delphinapterus leucas*) in human care. Aquat. Mamm. 20: 81–97.

Kershaw, J.L., Ramp, C.A., Sears R., Plourde, S., Brosset, P., Miller, P.J.O., Hall, A.J. 2020. Declining reproductive success in the Gulf of St. Lawrence's humpback whales (*Megaptera novaeangliae*) reflects ecosystem shifts on their feeding grounds. Glob. Change Biol. 27: 1027–1041.

Kingsley, M.C.S. 1998. Population index estimates for the St. Lawrence belugas, 1973–1995. Mar. Mamm. Sci. 14: 508–530.

Kleinenberg, S.E., Yablokov, A., Belkovich, B.M., Tarasevich, M.N. 1964. Beluga (*Delphinapterus leucas*): investigation of the species. Israel Program for Scientific Translations, Jerusalem, No. TT-67-51345 (original publication in Russian, Moscow, 1964)

Klemm, K., Cembella, A., Clarke, D., Cusack, C., Arnebord, L., Karlson, B., Liu, Y., Naustvoll, L., Siano, R., Gran-Stadniczenko, S., John, U. 2022. Apparent biogeographical trends in *Alexandrium* blooms for northern Europe: identifying links to climate change and effective adaptive actions. Harmful Algae 119: 102335.

Knowlton, A.R., Clark, J.S., Hamilton, P.K., Krauss, S.D., Pettis, H.M., Rolland, R.M., Schick, R.S. 2022. Fishing gear entanglement threatens recovery of critically endangered North Atlantic right whales. Conserv. Sci. Pract. 2022: e12736.

Lair, S., Martineau, D., Measures, L.N. 2014. Causes of mortality in St. Lawrence Estuary beluga (*Delphinapterus leucas*) from 1983 to 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/119: iv + 37 p.

Lair, S., Gentes, M.-L., Measures, L.N. 2015. Documentation de l'évolution du protocole d'examen des carcasses de béluga de l'estuaire du Saint-Laurent de 1983 à 2012. Rapp. Tech. Can. Sci. Halieut. Aquat. 3143: viii + 65 p.

Lair, S., Measures, L.N., Martineau, D. 2016. Pathological findings and trends in mortality in the beluga (*Dephinapterus leucas*) population of the St Lawrence Estuary, Québec, Canada, from 1983 to 2012. Vet. Pathol. 53: 22–36.

Larocque, R., Cembella, A.D. 1990. Ecological parameters associated with the seasonal occurrence of *Alexandrium* spp. and consequent shellfish toxicity in the lower St. Lawrence Estuary (eastern Canada). pp. 368-373. In Granéli, E, Anderson, D.M., Edler, L. (eds). *Toxic Marine Phytoplankton*. New York: Elsevier.

Laughlin, T.R. (ed.) 1994. Oil damage: Marine mammals and the Exxon Valdez. Academic Press Inc., San Diego, CA.

Lavigne, D.M., Scmitz, O.J. 1990. Global warming and increasing population densities: a prescription for seal plague. Mar. Pollut. Bull. 21: 280–284.

Lavoie, D., Lambert, N., Rousseau, S., Dumas, J., Chassé, J., Long, Z., Perrie, W., Starr, M., Brickman, D., and Azetsu-Scott, K. 2020. Projections of future physical and biochemical conditions in the Gulf of St. Lawrence, on the Scotian Shelf and in the Gulf of Maine using a regional climate model. Can. Tech. Rep. Hydrogr. Ocean Sci. 334: xiii + 102 p.

Lawson, J.W., Stevens, T.S. 2014. Historic and current distribution patterns, and minimum abundance of killer whales (*Orcinus orca*) in the north-west Atlantic. J. Mar. Biol. Assoc. UK 94: 1253–1265.

Lawson, J.W., Hammill, M.O., Stenson, G.B. 2006. Characteristics for recovery: Beluga whale. Can. Sci. Advis. Secr. Res. Doc. 2006/075.

Leatherwood, S., Reeves, R.R., Perrin, W.F., Evans, W.E. 1988. Whales, dolphins, and porpoises of the Eastern North Pacific and adjacent Arctic waters. New York : Dover Publications, Inc. 245 pp.

Lebeuf, M., Measures, L., Noël, M., Raach, M., Trottier, S. 2014. A twenty-one year temporal trend of persistent organic pollutants in St. Lawrence Estuary beluga, Canada. Sci. Total Environ. 485: 377–386.

Leguia, M., Garcia-Glaessner, A., Muñoz-Saavedra, B., Juarez, D., Barrera, P., Calvo-Mac, C., Jara, J., Silva, W., Ploog, K., Colchao-Claux, P., Johnson, C.K., Uhart, M.M., Nelson, M.I., Lescano. J. 2023. Highly pathogenic avian influenza A (H5N1) in marine mammals and seabirds in Peru. Nature Comm. 14: 5489.

Lemieux-Lefebvre, S., Michaud, R., Lesage, V., Berteaux, D. 2012. Identifying high residency areas of the threatened the St. Lawrence beluga whale from fine-scale movements of individuals and coarse-scale movements of herds. Mar. Ecol. Prog. Ser. 450: 243–257.

Le Net, R., Larrat, S., Michaud, R., Lair, S. 2021. Pathological and epidemiological investigation of skin lesions in belugas (*Delphinapterus leucas*) from the St. Lawrence Estuary, Quebec, Canada. Mar. Mamm. Sci. 38: 653-681.

Lesage, V. 2014. Trends in the trophic ecology of St. Lawrence beluga (*Delphinapterus leucas*) over the period 1988-2012, based on stable isotope analysis. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/126: iv + 25 p.

Lesage, V. 2018. Le beluga de l'estuaire du Saint-Laurent. Un examen scientifique de l'efficacité des mesures de rétablissement pour trois populations de baleines en péril. Rapport préparé pour Pêches et Océans Canada, Otttawa. 74 p.

Lesage, V. 2021. The challenges of a small population exposed to multiple anthropogenic stressors and a changing climate: the St. Lawrence Estuary beluga. Polar Res. 40: 5523.

Lesage, V., Kingsley, M.C.S. 1995. Bilan des connaissances de la population de bélugas (*Delphinapterus leucas*) du Saint-Laurent. Rapp. tech. can. sci. halieut. aquat. 2041: vii + 44 p.

Lesage, V., Kingsley, M.C.S. 1998. Updated status of the St Lawrence River population of the Beluga, *Delphinapterus leucas*. Can.-Fld Nat. 112: 98–113.

Lesage, V., Barrette C., Kingsley, M.C.S. 1999. The effect of noise from an outboard motor and a ferry on the vocal activity of beluga (*Delphinapterus leucas*) in the St Lawrence Estuary, Canada. Mar. Mamm. Sci. 15: 65–84.

Lesage, V., Hammill, M.O., Kovacs, K.M. 2001. Marine mammals and the community structure of the Gulf and Estuary regions of the St Lawrence (Canada). Mar. Ecol. Prog. Ser. 210: 203–221.

Lesage, V., Keays, J., Turgeon, S., Hurtubise, S. 2006. Bycatch of harbour porpoises (*Phocoena phocoena*) in the gillnet fishery of the Estuary and Gulf of St Lawrence, 2000-2002. J. Cetacean Res. Manage. 8: 67–78.

Lesage, V., Mosnier, A., Measures, L., Lair, S., Béland, P. 2014a. Mortality patterns in St. Lawrence Estuary beluga (*Delphinapterus leucas*), inferred from the carcass recovery data, 1983-2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/118: ii + 24 p.

Lesage, V., McQuinn, I.H., Carrier, D., Gosselin, J.-F., and Mosnier, A. 2014b. Exposure of the beluga *(Delphinapterus leucas*) to marine traffic under various scenarios of transit route diversion in the St. Lawrence Estuary. DFO Can. Sci. Advis. Sec., Res. Doc. 2013/125. iv + 28 p.

Lesage, V., Gosselin, J.-F., Lawson, J.W., McQuinn, I., Moors-Murphy, H., Plourde, S., Sears, R., Simard, I. 2018. Habitats important to blue whales (*Balaenoptera musculus*) in the western North Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/080: vi + 50 p.

Lesage, V., Lair, S., Turgeon, S., Béland, P. 2020. Diet of St. Lawrence Estuary Beluga, *Delphinapterus leucas*, in a changing ecosystem. Can. Fld-Nat. 134: 21–35.

Lewis, A., Hammill, M.O., Power, M., Doidge, D.W., Lesage, V. 2009. Movement and aggregation of Eastern Hudson Bay beluga whales (*Delphinapterus leucas*): a comparison of patterns found through satellite telemetry and Nunavik traditional ecological knowledge. Arctic 62: 13–24.

Lockyer, C. 1986. Body fat condition in Northeast Atlantic fin whales and its relationship with reproduction and food resources. Can. J. Fish. Aquat. Sci. 43: 142–147.

Loseto, L.L., Richard, P., Stern, G.A., Orr, J., Ferguson, S.H. 2006. Segregation of Beaufort Sea beluga whales during the open-water season. Can. J. Zool. 84: 1743–1751.

Loughlin, T.R. (ed.). 1994. Marine mammals and the 'Exxon Valdez'. Academic Press, San Diego, CA.

Lusseau, D., Bejder, L. 2007. The long-term consequences of short-term responses of disturbance experiences from whalewatching impact assessment. Int. J. Comp. Psychol. 20: 228–236.

Marchand, C., Simard, Y., Gratton, Y. 1999. Concentration of capelin in tidal upwelling fronts at the head of the Laurentian channel in the St. Lawrence estuary. Can. J. Fish. Aquat. Sci. 56: 1832-1848.

Marcogliese, D., Boily, F., Hammill, M.O. 1996. Distribution and abundance of stomach nematode (Anisakidae) among grey seals (*Halichoerus grypus*) and harp seals (*Phoca groenlandica*) in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 53: 2829–2836.

Martineau, D., Lagacé, A., Béland, P., Higgins, R., Armstrong, D., Shugart, L.R. 1988. Pathology of stranded beluga whales (*Delphinapterus leucas*) from the St. Lawrence Estuary, Québec, Canada. J. Comp. Pathol. 98: 287–311.

Martineau, D., De Guise, S., Fournier, M., Shugart, L.R., Girard, C., Lagacé, A., Béland, P. 1994. Pathology and toxicology of beluga whales from the St Lawrence Estuary, Quebec, Canada: past, present and future. Sci. Total Environ. 154: 201–215.

Martineau, D., Lemberger, K., Dallaire, A., Labelle, P., Lipscomb, T.P., Michel, P., Michaelian, I. 2002. Cancer in wildlife, a case study: beluga from the St Lawrence Estuary, Quebec, Canada. Environ. Health Perspect. 110: 285–292.

Matkin, C.O., Saulitis, E.L., Ellis, G.M., Olesiuk, P., Rice, S.D. 2008. Ongoing population-level impacts on killer whales *Orcinus orca* following the 'Exxon Valdez' oil spill in Prince William Sound, Alaska. Mar. Ecol. Prog. Ser. 356: 269–281.

Matthews, C., Breed, G.A., LeBlanc, B., Ferguson, S.F. 2020. Killer whale presence drives bowhead whale selection for sea ice in Arctic seascapes of fear. Proc. Nat. Acad. Sci. 117: 6590-6598.

McQuinn, I.H., Lesage, V., Carrier, D., Larrivée, G., Samson, Y., Chartrand, S., Michaud, R., Theriault, J. 2011. A threatened beluga (*Delphinapterus leucas*) population in the traffic lane: vessel-generated noise characteristics of the Saguenay–St. Lawrence Marine Park, Canada. J. Acoust. Soc. Am. 130: 3661–3673.

Ménard, N.R., Michaud, R., Chion, C., Turgeon, S. 2014. Documentation of maritime traffic and navigational interactions with St. Lawrence Estuary beluga (*Delphinaterus leucas*) in calving areas between 2003 and 2012. DFO Can. Sci. Advis. Secr. Res. Doc. 2014/003.

Meyer-Gutbrod, E.L., Greene, C.H., Sullivan, P.J., Pershing, A.J. 2015. Climate-associated changes in prey availability drive reproductive dynamics of the North Atlantic right whale population. Mar. Ecol. Prog. Ser. 535: 243–258.

Michaud, R. 1993. Distribution estivale du béluga du Saint-Laurent; synthèse 1986 à 1992. Rapp. tech. can. sci. halieut. aquat. 1906: vi + 28 p.

Michaud, R. 2005. Sociality and ecology of the odontocetes. pp. 303–326 In Ruckstuhl, K.E., Neuhaus, P. (eds.) *Sexual segregation in vertebrates: ecology of the two sexes.* Cambridge University Press, AU.

Michaud. R. 2007. Unpublished report presented to Fisheries and Oceans Canada. Disponible au : GREMM, 108 de la Cale Sèche, Tadoussac, G0T 2A0.

Michaud, R., Chadenet, V. 1990. Survols aériens pour l'estimation de la distribution printanière et des déplacements des bélugas du Saint-Laurent. Préparé par l'Institut National d'Écotoxicologie du Saint-Laurent, pour Pêches et Océans Canada. 36p. Disponible au GREMM, 108 de la Cale Sèche, Tadoussac, Québec Canada. G0T 2A0.

Michaud, R., Vézina, A., Rondeau, N., Vigneault, Y. 1990. Distribution annuelle et caractérisation des habitats du béluga (*Delphinapterus leucas*) du Saint-Laurent. Rapp. can. sci. halieut. aquat. 1757: v + 31 p.

Mikaelian, I, Labelle, P., Martineau, D. 1999. Metastatic mammary adenocarcinomas in two beluga whales (*Delphinapterus leucas*) from the St. Lawrence estuary, Quebec, Canada. Vet. Rec. 145: 738–739.

Miller, C.A., Reeb, D., Best, P.B., Knowlton, A., Brown, M.W., Moore, M.J. 2011. Blubber thickness in right whales *Eubalaena glacialis* and *Eubalaena australis* related to reproduction, life history status and prey abundance. Mar. Ecol. Prog. Ser. 438: 267–283.

Mitchell, E., Reeves, R.R. 1988. Records of killer whales in western North Atlantic, with emphasis on eastern Canadian waters. Rit Fiskideildar 11: 163–193.

Mosnier, A., Lesage, V., Gosselin, J.-F., Lemieux Lefebvre, S., Hammill, M.O., Doniol-Valcroze, T. 2010. Information relevant to the documentation of habitat use by St. Lawrence beluga (*Delphinapterus leucas*), and quantification of habitat quality. DFO Can. Sci. Advis. Secr. Res. Doc. 2009/098.

Mosnier, A., Doniol-Valcroze, T., Gosselin, J.-F., Lesage, V., Measures, L.N., Hammill, M.O. 2015. Insights into processes of population decline using an integrated population model: the case of the St. Lawrence beluga (*Delphinapterus leucas*). Ecol. Modell. 314: 15–31.

Mosnier, A., Larocque, R., Lebeuf, M., Gosselin, J.-F., Dubé, S., Lapointe, V., Lesage V., Lefaivre, D., Senneville, S., Chion C. 2016. Définition et caractérisation de l'habitat du béluga (*Delphinapterus leucas*) de l'estuaire du Saint-Laurent selon une approche écosystémique. Secr. can. de consult. sci. du MPO. Doc. de rech. 2016/052.

Mosnier A., Gosselin J.-F. et Lesage, V. 2022. Distribution saisonnière et concentration de quatre espèces de baleine à fanons dans l'estuaire du Saint-Laurent, basé sur 22 ans de données d'observations de Pêches et Océans Canada. Secr. can. des avis du MPO. Doc. de rech. 2020/053. iv + 121 p.

Mosnier, A., Dispas, A., Hammill, M.O. 2023. Spatial distribution and count of harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) in the Estuary and Gulf of St. Lawrence from an aerial survey conducted in June 2019. Can. Tech. Rep. Fish. Aquat. Sci. 3541 : v + 65 p.

Murie, D.J., Lavigne, D.M. 1991. Food consumption of wintering harp seals, *Phoca groenlandica*, in the St. Lawrence estuary, Canada. Can. J. Zool. 69: 1289–1296.

New, L.F., Clark, J.S., Costa, D.P., Fleishman, E., Hindell, M.A., Klanjscek, T., Lusseau, D., Kraus, S., McMahon, C.R., Robinson, P.W., Schick, R.S., Schwarz, L.K., Simmons, S.E., Thomas, L., Tyack, P., Harwood, J. 2014. Using short-term measures of behaviour to estimate long-term fitness of southern elephant seals. Mar. Ecol. Prog. Ser. 496: 99–108.

Nielsen, O., Stewart, R.W., Measures, L., Duignan, P., House, C. 2000. A morbillivirus antibody survey of Atlantic walrus, narwhal and beluga in Canada. J. Wild. Dis. 36: 508–517.

Nielsen, O. Burek-Huntington, K.A., Loseto, L.L., Morell, M. Romero, C.H. 2017. Alphaherpesvirus: isolation, identification, partial characterisation, associated pathologic findings, and epidemiology in beluga whales (*Delphinapterus leucas*) in Alaska and Arctic Canada. Arctic Sci. 4: 338–357.

Noël, M., Brown, T.M. 2021. Contaminants as a conservation threat to marine mammals. p. 401-420 *In* Underkoffler, S.C., Adams, H.R., eds. *Wildlife biodiversity conservation: Multidisciplinary and forensic approaches*. Springer Nature, Switzerland.

Norman, S.A., Dreiss, L.M., Niederman, T.E., Nalven, K.B. 2022. A systematic review demonstrates how surrogate populations help inform conservation and management of an endangered species — The case of Cook Inlet, Alaska belugas. Front. Mar. Sci. 9: 804218.

O'Corry-Crowe, G. 2018. Beluga whale. In: B. Würsig, J.G.M. Thewissen, Kit M. Kovacs, eds. Marine Mammal Encyclopedia. Academic Press, London, U.K.

O'Corry-Crowe, G., Suydam, R., Quakenbush, L., Potgieter, B., Harwood, L., Litovka, D., Ferrer, T., Citta, J., Burkanov, V., Frost, K., Mahoney, B. 2018. Migratory culture, population structure and stock identity in North Pacific beluga whales (*Delphinapterus leucas*). PLoS ONE 13: e0194201.

O'Corry-Crowe, G., Suydam, R., Quakenbush, L., Smith, T.G., Lydersen, C., Kovacs, K.M., Orr, J., Harwood, L., Litovk, D., Ferrer, T. 2020. Group structure and kinship in beluga whale societies. Sci. Rep. 10: 11462.

Ouellet, J.-F., Michaud, R., Moisan, M., Lesage, V. 2021. Estimating the proportion of a beluga population using specific areas from connectivity patterns and abundance indices. Ecosphere 12: e03560.

Palsbøll, P.J., Heide-Jørgensen, M.-P., Bérubé, M. 2002. Analysis of mitochondrial region nucleotide sequences from Baffin Bay beluga – detecting pods or sub-populations. NAMMCO Sci. Publ. 4: 39–50.

Peterson, C., Rice, S., Short, J., Esler, D., Bodkin, J.L., Ballachey, B.E. et Irons, D. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. Science 302: 2082–2086.

Pippard L. 1985. Status of the St. Lawrence River population of beluga, Delphinapterus leucas. Can. Fld-Nat. 99: 438–450.

Pippard, L., Malcolm, H. 1978. White whales (*Delphinapterus leucas*): observations on their distribution, population and critical habitats in the St. Lawrence and Saguenay Rivers. The Department of Indian and Northern Affairs, Parks Canada. Manusc. Rep. 159 p. Available via the DFO library, Darthmouth, NS.

Pirotta, E., Merchant, N.D., Thompson, P.M., Barton, T.R., Lusseau, D. 2015. Quantifying the effect of boat disturbance on bottlenose dolphin foraging activity. Biol. Conserv. 181: 82–89.

Pirotta, E., Mangel, M., Costa, D.P., Goldbogen, J., Harwood, J., Hin, V., Irvine, L.M., Mate, B.R., McHuron, E.A., Palacios, D.M., Schwarz, L.K. New, L. 2019. Anthropogenic disturbance in a changing environment: modelling lifetime reproductive success to predict the consequences of multiple stressors on a migratory population. Oikos 128: 1340–1357.

Pirotta, E., Booth, C.G., Cade, D.E., Calambokidis, J., Costa, D.P., Fahlbusch, J.A., Friedlander, A.S., Goldbogen, J.A., Harwood, J., Hazen, E.L., New, L., Southall, BL. 2021. Context-dependent variability in the predicted daily energetic costs of disturbance for blue whales. Conserv. Physiol. 9: coaa137.

Pirotta, E., Booth, C.G., Calambokidis, J., Costa, D.P., Fahlbusch, J.A., Friedlander, A.S., Goldbogen, J.A., Harwood, J., Hazen, E.L., New, L., Santora, J.A., Watwood, S.L., Wertman, C., Southall, BL. 2022. From individual responses to population effects: Integrating a decade of multidisciplinary research on blue whales and sonar. Anim. Conserv. 25: 796–810.

Pirotta, E., Schick, R.S., Hamilton, P.K., Harris, C.M., Hewitt, J., Knowlton, A.R., Kraus, S.D., Meyer-Gutbrod, E., Moore, M.J., Pettis, H.M., Photopoulou, T., Rolland, R.M., Tyack, P.L., Thomas, L. 2023. Estimating the effects of stressors on the health, survival and reproduction of a critically endangered, long-lived species. Oikos 2023: e09801.

Plourde S., Galbraith P., Lesage V., Grégoire F., Bourdages H., Gosselin J.-F., McQuinn I. & Scarratt M. 2014. Ecosystem perspective on changes and anomalies in the Gulf of St. Lawrence: a context in support of the management of the St. Lawrence beluga whale population. DFO Can. Sci. Advis. Secr. Res. Doc. 2013/129.

Poirier M.C., Lair S., Michaud R., Hernandez-Ramon E.E., Divi K.V., Dwyer J.E., Ester C.D., Si N.N., Ali M., Loseto L.L., Raverty S.A., St. Leger J.A., Van Bonn W.G., Colegrove K., Burek-Huntington K.A., Suydam R., Stimmelmayr R., Pierce Wise J. Sr., Wise S.S., Beauchamp G. & Martineau D. 2019. Intestinal polycyclic aromatic hydrocarbon-DNA adducts in a population of beluga whales with high levels of gastrointestinal cancers. Environ. Mol. Mutagen. 60: 29–41.

Postma, D. 2017. Genetic diversity, population structure and phylogeography among belugas (*Delphinapterus leucas*) in Canadian waters: broad to fine-scale approaches to inform conservation and management strategies. PhD thesis. University of Manitoba. 296 p.

Quakenbush, L.T., Suydam, R.S., Bryan, A.L, Lowry, L.F., Frost, K.J., Mahoney, B.A. 2015. Diet of beluga whales, *Delphinapterus leucas*, in Alaska from stomach contents, March-November. Mar. Fish. Rev. 77: 70–84.

Reeves, R.R., Katona, S.K. 1980. Extralimital records of white whales in eastern North American waters. Can. Fld-Nat. 94: 239–247.

Reeves R.R., Mitchell E. 1984. Catch history and initial population of white whales (*Delphinapterus leucas*) in the river and Gulf of St. Lawrence, eastern Canada. Can. Fld-Nat. 111: 63–121.

Richard, P.R., Stewart, B. 2008. Information relevant to the Identification of Critical Habitat for Cumberland Sound Belugas. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/085.

Richard, P.R., Heide-Jørgensen, M.-P., Orr, J.R., Dietz, R., Smith, T.G. 2001. Summer and autumn movements and habitat use by belugas in the Canadian High Arctic and adjacent areas. Arctic 54: 207–222.

Richardson, W.J., Greene, C.R. Jr., Malme, C.I., Thomson, D.H. 1995. Marine mammals and noise. Academic Press, San Diego.

Rivas, M.L., Guirado, E., Ortega, Z. 2024. Relation between beluga whale aggregations and sea temperature on climate change forecasts. Front. Mar. Sci. 11:1359429.

Rosen, D.A.S. 2009. Steller sea lions *Eumetopias jubatus* and nutritional stress: evidence from captive studies. Mamm. Rev. 39: 284–309.

Roy, N., Simard, Y. 2015. Bruit ambiant et fréquentation de la région de Cacouna par le béluga du Saint-Laurent à l'été 2014 par monitorage acoustique continu. Rapp. tech. can sci. halieut. aquat. 3141: vi + 22 p.

Roy, N., Simard, Y., Aulanier, F., and Giard, S. 2018. Fin whale continuous frequentation of St. Lawrence habitats detected from multi-year passive acoustic monitoring (PAM). DFO Can. Sci. Advis. Sec. Res. Doc. 2018/059: iv + 14 p.

Ryan, S.A., Wohlgeschaffen, G., Jahan, N., Niu, H., Ortmann, A.C., Brown, T.N., King, T.L., and Clyburne, J. 2019. State of Knowledge on Fate and Behaviour of Ship-Source Petroleum Product Spills: Volume 4, St. Lawrence Seaway, Montreal to Anticosti, Québec. Can. Manuscr. Rep. Fish. Aquat. Sci. 3176: viii + 42 p.

Sanderson, C.E., Alexander, K.A. 2020. Unchartered waters: Climate change likely to intensify infectious disease outbreaks causing mass mortality events in marine mammals. Glob. Chang. Biol. 26: 4284–4301.

Saucier, F.J., F. Roy, S., Senneville, G., Smith, D., Lefaivre, D., Zakardjian, B., Dumais, J.-F. 2009. Modélisation de la circulation dans l'estuaire et le golfe du Saint-Laurent en réponse aux variations du débit d'eau douce et des vents. Rev. Sci. de l'Eau 22: 159–176.

Savenkoff, C., M. Castonguay, D. Chabot, M.O. Hammill, H. Bourdages, and L. Morissette. 2007. Changes in the northern Gulf of St. Lawrence ecosystem estimated by inverse modelling: Evidence of a fishery-induced regime shift? Estuar. Coast. Shelf Sci. 73: 711–724.

Scarratt, M., Michaud, S., Measures, L., Starr, M. 2014. Phytotoxin analyses in St. Lawrence Estuary beluga. DFO Can Sci Advis Sec Res Doc 2013/124: v + 16 p.

Scheifele, P.M., Andrew, S., Cooper, R.A., Darre, M., Musiek, F.E., Max, L. 2005. Indication of a Lombard vocal response in the St. Lawrence River beluga. J. Acoust. Soc. Am. 117: 1486–1492.

Schleimer, A., Ramp, C., Delarue, J., Carpentier, A., Bérubé, M., Palsbøll, P.J., Sears, R., Hammond, P.S. 2019. Decline in abundance and apparent survival rates of fin whales (*Balaenoptera physalus*) in the northern Gulf of St. Lawrence. Ecol. Evol. 2019: 1–14.

Seaman, G.A., Lowry, L.F., Frost, K.J. 1982. Foods of belukha whales (*Delphinapterus leucas*) in western Alaska. Cetology 44: 1–19.

Sears, R., Williamson, J.M. 1982. A preliminary aerial survey of marine mammals for the gulf of the St Lawrence to determine their distribution and relative abundance. Parks Canada. Contract #81-1272. Mingan Island Cetacean Study (MICS Project M06), Falmouth, MA and Sept-Iles, Quebec. Available from DFO Library, Dartmouth, NS.

Senigaglia, V., Christiensen, F., Bejder, L., Gendron, D., Lundquist, D., Noren, D.P., Schaffar, A., Smith, J.C., Williams, R., Martinez, E., Stockin, K., Lusseau, D. 2016. Meta-analyses of whale-watching impact studies: comparisons of cetacean responses to disturbance. Mar. Ecol. Prog. Ser. 542: 251–263.

Sergeant, D. E. 1973. Biology of white whale in western Hudson Bay. J. Fish. Res. Brd Can. 30:1065–1090.

Sergeant, D.E. 1986. Present status of white whales *Delphinapterus leucas* in the St. Lawrence Estuary. Natur. Can. 113: 61–81.

Sergeant, D.E. 1991. Harp seals, man and ice. Can. Spec. Publ. Fish. Aquat. Sci. 114: 1–153.

Sergeant, D. E., Brodie, P.F. 1969. Body size in white whales, *Delphinapterus leucas*. J. Fish. Res. Brd Can. 26: 2561–2580.

Sergeant, D. E., Brodie, P.F. 1975. Identity, abundance, and present status of populations of white whales, *Delphinapterus leucas*, in North America. J. Fish. Res. Board Can. 32: 1047–105.

Sergeant, D.E., Hoek, W. 1988. An update of the status of white whales *Delphinapterus leucas* in the St. Lawrence Estuary, Canada. Biol. Conserv. 45: 287–302.

Sergeant, D.E., Mansfield, A.W., Beck, B. 1970. Inshore cetacean records for eastern Canada, 1949-68. J. Fish. Res. Brd. Can. 27: 1903–1915.

Simard, Y., Lavoie, D., Saucier, F.J. 2002. Channel head dynamics: Capelin (*Mallotus villosus*) aggregation in the tidally-driven upwelling system of the Saguenay – St. Lawrence Marine Park's whale feeding ground. Can. J. Fish. Aquat. Sci. 59: 197-210.

Simard, Y., Lepage, R., Gervaise, C. 2010. Anthropogenic sound exposure of marine mammals from seaways: estimates for lower St. Lawrence Seaway, eastern Canada. Appl. Acoust, 71: 1093–1098.

Simard, Y., Roy N., Giard, S., Yayla, M. 2014. Canadian year-round shipping traffic atlas for 2013: volume 1, East Coast marine waters. Can .Tech. Rep. Fish. Aquat. Sci. 3091 (Vol. 1) East coast waters.

Simard, Y., Roy, N., Giard, S., Aulanier, A. 2019. North Atlantic right whale shift to the Gulf of St. Lawrence in 2015, revealed by long-term passive acoustics. Endang. Species Res. 40: 271–284.

Simard, Y., Claing, C., Gervaise, C., Roy, N., Bourdages, L., Aulanier. F. et Conversano, M. 2022. Estimation des niveaux de bruit de bateaux d'écotourisme opérant dans le parc marin du Saguenay–Saint-Laurent au moyen d'un observatoire acoustique. Rapp. tech. can. sci. halieut. aquat. 3480: viii + 49 p.

Simard, Y., Giard, S., Roy, N., Aulanier, F., Lesage, V. 2023. Mesoscale habitat use by St. Lawrence Estuary beluga over the annual cycle from an acoustic recording network. J. Acoust, Soc. Am. 154: 635–649.

Simeone, C.A., Gulland, F.M., Norris, T., Rowles, T.K. 2015. A systematic review of changes in marine mammal health in North America, 1972–2012: The need for a novel integrated approach. PLoS ONE 10: e0142105.

Simond, A.E., Houde, M., Lesage, V., Verreault, J. 2017. Temporal trends of PBDEs and emerging flame retardants in belugas from the St. Lawrence Estuary (Canada) and comparisons with minke whales and belugas from the Canadian Arctic. Environ. Res. 156: 494–504.

Simond, A.E., Houde, M., Lesage, V., Michaud, R., Zbinden, D., Verreault, J. 2019. Associations between organohalogen contaminant and thyroid- and steroid-related gene responses in St. Lawrence Estuary beluga and minke whales. Mar. Pollut. Bull. 145: 174–184.

Simond, A., Houde, M., Lesage, V., Michaud, R., Verreault, J. 2020. Metabolomic profiles of the endangered St. Lawrence Estuary beluga population and associations with organohalogen contaminants. Sci. Total Environ. 717: 137204.

Simond, A.E., Noël, M., Loseto, L., Houde, M., Kirk, J., Elliott, A., Brown, T.M. 2022. A multi-matrix metabolomic approach in ringed seals and beluga whales to evaluate contaminant and climate-related stressors. Metabolites 12: 813.

Simond, A.É., Ross, P.S., Cabrol, J., Lesage, V., Lair, S., Woudneh, M., Peng, H., Colbourne, K., Brown, T.M. 2023. Declining concentrations of chlorinated paraffins in endangered St. Lawrence estuary belugas (*Delphinapterus leucas*): Response to regulations or a change in diet? Sci. Total Environ. 868: 161488.

Sjare, B., Smith, T. G. 1986a. The vocal repertoire of white whales, *Delphinapterus leucas*, summering in Cunningham Inlet, Northwest Territories. Can. J. Zool. 64: 2075-2080.

Sjare, B., Smith, T.G. 1986b. The relationship between behavioral activity and underwater vocalizations of the white whale, *Delphinapterus leucas*. Can. J. Zool. 64: 2824–2831.

Skovrind, M., Louis, M., Westbury, M.V., Garilao, C., Kaschner, K., Samaniego Castruita, J.A., Gopalakrishnan, S., Knudsen, S.W., Haile, J.S., Dalén, L., Meshchersky, I.G., Shpak, O.V., Glazov, D.M., Rozhnov, V.V., Litovka, D.I., Krasnova, V.V., Chernetsky, A.D., Bel'kovich, V.M., Lydersen, C., Kovacs, K.M., Heide-Jørgensen, M.P., Postma, L., Ferguson, S.H., Lorenzen, E.D. 2021. Circumpolar phylogeography and demographic history of beluga whales reflect past climatic fluctuations. Mol. Ecol. 30: 2543-2559.

Smith, T.G., Hammill, M.O., Martin, A.R. 1994. Herd composition and behaviour of belugas, *Delphinapterus leucas*, in two Canadian Arctic estuaries. Medd, Grøenland Biosci. 39: 175–184.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J. Gentry, R.L., Greene, Jr., C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.R., Thomas, J.A., Tyack, P.L. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquat. Mamm. 33, 411–521.

Southall, B.L., Finneran, J.J., Reichmuth, C., Nachtigall, P.E., Ketten, D.R., Bowles, A.E., Ellison, W.T., Nowacek, D.P., Tyack, P.L. 2019. Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects. Aquat. Mamm. 45: 125–232.

Southall, B.L. Nowacek, D.P., Bowles, A.E., Senigaglia, C., Bejder, L., Tyack, P.L. 2021. Marine mammal noise exposure criteria: Assessing the severity of marine mammal behavioral responses to human noise. Aquat. Mamm. 47: 421–464.

St. Aubin, D.J., Smith, T.G., Geraci, J.R. 1990. Seasonal epidermal molt in beluga whales, *Delphinapterus leucas*. Can. J. Zool. 68: 359–367.

Starr M., Lair S., Michaud S., Scarratt M., Quilliam M., Lefaivre D., Robert M., Wotherspoon A., Michaud R., Ménard N., Sauvé G., Lessard S. and Measures L. 2017. Multispecies mass mortality of marine fauna linked to a toxic dinoflagellate bloom. PLoS One 12: e0176299.

Stenson, G. B., Haug, T., Hammill, M. O. 2020. Harp seals: Monitors of change in differing ecosystems. Front. Mar. Sci. 7: 569258.

Storrie, L., Hussey, N.E., MacPhee, S.A., O'Corry-Crowe, G., Iacozza, J., Barber, D.G., Nunes, A., Loseto, L.L. 2022. Year-round dive characteristics of male beluga whales from the Eastern Beaufort Sea population indicate seasonal shifts in foraging strategies. Front. Mar. Sci. 8:715412.

St-Pierre, A.P., Lesage, V., Mosnier, A., Tinker, M.T. et Gosselin, J.-F. 2024. Estimations de l'abondance estivale du béluga (*Delphinapterus leucas*) dans l'estuaire du Saint-Laurent basées sur 52 relevés visuels et 11 relevés photographiques réalisés de 1990 à 2022. Secr. can. des avis sci. du MPO, doc. de rech. 2023/048. v + 86 p.

Stringel, T., Hill, D., Rees, D., Rees, F., Rees, P., Morgan, G., Morgan, L., Morris, C. 2015. Predation of harbour porpoises (*Phocoena phocoena*) by grey seals (*Halichoerus grypus*) in Wales. Aquat. Mamm. 41: 188-191.

Suydam, R.S., Lowry, L.F., Frost, K.J., O'Corry-Crowe, G.M., Pikok, D., Jr. 2001. Satellite tracking of eastern Chukchi Sea beluga whales into the Arctic Ocean. Arctic 54: 237–243.

Svanbäck, R., Bolnick, D.I. 2007. Intraspecific competition drives increased resource use diversity within a natural population. Proc. R. Soc. B Biol. Sci. 274, 839–844.

Therriault, J-C, Painchaud, J, Levasseur, M. 1985. Factors controlling the occurrence of *Protogonyaulax tamarensis* and shellfish toxicity in the St. Lawrence Estuary: freshwater runoff and the stability of the water column. pp. 141-146. *In* Anderson DM (ed.) *Toxic Dinoflagellates*. Elsevier, New York.

Thorsson, E., Zohari, S., Roos, A., Banihashem, F., Bröjer, C., Neimanis, A. 2023. Highly pathoggenic avian influenza A(H5N1) virus in a harbor porpoise, Sweden. Emerging Inf. Dis. 29: 852–855.

Tinker, M.T., Mosnier, A., St-Pierre, A.P., Gosselin, J.-F., Lair, S., Michaud, R. et Lesage, V. 2024. Modèle de population intégrée des bélugas (*Delphinapterus leucas*) de l'estuaire du Saint-Laurent. Secr. can. des avis sci. du MPO. Doc. de rech. 2023/047. iv + 65 p.

Tomilin, A.G. 1967. Mammals of the U.S.S.R. and adjacent countries. Volume IX, Cetacea. Izdatel'stvo Akademi Nauk SSSR, Moscow. Translated from Russian. Israël Program for Scientific. Translation, Jerusalem, 1967. 717 p. Available via DFO library, Dartmouth, NS.

Turgeon, J., Duchesne, P., Colbeck, G.J., Postma, L.D., Hammill, M.O. 2012. Spatiotemporal segregation among summer stocks of beluga (*Delphinapterus leucas*) despite nuclear gene flow: implication for the endangered belugas in eastern Hudson Bay (Canada). Conserv. Genet. 13: 419–433.

Turl, C.W., Penner, R.H., Au, W.W.L. 1987. Comparison of target detection capabilities of the beluga and bottlenose dolphin. J. Acoust. Soc. Am. 82: 1487-1491.

Tyack, P.L., Clark, C.W. 2000. Communication and acoustic behavior of dolphins and whales. pp. 156-224. *In* Au, W.W.L., Fay, R.R. (eds) *Hearing by whales and dolphins*. Springer, New York.

Van Dolah, F.M. 2000. Marine algal toxins: Origins, health effects, and their increased occurrence. Environ. Health Perspect. 108: 133-141.

Van Neer, A., Gross, S., Kesselring, T., Grilo, M.L., Ludes-Wehrmeister, E., Roncon, G., Siebert, U. 2020. Assessing harbour porpoise carcasses potentially subjected to grey seal predation. Sci. Rep. 10:16345.

Valiquette, É., Harvey, V. et Pelletier, A.-M. 2017. Mise à jour des connaissances sur l'identification, la description et l'utilisation spatio-temporelle des habitats du bar rayé (*Morone saxatilis*) de la population du fleuve Saint-Laurent, Québec. Secr. can. de consult. sci. du MPO. Doc. de rech. 2017/005. ix + 55 p.

Vergara, V., Wood, J., Lesage, V., Ames, A., Mikus, M.-A., Michaud, R. 2021. Can you hear me? Impacts of underwater noise on communication space of adult, sub-adult and calf contact calls of endangered St. Lawrence belugas (*Delphinapterus leucas*). Polar Res. 40: 5521.

Villeneuve, S., Quilliam, L. 1999. Les risques et les conséquences environnementales de la navigation sur le Saint-Laurent. Rapp. sci. tech. ST-188. Centre Saint-Laurent. Montréal, QC. 160 p.

Vladykov, V.D. 1944. Études sur les mammifères aquatiques. III. Chasse, biologie et valeur économique du marsouin blanc ou béluga (*Delphinapterus leucas*) du fleuve et du golfe du Saint-Laurent. Département des Pêcheries, Province de Québec. 194 p.

Vladykov, V.D. 1946. Études sur les mammifères aquatiques. IV. Nourriture du marsouin blanc (*Delphinapterus leucas*) du fleuve Saint-Laurent. Département des Pêcheries. Province de Québec.

Wade, P.R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Mar. Mamm. Sci. 14: 1-37.

Wade, P.R., Reeves, R.R., Mesnick, S.L. 2012. Social and behavioural factors in cetacean responses to overexploitation: are odontocetes less “resilient” than mysticetes? J. Mar. Biol.

Watts, P.D., Draper, B.A., Henrico, J. 1991. Preferential use of warm water habitat by adult beluga whales. J. Thermal Biol. 16: 57-60.

Whalen, D., Loseto, L.L., Hornby, C.A. et al. 2020. Mapping and understanding the role of seabed morphology in relation to beluga whale (*Delphinapterus leucas*) hotspots and habitat ise in the Mackenzie Estuary, NT. Estuaries Coasts 43: 161–173.

Williams, R., Noren, D. 2009. Swimming speed, respiration rate and estimated cost of transport in killer whales. Mar. Mamm. Sci. 25: 327-350.

Williams, R., Lusseau, D., Hammond, P.S. 2006. Estimating relative energetic costs of human disturbance to killer whales (*Orcinus orca*). Biol. Conserv. 133: 301-311.

Williams, R., Erbe, C., Ashe, E., Clark, C.W. 2015. Quiet(er) marine protected areas. Mar. Pollut. Bull. 100: 154-161.

Williams, R., Lacy, R.C., Ashe, E., Hall, A., Plourde, S., McQuinn, I., Lesage, V. 2021. Climate change exacerbates the effects from anthropogenic threats including ocean noise, on the survival and recovery of St. Lawrence beluga. Mar. Pollut. Bull. 173B: 113096.

Wong, S., M. Fournier, D. Coderre, W. Banska and K. Krzystyniak. 1992. Environmental toxicology. pp.167-281. *In* D. Peakall (ed.) *Animal biomarkers as pollution indicators*. Chapman & Hall, New York.

Worm, B., Myers, R.A. 2003. Meta-analysis of cod-shrimp interactions reveals top-down control in oceanic food webs. Ecology 84: 162–173.

WSP Canada Inc. 2014. Risk assessment for marine spills in Canadian waters. Phase 1: Oil spills South of 60th Parallel. Prepared for Transport Canada. Report number 131-17593-00.

Yu, L., Han, Z., Liu, C. 2015. A review on the effects of PBDEs on thyroid and reproduction systems in fish. Gen. Comp. Endocrinol. 219, 64–73.

Zahn, M.J., Laidre, K.L., Stilz, P., Rasmussen, M.H., Koblitz, J.C. 2021. Vertical sonar beam width and scanning behavior of wild belugas (*Delphinapterus leucas*) in West Greenland. PLoS ONE 16(9): e0257054.

PARTICIPANTS LIST

Name	Affiliation
Abraham, Christine	DFO - Science, National Capital Region
Albuquerque, Cristiane	Saguenay St. Lawrence Marine Park, Parks Canada
Aulanier, Florian	DFO - Science, Quebec Region
Barreau, Emmanuelle	DFO - Science, Quebec Region
Bordeleau, Xavier	DFO - Science, Quebec Region
Bowen, Don	Emeritus; DFO - Science, Maritimes Region
Brown, Tanya	DFO - Science, Pacific Region
Buren, Alejandro	Consejo Nacional de Investigaciones Científicas y Técnicas, CONICET
Cabrol, Jory	DFO - Science, Quebec Region
den Heyer, Cornelia	DFO - Science, Maritimes Region
Doniol-Valcroze, Thomas	DFO - Science, Pacific Region
Ferguson, Steve	DFO - Science, Ontario and Prairie Region
Giard, Samuel	DFO - Science, Quebec Region
Gosselin, Jean-François	DFO - Science, Quebec Region
Goulet, Pierre	DFO - Science, Newfoundland Labrador Region
Guldborg Hansen, Rikke	Greenland Institute of Natural Resources
Hamilton, Charmain	DFO - Science, Newfoundland Labrador Region
Hammill, Mike	Emeritus; DFO - Science, Quebec Region
Harvey, Valérie	DFO - Science, Quebec Region
Irani, Alymuhammad	DFO - Science, Quebec Region
Khan, Sarah	Nunavik Marine Region Wildlife Board (NMRWB)
Lang, Shelley	DFO - Science, Newfoundland Labrador Region
Lapointe St-Pierre, Mathilde	Makivik Inc
Le Mer, Charline	DFO - SARA Program, Quebec Region
Lesage, Véronique	DFO - Science, Quebec Region
Lidgard, Damian	DFO - Science, Maritimes Region
MacConnachie, Sean	DFO - Science, Pacific Region
Majewski, Sheena	DFO - Science, Pacific Region
Matthews, Cory	DFO - Science, Ontario and Prairie Region
Mosnier, Arnaud	DFO - Science, Quebec Region
Nanayakkara, Lushani	DFO - CSAS, National Capital Region
Nordstrom, Chad	DFO - Science, Pacific Region
Pellerin, Mathieu	DFO - Resource Management, Quebec Region
Provencher St-Pierre, Anne	DFO - Science, Quebec Region
Rioux, Ève	DFO - Science, Quebec Region
Sauvé, Caroline	DFO - Science, Quebec Region
Sawatsky, Chantelle	DFO - Science, Ontario and Prairie Region
Setterington, Lisa	DFO - CSAS, National Capital Region
Simard, Yvan	DFO - Science, Quebec Region
Smith, Heather	DFO - Science, National Capital Region
Tucker, Strahan	DFO - Science, Pacific Region

Name	Affiliation
Van de Walle, Joannie	DFO - Science, Quebec Region
Watt, Cortney	DFO - Science, Ontario and Prairie Region
Wright, Andrew	DFO - Science, Arctic Region
Wright, Brianna	DFO - Science, Pacific Region
Yurkowski, Dave	DFO - Science, Ontario and Prairie Region