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Design and Analytical Methodology for the Atlantic Herring (*Clupea harengus*) Summer Acoustic Survey in NAFO Divisions 4RSw (2019-2023)

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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.

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ABSTRACT

Since 1991, hydroacoustic surveys have been conducted in the fall in Northwest Atlantic Fisheries Organization (NAFO) divisions 4RSw to assess the spring and fall spawning stock biomass of Atlantic herring (*Clupea harengus*). In 2019, a summer hydroacoustic survey was introduced, as it was hypothesized to better and more consistently cover the total herring abundance in the area. The fall hydroacoustic survey was discontinued in 2022, and the summer survey became the primary source of fishery-independent input to the herring stock assessment. The implementation of the summer hydroacoustic survey was accompanied by several changes to the methodology and survey design, including the addition of strata in the northern portion of the survey and the standardization and automation of the analytical workflow. Given the significant changes in methodology, survey coverage, and survey timing, the summer hydroacoustic survey is unlikely to yield directly comparable results to the historical fall hydroacoustic survey. In terms of methodology, the most impactful difference between the two approaches originates from the differentiation between fish with and without a swim bladder, which leads to a generally larger area backscattering coefficient (s_a), a proxy for fish abundance, with the new method. We conclude that the updated method improves efficiency, reliability and replicability of the herring biomass estimates compared to the previous method applied to the fall hydroacoustic surveys.

1. INTRODUCTION

Atlantic herring (*Clupea harengus*) is a forage fish species found in North Atlantic waters. It performs yearly migrations associated with spawning, feeding and wintering, and visits the same grounds each year. In the northern Gulf of St. Lawrence, Atlantic herring occupies shallow waters off the coast of Labrador and in the Strait of Belle Isle during summer months, while it inhabits deeper offshore waters during winter (McQuinn and Lefebvre 1995).

Since 1991, a hydroacoustic survey conducted on the west coast of Newfoundland in the fall has been the primary source of fishery-independent data for Atlantic herring stock assessments in Northwest Atlantic Fisheries Organization (NAFO) divisions 4RSw (Émond et al. 2024). A first survey time series conducted from 1991 to 2002 (Beaulieu et al. 2010; McQuinn and Lefebvre 1999) produced patterns of relative abundance-at-age that were overall consistent with attrition and stationary catchability for individual cohorts. A second series of surveys was conducted between 2009 and 2022 (Émond et al. 2024), however this series showed inconsistent patterns of abundance-at-age, underlying potential challenges with either the analytical methods or the survey catchability and coverage (Chamberland et al. 2022). These inconsistencies led to the rejection of the analytical population framework in the peer-review meeting of November 2020 (DFO 2021). An attempt was made to correct and standardize the analytical methods of the 2009-2022 time series (Beaudry-Sylvestre et al. 2024); however, some inconsistencies persisted.

In an effort to improve the representativity of the acoustic survey index, a survey was implemented in 2019 during the summer season, a period hypothesized to better and more consistently cover peak herring abundance in the survey area (Chamberland et al. 2022). Two strata were added in the Strait of Belle Isle (BI01 and BI02), to account for reports from harvesters of very high herring abundances in this area since at least 2017 (Chamberland et al. 2022). The adjacent 4Sw NAFO unit area, surveyed since 2009, was also incorporated to 4R following evidence of high levels of herring movement between those two areas (DFO 2024a).

For the 2019-2023 summer hydroacoustic time series, the methodologies for biological sampling and acoustic data analysis were updated from the ones used for the 2009 to 2022 fall hydroacoustic time series (Beaudry-Sylvestre et al. 2024). These modifications were necessary in part due to incompatibilities between the previously used analytical software (CH2, Simard et al. 2000) and the newly updated data acquisition software (EK80, Kongsberg Maritime AS). The new method also aimed at improving efficiency, objectivity, replicability, and accuracy through the introduction of automated processes. The method was presented at the Canadian Science Advisory Secretariat (CSAS) peer review of the assessment framework for Atlantic herring stocks on the west coast of Newfoundland and the Lower North Shore of Quebec (NAFO divisions 4RSw) held on April 4-5, 2023 (DFO 2024a). The fall 2022 survey was used as the basis for a comparative analysis between the methods used for the fall 2009-2022 and the summer 2019-2023 time-series. This dataset was chosen because it was the only one for which both approaches overlapped.

In this document, we introduce the new methodology and present the comparative analysis and preliminary results of the Atlantic herring summer hydroacoustic surveys for the period covering 2019 to 2023. We do not present abundance estimates by age groups; these results and their methods will be presented in a future document.

2. METHODS

2.1. HYDROACOUSTIC SURVEY DESIGN AND DATA ACQUISITION

The summer herring hydroacoustic survey is stratified into fourteen strata designed to capture the major physical characteristics of the herring habitat as well as the spatial occurrence of herring in past and ongoing scientific surveys and commercial catches (Figure 1). The current stratification is based on the model proposed by McQuinn and Lefebvre (1999) and was expanded to account for herring in the southern (BI01; 1,163 km^2) and northern (BI02; 626.8 km^2) Strait of Belle Isle (BI), located in NAFO unit area 4Ra (Chamberland et al. 2022). The survey also includes the easternmost segment of Quebec's Lower North Shore, in the adjacent NAFO unit area 4Sw (stratum 4Sw; 2,195 km^2), which has been merged to the 4R division (Beaudry-Sylvestre et al. 2024). In 2023, stratum 4Sw was subdivided into two strata (4Sw01 and 4Sw02) to account for the considerable difference in estimated biomass between the eastern and western portions of the stratum. The survey now covers a bathymetry ranging from 20 to 250 m.

All surveys were conducted at night (17:00-07:00, Atlantic Time) in accordance with known diurnal cycles of herring (McQuinn and Lefebvre 1999) to increase the likelihood that fish can be distinguished from the seafloor and thus minimize the uncertainty associated with the acoustic dead zone (Mitson 1983). The survey followed a systematic stratified design, where transects in each stratum were parallel and oriented perpendicular to the coast, with the first transect placed randomly at either end of the stratum and subsequent transects placed at equal distance from one another. From 2019 to 2022, inter-transect spacing in all strata was 5 or 7.5 nm depending on available ship time. In 2023, an alternative method for estimating the optimal number of transects per stratum (n_s) was used, based on the spatial occupation of herring in previous surveys and a predefined level of precision (i.e. coefficient of variation), following Robotham and Castillo (2009). The coefficient of variation for each stratum was defined according to the stratum's average herring density (CV=0.75, 0.50, and 0.25 for low, medium and high-density strata, respectively).

The vessels employed for each survey were equipped with a hull-mounted, split-beam SIMRAD EK60 (survey years: 2019-2020) or EK80 (survey years: 2021-2023) echosounder operating at up to five frequencies (38, 70, 120, 200, and 333 kHz). Note that only the 38, 120 and 200 kHz frequencies were used. The transducers were calibrated prior to each survey according to the standard sphere methods presented in Demer et al. (2015) for real-time recording of data. Data were collected at a sampling rate of 1 second. A pulse duration of 1.024 ms was used for all frequencies. Table 1 presents a summary of each survey characteristics. Conductivity, temperature and depth profiles (CTD) were collected in each stratum and used to adjust sound speed and absorption coefficient during data collection for that stratum.

2.2. BIOLOGICAL SAMPLING

In 2023 and during the fall 2022 survey, a revised sampling plan was applied to the trawl survey for the collection of biological samples (see Table 2). The goal was to move from targeted sampling (the chartered fishing vessel choosing the location of the sample collection) to randomized sampling, where the fishing vessel was given a pre-established sampling plan for biological sample collection (see Figure 2).

Biological samples were collected in the survey area at the same time period as the hydroacoustic surveys. Logistical constraints prevented a direct match between acoustic and biological data collection. In addition to vessel speed limitations, ship time availability for the acoustic surveys amounted to three weeks, whereas biological sampling occurred on a period of five to seven days. The fishing vessel followed systematic diagonal transects and performed pelagic trawling upon detecting fish aggregations on its echosounder. Maximum transect distance (i.e. distance between the end of the diagonals) was set to 10 km and was chosen as the minimum distance allowing the vessel to cover the entire survey area in the allocated time. Point locations were defined along the transects; once a trawl was conducted, the vessel was not allowed to trawl again until it reached the next point location, to avoid fishing the same aggregation twice. Points were determined using a random function with a minimum Euclidian distance of 0.3 and a maximum number of points per stratum of 2 to 4 depending on the stratum area. The fishing vessel used a Pandalus III semi-pelagic trawl, with an area of 154 m^2 and a mesh size of 50 mm in the codend. All species of fish with a swim bladder were identified and the total catch per species was weighted. A subsample (100 individuals for herring and capelin, 30 individuals for all other species) of each swim bladdered fish species was collected for each deployment, and each sub-sampled individual was measured and weighted.

2.3. ACOUSTIC DATA ANALYSIS

The acoustic data were visualized and processed as the volume backscattering strength (S_v, dB re 1 m^{-1}; a proxy for fish density), which represents the mean backscattering intensity per cubic meter, in the logarithmic domain:

$$S_v = 10\ log_{10}(s_v) \tag{1}$$

where

$$s_v = \frac{\sum \sigma_{bs}}{V} \tag{2}$$

The term s_v is the volume backscattering coefficient (m^{-1}), σ_{bs} is the backscattering cross-section (m^2) and V is the volume sampled (m^3). All symbols and units follow the conventions proposed by MacLennan et al. (2002).

The analyses were conducted in Echoview 13 (Myriax Pty, Ltd., Hobart, Tasmania, Australia) and the R software for statistical computing (version 4.0.2, R Core Team 2020) with RStudio (version 1.3.1056, RStudio Team 2020). Impulse noise was removed from the S_v echograms following the method described in Ryan et al. (2015). Areas of impulse noise were replaced by the mean of the surrounding cells. Background noise was removed following the method by De Robertis and Higginbottom (2007). A minimum signal to noise ratio of 10 dB and an averaging cell of 40 pings (one ping corresponds to one individual sound burst) and 10 vertical meters were used. The maximum noise as described by De Robertis and Higginbottom (2007) was determined empirically through passive acoustic recordings of the echosounder.

An attenuated acoustic signal can result from the presence of air bubbles underneath the hull and the transducer. Areas of attenuation were manually removed from the analysis. Each echogram was visually scrutinized to remove unwanted signal such as instruments in water or noise that was not successfully removed by the previously described data cleaning protocol.

Acoustic data above a depth corresponding to the transducer depth plus 5 m were excluded from the analysis. A bottom line was defined using Echoview's best bottom candidate algorithm with a minimum S_v threshold of -70 dB and a peak threshold of -50 dB. The acoustic dead zone, i.e. the portion of the spherical acoustic beam where herring cannot be detected near the seabed, was estimated following Ona and Mitson (1996):

$$h_{eq_{y,s,i}} = 2404 \cdot \frac{\left(d_i - td_y\right) \cdot \tan\left(\frac{\emptyset_y \cdot \pi}{180}\right)^4}{{\emptyset_y}^2} + \frac{c_s \tau}{4} + bs \quad (3)$$

where d is the depth of the seafloor (m) for each ping i; td and $\emptyset$ are the transducer's depth (m) and the transducer's 3 dB half beam angle at 38 kHz (°) for survey y, respectively; c is the sound speed (m s^{-1}) for stratum s; and τ and bs are the pulse duration (s) and backstep (m), respectively. The backstep value was set to 0.3 m throughout the time series. The value of the backstep was chosen as a compromise to increase speed of analysis while retaining as much signal near the seafloor as possible. The volume backscattering strength within the acoustic dead zone was replaced by the mean volume backscattering strength (MVBS) one meter above the dead zone for each individual ping.

2.4. ACOUSTIC CLASSIFICATION OF HERRING

The classification of herring targets in the acoustic data was conducted through a three-step process. First, the signal corresponding to fish was separated from all other, weaker echoes. Second, acoustic signal from swim bladdered fish was isolated. Third, acoustic signal corresponding to herring was separated from the signal corresponding to all other swim bladdered fish species. These three steps contrast with the method used for the fall 2009-2022 survey time series (Beaudry-Sylvestre et al. 2024), where swim bladdered fish were selected with a distinct classification method, and non-herring targets were excluded through expert scrutiny.

2.4.1. Removing non-fish scatterers

A multi-frequency method based on Fernandes (2009) was used to select fish aggregations and remove unwanted weak scatterers. Combined frequency data is used to define aggregations boundaries. Fish exhibit a strong and stable acoustic amplitude across frequencies, compared to many other scatterers. As a result, combining echograms across frequencies amplifies the signal of fish, while diminishing the signal of other scatterers. This method has been used successfully in several studies (e.g. Fallon et al. 2016; Korneliussen et al. 2016; Korneliussen 2018). It is efficient at retaining echoes from both fish with and without a swim bladder including herring, capelin, mackerel and sandeel. Echograms of the volume backscattering strength were summed following $(3S_{v_{38}} + S_{v_{120}} + S_{v_{200}})/5$, where $S_{v_{38}}$, $S_{v_{120}}$ and $S_{v_{200}}$ are the volume backscattering strength (dB re 1 m^{-1}) at 38, 120 and 200 kHz, respectively. The resulting virtual echograms were smoothed with a 2D gaussian convolution kernel with a standard deviation of 1.0 and a window of 3 samples and 3 pings (equivalent to 0.55 m x 18.5 m). A gaussian convolution puts a higher weight on the center pixel and emphasizes edges. It is a low pass filter – as a result isolated pixels are removed. A threshold of -70 dB was applied on the resulting echogram, followed by a 5x5 dilation filter (equivalent to 0.92 m x 30.83 m). This latter step helps retain all features of the aggregations including edges. Finally, a bitmap was used to mask the original S_v data at all frequencies with the virtual echogram, i.e. all true values in the virtual echogram were replaced with the original S_v values, while all false values were excluded from the echogram.

2.4.2. Selecting swim bladdered fish

A threshold of 0 dB was applied to the difference between the 38 and the 200 kHz echograms $(S_{v_{200}} - S_{v_{38}})$ to separate fish with and without a swim bladder, following findings from several studies that fish with a swim bladder such as herring and capelin exhibit a stronger signal at 38 kHz while fish without a swim bladder exhibit a stronger signal at 200 kHz (Gorska et al. 2004; Fernandes 2009; Korneliussen 2018). A running mean (window: 3 samples by 3 pings, equivalent to 0.55 m x 18.5 m), was applied to smooth the echograms prior to subtracting the frequencies. A 5x5 dilation filter was applied to retain all features of the aggregations, and a bitmap was applied to mask the original $S_{v_{38}}$ data with the virtual echogram. Finally a threshold of -70 dB was applied on the masked $S_{v_{38}}$ echograms.

In 2020, a different vessel was used and the 200 kHz frequency was not available. Thus, the method was slightly modified to account for the absence of this frequency. First, echograms of the volume backscattering strength were summed following $(3S_{v_{38}} + S_{v_{120}})/4$. Second, fish without a swim bladder were removed by applying a threshold of 5 dB on the difference between the 38 and the 120 kHz echograms ($S_{v_{120}} - S_{v_{38}}$) following McQuinn et al. 2015.

2.4.3. Selecting herring

Acoustic data below 120 m were excluded to remove signal from redfish (*Sebastes* sp.). The segregation between herring (<120 m) and redfish habitat (>120 m) during the summer months in the survey area was confirmed by the biological sampling surveys.

The volume backscattering coefficient resulting from the previous steps was integrated over the water column to a value of area backscattering coefficient (m^2 m^{-2}) per transect *t*:

$$s_{a_{y,s,t}} = \int_{z1}^{z2} s_{v_{y,s,t}}\, dz \qquad (4)$$

where $z1$ is equal to 7.7 m and $z2$ is equal to the bottom depth up to a maximum of 120 m. To separate herring from the non-herring swim bladdered fish (cod and capelin, mostly) in the acoustic data, the acoustic signal was classified following the proportion (in biomass) of each species found in the biological samples collected by the trawling vessel in each stratum. When no biological samples were available for a given stratum, the species composition associated with the samples in the closest stratum was used instead (see Table 3). This approach was used for the fall 2022 and the summer 2023 surveys, where random biological samples were available. For the summer 2019 to 2022 surveys, the exclusion of non-herring swim bladdered fish was conducted through expert scrutiny.

The proportion of area backscattering coefficient corresponding to herring in transect t was estimated as follow:

$$s_{a_{h_{y,s,t}}} = \frac{w_{h_{y,s}} 10^{\frac{TS_h}{10}}}{\sum_j \left[w_{j_{y,s}} 10^{\frac{TS_j}{10}} \right]} s_{a_{y,s,t}} \qquad (5)$$

where w is the proportion of herring (h) or swim bladdered fish species j relative to total catch in stratum s and TS is the target strength ($TS = 10log_{10}(\sigma_{bs})$, dB re 1 m^2). The species proportions were obtained from the standardized trawl data averaged over each stratum. Tables 4 and 5 show the species proportions found in each stratum for the fall 2022 and summer 2023 surveys, respectively.

The target strength was derived from a TS to mean length relationship for each swim bladdered fish species found in the biological samples, and is available from the literature (Table 6). Mean length of each species per stratum were weighted by the number of individuals in each standardized tow.

The mean s_a corresponding to herring (not disaggregated by spawning stock) for each combination of stratum s and survey year y is presented as:

$$\overline{s_{a_{h_{y,s}}}} = \frac{\sum_{t=1}^{t=T_{y,s}} \left(s_{a_{h_{y,s,t}}} \cdot \omega_{y,s,t} \right)}{T_{y,s}} \tag{6}$$

where $\omega_{y,s,t}$ are the transect length weighting factors, i.e. the length of transect t divided by the average length of the $T_{y,s}$ transects surveyed.

The variance for this estimate, $\sigma^2_{\overline{s_{a_{h_{y,s}}}}}$, was defined as a measure of inter-transect variability in the abundance of herring within each stratum,

$$\sigma^2_{\overline{s_{a_{h_{y,s}}}}} = \frac{\sum_{t=1}^{t=T_{y,s}} \left({\omega_{y,s,t}}^2 \cdot \left(s_{a_{h_{y,s,t}}} - \overline{s_{a_{h_{y,s}}}} \right)^2 \right)}{T_{y,s}\left(T_{y,s} - 1\right)} \tag{7}$$

The means and variances were then summed across strata within each survey for an estimate of total s_a at the survey level.

2.5. ESTIMATION OF THE MEAN HERRING BIOMASS DENSITY BY SPAWNING GROUP

The mean herring biomass density ($\overline{D_{y,s,t,g}}$ in kg m^{-2}) per survey y, stratum s, transect t and spawning group g was calculated as follows:

$$\overline{D_{y,s,t,g}} = \frac{s_{a_{h_{y,s,t}}} \cdot P_{y,s,g}}{\sum_{g=1}^{G} \left(10^{\frac{\overline{TS_{W_{y,s,g}}}}{10}} \cdot P_{y,s,g} \right)} \tag{8}$$

where $P_{y,s,g}$ are the weight-based proportions of each spawning group in the biological samples. Biological samples provided the mean herring lengths and weights per stratum and spawning group, as well as the proportion by weight of each spawning component.

Following the depth-independent equation proposed by Ona (2003) for Atlantic herring at 38 kHz, target strength (TS in dB re 1 m^2) was estimated as,

$$TS_{L_{y,s,g}} = 20 \cdot log_{10}\left(L_{y,s,g}\right) - 67.3 \tag{9}$$

where *L* represents mean length (cm) and was estimated for each survey y, stratum s and spawning group g.

Equation 9 was converted to target strength per unit weight (kg) using

$$TS_{W_{y,s,g}} = TS_{L_{y,s,g}} + 10 \cdot log_{10}\left({W_{y,s,g}}^{-1}\right) \tag{10}$$

where W is the average weight (kg) of individual herring in the biological samples assigned for survey y, stratum s and spawning group g.

These transect-specific means were then averaged at the stratum level following the equations described in O'Boyle and Atkinson (1989) for surveys with varying transect lengths:

$$\overline{D_{y,s,g}} = \frac{\sum_{t=1}^{T_{y,s}} \left(\overline{D_{y,s,t,g}} \cdot \omega_{y,s,t} \right)}{T_{y,s}} \tag{11}$$

The total herring biomass (in tons) in survey y, stratum s and spawning group g, $B_{y,s,g}$, were estimated as the product of the mean herring densities $\overline{D_{y,s,g}}$ (expressed in kg m^{-2}) and strata surface areas $A_{y,s}$ (in km^2), as follows (O'Boyle and Atkinson 1989):

$$B_{y,s,g} = \overline{D_{y,s,g}} \cdot A_{y,s} \cdot 1000 \qquad (12)$$

with the variance between transects within a stratum given by:

$$\sigma^2{}_{B_{y,s,g}} = \frac{\left(1000 \cdot A_{y,s}\right)^2 \sum_{t=1}^{T_{y,s}} \left(\omega_{y,s,t}{}^2 \cdot \left(\overline{D_{y,s,t,g}} - \overline{D_{y,s,g}}\right)^2\right)}{T_{y,s}\left(T_{y,s} - 1\right)} \qquad (13)$$

Strata surface areas were estimated following the updated method described in Beaudry-Sylvestre et al. (2024). The means and variances for each spawning group were then summed across strata within each survey for an estimate of total biomass at the survey level.

3. RESULTS AND DISCUSSION

3.1. COMPARATIVE ANALYSIS

The acoustic methodology presented in this document was compared to the standardized methodology applied to the 2009 to 2022 fall hydroacoustic survey series (DFO 2024b; Beaudry-Sylvestre et al. 2024). We conducted a duplicated analysis of the fall 2022 survey and evaluated values of s_a, which is linearly proportional to abundance for a given species.

An increase of 40% was observed when comparing total s_a from this study with that obtained from Beaudry-Sylvestre et al. (2024) (Figure 3). The difference was most pronounced in stratum BI01; however an increase was observed throughout the time series (Figure 4). Further investigation showed that the methods used for the classification of swim bladdered fish was responsible for most of this discrepancy. An example is presented in Figures 5 to 7. To exclude non-swim bladdered fish, Beaudry-Sylvestre et al. (2024) used a threshold polygon that was developed based on the validation of fish acoustic signatures with biological samples and expert knowledge (I. McQuinn, pers. comm.). However, visual scrutinization of the classified echograms showed that within a given aggregation, some pixels were included while others were not (Figure 5). From an ecological point of view, this is likely inaccurate, as herring and other schooling fish species are known to aggregate as mono-specific aggregations (Fréon and Misund 1999). Moreover, there was no clear separation (or clustering) of those pixels within the swim bladdered and non-swim bladdered fish polygons (Figure 6), further suggesting that those pixels belonged to the same group. A visual scrutiny of the post-classification data was indeed part of this method, and manual corrections to the classification were often applied. On the other hand, the classification method presented in this study retained all acoustic signals within an aggregation that had been classified as swim bladdered fish (Figure 7), and no manual re-classification was involved.

The exclusion of redfish acoustic backscatter through an exclusion line at 120 m (this study) and through expert scrutiny (Beaudry-Sylvestre et al. 2024) led to similar results. The 120 m exclusion line was mostly successful at removing all redfish; when redfish was detected at shallower depth, the strength of the acoustic signal was not significant enough to generate important differences in the resulting herring s_a. It was raised during the assessment framework review held on April 4-5, 2023 that the application of a 120 m exclusion line may result in the exclusion of a significant amount of herring acoustic backscatter; however it was agreed that this was unlikely the case in the area and the time period covered by the survey. It was also confirmed through biological samples collected at depths greater than 120 m during the 2022 summer and fall surveys (data not shown).

The exclusion of other swim bladdered fish (mostly capelin and cod) through species composition in the biological samples (this study) and through expert scrutiny (Beaudry-Sylvestre et al. 2024) also led to similar results. This is unsurprising, given the small proportions of these species compared to herring in the survey area in 2022. However, this may not always be the case, and expert scrutiny may cause important discrepancies when a large proportion of non-herring swim bladdered fish is found in the biological samples, or when expert scrutiny leads to the manual exclusion or inclusion of important backscatter.

During the fall 2022 survey, biological samples corresponding to swim bladdered fish other than herring were only collected in significant amounts (>1%) in stratum 03, with 23% of the biomass corresponding to cod. This led to a small decrease in s_a in this stratum, because no signal had been manually removed as cod with the previous method, but the impact on overall herring s_a was limited (Figure 3).

Species composition found in the trawl was similar in the 2022 fall survey and in the 2023 summer survey. The largest proportion of cod was consistently found in stratum 03 (23% and 30% cod, respectively). Other strata were all dominated by herring (Tables 4 and 5).

3.2. SUMMER SURVEY SERIES

Tables 7 to 11 summarize the results of the 2019 to 2023 summer hydroacoustic surveys in NAFO divisions 4RSw, and Figure 8 shows the survey coverage for each year of the time series. In 2022, an important number of strata were missed on the west coast of Newfoundland due to vessel operation challenges. The northern portion of stratum BI01 was also often missed (2019, 2021 and 2022). Stratum BN was only covered in 2019 and 2020, but its impact on overall biomass was low (Figure 9).

During all survey years, most of the herring abundance was found in strata 10, 4Sw and BI01 (Figures 9 and 10). Herring s_a was high in strata 05 and 07 in 2019, and to a lesser extent in 2020. It was also higher than other years in stratum 06 in 2020, and to a lesser extent in 2021. In 2023, herring s_a was higher than other years in stratum BI02.

Total herring s_a increased from 2019 to 2020, then remained stable (Figure 11). From 2020 to 2023, we observe opposing trends between the biomass of spring and fall spawning stocks (Figure 12). Except in 2022, fall spawners biomass was always higher than spring spawners.

Biomass estimated with the method described in Beaudry-Sylvestre et al. (2024) were available for the summer acoustic surveys from 2019 to 2022 and were added to Figure 12 for comparison. Although biomass estimated with the method described in this study were slightly higher for most years, the difference was not as pronounced as in section 3.1. This is likely due to differences in expert scrutiny. For the fall 2022 survey data, no acoustic backscatter classified as non-swim bladdered fish was re-classified as swim bladdered fish, despite such correction being applied in all summer survey years. It is possible that the analyst chose to be more conservative in the expert scrutiny for this survey, as it was known that it was going to be used for comparison with the new method. As previously mentioned, the expert scrutiny often served to correct the imperfect classification, resulting in estimates that were more similar to this study. However it is difficult to apply in a consistent manner, as is observed in the fall 2022 survey. This underlies the need to remove the analyst’s judgement to reduce uncertainty.

4. CONCLUSION

In this document, we describe the design and analytical methods adopted for the Atlantic herring summer hydroacoustic survey in NAFO divisions 4RSw. This survey was implemented in 2019, and in 2023 it became the only ongoing hydroacoustic survey in 4RSw.

In terms of analytical methods, the different approach used to classify swim bladdered fish from non-swim bladdered fish in the acoustic data was the main cause of discrepancy between this study and Beaudry-Sylvestre et al. 2024, and suggests an overall increase in s_a with the new methodology. However, we are confident that the updated method leads to more accurate and consistent results, as it avoids the occasional exclusion of swim bladdered fish observed with the method described in Beaudry-Sylvestre et al. 2024. Expert scrutiny is also a factor of discrepancy, and could lead equally to a higher or lower s_a.

The difference in survey timing (summer versus fall) and coverage (addition of two strata in the Strait of Belle-Isle) may also lead to differences in abundance and stock composition that are difficult to predict. Thus, the two survey time series are likely not comparable.

The design and methodology described in this study present several improvements over the method described in Beaudry-Sylvestre et al. 2024. First, the standardization and automation of the analytical workflow improves efficiency, reliability and replicability. The subjectivity introduced by the analyst's involvement in the classification of echoes is removed. This subjectivity can cause important changes in the resulting biomass densities, leading to important year-to-year variations that may impact the feasibility of a population model.

The biological sampling plan was modified from targeted sampling, where fishers were tasked with choosing the location of herring samples collection in each stratum of the survey area, to random sampling, where they were given a predefined random stratified sampling plan, effectively removing the fisher's knowledge and experience from the equation. This approach, with the elimination of the use of commercial samples in the estimation of herring densities from hydroacoustic surveys, will likely improve the reliability of the age and length distributions and the spawning stock proportions.

The inclusion of two strata in the Strait of Belle-Isle and one stratum in 4Sw to the survey design follows recommendations from McQuinn and Lefebvre (1995) and is supported by preliminary results from an ongoing acoustic telemetry experiment (DFO 2024a).

Finally, a summer survey is preferable logistically, as it tends to decrease the number of days lost to poor weather, thereby improving survey coverage. Moreover, during August, herring are aggregating in the north (DFO 2024a). The fall hydroacoustic survey took place in November, when herring have already begun their southward migration. This increases the risk of duplication, with herring schools potentially moving south at the same time as the vessel, and of missing important herring abundance in the deep bays of the west coast of Newfoundland, where sampling is more challenging and transects have often been skipped.

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7. TABLES

Table 1. Summary of the vessels used for the acoustic surveys, survey dates, frequencies recorded and method used to classify swim bladdered fish species for each survey presented in the current study.

Survey	Frequency recorded	Vessel (date range)	Herring classification	Inter-transect distance
2019	38, 120, 200	CCGS *F. G. Creed* (11 Aug - 23 Aug)	Expert scrutiny	Constant
2020	38, 120	CCGS *Leim* (08 Aug - 30 Aug)	Expert scrutiny	Constant
2021	38, 120, 200	RV *Novus* (04 Aug - 18 Aug)	Expert scrutiny	Constant
2022	38, 120, 200	RV *Novus* (03 Aug – 31 Aug)	Expert scrutiny	Constant
2022 (fall)	38, 120, 200	RV *Novus* (13 Oct – 10 Nov)	Species composition	Constant
2023	38, 120, 200	RV *Novus* (02 Aug – 30 Aug)	Species composition	Variable

Table 2. Summary of the vessels used for the biological sampling surveys, survey dates, number of trawl samples collected and sampling design. Targeted means that the fishing vessel was instructed with collecting trawl samples in the survey area at known herring hotspot locations; random means that the fishing vessel was provided with a random sampling plan to follow.

Survey	Vessel (date range)	Number of successful trawl samples collected	Sampling design
2019	FV *Steven Paul* (11 Aug – 23 Aug)	12	Targeted
2020	FV *Meridian 66* (19 Aug – 24 Aug)	12	Targeted
2021	FV *Meridian 66* (28 Aug – 31 Aug)	4	Targeted
2022	FV *Meridian 66* (18 Aug – 22 Aug)	13	Targeted
2022 (fall)	FV *Meridian 66* (05 Nov – 10 Nov)	12	Random
2023	FV *Meridian 66* (26 Aug – 30 Aug)	16	Random

Table 3. Summary of missing strata replacement for the determination of species composition for the fall 2022 and summer 2023 surveys. NA means that the stratum was not surveyed with the acoustic survey vessel.

Stratum	Stratum used (fall 2022)	Stratum used (summer 2023)
01	03	NA
02	NA	03
03	03	03
04	04	04
05	05	05
06	NA	06
07	NA	05
08	NA	06
09	10	10
10	10	10
4Sw	4Sw	4Sw
BI01	BI01	BI01
BI02	BI02	BI02
BN	NA	NA

Table 4. Species proportions (by weight) used to apportion s_a to herring for each stratum surveyed by the trawling vessel in fall 2022.

Stratum	Herring	Cod
03	0.77	0.23
04	1.00	0.00
05	0.99	0.01
10	0.93	0.07
4Sw	0.99	0.01
BI01	1.00	0.00
BI02	1.00	0.00

Table 5. Species proportions (by weight) used to apportion s_a to herring for each stratum surveyed by the trawling vessel in summer 2023.

Stratum	Herring	Cod
03	0.70	0.30
04	1.00	0.00
05	1.00	0.00
06	0.93	0.07
10	1.00	0.00
4Sw	1.00	0.00
BI01	0.96	0.04
BI02	0.99	0.01

Table 6. TS to length relationships used in the calculation of herring s_a for the fall 2022 and summer 2023 surveys.

Species	Equation	Reference
Atlantic herring	$TS = 20 \log_{10}(L) - 67.3$	Ona (2003)
Atlantic cod	$TS = 20 \log_{10}(L) - 66.0$	Rose and Porter (1996)
Capelin	$TS = 21.1 \log_{10}(L) - 74.3$	Rose (1998)

Table 7. Summary of the data inputs and results for the 2019 acoustic survey, with their standard errors (S.E.) and coefficients of variation (C.V.). Stratum 04 was not surveyed.

2019	Stratum				Herring area backscattering coefficients (s_a)					Fall spawners				Spring spawners			
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km · km^{-2})	Total s_a (m^2)	Weighted mean s_a Mean (m^2 · m^{-2})	Weighted mean s_a S.E.	Weighted mean s_a C.V.	Biomass density (kg · m^{-2})	Biomass Total (t)	Biomass S.E.	Biomass C.V.	Biomass density (kg · m^{-2})	Biomass Total (t)	Biomass S.E.	Biomass C.V.
St. Georges S.	01	216.3	3	7,947	1.102e-01	1,046	4.834e-06	4.653e-06	96.3	0.00394	852.9	821	96.3	0.00054	116.8	112.4	96.3
St. Georges N.	02	302.7	6	6,904	1.368e-01	1,428	4.717e-06	3.890e-06	82.5	0.00385	1,165.0	961	82.5	0.000527	159.5	131.5	82.5
Port-au-port G.	03	815.9	5	10,663	6.535e-02	1,741	2.134e-06	1.500e-06	70.3	0.00174	1,420.0	998	70.3	0.000238	194.5	136.7	70.3
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	474.5	4	15,120	1.275e-01	21,892	4.614e-05	4.161e-05	90.2	0.0517	24,522.8	22,118	90.2	0.00436	2,066.6	1,864.0	90.2
Bonne Bay Bank	06	1,148.2	11	11,991	1.149e-01	4,034	3.514e-06	1.318e-06	37.5	0.00292	3,351.1	1,257	37.5	0.000767	881.2	330.4	37.5
Bay of Islands	07	299.9	3	17,350	1.736e-01	12,802	4.269e-05	1.930e-05	45.2	0.0281	8,441.3	3,816	45.2	0.00629	1,886.5	852.8	45.2
Bras Nord	BN	35.5	4	3391	3.825e-01	432	1.219e-05	3.294e-06	27.0	0.0114	404.9	109	27.0	0.00133	47.2	12.8	27.0
Bonne Bay	08	58.5	6	3,116	3.196e-01	1,461	2.497e-05	9.009e-06	36.1	0.0194	1,132.5	409	36.1	0.00525	307.2	110.8	36.1
Hawk's Bay	09	499.8	6	9,065	1.088e-01	557	1.114e-06	2.422e-07	21.7	0.00103	515.7	112	21.7	0.00022	109.8	23.9	21.7
St. John Bay	10	996.9	7	15,923	1.118e-01	20,879	2.094e-05	1.228e-05	58.7	0.0209	20,794.7	12,198	58.7	0.00276	2,753.3	1,615.0	58.7
Basse-Côte-Nord	4Sw	643.3	6	11,280	1.052e-01	946	1.470e-06	4.764e-07	32.4	0.00163	1,047.7	339	32.4	0.000131	84.2	27.3	32.4
Belle Isle S.	BI01	384.8	7	5,486	9.981e-02	4,852	1.261e-05	5.129e-06	40.7	0.0117	4,491.8	1,827	40.7	0.000972	373.9	152.1	40.7
Belle Isle N.	BI02	562.1	7	9,086	1.132e-01	740	1.316e-06	7.916e-07	60.1	0.00122	685.0	412	60.1	0.000101	57.0	34.3	60.1
Average/Total	-	**6,438.5**	**75**	**9,744**	**1.135e-01**	**72,810**	**1.786e-04**	**4.914e-05**	**27.5**	**0.0107**	**68,794.9**	**25,701**	**37.4**	**0.0014**	**9,022.4**	**2,643.8**	**29.3**

Table 8. Summary of the data inputs and results for the 2020 acoustic survey, with their standard errors (S.E.) and coefficients of variation (C.V.). Stratum 01 was not surveyed.

2020	Stratum				Herring area backscattering coefficients (s_a)					Fall spawners				Spring spawners			
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km · km^{-2})	Total s_a (m^2)	Weighted mean s_a			Biomass density (kg · m^{-2})	Biomass			Biomass density (kg · m^{-2})	Biomass		
							Mean (m^2 · m^{-2})	S.E.	C.V.		Total (t)	S.E.	C.V.		Total (t)	S.E.	C.V.
St. Georges S.	01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
St. Georges N.	02	302.7	4	6,479	8.561e-02	3,156	1.042e-05	2.183e-06	20.9	0.00803	2,429.7	508.72	20.9	0.00182	551.7	115.51	20.9
Port-au-port G.	03	795.8	4	8,874	4.461e-02	13,810	1.735e-05	3.462e-06	19.9	0.00876	6,973.5	1,391.14	19.9	0.0056	4,456.3	888.98	19.9
Port-au-port	04	352.0	3	19,148	1.632e-01	3,175	9.020e-06	1.971e-06	21.9	0.00425	1,496.8	327.16	21.9	0.00314	1,106.7	241.89	21.9
Bay of Islands G.	05	477.9	5	14,963	1.566e-01	11,373	2.380e-05	5.760e-06	24.2	0.00996	4,759.6	1,151.98	24.2	0.00928	4,436.4	1,073.77	24.2
Bonne Bay Bank	06	1,157.2	3	13,604	3.527e-02	24,308	2.101e-05	3.109e-06	14.8	0.00928	10,743.1	1,590.25	14.8	0.00854	9,885.0	1,463.22	14.8
Bay of Islands	07	293.2	4	16,005	2.183e-01	9,169	3.127e-05	4.927e-06	15.8	0.0147	4,323.2	681.28	15.8	0.0109	3,196.5	503.73	15.8
Bras Nord	BN	32.9	3	3,258	2.969e-01	223	6.786e-06	2.687e-07	4.0	0.0032	105.4	4.17	4.0	0.00237	77.9	3.08	4.0
Bonne Bay	08	58.5	6	2,998	3.075e-01	721	1.232e-05	2.627e-06	21.3	0.00904	528.9	112.73	21.3	0.00318	185.9	39.62	21.3
Hawk’s Bay	09	499.7	3	10,135	6.085e-02	1,263	2.527e-06	1.451e-06	57.4	0.00139	693.2	398.08	57.4	0.000871	435.2	249.93	57.4
St. John Bay	10	959.1	9	11,776	1.105e-01	9,194	9.586e-06	2.443e-06	25.5	0.00781	7,488.9	1,908.35	25.5	0.00187	1,792.5	456.77	25.5
Basse-Côte-Nord	4Sw	2,169.6	13	12,347	7.399e-02	3,783	1.744e-06	4.150e-07	23.8	0.00142	3,081.8	733.40	23.8	0.00034	737.6	175.54	23.8
Belle Isle S.	BI01	774.0	8	7,488	7.741e-02	52,928	6.839e-05	3.032e-05	44.3	0.0557	43,111.9	19 ,112.92	44.3	0.0133	10,319.1	4,574.78	44.3
Belle Isle N.	BI02	603.7	5	11,606	9.612e-02	2,104	3.485e-06	1.661e-06	47.6	0.00284	17,14.0	816.57	47.6	0.00068	410.3	195.45	47.6
Average/Total	-	**8,476.4**	**70**	**10,587**	**8.744e-02**	**135,207**	**2.177e-04**	**3.201e-05**	**14.7**	**0.0103**	**87,450.1**	**19,415.01**	**22.2**	**0.00443**	**37,591.2**	**5,067.56**	**13.5**

Table 9. *Summary of the data inputs and results for the 2021 acoustic survey, with their standard errors (S.E.) and coefficients of variation (C.V.). Strata 02, 08, BN and BI02 were not surveyed.*

2021	Stratum				Herring area backscattering coefficients (s_a)					Fall spawners				Spring spawners			
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density ($km \cdot km^{-2}$)	Total s_a (m^2)	Weighted mean s_a			Biomass density ($kg \cdot m^{-2}$)	Biomass			Biomass density ($kg \cdot m^{-2}$)	Biomass		
							Mean ($m^2 \cdot m^{-2}$)	S.E.	C.V.		Total (t)	S.E.	C.V.		Total (t)	S.E.	C.V.
St. Georges S.	01	302.9	8	3,793	1.002e-01	2,215	7.313e-06	5.273e-06	72.1	0.000832	251.9	182	72.1	0.00836	2,533.3	1,826.8	72.1
St. Georges N.	02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-port G.	03	796.3	5	10,429	6.549e-02	4,835	6.071e-06	1.126e-06	18.6	0.00255	2,029.6	377	18.6	0.00248	1,976.6	366.7	18.6
Port-au-port	04	352.5	4	10,262	1.164e-01	4,718	1.338e-05	6.274e-06	46.9	0.00562	1,980.8	929	46.9	0.00547	1,929.0	904.3	46.9
Bay of Islands G.	05	477.9	4	12,881	1.078e-01	4,968	1.039e-05	4.833e-06	46.5	0.00436	2,085.5	970	46.5	0.00425	2,031.0	944.3	46.5
Bonne Bay Bank	06	1,157.3	10	11,947	1.032e-01	13,804	1.193e-05	2.447e-06	20.5	0.00808	9,352.1	1 919	20.5	0.00689	7,979.4	1,637.3	20.5
Bay of Islands	07	306.2	4	12,591	1.645e-01	2,880	9.407e-06	1.878e-06	20.0	0.00395	1,209.1	241	20.0	0.00385	1,177.5	235.1	20.0
Bras Nord	BN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	09	499.7	6	9,464	1.136e-01	5,239	1.048e-05	2.910e-06	27.8	0.0071	3,549.1	985	27.8	0.00606	3,028.2	840.8	27.8
St. John Bay	10	983.3	9	11,441	1.047e-01	19,402	1.973e-05	7.117e-06	36.1	0.0283	27,856.8	10 049	36.1	0.000168	165.4	59.7	36.1
Basse-Côte-Nord	4Sw	2,194.9	14	11,318	7.219e-02	43,228	1.969e-05	1.689e-05	85.8	0.0283	62,066.1	53 243	85.8	0.000168	368.5	316.1	85.8
Belle Isle S.	BI01	301.6	7	3,906	9.068e-02	23,439	7.772e-05	3.370e-05	43.4	0.112	33,653.2	14 594	43.4	0.000662	199.8	86.6	43.4
Belle Isle N.	BI02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average/Total	-	**7,372.7**	**71**	**9,725**	**9.365e-02**	**124,727**	**1.861e-04**	**3.977e-05**	**21.4**	**0.0195**	**144,034.2**	**56 173**	**39.0**	**0.0029**	**21,388.7**	**2,955.5**	**13.8**

Table 10. Summary of the data inputs and results for the 2022 acoustic survey, with their standard errors (S.E.) and coefficients of variation (C.V.). Strata 04, 06, 08, 09 and BN were not surveyed.

2022	Stratum				Herring area backscattering coefficients (s_a)					Fall spawners				Spring spawners			
Name	Stratum	Area (km²)	Transcect number	Transect average length (m)	Sampling density (km · km⁻²)	Total s_a (m²)	Weighted mean s_a Mean (m² · m⁻²)	Weighted mean s_a S.E.	Weighted mean s_a C.V.	Biomass density (kg · m⁻²)	Biomass Total (t)	Biomass S.E.	Biomass C.V.	Biomass density (kg · m⁻²)	Biomass Total (t)	Biomass S.E.	Biomass C.V.
St. Georges S.	01	410.9	10	4,148	1.010e-01	1,599	3.891e-06	1.884e-06	48.4	0.00137	563.8	273	48.4	0.000718	295.1	143	48.4
St. Georges N.	02	305.3	6	6,052	1.189e-01	1,916	6.275e-06	2.978e-06	47.5	0.00198	604.5	287	47.5	0.00205	625.7	297	47.5
Port-au-port G.	03	803.8	6	7,465	5.573e-02	7,021	8.735e-06	3.070e-06	35.1	0.00179	1,436.8	505	35.1	0.00677	5,444.4	1,914	35.1
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	482.9	2	16,543	6.851e-02	5,617	1.163e-05	9.701e-06	83.4	0.00238	1,149.6	959	83.4	0.00902	4,356.1	3,633	83.4
Bonne Bay Bank	06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands	07	309.3	3	16,353	1.586e-01	2,836	9.170e-06	2.717e-06	29.6	0.00188	580.4	172	29.6	0.00711	2,199.5	652	29.6
Bras Nord	BN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk’s Bay	09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
St. John Bay	10	386.8	4	11,479	1.187e-01	20,317	5.252e-05	3.640e-05	69.3	0.0215	8,329.2	5,772	69.3	0.0307	11,866.4	8,224	69.3
Basse-Côte-Nord	4Sw	2,225.3	18	11,211	9.069e-02	3,518	1.581e-06	1.002e-06	63.4	0.000924	2,056.8	1,303	63.4	0.00071	1,580.0	1,001	63.4
Belle Isle S.	BI01	590.5	9	5,360	8.169e-02	99,454	1.684e-04	2.964e-05	17.6	0.069	40,772.9	7,175	17.6	0.0984	58,088.1	10,222	17.6
Belle Isle N.	BI02	600.9	8	8,147	1.085e-01	2,829	4.708e-06	1.368e-06	29.1	0.00193	1,159.9	337	29.1	0.00275	1,652.4	480	29.1
Average/Total	-	**8,216.9**	**66**	**8,574**	**6.887e-02**	**145,108**	**2.669e-04**	**4.826e-05**	**18.1**	**0.00689**	**56,653.9**	**9,380**	**16.6**	**0.0105**	**86,107.6**	**13,811**	**16.0**

Table 11. *Summary of the data inputs and results for the 2023 acoustic survey, with their standard errors (S.E.) and coefficients of variation (C.V.). Stratum 01 and BN were not surveyed.*

2023	Stratum				Herring area backscattering coefficients (s_a)					Fall spawners				Spring spawners			
Name	Stratum	Area (km²)	Transect number	Transect average length (m)	Sampling density (km · km^{-2})	Total s_a (m²)	Weighted mean s_a			Biomass density (kg · m^{-2})	Biomass			Biomass density (kg · m^{-2})	Biomass		
							Mean (m² · m^{-2})	S.E.	C.V.		Total (t)	S.E.	C.V.		Total (t)	S.E.	C.V.
St. Georges S.	01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
St. Georges N.	02	302.7	4	7,686	1.016e-01	847	2.798e-06	1.847e-06	66.0	0.0018	546.0	360.3	66.0	0.000831	251.6	166.0	66.0
Port-au-port G.	03	796.3	6	8,474	6.385e-02	1,186	1.489e-06	5.156e-07	34.6	0.00096	764.4	264.7	34.6	0.000442	352.2	122.0	34.6
Port-au-port	04	352.5	4	9,404	1.067e-01	2,829	8.025e-06	2.853e-06	35.6	0.00517	1,823.2	648.3	35.6	0.00238	840.1	298.7	35.6
Bay of Islands G.	05	477.9	4	14,494	1.213e-01	2,453	5.134e-06	2.351e-06	45.8	0.00284	1,356.1	621.1	45.8	0.00212	1,013.6	464.3	45.8
Bonne Bay Bank	06	1,157.3	8	11,549	7.984e-02	5,128	4.431e-06	1.456e-06	32.9	0.00253	2,931.9	963.6	32.9	0.00173	1,998.2	656.7	32.9
Bay of Islands	07	306.2	4	21,561	2.817e-01	4,436	1.449e-05	5.588e-06	38.6	0.0097	2,969.0	1,145.0	38.6	0.00451	1,379.5	532.0	38.6
Bras Nord	BN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	08	58.5	12	4,409	9.044e-01	284	4.863e-06	1.314e-06	27.0	0.00293	171.3	46.3	27.0	0.00156	91.5	24.7	27.0
Hawk's Bay	09	499.7	5	9,947	9.953e-02	3,094	6.192e-06	3.176e-06	51.3	0.00465	2,325.8	1,192.9	51.3	0.00131	655.1	336.0	51.3
St John Bay	10	965.1	12	12,670	1.575e-01	7,417	7.685e-06	2.267e-06	29.5	0.00652	6,291.9	1,856.1	29.5	0.00111	1,075.5	317.3	29.5
Basse-Côte-Nord O.	4Sw01	1,112.1	3	11,856	3.198e-02	660	5.931e-07	3.412e-07	57.5	0.000513	570.8	328.4	57.5	0.000123	136.4	78.5	57.5
Basse-Côte-Nord E.	4Sw02	1,082.8	12	11,846	1.313e-01	11,248	1.039e-05	5.890e-06	56.7	0.00899	9,734.3	5,519.1	56.7	0.00215	2,326.0	1,318.8	56.7
Belle Isle S.	BI01	1,042.9	16	8,546	1.311e-01	59,810	5.735e-05	2.021e-05	35.2	0.0445	46,401.0	16,348.8	35.2	0.0152	15,886.0	5,597.2	35.2
Belle Isle N.	BI02	626.8	8	7,244	9.246e-02	18,923	3.019e-05	1.230e-05	40.8	0.0269	16,877.8	6,878.9	40.8	0.00637	3,993.7	1,627.7	40.8
Average/Total	-	**9,221.6**	**98**	**10,030**	**1.066e-01**	**118,316**	**1.536e-04**	**2.573e-05**	**16.8**	**0.0101**	**92,763.3**	**18,795.9**	**20.3**	**0.00325**	**29,999.5**	**6,082.7**	**20.3**

8. FIGURES

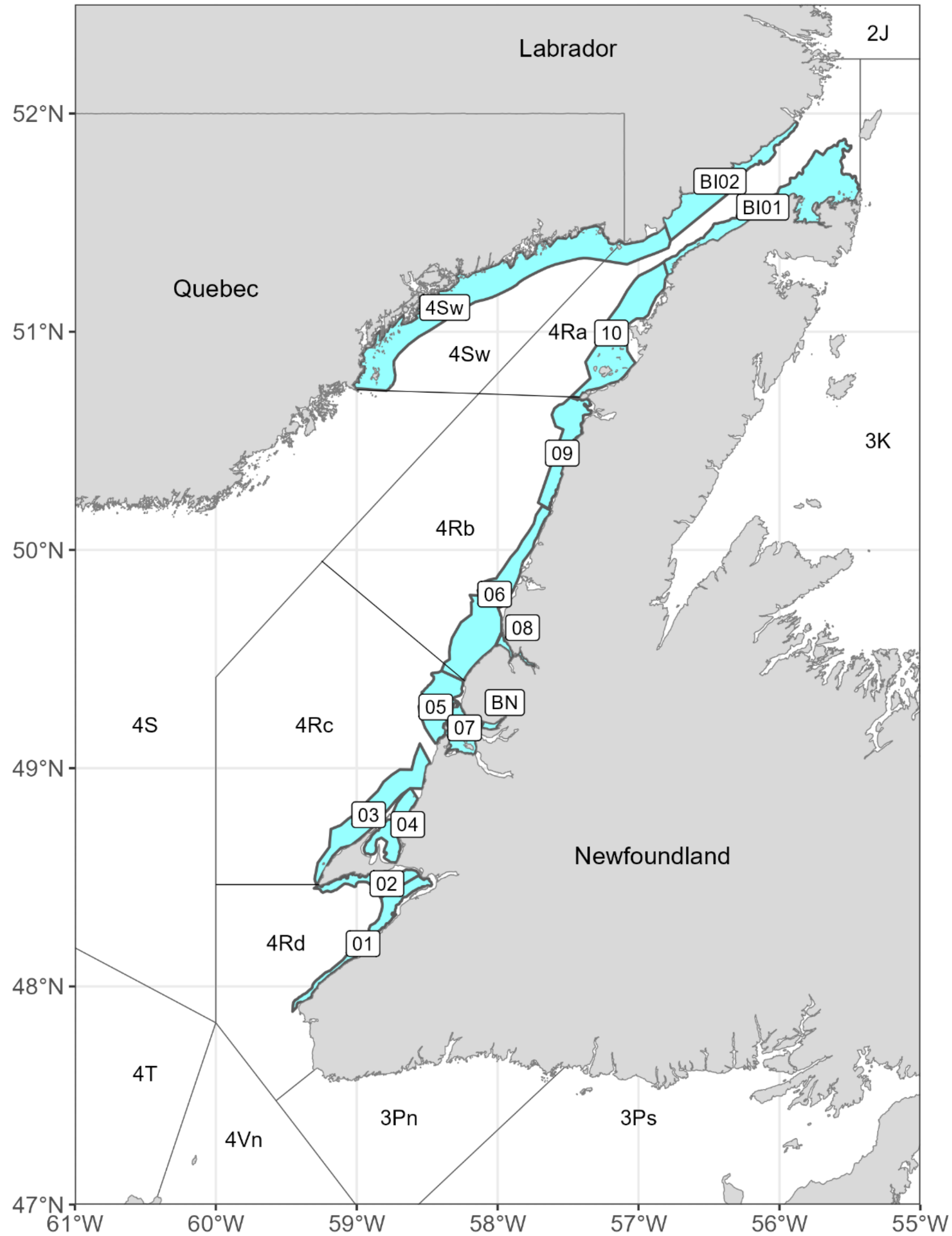

Figure 1. Strata definitions used for the 2019 to 2023 summer surveys and for the fall 2022 survey. NAFO divisions and unit areas of 4R and 4Sw are also shown.

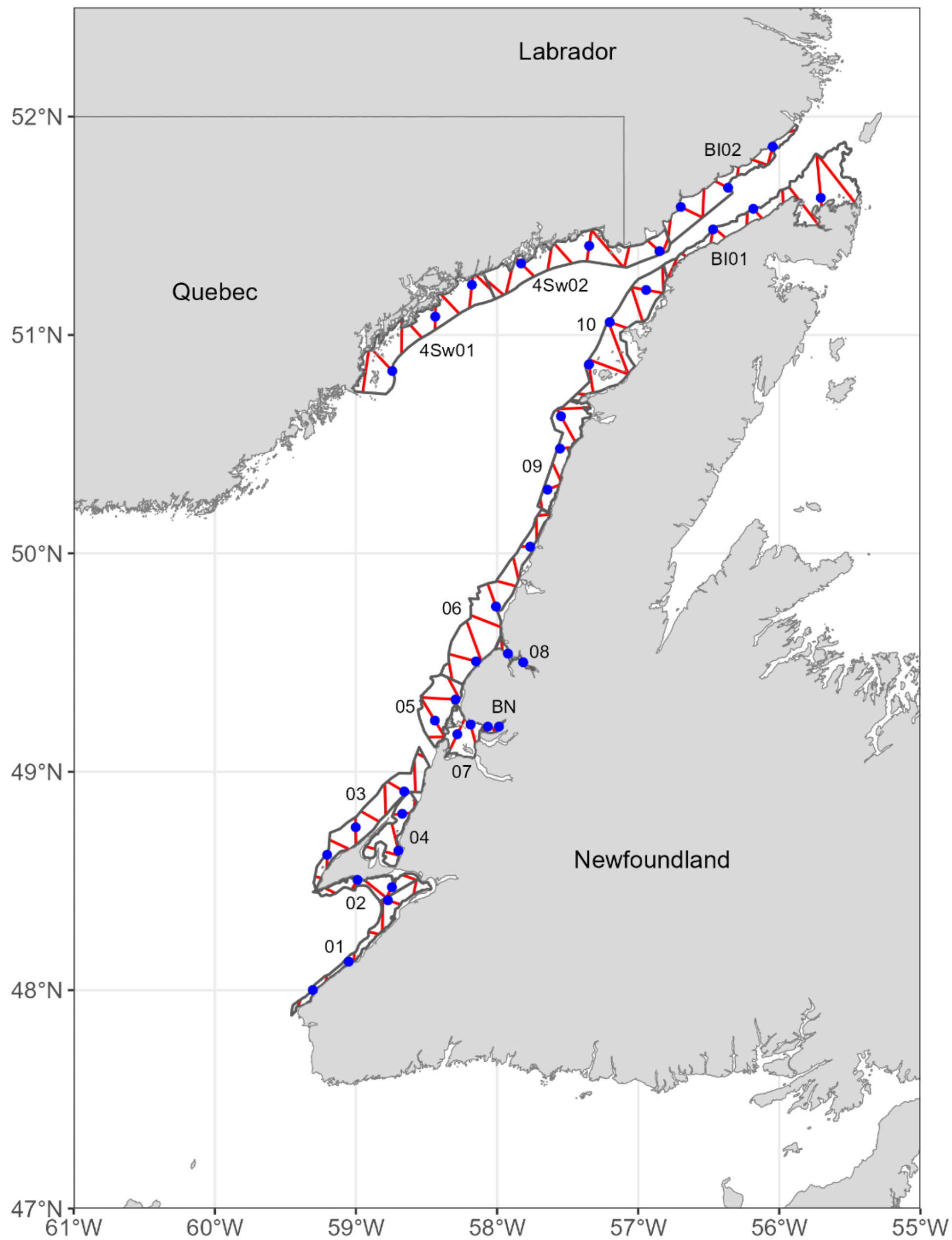

Figure 2. Example sampling plan for the collection of biological samples (fall 2022 survey). Red lines represent the trajectory followed by the fishing vessel. Blue dots represent the minimal distance between consecutive trawling stations.

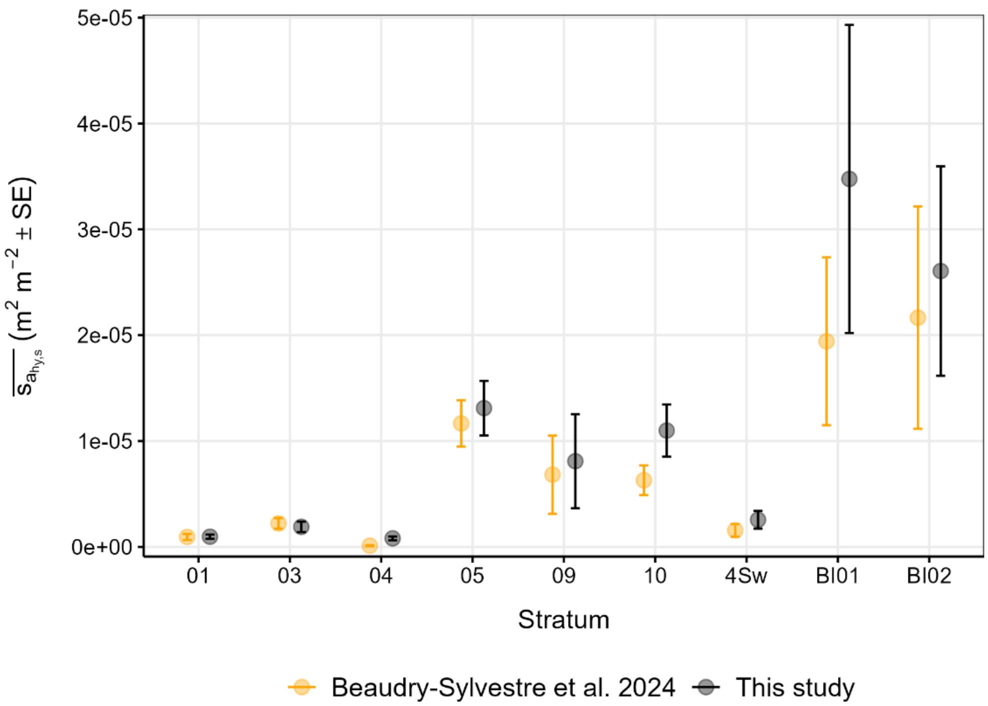

Figure 3. Comparison of the $\overline{s_{a_{hy,s}}}$ (m² m^{-2}) and standard error (SE, $\sqrt{\sigma^2 \overline{s_{a_{hy,s}}}}$) estimated with the method described in Beaudry-Sylvestre et al. (2024) and this study, for observed strata during the fall 2022 acoustic survey.

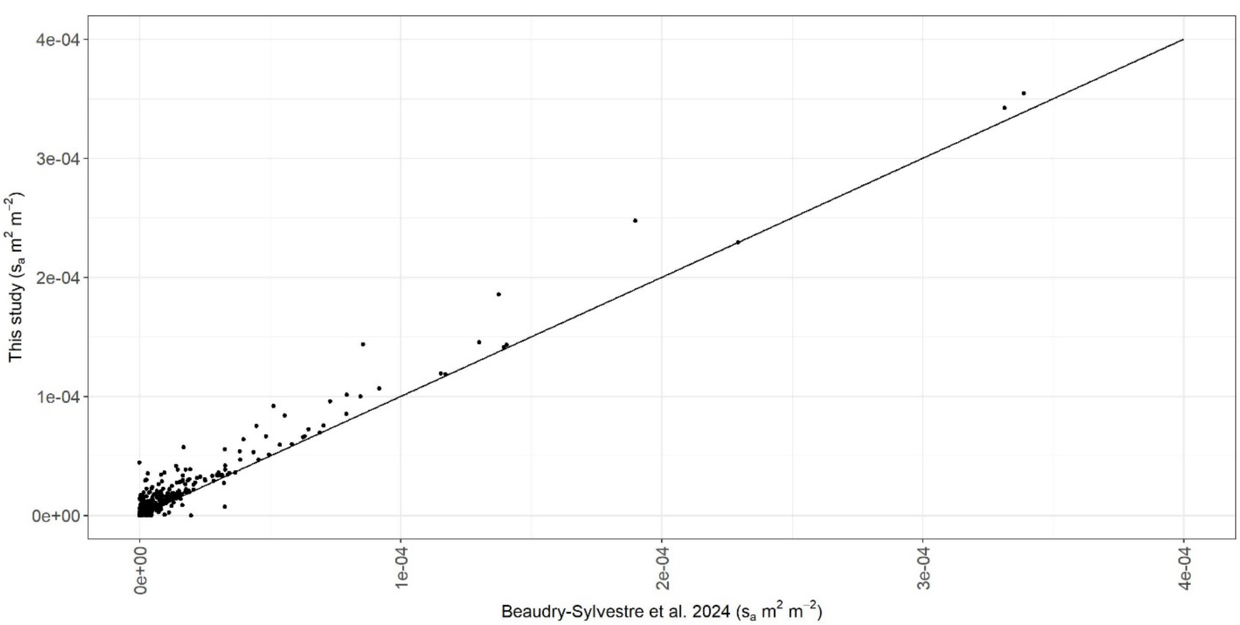

Figure 4. Comparison of the fall 2022 survey s_{a_h} per 500 m step distance with the method described in Beaudry-Sylvestre et al. (2024), and this study. The 1:1 equivalence (solid line) is also indicated.

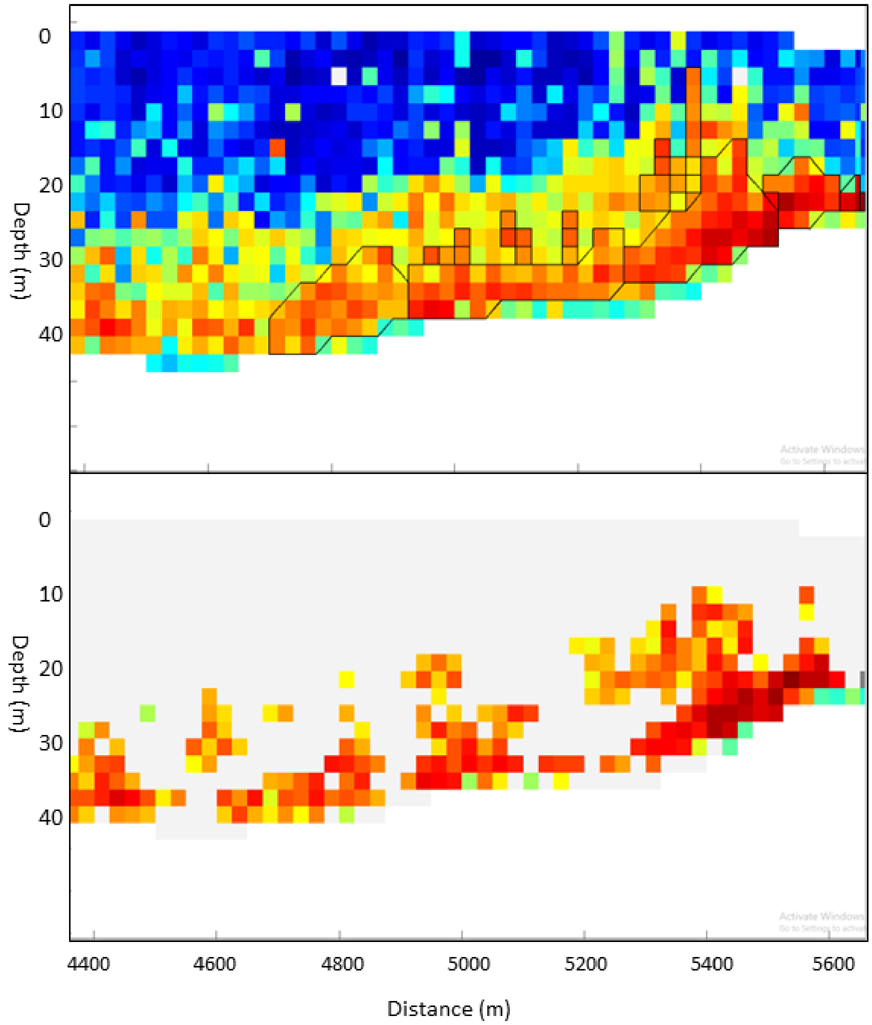

Figure 5. Echogram at 38 kHz showing a snippet of data prior to (upper panel) and post (lower panel) swim bladdered fish classification using the method described in Beaudry-Sylvestre et al. (2024). Data was collected in transect 07 of stratum BI01 during the fall 2022 acoustic survey. Pixels surrounded by a black line (upper panel) indicate the data included in Figure 6.

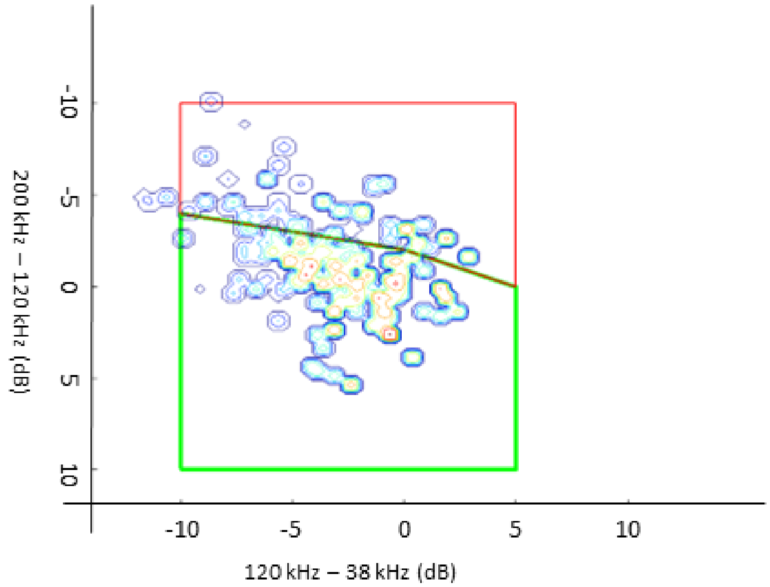

Figure 6. Classification polygon of swim bladdered (green) and non-swim bladdered (red) fish obtained from the method described in Beaudry-Sylvestre et al. (2024). Pixels surrounded by the black lines in Figure 5 (upper panel) are shown here. Both axes represent pairwise frequency differences of volume backscattering strength S_v (dB re 1 m^{-1}), i.e., $\Delta S_{v,i-j} = S_{v,i} - S_{v,j}$, where i and j are indices denoting frequency in kHz.

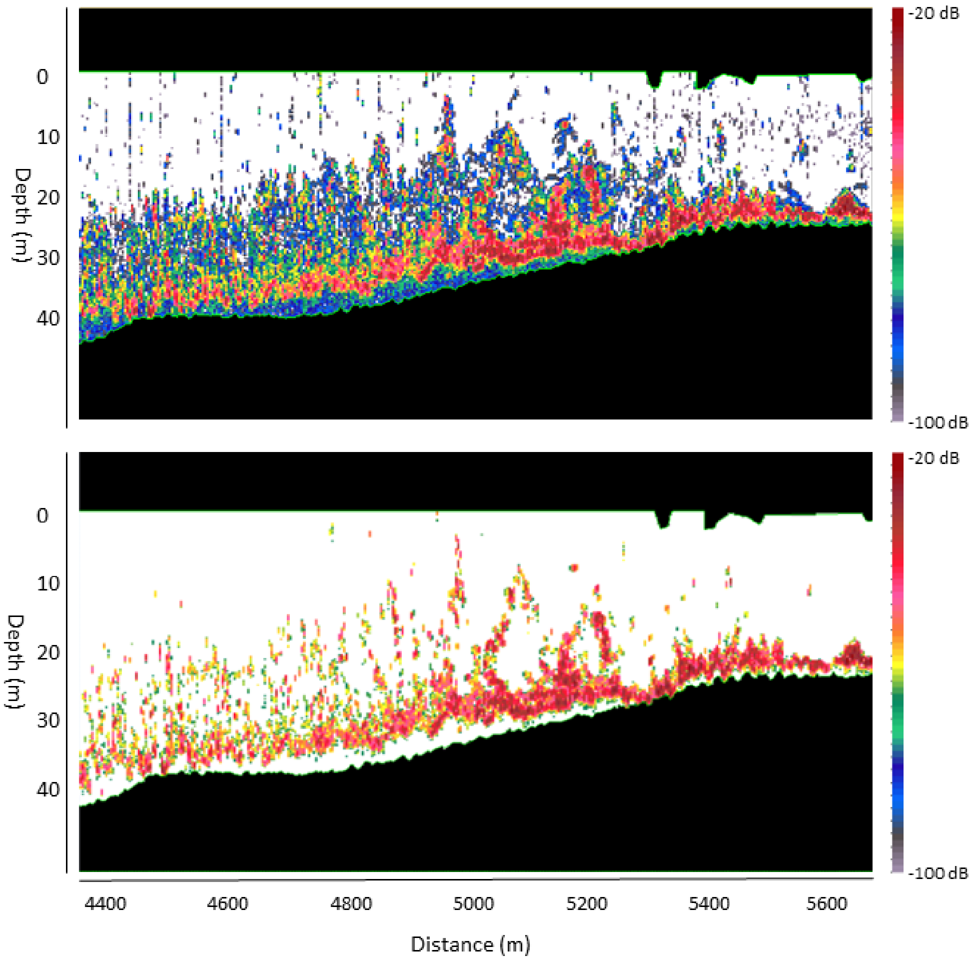

Figure 7. Echogram at 38 kHz showing a snippet of data prior (upper panel) and post (lower panel) classification using the method described in this study. The upper panel shows the echogram following processing steps described up to section 2.3. The lower panel shows the echogram following processing steps described in section 2.4.1 and 2.4.2. Data was collected in transect 07 of stratum BI01 during the fall 2022 acoustic survey.

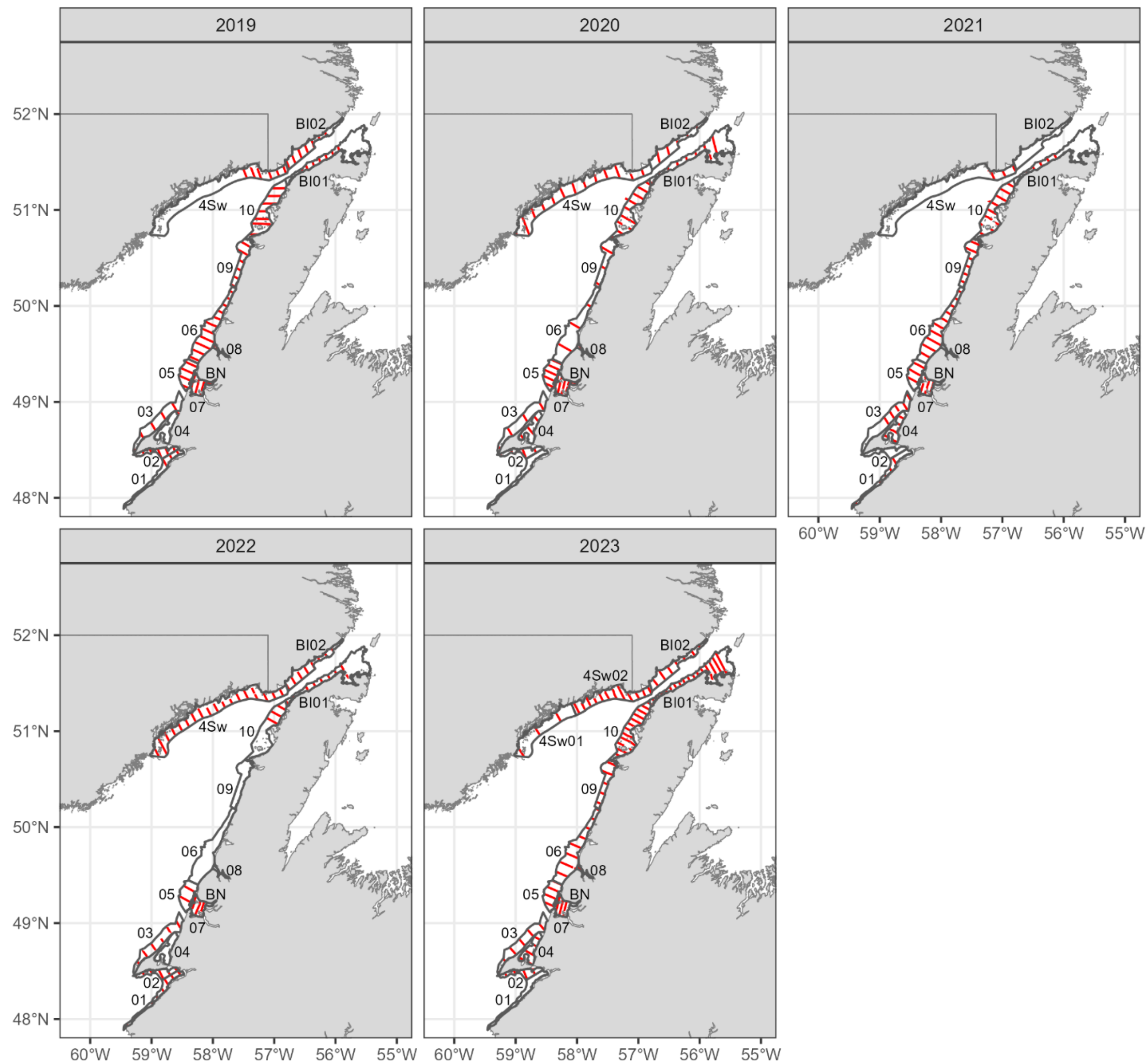

Figure 8. Transects successfully completed during the 2019 to 2023 summer acoustic surveys.

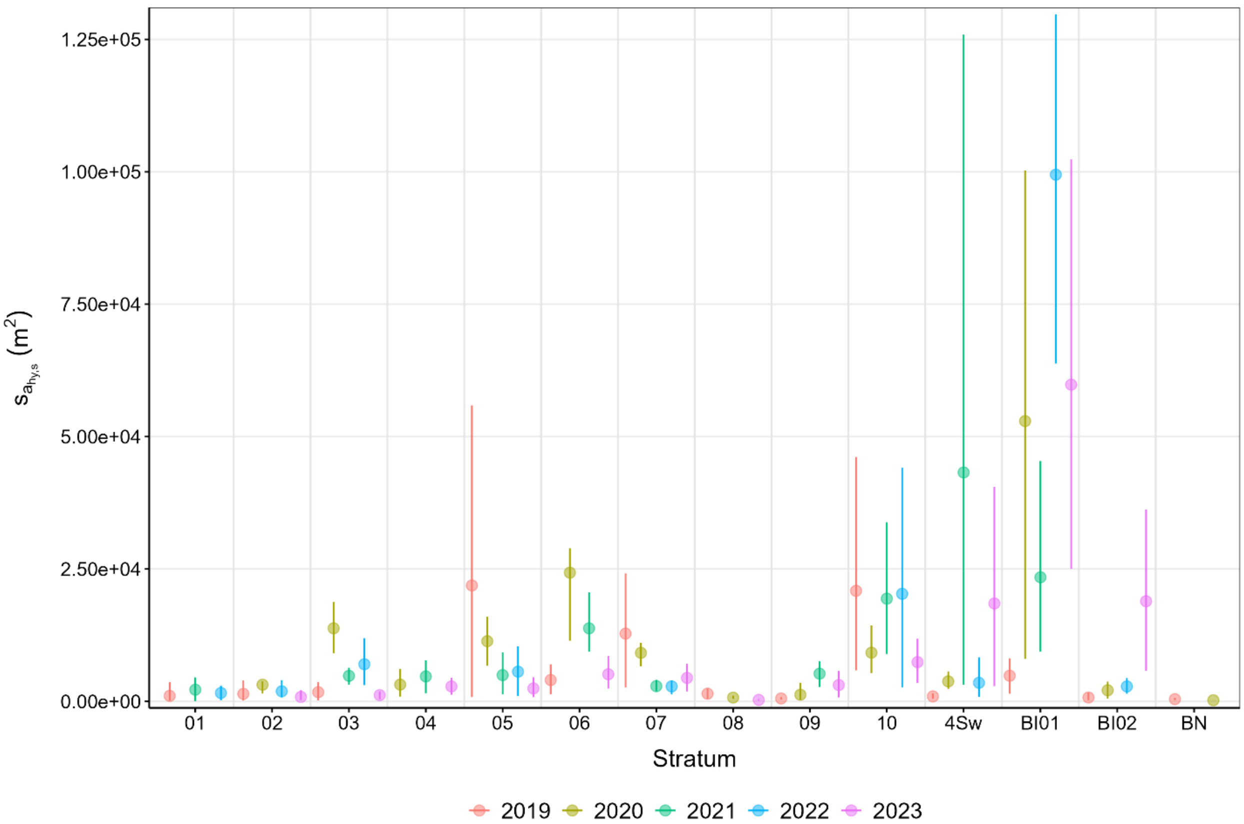

Figure 9. Area backscattering coefficient summed over each stratum ($s_{a_{hy,s}}$, m²) for each year of the summer acoustic surveys. Error bars represent bootstrapped 95% confidence intervals. Both spawning groups are included. Note that stratum 01 was not sampled in 2020 and 2023, stratum 02 in 2021, stratum 04 in 2019 and 2022, stratum 06 in 2022, stratum 08 in 2021 and 2022, stratum 09 in 2022, stratum BI02 in 2021, and stratum BN in 2021, 2022 and 2023.

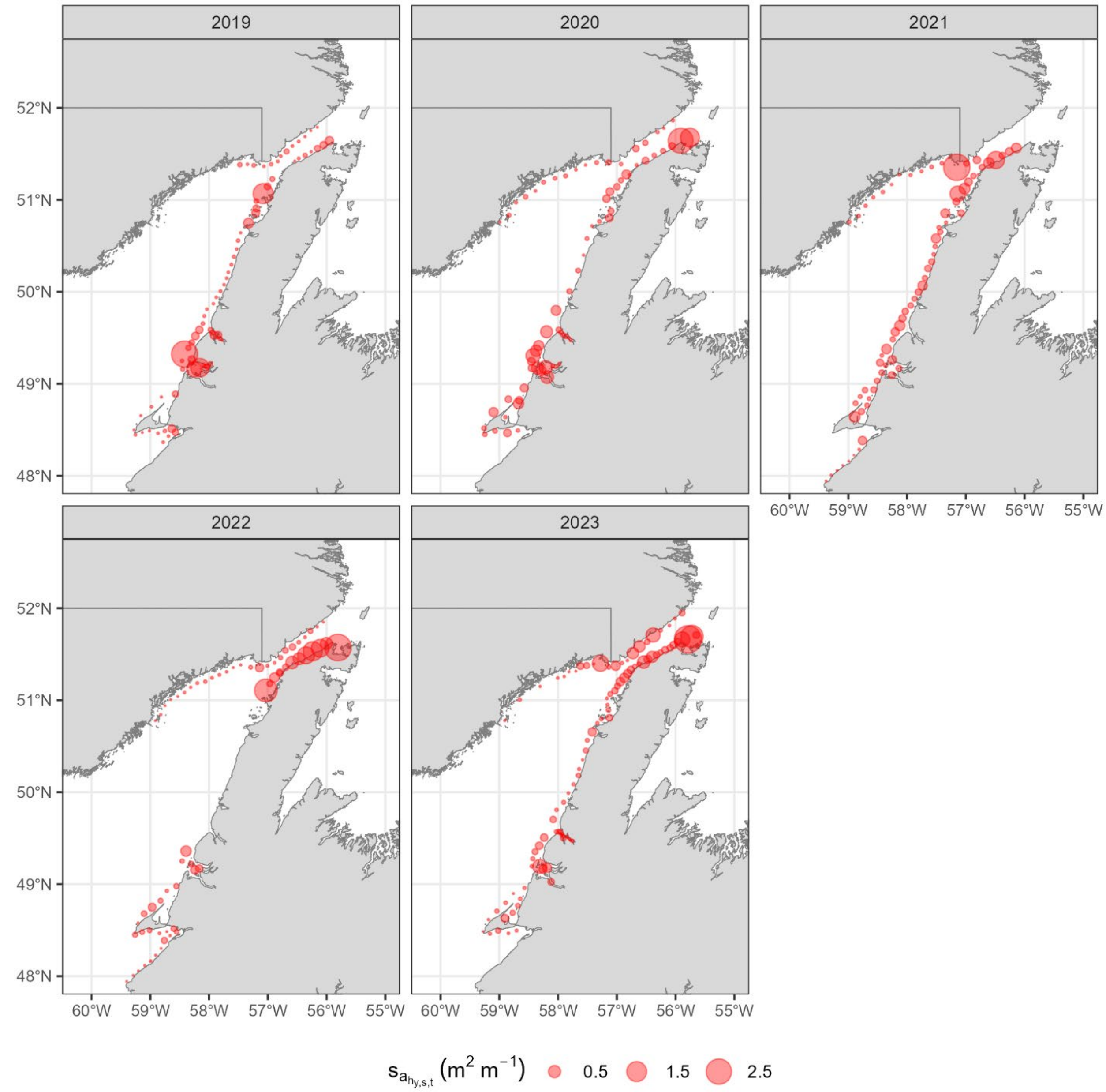

Figure 10. Area backscattering coefficient per transect, multiplied by transect length ($s_{a_{h_{y,s,t}}}$, m^2 m^{-1}), for each year of the summer acoustic survey. Both spawning groups are included.

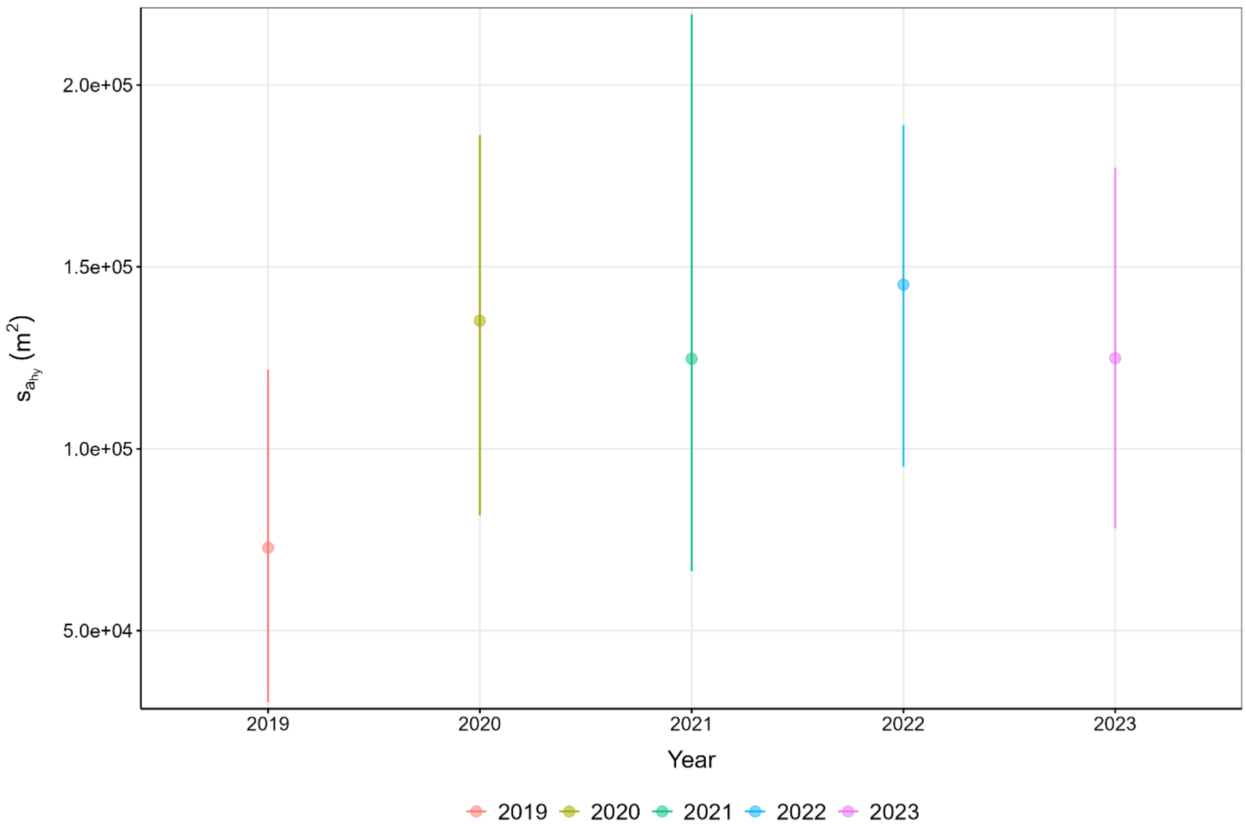

Figure 11. Total area backscattering coefficient per year ($s_{a_{hy}}$, m²) for the summer acoustic survey. Error bars represent bootstrapped 95% confidence intervals. Both spawning groups are included.

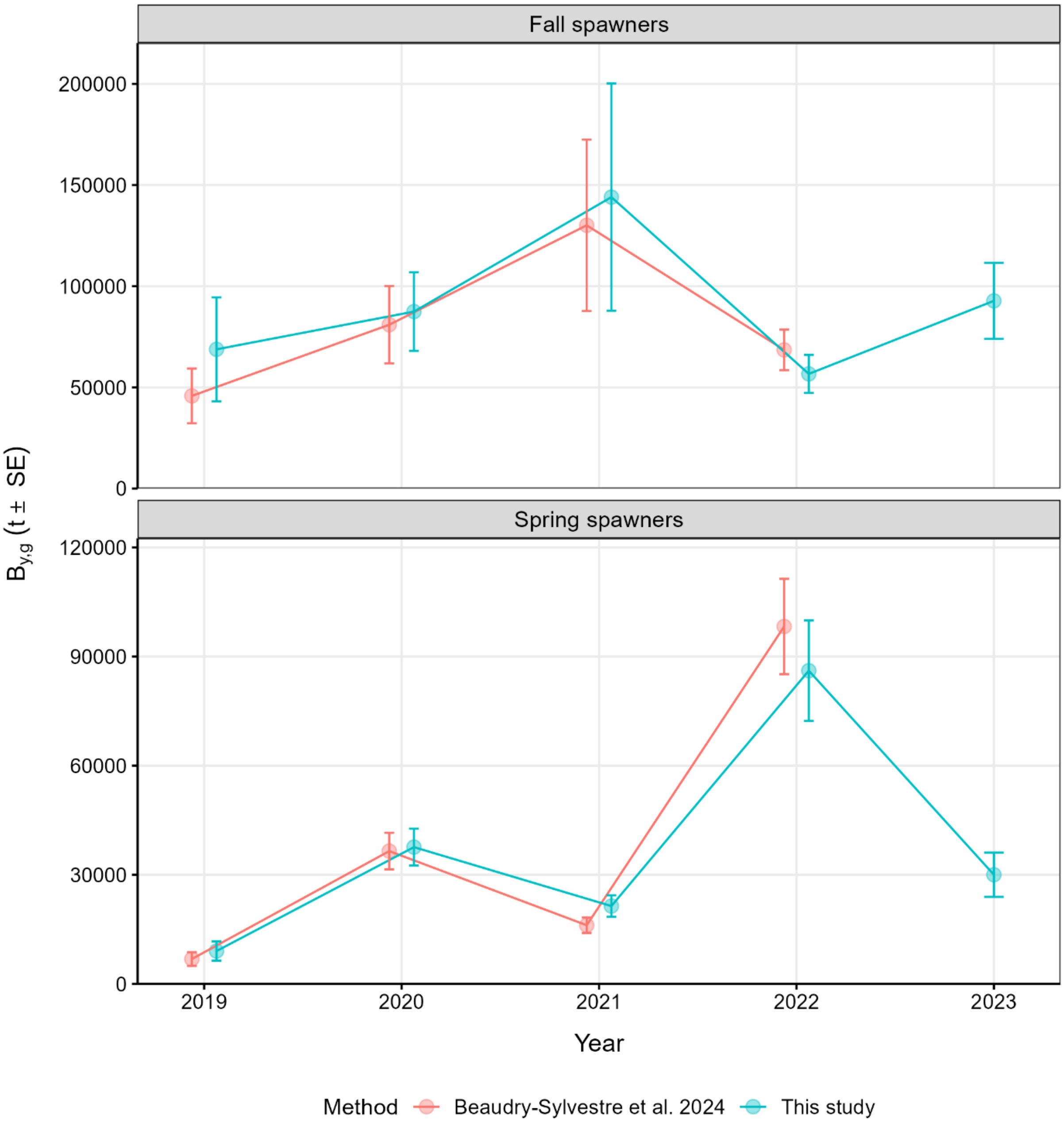

Figure 12. Summer acoustic survey biomass index ($B_{y,g}$, t) and standard error (SE, $\sqrt{\sigma^2{}_{B_{y,g}}}$) per year per spawning group estimated with the method described in Beaudry-Sylvestre et al. (2024) and this study.