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Harbor Porpoise and Beluga Whale Habitat Use in the Saguenay-St. Lawrence Marine Park (Canada) Revealed by a Combination of Visual and Acoustic Survey

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ABSTRACT

Studying habitat use of cetaceans that spend most of their lives underwater poses challenges, prompting the use of complementary methods. Non-invasive methods, land-based surveys (LBS) and passive acoustic monitoring (PAM), were used to characterize occurrence patterns of beluga whales, harbor porpoises, and vessels in the Saguenay–St. Lawrence Marine Park. Between 2020 and 2023, LBS totaled 512 h, while PAM recorded 1591 h in 2023, with 78 h concurrent. LBS results indicate a high occurrence of porpoises and whales (43.3%) and vessels (76.2%), and the presence of calves for both cetacean species. PAM indicates regular use of the area with higher occurrence during periods of reduced vessel traffic (e.g., 2020 for belugas and nighttime for both). During concurrent periods, PAM detections of belugas and porpoises were higher (2.8 and 1.5 times respectively). However, PAM performance was constrained for belugas as their communication band was susceptible to vessel masking. While LBS were limited by weather, they provided supplementary data including detection range, group composition, relative abundance and activity. Combined, the methods improved detection and offset individual limitations. Results support including this portion of the estuary within the beluga critical habitat while highlighting its importance for harbor porpoise foraging and mother-calf pairs.

1 | Introduction

For thousands of years, marine mammals have been studied (Würsig et al. 2018) initially relying on visual monitoring from shore and eventually expanding to other types of platforms such as vessels, airplanes, drones, and satellites (Nowacek et al. 2016; Piwetz et al. 2018; Würsig et al. 2018). Given that sound travels significantly faster and especially farther in water than in air (Zimmer 2011) and plays a critical role in communication, feeding, and other important activities of numerous marine mammals (Clausen et al. 2011; Sørensen et al. 2018), acoustic monitoring emerged (Schevill and Lawrence 1949) to complement and enhance visual surveys. Despite numerous studies,

the ecology of many cetacean populations remains poorly understood, partly because these animals spend more than 80% of their time below the water surface and often occupy areas that are difficult to access, limiting the availability of data needed to guide effective conservation measures (Braulik et al. 2017; Nelms et al. 2021; Parsons et al. 2015).

From a conservation perspective, acquiring knowledge on marine mammals must be balanced with minimizing disturbance at individual, population, and ecosystem levels to ensure ethically responsible monitoring (Gales et al. 2009). Land-based surveys (LBS) support this objective by avoiding direct interaction with animals while providing valuable insights into behavioral

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ecology (Morete et al. 2018). LBS enable the study of occurrence patterns (Cornick and Kendall 2008; Dolman et al. 2014), behavioral ecology (Anderson et al. 2017; Roberts et al. 2019), habitat use (Cornick et al. 2011; Jones et al. 2014), and effects of anthropogenic activities (Krasnova et al. 2020; Oakley et al. 2017), all with limited disturbance and lower organizational constraints and costs, especially when compared to aerial or boat-based surveys (Cole and Vidal 2024; Piwetz et al. 2018). However, these surveys are restricted to small, mainly coastal areas (Castelblanco-Martínez et al. 2019; Morete et al. 2018), and are sensitive to weather and visibility conditions (Cole and Vidal 2024; Giacoma et al. 2013).

Passive Acoustic Monitoring (PAM) allows the study of cetaceans even when they are not visible at the surface (Sousa-Lima et al. 2013). This approach provides valuable insights into the occurrence (Holdman et al. 2019; Lammers et al. 2013), behavior (Panova et al. 2012; Todd et al. 2022), habitat use (Castellote et al. 2020; Simon et al. 2010), and on the effect of potential threats (Benhemma-Le Gall et al. 2021; Castellote et al. 2018). It also enables long-term monitoring of marine mammals in conditions where visual surveys are challenging (Cole and Vidal 2024; Wood 2010; Zimmer 2011). However, PAM performance can be affected by environmental (Erbe, Verma, et al. 2015) and anthropogenic noise (Erbe et al. 2016; Gabriele et al. 2018; Mérindol et al. 2024), which can mask signals or alter animal behavior (Erbe et al. 2016; Ross et al. 2023; Zimmer 2011). Another limitation is that only vocalizing species can be detected (Browning

et al. 2017), and vocal activity varies by species, behavior, group composition, season, and other factors (Mellinger et al. 2007; Tyack 2017; Zimmer 2011).

This study evaluates the efficiency of LBS and PAM for characterizing occurrence patterns and habitat use of the St. Lawrence Estuary (SLE) beluga whale (*Delphinapterus leucas*) and harbor porpoise (*Phocoena phocaena*) in the lower Estuary portion of the Saguenay–St. Lawrence Marine Park (SSLMP), in Quebec, Canada. The SSLMP was established primarily to conserve the SLE beluga, the southernmost population of belugas worldwide (Lesage 2021). This endangered population is protected (Species at Risk Act, 2002) and faces several threats, including chronic exposure to vessel traffic, noise, and chemical pollution, as well as a decline in prey quality and availability (DFO 2012; DFO 2020). The SSLMP lies at the core of the belugas' summer distribution and encompasses 37% of their summer critical habitat (Ménard et al. 2022) (Figure 1). The study area was left outside of their summer critical habitat, as the adoption definition targeted areas used by mother and calves (Mosnier et al. 2016). The area is well known to be used by herds of males (Lemieux-Lefebvre et al. 2012) but lacks systematic monitoring. The SLE beluga distribution varies seasonally, and habitat use can vary based on sex, age, and community segregation (Bonnell et al. 2022; Lesage et al. 2024; Simard et al. 2023). High-residency or high concentration areas have been identified in several places within their summer range (Lemieux-Lefebvre et al. 2012; Lesage et al. 2024; Mosnier

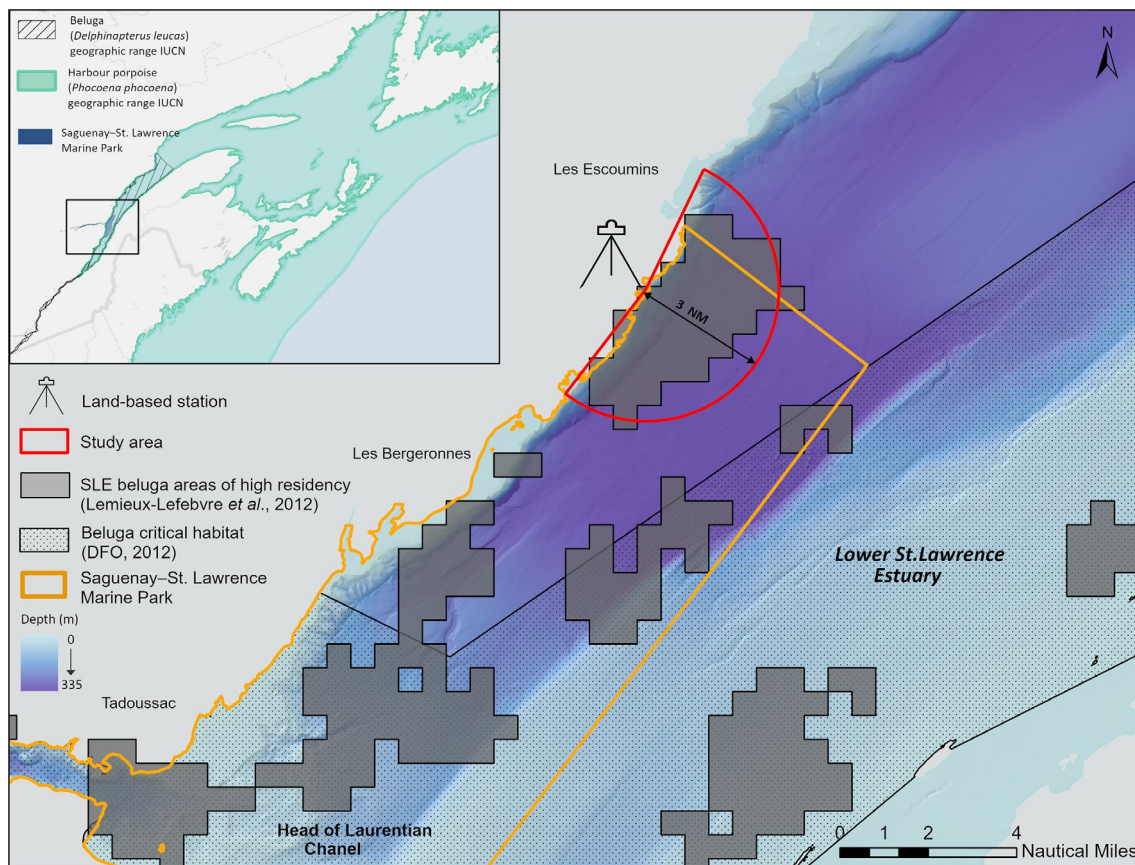


FIGURE 1 | Geographic range of belugas and harbor porpoises in Eastern Canada (inset map). Limits for the Marine Park (yellow box), high residency areas (gray shaded areas) and summer critical habitat (dotted area) identified for beluga whales are also presented, along with, the observation site and study area (red).

et al. 2016) (Figure 1), one of which lies in the study area, which is also within the transit corridors described for the population (Ouellet et al. 2021). Belugas are highly vocal and produce a broad repertoire of medium to high frequency vocalizations—clicks, whistles, buzzes, and growls (Faucher 1989; Garland et al. 2015; Sjøre and Smith 1986b)—making PAM an effective tool for studying this population.

Harbor porpoises (*Phocoena phocoena*) observed in the SLE belong to the Northwest Atlantic population, listed as of special concern (Government of Canada 2002). Porpoises occur in the SLE during the ice-free season and typically forage in continental shelf waters (COSEWIC 2022; Hammond et al. 2008; Lacroix-Lepage 2018). Among the three subpopulations, the Gulf of St. Lawrence subpopulation is the one that visits the SLE and is thought to reach Saint-Siméon (~65 km west of the study area) during summer, although the exact extent of its habitat and its patterns of use remain poorly understood (COSEWIC 2022; Lesage et al. 2007). To our knowledge, this is the first study to target harbor porpoise in the SLE. Harbor porpoises use echolocation for navigation and prey detection (Au and Hastings 2008), and their vocal repertoire relies exclusively on ultrasonic echolocation clicks (Goodson and Sturtivant 1996).

This study aimed to improve understanding of habitat use and the potential effects of vessel traffic on these species in the SLE while highlighting the strengths, limitations, and practical applications of each method to guide future studies. We also assessed the degree of bias introduced by PAM analyst on detection rates.

2 | Methods

2.1 | Study Area and Period

LBS and PAM were carried out from the Marine Environment Discovery Center, a Parks Canada site, located at the northeastern point of Anse-aux-Basques, Les Escoumins (N48° 19' 10.4640"; W69° 24' 46.6497", 18.45 m above mean sea level) (Figure 1). A hydrophone was moored 50 m from the shore and at a depth of approximately 34 m at low tide, 3 m off the sea floor. The study area is characterized by a steep cliff with depths reaching up to 300 m very close to shore. Upwelling creates strong vertical mixing that decreases temperature and increases salinity in surface waters (Galbraith et al. 2023). Surface water temperature is around 5°C–6°C during summer at the head of the Laurentian Channel (Galbraith et al. 2023) and with a mean surface salinity that varies around 30 PSU based on data acquired by Parks Canada. LBS were performed from June through September of 2020–2023, whereas PAM were conducted over a period of 2 months, from early August to early October 2023.

2.2 | Land-Based Surveys

LBS were conducted using Bushnell 7×50 reticulated binoculars mounted on a fixed-position tripod and adjusted daily using angle and reticule of visual landmarks established at the beginning of each season and calibrated annually with a boat. Data were collected following a survey protocol (Mann 1999; Morete

et al. 2018), and the predominant activity sampling method was used to characterize the behavior of marine mammals and marine traffic. A survey was defined as a 10-min period, referred to as observation block (OB), during which all elements in the field of view were noted and positioned with the binoculars. OBs, punctuated by pauses, were repeated over 1–2-h periods, each followed by a 30 min to 1 h break to reduce bias associated with observer fatigue (Morete et al. 2018; Verfuss et al. 2018). Daily sampling did not exceed 5.5 h of active monitoring. Each vessel and each group of marine mammals observed within an OB was given an observation number and was characterized by several variables depending on their type.

Sampling-related data included temporal variables (date, time), environmental variables (wind speed—Beaufort scale and visibility) (Appendix A), vessel-related variables (type, activity) (Appendix A), and marine mammal related variables (species, minimum and maximum group/herd size, activity, group composition) (Appendix A). Predominant activities recorded were transiting, feeding/foraging, resting, and socializing as defined by Martins (2019) and Martins and Bernier-Breton (2020) (see example at Bernier-Breton 2024). A group was defined as individuals exhibiting similar behavior and being within four body lengths of each other. An animal swimming alone constituted a group of a single individual. Belugas classified as calves were individuals born the same summer or yearlings and could be recognized by their small size, dark gray skin, and close association with one or more adults (McGuire et al. 2020). Harbor porpoise calves were identified as animals no more than half the size of adults and observed in proximity to an adult (Bjorge and Tolley 2009).

2.3 | Passive Acoustic Monitoring

An acoustic recorder, *Soundtrap* ST600HF, recorded continuously from August 4 to October 10, 2023, at a sampling frequency of 384 kHz to ensure the detection of ultrasonic harbor porpoise clicks (Sørensen et al. 2018; Todd et al. 2022). The end-to-end sensitivity was 175.6 dB, as factory calibrated by the manufacturer. No high-pass filter was used to preserve our ability to measure broadband ambient noise. Recordings were stored as 5-min files and were processed manually. Automated detection of harbor porpoise clicks was explored using PAMGuard (version 2.02.17) (Gillespie et al. 2008). Both the default porpoise detector settings and parameter settings previously validated in a comparable study were tested (Findlay 2022).

Belugas produce a wide range of sounds, including social calls between approximately 1 and 12 kHz (Figure 2b) and echolocation clicks between 20 and 40 kHz (Figure 2a) (Lammers et al. 2013). In general, a beluga individual produces approximately 1 to 10 vocalizations per minute, although this number may vary depending on factors such as group composition, anthropogenic disturbance, and ongoing activity, which also influences the types of vocalizations used (Castellote et al. 2022; Chmelnitsky 2010; Halteman and Ryan 2019; Lesage et al. 1999; Panova et al. 2012). Harbor porpoises emit between 20 and several 100 clicks per second at frequencies centered around 130 and 160 kHz (Figure 2a) (Clausen et al. 2011; Goodson and Sturtivant 1996; Teilmann et al. 2002). Vessels were identified

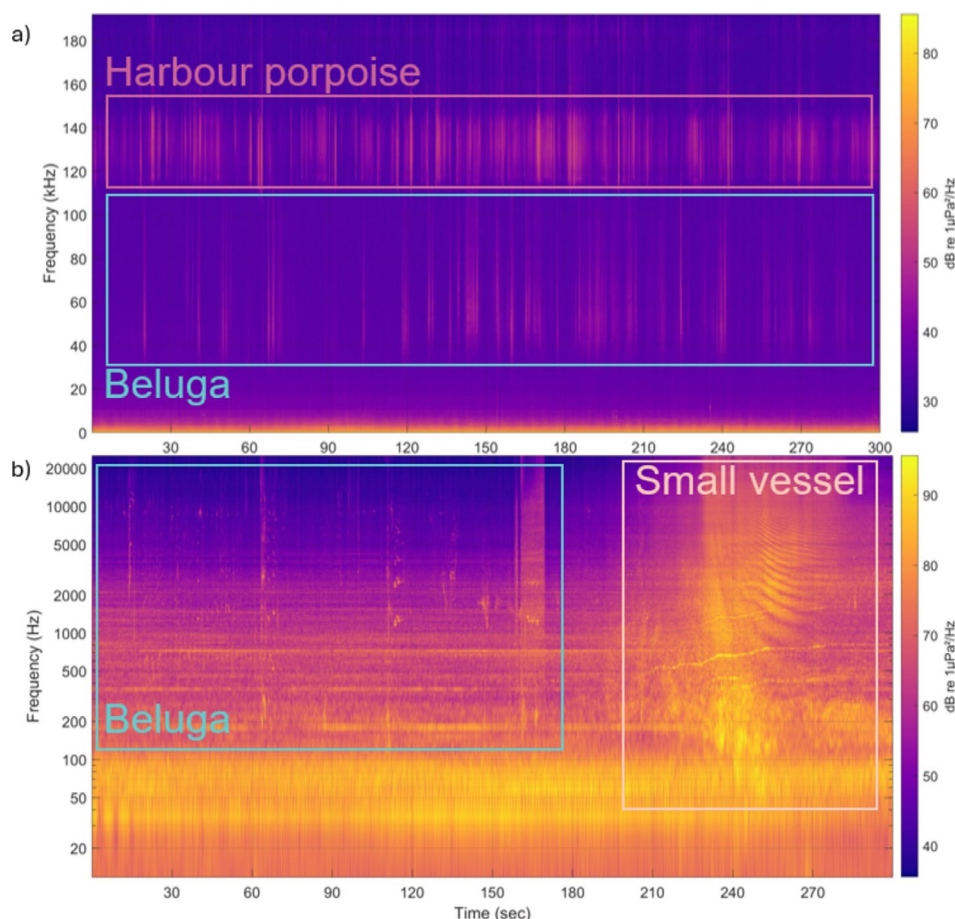


FIGURE 2 | Spectrograms with detections of (a) beluga and harbor porpoise clicks and (b) beluga vocalizations and small vessel passage.

by their high noise levels, reaching hundreds of decibels at the source, and covering a wide range of frequencies from a few hertz to over 100 kHz. This noise can vary significantly depending on various characteristics of the boat and the environment (Figure 2b) (Erbe et al. 2019) (Figure 2).

Two spectrograms were created for each file, with parameters specifically optimized for detection of beluga and porpoise clicks (11 ms Hann window, 50% overlap, linear 10–200,000 Hz frequency scale) (Figure 2a), and detection of beluga whistle and vessel noise (85 ms Hann window, 50% overlap, logarithmic 10–20,000 Hz scale) using Matlab (The MathWorks Inc 2022) (Figure 2b). Spectrograms were visually inspected and annotated using Adobe Bridge software (Adobe Inc. 2022), for presence of belugas, porpoises, and/or vessels, with the opportunity to audio-visually inspect the files using Audacity (Version 3.4.2) (Audacity Team 2024) when needed. Annotations were later extracted using a Python code (Python Software Foundation 2023) to create a document containing all files and their respective detections.

To assess potential biases associated with PAM data analysis, 1500 of the annotated files were randomly selected and annotated by an independent analyst who applied the same protocol for the detection of belugas, porpoises, and vessels.

For PAM observations, environmental data such as wind (wind intensity at 10 m above ground in knots), surface current velocity (in km/h), precipitation (in mm per h), and cloud cover

(in %) were downloaded from the Open-Meteo weather API (Zippenfenig 2023) and extracted for the weather station of Les Escoumins. These were then categorized similarly to our visual protocol (Appendix A).

2.4 | Data Analysis

Periods when LBS and PAM were conducted simultaneously were extracted to compare detection rates among methods. Detection agreement and discordance among visual, acoustic, and combined approaches (i.e., addition of visual and acoustic detections) for belugas, harbor porpoises, and vessels were assessed using McNemar's tests (McNemar 1947) implemented using the *stats* package (R Core Team 2024). This test is appropriate for paired binary data and was used to determine whether detection proportions differed significantly between methods (McNemar 1947; Pembury Smith and Ruxton 2020). Contingency tables were constructed to summarize detection combinations (visual only, acoustic only, both, or neither), and the proportion of observation blocks in each category was used to quantify method discordance.

The same statistical approach (McNemar's test) was also applied to assess potentially significant discordances in detections between PAM analysts. In addition, the strength of agreement between analysts was assessed using Cohen's Kappa coefficients extracted from the 1500 files read in duplicate ("caret"

R package, Kuhn 2008), which were interpreted following the categories defined by Landis and Koch (1977).

Daily detection rates for belugas, porpoises, and vessels were also estimated for each method as the percentage of sampling time in a day with beluga, porpoise, or vessel presence. Daily detection rates were compared between visual, acoustic, and combined methods using a Kruskal-Wallis test. Non-parametric variance analyses were used here since non-normality in the distribution of daily detection rates was noted for belugas, porpoises, and vessels (Shapiro-Wilk tests; p -value of 0.02, 0.003, and <0.001 , respectively), while homogeneity of variance was respected for the three elements studied (Levene's test, all $p > 0.05$), and independence of observations was met since there was no temporal dependence between days in the sampling method (Ostertagová et al. 2014; Stahle and Wold 1989). Post hoc Dunn tests with Bonferroni correction were conducted using the “FSA” R package (Ogle et al. 2023) to evaluate where the differences were between the methods (Dinno 2015).

Sound pressure levels were extracted for three frequency bands corresponding to beluga whistles (0.6–15 kHz), beluga clicks (25–80 kHz), and porpoise clicks (110–150 kHz) (Clausen et al. 2011; Lammers et al. 2013) with a 1-s window. Sound pressure levels were summarized using the 75th percentile for each recording to reduce the influence of transient extreme values while focusing on elevated sound levels. The influence of biological and anthropogenic factors on sound pressure levels was analyzed using linear mixed-effects models. Marine mammal (beluga or harbor porpoise) and vessel presence were included as fixed effects in their corresponding frequency bands, while date was included as a random intercept to account for temporal non-independence among recordings collected on the same day. Separate models were fitted for each frequency band using the “lme4” package (Bates et al. 2015). Model assumptions were assessed visually using residual diagnostics. The statistical significance of fixed effects was assessed using likelihood ratio tests comparing nested models fitted with maximum likelihood (Bolker et al. 2009). Effect sizes were reported with 95% confidence intervals, calculated using Wald approximation (Bolker et al. 2009).

To estimate the limits of detection probabilities for each method, the entire visual (2020–2023) and acoustic datasets (2023) were used. Because multiple observations were likely non-independent within the same hour, generalized linear mixed models were fitted, for each species and methods, using the “glmer” function of the “lme4” package (Bates et al. 2015) including sampling hour (date $\times$ hour) as a random intercept to assess detection probability. Model comparison strongly supported the mixed-effects models over simple GLMs (Δ AIC between 492 and 5434) (Bozdogan 1987), and the random effect variance indicated substantial temporal clustering. Binomial error distribution was used to account for the binary nature of the dependent variable (presence or absence) (Zuur et al. 2009). Model diagnostics indicated no evidence of overdispersion (dispersion between 0.90 and 0.99). Although odds ratios were initially computed, results were ultimately interpreted using predicted detection probabilities derived from estimated marginal means on the response

scale, calculated with the “emmeans” package (Lenth and Piaskowski 2025). For categorical predictors, reference levels were selected based on median observational conditions. For continuous predictors, predicted probabilities were evaluated at the 10th and 90th percentiles to facilitate interpretation of effect magnitude under contrasting environmental conditions. The distance from the observer to each visual observation was obtained using an R function that implemented Lerczak and Hobbs (1998) to convert binoculars angle and reticule in latitude and longitude. All above mentioned analyses were performed with R 4.4.1 (R Core Team 2024), and results were considered significant when $\alpha < 0.05$. The graphs were created using the “ggplot2” package (Wickham 2016).

3 | Results

3.1 | Land-Based Surveys

LBS totaled 512.17 h of observation in 2020–2023 and 984 observations of belugas, 2703 of harbor porpoises, and 3678 passages of boats in 2340 different OBs were recorded. Overall, during LBS belugas, harbor porpoises, and boats were detected 18.5%, 43.3%, and 76.2% of the observation time, respectively. Approximately 1.07 ± 4.06 belugas were observed per BO and 3.41 ± 7.99 porpoises, with a maximum of 55 and 168 respectively. In 2020, belugas exhibited the highest presence rate and the highest number of individuals per OBs, coinciding with the lowest rate of vessel presence (Table 1). However, highest presence of calves for this species was recorded in 2023 (Table 1). In contrast, harbor porpoises showed their highest presence rate, the greatest number of groups with calves, and the highest number of individuals detected per OBs in 2022, with up to 168 individuals observed within a 10-min period (Table 1).

When belugas were visually present, they spent an average of 84.1% of their time traveling, 11.7% foraging, 3.5% resting, and 1.1% socializing, while harbor porpoises allocated approximately 72.8%, 18.6%, and 4.6% of their time to these activities, respectively (socializing was not noted for this species) and 3.9% doing indeterminate activities. Although various types of vessels spent over 50% of their time in motion, LBS allowed for capturing their activities when they were not moving, which is hard to do with acoustic or AIS data only. It showed that excursion boats, the most detected type of vessels, and human-powered vessels were the two types that spent more time observing marine mammals (25.9% and 24.6% respectively) (Figure 3).

According to the visual survey, the farthest group of belugas detected was at 5.4 km from the observation point, while it was 3.9 km for harbor porpoises (Figure 4). However, over 95% of porpoise observations were made at less than 1.6 km, and less than 2.6 km for belugas (Figure 4).

3.2 | Passive Acoustic Monitoring

PAM totaled 1591 h of recording, with 18,488 five-minute files analyzed. Belugas, harbor porpoises, and vessels were detected 49%, 71%, and 67% of the time, respectively. The acoustic detection rate was higher for both studied species between 19:30 and

TABLE 1 | Information collected during 4 years (2020–2023) of land-based surveys about presence, abundance, and group composition for belugas, harbor porpoises, and boats. OB indicates observation block.

Years		2020	2021	2022	2023
Total OBs		547	650	883	993
Belugas	Presence (%)	23.8	18.6	15.9	17.8
	% of OBs w/calves	0.2	0.5	0.7	1.3
	Individuals/OB (mean $\pm$ sd (max))	2.64 $\pm$ 7.53 (55)	0.85 $\pm$ 3.03 (37)	0.88 $\pm$ 3.06 (27)	0.98 $\pm$ 3.28 (27)
Harbor porpoises	Presence (%)	39.1	25.5	58.0	44.0
	% of OBs w/calves	1.1	13.9	21.1	5.1
	Individuals/OB (mean $\pm$ sd (max))	3.89 $\pm$ 9.98 (104)	2.23 $\pm$ 5.37 (41)	5.86 $\pm$ 11.5 (168)	1.66 $\pm$ 3.15 (43)
Boats	Presence (%)	70.2	74.5	79.2	78.0
	Number/OB (mean $\pm$ sd (max))	2.04 $\pm$ 2.12 (9)	1.85 $\pm$ 1.70 (8)	2.14 $\pm$ 1.79 (13)	2.27 $\pm$ 2.04 (12)

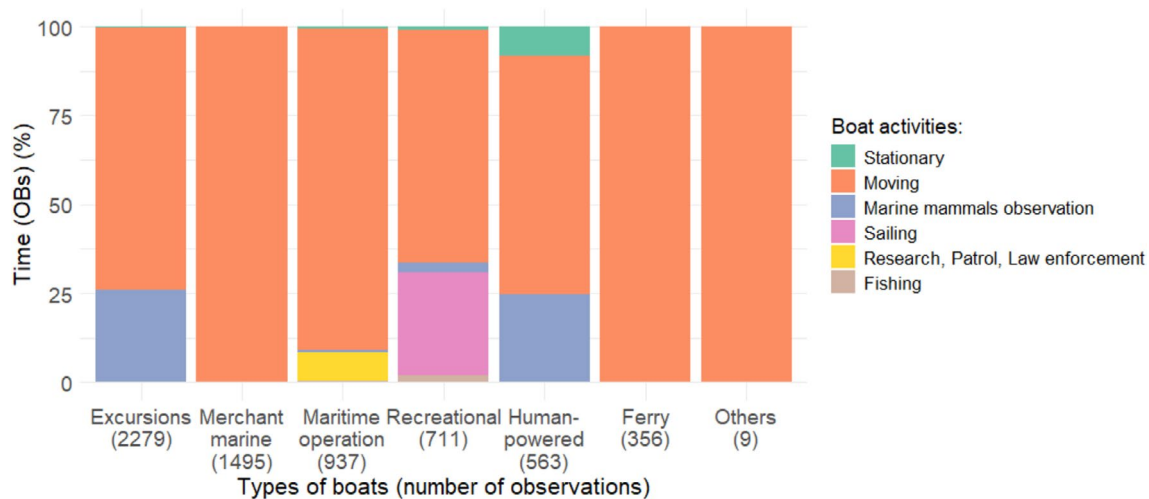


FIGURE 3 | Types of boats recorded and percentage of time (expressed in number of observation blocks) spent in the different activities.

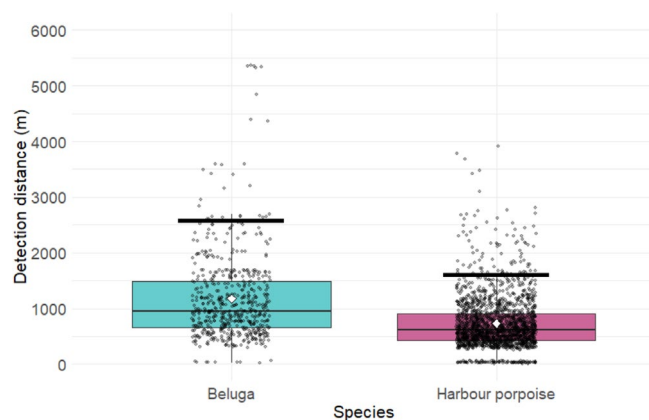


FIGURE 4 | Distance between observer and species of marine mammals. Boxplot shows median, quartiles, mean (diamond) and quantile 95 (bold black line).

6:30 local time (UTC –4) (83.2% for porpoises and 54.5% for belugas), while it was lower for boats for the same period (58.6%) (Figure 5). Beluga detections peaked between 03:00 and 07:00, with a detection rate of 68.8%.

Sound pressure levels across all three frequency bands of interest were significantly affected by the presence of cetaceans and vessels (Table 2). In the frequency band of beluga whistles, vessel presence was associated with a substantial increase of almost 10 dB re 1 μ Pa, whereas beluga presence was associated with a decrease in sound pressure level (Table 2). This indicates the major contribution of anthropogenic noise in this frequency band. Similar patterns were observed in the beluga clicks frequency band, although the effects were less pronounced. In the harbor porpoise frequency band, sound pressure levels were primarily driven by biological sources, with anthropogenic contributions being considerably weaker than in the other bands (Table 2).

3.3 | Comparison of Detection Rates

Approximately 78 h distributed between 6:30 and 19:30 over the course of 28 days of simultaneous LBS and PAM sampling were available for analysis, during which belugas were detected for 50 h, porpoises for 56.2 h, and boats for 73.5 h. PAM had 2.8 times more detections than LBS for belugas and 1.5 times for harbor porpoises (Table 3). Detections from LBS only represent

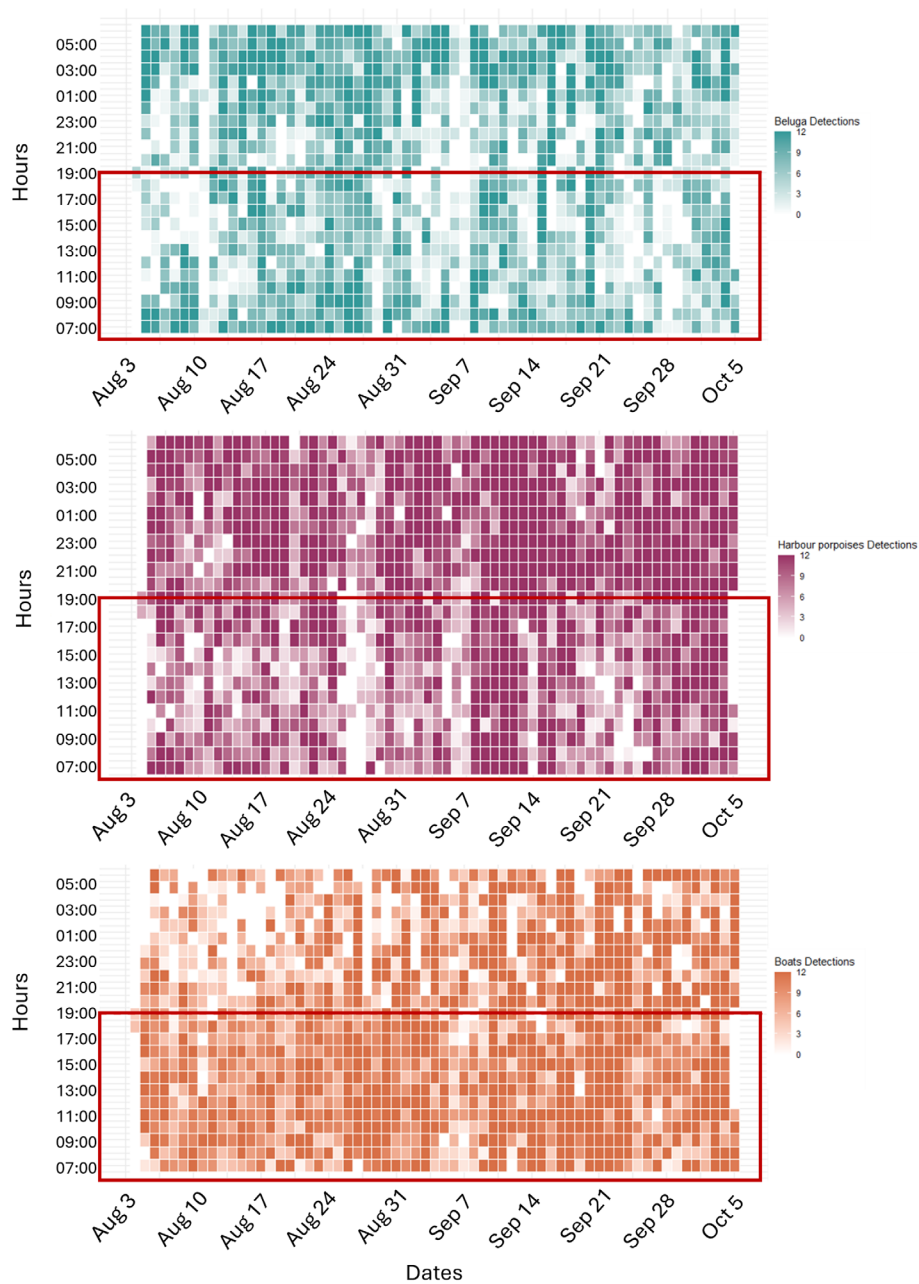


FIGURE 5 | Number of files with detections of belugas, harbor porpoises and vessels per hour for each day and hour of recordings. The red rectangle indicating the theoretical range of land-based surveys (conducted during daylight between 7:00 and 19:30).

TABLE 2 | Effects of cetacean and vessel presence on mean ambient sound pressure level (dB re 1μPa) based on the 75th percentile across three frequency bands of interest. Results from linear mixed-effects models, showing estimates, 95% confidence intervals, and likelihood ratio test.

Frequency bands	Predictor presence	Estimate (β , dB re 1 μ pa)	95% CI	χ^2 (LRT)
Beluga whistles (0.6–15 kHz)	Beluga	−5.4	[−5.7; −5.2]	1604.23
	Vessel	+9.5	[9.3; 9.8]	4015.19
Beluga clicks (25–80 kHz)	Beluga	−2.0	[−2.2; −1.7]	314.26
	Vessel	+3.9	[3.7; 4.1]	1059.30
Porpoise clicks (110–150 kHz)	Porpoise	+2.7	[2.5; 2.8]	815.41
	Vessel	+1.0	[0.8; 1.2]	130.92

TABLE 3 | Contingency of detections (absence/presence) between LBS and PAM for belugas, harbor porpoises, and boats as well as combined method.

	LBS	PAM		Combined
		Absence	Presence	
Belugas	Absence	170	202	170
	Presence	19	79	300
Harbor porpoises	Absence	133	130	133
	Presence	30	177	337
Boats	Absence	29	51	29
	Presence	34	356	441

less than 10% of the total observations for both species and boats. However, combining the two methods ensures a higher detection rate, with species being completely absent only 36.2% of the time for belugas and 28.3% for porpoises (Table 3). For vessels detection, LBS provides a detection rate almost as high as PAM, and vessels were completely absent only about 6% of the time (Table 3). Significant differences were observed among the PAM, LBS, and combined methods to detect belugas, porpoises, and vessels (McNemar's tests; all $p > 0.0001$), suggesting they do not detect these elements consistently (Table 3). The largest discrepancies were noted for belugas and harbor porpoises between LBS and PAM methods (belugas $\chi^2(1) = 149.88$; harbor porpoises $\chi^2(1) = 61.26$) as well as between LBS and combined methods (belugas $\chi^2(1) = 200.00$; harbor porpoises $\chi^2(1) = 128.01$). The smallest discrepancies were noted between LBS and PAM detections of vessels ($\chi^2(1) = 10.39$). Daily detection rates also differed significantly across methods (Kruskal-Wallis' tests, belugas: $\chi^2(2) = 31.16$, $p < 0.001$; harbor porpoises: $\chi^2(2) = 16.42$, $p < 0.001$; boats: $\chi^2(2) = 10.39$, $p = 0.006$) (Table 2). Post hoc comparisons using Dunn's test confirmed that for belugas ($Z = -5.04$ and -4.60 , respectively; adjusted $p < 0.001$), harbor porpoises ($Z = -3.83$ and -3.06 , adjusted $p = 0.007$ and < 0.001), and vessels ($Z = -3.13$ and -0.90 , adjusted $p = 0.005$ and 1), PAM and combined methods detected significantly more daily presences than LBS.

3.4 | Detection Limits

Generalized linear mixed models with binomial regression support the hypothesis that environmental and anthropogenic variables can limit the detection rate for both methods (Table 4). The models comparing the presence/absence of the species based on weather-related conditions and vessel activity show significant effects on detection probability.

Both LBS and PAM detections were affected by strong wind conditions, but the magnitude of the effect differed between methods and species. For belugas, LBS detections decreased by approximately 50% and 67% at Beaufort 3 and 4 respectively, whereas PAM detection dropped only by 17% at Beaufort 3 but by 74% at Beaufort > 4 . This indicates that LBS detections are generally more sensitive to wind conditions, whereas acoustic detections are more strongly affected under severe sea-state conditions. In

contrast to LBS detections, PAM detections of harbor porpoises did not decrease with increasing wind speed. While LBS detection decreased by 67% and 76% at Beaufort 3 and higher than 4, PAM detections remained stable or slightly increased (+3% at Beaufort 3 and +7% at Beaufort > 4). Horizontal visibility also influenced LBS detections. For harbor porpoises, visual detection probabilities were negatively affected at moderate visibility (< 2 nm: -60%) while severe visibility reduction led to a marked decrease for both species. Strong precipitation (> 1 mm/h) reduced PAM detection probability of belugas by more than 60% but had little to no influence on porpoises. At high current velocity (90th percentile), harbor porpoise detections were not affected, whereas PAM detection probability of belugas was 41% lower compared to low current conditions (10th percentile). Vessel presence significantly reduced PAM detection probability for both species, with a substantially stronger effect for belugas (-66%) than for harbor porpoises (-9%). LBS detections of belugas were also reduced (-44%) in the presence of vessels, while harbor porpoises LBS detections increased (+17%) (Table 4).

3.5 | Observer Bias

Analysis of PAM detections made by the two observers ($n = 1426$) showed a significant difference in beluga and vessel detection (McNemar's test; belugas: $\chi^2(1) = 121.59$, $p < 0.001$; boats: $\chi^2(1) = 290.76$, $p < 0.001$). However, the Kappa coefficient indicates moderate agreement for belugas (Kappa = 0.48) and minimal agreement for vessels (Kappa = 0.04), indicating that the agreement between observers was only 4% better than random expectation (Landis and Koch 1977). Specifically, for belugas, the second observer recorded 638 presences that matched the main observer's detection, while missing 278 and finding 71 more detections missed by the main observer. For vessels, 910 detections matched between observers, but 393 detections recorded by the main observer were not detected by the second one. The two acoustic observers, however, similarly detected the presence of harbor porpoises (McNemar's test; $\chi^2(1) = 0.94$, p -value = 0.33) with substantial agreement (Kappa = 0.83). Both observers recorded 983 detections that were matching while only 38 were discordant, showing a high level of consistency between observers for this species.

4 | Discussion

This is the first systematic characterization of the occurrence patterns of belugas and harbor porpoises in the downstream portion of the Marine Park. Moreover, it provides the first detailed characterization of vessel occurrence while exploring its effects on the target species. Gathered results contribute to the knowledge of an important sector of this Marine Protected Area (MPA) and its long-term monitoring, while providing essential evidence-based information to guide adaptive management.

4.1 | Habitat Use

This study presented the first results (2020–2023) of the systematic LBS implemented by Parks Canada aiming to monitor marine mammals and marine traffic habitat use patterns in an

TABLE 4 | Predicted effects of environmental and anthropogenic variables on LBS and PAM detection probabilities of belugas and harbor porpoises derived from generalized linear mixed models. Values represent predicted relative detection probabilities (odd ratios) compared to the reference category (value = 1.00) and significance levels are indicated as: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, • $p < 0.1$, no asterisk $p > 0.1$.

Methods	Variables	Categories	Beluga	Harbor porpoise
LBS	Wind speed (Beaufort scale)	None	2.90	4.49***
		1	1.57	2.80***
		2	1.00	1.00
		3	0.50•	0.33***
		> 4	0.34•	0.25***
	Visibility (nautical miles)	None	0.0005*	0.002***
		< 1 nm	0.19	0.55
		< 2 nm	1.55	0.40**
		< 3 nm	0.95	0.74
		> 4 nm	1.00	1.00
PAM	Vessel	Presence	0.56*	1.17
		Absence	1.00	1.00
	Wind speed (Beaufort scale)	None	0.89	0.91
		1	0.85•	0.97
		2	1.00	1.00
		3	0.83*	1.03**
		> 4	0.26***	1.07*
	Precipitation	None	1.00	1.00
		Weak (< 1 mm/h)	0.90	0.96
		Strong (> 1 mm/h)	0.36***	1.02
	Vessel	Presence	0.34***	0.91***
		Absence	1.00	1.00
	Current velocity	q10	1.00	1.00
		q90	0.59***	0.99

important hotspot of this MPA. LBS results indicate a high occurrence of porpoises (43.3%) and vessels (76.2%) in this coastal area of the Lower SLE. Beluga whales were regularly observed (including groups with calves) with rates that varied between seasons (overall 1.07 ± 4.06 individuals by OB; max = 55). It is known that the study area is an important transit corridor for belugas (Ouellet et al. 2021), but the present study allowed confirming the presence of calves and the use of this area for foraging activities. Harbor porpoises were very frequent, present in higher numbers (overall 3.41 ± 7.99 individuals by OB; max = 168), and had a high percentage of calf presence. This is the first study on harbor porpoise's habitat use in the SLE, and although restricted to a small area, the results demonstrate a high frequency of foraging activities and of females with calves of this species considered of concern. Interestingly, harbor porpoises' higher numbers of individuals and calves in 2022 coincides with a higher mortality rate in the estuary for this same year, almost four times higher than the average for 2012 to 2021 (Lair et al. 2023).

LBS allowed collecting information not captured by PAM surveys, such as count, location, activity budget, and group composition for both species. Such information is essential to improve our knowledge about these species' habitat use patterns, as a baseline for monitoring purposes and to guide management. The study area is within an important touristic destination and is known to present a high density of vessels (Ménard et al. 2022; Turgeon 2019); nevertheless, this is the first time that vessel occurrence is characterized to this level (number of boats by OB during the summer months) at this spatial scale and for a variety of boat types, including vessels without automatic identification system. LBS survey began in 2020, and the information has already been used to guide warden patrols in this portion of the Marine Park and to improve awareness campaigns mainly targeting recreational boats (commercial and private), and human-power activities that were often observed still, probably to maximize encounters with marine mammals.

It is known that land-based platforms provide an ideal framework for studying behavioral ecology while minimizing disturbance (Morete et al. 2018). However, to date, few studies have explored its use to characterize vessel occurrence and their co-occurrence with marine mammals for management purposes. Here, a higher number of belugas per OB was observed in 2020. It is possible that the delayed beginning of the touristic season and the reduced number of vessel passages in 2020 due to the COVID-19 pandemic have a relationship with the higher presence of belugas closer to the shore, an effect observed in other species of marine mammals elsewhere (e.g., Fernández et al. 2024; Israngkura 2022; Qiu et al. 2025). However, such an analysis was beyond the scope of this article and would not have been possible due to a lack of prior data.

Although limited to a single season, PAM data allowed for continuous observation, including nighttime and poor weather conditions. Results indicate regular use by both species with higher occurrence during periods of reduced vessel traffic (e.g., 2020 for belugas and nighttime for both), an important insight for understanding their habitat use. Several acoustic studies have examined diel patterns of beluga presence (Booy et al. 2021; Coppolaro et al. 2024; Giard et al. 2020; Meirelles et al. *in review*), with variable results, some of which—like the present study—have reported increased nocturnal presence (Castellote et al. 2015; Roy and Simard 2015). Higher presence at night could be explained, for example, by a decrease in anthropogenic noise of vessels (e.g., Bas et al. 2017), an increase in prey availability or an increase in echolocation clicks due to darkness increasing detection rate (Zein et al. 2019). Further studies, aiming to characterize not only occurrence patterns but activity budget based on PAM data are highly recommended to evaluate what explains the higher nocturnal presence of belugas and porpoises in this area.

Activity budgets can be derived from PAM data, but a lot of knowledge is still missing to do so from acoustic datasets alone. In harbor porpoises, as vocalizations are not highly diverse and consist exclusively of clicks, numerous studies have focused on describing click characteristics and their implications for group activities (Clausen et al. 2011; Sørensen et al. 2018; Todd et al. 2022; Wright et al. 2017). Such study is still lacking for the population visiting the SLE. Here, we have performed two essential steps required for such analysis, which consist of annotating presence data and acquiring visual behavioral data. On the other hand, while the vocal repertoire has been described for some beluga populations (e.g., Brewer et al. 2023; Chmelnitsky and Ferguson 2012; Garland et al. 2015; Sjare and Smith 1986b), few studies, generally combining visual and acoustic observations, have linked vocalizations to behavioral activities (Chmelnitsky 2010; Faucher 1989; Panova et al. 2012; Sjare and Smith 1986a). Likewise, the extent of the vocal repertoire and the vocalizations functions are still poorly understood for the SLE beluga population (Cotillard et al. 2024; Vergara 2011). The combination of both methods can be used to develop algorithms to enhance processing efficiency, result reliability, and acoustic analysis capabilities. This approach could lead to tools based on acoustics to gather information on group composition, abundance, and activities, thereby improving our understanding of habitat use.

We acknowledge that the present study represents a very small portion of the target species occurrence. However, it covers an important marine mammal habitat (e.g., Martins et al. 2022) within the Marine Park and contributes to its long-term monitoring. Systematic LBS with a similar protocol are conducted from four other stations within and around the Marine Park, and a second PAM station was put in place in 2022 in the Upper estuary. We strongly recommend that future analysis include multiple stations and an evaluation of management measures aiming to minimize acoustic and physical disturbance to marine mammals.

4.2 | Detection Efficiency

Both LBS and PAM detections were affected by environmental, anthropogenic, and physical constraints. Wind-generated waves affect LBS (Ryan et al. 2014), especially for small species like porpoises (Teilmann 2003), or white species like belugas which tend to blend in with breaking waves (Fretwell et al. 2023). Several studies limit LBS to times with low wind speed to minimize biases (e.g., Heide-Jørgensen et al. 1993; Morete et al. 2018; Piwetz et al. 2018). Our results provide evidence to limit LBS to Beaufort 2 or lower for porpoises and 3 or lower for belugas. LBS was also affected by horizontal visibility. This variable is in the data collection protocol to allow filtering the data to days with good visibility in the whole study area. As expected, detection rates were reduced under poor visibility conditions (less than 2 nm); however, no difference was observed between periods with visibility below 3 nm and those exceeding 4 nm, likely reflecting the detection range of the species. Indeed, the vast majority of LBS observations were within 2.4 km for belugas and 1.4 km for porpoises and no observation were recorded beyond 3 nm. This indicates that animals farther from shore might be missed by the observer and that this monitoring should focus on the coastal area, within 2 km, for both species to allow long-term comparison of occurrence.

Vessel presence highly influenced the probability of detecting belugas both from LBS and PAM, while to a lesser extent porpoises from PAM. PAM detection can be reduced by a modification of beluga and porpoise vocal behavior, or by acoustic masking from vessel noise (Clark et al. 2009; Erbe 2002; Erbe et al. 2019). Belugas are highly vocal in most circumstances (e.g., Sjare and Smith 1986b), so visual observations are usually accompanied by vocalizations (Schevill and Lawrence 1949). However, they can dive for more than 20 min (Martin et al. 1998), a factor which could explain why PAM detections were higher than LBS detections for this species since OBs were of only 10 min. Notwithstanding, LBS allowed for some detections of belugas that were not detected by PAM especially when sound levels were high and when belugas were further from the coast.

Distance from the coast is also a factor influencing beluga detections, but acoustic detection range can be challenging to estimate, an aspect pointed out as a knowledge gap in the field (Clausen et al. 2019; Barlow et al. 2021) and in the study area. Previous studies reported PAM detection range for belugas spanning from a few kilometers (Giard et al. 2020; Lammers

et al. 2013) to over 30 km (Gervaise et al. 2012). In other words, PAM detections of belugas might include animals using an area outside the LBS range. The hydrophone used in this study was deployed in shallow water, close to the shoreline, in an area with a particular underwater topography. Besides, as it is situated near several potential sources of anthropogenic noise, it would be valuable to conduct a study to characterize acoustic detection range.

Higher sound levels also affected beluga PAM detections which could be attributed to environmental and anthropogenic noises. Wind-generated noise (Cauchy et al. 2018; Wenz 1962) and rain-generated noise (Ma et al. 2005) cover a broad frequency range up to 20 kHz, which significantly contributes to the soundscape in frequency bands used by belugas (Mérindol et al. 2026) and affecting its detection. Current velocity also affected PAM detection of belugas. However, this effect is a consequence not of current itself, but of the current-induced mooring noise (Erbe, Reichmuth, et al. 2015). In the frequency band of beluga whistles, our observation showed increased sound pressure level associated to vessel presence and absence of beluga detection, confirming vessel noise as the main contributor at those frequencies, potentially masking beluga vocalizations (Brewer et al. 2023; Erbe 2008; Vergara et al. 2025). As for LBS, the significantly lower detection rate of belugas associated to vessel presence suggests avoidance behavior, possibly through displacement to areas with lower vessel traffic or altered diving patterns (Martin et al. 2023). We suggest further investigation to evaluate the occurrence of diel patterns, already identified for the population (e.g., Giard et al. 2020) and the possible influence of vessels presence.

Harbor porpoises vocalize frequently for echolocation and are therefore easily detectable with PAM, while their small size and low surface time make them cryptic and difficult to detect by LBS (Macaulay 2020), which could explain why PAM also detected this species more often than LBS. In this study, the few times when porpoises were seen but not heard occurred mainly when they were traveling alone or more than 2 km away from the observation site. Harbor porpoises are generally acoustically detected at distances of less than 1 km from the hydrophone (Clausen et al. 2019; Macaulay 2020; Todd et al. 2025). This indicates that the detection range for harbor porpoises is similar between both methods. Porpoise echolocation clicks, occurring at frequencies beyond the extent of rain- and wind-generated noise (Lammers et al. 2013), were not as affected by environmental masking as belugas. In the frequency band of harbor porpoise clicks, our observation showed increased sound pressure level associated to porpoise detection, with a stronger intensity than the increase associated to vessel presence, suggesting that porpoise clicks are the main contributor to sound level at those very high frequencies.

Vessel presence was associated with increased LBS detection. It is known that harbor porpoises react negatively by avoidance behavior in the presence of boats (e.g., Roberts et al. 2019; Wisniewska et al. 2018), or that they can display aerial behaviors (e.g., porpoising, breaching) as a response to the presence of boats (Oakley et al. 2017), which could help observers to spot them. Although this aspect was not studied in the scope of this article, the higher probability of detecting

porpoises in the presence of boats for visual data suggests the presence of a response to boat presence. We recommend integrating these findings into awareness campaigns targeting multiple users to improve knowledge of the species' behavior and ecological needs.

Vessels were detected almost as often with LBS than PAM. However, LBS were the only method to detect unmotorized vessels (e.g., kayaks and sailing boats) and stationary boats, which is usual while observing marine mammals, especially at further distance from the coast. When combined, LBS increased PAM detections of approximately 10% for both species and vessels. Similar results were presented by other studies focusing on comparing detections between different sampling methods for Yangtze finless porpoises (*Neophocaena phocaenoides asiaeorientalis*), harbor porpoises and diverse species of the Canadian and Brazilian Atlantic, respectively (e.g., Dalpaz et al. 2021; Kimura et al. 2009; Smith et al. 2020; Williamson et al. 2017). Nevertheless, the encountered discrepancies confirm the singularities and limitations of each method, highlighting the importance of the dual approach.

4.3 | Observer Bias

When data collection relies on human observers, it carries the potential for bias. Although not tested here, as LBS were mainly conducted by one observer, it would be relevant to conduct simultaneous visual observations to assess observational bias for LBS studies with multiple observers (Oliveira-Rodrigues et al. 2022). For the PAM dataset, the greatest discrepancy between the two acoustic data analysts was in the vessel detection, suggesting a substantial divergence in the observers' sensitivity or interpretation of detection criteria. However, we realized that one analyst had the tendency to include more distant merchant vessels (clearly outside the study area) despite their lower received noise levels, which explained most discrepancies. The discrepancies for beluga identification were probably due to boat masking affecting the analyst detections. Moreover, our results support the importance to include a bias evaluation in studies that apply manual identification of acoustic data. Additionally, whenever possible, automatic detection algorithms should be used to reduce observer bias (Cole and Vidal 2024). However, while testing PAMGuard to detect clicks of porpoises, detections were identified in more than 99% of recordings, suggesting an unacceptably high false-positive rate. This issue likely reflects differences in deployment configuration, as PAMGuard detectors are primarily optimized for multi-hydrophone or towed array systems, whereas this study relied on a single, bottom-moored hydrophone that can limit the ability to evaluate detection probability and false positive rates (Clausen et al. 2019). Also, the hydrophone was deployed in a complex coastal environment. Under such conditions, transient broadband noise and propagation effects can generate signals in the frequency band of porpoise's clicks, inflating automated detections (Clausen et al. 2019). Given these limitations, a conservative manual presence/absence approach was retained for subsequent analyses, prioritizing detection reliability over detection rate that was validated by high concordance between the two analysts for this species.

5 | Conclusion

Visual and acoustic observations revealed high presence of belugas and harbor porpoises in the study area, which appears to be primarily used for displacement and foraging, with regular observations of calves—particularly for harbor porpoises. These findings provide evidence-based support to include this portion of the estuary within the beluga whale critical habitat while highlighting its importance for harbor porpoise, for which habitat use in the estuary remains poorly understood. Our results also suggest a decrease in beluga detections in the presence of vessels. PAM detected higher beluga presence at night, when vessel traffic was lower, while LBS recorded higher presence and greater numbers of individuals during the year with the lowest vessel activity. Furthermore, noise analysis within the species' frequency bands indicated stronger masking effects for belugas than for harbor porpoises. In contrast, LBS showed increased visual presence of harbor porpoises in the presence of vessels, a pattern that warrants further investigation to better understand the influence of vessel on visual detections. Ultimately, the combined use of both methods allowed for a higher detection rate and provided a clearer portrait of the presence and activity patterns of belugas, harbor porpoises, and vessels in the study area and should be prioritized in future monitoring efforts. This study shows how those two cost-effective, non-invasive and low ecological footprint methods can be used to better understand the habitat use of both species while providing essential information to guide management.

Author Contributions

Cristiane C. A. Martins: conceptualization, funding acquisition, methodology, validation, visualization, writing – review and editing, project administration, supervision, resources, data curation. **Léna Velé:** validation, data curation, writing – review and editing. **Pierre Mercure-Boissonnault:** data curation, validation, writing – review and editing. **Pierre Cauchy:** conceptualization, funding acquisition, writing – review and editing, project administration, resources, supervision, validation, methodology. **Coralie Bernier-Breton:** conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, validation, visualization, writing – original draft. **Gesche Winkler:** conceptualization, project administration, supervision, validation, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Raw LBS and PAM data that were used for this study are a property of Parks Canada and could be shared upon request to ssl.conservation@pc.gc.ca. Acoustic annotated data could be made available upon request to the corresponding author.

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Appendix A

Categories and Their Description for Environmental Data Noted During Land-Based Surveys and Used to Classify Variables for Passive Acoustic Monitoring for (a) Horizontal Visibility and (b) Wind Speed According to Beaufort Scale, as Well as (c) Speed Class of Vessels and (d) Vessel Activities Detected by Land-Based Surveys

a)	Code	Visibility (nautical miles)	Study area
	0	none	No visibility
	1	1nm	Restricted beyond 1nm
	2	2nm	Restricted beyond 2nm
	3	3nm	Restricted beyond 3nm
	4	> 4nm	Perfect for all study area

b)	Beaufort	Conditions	Speed of wind (kn)	Visual Clues
	0	Calm	<1	Sea is like a mirror
	1	Light air	1 to 3	Ripples with the appearance of scales are formed, but without foam crests
	2	Light breeze	4 to 6	Small wavelets, short but more pronounced, crests have glassy appearance and do not break.
	3	Gentle breeze	7 to 10	Large wavelets, crests begin to break, Foam of glassy appearance. Perhaps scattered white caps
c)	Code	Speed class (kn)	Description	
	0	Immobile	Boat is drifting or remains stationary	
	1	< 5	Boat moves without splashing	
	2	5-10	Boat moves with splashing	
	3	10-20	Boat moves producing a lot of splashes and waves	
	4	> 20	Boat moves producing excessive splashes and waves	

d)	Code	Activity	Description
	0	Stationary	Boat drifting or stationary
	1	Moving	Boat moving from point A to point B
	2	Beluga observation	Boat searching actively, approaching or maintaining a distance of less than 400m from a group of belugas.
	3	Marine mammal observation	Boat searching actively, approaching or maintaining a distance of less than 400m from a group or individual of marine mammals other than belugas.
	4	Sailing	Sailboat sailing
	5	Fishing	Boat is fishing
	6	Patrol/Law enforcement	Boat is doing law enforcement or patrol
	7	Research	Boat is doing research