

**Assessing the James Bay Beluga whale population through passive
acoustic monitoring to outline seasonal presence**

by

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A Thesis submitted to the Faculty of Graduate and Postdoctoral Studies of

The University of Manitoba

In partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

Department of Environment and Geography

University of Manitoba

Winnipeg

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Abstract

Beluga whales, (*Delphinapterus leucas*), are primarily characterized as undergoing seasonal migrations, summering in estuaries and wintering in deeper waters. However, the James Bay population may remain in the Bay year-round. Beluga have a complex vocal repertoire, producing a variety of call types. The aim of this research is to determine the year-round presence of the James Bay population using click vocalizations and understand the influence of environmental factors on presence; furthermore, assuming beluga are present, we want to define beluga call types in winter months to relate them to behaviours such as feeding and communicating. First, we used passive acoustic monitoring to record beluga vocalizations year-round at two different locations in James Bay, the northwest (2021-22) and the southeast (2022-23). We used both an automatic detector and manual analyses to detect the presence of clicks. We then used environmental parameters including sea surface temperature, salinity, and sea ice concentration to test the influence of these factors on the presence/absence of beluga. Results showed year-round presence of beluga click vocalizations at both locations in the northwest and southeast of James Bay. However, click presence was influenced differently by environmental factors at the two locations. At the northwest location we found an increased presence during warmer sea surface temperatures, and a negative effect from sea ice cover. In contrast, the southeast region showed a positive relationship between beluga presence and cooler sea surface temperatures and sea ice-freeze up, specifically occurring in December and January. These findings suggest that the northwestern area of James Bay may be a suitable area for summer aggregating zones whereas the southeastern area of James Bay may be a more suitable overwintering environment. Spatial analysis comparing presence at the mooring locations and sea ice concentration across the James Bay revealed a spatial distribution along the eastern coastline, suggesting that beluga are following flaw leads (i.e. the floe edge) and exploiting the polynya extending from the La Grande River. Secondly, we defined call types and related behaviours in December 2022, an ice freeze-up regime, and January 2023, an ice-covered regime. Call types included echolocation click trains, used for navigational purposes, click trains ending with a terminal buzz, indicating feeding, as well as whistles and broadband pulsed calls, both used for communication. Results indicate that the total number of calls was greater in December compared to January. We then developed a foraging index to quantify how frequently foraging behaviour occurred across all acoustic files with confirmed beluga presence. The foraging index was higher in December (i.e. 14.8) compared to January (9.9), suggesting that feeding activity was more prevalent during open-water or early freeze-up conditions than during periods of extensive ice cover. Overall, we found a year-round presence of beluga in James Bay. However, beluga presence was highest during ice-freeze-up in the south, with the occurrence of both foraging and social call types, indicating flaw leads and/or polynyas may be providing suitable overwintering habitat for James Bay beluga. Using these results can help inform regional planning and the establishment of conservation areas and management systems relevant to beluga habitat in James Bay.

Dedication

I dedicate this thesis to my Papa, for inspiring a love for the outdoors, and to my Dad, for resilience and the habit of always moving forward.

Acknowledgements

I would like to thank my advisors Dr. Marianne Marcoux and Dr. Lisa Loseto, for giving me the opportunity to complete this research. You have provided a supportive, safe and enjoyable environment, consistently offering guidance and encouragement. I would also like to thank my committee members, Dr. C.J. Mundy and Dr. Zou Zou Kuzyk who played an influential role in this project and am very grateful for the help.

Thank you to the Eeyou Marine Region Wildlife Board, and Mushkegowuk Council for your collaborations and initiative, this project would not have happened without these partnerships. Additionally, thank you to the crew of the RV William Kennedy for your hard work in the field, deploying and retrieving the moorings.

There are many people to thank for playing a small role in this project. I'd like to thank Bryanna Sherbo for technical help as well as constant positivity in our lab! Thank you to Fanny Dupont for assistance on statistical analyses. Thank you to Veronica Coppolaro for providing help on beluga vocal analyses. Thank you to Kim Ovitz for emphasizing and educating the importance of IK and challenging my knowledge system as a western scientist. Thank you to Kevin Scharffenberg for assistance on beluga vocal analyses as well as detector code. Thank you to Kaushik Gupta for guidance in ArcGIS and data collection for sea ice concentrations. Big thank you to Emma Ausen and Alessia Guzzi for the constant support at CEOS.

I am very grateful for the DFO graduate students I have met on this journey (you know who you are), I am happy to call you lifelong friends. Sarah, I don't know where I would be in all of this without you by my side (glad I pulled you in from Queen's), I am beyond grateful to have

you in my life. Thank you for not only being my best friend, but my rock through this all. Thank you to my partner Brayden for your constant support and belief in me. You have put up with many conversations, rambles and high stress moments, and for that I am appreciative.

Lastly, thank you to my mom, dad and four brothers. Your support and patience with me has meant more than I can express. Despite the hiccup we hit in 2024, you six have remained my biggest supporters ... "be brave + be brilliant"

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Author Contributions

The following are author contributions for Chapter 2 and 3:

Abigail Long (thesis author): conceptualization, data curation, formal analysis, methodology, visualization, writing – original draft.

Marianne Marcoux – primary supervisor, conceptualization, methodology, writing - review and editing.

Lisa Loseto – co supervisor, conceptualization, writing - review and editing.

C.J. Mundy – conceptualization, funding acquisition, methodology, data curation, writing - review and editing.

Zou Zou Kuzyk – conceptualization, funding acquisition, methodology, writing - review and editing.

Thesis Format

This thesis follows a grouped manuscript format. Chapter 1 presents a general introduction and background to contextualize the research. Chapter 2 and 3 are structured as standalone manuscripts, with an abstract, introduction, methods, results, discussion, conclusion, references, tables, and figures. Chapter 4 is a concluding chapter summarising findings and key results, as well as discusses the limitations, and directions for future research.

Chapter 1. General Introduction

1.1 Movement Patterns & Habitat Selection

Migration is a special type of movement from one region to another, aimed at meeting energy requirements or responding to alternating favourable or unfavourable conditions in the environment (Bailleul et al., 2012; Dingle & Drake, 2007). Interpretation of migration is dependent on many details such as the organism, population dynamics, genetics, environmental conditions of selected home ranges, and lastly, temporal and spatial variations (Dingle & Drake, 2007). Migration is a particularly preferred strategy involved in population dynamics, specifically in those categorized as iteroparous species, breeding more than once in their lifetime (Dingle & Drake, 2007; Mueller & Fagan, 2008). Organisms select habitat with high energetic benefits, and suitable resources while taking into consideration predation, competition, and abiotic factors (i.e. water temperatures, salinity etc.). Storrie et al. (2023) emphasize migration as being an adaptation to resource availability, reinstating the idea that selection of habitat means an area of high energetic values to both the population and individual level.

In contrast, nomadism indicates a sporadic distribution and unpredictability of suitable resources in a large area, whereby a population or individuals are neither residents nor exhibiting migratory behaviour (Mueller & Fagan, 2008; Storrie et al., 2023). Instead, individuals are moving within a large area with no predicted trajectory of spatiotemporal distribution (Mueller & Fagan, 2008). Migration and nomadism allow species to utilize resources across different regions (Mueller & Fagan, 2008; Storrie et al., 2023).

Beluga are characterized as undergoing seasonal migrations where they spend summering months in warm, less saline waters especially estuaries then migrate to deeper open water systems with partial ice coverage, following ice edges (Barber et al., 2001; Sergeant, 1973). Estuaries are created when a river meets the ocean, creating an interaction of salt and fresh water. There are many hypotheses as to why these areas may be favoured by beluga,

including, a suitable area to moult, thermal advantage for calving, an area of influx in nutrients from river discharge, and predator avoidance from killer whales (Aubin et al., 1990; Hornby et al., 2016; Scharffenberg et al., 2019; Sergeant, 1973; Smith et al., 2017). Generally, beluga can be found in warm estuarine waters from approximately June to October before environmental conditions trigger a state of movement.

1.2 Climate Change

Arctic and subarctic ecosystems are experiencing rapid climate change as temperatures are increasing at four times the global rate (Rantanen et al., 2022). These changes include increased water temperatures, shorter sea ice periods, and increased storm activity, altering ecosystems and in turn effecting the organisms dependent on these ecosystems (Rantanen et al., 2022). Marine mammals, such as beluga, rely on sea ice in these regions to survive with the purpose of protection, navigation, and food. As global warming continues to decrease the length of the sea ice seasons as well as sea ice thickness, corridors within the ice will begin to open for organisms to take advantage of, potentially shifting movement and migration patterns (Kuletz et al. 2024). These patterns have been documented in beluga and killer whales, where changes in sea ice such as low ice years with early break up, led Beaufort Sea beluga to remain in summer grounds longer and take to alternate routes for migration (O’Corry-Crowe et al., 2016).

Furthermore, as sea ice opens earlier, killer whales have the ability to enter these areas usually ice covered, driving beluga to use alternative routes (O’Corry-Crowe et al., 2016). In addition to open water periods lengthening and creating more areas to exploit, prey availability for larger organisms such as marine mammals can begin to shift. An example is seen between Arctic cod and capelin, where in Cumberland Sound, beluga diets shifted from the previously dominant Arctic cod to increased capelin consumption (Watt et al., 2016) This potentially reflects a broader climate driven change allowing capelin at more northern latitudes.

The James Bay beluga whale population is considered the second southernmost population in Canada, experiencing different environmental conditions, such as sea ice coverage periods and warmer water temperatures, compared to high Arctic populations. James Bay has also experienced marine heat waves, defined as a prolonged periods of unusually warm sea surface temperatures lasting for varying periods of time, including weeks or years (Bruneau et al., 2025). Between 1982-2021, 11 of these events were documented and linked with earlier sea ice break-up (Bruneau et al., 2025). Therefore, alongside climate change, marine heat waves represent a critical factor to monitor as they may affect beluga and other James Bay organisms. Understanding presence, movements and migrations of animals living in the Arctic and subarctic waters is increasingly important as environmental changes persist. The James Bay beluga represent an understudied population living in a unique environment, making continued research essential to track small and large scale movements, vocal patterns and associated behaviours, diet, and preferred habitats. This type of work will help detect shifts and predict how warming temperatures may impact this region.

1.3 Beluga

Beluga whales (*Delphinapterus leucas*) are one of two species in the Monodontidae family, along with the narwhal (*Monodon monoceros*) (O'corry-Crowe, 2009; Stewart & Stewart, 1989). They are medium sized odontocetes, meaning toothed whales, with no dorsal fin and unfused vertebrae to allow for flexibility (O'corry-Crowe, 2009). Beluga exhibit a near circumpolar distribution as they are endemic species to the Arctic and Subarctic waters. In total, there are 22 stocks, eight of which are in Canada (Hobbs et al., 2020).

Beluga are very mobile and have the ability to survive in different habitat types including both shallow and deep water regimes, estuaries, and high concentrations of sea (Bailleul et al., 2012a; Barber et al., 2001; Laidre et al., 2008; Loseto et al., 2009). Beluga are considered to be generalist feeders, feeding on a variety of species, including fish such as Capelin (*Mallotus*

villosus) and Arctic Cod (*Boreogadus saida*) (Laidre et al., 2008; Lesage et al., 2020; Loseto et al., 2009) as well as invertebrate such as squid, crabs, shrimp, and bivalves (Quakenbush et al., 2015). Killer whales, polar bears, and humans are predators to the species; while sea ice entrapment is another major threat (Ferguson et al., 2012; Higdon et al., 2012; Westdal et al., 2017). Studies have incorporated environmental covariates such as tidal trends, wave heights, wind speeds, salinity, and temperature to better understand presence; however, most studies do not consider the potential effects of sea ice and floe edges (Ausen et al., 2023; Goetz et al., 2012; Hornby et al., 2016; Scharffenberg et al., 2019; Smith et al., 2017).

Beluga whales are commonly referred to as “the canaries of the sea” due to their vocal nature and wide repertoire; call types can include 1) whistles, 2) pulsed tones, 3) echolocation clicks, 4) terminal buzzes following echolocation clicks, and 5) combined calls (Chmelnitsky & Ferguson, 2012; O’corry-Crowe, 2009; Panova et al., 2012; Sjare & Smith, 1986). Whistles are a communicative call, typically having a narrowband (small frequency), creating a unique, contour shape both ascending and descending (Chmelnitsky & Ferguson, 2012; O’corry-Crowe, 2009). Whistles are specific to an individual and used between conspecifics. Pulsed tones often consist of a series of rapid pulses, having a more broadband range (Chmelnitsky & Ferguson, 2012; Belikov & Bel’kovich, 2008; Sjare & Smith, 1986). These calls may repeat themselves several times in the same time period (Vergara & Mikus, 2019). Contact calls are a type of broadband/pulse calls. They form a very complex repertoire and can be divided into simple and complex calls used for communication purposes. Simple contact calls are repetitive broadband pulsed calls, more often seen in calves because they have not developed a complex vocal repertoire (Vergara et al., 2010). A complex contact call is of similar structure but has an overlapping lower tonal frequency occurring simultaneously (Vergara et al., 2010). Pulsed calls can be emitted in different situations, rest or social interactions or in situations of danger and stress, such as during birth, deaths, or being held captive (Vergara et al., 2010; Vergara & Mikus, 2019). Contact calls have been shown to differ among individuals (Vergara et al., 2010;

Vergara & Mikus, 2019). In addition to distinct contact calls in captive beluga (Mishima et al., 2015; Morisaka et al., 2013; Panova et al., 2017) these types of calls have also been identified in wild beluga (Vergara & Mikus, 2019) and are seen as being a shared characteristic with their related Arctic species, narwhal (Vergara & Mikus, 2019).

Echolocation clicks are also broadband pulses with the primary purpose of navigation and foraging. Studies have concluded these classified clicks are not a form of communication, unlike pulsed tones and whistles (Belikov & Bel'kovich, 2008). This ability to produce clicks for echolocation has been well adapted by the beluga to survive in regions of sea ice cover, allowing for signals to be received from the surface to navigate heavy ice and open water (O'corry-Crowe, 2009).

Terminal buzzes are similar to echolocation clicks, but the inter-click interval (ICI), the time between individual clicks, gets progressively shorter. In most cases this buzz is found following a click train and can be an indication of the animal foraging and feeding (Castellote et al., 2021; Johnson et al., 2008; Miller et al., 2004; Roy et al., 2010). Echolocation click trains and buzzes are call types seen in other toothed whales and dolphins, such as beaked whales, sperm whales and bottlenose dolphins to indicate prey searching and prey capture (Herzing, 1996; Johnson et al., 2004, 2008; Miller et al., 2004). Lastly, combined calls are the described calls above being produced simultaneously, including a pulsed tone and overlaying tonal calls or two different call types being emitted together (O'corry-Crowe, 2009; Vergara & Barrett-Lennard, 2008). Using these vocalizations can be a non-invasive method to study beluga compared to tagging, providing accurate and long-term data relevant to understanding beluga behaviour, seasonal occurrence, and the presence/absence of beluga in an area.

There are eight identified beluga stocks in Canada including the Eastern High Arctic-Baffin Bay, Western Hudson Bay, Eastern Hudson Bay, St. Lawrence Estuary, Cumberland Sound, Ungava Bay, Eastern Beaufort Sea and James Bay (Hobbs et al., 2020). Of these identified stocks, five are classified as migratory, whereas St. Lawrence Estuary, Cumberland

Sound and James Bay are considered residents. However, although not identified as making classic long-route migrations in spring and winter months, these stocks have been found to make small scale movements, for example, the Cumberland Sound beluga spend the summer months in the northwestern parts of the area, as well as in Clearwater Fjord, but move outwards to the mouth of Cumberland Sound in the winter (Richard & Stewart, D.B., 2008). Cook Inlet, beluga, a stock located in a body of water in Alaska not a part of the listed Canadian stocks, travel shorter distances to the mouth of the fjord and back seasonally (Castellote et al., 2020; Rugh et al., 2005). Similarly, St. Lawrence Estuary beluga also exhibit a seasonal shift from the upper to lower estuary (Rugh et al., 2005).

1.4 Population Separation

The Hudson Bay marine region has several beluga populations including Western Hudson Bay, Eastern Hudson Bay, Belcher Islands and James Bay. Based on observations of reoccurring aggregations in particular estuaries, Reeves & Mitchell (1987) outlined a framework where summer aggregations formed a separate management stock, creating multiple stocks within an area (i.e. Hudson Bay). This framework was further supported through the use of genetic and contaminant evidence, demonstrating that beluga stocks returned to the same area annually (Brennin et al., 1997; Brown Gladden et al., 1999; De March & Postma, 2003). Furthermore, using telemetry studies, tracked individuals from summering aggregating regions did not have an overlap in winter distribution, aligning with the above framework (Bailleul et al., 2012a). With the use of telemetry data, genetic analyses of mitochondrial DNA sequences, and traditional ecological knowledge, James Bay beluga were found aggregating in southern James Bay and not migrating through Hudson Strait (as the other populations do in fall and spring) to winter outside of Hudson Bay. James Bay beluga were therefore recognized as their own population/stock (Postma et al., 2012). The James Bay beluga is a distinct population separate from the Western Hudson Bay population. The James Bay population structure was officially

accepted by The Committee on the Status of Endangered Wildlife in Canada (COSWEIC), and renamed in November 2020 (COSEWIC, 2020). There is a gap in knowledge in terms of understanding the population, including understanding their presence/absence yearly.

There is very limited information on James Bay, separate from the Hudson Bay stocks. Past work on this population included aerial surveys of James Bay that took place in 1985, 1993, 2001, 2004, 2008, 2011, 2015, 2021, and 2024 during the months July and/or August (Gosselin et al., 2009, 2013, 2017; Kingsley, 2000; Smith & Hammill, 1986; St-Pierre et al., 2023, Van de Walle et al., 2025). The 2024 aerial survey, combined with population modelling, estimates James Bay beluga abundance at approximately 16,000 (Van de Walle et al., 2025). In addition, a 2012 study was done in James Bay using 12 tagged individuals, providing insights on beluga presence and movement specifically aggregating in southeastern James Bay and making movements to the mouth of the Bay in winter; however tags did not work year-round but only provided data from summer to between November and February (Bailleul et al., 2012a).

1.5 James Bay

James Bay is an estuarine-like body of water, located adjacent to Hudson Bay, and remains one of the least studied bodies of water in Canada. James Bay is settled between Ontario and Quebec, Canada, and covers an area of approximately 68,300 km² with an average depth of 28 meters and a maximum of 110 meters (El-Sabh & Koutitonsky, 1977; Évrard et al., 2023).

James Bay has been characterized as having a straight and steady offshore slope whereas eastern James Bay is more complex due to the presence of offshore islands creating a declining and increasing slope (Gupta et al., 2022). Sea ice begins to form in the bay in December, taking approximately 15 days to freeze. Undeformed seasonal ice reaches a maximum depth near one metre, and begins to melt in June (Eastwood et al., 2020). Sea ice break-up continues into the month of July in northern areas of the Bay (Yurkowski et al., 2023).

Landfast sea ice is a type of sea ice that forms attached to the coastline or seafloor where it then remains stationary (Gupta et al., 2022). Landfast ice presence and stability is influenced by the surrounding bathymetry, tides, seafloor dynamics, and other local conditions. These conditions can also include the presence of islands, which are a common influence on landfast ice formation in eastern James Bay. In western Hudson Bay, studies have shown a delay in freezing; however, in eastern Hudson Bay, freeze-up dates are occurring earlier (Gupta et al., 2022). A similar trend is also being seen in James Bay where the western side, including areas near Attawapiskat and Moosonee, are trending towards a delay in freeze-up, whereas on the eastern side, including Chisasibi, trends are showing earlier freeze-up dates (Gupta et al., 2022). In contrast, sea ice break-up appears to be occurring earlier (Bruneau et al., 2025).

James Bay is considered the most river-influenced water body of the Hudson Bay marine region contributing 38% of total annual freshwater input to Hudson Bay (Évrard et al., 2023). The La Grande hydroelectric complex, on the eastern coastline of James Bay, has altered the flow of river water, both reducing it at Eastmain and increasing it at Chisasibi where the La Grande River (LGR) discharges. Specifically, LGR shows about 10-fold higher flow in the winter season in recent years compared to pre-development (1975) (Peck et al., 2022). There are many rivers on the eastern coast of James Bay; however, the LGR is the largest due to a large portion of flow from other rivers such as the Eastmain, Opinaca, and Rupert Rivers diverted for the production of hydroelectricity (Messier et al., 1986). The La Grande is now the largest contributor of freshwater into the Hudson Bay system, producing approximately 53% of the total annual river discharge into the region (De Melo et al., 2022). Regulated river discharge from the La Grande River during the winter causes a plume of freshwater under the sea ice (Eastwood et al., 2020). Simultaneously, while sea ice formation releases cold, saline brine that sinks to subsurface layers, river input introduces a plume of warmer, less saline water that floats on top of the salty water and results in a vertical density gradient creating a strong stratification (Eastwood et al., 2020; Meilleur et al., 2023). Notably, James Bay is considered a heterotrophic

environment, meaning there is little photosynthetic activity occurring in offshore surface waters (P.Bouchard, pers. comm, 2025). Eastern James Bay hosts nearshore seagrass meadows (eelgrass; *Zostera marina*) that, prior to the late 1990s, were among the largest in North America; following a massive decline, they have shown some limited recovery with continued short shoot lengths, discontinuous and sparse cover, and patchy beds that are limited to shallower water than before the decline (Leblanc et al. 2023). There is very limited information on nutrient availability in James Bay (although see Guzzi et al., 2024), including what could support primary and secondary production and sustain beluga presence year-round. Lee et al. (2023) suggested that river nutrients contribute only 2.4% to new primary production at the bay-wide scale but could be significant locally.

In addition to the unique river input, polynyas are another notable feature in James Bay. Polynyas are classified as areas of open water or low ice concentration that often reoccur in the same regions over time; they are found near islands, coastal regions and fast ice edges. Wind speeds, tides, and currents all have an impact on the formation of polynyas. There is a large polynya in the southwest region of the Belcher Islands extending down to northern James Bay (Eastwood et al., 2020). Beyond the outer edge of the landfast ice in eastern James Bay there is also an intermittent polynya called a 'flaw lead' (cf., Taha et al., 2019). In general, flaw leads are also considered areas of open water but are not consistently occurring in the same regions, i.e., are only open intermittently (Barber & Massom, 2007). These are caused by winds and currents forming long linear openings, such as along fast ice edges and are often results of ice separating from land-attached ice (Durkalec & Breton-Honeyman, 2021). In eastern James Bay, the flaw lead opens up when ice floes drift westward, away from shore, under the influence of easterly winds, and closes when the ice floes drift eastward toward shore under the prevailing westerly winds (Taha et al., 2019; Peck et al., 2022). Polynyas and flaw leads are considered the most biologically productive areas in Arctic regions during winter as they provide a suitable

habitat for large mammals that need to surface and breathe (Stirling, 1980, 1997). To our knowledge, wildlife use of polynyas in James Bay has not been studied.

1.6 Passive Acoustic Monitoring

Passive acoustic monitoring (PAM) is a technique that records underwater sounds, with the primary goal to better understand the underwater environment (Zimmer, 2011). Presence of noise could source from natural occurring phenomena, anthropogenic sounds, as well as noise and emitted calls from submerged animals, such as beluga. Using acoustics to characterize movement and habitat use of beluga can be a less invasive technique relative to tagging to obtain long-term data relevant to understanding beluga behaviour, seasonal occurrence, and the presence/absence of an area, as well as a way to monitor in remote locations that are often difficult to access year-round. However, a limitation with using PAM is the large amount of data it generates. These data cannot feasibly be manually analyzed in an efficient time period; therefore, automatic detectors were developed to assist and accelerate the process of analyzing sound files. Another limitation includes the spatial coverage, the data is only collected at the location of the mooring and therefore reflective of a narrow PAM has been a common method to detect beluga presence seasonally, and better understand the effects of environmental factors on beluga presence, such as temperatures, salinity, and sea ice (Castellote et al., 2020; Halliday et al., 2017; Marcoux et al., 2017; Scharffenberg et al., 2019).

1.7 Marine Region Planning

The urgency for improving understanding of the James Bay beluga population stems in part from ongoing marine region planning efforts. In 2010, the Cree Offshore Agreement was signed with the Government of Canada. Similar to the James Bay Northern Quebec Act, it is modern a land claim agreement with the purpose of addressing ownership of islands in eastern James Bay, mineral rights, harvesting rights, and participation of the Eeyou Marine Region Wildlife Board (The Grand Council of the Crees (Eeyou Istchee) / Cree Nation Government, n.d.). The

land claim is also meant to ensure protection of Cree rights, including self-governance, and the inclusion of Cree People in the government employment system (The Grand Council of the Crees (Eeyou Istchee) / Cree Nation Government, 2026). The land claim area covers approximately 61, 270 km² offshore of eastern James Bay. In 2019, the Government of Canada and Eastern James Bay Cree began a feasibility assessment to create a National Marine Conservation Area (NCMA) in eastern James Bay, within the Eeyou Marine Region. Information about the beluga population will help support this NMCA initiative.

In terms of western James Bay, the Government of Canada and Mushgowuk Council have recently and successfully completed the feasibility assessment for the proposed NCMA in western James Bay and southwestern Hudson Bay (Parks Canada Agency, 2025). This area will contribute 1.5% of the total goal of 30% protected waters by 2030, spanning approximately 91,000 km² (Parks Canada Agency, 2025). With the development of this NCMA, Mushkegowuk Council has proposed a potential agreement with Eeyou Istchee for the overlapping usage and boundaries of James Bay (Mushkegowuk Council et al., 2023). The most significant harvest and time spent hunting occur with waterfowl hunting (8% participation rate), fishing, then big game, indicating marine mammals are not a focal point in hunting traditions. Nevertheless, marine and estuary areas are necessary to maintain a healthy ecosystem (George et al., 1996). George et al. (1996) states, “According to Cree peoples, aboriginal identity is defined in terms of having access to bush food, and indeed wildlife harvesting is central to core culture values such as sharing.” Thus, although James Bay beluga may not be essential for Cree diet, they are considered important in culture, identity, food security, and maintaining generations of Indigenous knowledge.

1.8 Objectives and Hypotheses

The overall objective of this thesis is to determine the annual use of James Bay by the James Bay beluga population, using PAM in the northwestern and southeastern coasts, areas of

James Bay. Furthermore, we wanted to understand how the environment, specifically, salinity, sea surface temperature, and sea ice concentrations influenced beluga presence and use of the area. To do so, we conducted PAM to record underwater sounds, which were then processed via an automatic detector to detect the presence or absence of beluga, followed by manual analysis to confirm the accuracy of the automatic detector as well as annotate call types to better understand behaviours.

The objective of my first data chapter (Chapter 2) was first to confirm the population's residency time by determining their year-round presence based on click vocalizations at two locations, the southeast and northwest areas of James Bay. Second, I wanted to assess how sea ice concentration, salinity, and sea surface temperature influence beluga presence in the northwest and southeast regions of James Bay. I hypothesized there would be year-round presence based on communities' observations and a previous study done by Bailleul et al. (2012a), specifically higher presence at the northwest location in summer months and higher presence at the southeast location during winter months. However, I expected there to be variation among hydrophone locations using previous knowledge on aerial surveys, and the dynamics of freshwater input and sea ice concentration in the Bay. Additionally, I hypothesized that beluga presence in the southeast would be influenced by salinity, with lower salinity increasing click activity, and that decreasing sea surface temperature and sea ice concentration will similarly drive higher click presence.

The objective of my second data chapter (Chapter 3) was to identify call types during winter months under different sea ice regimes (i.e. freeze-up in December and a fully frozen state in January) to better understand beluga behaviour related to foraging, communication and navigation activities. Using a foraging and feeding associated call type, I explored feeding frequency assumed to be associated with foraging call types. I hypothesized that a variety of call types would be detected, with navigational calls occurring most frequently, followed by communicative calls, and fewer foraging calls overall. Additionally, I hypothesized that the

foraging index would be greater in December than in January due to the transition from open water to a freeze-up ice regime and the hydrophone's location within a developing sea ice state.

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Chapter 2. Determining the year-round presence of the James Bay beluga whale population through click detection using passive acoustic monitoring

2.1 Abstract

Beluga, (*Delphinapterus leucas*) primarily migrate seasonally, summering in estuaries and wintering in deeper waters; however, preliminary evidence indicates the James Bay population may remain in the Bay year-round. James Bay, an estuarine-like body of water adjacent to Hudson Bay, has one of the southernmost and least studied beluga populations. In this study, we used passive acoustic monitoring to assess year-round beluga presence, by deploying hydrophones in the northwest (2021–22) and southeast (2022–23) of James Bay for year-long periods. This type of monitoring takes advantage of the fact that beluga are very vocal, producing whistles and pulsed tones as communicative calls, and echolocation clicks that indicate foraging and feeding. For both datasets, we used click vocalizations to confirm the population's year-round residence, and we integrated environmental data to assess how sea ice cover, salinity, and sea surface temperature influenced beluga presence in these regions. At the northwest site, 69% of days had beluga clicks detected. Vocal presence was less likely during ice-covered (>80% sea ice concentration, meaning >80% of the ocean's surface is ice-covered) and open water periods (<15% sea ice concentration), and more likely with increasing sea surface temperatures. At the southeast site, 85% of days had beluga clicks detected. Vocal presence was less likely during ice-covered and open water periods, and most likely during the transition seasons, especially ice freeze-up (15-80% sea ice concentration). Clicks increased as sea surface temperature decreased. This new information improves our understanding of the movement strategies of the second southernmost population in Canada, where climate change is rapidly changing environmental conditions such as ice breakup dates and sea surface temperatures. These results can help inform the local marine region planning and management systems relevant to beluga habitat in James Bay.

2.2 Introduction

Beluga whales (*Delphinapterus leucas*) play an important ecological role in James Bay as a key Arctic/Subarctic predator as well as a key cultural role to surrounding Cree and Inuit communities, yet our understanding of their movements and presence is poorly understood amongst climate change (i.e. warming water temperatures and shorter ice seasons). These changes over time can impact not only ideal environmental conditions such as water temperatures, declining sea ice but also shifting prey availability from upwelling changes, threatening seasonal habitat use in this region. Migration is the movement of an organism between regions that is driven by energy requirements or a shift in environmental conditions (Bailleul et al., 2012; Dingle & Drake, 2007). It is dependent on the species, population dynamics, genetics, environmental conditions of selected habitats, and includes temporal and spatial variations (Dingle & Drake, 2007). Therefore, food availability, predation, competition, and abiotic factors (e.g. water temperature, and salinity) affect migration patterns. These factors in combination with climate change make understanding beluga movements in James Bay critical to track changes over time as well as for conservation efforts and regional planning. Storrie et al. (2023) emphasize migration as an adaptation to resource availability, reinstating the idea that selection of habitat means an area of high energetic values at both the population and individual level. Nomadism indicates a sporadic distribution and unpredictability of suitable resources in a large area, whereby a population or individuals are neither residents nor exhibiting migratory behaviour (Mueller & Fagan, 2008; Storrie et al., 2023). Instead, individuals are moving within a large area with no predicted trajectory of spatiotemporal distribution (Mueller & Fagan, 2008). Both migration and nomadism allow access to resources across different regions; however, only migration includes a temporal aspect, demonstrating seasonal patterns, while nomadism is associated with environments where resource distribution is variable (Mueller & Fagan, 2008; Storrie et al., 2023).

Beluga whales are a marine Arctic mammal that exhibit a near circumpolar distribution endemic to the Arctic and Subarctic waters of North America. There are 22 identified stocks; eight in Canada, which include both the Arctic and Subarctic stocks (Hobbs et al., 2020). Information varies greatly across stocks, and as Arctic warming continues, understanding these stocks becomes increasingly important (Hobbs et al., 2020; Kovacs et al., 2021). Belugas are highly migratory and have the ability to survive a wide range of habitats including heavy ice concentration, open water, and shallow regimes including estuaries and their connecting rivers (Barber et al., 2001; Sergeant, 1973). Most beluga populations undergo seasonal migrations where they spend the summer months in warm, estuarine waters before migrating to overwinter in deeper, open water and partially ice-covered systems following ice edges where sea ice entrapment is not a concern (Barber et al., 2001; Sergeant, 1973). Sea ice formation is often determined as a limiting factor, triggering beluga to leave or delay arrival to the coastal summering area (Hauser et al., 2017, 2018; Noel et al., 2022; O’Corry-Crowe et al., 2016).

During summer, beluga presence in estuaries is influenced by a combination of environmental factors including sea ice extent, turbidity, sea surface temperature, prey availability, rivers, and other coastal/bathymetric features, seafloor substrate; however, the impact of each of these factors varies by location (Aubin et al., 1990; Ausen et al., 2023; Goetz et al., 2007, 2012; Scharffenberg et al., 2019; Sergeant, 1973; Watt et al., 2016). There are many hypotheses as to why belugas may be found in estuaries in the summer including moulting, thermal advantage for calving, foraging opportunities, genetic predisposition and predator avoidance from killer whales although human hunting often remains an additional factor in these regions (Aubin et al., 1990; Sergeant, 1973). High temperatures and low salinity conditions have been proposed as driving factors, this finding was seen in the Mackenzie Estuary where there was an attraction to warm fresh waters, along with a negative association with increased wave height and wind (Scharffenberg et al., 2019). Belugas have been documented rubbing themselves on the substrate, which when integrated with Indigenous

knowledge, suggests a preference for warm, fresh water conditions during the moulting process, with a potential thermal advantage for calves (Watts et al., 1991; Whalen et al., 2020). Warm, low salinity water assists in the regeneration of skin tissues for epidermal growth, allowing for quick turnover in the moulting process (Aubin et al., 1990; Watts et al., 1991). Additionally, a preference for mudflats and tidal flats has been reported, which may further assist in the moulting process (Goetz et al., 2007, 2012). Generally, beluga can be found in these waters from approximately June to October before environmental conditions, commonly heavy sea ice concentrations, trigger a state of movement.

Belugas are very vocal animals, and use a combination of call types including whistles, pulsed tones, echolocation clicks, and combined calls (Chmelnitsky & Ferguson, 2012; O'corry-Crowe, 2009; Panova et al., 2012; Sjare & Smith, 1986). Passive acoustic monitoring, hereafter referred to as PAM, is an accurate, long-term method used in recording beluga behaviour, seasonal occurrence, and the presence/absence of beluga in an area (Zimmer, 2011). To further our understanding of the seasonal presence and absence of beluga, this paper uses annual PAM deployments to examine the residency time of the James Bay beluga whale population. Their year-round presence was confirmed based on click vocalizations as well as to assess how sea ice cover, salinity, and sea surface temperature influence beluga presence in the northwest and southeast regions of James Bay.

2.3 Methods

2.3.1 Study area

James Bay is an estuarine-like body of water, located adjacent to the Hudson Bay, settled between Ontario and Quebec, Canada. James Bay covers an area of approximately 68,300 km² with an average depth of 28 meters (El-Sabh & Koutitonsky, 1977; Évrard et al., 2023). The James Bay coastlines are highly river dominated having a strong contribution of dissolved organic matter (Évrard et al., 2023; Gosselin et al., 2010). James Bay contributes 38% percent

of total annual freshwater input to Hudson Bay, with a majority of 26% coming from the east coast (Évrard et al., 2023). The James Bay hydroelectric complex has altered the flow of river water, increasing flow in the winter season and decreasing the spring freshet, modifying regional stratification among other impacts (Eastwood et al., 2020; Messier et al., 1986). With the development of these structures water has been diverted to other rivers, such as the La Grande River complex drastically changing its output. The La Grande River is the largest river of the Hudson Bay system and supplies approximately 53% of the total annual river discharge into the region (De Melo et al., 2022) .

Sea ice begins to form in December, taking approximately 15 days to freeze at a maximum depth near 1 meter, and begins to melt in June (Bailleul et al., 2019; Eastwood et al., 2020). Ice break-up continues into the month of July in northern areas of the Bay (Yurkowski et al., 2023). Notably, there is a polynya, in the southwest region of the Belcher Islands, that extends down to the La Grande River (Eastwood et al., 2020). This area as well as other polynyas in the Bay can remain open throughout the winter due to local tidal currents (Eastwood et al., 2020; Gilchrist & Robertson, 2000).

The two mooring locations differed in their local environmental conditions, particularly the icescape. The southeast mooring was placed in a deeper point of the Bay (~80 m), along the landfast ice edge, and surrounded by many small islands. In comparison, the northwest mooring was placed in slightly shallower water (~62m) with little to no surrounding islands, and far from the landfast ice.

2.3.2 Sound Collection

This study is part of a larger program of data collection in southern Hudson Bay and James Bay during 2021-2023, aimed at better understanding the unique environment, including nutrient cycling and availability, food webs, sea ice dynamics, freshwater influence and the aquatic organisms and mammals that live there. Two moorings were deployed and retrieved in southern James Bay as part of this program (Figure 2.1; Table 2.1). The two locations include the

southeast (JB-H: 52.431°N 79.409 W; August 2022 to August 2023) and northwest (JB-M2: 54.166°N 81.288°W; August 2021 to August 2022). Locations were selected based on previous understanding of beluga presence, depth and providing good spatial coverage (Figure 2.1). Moorings were equipped with a SoundTrap ST600 (Ocean Instruments^{nz} Acoustic Monitoring Program) hydrophone and RBR XR-420 Conductivity, Temperature and Depth (CTD) (Figure S2.1, Figure S2.2). The mooring was assembled using a line connecting a subsurface float to an acoustic release attached to an anchor at 62 and 78 m depth (Table 2.1). The sampling rate for each hydrophone was set at 192 kHz, capturing sounds in the range of frequencies up to 96 kHz, following the Nyquist theorem (Fleishman et al., 2023). A higher sampling rate allows for detailed recording and analysis of beluga vocalizations, including their click peak frequencies, which can vary widely from 30 kHz to 120 kHz (Roy et al., 2010). The rate of 192 kHz was chosen as it can capture a broad range of frequencies, such as beluga social calls, broadband calls, and echolocation clicks, ensuring vocalizations were not missed. The duty cycle was set to record 7 minutes every hour. The CTD measured conductivity, turbidity, salinity, and temperature in five-minute intervals.

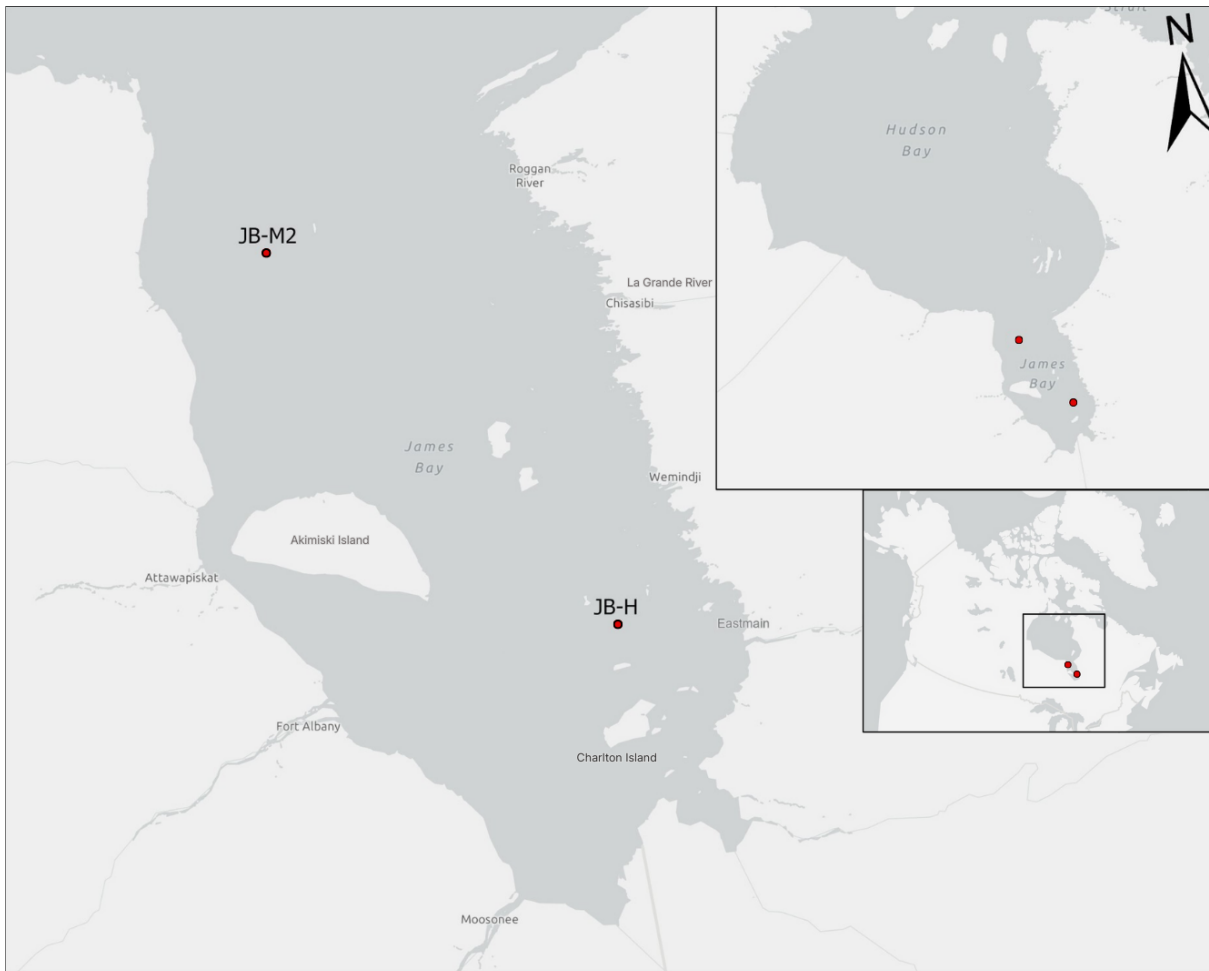


Figure 2.1 Map of the mooring locations deployed and retrieved in James Bay. JB-M2 was deployed in August 2021 and retrieved in August 2022 while JB-H was deployed in August 2022 and retrieved in August 2023.

Table 2.1 Location, deployment dates, approximate water depth, hydrophone depth, and CTD depth, and number of 7-min acoustic files for each hydrophone deployed in James Bay between the years 2022-2024.

Location	Latitude	Longitude	Start Date	End Date	Water Depth (m)	Hydrophone Depth (m)	Number of files	CTD Depth (m)
JB-M2 north west	54.166	81.287	2021-08-16	2022-08-19	62	59	8830	41
JB-H south east	52.431	79.408	2022-08-16	2023-08-15	80	62	8705	63

2.3.3 Acoustics

2.3.3.1 Sound Analysis Detector

An automatic detector was run using an R script in R software v4.3.2. Data curation and graphical outputs were also done using R and RStudio. Beluga presence was determined by detecting clicks within each sound file. Recordings were first filtered using a 30-75 kHz band-pass filter to eliminate other frequencies outside the typical range of beluga clicks. Click detections were then carried out using an automatic click detector that identifies beluga clicks based on the Teager-Kaiser Energy Operator (Marcoux et al., 2017; Roy et al., 2010; Scharffenberg et al., 2019). The TKEO was applied to the signal to enhance signal-to-noise ratio. A rolling average was then calculated by averaging a signal over 5 samples to reduce random noises. An amplitude threshold was used to find the start and end of clicks, and a value of 125 was empirically selected to optimize detection and avoid false ones. The time of the start of the click, end of the click, and the inter click interval were saved for each click detection (details on detector in Roy et al., 2010). Additionally, <1% of files at the northwestern could not be run using the TKEO based detector and were analysed manually (see below for details on manual inspections of files).

2.3.3.2 Presence/Absence Validation

The goal of this detector was not to count the number of clicks, but rather to assess the presence/absence of beluga detection in a sound file. Ten percent of all files were verified manually to determine the detector performance by systematically inspecting 1 file every 10. Sound files were manually analyzed in Raven Pro V1.6.5 where they were analyzed using a 512-point Hann window with 50% overlap and a 2048-point DFT. This produces a time resolution of 2.7 ms and a frequency resolution of 47 Hz. Manual analyses were used to verify the presence/absence of beluga clicks in a sound file, i.e. a file was classified as true positive (TP) if the detector identified a minimum number of clicks (see below) and the presence of clicks was verified manually. Similarly, files were classified as true negative (TN), false positives (FP) and false negative (FN) depending on whether the presence/absence of beluga click matched the detector findings. A majority of files that were classified as FP contained a small number of detected clicks due to background noise. To determine an appropriate threshold for the minimum number of click detections per file, we used an error trade-off approach that minimized FP while maximizing true positives (TP) by evaluating a range of cutoff values. Density plots were used to visually identify the cutoff. Lastly, accuracy, precision and recall were calculated based on the cutoff calculated above (Equations 1-3). Accuracy allows us to understand how well the detector is performing, specifically how well it is able to detect both files with beluga clicks and without beluga clicks. Precision focuses on positive occurrences, specifically the proportion of true positive predictions out of all predicted positive instances (low precision = high false positive rate). Recall focuses on how many of the actual positives were correctly predicted.

$$(1) \textit{Accuracy} = (\text{True Positive} + \text{True Negative}) / (\text{True Positive} + \text{False Positive} + \text{True Negative} + \text{False Negative})$$

$$(2) \textit{Precision} = (\text{True Positive}) / (\text{True Positive} + \text{False Positive})$$

$$(3) \textit{Recall} = (\text{True Positive}) / (\text{True Positive} + \text{False Negative})$$

2.3.3.3 Proportion of Presence

In order to determine the year-round presence of beluga for each recording year we first determined the daily proportion of presence. We calculated the total recording hours in the day, which theoretically was 24 recording hours; however, some days had corrupt sound files, and the deployment and retrieval days included fewer recording hours. The proportion of presence was then calculated by dividing the number of hours with click vocalizations by the total number of recording hours (Equation 4).

$$(4) \text{ Proportion of Presence} = \frac{\text{Number of hours with vocalizations}}{\text{Total number of recording hours in day}}$$

2.3.4 Environmental Covariates

To better understand beluga click presence, we collected salinity and sea surface temperature at the mooring location and sea ice concentration within a 2.5 km radius around the hydrophone. This value was chosen based off previous studies examining the distance at which communicative calls travel in noisy conditions (Coppolaro et al., 2024; Eickmeier & Vallarta, 2023; Halliday et al., 2019; Scharffenberg et al., 2019).

2.3.4.1 Sea Ice

The dataset used for sea ice concentration came from the archived ice charts from Canadian Ice Service Digital Archives, hereafter referred to as CSIDA. This data includes weekly regional ice charts in the Hudson Bay area. The CSIDA integrate data from satellite remote, aerial reconnaissance survey, ship-based observations, and results of operational models. Furthermore, experts incorporate both real time observations and delayed data sources not immediately available to refine incomplete data (Galley et al., 2012; Tivy et al., 2011). Ice charts are composed of weekly polygons that represent the total ice concentration, in the form of tenths. In cases where multiple polygons fell within the radius where we collected data, the values were averaged to calculate a mean ice concentration for the week. For example, occasionally during winter the land fast ice edge and pack ice fell within the radius area. Ice

charts were downloaded as shapefiles (shp) and analyzed in ArcGIS Pro 2.9.8. Ice concentration values (0/10-10/10) were then classified into freeze-up, break-up, ice cover, and open water. Ice concentration related to seasonality was separated into fall/winter and spring, then subsequently defined as winter freeze-up (occurred when ice concentration went from 15% to 80%), ice covered (occurred at >80%), spring break-up (occurred when ice concentration dropped from 80% to 15%), and open water (occurred at <15%) (Bliss et al., 2019; Cavalieri et al., 1999; Coppolaro et al., 2024; Walsh et al., 2022). Importantly, the “freeze-up” category did not apply at the JB-M2 location under the defined criteria and was not included in the analysis (concentration 15-80%).

Table 2.2 Sea ice concentration values and associated seasonal definition.

Ice Concentration (tenths)	CSI Category	Seasonal Definition	
		Fall/Winter	Spring
0/10	Open water	Open water	Open water
1/10	Very open drift	Open water / freeze-up begins	Break-up
2/10	Very open drift	Freeze-up	Break-up
3/10	Very open drift	Freeze-up	Break-up
4/10	Open drift	Freeze-up	Break-up
5/10	Open drift	Freeze-up	Break-up
6/10	Open drift	Freeze-up	Break-up
7/10	Close pack	Freeze-up	Break-up
8/10	Close pack	Ice cover begins	Break-up begins
9/10	Very close pack	Ice cover	Ice cover
9+/10	Very close pack	Ice cover	Ice cover
10/10	Fast ice	Ice cover	Ice cover

In addition to accounting for sea ice at each mooring location within the 2.5 km radius, we examined sea ice dynamics over the entirety of James Bay across the 2021-22 and 2022-23 years. We followed the same total ice concentration values from the CSIDA archived charts, but rather than using a 2.5 km radius to determine sea ice concentration, we used the presence of landfast ice as the marker for the first week of ice freeze-up, in this case landfast ice freeze-up.

By identifying the week of landfast freeze-up we could then use maps starting at this week to examine sea ice in James Bay up until the week of landfast ice break-up. NASA Worldview satellite imaging was used to assist in confirming these dates. The goal of this analysis was to understand beluga movement in relation to sea ice concentration.

2.3.4.2 Sea Surface Temperature

Sea surface temperature, hereafter referred to as SST, data was obtained from Climate Data Store, using the OSTIA ERA5 CDS dataset. This dataset includes daily sea surface temperature measurements at approximately 5 km x 5 km grid resolution, using both in situ and satellite data. Average daily SST for each mooring was obtained by documenting SST within a 2.5 km radius of the hydrophone.

2.3.4.3 Salinity

Salinity measurements were taken in 5-minute increments from the attached RBR XR-420 devices at a depth of ~41 (JB-M2) and ~63 (JB-H) on the oceanographic moorings. Ruskin Software v2.23.1 and MATLAB v2025a (The MathWorks Inc., 2025) were used to extract these measurements. Salinity values were grouped by day and averaged to get a mean value per day (Figure S2.3).

2.3.5 Data Analysis

A generalized linear model with a binomial distribution for proportional data was the best fitting model used to look at the effects of selected environmental parameters on proportion of beluga presence. We determined that using two separate models would be more appropriate because we expected that environmental effects at each location would affect beluga presence differently. Daily proportion of beluga presence was used as the response variable with all environmental parameters (i.e., ice concentration, SST, salinity) as predictor variables. The total hours recorded per day were used as a weighting factor, meaning days with more hours contributed more weight than days with fewer hours (i.e. deployment and retrieval days). Using

the dredge function from the MuMIn package in R (v1.48.4; Barton, 2025), we evaluated all possible versions of the full model and calculated corrected Akaike Information Criteria (AIC) values (Table S2.1, Table S2.4).

To better understand the association between the covariate and proportion of beluga presence we fit one model per covariate, which we refer to as an unadjusted model for that covariate, and compared these to an adjusted model including all covariates to assess the potential influence of multicollinearity (Table S2.2, Table S2.5, Figure S2.4, Figure S2.5, Figure S2.6, Figure S2.8, Figure S2.9, Figure S2.10). Comparing results from individual covariate models to the fully adjusted model, allowed us to assess potential confounding or shared explanatory power among environmental variables, which can suggest correlation among covariates. Confidence intervals were compared between adjusted and unadjusted models to assess the stability of the environmental parameter effects. In addition to assessing the confidence intervals, standard errors were also reviewed to further understand the precision of the estimates. After assessing these factors across both adjusted and unadjusted models, key environmental parameters could be selected for inclusion in the final adjusted model (Table S2.3, Table S2.6).

2.4 Results

2.4.1 Detector Accuracy

We determined a cut off value for the detector that would minimize FP and maximize TP. For the southeastern mooring (JB-H), this threshold was marked at 475 clicks, therefore we corrected any files below 475 total clicks that were classified as present to absent (Figure 2.2, Table 2.3). For the northwestern mooring (JB-M2), this threshold was marked at 350 clicks, therefore we corrected any files below 350 total clicks that were classified as present to absent (Figure 2.2, Table 2.3). The additional <1% of files from this region that did not run through the detector were removed from the final analysis because the number of clicks could not be

accounted for and therefore not included in the threshold cutoff. Accuracy, precision and recall at the northwest location were calculated on 10% (869) of the files that were manually inspected and were determined as 0.67, 0.48, and 1, respectively. Similarly, accuracy, precision and recall were calculated on the 10% manually analyzed southeast files (870) and were determined as 0.82, 0.67, and 1, respectively.

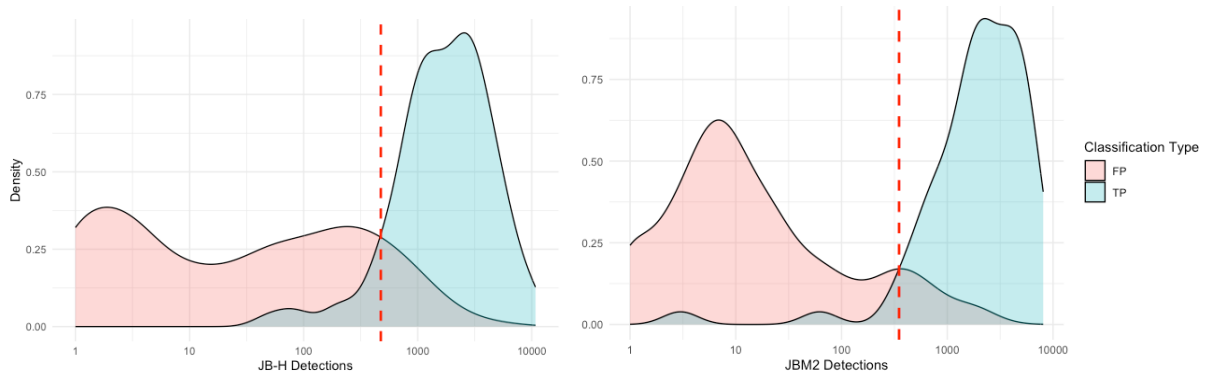


Figure 2.2 JB-H and JB-M2 false positive (FP) vs true positive (TP) plot to determine the cutoff for clicks that can be determined as beluga. Red vertical dashed line shows value for JB-H on the left (cutoff=475) and JB-M2 on the right (cutoff =350).

Table 2.3 Breakdown of the 10% manual analysis. Numerical values represent the total number of files with the associated classification at each hydrophone location. TN are true negatives, TP are true positives, FN are false negatives and FP are false positives.

Classification	JB-M2 (<350)	JB-H (<475)
TN	73	184
TP	62	144
FN	0	0
FP	68	70

2.4.2 Beluga Detections

2.4.2.1 JB-M2 2021-22 – Northwest

Beluga presence was found year-round at this location, with more detections occurring in fall (2021) and summer (2022). Between August 16, 2021, and August 16, 2022, 8692 recordings were analyzed. Across the study period, 68.9% days had documented beluga clicks present (Figure 2.3). Based on the spread of presence, there is strong variation among seasons. There are two prominent peaks of presence throughout this year, first, in October as SST begins to drop, presence gradually increases reaching a presence greater than 50% then drop before sea ice forms (Figure 2.3). Secondly, another peak of presence occurs during June and July as sea ice break-up is occurring, reaching above 80% presence (Figure 2.3). Between these two peaks are months dominated by sea ice, during which beluga presence is quite low (Figure 2.3).

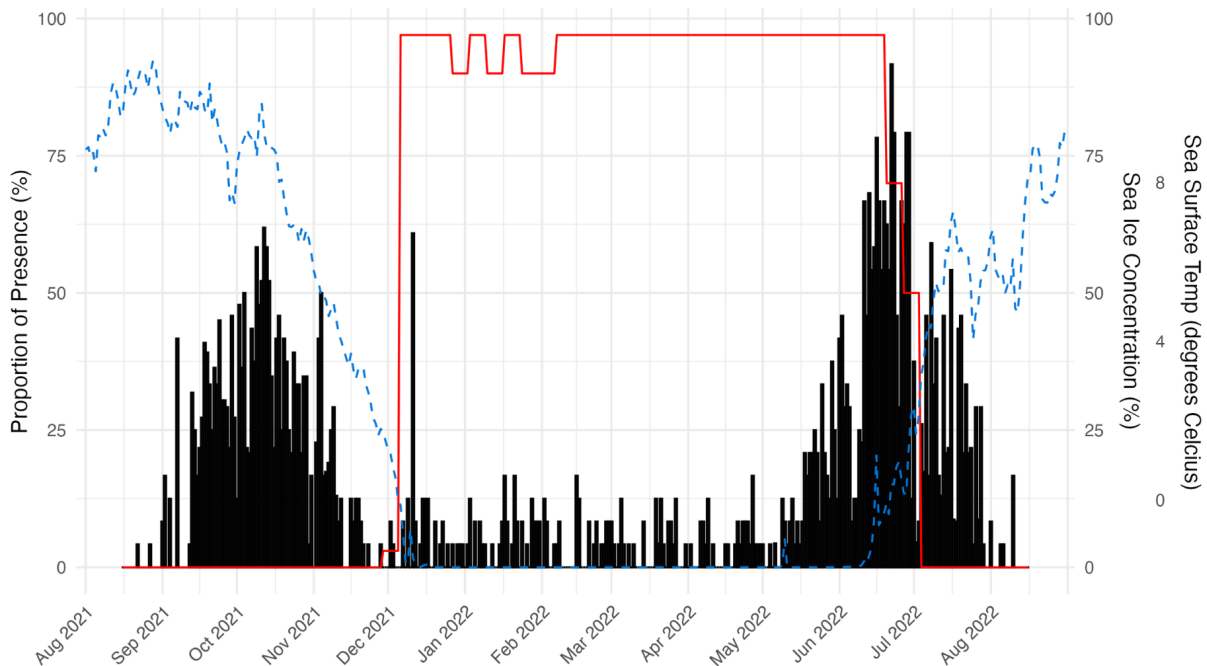


Figure 2.3 Daily proportion of beluga presence and sea ice concentration from August 2021 to August 2022 at mooring location JB-M2. Daily proportion of presence (%) is on the primary y axis. Sea ice concentration (%) is outlined by the line in red on the secondary y axis and is using values from Canadian Ice Service Archived Charts. Sea surface temperature (°C) is outlined by the dashed blue line on the secondary y axis and is data from OSTIA.

2.4.2.2 JB-H 2022-23 - Southeast

Similar to the northwest, beluga presence was found year-round at this location; however, most detections were found in fall (2022), December (2022), and June (2023). Notably, unlike the northwest, more detections occurred throughout the winter months. Between August 16, 2022, to August 14, 2023, 8704 recordings were analyzed. Across the study period, 84.6% days had documented beluga clicks present (Figure 2.4). Presence across this time period showed, three, potentially four prominent peaks of presence, similarly to JB-M2, showing strong seasonal variation. Similarly to JB-M2 there is a gradual increase in presence during October, reaching greater than 50%. Following this increase there is a gradual drop as SST begins to decline and before sea ice freeze-up. The second peak aligns with sea ice freeze-up during December and January reaching up to 100% presence. Once sea ice prominently dominated the region, presence began to decrease throughout January however there is a third and brief peak in February reaching 90% presence. Lastly, and similarly to JB-M2 the final peak happens in June coinciding with sea ice break-up.

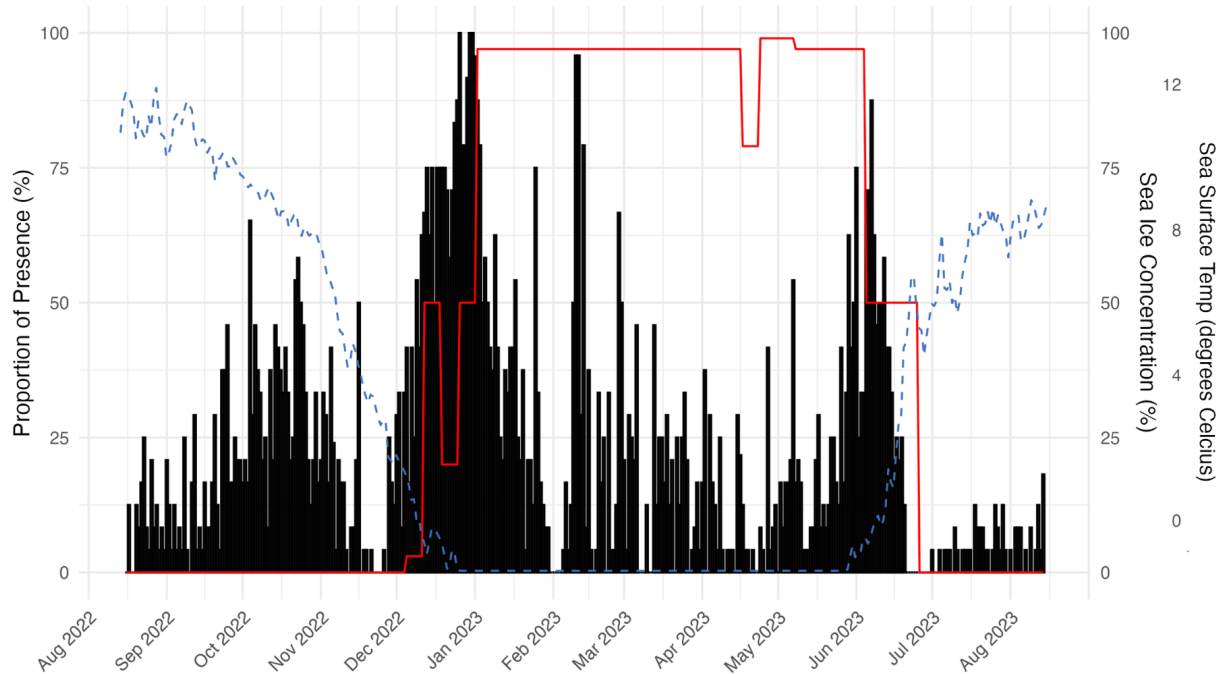


Figure 2.4 Daily proportion of beluga presence and sea ice concentration from August 2022 to August 2023 at mooring location JB-H. Daily proportion of presence (%) is on the primary y axis. Sea ice concentration (%) is outlined by the line in red on the secondary y axis and is using values from Canadian Ice Service Archived Charts. Sea surface temperature (°C) is outlined by the dashed blue line on the secondary y axis and is data from OSTIA.

2.4.3 Environmental Covariates & Model

2.4.3.1 Adjusted vs Unadjusted Models

Based on AIC values, weight, and R2 values, the full model including all covariates was initially selected for both models (JB-H and JB-M2). However, when comparing the adjusted vs unadjusted models to assess multicollinearity, it was determined that salinity was not significant in the JBM2 northwestern full model ($p > 0.1$; Figure 2.5). In addition, there was multicollinearity between salinity and ice category covariates in the JB-H southeastern full model (Figure 2.6). As result, we excluded salinity from the JB-H analysis as well.

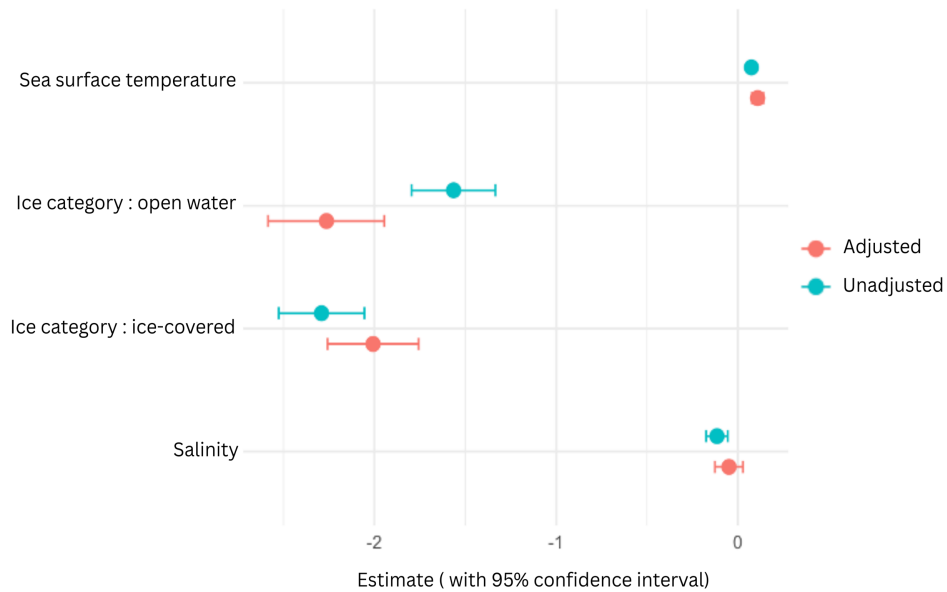


Figure 2.5 Comparison of adjusted and unadjusted models, beluga presence response to environmental variables at site JB-M2. The red horizontal lines are the 95% confidence interval values for that covariates estimate from the JB-M2 full model, labelled as adjusted. The blue horizontal lines are the confidence interval values for that covariates estimate from each individual JB-M2 model, labelled as unadjusted.

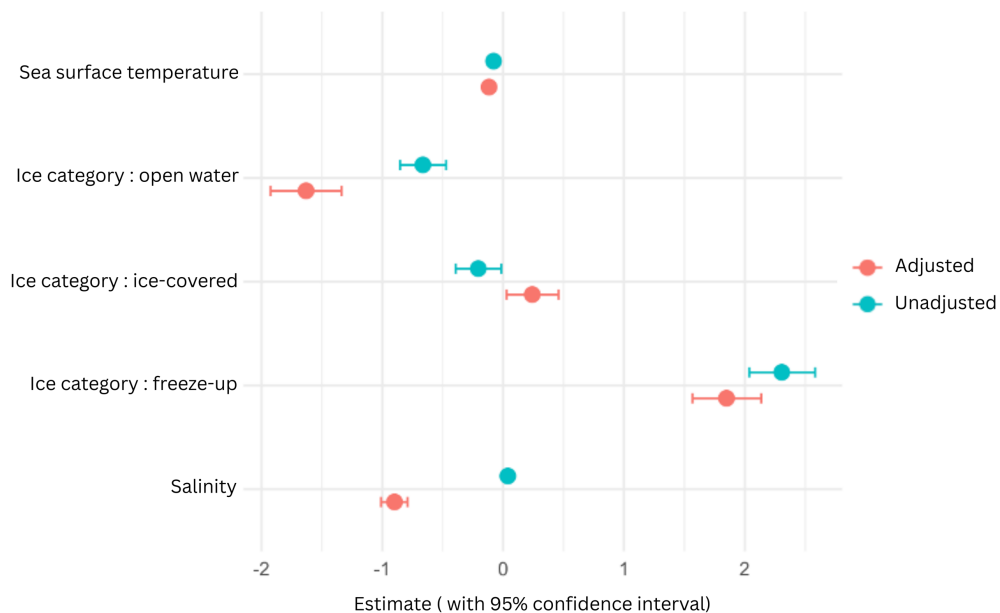


Figure 2.6 Comparison of adjusted and unadjusted models, beluga presence response to environmental variables at site JB-H. The red horizontal lines are the 95% confidence interval values for that covariates estimate from the JB-H full model, labelled as adjusted. The blue horizontal lines are the confidence interval values for that covariates estimate from each individual JB-H model, labelled as unadjusted.

2.4.3.1 JBM2 2021-22 – Northwest

The model that best explained beluga vocal activity included the variables sea ice concentration and sea surface temperature (AIC= 2578, $R^2 = 0.14$). Beluga vocal presence was less likely during periods of ice cover, defined as when ice concentration is >80% ($p < 0.001$). Beluga vocal presence was also less likely during the open water periods, defined as when ice concentration is <15% ($p < 0.001$). Sea surface temperature had a positive effect on beluga vocal presence, where clicks were more likely to be detected with increasing sea surface temperature ($p < 0.001$).

2.4.3.2 JBH 2022-23 - Southeast

Similarly to the JB-M2 location, the model that best explained beluga vocal activity included the variables sea ice concentration and sea surface temperature (AIC = 2897.2, $R^2 = 0.26$). Beluga vocal presence was less likely during periods of ice cover, defined when ice concentration is >80% ($p < 0.001$). Beluga vocal presence was also less likely during the open water periods, defined as when ice concentration is <15% ($p < 0.001$). Ice freeze-up had a strong positive effect on beluga clicks (concentration 15-80%; $p < 0.001$). The proportion of beluga presence was highest during ice freeze-up at the JB-H location. Sea surface temperature had a negative effect on beluga vocal presence, meaning clicks were more likely to be detected in warmer temperatures (i.e. spring and summer) ($p < 0.001$).

2.4.4 Sea Ice Spatial Analysis

2.4.4.1 JBM2 2021-22 – Northwest

During winter 2021-2022, the week of landfast ice freeze-up across James Bay was December 6th, 2021, and landfast ice break-up was June 13, 2022. Beluga click vocal presence appeared to decrease as sea ice developed (refer to Table S2.7 for exact proportions and fluctuations per week). The largest drop in proportion of presence among these weeks occurred during the weeks following landfast ice freeze-up (December 6 - 12 to December 13 - 19). After January, sea ice concentration reached high concentrations and there was a further drop in the

proportion of beluga presence, specifically from January 31 to February 7 (Figure 2.7). In January and March 2022, the coastline near the mooring had a lower ice concentration, and we saw a general increase in the proportion of beluga presence (Figure 2.7). The largest increase in proportion of presence occurred from weeks May 9-15 to May 16 – 22. During this time, sea ice concentration began to decrease in areas surrounding the hydrophone location. Following these weeks, sea ice concentration decreased.

2.4.4.2 JBH 2022-23 - Southeast

During winter 2022-23, the week of landfast ice freeze-up in James Bay was about 20 days later than in the previous year, specifically December 26th, 2022, and landfast ice break-up was more than a week earlier at June 5th, 2023. The proportion of presence was highest during landfast ice freeze-up and landfast ice break-up (refer to Table S2.7 for exact proportions and fluctuations per week). However, beluga vocal presence generally remained high throughout the ice-covered period, despite high ice concentration (Figure 2.7). This contrasts sharply with the northwest location. From the week of January 23 - 29 to the following week, January 30 - February 5, ice concentration across the Bay increased to >90% and during this time we saw the largest decrease in proportion of presence (Figure 2.7). From January 23 - 29 there was an area of lower ice concentration in the southwest region of the Bay; however, the following week saw a return to high ice concentrations, and this is when the decrease in vocal presence occurs (Figure 2.7). Quickly following the decrease in vocal presence in late January, we saw the largest increase in proportion of presence between the week of January 30 - February 5 and the following week, February 6 – 12. During this time period, ice concentration was at 9.7 and higher, with no evidence of low ice concentration or polynyas/open water in CIS chart data (Figure 2.7). From February 27 - March 5 to the following week, March 6 – 12, ice concentration decreased on the west coast of the Bay extending to the south within close proximity to hydrophone location, and notably there was a small decrease in proportion of presence (Figure 2.7). During the weeks March 27 - April 2 and April 17 – 23, ice concentration lowered between

40-80% in the northeast region of the bay extending south to the hydrophone location, and proportion of presence increased (Figure 2.7).

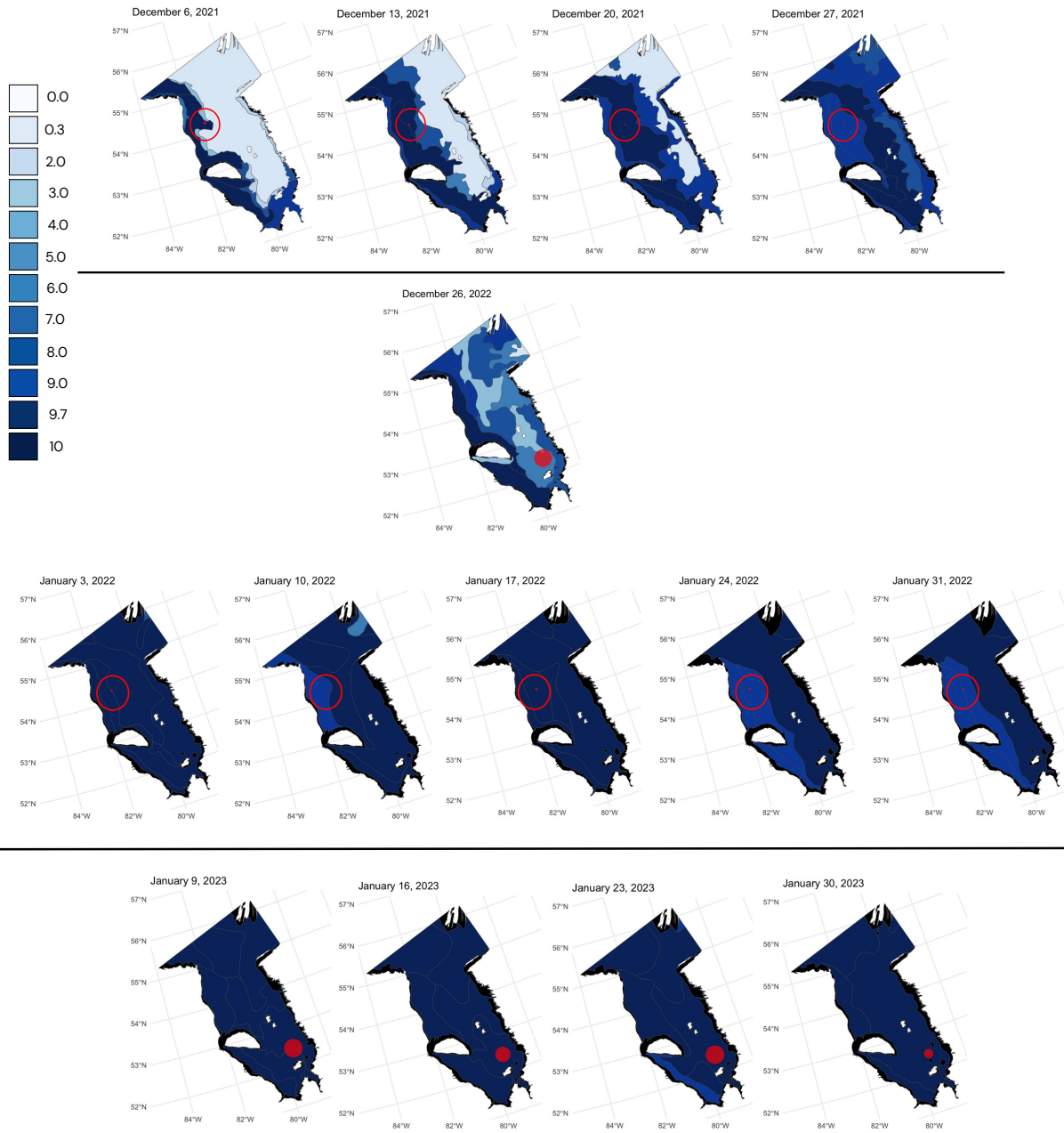


Figure 2.7 The individual maps represent the corresponding week from the Canadian Ice Service Archived Charts, with coloured sections representing the sea ice concentration in that region. The red dot represents the weekly proportion of beluga presence where the size of the dot matches the size of the proportion. If the proportion of presence is <0.20 then it is outlined by a red circle. Each row represents a month from December 2021 and 2022 to June 2021 and 2022, with the 2021-22 year diagrams on top of the 2022-23 diagrams, the black line delineates this separation.

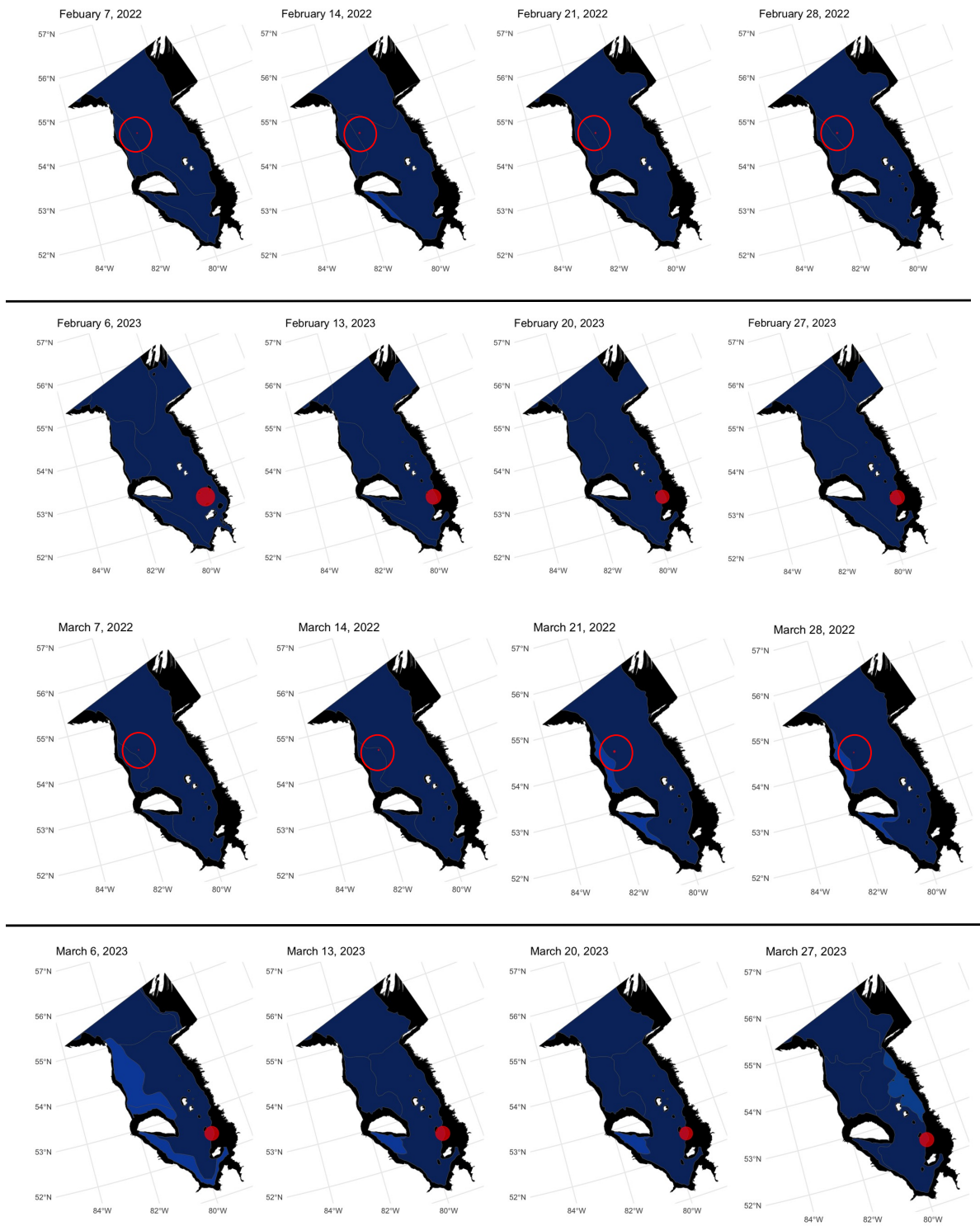


Figure 2.7 (continued) The individual maps represent the corresponding week from the Canadian Ice Service Archived Charts, with coloured sections representing the sea ice concentration in that region. The red dot represents the weekly proportion of beluga presence where the size of the dot matches the size of the proportion. If the proportion of presence is <0.20 then it is outlined by a red circle. Each row represents a month from December 2021 and 2022 to June 2021 and 2022, with the 2021-22 year diagrams on top of the 2022-23 diagrams, the black line delineates this separation.

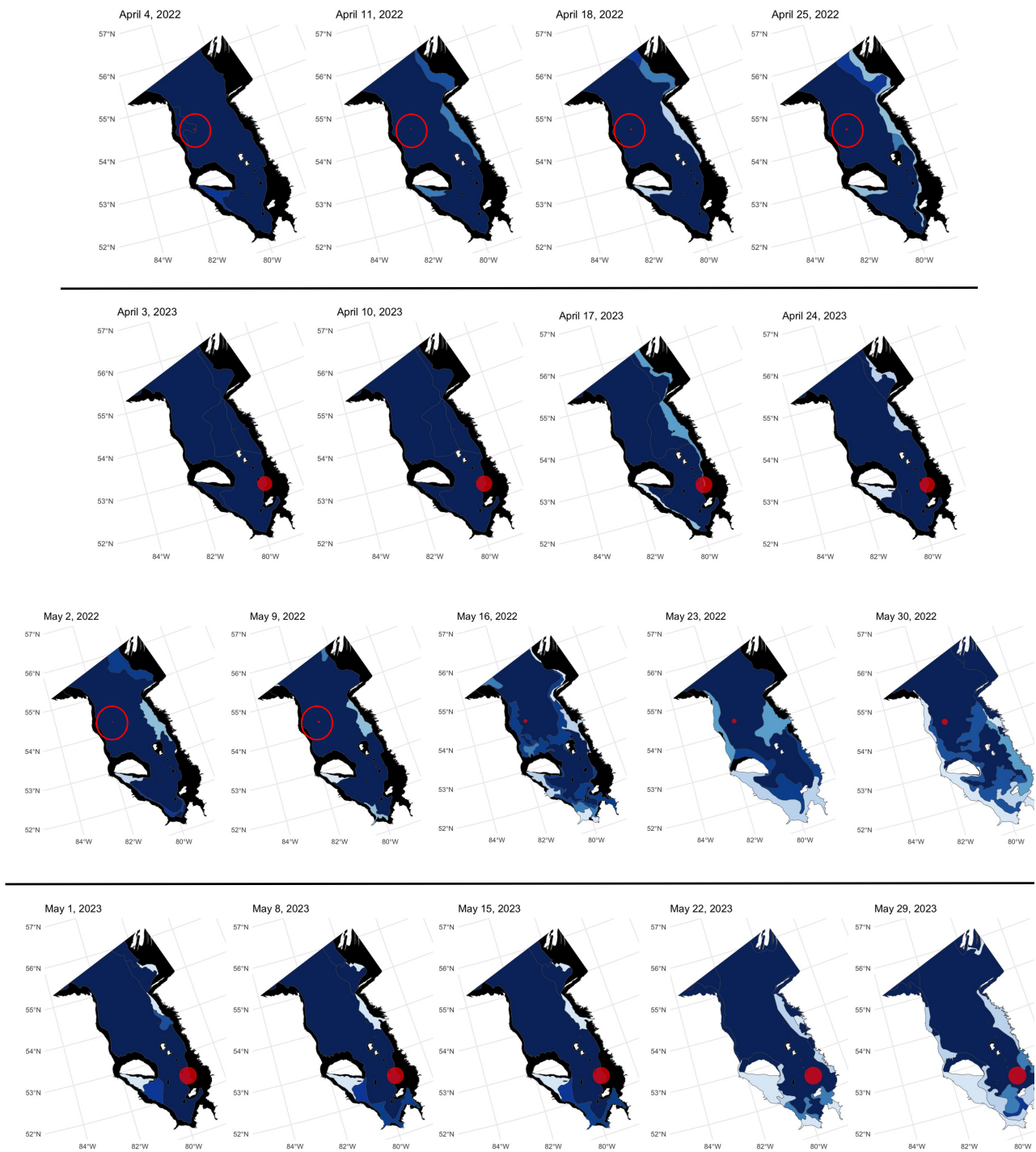


Figure 2.7 (continued) The individual maps represent the corresponding week from the Canadian Ice Service Archived Charts, with coloured sections representing the sea ice concentration in that region. The red dot represents the weekly proportion of beluga presence where the size of the dot matches the size of the proportion. If the proportion of presence is <0.20 then it is outlined by a red circle. Each row represents a month from December 2021 and 2022 to June 2021 and 2022, with the 2021-22 year diagrams on top of the 2022-23 diagrams, the black line delineates this separation.

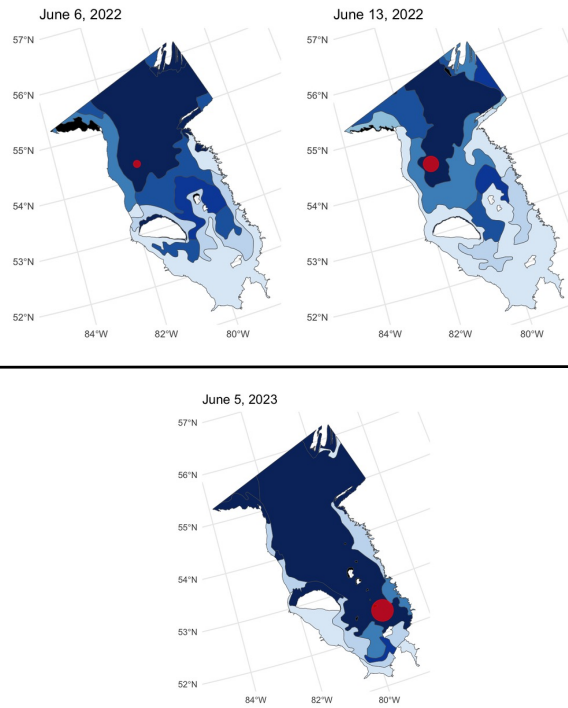


Figure 2.7 (continued) The individual maps represent the corresponding week from the Canadian Ice Service Archived Charts, with coloured sections representing the sea ice concentration in that region. The red dot represents the weekly proportion of beluga presence where the size of the dot matches the size of the proportion. If the proportion of presence is <0.20 then it is outlined by a red circle. Each row represents a month from December 2021 and 2022 to June 2021 and 2022, with the 2021-22 year diagrams on top of the 2022-23 diagrams, the black line delineates this separation.

2.5 Discussion

Our results highlight that beluga in this region remain year-round in James Bay in changing environmental conditions. In this study, PAM was used to determine the year-round presence of the James Bay beluga population. This data was then combined with time series of water temperatures and sea ice concentrations at northern and southern regions. This approach allowed us to conduct an analysis of beluga presence proportions in relation to environmental factors including sea ice concentration, salinity, and SST. Differences were observed in the two regions, whereby beluga clicks were present in 68.9% of days in the northwest region. Sea ice concentration did have an effect on beluga presence, with clicks occurring most during sea ice break-up and open water periods, and only minimally during ice cover. Additionally, beluga click activity in this region increased with rising SST. On the other hand, the southeast site had 84.6% of days documented with beluga clicks present, with beluga clicks occurring most during ice freeze-up and continuing during periods of ice cover. Additionally, click activity in this region increased as SST declined.

2.5.1 Environmental Drivers

Although sea ice development and break-up have been associated with beluga migration timing, previous findings have found it not to be the primary driver but rather sea surface temperature, a pattern reflected in our findings. Sea ice often affects beluga distribution due to an increased risk of entrapment (Higdon et al., 2023). As sea ice takes over shallow regions, including tidal flats, beluga are forced to relocate from summer aggregating areas to their winter areas, including deeper water, with more available open water rather than increasing sea ice coverage. This pattern may be reflected in our findings at the southeastern mooring. As sea ice-freeze up was occurring click presence increases, indicating that beluga could be getting pushed from coastal regions to the edge of the landfast ice. Similarly, at the northwest mooring, click presence and sea ice had a negative relationship, whereby beluga were not detected as frequently in winter months suggesting sea ice could be a limiting factor in this area. This site

was ~50-60 km off the coastline, where high concentrations of ice floes with ≤ 1 m thickness keep drifting with the wind and currents from January to May (Taha et al., 2019). Although migration is a common behavioural adaptation by beluga, it is not done by all populations, including ones in Cook Inlet, and Cumberland Sound, which tend to travel shorter distances to the mouth of the fjord and back (Castellote et al., 2020; Marcoux et al., 2017; Rugh et al., 2005), and the one in the St. Lawrence Estuary, which shifts seasonally from the upper estuary to the lower estuary (Harvey et al., 2025). Based on the new data, the James Bay population appears to follow these trends and travelling short distances within the region year-round. The simplest explanation for the regular, nearly daily detections of beluga clicks from December – May at the southeastern site is that beluga were actively transiting through this area on a regular basis. This is not consistent with expectations for a population with a large-scale seasonal migration pattern.

Observations from coastal communities reinforce the year-round presence of James Bay beluga (McDonald et al., 1997) as do results of previous Fisheries and Oceans Canada (DFO) aerial surveys and findings from Bailleul et al. (2012) using tagged beluga data. Community observations found that in October, beluga were present in the southern waters of James Bay around Moose Factory and Hannah Bay (McDonald et al., 1997). In months following sea ice break-up as open water expands, beluga were observed by communities first in western James Bay near Attawapiskat and Moose Factory and travelling to open water areas in the Charlton Island area (McDonald et al., 1959). Studies on Pacific Arctic beluga populations indicate that an overall decline in sea ice extent is causing beluga to inhabit summer aggregating zones for longer periods of time, suggesting onset of freeze-up of ice is associated with the migration timing in beluga (Hauser et al., 2014, 2017, 2018; Heide-Jørgensen et al., 2010). Although beluga presence persists year-round during high sea ice concentrations, there are fluctuations of presence and absence in both high and low ice concentrations which is also demonstrated through our model results. Landfast ice, specifically during landfast ice freeze-up, may directly

impact beluga presence and movements however can also be a factor that influences/changes the surrounding environment, indirectly affecting beluga presence.

Sea surface temperature was a significant driver of beluga vocal presence but trends at each hydrophone location differed. During the year 2021-22 at the northwest location, clicks increased as temperature increased whereas in the 2022-23 year at the southeast location, clicks increased as temperature decreased. Beluga estuary use has been linked to warmer water temperatures, hypothesized to be due to thermal advantages used in moulting and calving activity (Ausen et al., 2023; Scharffenberg et al., 2019). Higher click presence in the southern region of the Bay with decreasing temperatures demonstrates that beluga whales are using this area primarily during the winter months as sea ice develops and remain present during high concentrations of sea ice cover. Similarly, in a previous study done in James Bay in the same southeast region, results found that beluga preferred a warm, shallow water habitat with a strong stratification during summer; however, as temperatures dropped in winter months, presence remained, and diving behaviour increased (Bailleul et al., 2012a). Increased diving behaviour suggests active beluga foraging, while a seasonal shift in diving depth indicates a shift in prey from warmer to cooler months, or potentially accessing warmer subsurface waters (Bailleul et al., 2012a). This shift creates a trade-off between foraging success and energy expenditure, as deeper dives are more energetically costly however the payoff may be better for larger fish compared to smaller shallow fish (Watt et al., 2016). Similar prey shifts in beluga have been seen in other populations such as Cumberland Sound (Watt et al., 2016). A high click presence during winter months, specifically in the southeast, considered together with evidence of increased diving behaviour (Bailleul et al., 2012a), suggests sufficient prey availability under ice covered conditions. As the Arctic and Subarctic waters continue to warm, understanding prey distribution is increasingly important as southern species start to shift north as sea ice decreases; an example of this is capelin, whose northward movements have been documented (Gaston et al., 2003), potentially affecting beluga distribution.

In contrast to the southeast, presence of beluga clicks at the northwest hydrophone was associated with warmer sea surface temperatures, suggesting this area may be preferred as a summering area. These results are supported by the findings of past DFO aerial surveys. Surveys of James Bay took place in 1985, 1993, 2001, 2004, 2008, 2011, 2015, 2021, and 2024 during the months July and/or August (Gosselin et al., 2009, 2013, 2017; Kingsley, 2000; Smith & Hammill, 1986; St-Pierre et al., 2023). A common finding amongst the surveys was the high sighting occurrence in the northwest region of the Bay along the western coastline. Some of these detections were made at the same latitudinal position as the mooring from our study (JB-M2), but closer proximity to the coast and not in close enough range to the hydrophone to be able to pick up vocalizations. In the most recent survey (2024), few detections were made in the region of the southeast mooring, however; there seemed to be many sightings surrounding Akimiski Island and southwest of Charlton Island (Sauve et al., 2024). In previous years, sightings of beluga near the major river mouths appeared to be limited. Additionally, in survey years prior to 2024, sightings in the southeast region were far fewer compared to the northwest, although groups were consistently documented southwest of Charlton Island (Sauve et al., 2024). Overall, most group sightings throughout July and August occurred in the northwest region of the Bay suggesting that this area serves as a common aggregating area for the population(s).

Salinity is often considered a potential proxy of presence of beluga in summer aggregation (Aubin et al., 1990; Moore et al., 2000; Scharffenberg et al., 2019; Smith et al., 2017). We hypothesized that salinity would have varying impacts on click presence at hydrophone locations due to high freshwater input on the eastern coast. However, no significant impact on clicks was found. Although salinity did not drive variation in beluga click presence between locations and years, there were differences between hydrophone locations, with higher year-round values at the northwest location compared to the southeast. This is consistent with higher freshwater discharge coming from the eastern coast. An important note to this finding is

that salinity measurements were not taken at the surface like temperature but rather at the depth of the devices on the mooring (~41 and ~63 m at NW and SE, respectively; Table 2.1). This means that salinity measurements represent subsurface (intermediate) waters, which would tend to increase in salinity throughout winter as sea ice releases brine into the surface layer and river discharge reaches seasonal lows (cf., De Melo et al., 2022). Had salinity been measured throughout the year at the surface, it would have recorded a decrease from winter to summer as river input creates a plume of less saline water causing a stratification due to density differences (Eastwood et al., 2020; Meilleur et al., 2023).

2.5.2 Spatial and temporal variation in beluga presence

Beluga presence at the southeast location showed a pattern of potential movements along the eastern coast based on fluctuating sea ice concentration values at the landfast ice edge, La Grande River plume, northern polynya and general packed ice regions. In contrast, the northwest location had very little presence even in changing sea ice concentrations until landfast sea ice break-up occurred in the spring. Spatial analysis demonstrates that beluga presence exhibits a shift in distribution seasonally. Specifically, in winter months showing a lack in presence in the northwestern region of the Bay and a north to south distribution along the western coast of the Bay. Based on the seasonal movement patterns found in this analysis, hypotheses regarding population dynamics surfaced. Specifically, the possibility of segregation determined by the lack in click presence at the northwestern location and the abundance of click presence in the southeast during winter. Although the James Bay beluga population is genetically distinct from the Hudson Bay complex stocks, segregation within James Bay could be possible based on seasonality distribution and patterns. A recent study exploring the distinct genetic differences and population sizes across Atlantic beluga populations found genetic differences in the beluga located in James Bay (Müller et al., 2025). Those sampled in the south were genetically distinct and a part of the James Bay population, whereas those sampled in the

north were classified as Hudson Bay beluga, specifically from Eastern Hudson Bay (Müller et al., 2025). The lack of click presence at the northwest location during ice freeze-up and ice-covered months and increase in click presence with warming sea surface temperatures complement Müller et al. (2025) findings. Beluga in eastern and western Hudson Bay migrate to the Hudson Strait during the fall as sea ice develops and return back to summer aggregation areas in the spring as sea surface temperatures warm. These known migrations of both Hudson Bay beluga populations, together with our findings of decrease click presence during sea ice-freeze-up at the northwestern location, limited winter click activity and increased in click presence during sea ice break-up, suggest that the northwestern region may also be used by Eastern Hudson Bay beluga rather than only James Bay beluga.

2.5.4 Detector Accuracy

The results of this study confirm the effectiveness of the detector function with accuracy values of 0.82 and 0.67, precision values of 0.48, and 0.67, and recall values of 1. Overall, these detector values fall within range of the same reported values in previous studies, even with variation across hydrophone locations (Booy et al., 2021; Halliday et al., 2017; Scharffenberg et al., 2025). Ambient noise was evident specifically at the southeast location during most times of the year, whereas the northwest location did not always show the same noise levels. The same detector parameters were used at each location therefore it is possible there could have been an overestimation of clicks at the northwest site as we made sure the clicks would be clearly detected in higher noise levels at this location.

2.5.5 Limitations and Future Directions

Recording underwater sounds has both benefits and limitations; for example, we can only detect beluga if they are vocalizing. Furthermore, this study only used click vocalizations, even though beluga emit many call types (ex. Whistles and broadband pulses; Chmelnitsky & Ferguson,

2012; O'corry-Crowe, 2009; E. M. Panova et al., 2012; Sjare & Smith, 1986). This would tend to underestimate total beluga presence.

Beluga must also be within a certain distance of the hydrophone to be detected. We did not measure the distance directly at which beluga click vocalization can be heard; however, previous studies have detected beluga within 2.5 km of a hydrophone in a range of conditions (Coppolaro et al., 2024; Eickmeier & Vallarta, 2023; Halliday et al., 2019; Scharffenberg et al., 2019). Future work should continue to use hydrophones as a method to better understand this marine mammals behaviour as we can use this data to improve comprehension on the presence/absence of the animal as well as behaviour, based on call detections. PAM offers great temporal coverage but is limited to the location of the hydrophone. PAM works great with other methods that offer better spatial coverage such as ariel surveys, tagging data and local Indigenous knowledge. This study is a snapshot of the beluga presence/absence in James Bay at a single location for the year 2021-22 and 2022-23.

Continuous research, in collaboration with eastern and western communities of James Bay, should be followed with more hydrophones in hotspot areas based on the DFO summer arial surveys as well as the seasonal patterns in this study. Having multiple hydrophones across the same time period allows us to better understand beluga presence, movements, distance from hydrophone, and unique call signatures that can help us identify individuals and their specific movements. Using a triangulation method gives us the ability to understand the movement of beluga, the range from which the hydrophone can record calls, as well as better ability to follow the movement of individuals using their signature calls (Roy et al., 2010).

These data provide a temporal understanding of the environment under which beluga detections were recorded. However, they do not capture the spatial variation of habitat potentially used by beluga, particularly fine-scale movement, north-south movements along the floe edge, or use of estuaries. SST was only measured at one point at the mooring location,

salinity was taken at the depth of the attached CTD rather than at surface, and sea ice concentration was taken within a 2.5 km radius of the hydrophone.

2.5.6 Conclusion

This was the first year-round study to characterize the presence of the James Bay beluga whale population using passive acoustic monitoring. Our findings indicate the year-round presence of beluga, though patterns of presence vary across locations within James Bay. Rather than migrating during ice covered months similar to their neighbouring stocks Eastern Hudson Bay and Western Hudson Bay, they remain residents year-round. Based on a sea ice analysis comparing sea ice dynamics and click presence at mooring locations, we found a shift in distribution being made rather than a true migration. We speculate that during periods of high ice concentration, there was northward movement of beluga along the eastern coast following the prominent flow edge leading to the La Grande River plume and polynya. Although click presence was limited at the northwestern location in ice covered months, there was an increase in click presence as sea surface temperatures warmed. This confirms regions of the Bay may be preferred for summer aggregating areas, which is supported by findings in the DFO aerial surveys. Combining the dynamic sea ice, the La Grande River greater river discharge in winter months, limited predation, available food sources, and high freshwater volumes, the Bay creates a suitable habitat for the beluga to survive in year-round. This is a unique system compared to High Arctic beluga populations who often migrate. James Bay is the second southernmost population in Canada, therefore understanding the limits of their habitat and survival in this environment can also help support understandings of higher Arctic stocks as climate warming continues. Beluga can help indicate biologically productive areas within the Bay based on their presence. The results in this study support regional planning including the Eeyou Marine Region on the eastern side of James Bay and the Mushkegowuk Marine National Conservation Management Area on the western side.

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Supplementary Materials

Supplementary Datasets

- In process of linking acoustic data from hydrophones to Canwin
- Weekly ice charts from The Canadian Ice Service:
(<https://iceweb1.cis.ec.gc.ca/Archive/page1.xhtml?>)
- Daily sea ice concentration observations:
<https://worldview.earthdata.nasa.gov/>
- Hourly sea surface temperature measurements that were averaged per day:
<https://cds.climate.copernicus.eu/datasets/derived-era5-single-levels-daily-statistics?tab=download>

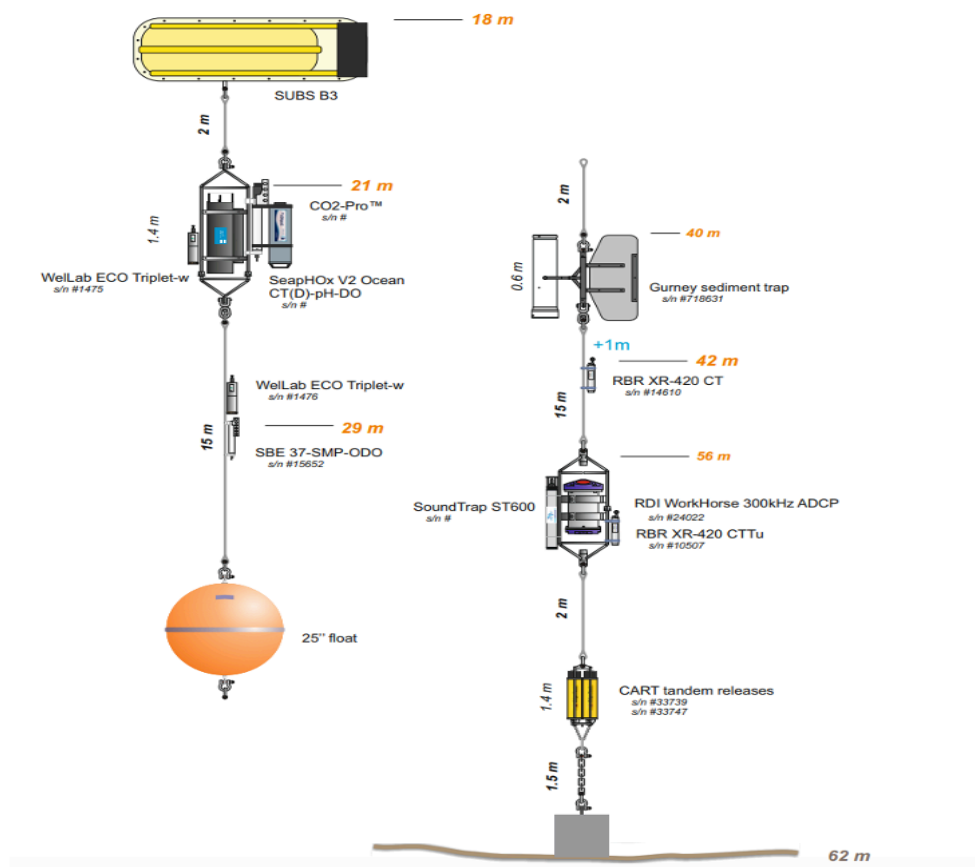


Figure S2.1 Diagram of mooring JB-M2, with the attached ST600 and RBR XR-420 CTD profiler. Deployment took place in August 2021, and retrieval took place in 2022, both done from the RV William Kennedy in northwestern James Bay.

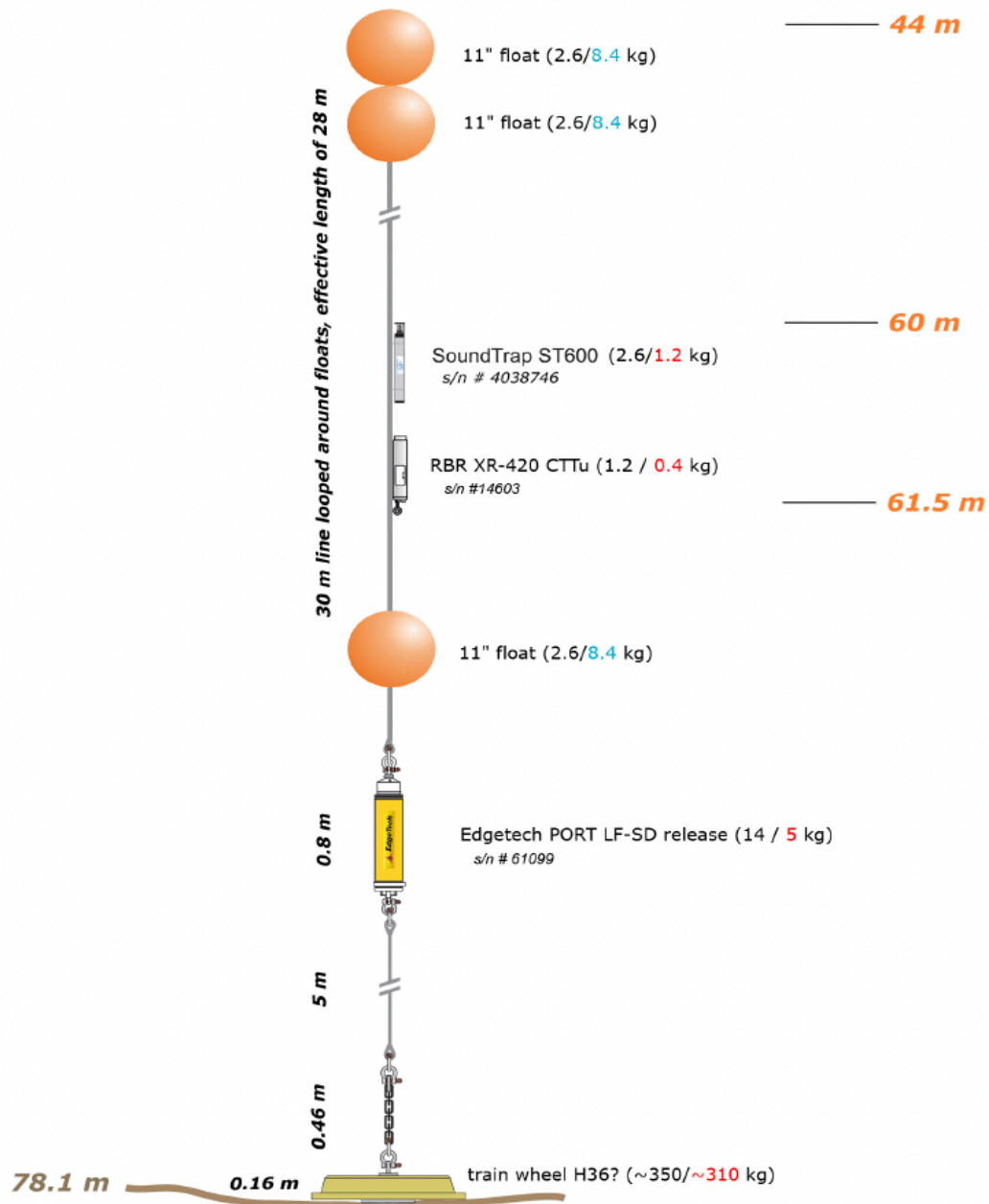


Figure S2.2 Diagram of mooring JB-H, with the attached ST600 and RBR XR-420 CTD profiler. Deployment took place in August 2022, and retrieval took place in 2023, both done from the RV William Kennedy in southwestern James Bay.

JB-M2 Supplementary Information



Figure S2.3 JB-M2 time series of daily average salinity values from August 2021 to August 2022. Measurements taken from CTD in 5 minute increments located on the mooring at a depth of ~41m.

Table S2.1 JB-M2 Model selection table based on Akaike's Information Criterion (AIC) values for various generalized linear models with a binomial distribution, incorporating sea ice concentration, salinity, and sea surface temperature as predictor variables.

	Sea Ice	Salinity	SST	AIC	Delta	Weight	Dev.Exp (%)	R2
1	*		*	2578.0	0.0	0.56	18.76	0.143
2	*	*	*	2578.5	0.52	0.52	18.83	0.143
3	*			2619.4	41.37	41.37	16.85	0.13
4	*	*		2621.2	43.22	43.22	16.96	0.13
5			*	2869.9	291.83	291.83	5.76	0.04
6		*	*	2871.8	293.75	293.75	5.77	0.04
7		*		2986.3	408.25	408.23	0.65	0

Table S2.2 JB-M2 model summary of unadjusted generalized linear model. This model includes all predictors, salinity, sea surface temperature and sea ice concentration. Coefficients are shown as log-estimates with associated standard errors. Significance of each coefficient is shown as codes: ***p<0.0001, **p<0.01, *p<0.05.

	Estimate	Std. Error	P - value	Odds Ratio
Intercept	1.44976	1.20672		
Ice - cover	-2.00748	0.12793	***	0.13
Open water	-2.26383	0.16321	***	0.10
SST	0.10859	0.01644	***	1.12
Salinity	-0.04899	0.03939		0.96

Table S2.3 JB-M2 model summary of adjusted generalized linear model This model excludes salinity. Coefficients are shown as log-estimates with associated standard errors. Significance of each coefficient is shown as codes: ***p<0.0001, **p<0.01, *p<0.05.

Final Adjusted Model: Glm (formula = presence_proportion ~ ice_category + sst, family = binomial (link = "logit"), weights = total_hours).

	Estimate	Std. Error	P - value	Odds Ratio
Intercept	-0.04479	0.11050		
Ice - cover	-2.0300	0.12684	***	0.13
Open water	-2.20563	0.15661	***	0.11
SST	0.10407	0.01610	***	1.11

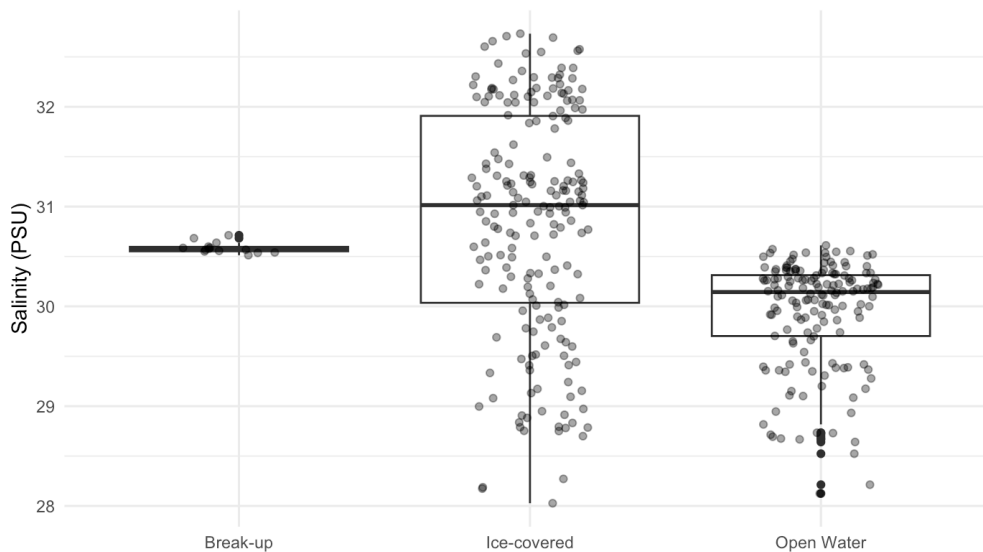


Figure S2.4 JB-M2 salinity distributions in different ice categories including, break-up, ice covered, and open water across 2021-22. Boxplot indicates median and interquartile range, with points representing the individual measurements. On the y axis are salinity measurements were taken from CTD in 5 minute increments located on the mooring at a depth of ~63m and on the x axis are sea ice values are from the Canadian Ice Service Archived Charts.

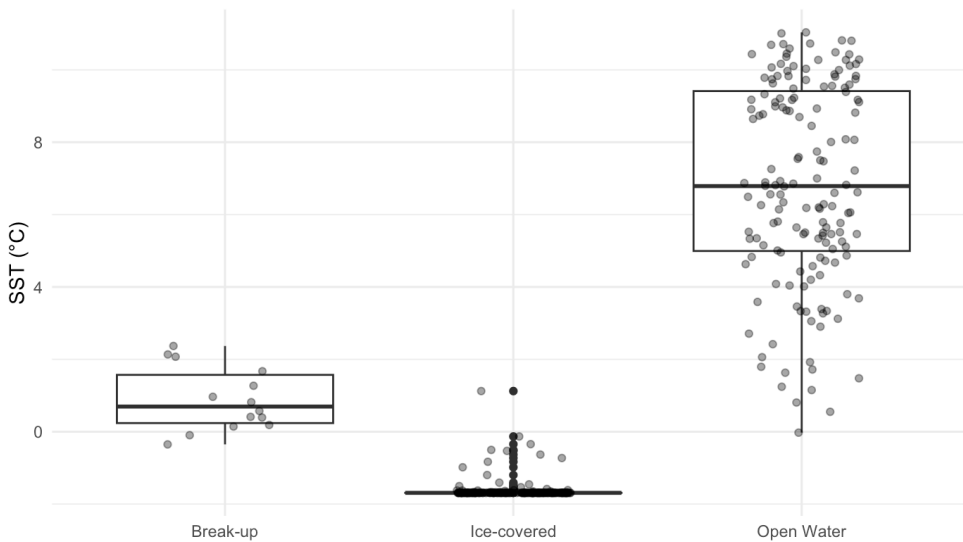


Figure S2.5 JB-M2 sea surface temperature (°C) distributions in different ice categories including, break-up, ice covered, and open water across 2021-22. Boxplot indicates median and interquartile range, with points representing the individual measurements. On the y axis are sea surface temperature measurements were taken from OSTIA and on the x axis are sea ice values are from the Canadian Ice Service Archived Charts.

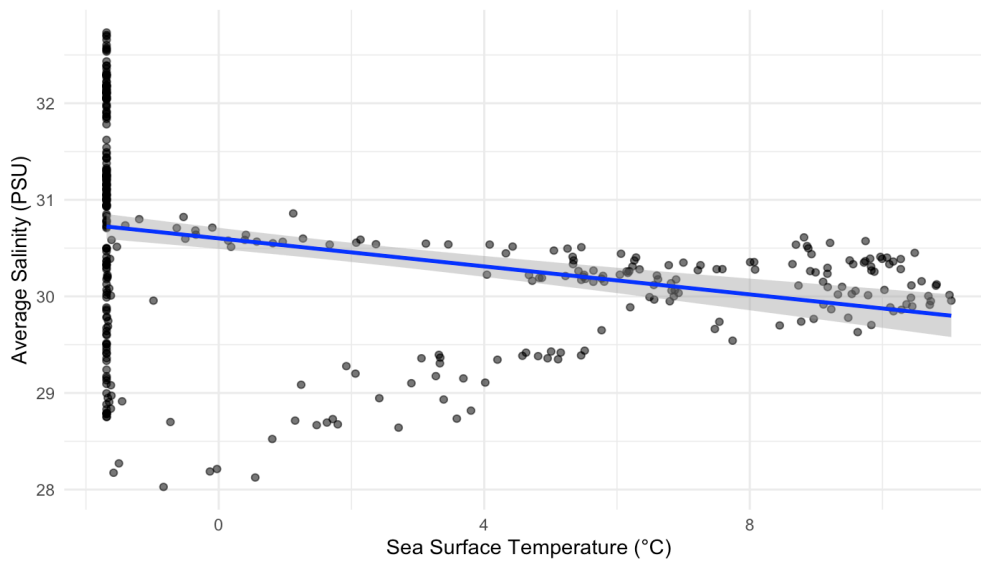


Figure S2.6 JB-M2 relationship between salinity and sea surface temperature (°C) across the year 2021-22. Points represent individual observations, with a fitted linear regression (blue line) with confidence intervals. Sea surface temperature measurements were taken from OSTIA and salinity measurements were taken from the CTD in 5 minute increments, located on the mooring at a depth of ~41m.

JB-H Supplementary Information

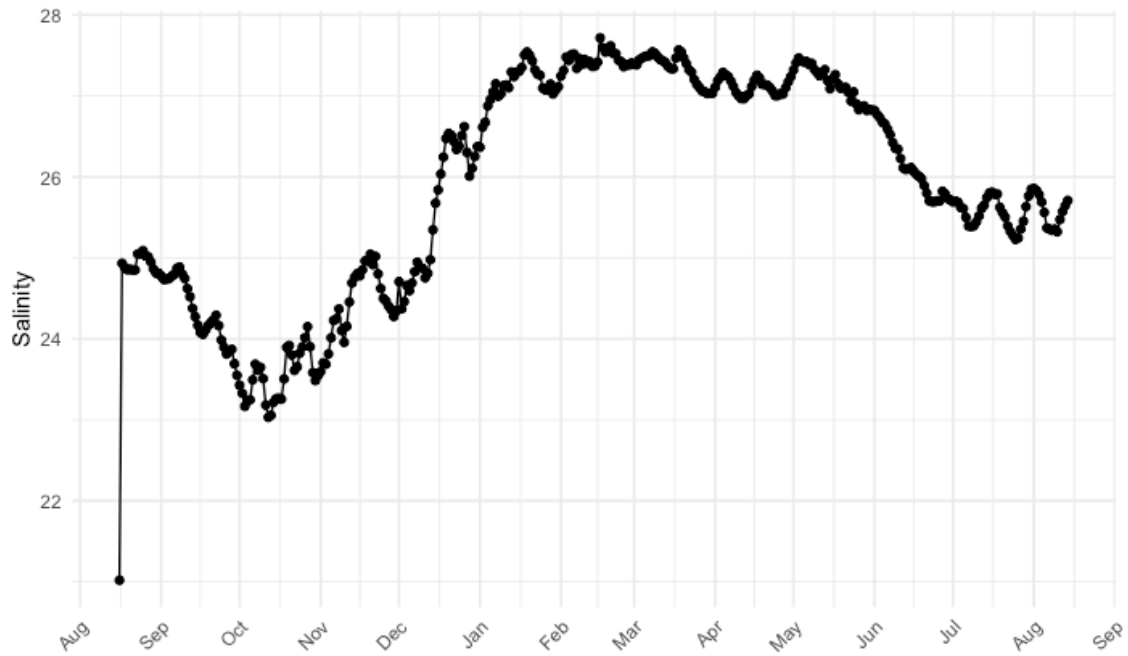


Figure S2.7 JB-H time series of daily average salinity values from August 2022 to August 2023. Measurements taken from CTD in 5 minute increments located on the mooring at a depth of ~63m.

Table S2.4 JB-H Model selection table based on Akaike's Information Criterion (AIC) values for various generalized linear models with a binomial distribution, incorporating sea ice concentration, salinity, and sea surface temperature as predictor variables.

	Sea Ice	Salinity	SST	AIC	Delta	Weight	Dev.Exp (%)	R2
1	*	*	*	2606.5	0.0	1	40.2	0.3
2	*	*		2677.7	71.2	0	37.6	0.28
3	*		*	2897.2	290.8	0	29.8	0.26
4	*			2910.1	303.6	0	29.3	0.22
5		*	*	3136.1	529.6	0	21.2	0.16
6			*	3514.7	908.3	0	7.6	0.06
7		*		3729.8	1123.3	0	0.1	0

Table S2.5 JB-H model summary of unadjusted generalized linear model. This model includes all predictors, salinity, sea surface temperature and sea ice concentration. Coefficients are shown as log-estimates with associated standard errors. Significance of each coefficient is shown as codes: ***p<0.0001, **p<0.01, *p<0.05.

	Estimate	Std. Error	P - value	Odds Ratio
Intercept	22.82987	1.47646	***	
Freeze - up	1.84837	0.14529	***	6.35
Ice - cover	0.24030	0.10973	*	1.27
Open water	-1.63163	0.14921	***	0.20
SST	-0.11742	0.01364	***	0.89
Salinity	-0.089973	0.05575	***	0.41

Table S2.6 JB-H model summary of adjusted generalized linear model This model excludes salinity. Coefficients are shown as log-estimates with associated standard errors. Significance of each coefficient is shown as codes: ***p<0.0001, **p<0.01, *p<0.05.

Final Adjusted Model: Glm (formula = presence_proportion ~ ice_category + sst, family = binomial (link = "logit"), weights = total_hours).

	Estimate	Std. Error	P - value	Odds Ratio
Intercept	-0.96416	0.08859	***	
Freeze - up	2.18962	0.14213	***	8.93
Ice - cover	-0.34525	0.10235	***	0.71
Open water	-0.34951	0.12659	**	0.71
SST	-0.04952	0.01273	***	0.95

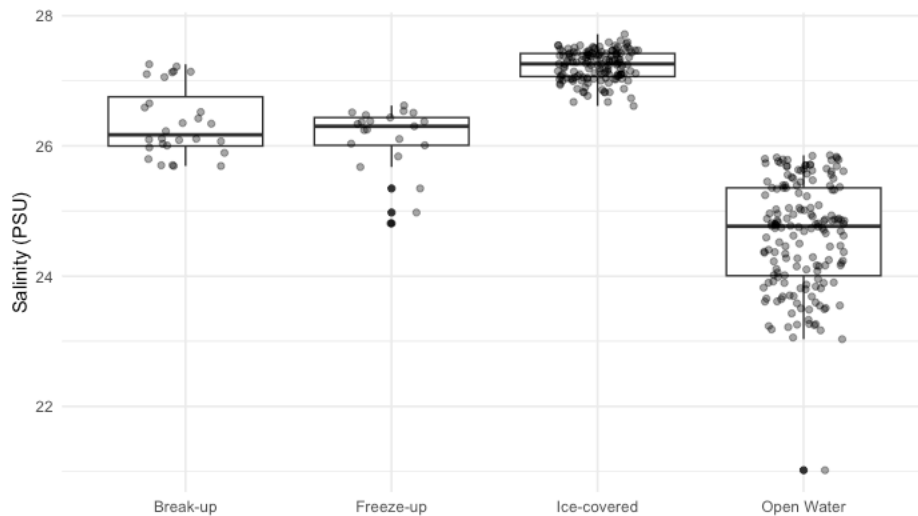


Figure S2.8 JB-H salinity distributions in different ice categories including, break-up, freeze-up, ice covered, and open water across 2023-23. Boxplot indicates median and interquartile range, with points representing the individual measurements. On the y axis are salinity measurements were taken from CTD in 5 minute increments located on the mooring at a depth of ~63m and on the x axis are sea ice values are from the Canadian Ice Service Archived Charts.

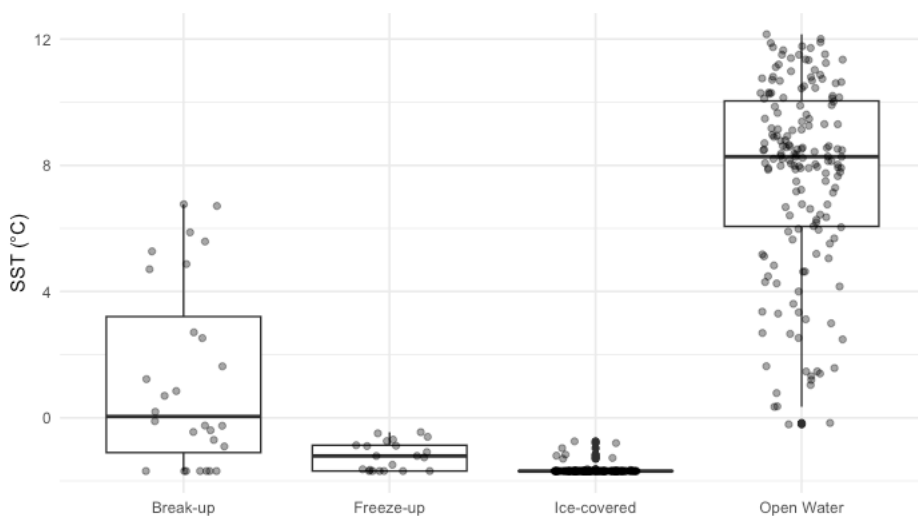


Figure S2.9 JB-M2 sea surface temperature (°C) distributions in different ice categories including, break-up, ice covered, and open water across 2022-23. Boxplot indicates median and interquartile range, with points representing the individual measurements. On the y axis are sea surface temperature measurements were taken from OSTIA and on the x axis are sea ice values are from the Canadian Ice Service Archived Charts.

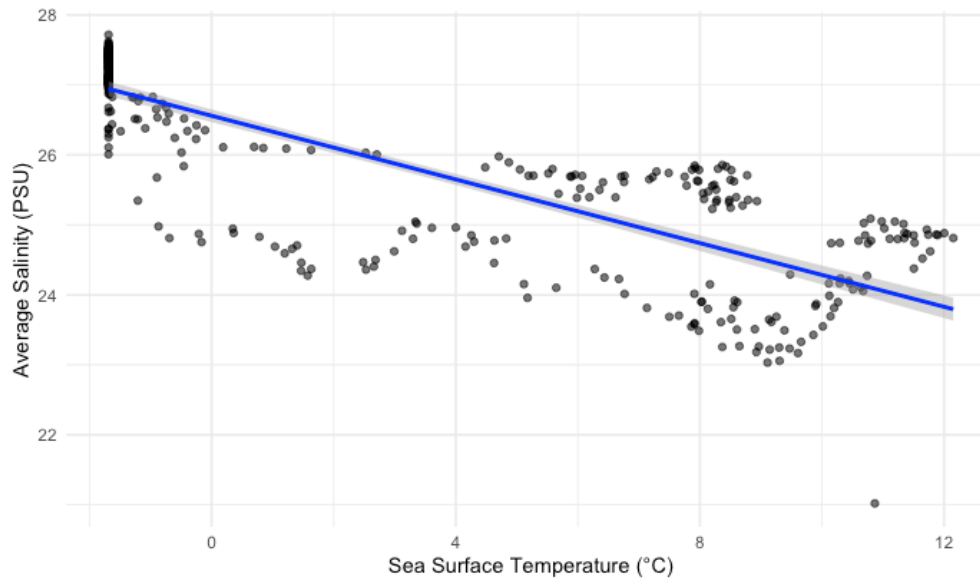


Figure S2.10 JB-H relationship between salinity and sea surface temperature (°C) across the year 2022-23. Points represent individual observations, with a fitted linear regression (blue line) with confidence intervals. Sea surface temperature measurements were taken from OSTIA and salinity measurements were taken from the CTD in 5 minute increments, located on the mooring at a depth of ~63m.

Table S2.7 Weekly dates documented from the Canadian Sea Ice Service Charts from 2021 – 2023, representing sea ice cover weeks with the associated proportion of beluga presence. The (+/-) columns represent the difference in proportion between weeks.

2021-22 Freeze up to Break up Weekly Dates	2021-22 Proportion of Presence	(+ / -)	2022-23 Freeze up to Break up Weekly Dates	2021-22 Proportion of Presence	(+ / -)
December 6 - December 12	0.13		December 26 – January 1	1.00	
December 13 - December 19	0.06	-0.07	January 2 – January 8	0.95	-0.05
December 20 - December 26	0.04	-0.02	January 9 – January 15	0.85	-0.10
December 27 – January 2	0.03	-0.01	January 16 – January 22	0.83	-0.02
January 3 – January 9	0.05	0.02	January 23 – January 29	0.86	+0.03
January 10 – January 16	0.02	-0.03	January 30 – February 5	0.46	-0.40
January 17 – January 23	0.08	+0.06	February 6 – February 12	0.89	+0.43
January 24 – January 30	0.06	-0.02	February 13 – February 19	0.80	-0.09
January 31 – February 6	0.05	-0.01	February 20 – February 26	0.71	-0.09
February 7 – February 13	0.02	-0.03	February 27 – March 5	0.80	+0.09
February 14 – February 20	0.05	+0.03	March 6 – March 12	0.73	-0.07
February 21 – February 27	0.04	-0.01	March 13 – March 19	0.75	+0.02
February 28 – March 6	0.06	+0.02	March 20 – March 26	0.68	-0.07
March 7 – March 13	0.01	-0.05	March 27 – April 2	0.72	+0.04
March 14 – March 20	0.04	+0.03	April 3 – April 9	0.79	+0.07
March 21 – March 27	0.07	+0.03	April 10 – April 16	0.87	+0.08
March 28 – April 3	0.01	-0.06	April 17 – April 23	0.92	+0.05
April 4 – April 10	0.05	+0.04	April 24 – April 30	0.84	-0.08
April 11 – April 17	0.02	-0.03	May 1 – May 7	0.98	+0.14
April 18 – April 24	0.05	+0.03	May 8 – May 14	0.93	-0.05
April 25 – May 1	0.07	+0.02	May 15 – May 21	0.95	+0.02
May 2 – May 8	0.01	-0.06	May 22 – May 28	0.98	+0.03
May 9 – May 15	0.08	+0.07	May 29 – June 4	1.00	+0.02
May 16 – May 22	0.17	+0.09	June 5 – June 11	1.00	0
May 23 – May 29	0.21	+0.04			
May 30 – June 5	0.31	+0.10			
June 6 – June 12	0.28	-0.03			
June 13 - 19	0.65	+0.37			

Chapter 3. Temporal patterns in foraging and communicative calls of beluga in southeastern James Bay during ice freeze-up and ice-cover

3.1 Abstract

Recording underwater sounds allows us to understand the underwater soundscape, including emitted calls from marine mammals. Different call types can give us insight on presence/absence, movement patterns, seasonal shifts, and related behaviours such as feeding and communicating. Beluga are a very vocal animal, with a very complex vocal repertoire that can allow us to better understand them using call type associated behaviours, and movement patterns. James Bay is a unique-estuarine environment, home to an overwintering beluga population. Passive acoustic monitoring and manual analyses were used to investigate call types and associated behaviours in the southeastern region of James Bay to explore habitat use and differences between foraging and communicative calls during ice-covered months. Furthermore, we created a foraging index to emphasize feeding occurrences in all beluga acoustic presence. A higher total number of calls was recorded in December, during the open water to ice freeze-up period, compared to January, which is characterized by fully ice-covered conditions. Click trains were emitted at higher rates than all other call types, followed by whistles (a communicative call type), buzzes (indicative of foraging), and broadband pulsed calls (also a communicative call type). In December, buzzes were detected in 14.8% of the monitored files where a call was detected, whereas in January, 9.9% of the files were identified with buzz calls. These results provide insight on beluga behaviour, specifically in winter months, and confirm that feeding is occurring even in high ice coverage throughout James Bay.

3.2 Introduction

Understanding call types provide insight into animal behaviour and their relationship with the environment, helping to address questions such as residency times, seasonal behaviours

(winter vs summer), and classification of communicative vs foraging vocalizations. Often animal vocal repertoires are documented and analysed using both auditory methods, such as recording and listening, and visual methods, such as examining spectrograms to classify calls based on time, frequency, and patterns (Babin et al., 2025; Brewer et al., 2023; Jones et al., 2020).

Recording underwater sounds can allow us to understand the underwater soundscape, including vocal repertoire and presence from submerged animals as well as anthropogenic and natural noises. The emission of underwater sounds by animals is especially important as it is crucial for survival functions including, communication, navigation, and foraging; however, it can be easily manipulated by many factors including environmental conditions, other sound emitting organisms, and anthropogenic stressors (Tyack et al., 2000; Zimmer, 2011). Differences in call types specifically those used for communication versus navigational versus foraging, can give us better insight as to why an animal may be occupying a particular area, leading us to questions such as: Do they use this area to feed or transit through? Is this region apart of a migration route? By interpreting calls, we can correlate behaviours and compare them across other populations, stocks, or regions (ex. north and south) within the same population to determine why an environment is favourable or not. As climate change continues to progress, especially quicker in Arctic and subarctic waters, marine mammals may begin to shift their movements due to changing water temperatures, increased storm activity, fewer sea ice days etc. Another important factor of this change is prey availability, marine mammals, for example beluga, depend on organisms such as fish, jellyfish, and crustaceans which are all highly sensitive to these changes. As temperatures increase we may begin to see a shift in species, for instance, capelin have become more prevalent at northern latitudes with increasing temperatures (Gaston et al., 2003; Watt et al., 2016). Therefore, analyzing call types in relation to behaviour and comparing over time across different regions can offer important insight into aggregation and migration patterns. It is important to document this information over time as climate change progresses and marine mammal habitats begin to change.

Beluga whale, *Delphinapterus leucas*, are odontocetes, with a near circumpolar distribution, living in both Arctic and Subarctic regions. Belugas are very vocal and social animals often referred to as “canaries of the sea” (Chmelnitsky & Ferguson, 2012). Belugas are highly mobile and have the ability to live in different habitats including both shallow and deep waters, rivers, and in varying coverage of sea ice (Barber et al., 2001). Many beluga populations undergo seasonal migrations where they summer in warm, estuarine waters before migrating to deeper offshore and partially ice-covered systems, often following along ice edges (Barber et al., 2001; Sergeant, 1973). In contrast, the James Bay beluga population remain in the Bay year-round. Similar patterns of year-round residency have been observed in other populations where local environmental conditions potentially meet the population requirements therefore negating the need for them to make long-distant migrations. Populations fitting this classification include the Cumberland Sound population with small movements extending to the mouth of the fiord, the Cook Inlet population, seasonally moving from the northern to southern Inlet (Castellote et al., 2020; Marcoux et al., 2017; Rugh et al., 2005) and St. Lawrence Estuary population (Harvey et al., 2025).

Call types that are used by beluga include: 1) whistles, 2) pulsed calls and contact calls, 3) echolocation clicks, 4) terminal buzzes, and 5) combined calls (Table 3.1). Whistles are a communicative type of call with a small frequency range (Sjare & Smith, 1986). These calls can be unique to an individual and are used as communication between conspecifics (i.e. communication between the same species). Pulsed calls have a larger frequency range (i.e. broadband) and are often measured using a pulse repetition rate because they are emitted multiple times in a time period (Sjare & Smith, 1986; Vergara et al., 2010; Vergara & Mikus, 2019). Combined calls, also referred to as mixed calls or complex contact calls, can be classified into two different types, either 1) one call contains both a pulsed component and overlapping tonal call or 2) two calls are overlapping but emitted by the same individual (Chmelnitsky & Ferguson, 2012; Sjare & Smith, 1986; Vergara & Barrett-Lennard, 2008).

Echolocation clicks are broadband pulses, varying from 30 kHz to 120 kHz, with a short interval between each pulse. Clusters of clicks are referred to as click trains and are primarily used for navigational purposes (Akamatsu et al., 2005; Au et al., 1985; Lammers & Castellote, 2009). Terminal buzzes are similar to echolocation clicks, but the inter-click interval (ICI), the time between individual clicks, gets progressively shorter. In most cases this buzz is found following a click train and can be an indication of the animal foraging and feeding (Castellote et al., 2021; Johnson et al., 2008; Miller et al., 2004; Roy et al., 2010). Echolocation click trains and buzzes are call types seen in other toothed whales and dolphins, such as beaked whales, sperm whales and bottlenose dolphins to indicate prey searching and prey capture (Herzing, 1996; Johnson et al., 2004, 2008; Miller et al., 2004).

Studies of beluga vocal repertoire and classification have been done on beluga populations including Western Hudson Bay, Eastern Beaufort Sea, Eastern High Arctic, White Sea, and Cook Inlet (Brewer et al., 2023; Chmelnitsky & Ferguson, 2012; Garland et al., 2015; Panova et al., 2012; Sjare & Smith, 1986). Although foraging calls and their related behaviors have been studied across different toothed whales including, killer whales (Schevill & Watkins, 1966), beaked whales and (Johnson et al., 2004, 2008; Miller et al., 2004), dolphins (Herzing, 1996), these calls and related behaviors are rarely studied during heavily ice-covered months as these animals are often on migration routes. An exception is a study of the Cook Inlet beluga presence and foraging occurrence during winter months (Castellote et al., 2020).

Factors that influence beluga presence are ice coverage, temperature, salinity, light availability, and wave height (Aubin et al., 1990; Ausen et al., 2023; Booy et al., 2021; Scharffenberg et al., 2019; Watts et al., 1991). However, knowledge of these factors during winter months is limited. Understanding these factors is important not only in summer aggregation areas but is particularly vital for populations that remain in the same regions year-round, as it provides greater insight into their feeding behaviours and movement patterns.

This study focuses on the James Bay beluga call classifications during winter months with varying ice concentrations. Sea ice concentration is often thought of as a limiting factor for beluga distribution and migration timing; this relationship may differ for the James Bay population where beluga are resident year-round. Sea ice freeze-up in James Bay occurs in December and ice cover persists until June; notably there is a prominent landfast ice extent of 10s to 100s of kms extending out from the coastlines (Bailleul et al., 2012a; Eastwood et al., 2020). However, due to spatial and temporal variability in sea ice conditions, driven by sea bottom bathymetry, and anthropogenic influences such as hydroelectric development and warming temperatures, sea ice dynamics fluctuate throughout the Bay and ice-covered days have declined (Eastwood et al., 2020; Gupta et al., 2022; Taha et al., 2019). This combination of environmental features and other factors allows for favourable year-round conditions for beluga residency of the Bay. Because this non-migratory behavior is unusual compared to most beluga populations, and this population is considered the second southernmost population in Canada living in different conditions than those in the high Arctic, understanding call types is crucial for gaining insight into their feeding and communicative/social behaviors.

3.3 Methods

3.3.1 Study Area

James Bay is a large body of water, located between Quebec and Ontario, Canada adjacent to Hudson Bay. James Bay covers an area of approximately 68,300 km² with an average depth of 28 meters and a maximum of 110 meters (El-Sabh & Koutitonsky, 1977; Évrard et al., 2023). James Bay is often described as an estuarine environment due to its shallow depths, warmer temperatures and high volume of freshwater input. Inflow from Hudson Bay is found to be mostly subsurface, entering James Bay on the western side, circulating along the coastline and exiting northwards, returning back into Hudson Bay on the southern side of the Belcher Islands (Prinsenbergh, 1986b).

The coastlines of James Bay are highly river dominated. Several freshwater river outflows are regulated due to dams and diversions associated with the La Grande hydroelectric complex. River waters along the eastern coast have been diverted and regulated (i.e. the La Grande River), creating a shift in freshwater discharge seasonally, specifically 10-fold increased discharge from La Grande River during the winter months and discharge of only 10% natural conditions at the mouth of the Eastmain River (Peck et al., 2022). The continuous input of freshwater from regulated rivers leads to rapid ice formation and, further, alters the production of brine that increases the surface salinity (Eastwood et al., 2020). However, with the mix of freshwater, a buoyancy effect occurs where mixing does not reach deeper depths (Eastwood et al., 2020). Rather, this freshened layer remains within the top 20 meters of the water column, while the warmer saltwater remains at the bottom (Eastwood et al., 2020). As a result, there is very limited mixing in winter, and a stratification persists. This phenomenon is associated with the La Grande freshwater plume; elsewhere in James Bay the water column tends to increase in salinity throughout winter and then decrease between spring and summer.

In addition to the unique river input, polynyas are another notable feature in James Bay. Polynyas are classified as areas of open water or low ice concentration that often reoccur in the same regions over time; they are found near islands, coastal regions and fast ice edges (Barber & Massom, 2007). Wind speeds, tides, and currents all have an impact on the formation of polynyas. There is a large polynya in the southwest region of the Belcher Islands extending down to northern James Bay (Eastwood et al., 2020). In contrast, flaw leads are also considered areas of open water but are not consistently occurring in the same regions (Barber & Massom, 2007). These are caused by winds and currents forming long linear openings, such as along fast ice edges and are often results of ice floes separating from land-attached ice (Durkalec & Breton-Honeyman, 2021). Polynyas and flaw leads are considered the most biologically productive areas in Arctic regions during winter and provide a suitable habitat to breathe for large mammals (Stirling, 1980, 1997).

3.3.2 Data Collection

A mooring equipped with a SoundTrap ST600 (Ocean Instruments^{nz} Acoustic Monitoring Program) hydrophone was deployed in August 2022 and retrieved in August 2023 in southeast James Bay (52.43170°N, 79.40890 W°, Figure 3.1, Figure S3.1). The mooring was secured to a line connecting a subsurface float to an anchor-mounted acoustic release, deployed in approximately 79.5 m of water. Importantly, the mooring was placed in a deeper region of the Bay, rather than an estuarine environment, as well as along the prominent landfast ice edge. The SoundTrap depth was calculated at approximately 61.5 meters. The sampling rate of the hydrophone was set at 192 kHz, capturing sounds in the range of frequencies up to 96 kHz, following the Nyquist theorem (Fleishman et al., 2023). The hydrophone recorded for 7 minutes every hour.

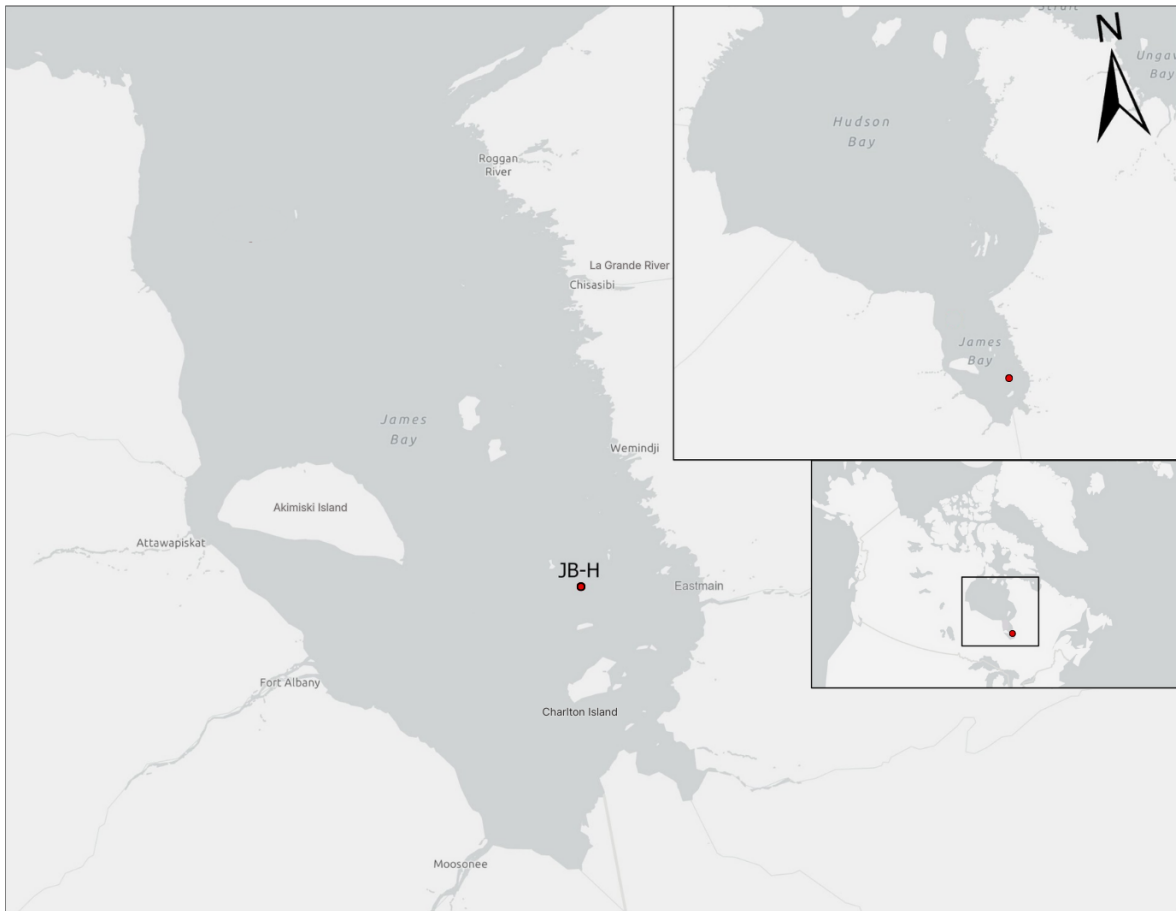


Figure 3.1 Map of the mooring location deployed in August 2022 and retrieved in August 2023 James Bay.

3.3.3 Sound Analysis

We used Raven Pro V1.6.5 to annotate and count calls for the months of December 2022 and January 2023 (Table S3.1). Prior to annotation, we used previous literature to define and characterize the call types that were identified in our preliminary observations (refer to Table 3.1 for literature). These definitions were refined using both published literature and our own informed judgment in preliminary observations. Recordings were 7 minutes long, but we only annotated the first minute of every file given the large number of calls per files. We only considered calls with a signal to noise ratio ($SNR = \text{Energy of click (dB)} - \text{energy of noise (dB)}$) of at least 10 dB for the analysis. For call types with energy >20kHz (i.e. click trains, click trains

with buzzes and broadband pulsed calls) sound files were uploaded in Raven Pro with a 512-point Hann window with 50% overlap and a 2048-point DFT. This produces a time resolution of 2.7 ms and a frequency resolution of 47 Hz. Call types 20kHz and below (i.e. whistles and broadband pulsed calls) were analyzed using a 6000-point Hann window with a 50% overlap and a 16384 DFT. This produces a time resolution of 31.2 ms and a frequency resolution of 6 Hz.

We identified the following vocalizations: 1) echolocation clicks (thereafter referred to as click trains), 2) click trains with a terminal buzz (thereafter referred to as buzzes), 3) whistles, 4) broadband pulsed calls including contact calls (thereafter referred to as BBPCs) as identified in previous studies (Table 3.1). Click trains are a rapid series of broadband clicks (Figure 3.2). A minimum of 6 clicks was required for a sequence to be classified as a click train, and the frequency range was defined between 30 kHz and 120 kHz. To delineate individual click trains from one another, the timing between each click train had to be double that of the ICI of the previous train. Terminal buzzes were defined as a click train with clicks having a progressively shorter ICI between 3-5 milliseconds (Figure 3.2). If a buzz was detected in a sound file but did not follow a click train, it was not included in the total call count to remain conservative. In cases of overlapping click trains, the end of a train was marked at the point where a buzz could be identified following the click train sequence even if another click train began overlapping. Whistles are a low frequency, narrowband call type with a flat or contour shape ascending or descending on the spectrogram (Figure 3.2). These call types often have a harmonic or overtone in addition to the main body of the call. In this study, whistles were counted as a call with a frequency between 0.2-20 kHz. Broadband/pulsed calls are call types that span a wide frequency ranges, beyond that of click trains, and have a longer duration than echolocation clicks (Figure 3.2). Often these calls may repeat themselves several times in the same time period (Vergara and Mikus, 2018). Contact calls are a type of broadband/pulse calls. They form a very complex repertoire and can be divided into simple and complex calls using for

communication purposes. However, for this study we decided to combine all pulsed calls into one category as broadband call types.

Table 3.1 Literature used to define call types.

Call Type	Description	Literature used to define call types
Echolocation Click Trains	Rapid series of broadband clicks, less defined pattern than a communicative pulsed call. Usually occurs at above human hearing range Above 30 kHz to 120 kHz or higher Minimum 6 clicks	(Eickmieser & Vallarata, 2022) (Akamatsu et al. 2005) (Au et al. 1985) (Belikov & Bel'kovich, 2008) (Chmelnitsky & Ferguson, 2012) (O'corry-Crowe 2009) (Roy et al. 2010) (Jones et al. 2022) (Le Bot et al. 2015) (Cottillard et al. 2023)
Echolocation Click Trains with a Buzz	These clicks occur more rapidly than those in echolocation trains. The interlick interval gets progressively smaller. Most instances it is following a click train Indication of feeding 3-5 milliseconds ICI	(Miller et al. 1995) Johnson et al. 2007) (Castellote 2021) (Roy 2010) (Cottillard et al. 2023) (Luis et al. 2016)
Whistles	Type of communicative call, typically having a narrowband (small frequency), creating a unique, contour shape both ascending and descending. 0.2 kHz to 20 kHz	(Sjare & Smith, 1986) (Eickmieser & Vallarata, 2022) (Chmelnitsky & Ferguson, 2012) (O'corry-Crowe 2009) (Belikov and Bel'kovich 2006)
Broadband / Pulsed tones / Contact Calls	Pulsed calls consist of a series of rapid pulses, having a more broadband range. Contact calls are broadband rapid pulse trains that can have an additional tonal or pulsed component overlapping. Contact calls must be 2 calls within a 10 sec segment Simple: Repetitive pulsed calls "Creaking" door sound More often seen in calves because they haven't developed a complex vocal repertoire Complex: Previous explanation but with an overlapping lower frequency (usually below 20 kHz) Energy is spread across wide frequency range, with 2+ calls within 10 second	(Sjare & Smith, 1986) (Chmelnitsky & Ferguson, 2012) (Eickmieser & Vallarata, 2022) (Belikov & Bel'kovich, 2008) (Morisaka et al. 2013) (Mishima et al. 2015) (Panova et al. 2017) (Vergara et al. 2010) (Vergara & Mikus, 2018) (Vergara & Mikus, 2019) (Ames & Vergara, 2020)

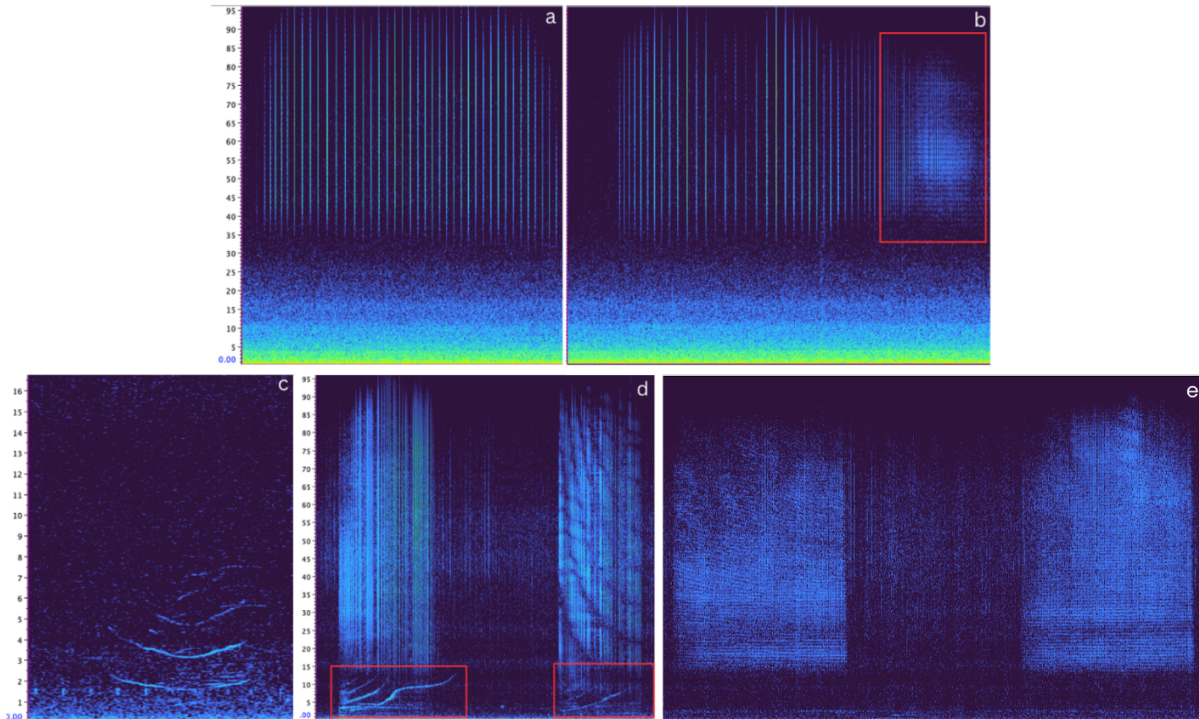


Figure 3.2 Representative examples of categorized beluga call types: (a) click train (b) click train followed by a terminal buzz outlined in the red box (c) whistle (d) complex contact call including an overlapping tonal call highlighted in the red box and (e) broadband pulsed call.

3.3.4 Environmental Data

3.3.4.1 Sea Ice

The dataset used for sea ice concentration came from the archived ice charts from Canadian Ice Service Digital Archives, hereafter referred to as CIS. These data include weekly, regional ice charts in the Hudson Bay area. The CIS regional ice charts integrate data from satellite remote sensing, aerial reconnaissance survey data, ship-based observations, and results of operational models. Furthermore, experts incorporate both real time observations and delayed data sources not immediately available to refine incomplete data (Galley et al., 2012; Tivy et al., 2011). Ice charts are composed of weekly polygons that represent the total ice concentration, in the form of tenths. The weekly ice concentration within a 2.5 km radius of the mooring location was assigned to each day of the associated week. In cases where multiple polygons fell within the radius where we collected data, the values were averaged to calculate a mean ice

concentration for the week. For example, occasionally during winter the land fast ice edge and pack ice fell within the radius area. Ice charts were downloaded as shapefiles and analyzed in ArcGIS Pro 2.9.8.

3.3.4.2 Tidal Trends

Tidal data were downloaded from the Government of Canada tidal and water level station data frame from the Strutton Islands weather station (52.08°N and 78.95°W). Data were transformed into a categorical variable for increasing, decreasing, or constant water height indicating the state of the tide (i.e. high and low tide).

3.3.4.3 Light Availability

Hours of illumination were calculated using the National Research Council of Canada's sunrise/sunset calculator (NRCC, 2020). Using the coordinates of the mooring location, daylight hours were calculated by the start of civil twilight to the end of civil twilight, equaling total hours of illumination. Hours with no light were calculated by subtracting total hours of illumination from 24. Every hour was then assigned its designated light availability category “day” or “night”.

3.3.5 Analysis

A negative binomial generalized linear model was the best type of model to understand the effects on the total number of calls during the months of December and January. Total number of calls was used as the response variable with call type (click trains, buzzes, whistles, and broadband), light period (day or night), tidal trend (flood, ebb, and slack), and month (December and January) as predictors. The month remained a fixed effect because the ice regimes differed between December and January, and as a consequence, we expected that beluga vocal behaviour would differ between the two months. Additionally, we tested for biologically significant interactions, such as call type with month, light period and tidal trend. Collinearity was tested by looking at variance inflation factors before moving forward, including interaction terms and main effects in model selection. Using the dredge function from the MuMIn package in R (v1.48.4; Barton, K., 2025), we evaluated all possible versions of the full model and calculated

the corrected Akaike Information Criteria for small sample size (AICc) values (Table 3.2). Once finding the best fit model, we checked for temporal autocorrelation of the model residuals using auto-correlation functions (ACF). To understand the effect size of each covariate, specifically the different call types, we calculated the incident rate ratio (IRR) by exponentiating the model's estimate (i.e. e^{β}) for each main effect (Table 3.3). The IRR indicates how each predictor influences the rate of beluga call occurrences; this is done to better interpret and conceptualize the result.

3.3.6 Foraging Index

We calculated a monthly foraging index by dividing the number of sound files that included 1≥ click trains followed by a buzz (foraging positive minute; FPM), by the number of hours in which any beluga call was detected (detection positive minute; DPM), and then multiplying this fraction by 100 (Castellote et al., 2020). Recordings were done 7 minutes every hour, but we only analyzed the first minute of these recordings. Therefore, this index represents a relative measure of foraging occurrence rather than absolute foraging time. We calculated an index for each week across both months, collecting all DPMs and FPMs for each corresponding week, to analyze if there was a pattern in foraging in relation to sea ice freeze-up. Additionally, we calculated the index for each month, which takes all DPMs and FPMs for each corresponding month, to better compare foraging estimates in different ice regime environments.

3.4 Results

3.4.1 Call Types and Environmental Model Analysis

We initially considered using a full model with all main effects and interaction terms including call type. However, after testing collinearity, results indicated that interaction terms increased multicollinearity substantially, therefore only main effects were used moving forward in model selection. Based on this finding, we calculated AICc for all models using the predictors, month, call type, light period, and tidal trend (Table 3.2). The model that best explained the effect on

total number of calls included the variables month, call type, and tidal trend (AICc = 9686.9, R² = 0.077, Table 3.2). Temporal autocorrelation was not a concern after testing the model residuals.

Table 3.2 Model selection results include a global model with parameters: month (December or January), period (day or night), and trend (flood, ebb, and slack tidal trend). Each row represents a model of different variation. Akaike's information criterion (AICc) was calculated for each model, comparing model fit, R-squared (R²) values were applied to each model to determine variation explained and lastly amount of deviance explained was calculated as a percentage. No interaction terms were used in the global model.

	month	period	trend	type	AICc	Dev Explained (%)	R2
1	+		+	+	9686.900	0.312	0.077
2	+	+	+	+	9688.900	0.312	0.077
3	+			+	9689.600	0.310	0.077
4	+	+		+	9691.600	0.310	0.077
5			+	+	9693.000	0.309	0.076
6		+	+	+	9695.000	0.309	0.076
7				+	9696.200	0.307	0.076
8		+		+	9698.200	0.307	0.076

The factors January, call type pulsed tones and a decreasing tidal trend were used as the baseline category. Beluga call count was significantly higher in December compared to January (IRR = 1.32, CI = 1.09-1.59, p<0.001) (Table 3.3). The call type click trains were emitted at higher rates than all other call types (IRR = 68.1, CI= 48.4 - 97.2, p<0.001) (Table 3.3). Call type click trains with buzzes occurred at significantly higher rates compared to pulsed tones (IRR = 3.61, CI=2.50 - 5.28, p<0.001) (Table 3.3). Call type whistles were emitted at significantly higher rates than pulsed tones, and buzzes (IRR = 37.54, CI= 26.6-53.7, p<0.001) (Table 3.3). Beluga calls did not differ significantly in a flooding tidal trend compared to an ebbing tidal trend (IRR = 1.18, CI= 0.96 - 1.44, p>0.05) (Table 3.3). Additionally, there was no significant difference in beluga calls when mean water height remained constant (i.e. slack tidal trend) compared to a decreasing tidal trend (IRR = 0.81, CI= 0.61 - 1.09, p>0.05) (Table 3.3).

Table 3.3 Model summary of the best fit negative binomial generalized linear model. Coefficients are shown as log-estimates with associated standard errors. Incidence rate ratios (IRR) were calculated as $\exp(\text{estimate})$. IRR has the associated 95% confidence intervals, upper and lower values. Significance of each coefficient is shown as codes: *** $p < 0.0001$, ** $p < 0.01$, * $p < 0.05$.

	Estimate	Std. Error	P-value	Significance	IRR	Confidence Intervals Lower (IRR)	Confidence Intervals Upper (IRR)
Intercept	-3.500	0.175	< 2e-16	***			
December	0.276	0.095	0.004	**	1.318	1.090	1.594
Click Train	4.221	0.176	< 2e-16	***	68.095	48.383	97.239
Buzz	1.283	0.189	0.00000	***	3.609	2.495	5.280
Whistle	3.625	0.177	< 2e-16	***	37.540	26.638	53.676
Flood Tide	0.161	0.102	0.114		1.175	0.960	1.437
Slack Tide	-0.208	0.153	0.175		0.812	0.608	1.094

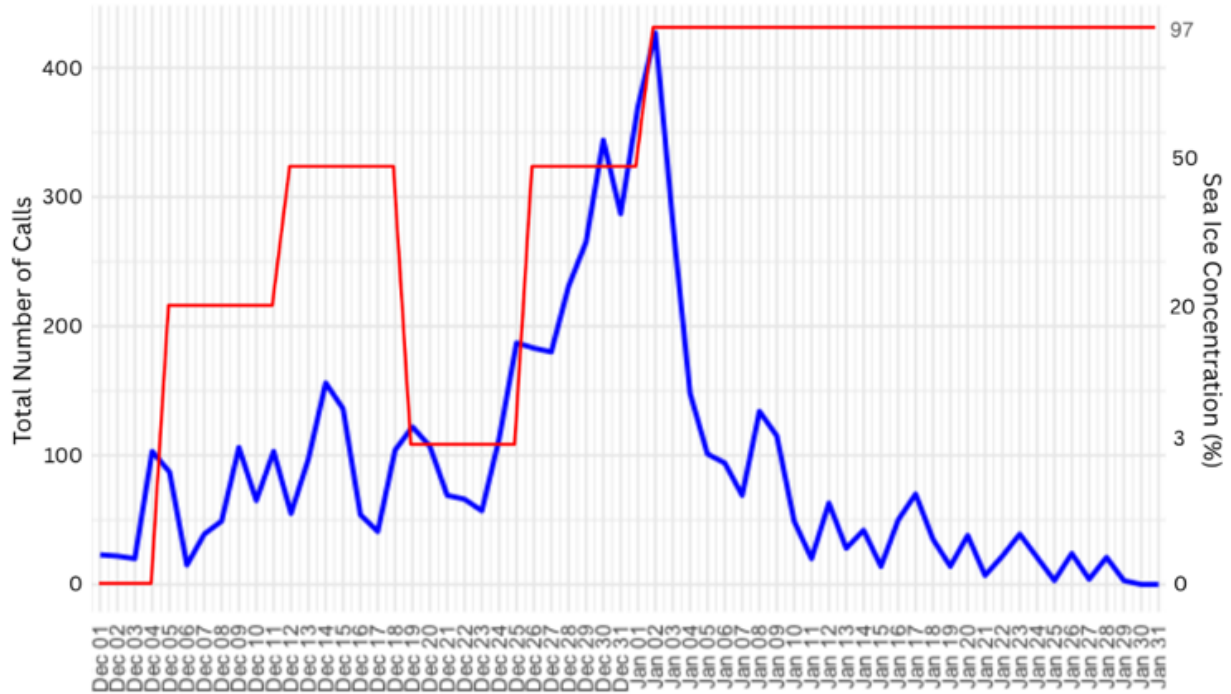


Figure 3.3 Beluga call activity is outlined in the blue line, and sea ice concentration (%) is outlined in the red line. The axis is the date from December 1, 2022, to January 31, 2023.

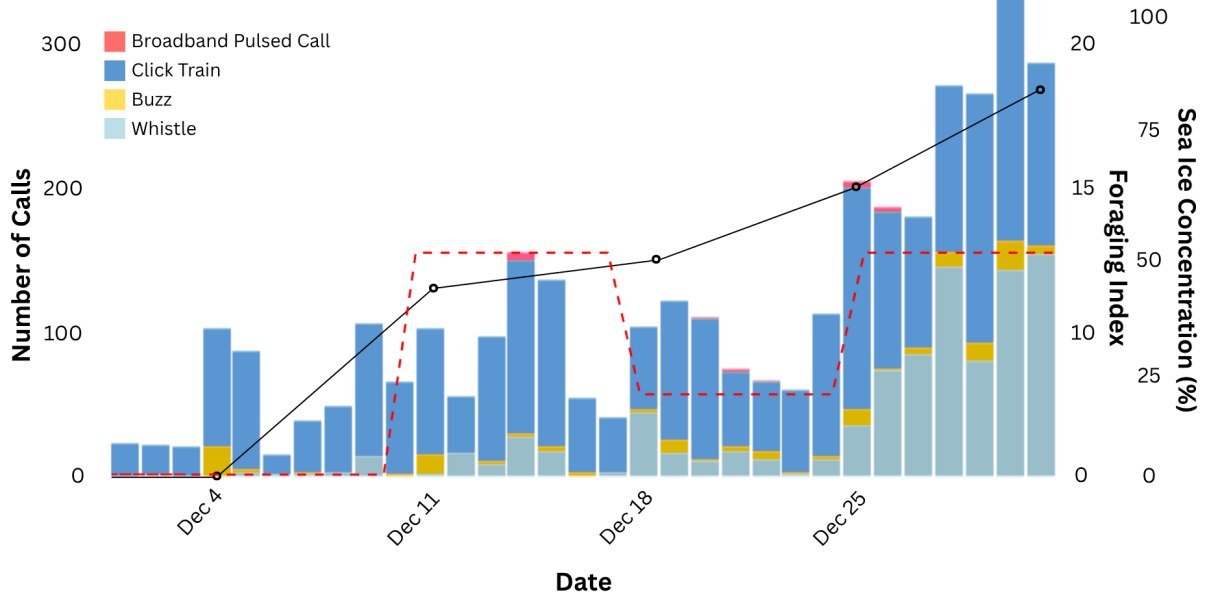


Figure 3.4 Daily call type occurrence across the month of December 2022. Each colour represents a call type, including click trains, broadband pulsed calls, whistles, and buzzes. The primary y axis is total number of calls and on the secondary y-axis is the calculated weekly foraging index outlined by the black circles and sea ice concentration (%) outlined by the dashed red line.

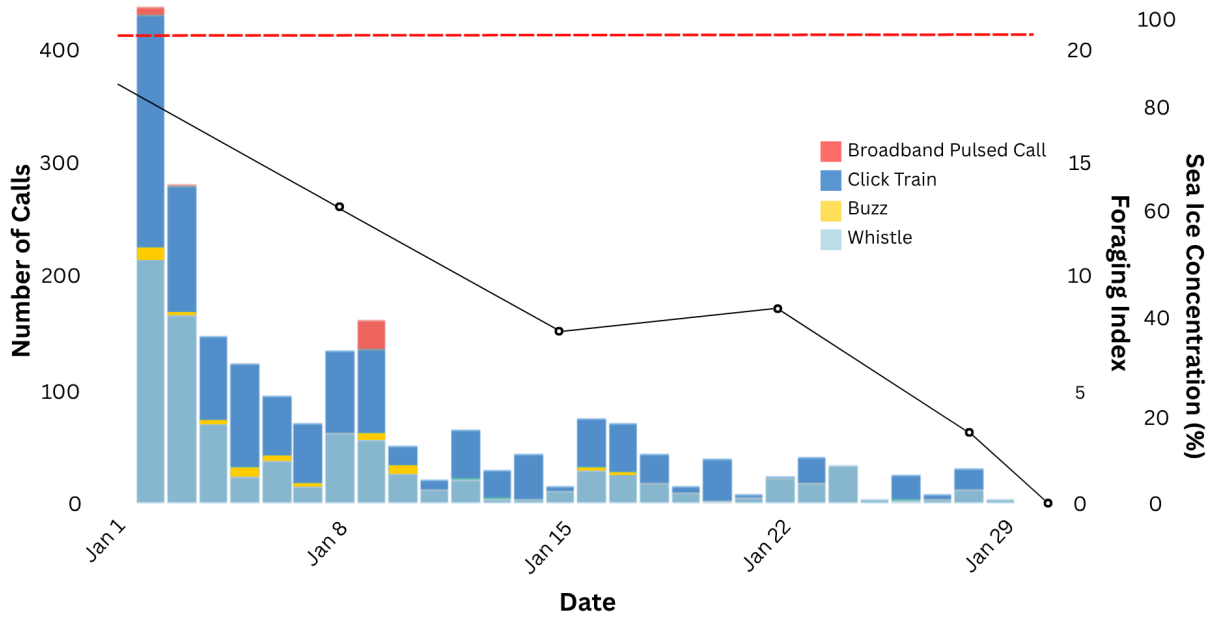


Figure 3.5 Daily call type occurrence across the month of January 2023. Each colour represents a call type, including click trains, broadband pulsed calls, whistles, and buzzes. The primary y axis is total number of calls and on the secondary y-axis is the calculated weekly foraging index outlined by the black circles and sea ice concentration (%) outlined by the dashed red line.

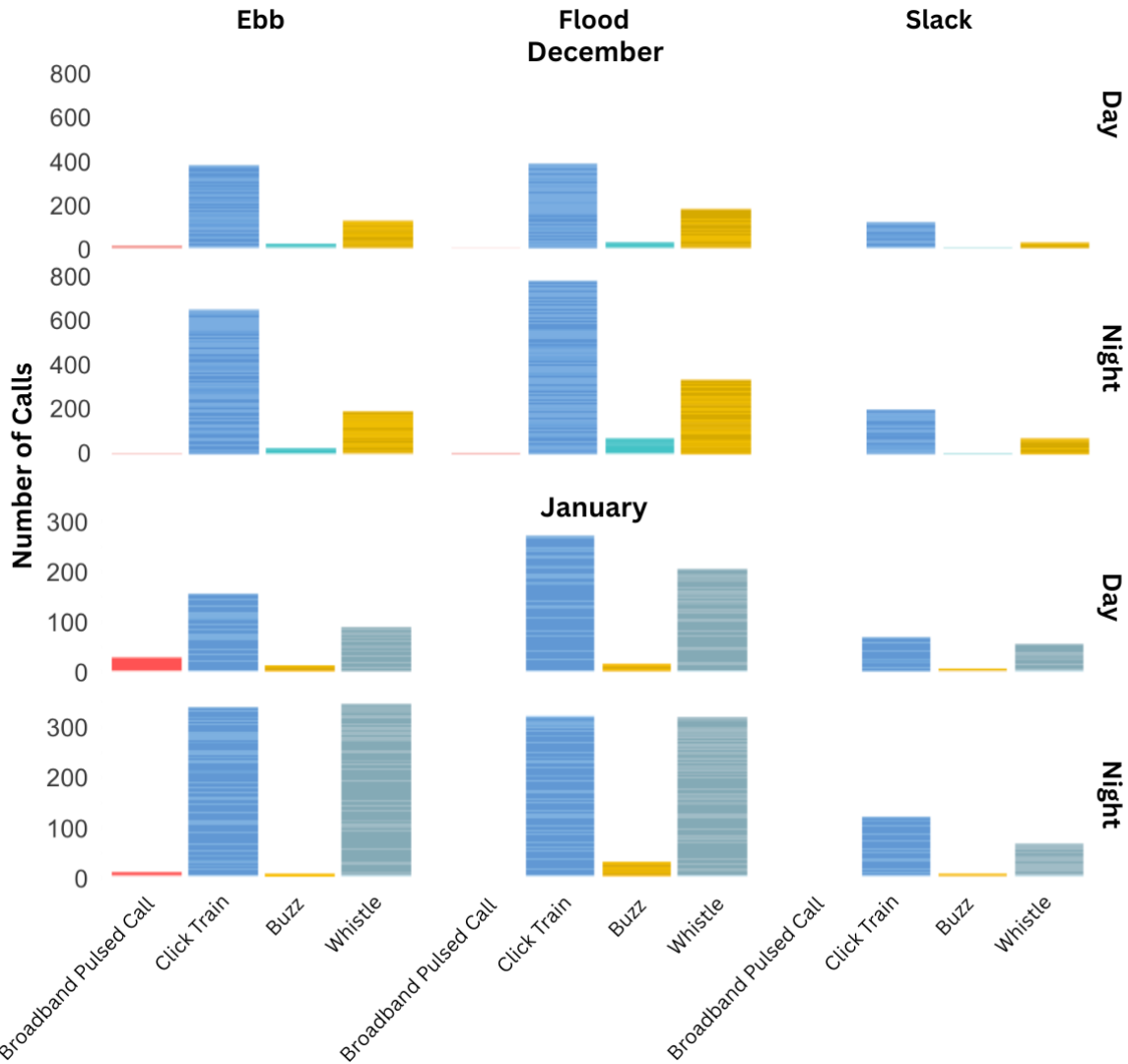


Figure 3.6 Number of beluga calls separated by each month December 2022 and January 2023, call type on the x axis (i.e. BBPCs, click trains, buzzes, and whistles) and light period on the secondary y axis (i.e. day and night). Lastly, each column in the plot represents the tidal trend (i.e. flood, ebb, and slack). The y axis extent differs between the two months.

3.4.2 Foraging Index

The foraging index for December was 14.8% (Figure 3.4; Table S3.2), i.e. click trains with buzzes were detected in 14.8% of the 1-minute sound files with other beluga call detections.

The foraging index for January was 9.9% (Figure 3.5, Table S3.2). The week of December 25, 2022, had the highest calculated weekly foraging index (Table S3.2). Similarly in January, the first week of January had the highest weekly foraging index in the month, second overall (Table S3.2). This time period also marks ice freeze-up in this region, peaking at its highest ice concentrations within these two listed weeks of high foraging occurrences (Figure 3.3).

3.5 Discussion

This study is the first to investigate call types of non-migrating James Bay beluga, during winter months, with a focus on communicative, navigational, and foraging calls. In addition to characterizing call types and related behaviours, we developed a foraging index to assess feeding occurrences across winter months, comparing December 2022 (ice freeze-up regime) and January 2023 (ice-covered regime). While previous studies have focused on outlining the vocal repertoire of beluga during summer months using estuarine habitat, this study looks at call types occurring in an offshore environment for a less commonly studied season. These results help advance our understanding of James Bay beluga whale behaviour during winter months and confirm they are actively foraging and feeding while sea ice undergoes freeze-up to cover the region.

3.5.1 Call Type Occurrences

Click trains were the most emitted call type across December and January. This call type is especially important as it is used for navigational and foraging purposes, specifically as a technique to maneuver in sea ice coverage by refracting sound off objects including sea ice and substrate (Lammers & Castellote, 2009; Penner et al., 1986). In December, we observed a gradual increase in total number of calls as sea ice concentration incrementally built up prior to

reaching high concentrations in January (Figure 3.3, Figure 3.4). Beluga have been shown to prefer heavy ice concentrations and floe edges during spring (Hornby et al., 2016). Because these habitat features are also present during winter months in James Bay, rather than being restricted to spring, these earlier findings are consistent with our results. Nonetheless, it is important to note that the relationship between beluga presence and sea ice concentration varies both spatially and temporally. Past studies have found beluga presence higher in both open water areas and heavily ice concentrated areas, showing variability in these preferences throughout years and dependent on other factors such as bathymetry, sex and age (Bailleul et al., 2012a, 2012b; Barber et al., 2001, 2012; Hornby et al., 2016; Mayette et al., 2023). An increase in number of calls at the study location, particularly click trains, may indicate site fidelity and suggest suitable habitat for overwintering beluga. Alternatively, a high presence of calls emitted could be a behavioural response to increased communication and navigational calls when sea ice concentrations are higher.

Following click trains, we observed a gradual increase of buzzes through December to the beginning of January, and then a gradual decline through January (Figure 3.4, Figure 3.5, Table S3.2). Similar to click trains, this result could be related to the ice-freeze up period during December when periods of open water are available. Evidently, as sea ice coverage builds and remains stable, we see a gradual decrease in buzzes at this location (Figure 3.4, Table 3.4). Ice coverage and flaw leads at the study location could be a limiting factor to beluga foraging occurrence. In January, beluga could be relocating to areas of open water and/or perusing flaw leads in search of more substantial foraging opportunities closer to coastal regions, if ice concentration becomes too prominent at the floe edge. The results in James Bay resemble those in the North Water polynya, which is an overwintering ground for marine mammals due to its year-round open water access, landfast ice conditions, and rapid sea ice formation creating a nutrient rich and productive hotspot (Heide-Jørgensen et al., 2013). Beluga in the North Water polynya were often detected in flaw leads and cracks (Heide-Jørgensen et al., 2013). Similarly ,

beluga in the Eastern Beaufort Sea have been observed increasing their under ice dives at the floe edge, which has been linked to feeding behaviours (Asselin et al., 2012).

Whistles were a prominent call type emitted out of the total number of calls. This is strictly a communicative type of call between conspecifics, indicating group activity, group cohesion, and individual identification for recognition within groups (Chmelnitsky & Ferguson, 2012; Janik & Slater, 1998). Similar to click trains and buzzes, whistle activity had a gradual increase throughout December and then a gradual decrease in January (Figure 3.4, Figure 3.5). Whistle occurrence reveals that beluga, most likely in groups, are occupying this region throughout winter based on favourable conditions in the ice cover and water column, allowing them to overwinter.

Lastly, BPPCs, another communicative call type, were the least emitted call out of the total number of calls. However, because this call type was not separated between simple and complex, we are unable to classify each BPPC. Studies have linked simple contact calls to communication in calves, due to the lack of complexity in the structure of the call (Vergara et al., 2010; Vergara & Mikus, 2019), whereas complex contact calls have been linked to situations of stress, and anxiety in entrapment situations (Vergara et al., 2010; Vergara & Mikus, 2019). In our results, we understand these calls as communicative and not following any notable patterns between the months December and January.

An interaction was found between month and call number, with December exhibiting a higher total number of calls. There was no significant relationship between specific call types and the month. These findings could be related to the different ice regimes. As ice freeze-up extends the lateral extent of the landfast ice, beluga are possibly pushed out of ice-covered coastal regions to more open water and floe edges, aligning with an increase in total calls at the mooring location during late December and early January (Figure 3.3). As sea ice concentrations build and persist through January, we see a decline in total number of calls. This

likely reflects movement in beluga to find desirable spots of open water for breathing and feeding opportunities.

3.5.2 Environmental Context

Regulated river flow of eastern rivers increases winter discharge, forming nutrient rich (nitrate and silica) under ice plumes (Lee et al., 2023). Flaw leads and polynyas provide open water and rapid ice formation, enabling sea ice algae growth (provided salinity is sufficiently high), and in turn beluga. Due to alternating periods of thin ice cover and open water, the amount and type of primary production becomes spatially and temporally variable, aligning with shift in foraging indexes (i.e. 14.8 – 9.9) between December and January. Higher calling and foraging activity during freeze-up may reflect a preference for open-water habitats, resulting in persistent movement as beluga seek out these areas throughout winter. Sea ice algae increases with closer distances to polynyas (Ahmed et al., 2025). In turn, this can attract and support zooplankton, and thus fish, both of which are prey for larger marine mammals, such as beluga (Ahmed et al., 2025; Heide-Jørgensen et al., 2013, 2016). Polynyas, such as the North Water Polynya, are associated with an increase in marine mammal presence and are known to support the overwintering of several species, such as polar bears, seals, beluga, narwhal, and sea birds (Heide-Jørgensen et al., 2013, 2016). The James Bay region, particularly offshore areas near floe edges, may function as polynya-like habitats during winter hosting localized overwintering areas. In this region, comparable physical properties especially vertical mixing that renews nutrients in surface waters may support biological production and sustain sympagic (ice associated) and pelagic organisms such as zooplankton, potentially providing a more reliable source for beluga foraging and feeding (Arrigo & Van Dijken, 2004; D.B Stewart & W.L. Lockhart, 2005; Guzzi et al., 2024; Lee et al., 2023; Schembri et al., 2023). It is important to note that sea ice algae production has yet to be understood in James Bay and therefore difficult to conclude if this a factor influencing beluga behaviours.

There was no biologically significant interaction between any of the call types and tidal trends but a small increase in total calls during a flooding tidal trend (Figure 3.6). Tides can alter ice and water conditions, indirectly affecting biological activity in the water column of these ice-covered regions (Prinsenberg, 1986a). The Hudson Bay complex experiences a semidiurnal tide, having two high and two low tides each day (Prinsenberg, 1986b). The tide begins in Hudson Strait, next reaching Hudson Bay, where part of it enters James Bay moving counterclockwise (Prinsenberg, 1986b). In winter, tidal currents are weakened by present sea ice; however, strong tidal currents along the floe edge cause movement in ice, opening and closing flow leads and/or polynyas in ice covered regions (Prinsenberg, 1986b). Previous Cook Inlet beluga presence was most detected in an ebbing tidal period in a river environment, suggesting they are taking advantage of the discharge of prey located in the river (Castellote et al., 2024). Similar to our study, vocalizations amongst Cook Inlet beluga increased during ebb and flood tides (increasing and decreasing) in an offshore environment in January, likely related to an increase in offshore feeding along the plume gradient (Castellote et al., 2024). These findings emphasize an importance of river discharge in winter months, as seen in James Bay, for overwintering beluga foraging. Our hydrophone was placed in a deeper point of the Bay (~60 m), as well as along the prominent landfast ice edge. Due to this placement, the number of calls and call types could be different from those that may be detected near the La Grande River or other open water areas of the Bay throughout winter. In a flooding tidal trend, there is a small increase in the number of calls, but no direct interaction between tidal trend and buzz call types (i.e. feeding occurrences).

Winter research on beluga is very limited. Many studies are conducted during summer months, when beluga migrate to summer aggregating sites where sea ice concentration is not a limiting factor when defining preferred habitat, foraging opportunities, call types, and movement patterns. Such studies have incorporated environmental covariates such as tidal trends, wave heights, wind speeds, salinity, and temperature to better understand presence; however, these

studies do not consider the potential effects of sea ice, floe edges, and polynyas (Ausen et al., 2023; Goetz et al., 2012; Scharffenberg et al., 2019; Smith et al., 2017). Call types including navigational calls, communicative calls, and foraging calls are rarely included in understanding beluga seasonal habitat, as beluga are typically absent from these ice-covered regions and on migration routes elsewhere.

3.5.3 Foraging Opportunities

Foraging occurrences happened more often during beluga presence in the month of December compared to January. Belugas are not considered primarily benthic or pelagic feeders but rather generalists, i.e. they forage on a variety of species in different habitats, with fish being a large portion of their diet (Laidre et al., 2008; Lesage et al., 2020; Loseto et al., 2009). Southern Hudson Bay and James Bay are characterized as more estuarine environments, supporting freshwater and anadromous species and few Arctic deepwater species compared to other areas of Hudson Bay (D.B Stewart & W.L. Lockhart, 2005). Subsistence fishing plays an important harvesting, cultural, and economic role in Cree communities in the James Bay, the O mushkego Cree in western James Bay and the Eeyou in eastern James Bay, giving us a better understanding of present species that would be a part of beluga diet. Identified fish species in this region include Lake Whitefish (*Coregonus clupeaformis*), Cisco (*Coregonus artedii*), Brook Trout (*Salvelinus fontinalis*), Northern Pike (*Esox lucius*), Longnose Sucker (*Catostomus catostomus*), Sturgeon (*Acipenseridae*), Burbot (*Lota lota*), and Walleye (*Sander vitreus*) (Belinsky et al., 1996; Bouchard et al., 2025; D.B Stewart & W.L. Lockhart, 2005; DeJong et al. 2017). In August 2021 and August 2022, trawls surveys were conducted across James Bay to sample zooplankton and fish and yielded a minimum of 32 species (Niemi et al., 2026). The most abundant taxa across both sample periods, which equated to 50% of catch was the Zoarcidae, commonly known as eelpouts (Niemi et al., 2026). Due to fish movements between completely fresh water, brackish water, and marine environments, most of these species are defined as anadromous and semi-anadromous fish. Common anadromous fish in this region

include the Lake Whitefish and Cisco; however, during winter months, both species can be found near the mouth of rivers as well as out of the river and in the Bay (D.B Stewart & W.L. Lockhart, 2005; Morin et al., 1981). If eastern rivers are providing enough biomass during winter due to regulated flow, such fish species could be feeding on zooplankton, in turn attracting beluga. In contrast, burbot can be characterized as winter-specialists, remaining in the deeper cool part of water systems following diel patterns (Harrison et al., 2016). Kastelein et al. (1994) conducted a study on captive beluga feeding habits and found that depending on the weight/age of the beluga, as well as water temperature, they are consuming between 1.2-4.5% of their body weight. For an adult beluga, this is equivalent to approximately 4900 kg of fish per year. Information on beluga diet in James Bay is very limited as diet studies are unavailable in this region, however it may be important to continue researching as this is a substantial amount of food supporting the population. Using documented fish species as well as understanding the James Bay system including sea ice dynamics, light availability, freshwater influence, and the water column, we can gain a better understanding how production may occur and support higher trophic level organisms such as fish and beluga.

Beluga populations have been found to shift their diets seasonally, specifically in winter months. Beluga in Cumberland Sound (i.e. an overwintering stock) spend summer months in the northwestern regions moving outwards to the mouth of Cumberland Sound in winter (Richard & Stewart, D.B., 2008). Deeper and longer dives were associated with winter months, suggesting a shift in prey from Capelin to Arctic Cod (Watt et al., 2016). These dive behaviour results align with Bailleul et al. (2012a) who reported increased diving behaviour in James Bay beluga during winter months, suggesting a shift in prey compared to summer months (Bailleul et al., 2012a). Consistent with this pattern, our hydrophone was positioned at the offshore floe edge and recorded an increase in calls and foraging buzzes occurring during ice-freeze up, suggesting a movement away from coastal regions toward the deeper offshore environments as ice forms. In relation to deeper diving and offshore environments, a recent study done in the

Belcher Islands found that south of the islands had a highly freshwater influenced environment, dominated by Arctic cod (Vachon, 2025), indicating Arctic cod could be a source of prey in ice covered months in James Bay. Results of Bailleul et al. (2012) gives us an indication that beluga may have available pelagic and benthic prey based on evidence of increased diving behaviour in this region, aligning with the increase in calls during ice freeze-up at our offshore hydrophone location.

This study finds a greater foraging index across the months of December and January compared to Cook Inlet beluga who are also year-round residents of their region (Hobbs et al., 2020; Rugh et al., 2005). During summer, they remain within rivers and estuaries, but then shift southward to the Lower Inlet, closer to open water, where sea ice is not as big of a concern (Castellote et al., 2020). Foraging occurrences were higher in the upper (northern) Inlet during summer months, particularly within rivers compared to winter where foraging happened across a greater spatial area (Castellote et al., 2020). Across all locations, incorporating both foraging-positive minutes and detection-positive hours, the foraging indices for December and January were 6.2 and 3.6, respectively (Castellote et al., 2020). Authors suggest, foraging may have occurred at different locations than where hydrophones were deployed, specifically offshore, indicating a possible shift toward benthic prey (Castellote et al., 2020). Hydrophones in the Cook Inlet study were deployed closer to river mouths and coastal regions, within ~2-16 km offshore, based on previous knowledge of the populations critical habitat, whereas in our study the hydrophone was placed further away from coastal rivers and closer to the floe edge (Castellote et al., 2020). As a result, authors suggest beluga in the Cook Inlet could be foraging offshore in a more dispersed pattern that was not captured by hydrophones as they did not monitor offshore waters (Castellote et al., 2020). Although the study areas differ, our results provide insight into offshore foraging behaviour, specifically in regions associated with flaw leads and packed ice, showing a higher foraging index than the described areas in Cook Inlet.

3.5.4 Limitations and Future

Utilizing passive acoustic monitoring to investigate beluga presence and movements has both benefits and limitations. The beluga needs to be vocalizing in order for us to document their presence. Furthermore, beluga need to be within a certain distance of the hydrophone in order for calls/sounds to be recorded, therefore, recordings in this study could represent a small part of vocalizations going on within the Bay. Previous studies have detected beluga vocals within 2.5 km of a hydrophone, however environmental factors (i.e. depth, ice coverage, temperature, wave action, bottom type), may affect this distance (Coppolaro et al., 2024; Eickmeier & Vallarta, 2023; Halliday et al., 2019; Scharffenberg et al., 2019). Future work should incorporate hydrophones in an array, to better understand beluga distance from the hydrophone, population presence, and pod movements (Roy et al. 2010). Hydrophones should be placed in areas of interest based on our results and current understanding of their presence and movements, and in collaboration with James Bay communities, boards and councils. This can help us further compare call types in different locations of the Bay, giving us a better interpretation of overwintering areas and better insight to potential prey species based on the different environments we detect foraging buzzes. In addition, we only analyze the first minute of every hour, limiting the number of recordings we include in the results. Having a lower duty cycle causes gaps in the study timelines, could potentially lead to missed patterns throughout the study period (Michel et al., 2025). However, the foraging index represents a relative measure of foraging occurrence rather than absolute foraging time. Additionally, we used literature to define the inter-click interval in a foraging buzz, and this value (~3-5 ms) could be considered not as conservative as other values used on the same call type, such as Castellote et al. (2020) where they used a value of 2 ms. Having a higher inter-click interval would potentially cause a higher buzz count than potentially being emitted by beluga, creating a greater foraging index. This could be a contributing factor as to why our index is higher than the Cook Inlet study.

3.5.5 Conclusion

Overall, with our use of analyzing underwater call types emitted by James Bay during winter months were able to confirm the presence of foraging, and communicative behaviours. Our findings indicate that beluga use various call types in winter, including broadband pulsed calls and whistles for communication, echolocation click trains for navigational purposes, and buzzes for foraging and feeding.

We compared beluga call types between two different winter months characterized by contrasting ice regimes, December, having an open water to ice freeze-up transition, and January, which was predominantly ice covered with high ice concentrations. Results indicate that total number of calls was greater in December compared to January. In addition to analyzing call types, we developed a foraging index to quantify how frequently foraging behaviour occurred across all acoustic files with confirmed beluga presence. The foraging index was higher in December, suggesting that feeding activity was more prevalent during open-water or early freeze-up conditions than during periods of extensive ice cover.

These findings are consistent with other overwintering beluga studies that report increased diving behaviours and a winter shift in prey toward offshore environments. In our study, the hydrophone was positioned at the offshore floe edge, detecting constant calls throughout the winter months, with elevated calls occurring during ice freeze-up, suggesting a movement away from coastal regions toward offshore environments such as flaw leads and polynyas as ice forms. This pattern supports the idea that offshore flaw leads and polynyas provide suitable overwintering habitat. However, regulated river flow from eastern rivers may also play an important role in winter by delivering the system with biomass, and nutrients creating an under ice plume, potentially supporting under-ice foraging during periods of high ice coverage, such as January when the index gets lower. The detection of vocalizations in this area, including communicative, navigational, and foraging calls, highlights the ecological importance of polynyas and flaw leads in James Bay. Future work should continue to assess

beluga call types across all months of the year and across different locations to better distinguish foraging occurrences from communicative occurrences, and to improve our understanding of seasonal foraging patterns and prey availability.

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Supplementary Materials

Supplementary Datasets

- Would like to link to Canwin for hydrophone data
- Weekly ice charts from The Canadian Ice Service:
(<https://iceweb1.cis.ec.gc.ca/Archive/page1.xhtml?>)
- Tidal Data: <https://tides.gc.ca/en/stations>
- National Research Council of Canada's sunrise/sunset calculator:
<https://nrc.canada.ca/en/research-development/products-services/software-applications/sun-calculator/>

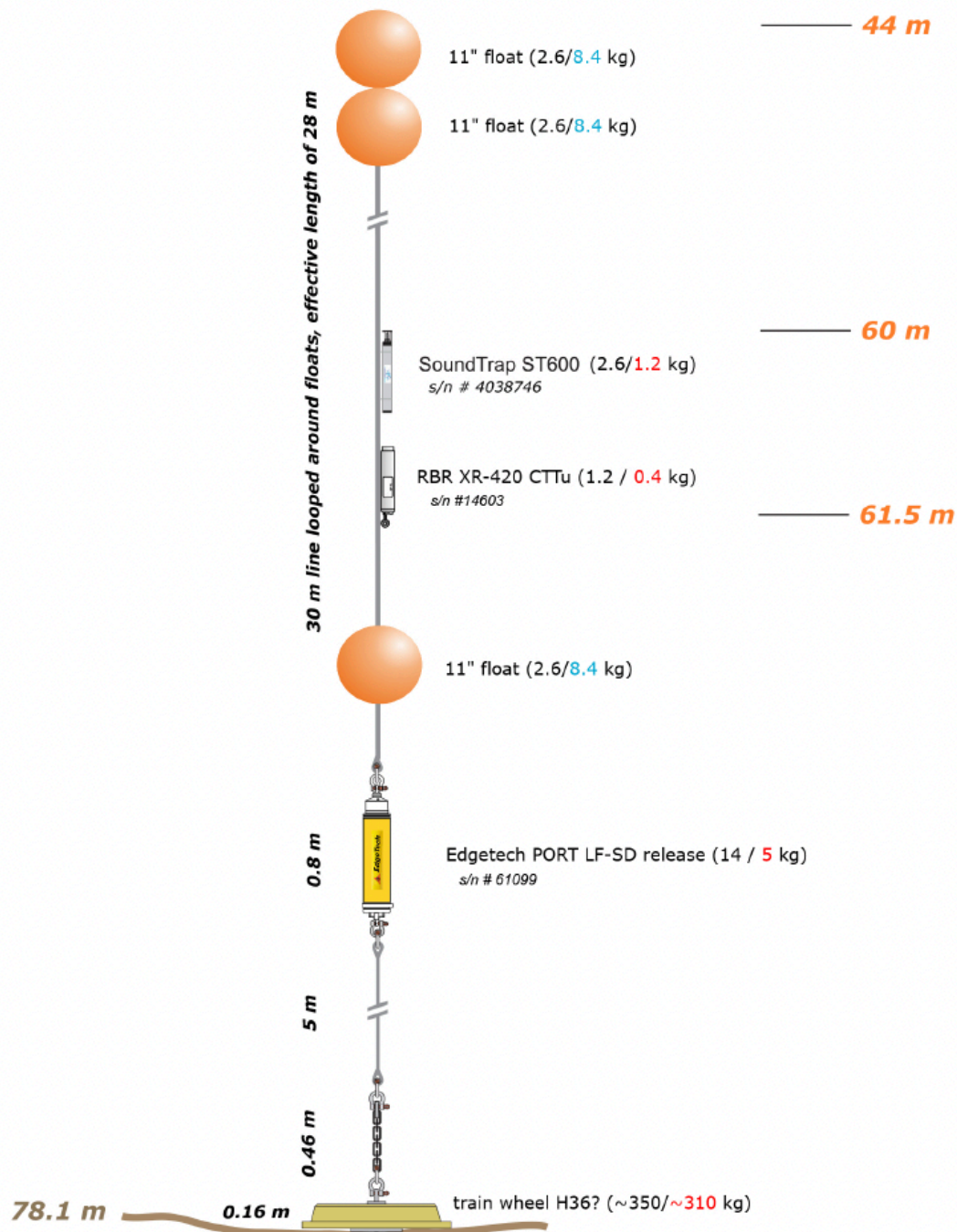


Figure S3.1 Diagram of mooring JB-H, with the attached ST600 and RBR XR-420 CTD profiler. Deployment took place in August 2022, and retrieval took place in 2023, both done from the RV William Kennedy in southwestern James Bay.

Table S3.1 Parameters measured in Raven Pro. Definitions sourced from the Raven Pro 1.4 User Manual.

Begin Time (s)	The time at which the selection begins.
End Time (s)	The time at which the selection ends.
Delta Time (s)	The difference between Begin Time and End Time for the selection.
Center Freq. (Hz)	The frequency that divides the selection into two frequency intervals of equal energy.
High Freq. (Hz)	The upper frequency bound of the selection.
Low Freq. (Hz)	The lower frequency bound of the selection.
Peak Freq. (Hz)	The frequency at which Max Power/ Peak Power occurs within the selection. If Max Power/ Peak Power occurs at more than one time and/or frequency, the lowest frequency at Max Time at which Max Power/ Peak Power occurs.
Energy (db FS)	This function was used to help determine a signal to noise ratio. Signals were measured in comparison to background noise, and it was determined that anything below 10 dB is considered in the analysis.

Table S3.2 Values represent the calculated weekly foraging index in December 2022 and January 2023. FPM is the number of files that had a foraging positive minute, which is when a click train followed by a buzz occurs 1≥ in a sound file. DPM, detection positive minutes represent total beluga acoustic presence, therefore any sound file that had beluga presence. Monthly total is the calculated total of DPM, FPM, to get the monthly foraging index.

<i>Week</i>	<i>DPM</i>	<i>FPM</i>	<i>Foraging Index</i>
2022-11-27	15	0	0
2022-12-04	52	6	11.5
2022-12-11	91	11	12.1
2022-12-18	93	14	15.0
2022-12-25	145	27	18.6
December Monthly Total	398	59	14.8
2023-01-01	115	16	13.9
2023-01-08	67	5	7.5
2023-01-15	47	4	8.5
2023-01-22	32	1	3.1
2023-01-29	1	0	0
January Monthly Total	262	26	9.9

Chapter 4. Conclusion

4.1 Summary

This thesis is the first study to assess the year-round presence of the James Bay beluga population, as well as interpret various call types including navigational, foraging, and communicative to understand call type associated behaviours. Furthermore, this stock has been identified as year-round residents, meaning they occupy James Bay during all seasons, including winter when beluga are often triggered by sea ice to leave for their migration routes (Barber et al., 2001; Sergeant, 1973). This study creates a baseline of seasonal presence throughout the Bay and provides insights on winter call types and related behaviours.

In Chapter 2, I demonstrated the year-round presence of beluga using click vocalizations at two different locations in the Bay, the northwest and the southeast. Although there were documented clicks at each location year-round, I showed that environmental factors influenced seasonal presence differently. At the northwest location, I found an increased presence during months with warmer sea surface temperatures, and a negative effect from sea ice cover. These results indicate that the northwest location may be more suitable and preferred habitat for summer aggregating areas, rather than an environment in which beluga will choose to overwinter. In contrast, the southeast region showed a positive association between beluga presence and cooler sea surface temperatures and sea ice freeze-up, specifically occurring in December and January. Although presence during the period of sea ice cover was lower compared to the freeze-up period, there were still many more detections occurring at this location during winter months than at the northwest location. When considering that the range of the hydrophone might be only 2.5 km, the detection of clicks nearly every day provides strong evidence that beluga were present continuously throughout winter in southeast James Bay. These findings suggest that the southern area of James Bay is a suitable environment for beluga to overwinter in.

In addition to click vocalizations we conducted a spatial analysis comparing proportion of presence at the mooring locations and sea ice concentration across the Bay. This analysis revealed a relationship between availability of open water (low sea ice concentration) along the eastern coastline and reduced click numbers at the southeast mooring site, suggesting that beluga are more likely continuously moving in search for open water areas. It is possible that beluga are following the floe edge northward away from the southeast mooring site when it closes up and exploiting the polynya extending from the La Grande as well as available flaw leads. Oppositely, there was limited click detections at the northwest location once sea ice freeze-up occurred, however as sea ice break up began in spring presence immediately increased. This finding suggests a possible distinction in groups within James Bay. Beluga at the northwest location could potentially be a part of the Eastern Hudson Bay beluga based on previous studies findings (Müller et al., 2025) as well as the limited click presence during winter and increase click presence in sea ice break-up, indicating a potential migration.

In Chapter 3, we analyzed and defined call types at the southeast location in the winter months December, representing an ice freeze-up regime, and January, an ice covered regime. Call types included echolocation click trains, used for navigational purposes, click trains ending with a terminal buzz, indicating feeding, as well as whistles and broadband pulsed calls, both used for communication. After counting the total number of calls, we created a foraging index using, detection positive minutes, which considers any minute with beluga presence regardless of the call type and foraging positive minutes, which is a minute that had $1 \geq$ buzzes (Castellote et al., 2020). This index allows us to understand how often feeding occurrences happened out of all positive beluga detection instances. We found an increased number of calls in December compared to January, as well as a greater foraging index in December. These findings indicate that beluga presence and foraging occurred more often in an ice-freeze up regime compared to high ice coverage at the offshore hydrophone location. In addition to greater calls in December,

we found slightly higher calls during an increasing tidal trend compared to a decreasing, but not biologically significant. These results, together with the lower foraging index observed in January during periods of high ice coverage, may reflect the influence of regulated freshwater input along the eastern coastline. In addition, the presence of offshore polynyas, flaw leads, and rapid ice formation allow for light availability, potentially increasing sea ice algae, attracting grazers and lower trophic level organisms in turn, creating prey availability for larger mammals such as beluga.

4.2 Limitations

Beluga must be vocalizing in order for us to document their presence. Although passive acoustic monitoring (PAM) offers great temporal coverage it is limited to the location of the hydrophone. In this study we use a 2.5 km radius around the hydrophone to account for environmental factors having a potential influence on the beluga detections at each location, although such environmental factors could also influence the distance at which detections are made (Coppolaro et al., 2024; Eickmeier & Vallarta, 2023; Halliday et al., 2019; Scharffenberg et al., 2019). As such, these measurements provide only a brief overview of the environmental context in which beluga detections were recorded. In Chapter 2, we only use click vocalizations to document presence, even though beluga emit many other call types such as whistles, buzzes and pulsed calls (Chmelnitsky & Ferguson, 2012; O'corry-Crowe, 2009; Panova et al., 2012; Sjare & Smith, 1986). Limiting call types being detected could create an underestimate of total beluga presence in.

Chapter 3 had similar limitations in the sense that we only used one location and heavily rely on beluga to vocalize at all times in order to capture call types and related behaviours. In this study, we only analyze the first minute of every hour, limiting the number of recordings we include in the results. Having a lower duty, such as one minute every hour, causes gaps in study timelines, potentially missing patterns throughout the study period (Michel et al., 2025).

Additionally, we used literature to define the inter-click interval in a foraging buzz, and this value (~3-5 ms) could be considered not as conservative as other values used on the same call type, such as Castellote et al. (2020) where they used a value of 2 ms. Having a higher ICI, would potentially cause us to count more buzzes than maybe being emitted by beluga, creating a greater foraging index.

This project is one contribution among many towards a larger southern Hudson Bay and James Bay Expeditions' project in which sea ice dynamics, freshwater influences, nutrient cycling and food web are being simultaneously studied. There is limited, available data (i.e. diet studies, and nutrient availability) on James Bay, specifically in understanding the qualities of this unique environment to home such a large number of beluga year-round. This project provides a benchmark for year-round presence. As studies continue over time, each of the above components will come together to produce a better picture as to why this environment may be able to overwinter and summer beluga.

4.3 Future Communications and Planning

Moving forward, I believe we should continue to collaborate with communities on what their next priorities are in terms of understanding the population further as well as hear their considerations to future hydrophone placement based on seasonal observations. I would recommend a hydrophone closer to the western coastline, potentially along floe edge and/or closer to the rivers, this would give a better depiction of summer aggregating spots, either on the same latitudinal gradient as JB-M2 or closer to Akimiski Island and Attawapiskat River. I would also recommend deploying a hydrophone near the La Grande River plume along the floe edge, this could help create a clearer picture of beluga distribution on the eastern side of the Bay, specifically in winter. It is important to also remain aware of the sea ice dynamics and bathymetry in James Bay as it is relatively shallow, with a prominent land fast ice edge. This means that if there is interest in deploying hydrophones in new areas, consideration of these

risk factors needs to be taken in order to ensure we can deploy and retrieve successfully without damaging or losing devices. During this analysis, other marine mammals were heard such as ringed and bearded seals as well as walrus clicks. This could be a complimentary addition to beluga presence understanding what mammals are overwintering in these areas together, specifically in the polynyas and flaw leads on the floe edge. Incorporating multiple hydrophones across the same time period, would enable the use of localization techniques, allowing researchers to estimate detection ranges from each hydrophone location, and track beluga movements (Roy et al., 2010). Lastly, although PAM faces its challenges, it also works great with other methods that offer better spatial coverage such as aerial surveys, tagging data and local Indigenous knowledge.

Although the Cree First Nation communities in James Bay do not rely on beluga subsistence harvesting, it is recognized that the animal is culturally significant and necessary for food security in terms of maintaining a healthy ecosystem for surrounding organisms. It is recognized through the development of regional planning and conservation areas, that James Bay is home to a very unique beluga population, and maintaining this dynamic is very important for both the marine environment and people.

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