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

Canadian Science Advisory Secretariat (CSAS)

Research Document 2025/029

Quebec Region

Preliminary Results from an Acoustic Telemetry Study on Atlantic Herring in the Northern Gulf of St. Lawrence

Kim Émond and Pedro Nilo

Maurice Lamontagne Institute
Fisheries and Oceans Canada
850, Route de la Mer
Mont-Joli, Quebec, G5Z 3Z4

May 2025

Canada

Foreword

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

Published by:

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

http://www.dfo-mpo.gc.ca/csas-sccs/
DFO.CSAS-SCAS.MPO@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-76913-4 Cat. No. Fs70-5/2025-029E-PDF

Correct citation for this publication:

Émond, K., and Nilo, P. 2025. Preliminary Results from an Acoustic Telemetry Study on Atlantic Herring in the Northern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2025/029. iv + 24 p.

Aussi disponible en français :

Émond, K. et Nilo, P. 2025. Résultats préliminaire d’une étude de télémétrie acoustique sur le hareng de l’Atlantique dans le nord du golfe du Saint-Laurent. Secr. can. des avis sci. du MPO. Doc. de rech. 2025/029. iv + 26 p.

TABLE OF CONTENTS

ABSTRACT

In September 2021, 80 Atlantic herring were tagged with acoustic transmitters in Blanc-Sablon, Quebec, at the boundary of NAFO unit areas 4Ra and 4Sw. In 2022, an additional 30 herring were tagged in early May in Port-au-Port, Newfoundland (unit area 4Rc), followed by 79 more tagged in Blanc-Sablon in mid-September. To track the movements of these tagged fish, an array of 36 acoustic receivers was deployed along the Lower North Shore of Quebec (unit areas 4Sv and 4Sw) and the west coast of Newfoundland (division 4R). Preliminary results from September 2021 to November 2022 provide key insights into the timing and spatial dynamics of herring migration in the northeastern Gulf of St. Lawrence, closely reflecting the migration patterns described in earlier studies and aligning with the spatio-temporal trends observed in commercial fishery landings. Our findings reveal extensive seasonal migrations between summer feeding, spawning and overwintering habitats, with herring utilizing the Blanc-Sablon/Strait of Belle Isle area in summer and early fall, then migrating to areas along Newfoundland's west coast, such as Bonne Bay, Bay of Islands, and deeper offshore waters, during the winter months, before returning northward in the spring and early summer. Notably, some herring appear to overwinter outside the previously identified Esquiman Channel, indicating the possibility of multiple overwintering grounds. These initial findings support the hypothesis that 4R and 4Sw stocks overlap seasonally, challenging the assumption of their discreteness and suggesting a potential need to consider 4R and 4Sw stocks as a single unit in future assessments. This study highlights the value of acoustic telemetry in capturing detailed, high-resolution movement data, which can be used to better understand habitat use and inform management decisions.

1. INTRODUCTION

Atlantic herring (*Clupea harengus*) is a highly migratory and abundant pelagic fish widely distributed throughout the North Atlantic Ocean, including adjacent waters such as the Baltic Sea (Brunel and Dickey-Collas 2010). In Canadian waters, its range spans from the coasts of Nova Scotia to Labrador. The stock structure of Atlantic herring is complex and is typically delineated based on Northwest Atlantic Fisheries Organization (NAFO) divisions (Melvin et al. 2009). Each stock consists of multiple populations that spawn in distinct areas, both spatially and temporally, and are presumed to return to the same spawning grounds each year (McQuinn 1997; Melvin et al. 2009; Stephenson et al. 2009). Herring also undertake extensive annual migrations between feeding, spawning and overwintering areas. During these migrations, populations from the same or adjacent stocks mix during feeding and overwintering periods, but separate into their respective components during the spawning season. Herring populations are further distinguished by the presence of two spawning groups: spring spawners, which generally spawn from April to May, and fall spawners, which spawn from August to September.

Stock assessment relies on the assumption that stock units are closed, and that no mixing occurs between units. When this assumption is violated, the results of stock assessments may be inaccurate, which can confound fishery management strategies. In the northern Gulf of St. Lawrence (nGSL, NAFO divisions 4R and 4S; Figure 1), herring are managed and assessed as two discrete stocks; one along the west coast of Newfoundland (NAFO division 4R) and another on the north coast of Quebec (NAFO division 4S). However, there is some evidence from capture-mark-recapture studies and commercial fishery data that mixing occurs between the herring stocks in 4R and eastern 4S during their feeding and overwintering migrations (Moores and Winters 1984; McQuinn and Lefebvre 1995). More specifically, McQuinn and Lefebvre (1995) suspected that herring which spawned along the Quebec Lower North Shore (NAFO unit area 4Sw) were subsequently caught along the west coast of Newfoundland during the fall commercial fishery, and suggested that the definition of 4R as a management unit be revised to include 4Sw. Biological differences (e.g., length and age composition), were also observed between the herring inhabiting the eastern and western regions of 4S, suggesting that 4S may comprise two separate stocks (Moores and Lilly 1982; Trudeau and McQuinn 1986).

Here, we present the preliminary findings of an ongoing acoustic telemetry study to monitor the spatio-temporal migration patterns of the Atlantic herring stocks in the nGSL in relation to fishery management areas (i.e., NAFO division 4R and unit area 4Sw). Passive acoustic telemetry was the principal tool used to monitor herring movements and this report covers the initial phase of this study which aimed at tracking individuals form September 2021 to November 2022. Success with this approach has already been demonstrated for Atlantic herring in the GSL estuary (Munro et al. 1998; Lacoste et al. 2001) and Pacific herring (*Clupea pallasii*) in Alaska (Seitz et al. 2010; Eiler and Bishop 2016). To our knowledge, this project is the first to use acoustic telemetry to determine continuous movements of a highly migratory small pelagic species over a period that covers a complete annual cycle and over extensive distances. Previous studies of Atlantic herring movements in the northwest Atlantic using traditional capture-mark-recapture techniques, which collect information only at the mark and recapture position of the tag, provided a poor spatio-temporal resolution and showed typically low recapture rates (e.g., <1%). Acoustic telemetry, on the other hand, provides high-resolution information on the distribution and migration patterns of individual herring, without requiring a 'classic' recapture.

This project is registered with the Ocean Tracking Network (OTN), an aquatic animal tracking and data management program based at Dalhousie University in Halifax, Nova Scotia, Canada (project code: GSLHER). OTN is dedicated to improving international exchange of telemetry information and increasing spatial coverage of individual studies by providing a collaborative platform that facilitates sharing of tag and detection data among OTN members.

2. MATERIAL AND METHODS

2.1. FISH CAPTURE AND TAGGING

Herring were captured using a purse seine during four separate fishing events between September 2021 and September 2022. The description provided in this section follows an approved animal care protocol (Fisheries and Oceans Canada, #21-1). The first two, as well as the last round of tagging, took place near Blanc-Sablon, located at the boundary of NAFO unit areas 4Sw and 4Ra, aboard the commercial fishing vessel Last Quarter on September 5-6, 2021, and September 10, 2022 (Table 1, Figure 2A). The third round of tagging took place on May 4, 2022 at the mouth of Port-au-Port Bay in NAFO unit area 4Rc aboard the fishing vessel Nancy Jillian (Figure 2A). Once a school of herring had been circled by the seine, the fish were concentrated near the vessel but not too tight in order to minimize scale loss and mortality. The fish were then scooped with a silicone mesh dipnet and placed in a Xactics™ holding tank (800-L capacity) filled with fresh, circulating seawater. Approximately 200 to 300 specimens were captured per round, and the rest of the school was released at the site of capture. A 'round' was considered as a complete cycle of capture-mark-release for a given batch of fish.

Individual fish were removed from the holding tank with the silicone dipnet and transferred in a cooler filled with an anesthetizing solution of tricaine methanesulfonate (TMS). There is little published information on the dosage of anesthetics for sedation of the *Clupea* genus, and in order to establish a correct level for *Clupea harengus*, we first anesthetized a few fish starting with a solution at a concentration of 53.4 mg/L of seawater (Seitz et al. 2010 mentioned 60 mg/L as being effective). These trials did not allow to reach a sufficient level of anesthesia, as some fish started to lose equilibrium after 3 min. and others after 10 min., and no individual showed 'gagging' reflex. The increase of TMS to a level of 71.2 mg/L of seawater produced much better results, as individuals started to lose balance after approximately 1 min., showed no response to stimuli (i.e., tail pinch) after approximately 4 min., and recuperation in the recovery tank took less than 2 min. (some as fast as 1 min.). Since we achieved the desired sedation within a maximum of 5 min. using this dosage, it was maintained as the induction level for the anesthesia cooler. When the time needed to properly sedate an individual jumped over 5 min., we decided to refresh the induction cooler by adding 0.7 g of TMS, giving a maximum level of 89.0 mg/L for the 'renewed' solution. Aerators pushed compressed air in the sedation cooler in order to maintain adequate oxygenation.

Once the fish was fully immobilized and unresponsive, its total length was measured to the nearest millimeter, and it was weighed to the nearest gram. Because the incisions made for tag insertion were very small, we were unable to differentiate between spring and fall spawning types, except during the tagging round in Port-au-Port, where the body cavities of nearly all the fish were filled with ripe gonads. The fish was then placed ventral side up in a surgical cradle, consisting of a V-shaped carved sponge covered with a damp natural chamois. To keep the gills oxygenated and moist while maintaining adequate sedation during surgery, an anesthetic solution of TMS at 53.4 mg/L was administered through a small pump and vinyl tubing inserted into the fish's mouth.

Herring were then tagged with Innovasea (Halifax, Nova Scotia, Canada) V9-2L acoustic transmitters operating at 69 kHz with a power output of 146 dB re 1 μ Pa at 1 m distance from the tag (considered low power). These tags have a diameter of 9 mm, a length of 27.5 mm, and weight 4.5 g in air and 2.7 g in water. In order to maximize the tag life duration (912 days) and enable long-term tracking, tags were programmed to randomly ping at intervals ranging between 130 and 230 s (average signal transmission of 180 s). The vinyl label, including bar code and tag ID, attached to each unit was removed before implantation, because this material is not bio-compatible (Innovasea, pers. comm.). Particular attention has been provided to deploy the tags as quickly as possible in order to get maximum battery life. To avoid any negative impact on swimming performance, growth, or survival, we aimed to tag individuals within a size range that kept the tag burden below the recommended limit (2% tag:body weight ratio; Brownscombe et al. 2019). Additionally, to reduce the risk of size-related mortality, we only tagged fish larger than 250 mm.

We made a small incision just large enough (~15 mm) to allow the passage of the transmitter with a scalpel (size #10 curved blade) along the ventral midline of the fish, as described by Eiler and Bishop (2016). Each transmitter was activated, tested for proper signal transmission in air with the VR100-300 tracking acoustic receiver and the VHTx transponding hydrophone, soaked in a solution of isopropyl alcohol, rinsed in distilled water, and then gently inserted into the abdominal cavity. The incision was closed with two or three sutures consisting of four simple surgeon knots using a reverse cutting needle (size 4-0, model FS-2) and 36 inches of Monocryl Plus filament (Johnson & Johnson). Due to scarcity of medical equipment and costs, we used a single needle for more than one fish and as many as 6 or 7, dipping the needle and filament in alcohol after each specimen. All the surgical instruments were also sterilized in a solution of isopropyl alcohol after each intervention.

After surgery, the fish were transferred to a recovery tank (800-L capacity) filled with fresh, circulating seawater, monitored by observing their swimming behaviour, and kept under observation for periods of 4 to 6 hours for the majority of fish, and minimally for 2 hours for the last tagged individuals. We monitored water temperature in the anesthesia cooler, in air, and in the holding and recovery tanks throughout the tagging procedures in order to maintain optimal conditions for fish recovery post-surgery. The tagged fish were released together with untagged ones as a group, allowing them to form a small school immediately upon release. When possible, the fish were released close to a school of free-ranging herring.

2.2. TRACKING PROCEDURES

To monitor the movements of the tagged fish, a total of 39 stationary acoustic monitoring stations were deployed throughout the Lower North Shore of Quebec (NAFO unit areas 4Sv and 4Sw) and the west coast of Newfoundland (NAFO division 4R), including the Strait of Belle Isle (Table 2, Figure 2). Most stations were located at sites with the highest reported herring densities based on commercial fishery landings, while avoiding areas shallower than ~40 m (i.e., ice scouring) and known fishing grounds (i.e., longline, benthic dredges, gillnets and pots). Of the 39 stations deployed, the majority (31) were located at depths of less than 100 m, while six stations were placed in the 101-200 m depth range, and two in the 201-300 m range (Table 2).

Eight stations (BSA01-BSA08) were deployed near Blanc-Sablon in Quebec (NAFO unit areas 4Ra and 4Sw), seven of which were positioned around Île au Bois and L'Île-Verte, and one (BSA01) located separately on a bank that may be used for spawning according to local harvesters (Figure 2D). The outer coastal inlet of St. Paul River, another significant area for herring concentrations along Quebec's Lower North Shore, was monitored with two stations (RSP01 and RSP02; Figure 2D). Across the Strait of Belle Isle, which is considered an important summer-fall feeding area for herring (Moores and Winters 1984, McQuinn and Lefebvre 1995), ten receivers (SBW01-SBW10) were deployed in a linear arrangement approximately 1,800 m apart (Figure 2D). Four receivers were also placed near the

Ouapitagone Archipelago (OPT01-OPT04) on the Quebec North Shore (NAFO unit area 4Sv), selected to mark the east-west boundary of NAFO division 4S (Figure 2B).

Thirteen stations were positioned along the west coast of Newfoundland, based on known spawning grounds (McQuinn 1997), overwintering habitats (McQuinn and Lefebvre 1995), and areas of high herring density (Table 2, Figure 2CD). From north to south, this included two stations near St. John Island (SJI01 and SJI02), three along the mouth of Bonne Bay (BBA01-BBA03), five within the fjord and embayment system of the Bay of Islands (BOI01-BOI05), and three in Port-au-Port (PAP01-PAP03), with one located at the head of the bay (PAP03). Additionally, two stations were deployed near Red Island at the tip of the Port-au-Port Peninsula (REDN1 and REDS1; Figure 2C) in May 2022 as part of a monitoring initiative for seal colonies in collaboration with DFO Science Marine mammals division from Quebec region.

All acoustic monitoring stations consisted of Innovasea VR2AR receivers equipped with acoustic release mechanisms. The receivers were moored to the sea floor using two or three blocks of concrete (16 x 8 x 8 in, approximative weight of 16 kg each out of water and 9 kg each when immersed in saltwater), and suspended about 1.8 m off the substrate with a nylon runner of 120 cm (2.2 tons traction resistance). Floatation was provided by various combinations of Pesca hard floats (3.5 kg and 8 kg) totaling 7 kg, 8 kg or 11.5 kg of positive buoyancy. Retrieval of the receivers was performed with communication from the VR100-300 aboard the vessel that triggers the acoustic release, using a push-off alloy lug and the attached floatation buoy to bring the released receiver to the surface. All stations were deployed for approximately one year, with durations ranging from 289 to 441 days, except for the two stations near Red Island, which were deployed for only 115 to 180 days (see Table 2). Out of the 39 receivers deployed, 36 were successfully retrieved, while the ones at stations OPT1, SJI01, and SBW07 were permanently lost. Most stations remain active at the time of publication, except for those in the Ouapitagone Archipelago (OPT1- OPT4).

Through our collaboration with OTN, we gain access to data from other studies conducted by OTN partners, enabling us to extend our coverage over a broader spatial scale (Figure 3). OTN maintains an acoustic receiver line across the Cabot Strait (OTN-Cabot) and uploaded data from 113 stations in 2022. OTN also operates a line spanning the entire width of the continental shelf off Halifax (OTN-HFX), with data from 234 stations uploaded in 2022. Since 2017, DFO Quebec operates an ongoing monitoring array in the GSL (V2LGSL) with 39 receivers. DFO also maintained a receiver array in Godbout (Quebec) as part of the Quebec Benthic Invertebrates project (QBI) with 78 receivers until the project ended in late 2021.The Atlantic Salmon Federation (ASF) maintains a summer line across the Strait of Belle Isle (ASF-SOBI) with 55 receivers and another line at Port Hope/Simpson (ASF-PHS) with 40 receivers. In collaboration with DFO, ASF also deployed a new line of 20 receivers in St. Anthony at the northern tip of Newfoundland (ASF-STA) in 2021-22, later expanded to 30 receivers for the 2022-23 season. Additionally, the Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs of Quebec maintains the Quebec St. Lawrence River network (QSLR), which included 123 coastal maritime stations in 2022.

2.3. DATA ANALYSIS

The data generated by this project—including receiver station locations, instrument deployment/recovery metadata, tagging metadata, and detection data—was submitted to OTN at the end of each field season (around November 2021 and 2022). OTN generates detection reports approximately every four months by gathering, validating, and updating detection data collected from acoustic receivers deployed by its researchers and partners. The updated data is then shared with authorized users through OTN's data portal.

False detections can occur when signals from multiple transmitters collide (i.e., signals transmitted simultaneously on the same frequency), causing the receiver to incorrectly assign a tag ID matching one of our deployed transmitters (Pincock 2012; Simpfendorfer et al. 2015). To filter out potentially false detections, we applied four criteria:

1. Detections recorded before the tag deployment date;
2. Multiple detections at the same receiver within a period shorter than the minimum tag delay (130 seconds);
3. Solitary detections, i.e., a single detection within a specified timeframe;
4. Detections suggesting movements faster than realistic swimming speeds.

For solitary detections, a common guideline is to exclude detections occurring only once within 30 times the average signal transmission delay (Pincock 2012). Based on this criterion, any detection occurring once within a 5,400-second window (30 x 180 s) was deemed spurious and removed. Swimming speeds were estimated using Dijkstra's Algorithm (Assis 2018) to calculate the shortest marine distance between two detection points, divided by the time elapsed between detections. A theoretical maximum swimming speed of 1.5 m/s was used as a threshold (Brawn 1960; Huse and Ona 1996).

An updated detection dataset was received from the European Telemetry Network (ETN), a partner of OTN. This dataset included 37 receptions from 12 tags, but all detections were invalid because the dates ranged from April 2, 2017 to August 20, 2021—before the first tag deployment on September 5, 2021. These data are not included in this report.

To explore individual tag detections and identify herring movement patterns, we created abacus plots (calendar plots). These plots provide a clear visualization of each tagged animal's residency and movement across the acoustic array. To enhance the detection of movement patterns, receiver stations within the same locality were grouped (see section 2.2 and Table 2 for description of each locality or region).

For conciseness, and given that this study is ongoing and will conclude in 2025, the data in this preliminary report is summarized for the period between September 2021 and November 2022, rather than organized by calendar years as done by OTN. The most recent update from OTN for the GSLHER project, included in this report, was received on March 17, 2023.

3. RESULTS

3.1. CAPTURE AND TAGGING

In total, we tagged and released 189 herring: 80 (in two separate rounds) near Blanc-Sablon on September 5 and 6, 2021, 30 at the mouth of Port-au-Port Bay on May 4, 2022, and another 79 in Blanc-Sablon on September 10, 2022 (Table 1). Overall, the herring responded very well to tagging, with low immediate surgery-related mortality (1.6%), and most regaining vertical equilibrium and normal swimming within 1-2 min of being placed in the recovery tank. Tagged fish had an average length of 304 mm (Standard Deviation (SD)=35.9 mm, range: 250-393 mm) and an average weight of 214 g (SD=72.9 g, range: 103-464 g). Fish from the last tagging round in September 2022 in Blanc-Sablon were significantly larger than those from the three previous rounds (ANOVA, $p<0.001$; Table 1). The average tag burden (i.e., tag weight/fish weight in air) was 2.35% (range: 0.97-4.37%). Although we were unable to identify the spawning group of each tagged fish, most of the round 3 tagged fish from Port-au-Port in early May appeared to be spring spawners, as their body cavities were filled with mature gonads ready for spawning.

3.2. SUMMARY OF ACOUSTIC TELEMETRY DETECTIONS

After removing false detections, the dataset included 39,926 valid detections from 88 herring, representing 46.6% of all tagged fish (Table 3). The filtering process eliminated 1.5% (n=585) of the total detections, consisting of 125 duplicate detections occurring within a period shorter than the minimum tag delay of 130 s (filter #2, see section 2.3), 452 single detections that were not confirmed by a second detection within the 5,400-second time window (filter #3), and 8 detections indicating unrealistic swimming speeds (filter #4). As a result, 8 acoustically tagged herring, each detected only once shortly after tagging, were excluded from the dataset.

The number of detections per fish across all acoustic monitoring arrays ranged from 2 to 4,442, with an average of 453.7 ± 756.8 (SD) (Table 3, Figure 4). The GSLHER array recorded 86 tags, representing nearly the total detections (97.6%) and tags reported across all networks (Table 3). It also had the highest average detections per tag, with 453.0—substantially more than any other network. In comparison, ASF-SOBI detected 13 tags with an average of 58.2 detections per tag, while ASF-STA recorded 5 tags, averaging 25.6 detections per tag. DFO's V2LGSL acoustic monitoring program detected 6 tagged fish, with an average of 12.3 detections per tag, although 1 tag detected by this program was not recorded by the GSLHER array. Both OTN-Cabot and OTN-HFX recorded very few detections, with OTN-HFX uniquely detecting 1 tag not reported by any other network.

Table 4 shows notable variations in herring tag detections across our acoustic monitoring stations. BSA02, BSA03, BSA04, and BSA05, located near Blanc-Sablon, exhibited exceptionally high detection frequencies. BSA02, in particular, stood out by detecting 44 tags and recording 8,039 detections at an average rate of 21.8 detections per day. Similarly, BSA03 and BSA05 registered between 5,972 and 4,065 detections, respectively, with daily detection rates exceeding 10. In contrast, stations such as PAP01, REDS1 (Port-au-Port), and nearly all stations in the Strait of Belle Isle (SBW) showed lesser activity, with detection rates as low as 0.005 per day, while stations OPT02, OPT03, and OPT04 recorded no detections. Additionally, stations along the mouth of Bonne Bay (BBA01-BBA03) also recorded moderate to high detection rates, ranging from 2.5 to 9.0 detections per day, indicating concentrated tag activity in that area.

3.3. MIGRATION PATTERNS

The most relevant data comes from herring that had been swimming freely for longer periods, particularly those tagged in rounds 1 and 2 (Blanc-Sablon, September 5-6, 2021; Figure A1). Despite initial concerns that tagging might affect post-release behavior and survival, more than 90% of the fish from these rounds were detected after their release (Table 5). Since detection probability increases with the duration of free roaming, the results from rounds 3 (Port-au-Port, May 4, 2022) and 4 (Blanc-Sablon, September 10, 2022) are presented, but they remain preliminary.

In September 2021, 73 (91%) of the fish tagged and released during rounds 1 and 2 were quickly detected by receivers near Blanc-Sablon, within 5 days of release (Figure 4). Most of these fish (n=67) were detected around Blanc-Sablon, St. Paul River, and the Strait of Belle Isle through September and October (Figure 5). However, a considerable portion (n=50) did not reappear at any of our monitoring stations or other OTN-affiliated arrays after this period. Some individuals (n=15) were later detected along Newfoundland's west coast (St. John Island, Bonne Bay, and Bay of Islands) during the winter months, though detection rates declined markedly from March to April, with only 747 detections (~2% of the total). By July 2022, 15 (21%) of the fish tagged in rounds 1 and 2 returned to Blanc-Sablon, St. Paul River, and the Strait of Belle

Isle, suggesting a possible return migration to this area (Figure 5). Overall, 21 (26%) fish from rounds 1 and 2 were detected in 2022 (Figure 4).

Fish from rounds 1 and 2 exhibited considerable movement between NAFO unit area 4Sw and division 4R, with 69% of fish from round 1 and 77% from round 2 crossing between these areas at least once (Table 5). Of the 15 fish that reappeared in the Blanc-Sablon and Strait of Belle Isle areas in the summer of 2022, 9 were tracked almost continuously from September 2021 to September 2022 (Figure 6). The herring initially stayed in the Blanc-Sablon area (including St. Paul River) and the Strait of Belle Isle until October or November, with the last detection in this area on December 12. Some individuals began migrating southward in early December and were detected near St. John Island. However, the majority were later observed further south, near the mouths of Bonne Bay and Bay of Islands (Figures 5 and 6).

Herring were present at the mouth of Bonne Bay from December 22 to February 7, peaking in January; only one fish was detected during the last week of June in this area. In the Bay of Islands, herring began arriving on December 16 and remained until as late as July 20, with peak presence extending from January through March. One fish was detected at the southwestern extremity of Newfoundland, near Cape Ray (OTN-Cabot line), at the end of October, reappeared in the same area at the end of May, and then returned to the Strait of Belle Isle area at the end of July (Figure 6, Fish #8).

The Bay of Islands W station, part of DFO’s monitoring array in the Gulf of St. Lawrence (V2LGSL) and located near the Esquiman Channel off the Bay of Islands, provided insights into deeper offshore areas. Five herring were detected at this station from November 30 to May 2, though no distinct peak in detections was observed (Figure 5). The return migration began in the spring of 2022, with the St. John Island area occupied from mid-June to mid-July, and the Blanc-Sablon area occupied as early as May 31. The Strait of Belle Isle was frequented from June to September, with some fish reaching St. Anthony in July and August, at the boundary of NAFO unit area 4Ra and division 3K.

In round 3, detection numbers were low (n=1,418), likely due to limited monitoring stations near Port-au-Port, where only 11 of the 30 released fish were detected (Table 5). Following tagging, some of these fish migrated quickly northward, reaching the Bay of Islands within 3 weeks and the Strait of Belle Isle and St. Anthony areas within 2 months (Figure 5). In round 4, detections were even lower (n=45), as expected, since these fish were tagged either just before or shortly after the retrieval of the monitoring stations (Table 2). Only 4 of the 79 released fish were detected (Table 5 and Figure 4). Notably, two fish were detected in the area of Port-au-Port within 10 days of being tagged in Blanc-Sablon, indicating a migratory pattern that was not observed in fish from rounds 1 and 2 (Figure 5). Additionally, one fish was detected twice at the OTN Halifax line approximately 2 months post-release.

4. DISCUSSION

The preliminary results presented in this document provide valuable insights into the timing and spatial patterns of herring migration in the northeastern GSL, a region for which we previously had limited information. Interestingly, the herring tracked during the study period (September 2021-November 2022) displayed movement patterns that closely match the annual migration pattern proposed by McQuinn and Lefebvre (1995), which was derived from commercial fishery and bottom-trawl survey data (see Figure A2). According to McQuinn and Lefebvre (1995), herring schools, after overwintering in the deeper waters of the Esquiman Channel, begin a northward and inshore migration in early spring, either to spawn (for spring spawners) or to feed (for fall spawners). By July, the herrings schools reach the northern areas to spawn (for fall spawners) or to reach summer feeding grounds (for spring spawners). In late fall, both spawning components concentrate along the west coast of Newfoundland, particularly near Bonne Bay, where a major fall fishery occurs (Émond et al. 2024). As winter approaches, the herring return to the deep waters of the Esquiman Channel to overwinter.

In this study, herring were present in the northern areas (i.e., Blanc-Sablon, St. Paul River, and Strait of Belle Isle) throughout September and October. Beginning in mid-November, they started migrating southward toward St. John Island. By late December and January, the herring were detected near the mouths of Bonne Bay and Bay of Islands, with some individuals remaining there through February-March and even until July. Five individuals were detected in late March in the deeper waters offshore from the Bay of Islands. Most fish were undetected during the remainder of winter, spring, and early summer, only to reappear in June/July around Blanc-Sablon, the Strait of Belle Isle, and St. Anthony areas.

The spatial and temporal patterns in acoustic detections closely matched those observed in commercial fishery landings throughout the study period (Figure 7). In September and October, landings were primarily concentrated in the Blanc-Sablon area and the Strait of Belle Isle. Starting in November, landings shifted southward, becoming more concentrated in Bonne Bay and the Bay of Islands during December and January. Landings in the Blanc-Sablon area resumed in June, remaining concentrated there and the Strait of Belle Isle through July and August, reflecting closely the patterns observed in acoustic detections.

The results presented here also shed light on potential spawning, overwintering, and feeding areas for herring. The northern region, particularly the Blanc-Sablon/Strait of Belle Isle area, appears to be a feeding ground for spring spawners during the summer and early fall, supporting Moores and Winter (1984) hypothesis. Additionally, this area may also be a spawning site for fall-spawning herring (McQuinn 1997). Our field observations corroborated that Port-au-Port Bay may be a major spawning area for spring spawners (DFO 1999), as nearly all herring tagged in Port-au-Port in early May were in spawning condition. Bonne Bay, Bay of Islands, as well as the deeper waters of the Esquiman Channel, likely provide overwintering habitats, as proposed by McQuinn and Lefebvre (1995). The reduced frequency of herring detections in telemetry arrays during late winter suggests a migration into deeper habitats, where coverage remains limited.

Our study also revealed migration patterns not previously described by McQuinn and Lefebvre (1995). For instance, one fish (ID 8) tagged in Blanc-Sablon in September 2021 migrated to the southwestern tip of Newfoundland, near Cape Ray, in December 2021 (Figure 6). It reappeared in the same area the following spring before returning to the Strait of Belle Isle in July. This finding suggests that some herring may overwinter in locations outside the Esquiman Channel. Moores and Winter (1984) proposed that herring from Division 4R might overwinter in the southern part of Newfoundland's west coast or along the western portion of its south coast (subdivisions 3Pn and 3Ps, west of Fortune Bay). An extensive tagging program conducted in the 1970s in southwest Newfoundland indicated that the herring present in this region during winter were primarily a mixture of spring- and fall-spawning herring from Division 4T, with a smaller proportion from Division 4R (Winters and Beckett 1978).

The detection of an individual near Halifax (Division 4W) was unexpected. This is unlikely to represent a direct migration; rather, it may have been the result of predation, possibly by an Atlantic bluefin tuna (*Thunnus thynnus*). In fact, the OTN Halifax line is situated along a tuna migration pathway to the GSL (Block et al. 2019).

Despite herring being considered sensitive to handling (i.e., they are prone to stress and easily lose scales), the tagged individuals responded very well to capture by purse seine and to the tagging procedure, showing rapid recovery, as described by Lacoste et al. (2001). The extensive movement of these fish across the study area—covering for some more than 450 km soon after release—suggests minimal negative effects from handling. Stobo et al. (1992) observed that for Atlantic herring tagged with conventional "spaghetti" tags, survival rates were size-dependent, with significantly higher mortality in fish under 170 mm, which they attributed to handling sensitivity. Conversely, Seitz et al. (2010) reported a consistent mortality rate of 4% following tagging in Pacific herring, a rate not significantly different from control groups.

This study found that 21% of tagged herring completed a return migration to the Blanc-Sablon/Strait of Belle Isle area (the primary tagging site), and that these individuals were trackable almost continuously throughout the study period. Such detailed movement data is uniquely possible with telemetry; a conventional tagging study would simply record recaptures at the release site, potentially misinterpreting the data as "no migration". Additionally, telemetry provides insights from locations without fishing activity, giving us a more comprehensive and complete view of habitat use. Finally, the speed at which telemetry data is generated is a clear advantage; after only 18 months, we were able to produce significant preliminary results.

The high level of movement between 4Sw and 4R as well as the general north-south migration pattern observed in this study and in commercial fishery landings suggests that it would be more appropriate to group the 4R stock unit with the Quebec lower north shore (NAFO unit area 4Sw) for stock assessment purposes, as previously suggested by McQuinn and Lefebvre (1995).

5. ACKNOWLEDGEMENT

We wish to thank Tony Beaudoin, captain of the Last Quarter, and Samuel Anderson, captain of the Nancy Jillian, and their crew for the capture of live herring and assistance in the field. We also thank the Atlantic Salmon Federation for maintaining our acoustic monitoring stations in the Strait of Belle Isle, as well as Jordan Ouellet-Plante and Mathieu Boudreau for their careful review of this document. The funding for this study is provided by the DFO Competitive Science Research Fund (project no. 21-FS-14-01).

6. REFERENCES CITED

Assis, J. 2018. Contour : Pairwise Marine Distances. San Francisco, CA: GitHub; [accessed September 19, 2024].

Block, B.A., Whitlock, R., Schallert, R.J., Wilson, F., Stokesbury, M.J.W., Castleton, M., and Boustany, A. 2019. Estimating natural mortality of Atlantic bluefin tuna using acoustic telemetry. Sci. Rep. 9: 4918.

Brawn, V.M. 1960. Underwater television observations of the swimming speed and behaviour of captive herring. J. Fish. Res. Bd. Canada. 17: 689-698.

Brownscombe, J.W., Lédée, E.J.I., Raby, G.D., Struthers, D.P., Gutowsky, L.F.G., Nguyen, V.M., Young, N., Stokesbury, M.J.W., Holbrook, C.M., Brenden, T.O., Vandergoot, C.S., Murchie, K.J., Whoriskey, K., Mills Flemming, J., Kessel, S.T., Krueger, C.C., and Cooke, S.J. 2019. Conducting and interpreting fish telemetry studies: considerations for researchers and resource managers. Rev. Fish. Biol. Fisheries. 29: 369-400.

Brunel, T., and Dickey-Collas, M. 2010. Effects of temperature and population density on von Bertalanffy growth parameters in Atlantic herring: a macro-ecological analysis. Mar. Ecol. Prog. Ser. 405: 15-28.

DFO. 1999. West Coast of Newfoundland Atlantic Herring (Division 4R). DFO Science Stock Status Report B4-01 (1999).

Eiler, J.H., and Bishop, M.A. 2016. Tagging response and postspawning movements of Pacific Herring, a small pelagic forage fish sensitive to handling. Trans. Am. Fish. Soc. 145: 427-439.

Émond, K., Dionne, H., Beaudry-Sylvestre, M., Paquet, F., Rousseau, S., Lehoux, C., and Nilo, P. 2024. Assessment of the West Coast of Newfoundland (NAFO Division 4R) Atlantic Herring (*Clupea harengus*) Stocks in 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2024/004. xi + 93 p.

Huse, I. and Ona, E. 1996. Tilt angle distribution and swimming speed of overwintering Norwegian spring spawning herring. ICES J. Mar. Sci. 53: 863-873.

Lacoste, K.N., Munro, J., Castonguay, M., Saucier, F.J., and Gagne, J.A. 2001. The influence of tidal streams on the pre-spawning movements of Atlantic Herring, *Clupea harengus* L., in the St. Lawrence estuary. ICES J. Mar. Sci. 58: 1286-1298.

McQuinn, I.H. 1997. Metapopulations and the Atlantic herring. Rev. Fish Biol. Fish. 7: 297-329.

McQuinn, I.H., and Lefebvre, L. 1995. Distribution, Movements and Size Composition of Spring-Spawning Herring in the Northern Gulf of St. Lawrence. DFO Atl. Fish. Res. Doc. 95/57.

Melvin, G.D., Stephenson, R.L., and Power, M.J. 2009. Oscillating reproductive strategies of herring in the western Atlantic in response to changing environmental conditions. ICES J. Mar. Sci. 66: 1784-1792.

Moores, J.A., and Lilly, G.R. 1982. Distribution of herring in the Northern Gulf of St. Lawrence in Winter. CAFSAC Res. Doc. 82/14.

Moores, J. A., and Winters, G. H. 1984. Migration patterns of Newfoundland west coast herring, *Clupea harengus*, as shown by tagging studies. J. Northw. Atl. Fish. Sci. 5: 17-22.

Munro, J., Gauthier, D., and Gagné, J.A. 1998. Description d’une frayère de hareng (*Clupea harengus* L.) à l’Île aux Lièvres dans l’estuaire moyen du Saint-Laurent. Rapp. tech. can. sci. halieut. aquat. 2239: vi + 34 p.

Pincock, D.G. 2012. False detections: what they are and how to remove them from detection data. Amirix Document DOC-004691 Version 03.

Seitz, A.C., Norcoss, B.L., Payne, J.C., Kagley, A.N., Meloy, B., Gregg, J.L., and Hershberger, P.K. 2010. Feasibility of surgically implanting acoustic tags into Pacific Herring. Trans. Am. Fish. Soc. 139: 1288-1291.

Simpfendorfer, C.A., Huveneers, C., Steckenreuter, A., Tattersall, K., Hoenner, X., Harcourt, B., and Heupel, M.R. 2015. Ghosts in the data: false detections in VEMCO pulse position modulation acoustic telemetry monitoring equipment. Anim. Biotelemetry. 3: 1-10.

Stephenson, R.L., Melvin, G.D., and Power, M.J. 2009. Population integrity and connectivity in Northwest Atlantic herring: a review of assumptions and evidence. ICES J. Mar. Sci. 66: 1733-1739.

Stobo, W.T., Fowler, G.M., and Sinclair, A.F. 1992. Short-term tagging mortality of laboratory held juvenile Atlantic herring (*Clupea h. harengus*). J. Northw. Atl. Sci. 12: 27-33.

Trudeau, C., and McQuinn, I. H. 1986. Fishery and Biological Characteristics of the 4S Herring Stocks in 1985. CAFSAC Res. Doc. 86/77.

Winters, G.H., and Beckett, J.S. 1978. Migrations, biomass and stock interrelationships of Southwest Newfoundland-Southern Gulf herring from mark-recapture experiments. ICNAF Res. Bull. No. 13: 67-79.

7. TABLES

Table 1. Summary details of acoustically tagged Atlantic herring from Blanc-Sablon (4Sw/4Ra) and Port-au-Port (4Rc), showing the tagging dates in 2021 and 2022, the latitude and longitude coordinates where the herring were released after tagging, the estimated tag life end dates, the sample sizes (N), and herring total lengths (mean and range) and weights (mean and range). Fish tagged during the second round were not weighed due to a malfunctioning scale.

Tagging round	Tagging date	Locality (NAFO unit area)	Latitude (DD.dddd°)	Longitude (DD.dddd°)	Tag life end date	N	Mean length (mm)	Mean weight (g)
1	2021-09-05	Blanc-Sablon (4Ra)	51.3710	-57.1499	2024-03-05	40	284 (251-376)	177 (110-340)
2	2021-09-06	Blanc-Sablon (4Sw)	51.3746	-57.2494	2024-03-06	40	285 (255-366)	-
3	2022-05-04	Port-au-Port (4Rc)	48.9458	-58.5431	2024-11-01	30	293 (273-346)	183 (141-431)
4	2022-09-10	Blanc-Sablon (4Ra)	51.3734	-57.1406	2025-03-10	79	328 (250-393)	239 (103-464)

Table 2. Acoustic receiver monitoring stations deployed in 2021 and 2022. Most stations are still active at the time of publication, except for stations in Ouapitagone Archipelago (OPT01-04).

Station	Locality (NAFO unit area)	Latitude (DD.dddd°)	Longitude (DD.dddd°)	Bottom depth (m)	Deployment date	Recovery date
PAP01	Port-au-Port (4Rc)	48.8537	-58.8110	52.2	2021-08-16	2022-10-30
PAP02	Port-au-Port (4Rc)	48.8549	-58.5886	47.9	2021-08-16	2022-10-30
PAP03	Port-au-Port (4Rc)	48.5773	-58.7317	49.4	2021-08-16	2022-10-31
REDS1	Red Island (4Rc)	48.5498	-59.2368	35.0	2022-05-03	2022-08-26
REDN1	Red Island (4Rc)	48.5727	-59.2231	23.0	2022-05-03	2022-10-30
BOI01	Bay of Islands (4Rc)	49.1510	-58.3629	123.7	2021-08-15	2022-08-20
BOI02	Bay of Islands (4Rc)	49.1631	-58.3613	238.3	2021-08-15	2022-08-20
BOI03	Bay of Islands (4Rc)	49.1748	-58.3616	98.2	2021-08-15	2022-08-20
BOI04	Bay of Islands (4Rc)	49.2277	-58.2421	186.1	2021-08-15	2022-08-21
BOI05	Bay of Islands (4Rc)	49.2342	-58.2258	203.4	2021-08-15	2022-08-21
BBA01	Bonne Bay (4Rb)	49.5623	-57.9756	103.6	2021-08-13	2022-08-20
BBA02	Bonne Bay (4Rb)	49.5695	-57.9633	194.4	2021-08-13	2022-08-20
BBA03	Bonne Bay (4Rb)	49.5773	-57.9518	97.8	2021-08-13	2022-08-20
SJI01	St. John Island (4Ra)	50.7954	-57.3199	69.8	2021-08-09	Lost
SJI02	St. John Island (4Ra)	50.9525	-57.2097	82.3	2021-08-09	2022-08-16
BSA01	Blanc-Sablon (4Sw)	51.3804	-57.4278	66.4	2021-09-05	2022-09-09
BSA02	Blanc-Sablon (4Sw)	51.3892	-57.2817	52.7	2021-09-05	2022-09-09
BSA03	Blanc-Sablon (4Sw)	51.3777	-57.2561	32.7	2021-09-05	2022-09-09
BSA04	Blanc-Sablon (4Sw)	51.3662	-57.1776	41.1	2021-09-05	2022-09-09
BSA05	Blanc-Sablon (4Ra)	51.3707	-57.1549	39.3	2021-09-05	2022-09-09
BSA06	Blanc-Sablon (4Ra)	51.3801	-57.1179	47.9	2021-09-05	2022-09-09
BSA07	Blanc-Sablon (4Sw)	51.3894	-57.1554	38.8	2021-09-05	2022-09-09
BSA08	Blanc-Sablon (4Ra)	51.4075	-57.0756	44.6	2021-09-05	2022-09-09
RSP01	St. Paul River (4Sw)	51.3741	-57.6207	61.4	2021-09-05	2022-09-09
RSP02	St. Paul River (4Sw)	51.3663	-57.6080	95.1	2021-09-05	2022-09-09
SBW01	Strait of Belle Isle (4Ra)	51.3934	-56.6343	62.2	2021-08-13	2022-08-17
SBW02	Strait of Belle Isle (4Ra)	51.4042	-56.6538	80.5	2021-08-13	2022-08-17
SBW03	Strait of Belle Isle (4Ra)	51.4150	-56.6735	73.2	2021-08-13	2022-08-17
SBW04	Strait of Belle Isle (4Ra)	51.4258	-56.6931	67.7	2021-08-13	2022-08-17
SBW05	Strait of Belle Isle (4Ra)	51.4367	-56.7130	67.7	2021-08-13	2022-08-17
SBW06	Strait of Belle Isle (4Ra)	51.4475	-56.7327	54.9	2021-08-15	2022-08-17
SBW07	Strait of Belle Isle (4Ra)	51.4584	-56.7524	60.4	2021-08-15	Lost
SBW08	Strait of Belle Isle (4Ra)	51.4692	-56.7721	109.7	2021-08-15	2022-08-17
SBW09	Strait of Belle Isle (4Ra)	51.4801	-56.7919	104.2	2021-08-15	2022-08-17
SBW10	Strait of Belle Isle (4Ra)	51.4908	-56.8116	36.6	2021-08-15	2022-08-17
OPT01	Ouapitagone Archipelago (4Sv)	50.1475	-60.0410	79.0	2021-10-21	Lost
OPT02	Ouapitagone Archipelago (4Sv)	50.1373	-60.0275	77.0	2021-10-21	2022-10-16
OPT03	Ouapitagone Archipelago (4Sv)	50.1268	-60.0130	53.0	2021-10-21	2022-08-05
OPT04	Ouapitagone Archipelago (4Sv)	50.1163	-59.9995	83.0	2021-10-21	2022-10-16

Table 3. Summary of herring detections between September 2021 and November 2022 from this project and other OTN-affiliated projects (ASF-SOBI: ASF's regular summer receiver line in the Strait of Belle Isle; ASF-STA: ASF's and DFO's St. Anthony receiver line; OTN-Cabot: OTN's Cabot Strait receiver line; OTN-HFX: OTN's Halifax receiver line; V2LGSL: DFO'S (Quebec region) ongoing monitoring array in the GSL). Other OTN-affiliated networks include NEP.COWCTT, QBI, V2LCELASE and V2LGAC. False detections were removed from dataset.

Network	Number of valid detections	Number of tags detected	Average number of detections per tag	Number of false detections
GSLHER	38,955	86	453.0	443
ASF-SOBI	757	13	58.2	85
ASF-STA	128	5	25.6	46
OTN-Cabot	10	1	10.0	0
OTN-HFX	2	1	2.0	0
V2LGSL	74	6	12.3	3
Other OTN-affiliated networks	0	-	-	8
Total	39,926	88	453.7	585

Table 4. Duration of deployment (in days), number of tags detected, total number of detections, and frequency of detections (number per day) presented for each GSLHER acoustic monitoring station (lost stations were removed; SJI01, SBW07 and OPT01).

Station	Duration of deployment (days)	Tags detected	Total detections	Detection frequency (number/day)
PAP01	440	1	3	0.007
PAP02	440	2	30	0.07
PAP03	441	6	1285	2.9
REDS1	115	1	2	0.02
REDN1	180	1	2	0.01
BOI01	370	4	16	0.04
BOI02	370	5	80	0.22
BOI03	370	3	156	0.42
BOI04	371	1	391	1.1
BOI05	371	3	320	0.86
BBA01	372	7	946	2.5
BBA02	372	6	3335	9.0
BBA03	372	5	957	2.6
SJI02	372	5	73	0.20
BSA01	369	14	1022	2.8
BSA02	369	44	8039	21.8
BSA03	369	55	5972	16.2
BSA04	369	58	2755	7.5
BSA05	369	56	4065	11.0
BSA06	369	39	3832	10.4
BSA07	369	27	1652	4.5
BSA08	369	30	2906	7.9
RSP01	369	6	531	1.4
RSP02	369	4	124	0.34
SBW01	369	4	22	0.06
SBW02	369	1	2	0.005
SBW03	369	1	2	0.005
SBW04	369	2	42	0.11
SBW05	369	5	90	0.24
SBW06	367	2	79	0.22
SBW08	367	4	18	0.05
SBW09	367	3	18	0.05
SBW10	367	6	188	0.51
OPT02	360	0	-	-
OPT03	288	0	-	-
OPT04	360	0	-	-

Table 5. Number of herring detected per tagging round, average number of detections per tag (with range), and number of tagged individuals that moved between NAFO divisions after release.

Tagging round	**Tagging location (NAFO unit area)**	**Tags detected (%)**	**Detections per tag (range)**	**Movement between areas (%)**
1	Blanc-Sablon (4Ra)	39 (97.5%)	295.8 (7-2326)	27 (69.2%)
2	Blanc-Sablon (4Sw)	34 (85.0%)	792.0 (2-4442)	26 (76.5%)
3	Port-au-Port (4Rc)	11 (36.7%)	128.9 (2-414)	2 (18.2%)
4	Blanc-Sablon (4Ra)	4 (5.1%)	11.3 (2-24)	3 (75.0%)

8. FIGURES

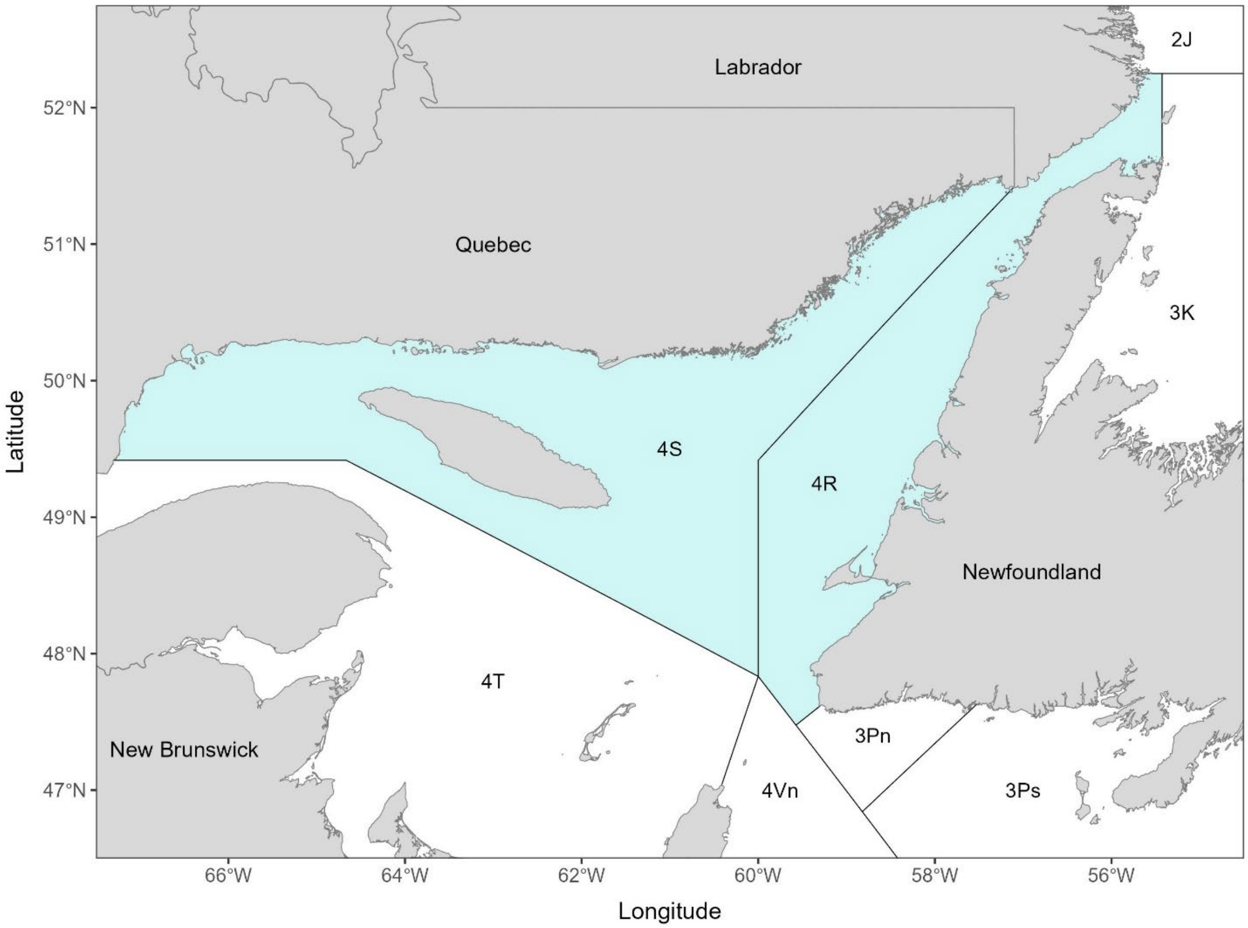

Figure 1. The Gulf of St. Lawrence and Northwest Atlantic Fisheries Organization (NAFO) divisions. The study area is the northern Gulf of St. Lawrence, which includes NAFO divisions 4R and 4S (in blue).

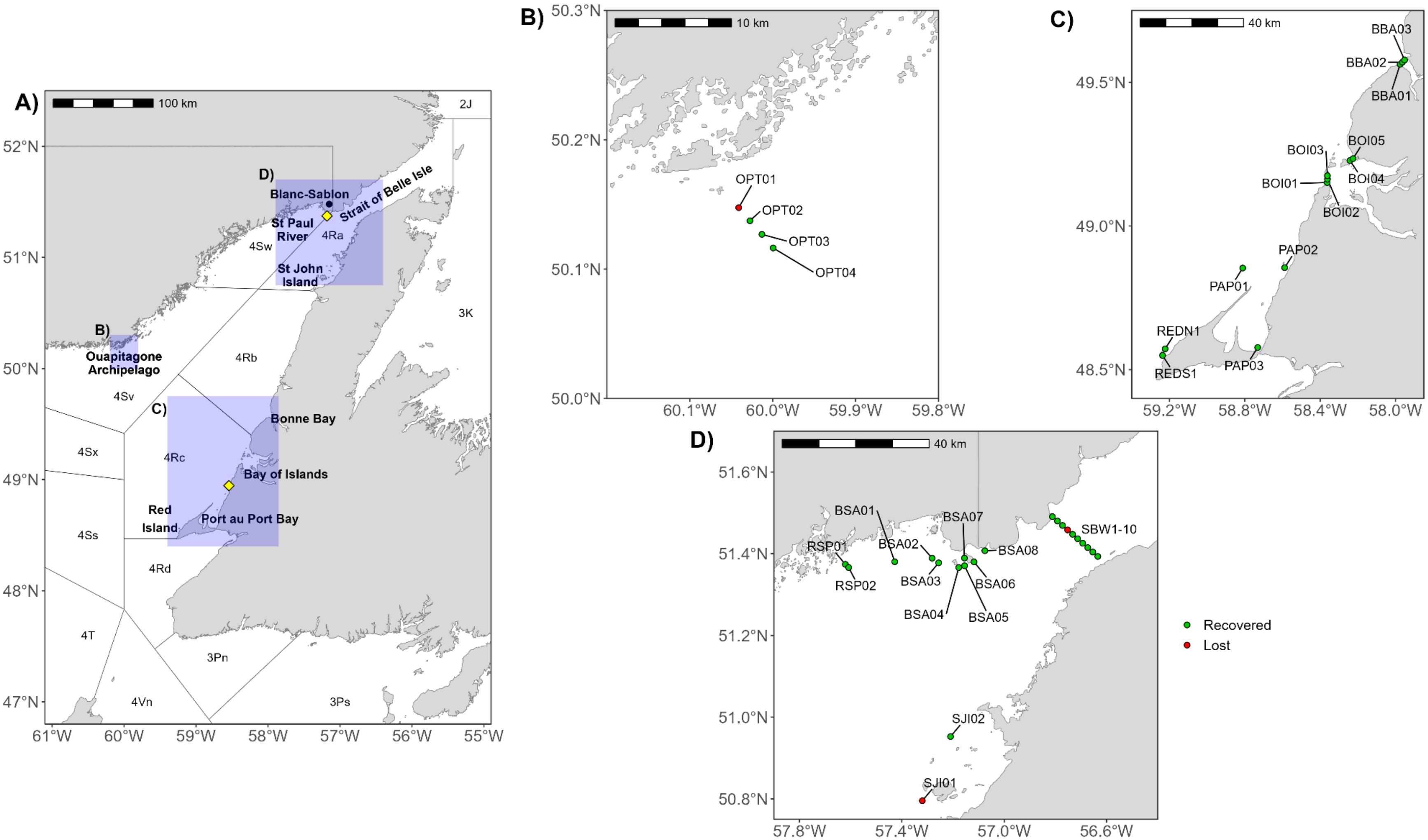

Figure 2. (A) Study area and NAFO divisions along the west coast of Newfoundland and the Lower North Shore of Quebec showing tagging/release sites of Atlantic herring (yellow diamonds). (B) Location of the deployed acoustic monitoring stations near Ouapitagone Archipelago (n=4). (C) Southern portion of the west coast of Newfoundland showing positions of the deployed acoustic monitoring stations (n=13). (D) Location of the acoustic monitoring stations near Blanc-Sablon, St. Paul River, and in the Strait of Belle Isle (n=22). All stations were recovered successfully, except OPT1, SJI01 and SBW07.

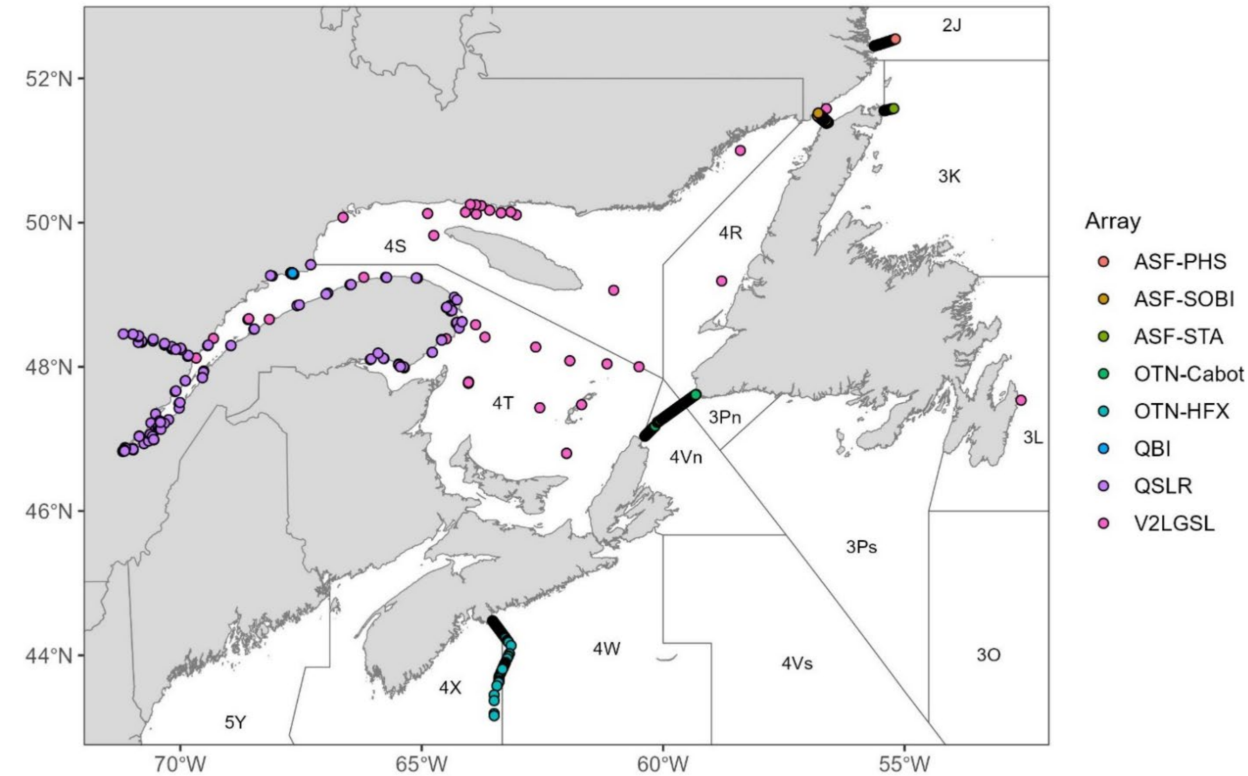

Figure 3. Map showing the acoustic monitoring stations of other OTN-affiliated networks in the Gulf of St. Lawrence and Northwest Atlantic available for this study in 2021 and 2022 (AFS-PHS: Atlantic Salmon Federation's Port-Hope/Simpson receiver line; ASF-SOBI: ASF's regular summer receiver line in the Strait of Belle Isle; ASF-STA: ASF's and DFO's St. Anthony receiver line; OTN-Cabot: OTN's Cabot Strait receiver line; OTN-HFX: OTN's Halifax receiver line; QBI: DFO's Quebec Benthic Invertebrates project in Godbout, Quebec; QSLR: Quebec's provincial acoustic telemetry network; V2LGSL: DFO'S (Quebec region) ongoing monitoring array in the GSL).

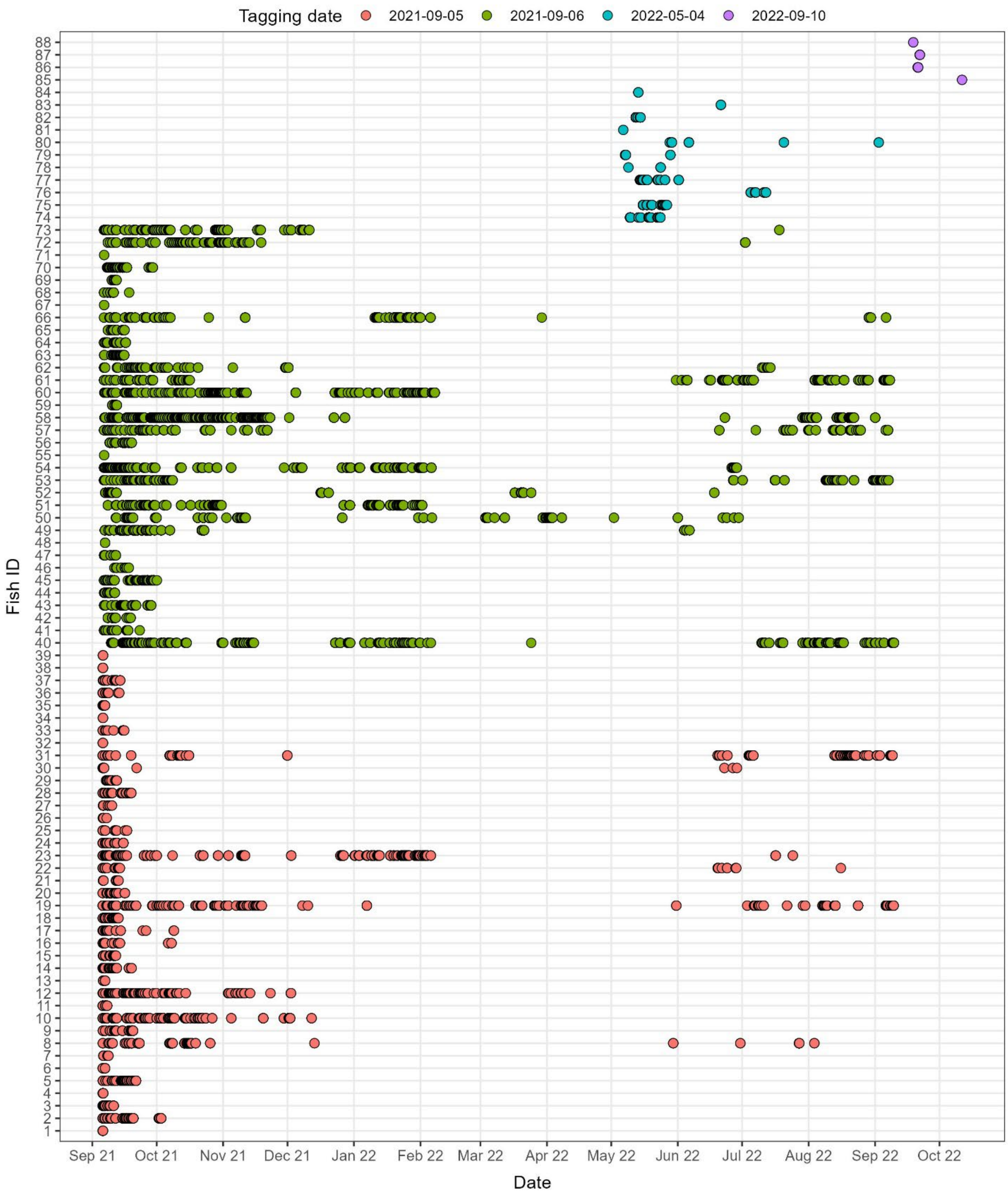

Figure 4. Abacus plot showing acoustic detections by date for each tagged and detected herring (n=88) between September 2021 and November 2022, colored by date of tagging. Each line represents the detections of an individual herring.

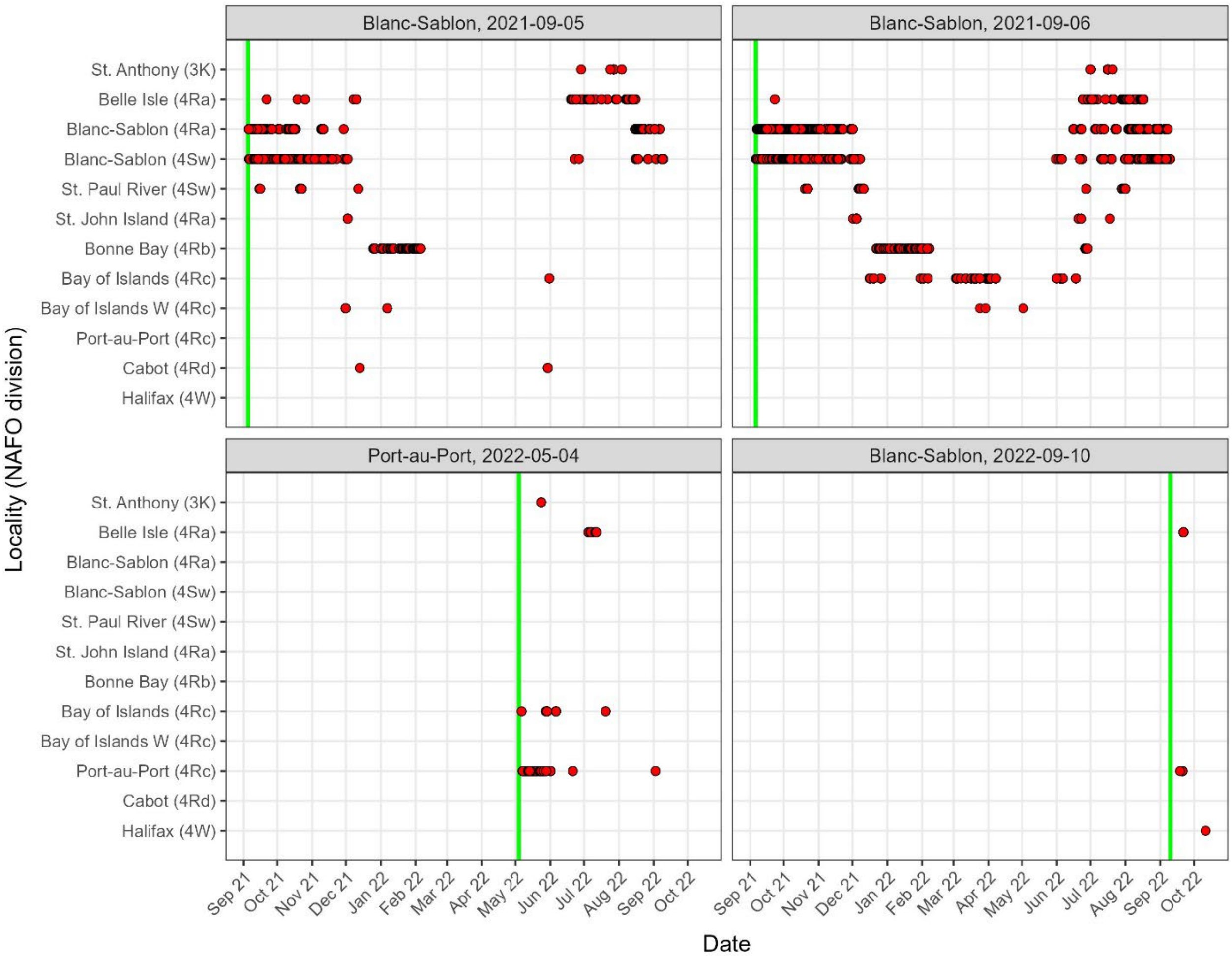

Figure 5. Abacus plot of acoustic detections by date for herring tagged during each of the four tagging rounds (panels). Detections from acoustic monitoring stations located within the same locality and NAFO division were grouped together (see Figure 2). The green vertical lines indicate the date of each tagging round. The Bay of Islands W. locality includes one station that is part of DFO's (Quebec Region) ongoing monitoring array in the Gulf of St. Lawrence, located off the coast of Bay of Islands, near the Esquiman channel (see Figure 3).

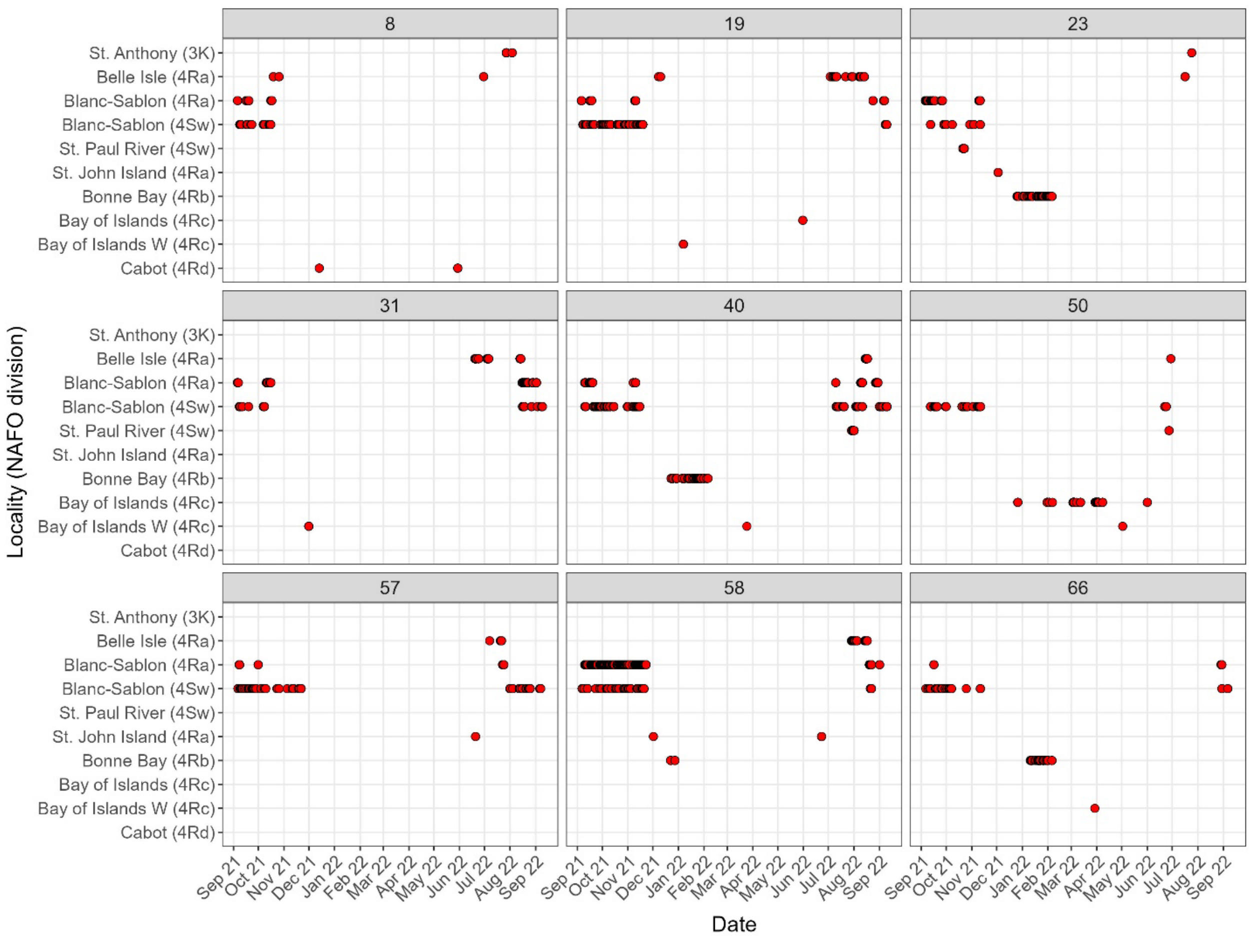

Figure 6. Abacus plot of acoustic detections by date for herring tagged in rounds 1 and 2, which were tracked almost continuously from September 2021 to September 2022. Each panel represents an individual fish (fish IDs are shown in Figure 4). The Bay of Islands W. locality includes one station that is part of DFO's (Quebec Region) ongoing monitoring array in the Gulf of St. Lawrence and is located off the coast of Bay of Islands, near the Esquiman Channel (see Figure 3).

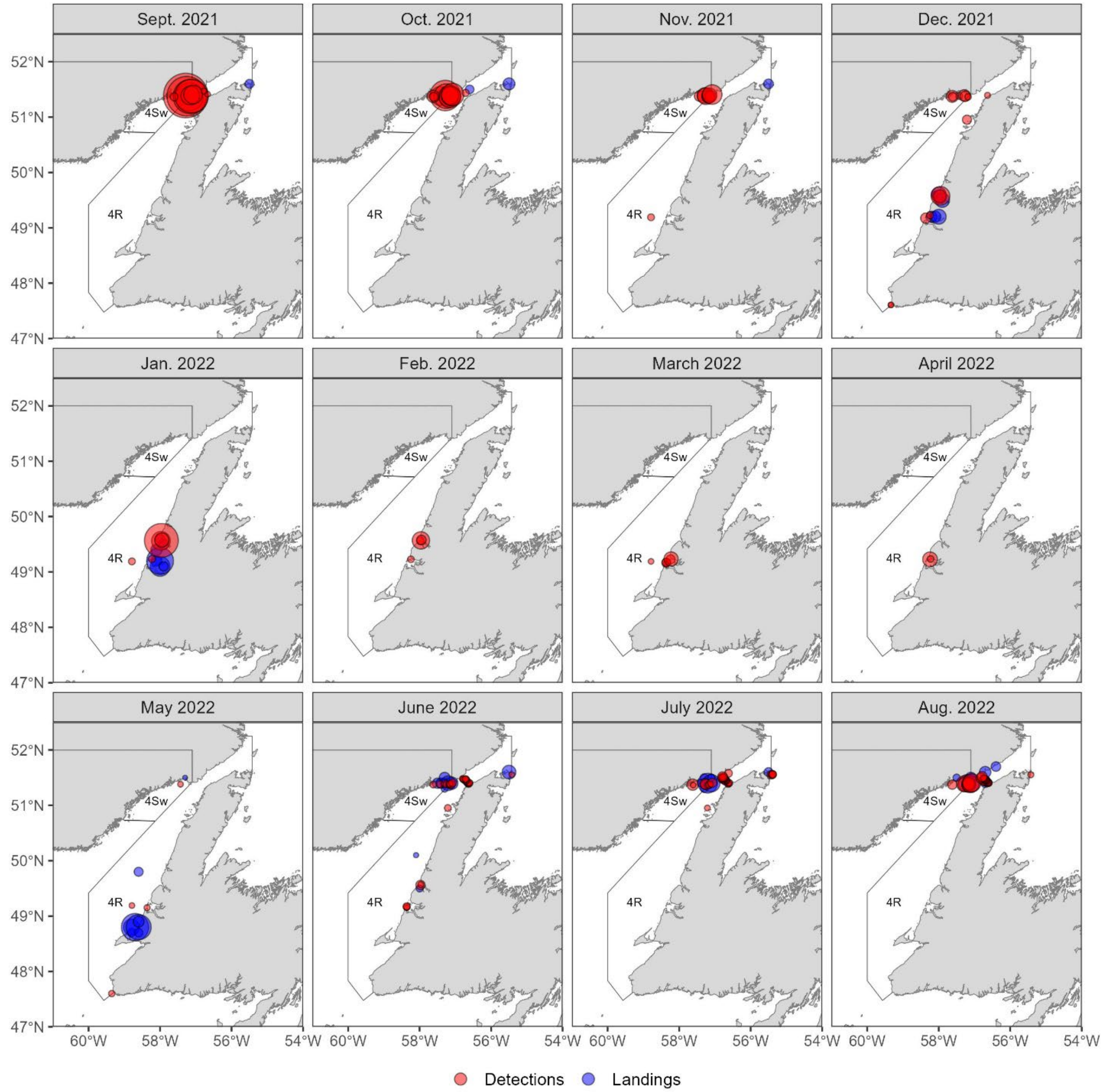

Figure 7. Monthly detections per acoustic monitoring station for herring tagged during rounds 1 and 2, along with commercial fishery landings, from September 2021 to August 2022 in NAFO division 4R and unit area 4Sw.

9. APPENDIX

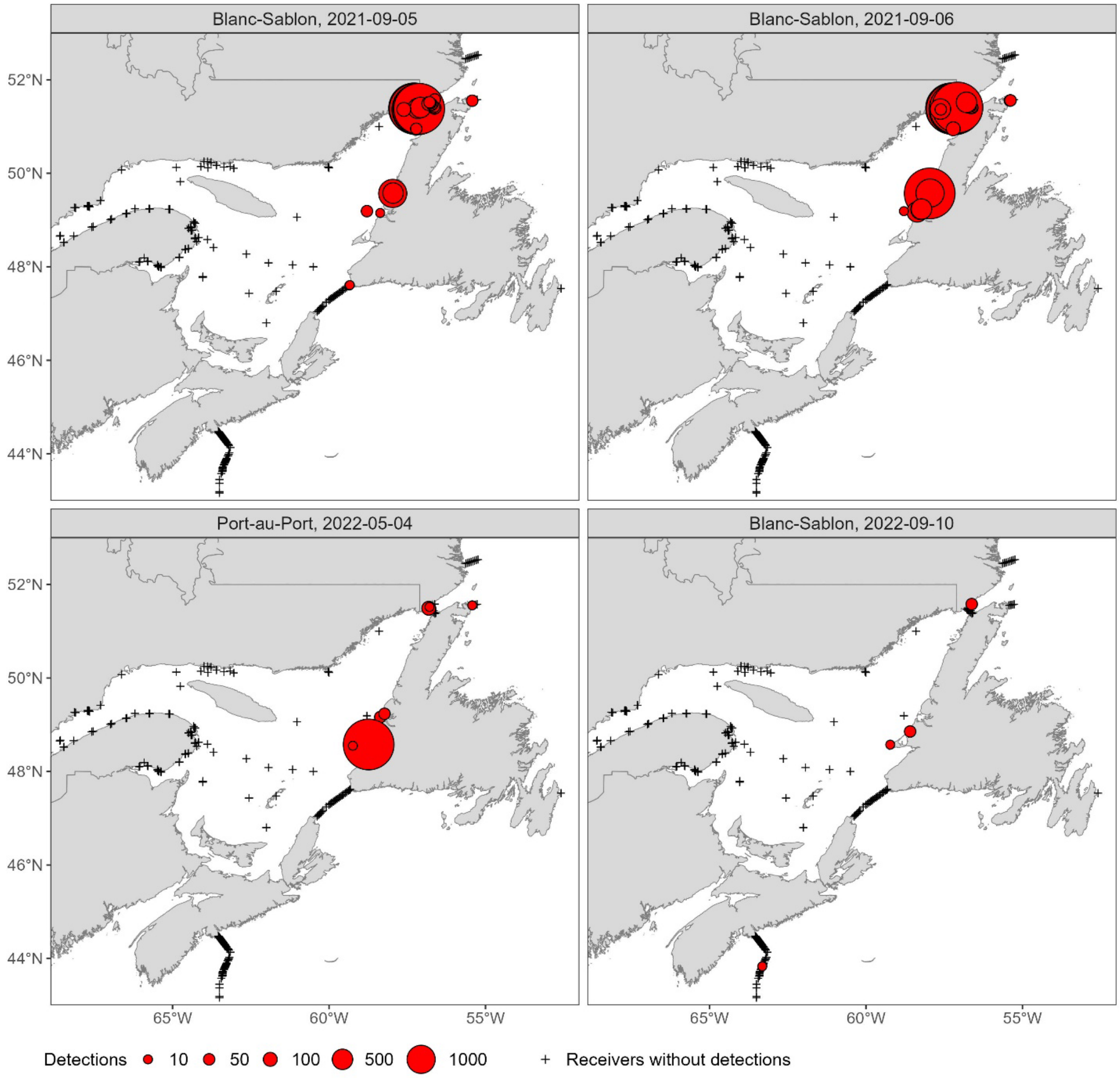

Figure A1. Number of detections per station of herring tagged in each of the four rounds (panels).

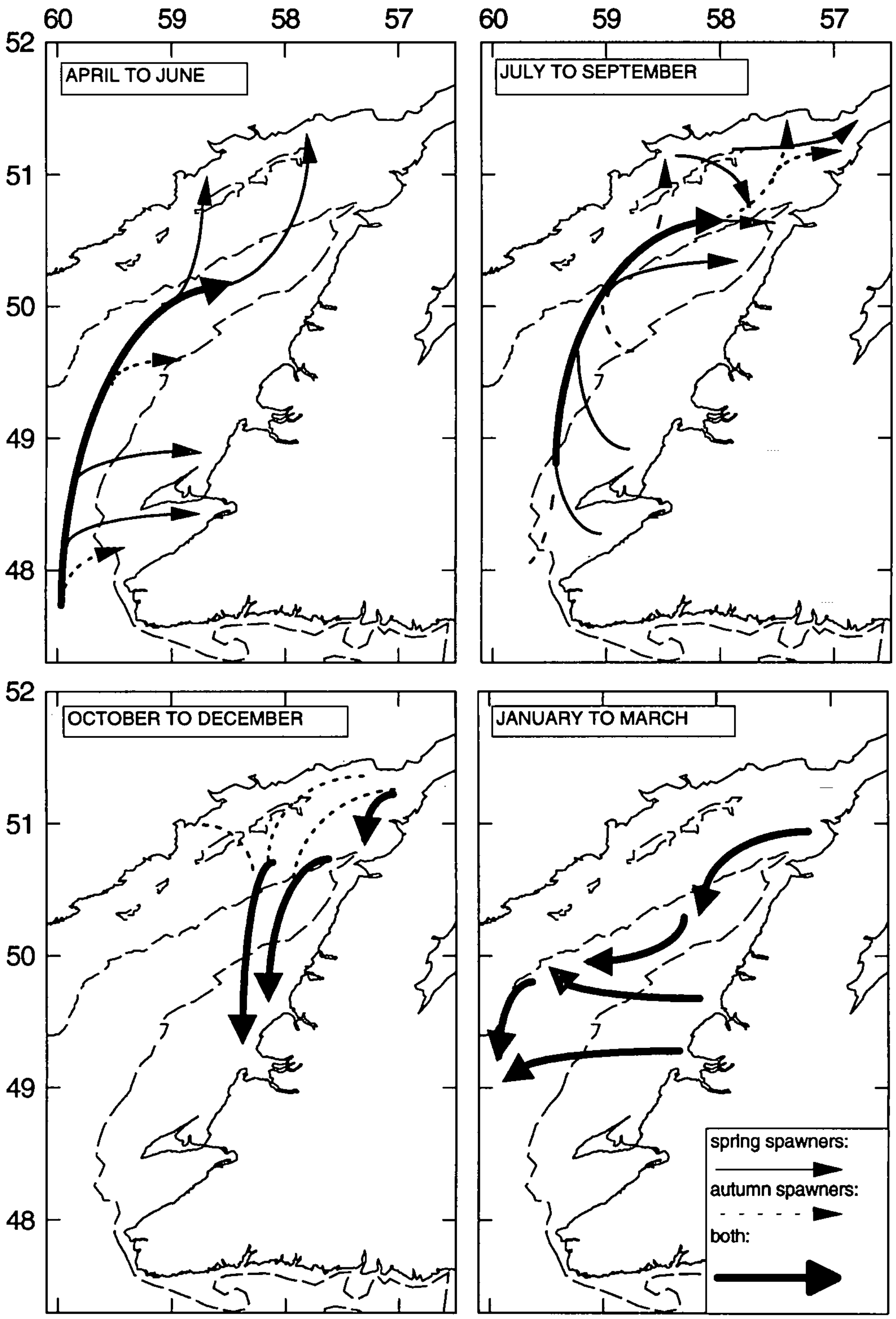

Figure A2. Probable annual migration pattern of spring- and fall-spawning herring in the northeastern Gulf of St. Lawrence, adapted from McQuinn and Lefebvre 1995.