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Pairing Etuaptmumk with Acoustic Telemetry to Uncover the Seasonal Distribution of Ji'kaw in Pitu’pa’q

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Abstract

Pitu'pa'q (Bras d'Or Lake) is a complex semi-enclosed estuary in Unama'ki (Cape Breton, Nova Scotia, Canada) with such significant ecological diversity and cultural importance that it has been designated as a UNESCO Biosphere Reserve. Selected for its importance to Mi'kmaw communities, Pitu'pa'q is a key study site for Apoqnmatulti'k, a collaborative partnership pairing Mi'kmaw and local ways of knowing with western science to enhance aquatic stewardship in Mi'kma'ki. Ji'kaw (striped bass; *Morone saxatilis*) use this spatially complex estuary during all seasons of the year, and Mi'kmaw communities have expressed questions about their seasonal distribution patterns. Through a co-developed research program, 45 Ji'kaw were tagged with acoustic transmitters in Pitu'pa'q and their movements within the lake were recorded from June 2024 until June 2025. During this time, clear differences in space use were seen between the seasons, and high connectivity was observed between the basins of Pitu'pa'q. Beyond Pitu'pa'q, 13 of these tagged Ji'kaw were detected in the Miramichi River, a known spawning site, during spring 2025, indicating that some contingent of Ji'kaw in Pitu'pa'q are members of the Southern Gulf of St. Lawrence population. Knowledge generated regarding the seasonal distribution of Ji'kaw in Pitu'pa'q has contributed to an important co-learning journey with results directly relevant to Mi'kmaw communities who can use this information for enhanced co-governance programs.

1. Background

Ji'kaw (striped bass; *Morone saxatilis*) is an anadromous species with a native distribution from the Gulf of Mexico to the Gulf of St. Lawrence (COSEWIC 2012). Across their range, Ji'kaw hold value in commercial and recreational fisheries, and are culturally important for coastal communities as a traditional food source (Russell 2025). The Mi'kmaw name Ji'kaw roughly translates to "fish that flakes", demonstrating that they have been part of the Mi'kmaw food system since time immemorial (Skyler Jeddore, pers. comm.). As generalist predators, Ji'kaw support diverse ecosystems and have a key role in maintaining ecological balance (Setzler-Hamilton et al. 1980; Hammerschlag et al. 2019; Hanson 2020). In Canada, three designatable units (DUs) of Ji'kaw are recognized and managed by the federal government, each of which had become depleted in previous decades following commercial exploitation in the 1900s (COSEWIC 2012). In an effort to protect the stocks, the commercial fisheries were closed from 1996 until 2018, and populations have been generally increasing since (Bradford et al. 2001). Ji'kaw demonstrate exceptionally diverse movement patterns, often exhibiting multiple migratory strategies within one spawning population (*i.e.;* "migratory contingents"; Clark 1968; Secor 1999; Gahagan et al. 2015; Buhariwalla 2018; Andrews et al. 2019a; Secor et al. 2020).

In Pitu'pa'q (Bras d'Or Lake, Nova Scotia), Ji'kaw numbers have been increasing as the Southern Gulf of St. Lawrence (sGSL) DU recovers (DFO 2023). Mi'kmaw and local knowledge holders in the region have begun questioning the movement patterns of these Ji'kaw as they move into, out of, and around the lake across seasons, contributing to recreational and subsistence fishing. Pitu'pa'q is a large inland estuary, composed of several semi-enclosed basins with only three connections to the Atlantic Ocean (Petrie and Bugden 2002; Parker et al. 2007). Pitu'pa'q is designated as a UNESCO Biosphere Reserve for its diverse

ecology and cultural importance to the Mi'kmaw communities living on its coastline (UNESCO 2011). Due to the complexity of Ji'kaw's migratory behaviour in other regions and the geographic complexity of the lake itself, the seasonal movements and distribution of Ji'kaw in Pitu'pa'q cannot be inferred from existing literature. Ji'kaw are present year-round in Pitu'pa'q (Andrews et al. 2019b, 2019a), but have been identified as members of the Miramichi River spawning population (COSEWIC 2012; LeBlanc et al. 2018, 2020). Community questions remain regarding their use of the lake, as well as the timing of immigration or emigration for the spawning run in Miramichi. Beyond questions about their occupancy patterns, the degree of exposure to anthropogenic threats within the lake remains unknown, and management strategies for Mi'kmaw constitutionally protected fisheries (Being Schedule B to the Canada Act 1982 (UK), 1982, c 11 1982 sec. 35) need to be informed by movement patterns across all basins in the lake.

To understand more about Ji'kaw in Pitu'pa'q, organisations representing Mi'kmaw, local, and western scientific ways of knowing have come together under the Apoqnmatulti'k partnership to track Ji'kaw using acoustic telemetry with the goal of informing shared stewardship (Bate et al. 2026). To support the collaborative nature of Apoqnmatulti'k, all decisions were informed by Indigenous, local, and western scientific knowledge holders using an Etuaptmumk (Two-Eyed Seeing) approach (Bartlett et al. 2012). Empowering partners at all stages is essential when weaving together diverse perspectives to inform a shared goal. Using an Etuaptmumk approach enhanced this program's objectives by engaging Mi'kmaw rightsholders in every phase of the research, making the outcomes directly applicable to affected communities and supportive of Indigenous fisheries sovereignty (Reid et al. 2021; Bate et al. 2026).

Using acoustic telemetry, we tracked 45 Ji'kaw in Pitu'pa'q for a period of 9-13 months from May 2024 until July 2025. Based on Mi'kmaw, local, and western scientific knowledge, and guided by community questions, we hypothesized that 1) Ji'kaw will show seasonal variation in their spatial distribution across Pitu'pa'q, 2) there will be high connectivity between the basins in Pitu'pa'q, and 3) some proportion of Ji'kaw will leave Pitu'pa'q and enter the Atlantic Ocean. The results of this project will uncover the spatio-temportal patterns of Ji'kaw in this culturally and ecologically important estuary.

2. Methods

2.1 Study Site

Located in Unama'ki (Cape Breton, Nova Scotia, Canada), Pitu'pa'q (Bras d'Or Lake) is a brackish inland estuary designated as a UNESCO Biosphere Reserve (UNESCO 2011). Important to Mi'kmaw people for rights-based harvesting, cultural identity, and relational kinship, this region has been identified by Apoqnmatulti'k partners as a site of ecological and cultural importance in Mi'kma'ki (CEPI 2006, 2011). The lake is 1080 km^2 in size, and is connected to the Atlantic Ocean by three narrow waterways:the Great Bras d'Or Channel, the Little Bras d'Or Channel, and the man-made St. Peter's Canal (Parker et al. 2007). Bottom depth ranges from shallow sand flats (<1 meters deep) to more than 200 meters deep, and tidal amplitude is generally less than 10 cm (Petrie and Bugden 2002; Parker et al. 2007; Murray 2022).

Pitu'pa'q holds extreme cultural significance to the Mi'kmaq, who have been stewards of this region since time immemorial. The spirit of the lake itself connects all non-human life with humans, making this a place that supports cultural preservation, rights-based fisheries, and Mi'kmaw sovereignty(CEPI 2011; Joseph 2025).

2.2 Experimental Design

Acoustic Receivers

To support the Apoqnmatulti'k acoustic telemetry program in Pitu'pa'q, the Ocean Tracking Network (OTN) and Unamaki Institute of Natural Resources (UINR) maintain an array across the lake consisting of compatible acoustic receivers (Figure 1), where detection data is offloaded annually (in June each year). The Centre for Marine Applied Research (CMAR) in Nova Scotia contributed three receivers to enhance the array. The deployment sites were selected based on local and Mi'kmaw harvester knowledge of Ji'kaw movements in the region, academic best practices for receiver detection coverage, and to prioritise sites of cultural importance (like coastal lagoons called barachois ponds; Ross and Fanning 2021) to reinforce an Etuaptmumk approach. The array was deployed in June 2024, consisting of 56 acoustic receiver stations: 7 in barachois ponds and other shallow sites, and 49 in the main lake. The data were downloaded, and the array was redeployed in June 2025. Some acoustic receivers deployed in coastal barachois ponds were downloaded periodically on a different schedule. Metadata showing a full history of receiver deployments, recoveries, and downloads is available here: https://members.oceantrack.org/project?ccode=BDLSPG. In total, four acoustic receivers were lost and not downloaded, and so these deployments have been removed from the map (Figure 1).

Tagging

Ji'kaw were angled from shore using rod-and-reel methods with barbless hooks. The fish were brought to shore as quickly as possible to minimize fight time and stress. Fish that were unfit for tagging, including those injured during capture or below the 35 cm minimum size threshold, were released immediately. Both fishing and tagging were accompanied by purposeful periods of spiritual connection, including ecological observation data collection and time for ceremony.[1]

Following discussions with Mi'kmaw partners at UINR, the project opted to use electro-immobilisation rather than chemical anesthesia for tagging surgeries. Chemical anesthesia has withdrawal effects and remains in animal tissues for weeks after application (Trushenski et al. 2012; Izzo et al. 2024; Fiolek and Weber 2025). Ji'kaw is a traditional food of the Mi'kmaq in Pitu'pa'q and tagged fish can re-enter the food system after release. Natural anesthesia like clove oil, while non-toxic, can result in a disrespectful waste of fish: if animals die, they will not be consumed by scavengers or humans due to the clove taste (Shelley Denny, pers. comm.). It was agreed that a suitable alternative is electro-immobilisation with electric fish handling gloves (Denny et al. 2025). Several studies have validated the use of these gloves for teleosts including other perciform fishes such as largemouth bass (*Micropterus salmoides*), lake trout (*Salvelinus*

namaycush), and lake whitefish (*Coregonus clupeaformis*; e.g. Reid et al. 2019, 2024; Izzo et al. 2024; Funnell et al. 2025). Experience with these gloves and published literature confirms that approximately three-minute-long surgeries conducted under electro-immobilisation while the fish receives water over the gills result in minimal harmful outcomes for the animal (Denny et al. 2025)**.** The co-development of research methods is a paramount example of how Etuamptmunk can contribute to research by pairing Mi'kmaw values with western/scientific values (Denny et al. 2025).

Captured Ji'kaw were measured (fork length/total length/girth) to the nearest half-centimetre. Sterilized acoustic transmitters (13 mm diameter, <15 g weight, with either temperature and pressure, or acceleration and pressure sensors) were surgically implanted into the ventral body cavity of the fish, between the pelvic and anal fins (Innis 2025).Tag weight did not exceed 2% of fish weight. The size of the incision was equal to the width of the base of the tag, and the incision was then closed with 2-3 interrupted stitches using ethilon monofilament sutures. To externally mark the animals for quick identification by harvesters, an external t-bar tag was inserted laterally into the body at a 45° angle between the anterior two spines of the primary dorsal fin. After surgery, electro-immobilisation ceased, and the Ji'kaw were held by hand in the water along the shoreline until equilibrium was confirmed and the Ji'kaw swam away.

Between May and October 2024, 45 Ji'kaw were tagged across five tagging sites and 29 sampling days (Figure 1). Metadata showing the animal tagging and releases are available here: https://members.oceantrack.org/project?ccode=BDLSPG and in Appendix A. Based on ecological observations, Ji'kaw were most likely to be caught when the water temperature was 14 °C, and no fish were captured below 10 °C. More fish were tagged during a unique solar flare event (October 10, 2024, n=11) than on any other sampling day. Tagged fish ranged from 38 cm to 80.5 cm total length, with a mean total length of 50.5 cm (+/- 8 cm) (details in Appendix C). Capture and tagging procedures were in accordance with Dalhousie University's Animal Care Committeeprotocol 24-016 and DFO Section 52 permit 372869 (Maritimes Region, Fishery (General) Regulations, Fisheries Act). Ethics approval was also obtained from Dalhousie Univerisity Research Ethics Board protocol 2021-5468.

Figure 1: Map of Pitu'pa'q (white) within Unama'ki (grey polygon), indicating the locations of acoustic receivers (blue points) and released tags (yellow diamonds), with the basins of Pitu'pa'q labelled by name. The number adjacent to each tagging location corresponds to the number of individual Ji'kaw tagged and released at that site.

2.3 Data Analysis

All analyses were conducted using R version 4.5.0 (2025-04-11) in RStudio (R Core Team 2025). All data manipulation and summaries were conducted using *tidyverse* (Wickham et al. 2019), and unless otherwise specified, plots were produced with *ggplot2* (Wickham 2016).

Filtering Detection Data

Detection data were downloaded from the OTN database, and the provided files, which match all receiver locations provided to OTN, were imported into R and filtered to remove spatially impossible detections occurring in the Great Lakes (n = 2 total detections). Potential mortalities were then identified by plotting each fish's movement track and removing fish with two or less detections (n = 2 fish removed).

Understanding Seasonal Movement Patterns

Biological seasons were used to classify movement patterns across the year. Detection data were plotted and summarised, looking for changes in fish movement metrics across time. The mean number of basins visited per week was determined to represent fish movements adequately.

To predict spatial patterns in their seasonal movements, the package *mgcv* (Wood 2017) was used to generate generalized additive models (GAMs) using the *bam*() function to model the relationship of animal detections with space and time. A GAM was selected because it offers functions that allow some control for spatial and temporal autocorrelation. GAMs have been widely applied to ecological data in the literature (e.g. Pedersen et al., 2019). Although statistical modelling is a western scientific method, Etuaptmumk was used to select relevant variables based on community-provided questions, so this model is a product of our collaboration and represents knowledge shared between multiple worldviews.

To test the hypothesis that Ji'kaw show seasonal variation in their spatial distribution across Pitu'pa'q, detection data were summarized to provide the number of individuals detected at each receiver location per month. This dataframe was then expanded to include zeroes at receiver locations that had no Ji'kaw detections within a given month (Whoriskey et al. 2019). A negative binomial model was formulated with a three-way tensor interaction between space (UTM easting and northing) and time (month). A thinplate spline was used for the interaction between easting and northing, while a cyclic spline was used for month, with the knots specified such that the first and last month of the dataset would have intersecting values. The estimated degrees of freedom were constrained by a k-value set for each term. The model formula is provided in Appendix B.

The model was evaluated using the *gratia* package (Simpson 2024), including the *appraise*() and *draw*() functions. Model predictions were then generated from the model and extrapolated across a grid representing all possible locations within the study area, constrained to the lake's borders using the *sf* package's *st_intersection()* function (Pebesma and Bivand 2023). A heatmap for each month of the year was plotted using *ggplot2* to show how Ji'kaw space-use varied across months at a 1 km scale.

Interconnectivity of Pitu'pa'q

To test the hypothesis that there is high connectivity between the basins in Pitu'pa'q, a network analysis approach was used to explore the ways in which Ji'kaw move through the lake. Network analysis is a graphical approach to quantify the degree of connectedness of the provided variables, and can be useful for animal movement data (Whoriskey et al. 2019). Network analysis requires a node-list, which contains the potentially interconnected entities, and an edge-list that denotes which nodes are connected to each

other. An edge-list can be weighted or unweighted. In this analysis, nodes were identified by grouping together receiver stations which fell within the same 10 km x 10 km grid to ensure they were spatially representative of the environment without overcomplicating the network and to reduce spatial autocorrelation across receiver locations. Edges were defined as the movement of animals between the spatially located nodes.

A network object showing Ji'kaw movements (edges) between nodes was created by summarizing data with packages including *glatos* (Holbrook et al. 2024)and pairing the edges with the node list into a network object using the package *sfnetworks* (van der Meer et al. 2024). The edges were weighted by counting the total number of Ji'kaw movements between each node pairing. Betweenness centrality is a metric that measures the connectedness of each node based on the number of connections to other nodes and how frequently a node appears on the shortest path between other nodes in the network. Node degree is the number of incoming and outgoing edges of a node. Node betweenness centrality and node degree were calculated using the *tidygraph* and *igraph* packages (Pedersen 2024; Csárdi et al. 2026) and plotted across the study site. From this analysis, important movement corridors (edges with high weights) and highly connected regions of the lake (nodes with high betweenness centrality or degree) were examined.

Exploring Emigration

To test the hypothesis that some proportion of Ji'kaw leave Pitu'pa'q and enter the Atlantic Ocean, the detection history of each individual fish was explored using data summaries and various visualizations. Based on this exploration, any individuals with a final detection at one of the lake exits (the mouth of the Great Bras d'Or Channel, the head of St. Andrews Channel, or the last receiver before the St. Peter's Canal), followed by several months without detections (aka: their "terminal" detection was at a lake-exit) were identified as having left the lake. The lake-exit events were summarized by date of occurrence, and the influence of tagging date and animal size were investigated. Unpublished data from collaborators in the Miramichi River were included to provide additional context about Ji'kaw movements after they exited the lake.

[1] Ceremony is a way of honouring, connecting with, and remaining accountable to the land and waters. Ceremony can include offerings like tobacco or sage to recognize the reciprocal relationship we have with the land. Honouring our relationship with the earth through research is a type of ceremony (Wilson 2008).

3. Results

Filtering Detection Data

A total of 193,528 detections of 43 Ji'kaw were recorded within Pitu'pa'q between June 2, 2024, and July 30, 2025. Two individuals (animal IDs 55 and 84) were never detected. After data filtering, an additional two individuals (animal IDs 79 and 80) were removed from the dataset because they had single or

sparse detections. This left 193,520 detections of 41 individuals for the following analyses. Ji'kaw were detected in every basin within Pitu'pa'q (Figure 2), and in each season. Of the 52 downloaded acoustic receiver stations, 11 (21%) did not collect any Ji'kaw detections.

Figure 2: Abacus plot showing detections of each individual Ji'kaw over time, coloured by basin. The red diamonds indicate a detection on the terminal lake-exit station (GB2), and the blue diamonds show the initial tag implantation date for each animal.

Understanding Seasonal Movement Patterns

Four biological seasons were defined based on observed movement patterns: a spring "emerging" period, a summer "exploration" period, a fall "returning" period, and an "overwintering" period (Figure 3). The onset of emergence was defined as the first detections of individuals in the lake outside of their overwintering locations, spanning from week 16 (first inter-basin movements) and lasting until week 22, when the average number of basins visited per week diminished (from 1.83 +/- 0/75 to 1.08 +/- 0.29). Summer exploration occurred between weeks 23 and 38, with an average of 1.17 (+/- 0.12) basins visited per week. Then, the returning period began when the average number of basins per week increased between week 39 and 45 (with a peak mean basins visited of 1.76 per week). Finally, the overwintering season began when 95% of Ji'kaw entered their overwintering sites (and were no longer detected in the main lake), and occurred from week 46 until 15.

Figure 3: Mean number of basins visited per individual per week, showing four distinct biological movement patterns across time. The blue sections indicate "overwintering" with minimal movement. Green represents "emerging" when the Ji'kaw cross between many basins as they exit their overwintering sites. Pink indicates "exploring", where movements between basins are sporadic. Yellow shows "returning" where Ji'kaw cross multiple basins again to return to their overwintering sites.

The GAM showed variation in predicted Ji'kaw occurrence across seasons, and had an adjusted R-squared value of 0.583 with 69.6% of deviance explained. To explore seasonal trends, the number of Ji'kaw was predicted across the lake for each month at a 1 km grid size (Figure 4). The predicted number of individuals ranged from 0 to 18 across months and locations. In winter, the predicted spatial range was limited to just 40 of all grid cells (n = 1051 total grid cells, 0.04%). During spring emergence, (weeks 16 to 23, or early April until early June), Ji'kaw were predicted in the northern region of the lake, especially in the Great Bras d'Or Channel, while during summer exploration, the model predicted the highest number of Ji'kaw moving around East Bay. When Ji'kaw returned to their overwintering sites, the highest number of Ji'kaw were predicted in Nyanza Bay, but there were also small numbers of Ji'kaw predicted to be present in West Bay at this time.

Figure 4: Predicted number of Ji'kaw across months in Pitu'pa'q, based on the results from a generalized additive mixed model using acoustic receiver detections of 41 tagged individual Ji'kaw. The colour scale denotes predicted Ji'kaw numbers across the lake, and each facet is one calendar month.

Interconnectivity of Pitu'pa'q

Based on the assembled network, edge weights (number of Ji'kaw movements between nodes) ranged from 1 to 98 across all seasons. Node betweenness and centrality across the entire year ranged from 0 to 120, and node degree ranged from 0 to 6 incoming/outgoing edges. Throughout the year, two regions show higher edge weights than others: a pathway connecting Nyanza to the mouth of the Great Bras d'Or Channel, and a pathway from mid-East Bay to the Barra Strait (Figure 5). Node betweenness centrality was highest for the node near the Barra Strait (120; Figure 5B). Betweenness centrality was very low for nodes in West Bay, Great Bras d'Or Channel, and along St. Andrew's Channel. Node degree was also highest for the nodes in the Barra Strait (6) and high for Nyanza Bay (6), Cain's Pond (5), Barachois Pond (5), and the mouth of East Bay (5; Figure 5A).

Figure 5: Network plot showing Ji'kaw movements ("edges", shown as grey lines) between areas in Pitu'pa'q ("nodes", shown as blue points). Edge weight (line thickness) represents the total number of distinct Ji'kaw movements between each node. Nodes were created by grouping acoustic receiver stations that fell within the same 10 km by 10 km grid cell. Panel A: nodes are sized based on node degree, *i.e*. the number of edges connecting to the node. Panel B: nodes are sized by betweenness centrality, *i.e.* a measure of how frequently a node appears on the shortest path between other nodes in the network, or how "connected" it is to other nodes.

Exploring Emigration

Of the three lake-exit stations, only GB2 (Great Bras d'Or Channel) showed "terminal" detections of Ji'kaw. In total, 24 Ji'kaw were detected leaving the lake (58.5% of all Ji'kaw used in analysis) through GB2 (Figure 6). Four individuals exited in the autumn months (between September 25, and October 25, 2024), and 20 emigrated in the spring emerging season. One fish (animal ID 95) approached the exit in the fall, but then returned and spent the winter in the lake before actually leaving in the spring. Of those that left in the spring, most left in the 18th week of the year (April 29, 2024 to May 5, 2024; n=9, 45% of all spring emigrants). The first animal exited the lake on April 21, 2025, and the last on May 16, 2025. Of the Ji'kaw that exited in the fall, two left during the 41st week and two during the 43rd week of the year (Figure 6).

Fish that left the lake and those that were not detected leaving were of similar size class (leavers mean total length of 0.544 m, +/- 0.08 m, stayers mean total length of 0.5 m, +/- 0.1 m). There was no discernible difference in size between fish that left the lake in the fall versus spring. There were no observations of tagging cohorts exiting together or showing a higher tendency to exit than other cohorts. Twenty individuals tagged at four different tagging sites left the lake in the spring at similar times (Baddeck River Mouth, Barachois Beach, Benacadie Pond Sluice, Dundee Beach, Twin Culverts) and in the fall four at similar times (Baddeck River Mouth, Dundee Beach, Whycocomagh Wharf). Some tagging regions that showed uniform exiting behaviours including Barachois (*i.e.*, if a Barachois-region tagged fish left, it did so in the spring; n = 4), Benacadie (*i.e.*, if a Benacadie-region tagged fish left, it did so in the

spring; n = 3), Twin Culverts (*i.e.*, if a Twin Culverts-region tagged fish left, it did so in the spring; n = 2), and Whycocomagh (*i.e.*, if a Whycocomagh-region tagged fish exited the lake, it was in the fall; n = 1).

Figure 6: Histogram showing the number of Ji'kaw that exited Pitu'pa'q per week of the year, based on terminal detections at station GB2.

Of the fish that exited the lake in spring 2025, one was recaptured 149 days later on October 1, 2025 in the Northumberland Strait (animal ID 64), a result that suggests the animal had not re-entered the lake since it exited on May 5, 2025. In total, this animal was transmitting for 355 days after tagging, which includes detections of its overwintering behaviour, lake exit timing, and recapture location.

From unpublished detection data provided by the Atlantic Salmon Federation (ASF), collected by receivers owned by ASF, the Canadian Rivers Institute (CRI), and DFO deployed in the Miramichi River and surrounding region, it appears that several Ji'kaw migrated to the spawning grounds of the Miramichi River (NW Miramichi) in spring 2025 (Figure 7). Note that DFO data was provided in a summarized format and was not included in any formal analysis. In total, three Ji'kaw overwintered in the Miramichi in winter 2024/2025 in advance of spawning, and 13 Ji'kaw are presumed to have spawned, including the three that wintered in the area beforehand (Scott Douglas, unpublished data; Figure 7). Some individuals (n=8) that spawned in spring 2025 returned to Miramichi in fall 2025, presumably to overwinter in advance of spawning in 2026, but additional data is needed to confirm this (Scott Douglas, unpublished data). An additional four Ji'kaw migrated to Miramichi in fall 2025, which were not spring 2025 spawners. Five Ji'kaw were present in coastal areas of the Miramichi in the spring but did not enter the spawning grounds and did not return to Miramichi in the autumn (Figure 7). One individual visited the Miramichi region in both the spring and fall of 2025, but remained on coastal receivers and was not detected in the spawning grounds. Five individuals were detected in Miramichi but were not detected leaving Pitu'pa'q through GB2. Of these, one individual (animal ID 80) was removed from the Pitu'pa'q dataset due to a lack of detections. The other four individuals appeared in Miramichi in fall 2025 and likely left Pitu'pa'q after GB2 was downloaded in June 2025.

Figure 7: Panel A: number of individual Pitu'pa'q-tagged Ji'kaw detected on receivers deployed by ASF, CRI, and DFO per month from November 2024 until November 2025. Points are coloured by region and sized by the number of individuals. Panel B: Map of the study area, including boxes denoted Pitu'pa'q and the region in Panel A. The red point in panel B indicates the Miramichi spawning grounds.

4. Discussion

Understanding Seasonal Movement Patterns within Pitu'pa'q

Results from this collaborative study support the hypothesis that Ji'kaw in Pitu'pa'q exhibit seasonal variation in their spatial distribution. Four biological seasons were observed, which were characterised by changes in fish movement and distribution across time, defined as emerging, exploring, returning, and overwintering. Mi'kmaw knowledge states that seasonal ecological patterns are tied to seasonal moons

and full moons are used to denote the changing seasons in the Mi'kmaw calendar (Chapman and LeBlanc 2021). Linking Ji'kaw patterns to their relevant Mi'kmaw moon is a way to decolonize these results and expand understandings beyond a Gregorian calendar, and so both ways of knowing will be used to explain the patterns. Mi'kmaw moons are tied to the ecological system as a way to connect more deeply with natural cycles.

In the spring (weeks 16 to 23, or early April until early June), as water warmed, Ji'kaw emerged from their overwintering sites and began distributing across the lake by moving through multiple basins. The beginning of emergence aligned with the full moon of *Penatmuiku's* (Mi'kmaw for "Birds Laying Eggs Time"), suggesting it is a reproductive season so many animals. Many Ji'kaw moved in a directed manner out of the mouth of the Great Bras d'Or Channel and into the Atlantic Ocean during this time, which is highlighted by the strong edge-weight between Nyanza Bay and the Atlantic Ocean. The individuals using this corridor in the spring may represent two different contingents: those that are sexually mature and migrating to the Miramichi River to spawn, and those that routinely forage outside the lake and only use the lake to overwinter. Some were confirmed to arrive in Miramichi to spawn (Scott Douglas unpublished data), but there are few ocean detections to show their movements at sea between Pitu'pa'q and the Miramichi River. This region of the Miramichi is part of traditional Mi'kmaq territory and nearby communities include Natoaganeg (Eel Ground First Nation), Metepenagiag (Red Bank First Nation), and Esgenoôpetitj (Burnt Church First Nation), each of whom relies on this river for sustenance and cultural practice. Because some Ji'kaw are known to show fidelity to their overwintering sites (Andrews et al. 2019a), the connection between the Atlantic Ocean and Pitu'pa'q may represent a significant exchange of biomass during the spring emerging and fall returning periods each year, as fish leave and return.

In the summer (weeks 23 to 38, or early June until mid-September), Ji'kaw demonstrated a diffuse distribution across the basins of the lake, with fewer inter-basin movements, here described as "exploring", but perhaps representing feeding or dispersal. This period aligns with *Nipniku's* (Mi'kmaw for "Trees Fully Leafed Time"), which describes the ecological period where plants are in full bloom. At the northern extent of Ji'kaw's range, the summer period is essential for feeding to build energy stores before winter, and their movements across Pitu'pa'q may follow prey (Setzler-Hamilton et al. 1980). During this time, Ji'kaw were predicted to concentrate most densely in East Bay, near Eskasoni First Nation. Eskasoni is the largest of five Mi'kmaw communities along the coast of Pitu'pa'q (Eskasoni Band Council n.d.). The barachois ponds and islands around Eskasoni are a source of culturally significant knowledge and medicine, and the region is known to support many fish species in the summer, including juvenile salmonids (Levi Denny Jr., pers. comm.; Ross and Fanning 2021; Joseph 2025). In particular, Mi'kmaw knowledge holders have identified that Ji'kaw follow the movements of Kaspelaw (Gaspereau; a term referring to both *Alosa pseudoharengus* and *Alosa aestivalis*), and their seasonal movement patterns are influenced by Kaspelaw spawning (Denny et al. 2013). Ji'kaw tagged in the Minas Basin showed strong summer site fidelity, with an almost 25% recapture rate, suggesting that summer fidelity may impact the "hotspot" of predicted Ji'kaw in East Bay (Broome et al. 2009; Broome 2014). It's likely

that Ji'kaw used East Bay for essential summer feeding, and it was highly visited by Ji'kaw as a transition zone as they entered and left East Bay.

During tagging activities in 2024, it was difficult to capture Ji'kaw during the summer exploration season, and few fish were tagged and released. The difficulty of angling Ji'kaw, paired with the low-density of Ji'kaw predicted across the lake in summer, may suggest there were fewer Ji'kaw in Pitu'pa'q at this time of year, since a portion of the fish exited in the spring, and had not yet returned to the lake. It is also possible that the limited number of active tags during summer 2024 contributed to the diffuse distribution predicted in the summer exploring period, but multiple years of data are needed to confirm this. Most Ji'kaw tagged in the beginning of the exploration period (early June) were tagged near the mouth of East Bay (Benacadie Pond, n = 9; 81% of fish tagged in spring season), which may also contribute to the "hotspot" predicted near Eskasoni in the summer months. It is hypothesized that fish tagged in 2024 that left in spring 2025 may have returned to Pitu'pa'q for the summer exploration period in 2025, but data from summer 2025 have yet to be collected to confirm this.

In the autumn (weeks 38 to 45, or mid-September to mid-November), Ji'kaw returned to their overwintering sites as water began to cool, and this "returning" period was characterized by a larger number of inter-basin movements compared to summer. This movement may have been triggered by dropping temperatures or shorter photoperiod. The onset of "returning" aligns with the moon of *Wikumkewiku's* (Mi'kmaw for "Mate Calling Time"), which describes the ecological changes seen in autumn where animals begin to gather. During this time, Ji'kaw were predicted to concentrate along the northern portions of the lake, specifically Nyanza Bay. Nyanza Bay is the traditional home of Wagmatcook First Nation, the oldest permanent Mi'kmaw settlement, who have relied on this region for food and medicine since time immemorial ("Wagmatcook First Nation" n.d.). Ji'kaw could concentrate in this area due to an abundance of available prey, including Plamu (Atlantic salmon; *Salmo salar*), which migrate through Nyanza Bay and into the Middle and Baddeck Rivers (Crossin et al. 2016). There are also numerous cultural sites, legends, and culturally significant species in the region, as identified through Mi'kmaw-led Areas of Interest mapping (Joseph 2025). McIsaac (2014) showed that Ji'kaw tagged and released in the Barra Strait in late September moved northward into Nyanza Bay as well, but did not have detections later than October 24. During this study Ji'kaw were most likely to be captured and tagged in the autumn returning season compared to exploring or emerging. Most Ji'kaw were captured at night, and the night with the highest tagging success occurred during a large solar flare event with visible aurora on October 10, 2024, supporting stories that angling success improves in alignment with natural phenomena (Skyler Jeddore, pers. comm.).

Nyanza Bay has significant freshwater input from two major rivers, so stronger stratification may occur during the winter here, creating warmer, saline water pockets for Ji'kaw. Petrie and Bugden (2002) found that this region had the highest surface temperatures available in Pitu'pa'q in both September and May (no sampling occurred in winter), which may be optimal for Ji'kaw to seek thermal refuge during the long winters at the northern extent of their range (Andrews et al. 2019a, 2020). During the winter (weeks 46 to 15, or mid-November to early April) Ji'kaw did not move across basins and were only predicted in

barachois ponds, likely exhibiting torpid overwintering behaviour. Winter behaviour is explored in detail in Bate et al. 2026 (*in prep*). The start of the "overwintering" season coincided with the full moon of *Keptekewiku's* (Mi'kmaw for "Rivers Starting to Freeze Time").

Interconnectivity, Emigration, and Implications for Fisheries

Network analysis confirmed the hypothesis that Ji'kaw move across basins in Pitu'pa'q in all seasons except winter, suggesting a highly connected system. Connectivity was higher in the spring emerging and fall returning seasons, since these act as transitional periods between spawning, foraging and overwintering behaviours. While non-Indigenous anglers in Pitu'pa'q currently follow Ji'kaw harvesting regulations (like slot size and bag limits) for the Maritime Region, this population of Ji'kaw is genetically part of the sGSL DU, which is managed by the Gulf Region. This mismatch is because Pitu'pa'q's falls on the border between the two governing regions and could lead to ineffective management of Ji'kaw since regulations from a different DU are being applied.

Future conservation changes in Pitu'pa'q may include the designation of this region as an Indigenous Protected and Conserved Area (IPCA), empowering Mi'kmaw governance of the lake based on traditional knowledge, harvesting practices and best available science. In this case, more nuanced stewardship of Ji'kaw may be possible, with rotating bag-limits depending on the basin and time of year, built on the knowledge that the entire lake is connected. For example, during the spring in Pitu'pa'q, Ji'kaw populations could be conserved by reducing harvest limits in the Great Bras d'Or Channel for several weeks to allow outmigrating Ji'kaw to exit the lake to spawn in Miramichi. By presenting fisheries timing recommendations using Mi'kmaw moons instead of Gregorian dates, this information can be more culturally relevant and nuanced for Mi'kmaw, and non-Indigenous fishers alike.

It is essential that any adjustments made to Ji'kaw management in the future be informed by Ji'kaw seasonal distribution across the entire lake, and not just certain basins. Ji'kaw anglers in the United States support the enhancement of science-based management practices, and some Canadian anglers feel the same, as evidenced by push-back from angling groups about proposed commercial fisheries quota increases in the sGSL (Russell 2025; Dinkelacker et al. 2025b). Adjustments to fish-handling practices like minimizing air exposure and fight time, using single-hooks, and avoiding high water temperatures are science-based recommendations that can be used for any catch-and-release anglers (Griffin et al. 2025; Dinkelacker et al. 2025a).

Detection data confirms that some Ji'kaw left Pitu'pa'q as hypothesized. The majority of fish exited the lake in the spring, with a small "fall run" also detected. Interestingly, Ji'kaw tagged in this study only entered the Atlantic Ocean through the Great Bras d'Or Channel, despite the existence of two other exits. Preliminary Kaspelaw tracking data collected by Apoqnmatulti'k shows that Kaspelaw also outmigrated predominantly through the Great Bras d'Or Channel (Denny and Marsala 2025, unpublished data). This contrasts with the movement of Pitu'pa'q Plamu, which have been shown through tracking studies to outmigrate exclusively through the Little Bras d'Or Channel (Crossin et al. 2016). This may suggest that Kaspelaw are at higher risk of Ji'kaw predation during outmigration than Plamu, since there is a higher

degree of spatial and temporal overlap (Daniels et al. 2018). This aligns with published stomach content analyses in neighbouring areas that show a higher number of Kaspelaw consumed by Ji'kaw, compared to Plamu (Andrews et al. 2019c). This is positive news for Plamu conservation initiatives, whose leadership bodies have expressed concerns about the potential causal relationship between Ji'kaw population recovery and Plamu decline in Atlantic Canada (Smith 2017; Withers 2018; CBC 2024). Plamu are also an exceptionally important species for the Mi'kmaq, and understanding how their presence in Pitu'pa'q may be affected by Ji'kaw is a priority for Apoqnmatulti'k partner organizations such as UINR.

The results demonstrate the presence of multiple migratory strategies within Pitu'pa'q's Ji'kaw. There were three apparent groups from the tracking data: (1) Ji'kaw that were resident to Pitu'pa'q throughout the study (44%, n = 17), (2) Ji'kaw that overwintered in Pitu'pa'q but outmigrated in the spring (at least 47%, n = 20) , and (3) Ji'kaw that outmigrated in the fall and spent the winter elsewhere (at least 9%, n = 4). Other populations of Ji'kaw exhibit similar partially migratory behaviour, classified as migratory contingents (Clark 1968; Secor 1999; Gahagan et al. 2015; Buhariwalla et al. 2023). Since Pitu'pa'q is a semi-enclosed, large estuarine lake, the classification of Ji'kaw contingents is not directly comparable to other literature that studied riverine systems. In river systems, there are often riverine residents, estuary residents, marine migrants and/or semi-resident groups. In Pitu'pa'q, since there are no known spawning rivers, any sexually mature Ji'kaw must leave for spawning. It is possible that the Pitu'pa'q resident contingent detected in this study represents individuals that were not sexually mature, or skipped spawning in spring 2025. The existence of migratory contingents in Pitu'pa'q may spread spatiotemporal threats across sections of the population, contributing to increased population resilience (Gahagan et al. 2015). Despite the absence of confirmed spawning rivers, it appears that Pitu'pa'q is an important feeding area in the summer as well as an overwintering site, which contributes to the presence of Ji'kaw in the lake all year.

The movement of Ji'kaw between Pitu'pa'q and the Atlantic Ocean represents a more important exchange of biomass than anticipated, since nearly 60% of study animals (n = 24) exited the lake in total. Previously shared community knowledge suggested that the sub-adult size-class of Ji'kaw most commonly seen in Pitu'pa'q, called "schoolies"[2], were potentially resident to the lake until they reached a larger size (since large Ji'kaw are rarely seen in Pitu'pa'q; Skyler Jeddore pers. comm.). However, detections from this study showed that more than half of the "schoolie" Ji'kaw in Pitu'pa'q migrated to the ocean, and 31% of tagged Ji'kaw were confirmed as spawners in the Miramichi River (n = 13). The high connectivity with the ocean and Miramichi River means that stressors affecting Ji'kaw across the sGSL will impact the population in Pitu'pa'q. The existence of a spawning migration to Miramichi means Ji'kaw migrate through the sGSL where commercial fisheries catches are slated to expand in the near future (Ibrahim 2018; Russell 2025). While nuanced fisheries governance in Pitu'pa'q can ensure culturally and scientifically appropriate harvest of Ji'kaw within the lake, the Government of Canada's sGSL DU regulations will impact Ji'kaw as soon as they exit the area. Diverse knowledge holders should be included in federal Ji'kaw management decisions to ensure a holistic and informed plan can be developed as regulations respond to increasing Ji'kaw numbers.

Reflections about Etuaptmumk

This research program was entirely shaped by Etuaptmumk, from project inception to execution, and shared values were interwoven into every decision (Bate et al. 2026). While the results presented above follow typical western academic statistical methods, they were guided by the collaborative nature of the Apoqnmatulti'k partnership. For example, the study site, study species, and research questions were co-selected by local and Mi’kmaw knowledge holders. The field methods, including animal handling protocols, receiver deployment locations, and tagging sites, were collaboratively designed to answer shared questions and uphold the values of multiple worldviews. Analysis results, while generated with western statistics, were co-interpreted together with local and Mi’kmaw knowledge holders so the results could be locally relevant and nuanced. Results were shared, and the discussed reasons for the observed patterns were discussed with knowledge holders. While reflecting on the role of Etuamptumk in this research, it can be concluded that all results would have differed significantly if they were not informed by a collaborative design. This study would not have the same objectives, methods, or interpretation since every phase was co-created. The resulting research paper is therefore informed by our shared knowledge.

[2] “Schoolie” is a term used by local anglers to describe sub-adult Ji’kaw that form schools. Loosely, the size range of a schoolie might range between 40 and 65 cm (Skyler Jeddore, pers. comm., 2024), but some harvesters may have different definitions of the size range.

5. Conclusions

By sharing ways of knowing, co-produced, culturally significant knowledge can be generated in a way that makes it directly actionable by affected communities, rightsholders and governance bodies. For Ji’kaw in Pitu’pa’q, we learned that they exhibit seasonal variation in their distribution across the lake, and there are significant inter-basin movements during some periods of the year, including outmigrations to the Atlantic Ocean and spawning in the Miramichi River. This locally-relevant knowledge is being used to assess potential Mi’kmaw stewardship strategies for Ji’kaw conservation, and will inform governance of a future IPCA in Pitu’pa’q. The knowledge of Ji’kaw movements is also a gift we are able to give back to the community, and supports rights-based Ji’kaw fisheries governance, traditional food sovereignty, and informed harvester decisions for Mi’kmaw communities. It is clear that Mi’kmaw communities in Pitu’pa’q share the same fish as the broader sGSL, and need to be included at the governing table, since Pitu’pa’q is within the natural range of sGSL fish. By working together, we are strengthening and building on each other's knowledge.

Abbreviations

ASF	Atlantic Salmon Federation
CMAR	Centre for Marine Applied Research
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CRI	Canadian Rivers Institute
DFO	Fisheries and Oceans Canada
DU	Designatable Unit
GAM	Generalized Additive Model
IPCA	Indigenous Protected and Conserved Areas
NSERC	Natural Sciences and Engineering Research Council of Canada
OTN	Ocean Tracking Network
sGSL	Southern Gulf of St. Lawrence
UINR	Unama'ki Institute of Natural Resources
UNESCO	United Nations Educational, Scientific and Cultural Organization

Declarations

Author Positionality

The authors represent individuals from both Mi'kmaw and western worldviews, living in Mi'kma'ki. Based on their lived experiences, each author brings unique perspectives to this project and contributes to the work through their own lens. Some authors are trained in the academic sciences, some are local knowledge holders, and many are a combination of both. Authors work in organizations including Indigenous aquatic research organizations, non-governmental research groups, academic institutions, and the Canadian federal government. Identifying the positionality of the authors is important to understand how data was interpreted together to promote equitable and transparent research (Cadman et al. 2024). This work was completed as part of the Apoqnmatult'ik project which values co-learning and mutual respect in its partnership (Bate et al. 2026).

Ethics approval and consent to participate

Capture and tagging procedures were in accordance with Dalhousie University's Animal Care Committeeprotocol 24-016 and DFO Section 52 permit 372869 (Maritimes Region, Fishery (General) Regulations, Fisheries Act). Ethics approval was also obtained from Dalhousie Univerisity Research Ethics Board protocol 2021-5468.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are available from the Ocean Tracking Network repository, https://members.oceantrack.org/project?ccode=BDLSPG.

Competing interests

The authors declare that they have no competing interests.

Author Contributions

CSB conceptulaized this manuscript, completed all analsyses, and wrote the initial draft. SJ, LD, and SD were instrumental in sharing traditional knowledge included in the design of this program, and supported all field work. JE and RJL contributed to editing, review, and analysis. JB, EV, AL provided project management support and manuscript review. RJL, RGB, and SKD provided supervision and study direction. All authors read and approved the final manuscript.

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Figures

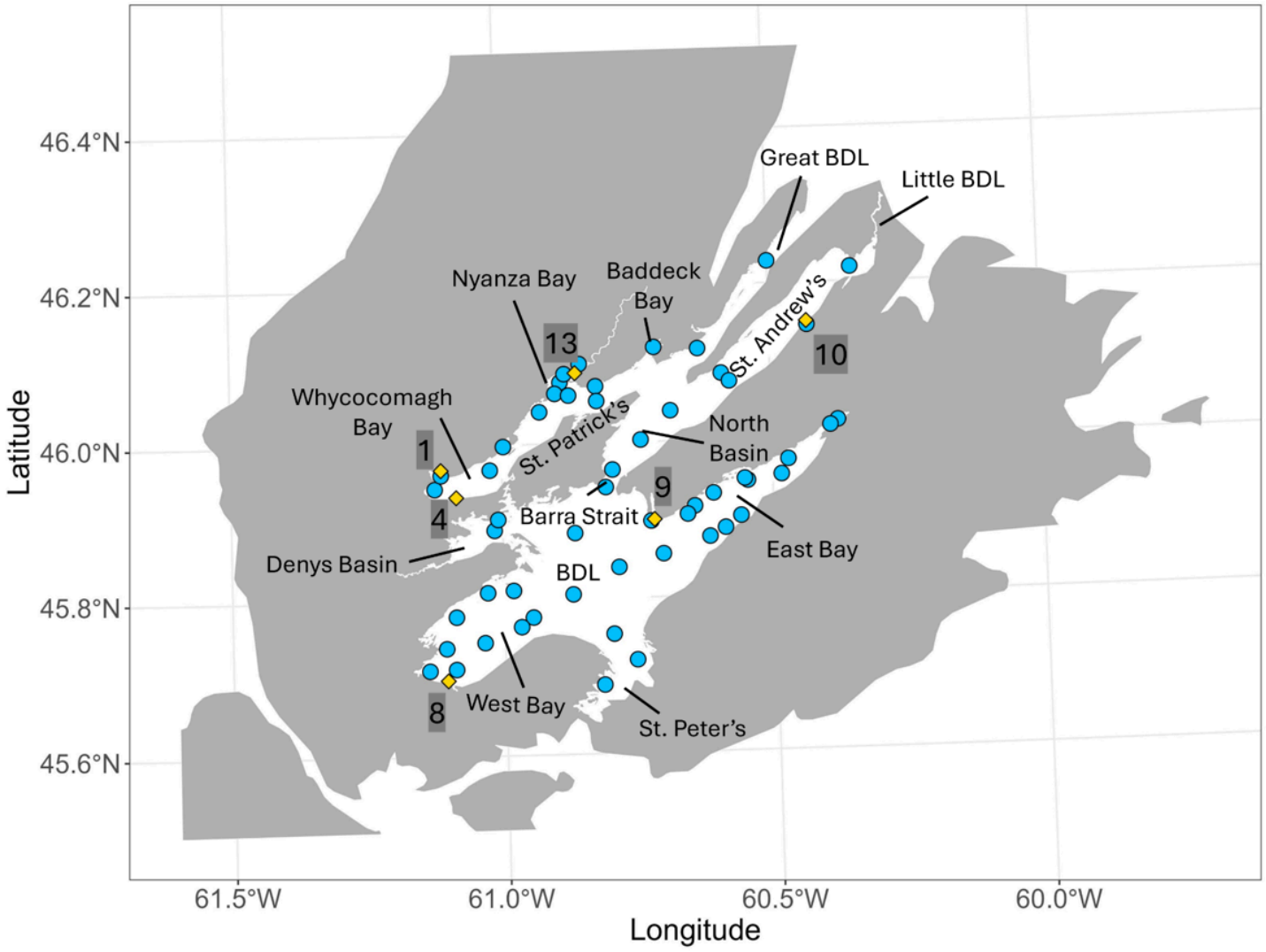


Figure 1

Map of Pitu’pa’q (white) within Unama’ki (grey polygon), indicating the locations of acoustic receivers (blue points) and released tags (yellow diamonds), with the basins of Pitu’pa’q labelled by name. The number adjacent to each tagging location corresponds to the number of individual Ji’kaw tagged and released at that site.

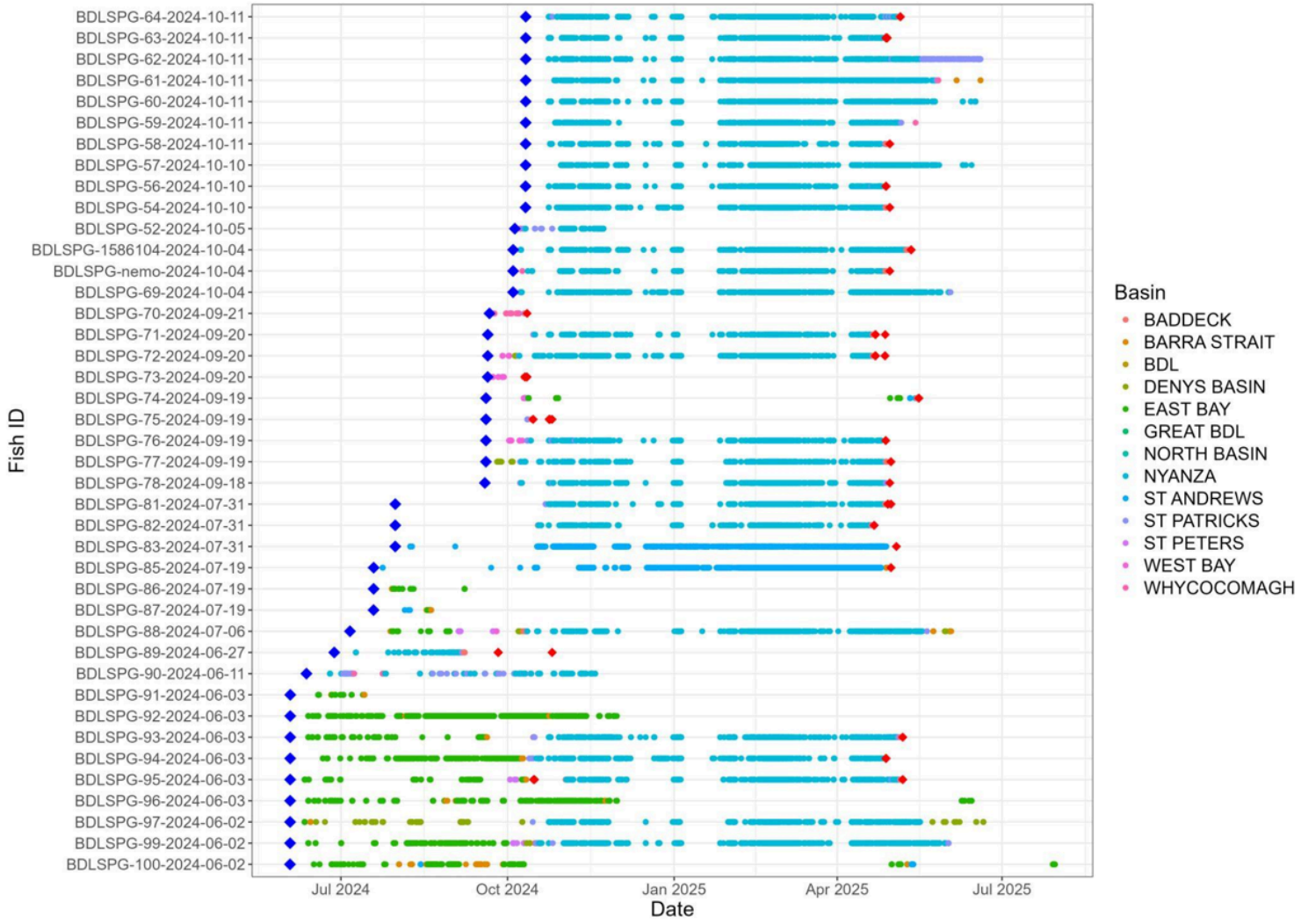


Figure 2

Abacus plot showing detections of each individual Ji’kaw over time, coloured by basin. The red diamonds indicate a detection on the terminal lake-exit station (GB2), and the blue diamonds show the initial tag implantation date for each animal.

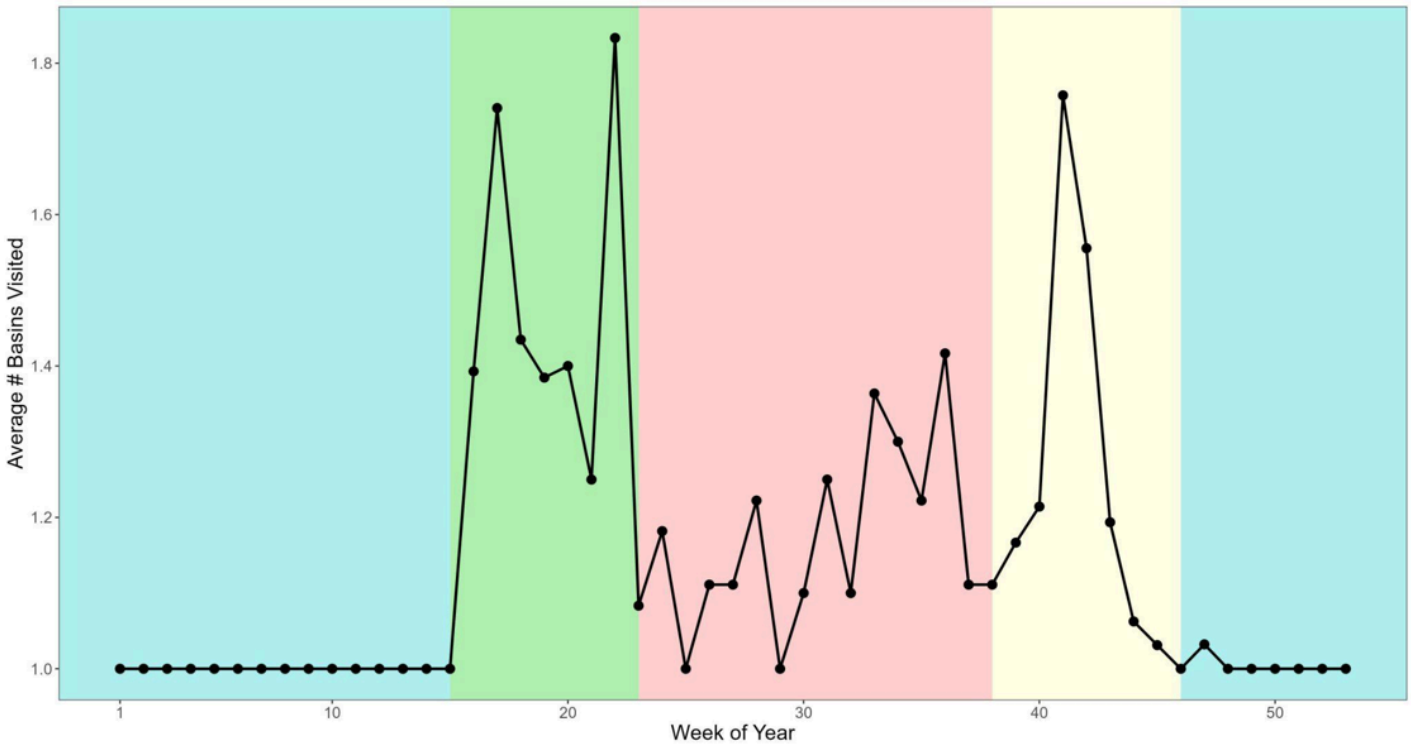


Figure 3

Mean number of basins visited per individual per week, showing four distinct biological movement patterns across time. The blue sections indicate “overwintering” with minimal movement. Green represents “emerging” when the Ji’kaw cross between many basins as they exit their overwintering sites. Pink indicates “exploring”, where movements between basins are sporadic. Yellow shows “returning” where Ji’kaw cross multiple basins again to return to their overwintering sites.

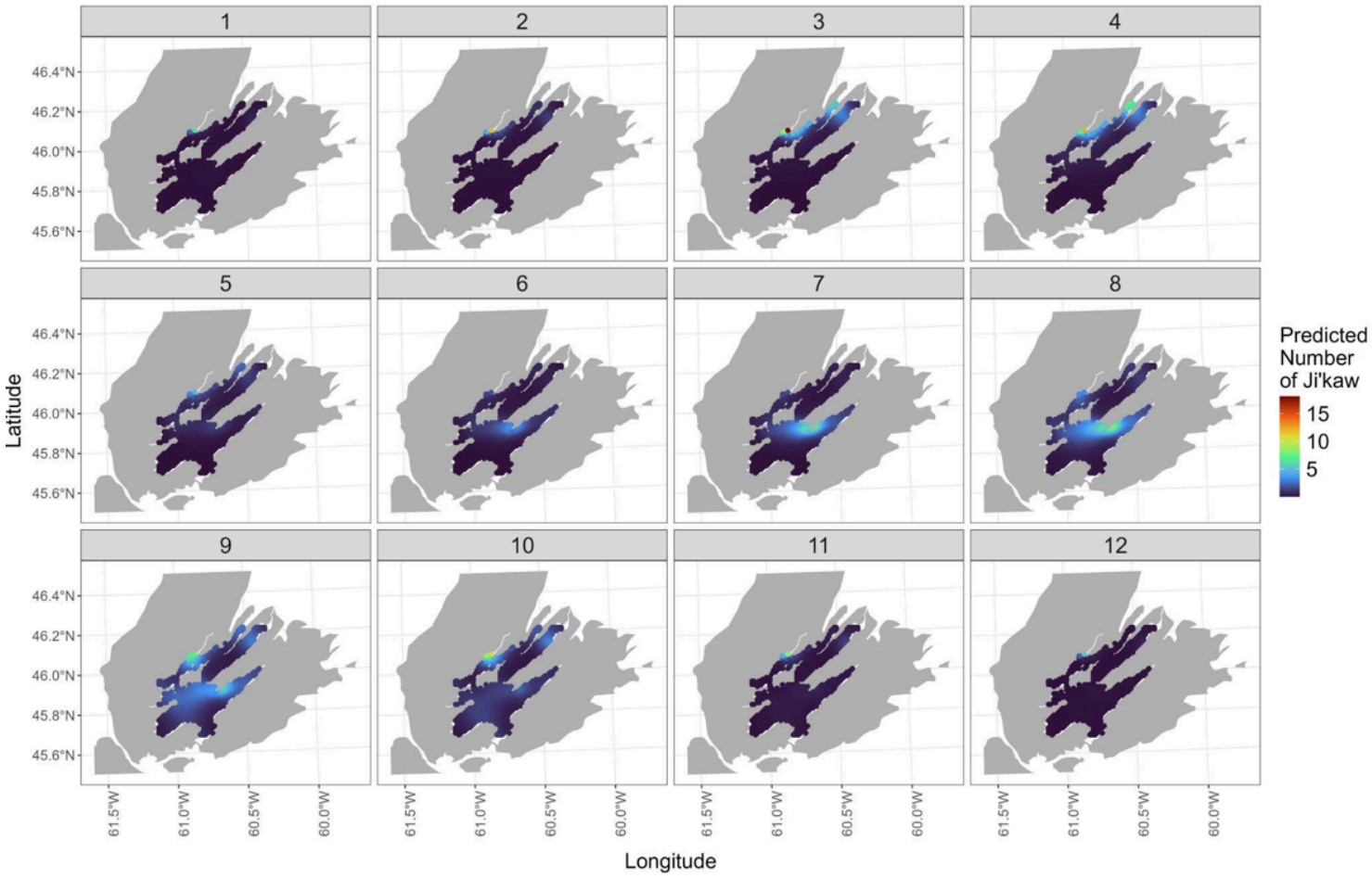


Figure 4

Predicted number of Ji’kaw across months in Pitu’pa’q, based on the results from a generalized additive mixed model using acoustic receiver detections of 41 tagged individual Ji’kaw. The colour scale denotes predicted Ji’kaw numbers across the lake, and each facet is one calendar month.

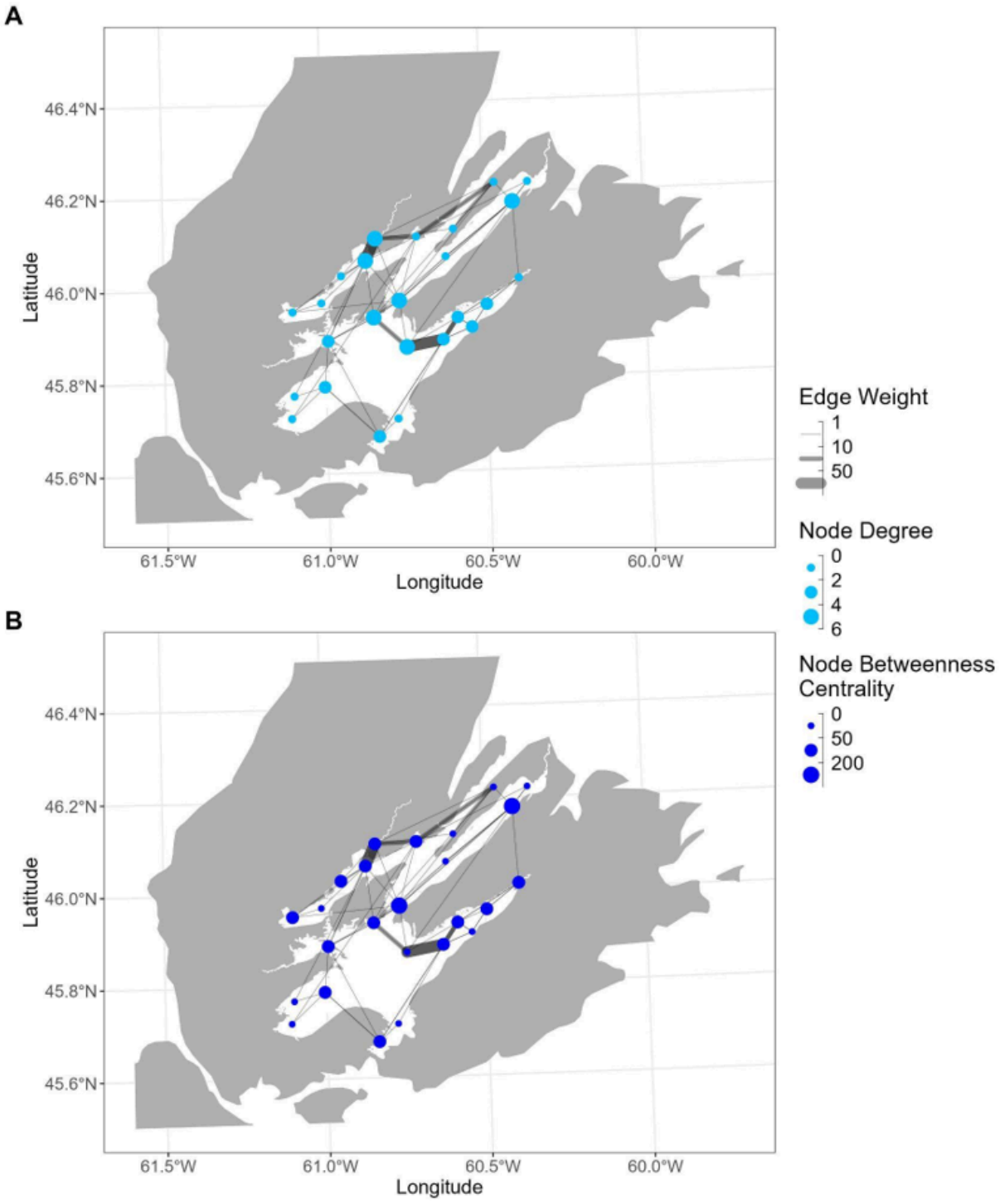


Figure 5

Network plot showing Ji'kaw movements ("edges", shown as grey lines) between areas in Pitu'pa'q ("nodes", shown as blue points). Edge weight (line thickness) represents the total number of distinct Ji'kaw movements between each node. Nodes were created by grouping acoustic receiver stations that fell within the same 10 km by 10 km grid cell. Panel A: nodes are sized based on node degree, *i.e.* the number of edges connecting to the node. Panel B: nodes are sized by betweenness centrality, *i.e.* a

measure of how frequently a node appears on the shortest path between other nodes in the network, or how “connected” it is to other nodes.

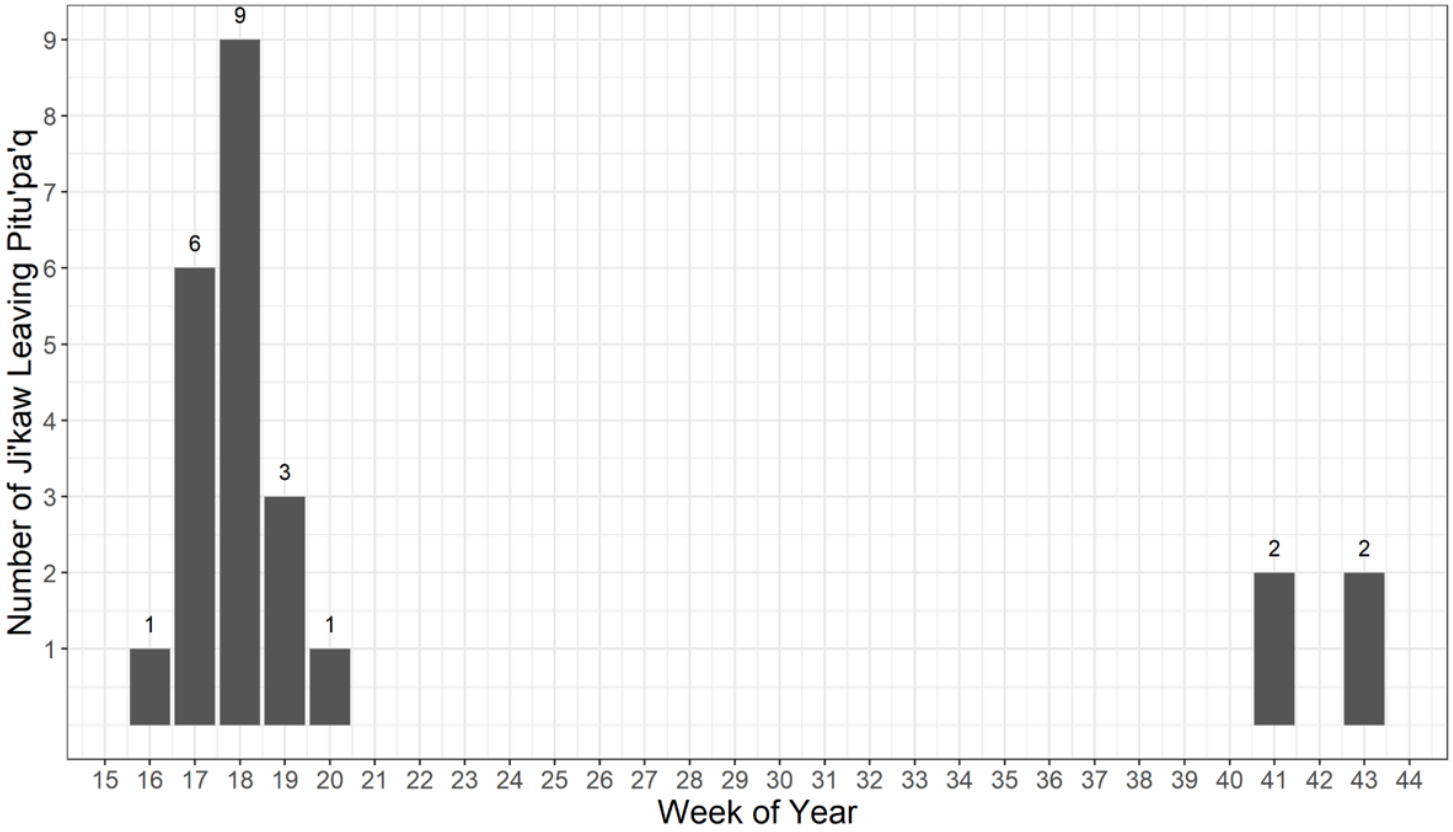


Figure 6

Histogram showing the number of Ji’kaw that exited Pitu’pa’q per week of the year, based on terminal detections at station GB2.

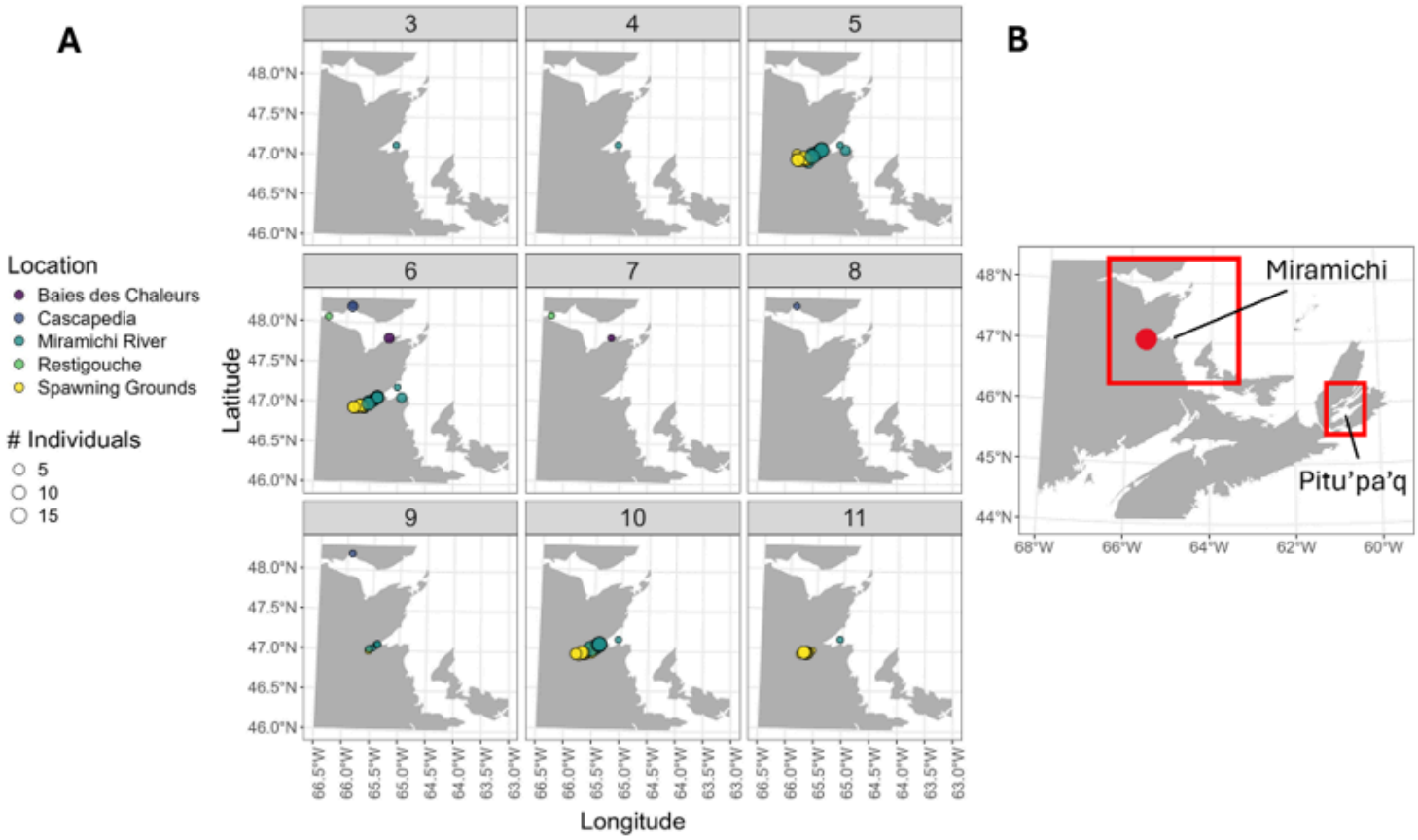


Figure 7

Panel A: number of individual Pitu'pa'q-tagged Ji'kaw detected on receivers deployed by ASF, CRI, and DFO per month from November 2024 until November 2025. Points are coloured by region and sized by the number of individuals. Panel B: Map of the study area, including boxes denoted Pitu'pa'q and the region in Panel A. The red point in panel B indicates the Miramichi spawning grounds.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- appendixA.docx
- AppendixBandC.docx