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Acoustic Survey Index Revision and Standardization for the Atlantic Herring (*Clupea harengus*) 2009-2021 Fall Series in NAFO Divisions 4RSw

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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

Hydroacoustic surveys provide the main input for the assessment of Atlantic herring (*Clupea harengus*) in Northwest Atlantic Fisheries Organization (NAFO) division 4R since 1991. While the time-series from 1991 to 2002 has been deemed acceptable based on available diagnostic tools, the series that began in 2009 encountered several methodological challenges which led to the rejection of its associated population model in 2020. Furthermore, the preliminary results of a recent tagging experiment suggest that herring in divisions 4R and 4Sw should be assessed together. Here, focusing on the surveys conducted in the combined divisions 4RSw in the fall from 2009 to 2021, we standardized three main aspects of the methods which are believed to have affected the comparability of estimates over time and among strata. Specifically, we (1) processed and analyzed the raw acoustic data files in a more consistent manner; (2) employed a target strength equation considered more representative for the present survey; and (3) revised the stratum surface areas, a key input for the estimation of the mean biomass by spawning component, stratum and survey. The largest deviations from original (unrevised) values occurred as a result of changing the target strength equation; this revision resulted in the density being reduced by a constant 65% across all strata and surveys. The effects of re-analyzing acoustic data and strata surface areas were highly stratum- and survey-specific, but had an overall negligible impact on the interannual variability in abundance. Although the present revisions have allowed for many improvements in our understanding of the methods, there remains a perception that the “optimal” spatio-temporal window for conducting the survey – that corresponding to a peak in herring abundance – has been missed over many of the years considered herein. Therefore, the next steps for this work will focus on identifying a better timing for future surveys, as well as on predicting missing observations and optimizing the use of biological samples within each stratum.

1. INTRODUCTION

Hydroacoustic methods have long been applied to monitor the biomass of aquatic resources. Their application in stock assessment generally involves estimating abundance indices by recording acoustic signals along transects, which themselves can be part of pre-defined survey polygons, or strata, and inferring the demographic composition and characteristics of the surveyed population through biological samplings. Deriving reliable abundance indices requires that survey design, data collection and analytical methods remain constant from one year to the next, which otherwise could generate significant bias in estimated and projected population parameters (e.g. growth, recruitment, natural mortality).

The west coast of Newfoundland fall acoustic survey has been the primary source of fishery-independent data for the assessment of Atlantic herring (*Clupea harengus*) in Northwest Atlantic Fisheries Organization (NAFO) division 4R since 1991. The first series of surveys, conducted in the fall every two or three years until 2002 (Beaulieu et al. 2010; McQuinn and Lefebvre 1999), was found to produce patterns of relative abundance-at-age that were overall consistent with attrition and stationary catchability for individual cohorts. However, evidence from the second series of surveys, conducted every year or two years in the fall since 2009, indicated that survey catchability may have changed relative to the 1991-2002 period (Chamberland et al. 2022). This variability in survey catchability has led to the rejection of the analytical population framework in the peer-review meeting of November 2020 and the recommendation that the data inputs and assessment framework be fully revised for this time period (DFO 2021a).

A number of factors have been proposed to explain the inconsistencies in catch-curve patterns evident in division 4R since 2009. First, the lack of detailed reporting of methods and the frequent change in personnel over the years generated inconsistencies in the way acoustic data were processed and analyzed. Second, due to logistic and/or time constraints, the study area was not consistently surveyed from year to year, raising questions about the validity of interannual comparisons. Third, the number and density of transects surveyed within each stratum and in total have largely decreased compared to the previous survey period (1991-2002), leading to a net loss in both the amount and quality of information available for assessment (see Figure A57 in Chamberland et al. 2022). Last, important shifts in the timing and location of fishing have occurred in the early 2000s (see Figure 56 in Chamberland et al. 2022), implying that the “ideal” temporal and spatial windows for the survey (i.e. those coinciding with the peak in herring abundance, with sufficient sampling coverage to quantify that abundance) may no longer match the survey design established for 1991-2002.

At the time of publication of this document, several initiatives have already been initiated to improve the acoustic biomass index and address current knowledge gaps:

- The addition of two strata in the Strait of Belle-Isle in 2019 (NAFO subdivision 4Ra), where harvesters have reported very high abundances of herring since at least 2017 (Chamberland et al. 2022) (note that these strata have been surveyed over 2019-2022 and will continue to be monitored as part of the regular survey program);
- The continued implementation of a summer (August) acoustic survey since 2019, a time of year hypothesized to better coincide with the peak in herring abundance in the survey area (Chamberland et al. 2022);
- The initiation of an acoustic tagging experiment in 2021 to monitor the species’ migratory routes in the northern Gulf of St. Lawrence, particularly in relation to the proposed inclusion of NAFO subdivision 4Sw into the assessment for division 4R (note that the combination of 4R and 4Sw was approved in April 2023, though the tagging program was still ongoing at the time of this publication).

These projects and initiatives aim at improving our understanding of herring stock spatial distribution and migration timing and the confidence in the fall acoustic survey index. The results relating to these projects will be published in separate documents.

The present research document is the result of 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. Here, we present revisions that have been applied to the 2009-2021 fall series in order to standardize the data inputs and analytical methods related to the herring acoustic index in NAFO divisions 4RSw (Table 1).

2. METHODS

2.1. SURVEY DESIGN AND DATA ACQUISITION

The herring acoustic survey is stratified into 14 polygons, hereafter strata, that were drawn to delineate the major physical characteristics of the habitat available as well as the reported spatial occurrence of herring in scientific surveys and commercial catches (Figure 1). The initial stratification proposed in 1991 comprised ten strata covering the 20 to 60 m isobaths (McQuinn and Lefebvre 1999) and ranging in surface area from 58.5 to 1,157 km^2. This scheme was first modified in 2010 to reduce the area of strata 03 and 10. In 2019, the study area was expanded to include herring on the southern (BI01; 1,163 km^2) and northern (BI02; 626.8 km^2) sides of the Strait of Belle Isle located in NAFO subdivision 4Ra (Chamberland et al. 2022). The 2019 stratification was later updated in 2020 to draw a clearer distinction between the Bay of Island (stratum 07; 306.2 km^2) and the *Bras Nord* (located in the North Arm of Bay of Islands) strata (BN; 32.93 km^2), which were previously accounted for as a larger stratum 07 during analysis (note that the North Arm area, if surveyed, was not reported as a stratum in the 1991-2002 period). Following the results of the herring acoustic telemetry study (DFO 2024), the survey area was further extended to include the easternmost segment of Quebec's Lower North Shore, in the adjacent NAFO subdivision 4Sw (stratum 4Sw; 2,195 km^2), which has been assessed as part of division 4S since 2009 (DFO 2021b). The updated stratification comprises 14 strata covering depths ranging from 20 to 250 m.

The nine acoustic surveys retained for the revision were conducted in the fall of 2009-2021 over one to three weeks each (Table 2). Although there have also been surveys in NAFO subdivision 4Sw in 2016 and 2018, as in the rest of 4S (DFO 2019), the latter two were not included in the present work as there were no corresponding data for division 4R (hence no possibility to estimate a total index for 4RSw). Revisions also excluded the 1991-2002 surveys given that most of their associated inputs (e.g. acoustic files, biological samples selected) could not be accessed with today's available tools; however, we note that their associated catch curves had been deemed acceptable by peer-review (Chamberland et al. 2022).

All surveys were conducted at night (17:00-07:00, Atlantic Time), in accordance with the species' known nocturnal feeding behavior (McQuinn and Lefebvre 1999), to minimize the uncertainty associated with the acoustic deadzone (Mitson 1983; see also section 2.2.3 for a definition of that term). The transects in each stratum were parallel and oriented perpendicular to the coastline, with the first transect placed randomly at either end of the stratum and subsequent transects placed at equal distance from one another, depending on the sampling time allocated for that particular stratum. At the start of each survey, the total number and distance between transects were calculated based on the allocated ship time minus 30%, the established margin for logistical field issues such as poor weather and mechanical breakdowns.

The vessels employed for each survey were equipped with a hull-mounted, split-beam SIMRAD EK60 (survey years: 2009-2020) or EK80 (survey year: 2021) echosounder operating at up to five frequencies (38, 70, 120, 200, and 333 kHz) and calibrated according to the standard methods presented in ICES (2015) for real-time recording of data. Note that only the 38, 120 and 200 kHz frequencies were used. Following the approach outlined in McQuinn et al. (2005), raw volume backscattering strength (S_v; dB re 1 m^{-1}) values were transformed into the standard HydroAcoustics (HAC) format and manually edited to remove signal near the surface and below the seafloor, external noise and logging artefacts. These edited files were integrated to 2 m (depth) by 25 m (horizontal distance) cells, using the software CH2 developed at the Maurice Lamontagne Institute and subsequently saved in the hydroacoustic echointegration (HEI) file format for further analysis (Simard et al. 2000).

In 2021, changes to the acoustic data acquisition software from ER60 to EK80 prevented the use of CH2 and the HAC format; the acoustic analyses for the 2021 survey were therefore conducted using the software Echoview 12 (Myriax Pty, Ltd., Hobart, Tasmania, Australia). For this year, the S_v was exported in .csv format and subsequently converted into HEI file format for further analysis.

The last published estimates for 2009-2021 (see DFO 2021b and Émond et al. 2024) will be referred to as “Original” in the remainder of the text, whereas subsequent estimates resulting from changes to inputs and methods will be incorporated as revisions 1, 2 and 3 (see Table 1). Note that, to ensure a consistent series of observations from 2009 to 2021, the two recently created strata in the Strait of Belle-Isle, BI01 and BI02, will only be presented in stratum-specific comparisons; their contributions to the total biomass index in each survey will not be considered in this document (otherwise this would cause a potentially artificial increase of total biomass estimates from 2019 onward, given the apparent northward displacement of herring toward the north end of the survey area).

2.2. REVISION 1: STANDARDIZATION OF THE ACOUSTIC DATA ANALYSIS

Since 2009, there has been a number of changes in staff and methodologies which have contributed to errors and inconsistencies in the acoustic data time series for NAFO divisions 4RSw. To address these issues, the acoustic data collected during the nine surveys over 2009-2021 were re-analyzed in a more uniform and transparent manner. Revision 1 includes the standardization of methods for 1) extraction of acoustic system calibration parameters, 2) acoustic data classification, 3) estimation of the acoustic deadzone, and 4) determination of transect numbers and lengths (Table 1). All calculation methods were implemented in the R software for statistical computing (version 4.1.1, R Core Team 2020) accessed via RStudio (version 1.3.1056, RStudio Team 2020). This constitutes a change from original methods, which mainly employed Microsoft Excel.

2.2.1. Calibration parameters

Errors in the calibration parameters can have appreciable effects on estimates of biomass indices (ICES 2015). To ensure that the calibration parameters were defined in a consistent manner across surveys, their values were automatically extracted from the header section of the HEI files (see Annex 1 in Simard et al. 2000).

2.2.2. Acoustic data classification

The method for classifying acoustic signals has not been uniform over the surveys covered by this revision. Up until 2013, schools of herring were manually identified through visual inspections of the echograms, where the analyst used their own interpretation of the echograms (e.g. shape, size, personal knowledge) to select herring echoes. From 2015 onwards, the classification followed a more reproducible, but still somewhat subjective method wherein acoustic signals were classified based on the differences in S_v between the 38, 120 and 200 kHz frequencies and their correspondence with expectations for swimbladdered (e.g. herring, Atlantic cod (*Gadus morhua*) and redfish (*Sebastes* spp.)) and nonswimbladdered species (e.g. Atlantic mackerel (*Scomber scombrus*) and sandlance (*Ammodytes* spp.)). In this method, fish with a swimbladder were selected using a threshold polygon (Figure A7) that was developed in the 1990s (I. McQuinn, pers. comm.). This polygon classification method is similar to that used in McQuinn et al. (2013) for the classification of two species of krill (*Thysanoessa raschii* and *Meganyctiphanes norvegica*), but has not been formally peer-reviewed for an application to fish classification.

Although most acoustic signals classified as swimbladdered fish were subsequently considered to be herring, echograms were nevertheless manually scrutinized by the analyst to remove non-herring targets or reassign acoustic signals to a different category (swimbladder or nonswimbladder) if deemed appropriate. To obtain a more consistent time series than the Original version, the acoustic data for the surveys prior to 2015 were reclassified according to the latter, more recent classification method (the method applied for 2015-2021). Furthermore, to reduce potential bias and subjectivity associated with the change in scientific staff over the years, all acoustic data from 2009 to 2021 were re-examined by the same two analysts.

Categorization based on the presence or absence of a swimbladder was based on the observation by McQuinn and Lefebvre (1999) that very few swimbladdered species co-occurred with Atlantic herring during the 1991-2002 survey period. Hence, the vast majority of swimbladdered signals recorded during that period could be confidently assigned to herring. However, recent and ongoing changes in the composition of nGSL ecosystems are likely to bring additional needs with regard to the distinction between herring and other swimbladdered species, notably an increase in the abundance of redfish species (Senay et al. 2023). This, in part, justifies the need for an update to classification methods from 2022 onward. At the CSAS peer-review meeting, a more objective classification method which includes an updated method to exclude nonswimbladdered fish and accounts for the more diverse presence of swimbladdered species was presented and approved for future surveys. The updated method will be published in a separate document.

Following classification, herring volume backscattering coefficients (s_v, m^{-1}) were integrated over the water column for each 25 m step distance i to an area backscattering coefficient value:

$$s_{a_i} = \int_{z1}^{z2} s_{v_i} dz \quad (1)$$

Values of s_a were then averaged at the transect, stratum, and survey levels for comparison with original assessment estimates (see Tables 7-10 and A20 in Émond et al. 2024). Note that the symbols and units for acoustic analyses follow the conventions proposed by MacLennan et al. (2002).

2.2.3. Estimation of the acoustic deadzone

In previous assessments, corrections associated with the loss of signal in the acoustic deadzone, i.e. the portion of the spherical acoustic beam where herring cannot be detected near the seabed, were made manually one transect at a time in Microsoft Excel and were, due to time and efficiency constraints, limited to transects perceived or deemed to have contributed most to biomass. In this revision, the acoustic deadzone was calculated and applied for each 25 m horizontal step i $(i = 1, 2, \ldots, I)$ throughout the time series.

The acoustic dead zone is expressed as the equivalent lost height (Ona and Mitson 1996) as follows:

$$h_{eq_{y,i}} = 2404 \cdot \frac{\left(bottom\ depth_{y,i} - td_y\right) \cdot \tan\left(\frac{\emptyset_y \cdot \pi}{180}\right)^4}{\emptyset_y^{\ 2}} + \frac{(c\tau)_y}{4} + BS \tag{2}$$

where $bottom\ depth$ is the average depth of the seafloor (m) for the 25 m step *i*; td, Ø, *c* and τ are the transducer's depth (m), transducer's 3 dB half beam angle at 38 kHz (°), sound speed (m s^{-1}) and pulse duration (s) for survey *y*, respectively, and BS is the backstep (m). The term $\frac{c\tau}{4}$ represents the vertical extent where a fish cannot be distinguished from the seafloor. The backstep value was set to 0.2 m and was applied consistently where fish were present near the seafloor, in contrast to the variable backstep applied inconsistently (when the analyst deemed it appropriate) in the Original method. The calibration parameters used to estimate the height of the acoustic deadzone for each survey are provided in Table A13.

The value of s_v integrated in the first 1 m above the deadzone, $s_{a_{BD1_{y,i}}}$, was used as the s_a value found within the deadzone ($s_{a_{DZ_{y,i}}}$), as follows:

$$s_{a_{DZ_{y,i}}} = s_{a_{BD1_{y,i}}} * h_{eq_{y,i}} \tag{3}$$

The total s_a per transect were then obtained by taking the combined s_a in the water column and deadzone for each 25 m horizontal step distance and averaging over the transect length.

2.2.4. Determination of transect numbers and lengths

Comparisons between the transect-specific inputs employed in previous assessments (see Émond et al. 2024) and the inputs considered for the present revision have revealed several differences. This is in part because of variable perceptions among analysts of what does and does not constitute a transect in the context of the survey (e.g. transects spanning multiple distinct HEI files to avoid an obstacle), as well as the erroneous inclusion of *intertransect* and *transit* files into the calculations. To address these issues, the number and average length of transects surveyed were re-extracted from the HEI files in a standardized manner. Specifically, the following rules were applied:

- All transects were retained unless the type of event (transect, intertransect or transit) had been misspecified in the original files (e.g. intertransects or transit files misspecified as transects);
- The number of transects per stratum and survey was determined automatically based on the revised HEI files – wherein one file usually equalled one transect – rather than from the HEI files employed in the original index; and
- Transects spanning more than one HEI file were defined as a single continuous transect, with the total length of that transect excluding any segment(s) without observation (e.g. physical obstacles, low-depth areas).

The outcomes of standardizing the acoustic methods were summarized at the stratum level by estimating the mean s_a for each combination of stratum and survey (year). As in previous assessments, the average s_a per survey y and stratum s, $\overline{s_{a_{y,s}}}$, were estimated as:

$$\overline{s_{a_{y,s}}} = \frac{\sum_{t=1}^{t=T_{y,s}} \left(\overline{s_{a_{y,s,t}}} \cdot \omega_{y,s,t}\right)}{T_{y,s}} \quad (4)$$

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

$$\sigma^2_{\overline{s_{a_{y,s}}}} = \frac{\sum_{t=1}^{t=T_{y,s}} \left(\omega_{y,s,t}{}^2 \cdot \left(\overline{s_{a_{y,s,t}}} - \overline{s_{a_{y,s}}}\right)^2\right)}{T_{y,s}(T_{y,s}-1)} \quad (5)$$

where the inputs were specified in the previous equations. Note that the variance defined herein does not quantify the statistical uncertainty in $\overline{s_{a_{y,s}}}$ but, rather, the variability in $\overline{s_{a_{y,s}}}$ between transects within the strata and surveys.

2.3. REVISION 2: CHANGE OF THE TARGET STRENGTH EQUATION

The estimation of herring biomass involves specifying a target strength equation for the conversion of acoustic signals into fish density. Revision 2 includes the use of a different and more appropriate target strength equation than the one used in the original series (Table 1).

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,

$$TS_{L_{y,s,g}} = 20 \cdot log_{10}\left(L_{y,s,g}\right) - 67.3 \quad (6)$$

where *L* represents mean length (cm) and was estimated for each survey y, stratum s and spawning group g (note that the biological samples employed for these calculations were the same as those used in previous assessments; a separate document will be published for a revised sample-selection method).

The adjustment of the target strength equation led to a constant decrease in “perceived” density, relative to the use of the Foote (1987) equation (Table 3). More specifically, herring densities ρ (ind. m^{-2}) obtained with Ona’s (2003) equation represent 35% of densities obtained with that of Foote (1987):

$$\frac{\rho_{Ona}}{\rho_{Foote}} = 10^{\frac{TS_{Foote} - TS_{Ona}}{10}} = 0.35 \quad (7)$$

The equation developed by Foote (1987) has been used to estimate herring biomass in stock assessments for a number of years in the present region (NAFO divisions 4RSw; McQuinn and Lefebvre 1999). However, more recent studies suggest higher TS values overall (Table 3). It can be observed that Foote’s relationship leads to the lowest TS, while Ona (2003) coincides with the mean of all the relationships that were found in the literature published after 1990, inclusive of the study by Foote (1987). Therefore, the Ona (2003) equation was chosen for this survey.

Most of the equations in Table 3, as well as the ones developed by Foote (1987) and Ona (2003), are based on herring data collected in the Norwegian and the Baltic seas. Wheeler (1991) described a TS to length relationship for herring from data collected on the east and south coasts of Newfoundland (NAFO divisions 3KLP), and it is currently used for the estimation of herring biomass in that region (Bourne et al. 2018). Although it would be preferable to use an equation that was developed from a herring population that is closer to our survey area, and likely more similar in morphology, we opted for an equation that was developed using a 38 kHz echosounder, as the acoustic signal of herring is stronger at this frequency, and the equation is supported by other studies (Reynisson 1993; Didrikas and Hansson 2004; Fassler et al. 2008).

Equation 6 was converted to target strength per unit weight (kg) using:

$$TS_{W_{y,s,g}} = TS_{L_{y,s,g}} + 10 \cdot log_{10}\left({W_{y,s,g}}^{-1}\right) \tag{8}$$

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

The mean biomass density per survey y, stratum s, transect t and spawning group g was calculated as follows:

$$\overline{D_{y,s,t,g}} = \frac{\overline{s_{a_{y,s,t,g}}} \cdot P_{y,s,g}}{\sum_{g=1}^{G}\left(10^{\frac{\overline{TS_{W_{y,s,t,g}}}}{10}} \cdot P_{y,s,g}\right)} \tag{9}$$

where $P_{y,s,g}$ are the weight-based proportions of each spawning group in selected samples and the output $\overline{D_{y,s,t,g}}$ is expressed in kg m^{-2}. 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 (Table 2).

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:

$$\overline{D_{y,s,g}} = \frac{\sum_{t=1}^{T_{y,s}}\left(\overline{D_{y,s,t,g}} \cdot \omega_{y,s,t}\right)}{T_{y,s}} \tag{10}$$

with the variance between transects corresponding to:

$$\sigma_{\overline{D_{y,s,g}}} = \frac{\sum_{t=1}^{T_{y,s}}\left(\left(\omega_{y,s,t}\right)^2 \cdot \left(\overline{D_{y,s,g}} - \overline{D_{y,s,t}}\right)^2\right)}{T_{y,s}\left(T_{y,s} - 1\right)} \tag{11}$$

As for the variance in $\overline{s_{a_{y,s}}}$, the values of $\sigma_{\overline{D_{y,s,g}}}$ should be interpreted as a measure of variability between transects only; they do not constitute a statistical measure of uncertainty.

2.4. REVISION 3: STANDARDIZATION OF METHODS FOR STRATA SURFACE AREAS

The goal of Revision 3 was to replace the inconsistently obtained strata surface areas in the original series with reviewed and standardized estimates of surface areas (Table 1).

The surface area of the strata or polygons surveyed, $A_{y,s}$, depends on the number and average length of transects surveyed. As for the transect-based inputs presented in Figure 2 and 3, a closer examination of the original $A_{y,s}$ revealed instances where the value did not reflect the area actually surveyed; such differences could be related, for example, to differences in how investigators dealt with partly covered strata (e.g. some applied the full theoretical surface areas to half-covered strata) or to issues related to the actual contours of each stratum (e.g. some excluded small physical obstacles from the area considered).

Given the potentially large impact of this input on biomass, the surface area for each stratum and year was re-estimated in the NAD83 Québec Lambert projection (unit: km^2). Similarly to the original methods, the shapefiles corresponding to the strata in each survey were redrawn with the vertex-editing tool in QGIS (QGIS Development Team 2023), with the following rules applicable:

1. The contours of each stratum were placed near the start and end positions of each transect surveyed, such that the shape of the revised strata closely matched the shape of the area covered;
2. The distance between the polygons' contours that are perpendicular to the coast and the first and last transects of each stratum corresponded to approximately half an intertransect each side (i.e. the orthogonal distance between two parallel transects);
3. The surface area for strata with unequal intertransect distances (e.g. stratum 02 in 2009) did not exclude the occasional empty spaces.

2.5. ESTIMATION OF THE MEAN BIOMASS BY SPAWNING GROUP AND SURVEY

The average herring biomass (in tons) in survey y, stratum s and spawning group g, $\overline{B_{y,s,g}}$, were estimated as the product of the mean densities $D_{y,s,g}$ (expressed in kg m^{-2}) and strata surface areas $A_{y,s}$ (in km^2; Figure 4), as follows (O'Boyle and Atkinson 1989):

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

with the variance between transects within a stratum given by:

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

This method is identical to the one used to generate the Original time series. The means and variances for each spawning group were then summed across strata within each survey – excluding strata in the strait of Belle Isle (BI01 and BI02) – for an estimate of total biomass at the survey level (Table 4-12). Total estimates which included BI01 and BI02 were also estimated for exploratory purposes only (these were not considered for scientific advice).

3. RESULTS AND DISCUSSION

Revisiting the data inputs and analytical methods for past acoustic surveys has been beneficial in informing the changes to be implemented in the upcoming assessments for both divisions 4R (planned in 2024) and 4S (planned in 2025). Here we present our revisions and discuss their implications for the assessment framework.

3.1. REVISION 1: STANDARDIZATION OF THE ACOUSTIC DATA ANALYSIS

As expected, the effects of revising the acoustic data inputs in Revision 1 were largest in magnitude for surveys conducted in 2009-2019, relative to those of 2020-2021. This is presumably due to the more significant revisions made to the corresponding HEI files (e.g. transect numbers and lengths, Figure 2 and 3) relative to the more minor revisions for 2020-2021 (e.g. calibration parameters, Table A13), though direct evidence in support of this assertion was not available.

Changes to the total numbers of transects have been most extensive over the period from 2009 to 2017 (Figure 2). The most consistently applied update in this period was the reassignment of up to half the number of transects surveyed in stratum 07 to the more northerly stratum BN. The distinctiveness of stratum BN in the survey design was supported by the revised 'acoustic logs' for each survey which unambiguously ascribed transects to either one or the other stratum in that region (these were previously combined at the biomass-estimation stage). For stratum 4Sw, the main updates since the last assessment (DFO 2021b) were the inclusion of 5 transects which had been surveyed, but not yet analyzed in 2017, as well as 18 transects in the fall 2021.

The differences illustrated in Figure 2 were highly case-specific, but their effects on perceived survey coverage could be substantial. In the 2011 survey, for example, the number of transects analyzed in stratum 09 was specified as 6 in the Émond et al. (2024) assessment and determined as 12 in Revision 1, representing a doubling relative to initial perceptions. The inverse situation occurred for the 2009 survey, when one transect in stratum 02 was removed due to having been surveyed twice out and back (pseudoreplication). Discrepancies of this nature have been less frequent in 2015 and 2017 and have not occurred in the 2019 to 2021 surveys.

The standardization of transect-related inputs in Revision 1 had similar consequences on the perceived average lengths of the transects surveyed (Figure 3). As expected, the transfer of transects from stratum 07 to BN led to increases in average length for stratum 07 and generated new estimates for BN. Changes were also observed at the northern and southern strata extremities, where issues with discontinuous transects tended to be more common, but such errors were not consistently observed across contexts.

Comparisons were drawn between the Original series for 2009-2021 (Tables 7-10 and Supplementary Table A20 in Émond et al. 2024) and the observations presented in Revision 1 (acoustic data classification, deadzone and transect information) by stratum and survey in Figure 5**.** The most clearly discernible changes from Original to Revision 1 estimates were for the surveys conducted in 2009-2019. Indeed, the combined standardization of acoustic classification, deadzone and transect information has resulted in the $\overline{s_{a_{y,s}}}$ increasing for the 2010, 2015, 2017 and 2019 surveys and decreasing for the 2009 and 2013 surveys. Minor revisions were also made for 2020-2021 since the last assessment to correct for minor errors in the acoustic calibration parameters.

3.2. REVISION 2: CHANGE OF THE TARGET STRENGTH EQUATION

The impact of replacing the target strength equation by Foote (1987) for Ona (2003), a change proposed in Revision 2, was substantial (Figure 6). Specifically, the densities estimated from Ona (2003) represented only 35% of those estimated from Foote (1987), regardless of the stratum or survey. This emphasizes that the acoustic index should be viewed as an index of relative abundance, until a target strength equation for the Northwest Atlantic herring is developed. It is worth noting that the methods and equations used to estimate biomass in herring stock assessments vary among DFO regions (e.g. see Bourne et al. 2018, LeBlanc et al. 1993, LeBlanc et al. 1996, Power et al. 2006), and that these "absolute" biomass estimates are therefore not comparable.

Given the constancy of this result across observations, we propose that the change of target strength equation should also apply to the earlier 1991-2002 acoustic data time series to maintain the comparability of observations across the two periods.

3.3. REVISION 3: STANDARDIZATION OF METHODS FOR STRATA SURFACE AREAS

Revised strata surface areas (Revision 3) tended to be smaller than those employed over past assessments, in part because the contours of the polygons representing each stratum more commonly followed their corresponding transects (Figure 4). Along with the redistribution of surface area from stratum 07 and BN in 2009-2019, the most important deviations from original $A_{y,s}$ have occurred for stratum 03 in 2009 and stratum 10 in 2013. Apart from these two instances, the changes were generally limited to replacing estimates from the theoretical design (see the caption under Figure 1) by the more consistently obtained values in QGIS.

4. CONCLUSION

Overall, the results presented herein suggest that there have not been any major shifts in perceptions of interannual variability from the original values summarized in Émond et al. (2024) to the revisions presented in this document. This implies that the present revisions have only partially addressed the methodological issues identified as part of the peer-review meeting that led to the rejection of the acoustic index (Chamberland et al. 2022).

The most important outcome of the present revisions is a better grasp of the uncertainties associated with the acoustic survey (in part by stepping outside a “methodological black box”). The difficulty in identifying the ideal time and location for the survey (those corresponding to the peak in herring biomass within the survey area and year) was partly addressed via the proposed inclusion of stratum 4Sw into the present analyses and of strata BI01 and BI02 into future analyses. Their inclusion will presumably help to encompass herring which have emigrated outside the original ten strata of the 1991-2002 survey design.

The acoustic inputs largely depend on the timing and location of the survey coinciding with the peak abundance window for herring (i.e. conducting the survey at the appropriate location and the right time). Perceptions that this window has been missed over many of the surveys conducted in the fall of 2009-2021 remain the primary source of uncertainty which could only be partially addressed within this document.

The present work is part of a larger project to develop a new analytical population model and biological reference points for herring in the combined divisions 4RSw. In the upcoming years, there will be additional efforts to better understand the uncertainty associated with missing strata and years and, to the extent possible, statistically predict acoustic values for these missing observations. There will also be efforts to revise the manner in which the biological samples are selected and assigned to each acoustic value, which has been another key source of subjectivity for that index. Finally, there will be continued efforts to document the spatial and temporal distribution of the stocks via the tagging program.

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TABLES

Table 1. Descriptions of the main methodological revisions applied to the acoustic survey index over the 2009-2021 fall series. Revisions were made to the original estimates and were applied in a step-wise, cumulative manner.

Revision	Description
Original	Estimates presented in the last published assessments for division 4R (Émond et al. 2024) and unit area 4Sw (DFO 2021b).
1	Standardization of acoustic analysis methods: calibration parameters, species classification, acoustic deadzone estimation, and transect length
2	Change of the target strength relationship from Foote (1987) to Ona (2003)
3	Standardization of strata surface areas

Table 2. Summary of the hydroacoustic vessels used, survey dates, number of samples per gear type used for the estimation of biomass (total number of herring in parentheses), and sampling vessels for each of the nine hydroacoustic surveys considered in this revision. For surveys conducted over 2009-2017 (excluding 2015), one or more commercial seiners were chartered for the sole purpose of collecting biological samples. For those conducted in 2019-2021, the chartered vessel was a pelagic trawler which was better equipped for the purposes of the survey. Note that all hydroacoustic and non-commercial sampling vessels were Canadian Coast Guard Ships (CCGS), except for the research vessel (RV) Novus which was chartered from LeeWay Marine in 2021. In some years, samples from the commercial fishery were used to fill gaps in sampling.

Survey	**Acoustic survey vessel (date range)**	**Fishing gear**						**Biological sampling vessels**
		Large seine	**Small seine**	**Tuck seine**	**Pelagic trawl**	**Gillnet**	**Trap**	
2009	CCGS F. G. Creed (21 Oct - 06 Nov)	8 (1,743)	0	0	0	0	1 (50)	Chartered fishing vessel, Commercial samples
2010	CCGS F. G. Creed (21 Oct - 02 Nov)	3 (625)	0	0	0	1 (400)	0	Chartered fishing vessel
2011	CCGS F. G. Creed (20 Oct - 01 Nov)	2 (497)	0	0	3 (633)	0	0	CCGS Calanus II, Chartered fishing vessel
2013	CCGS F. G. Creed (13 Oct - 22 Oct)	4 (566)	4 (324)	0	1 (92)	0	0	CCGS Leim, Chartered fishing vessel, Commercial samples
2015	CCGS Vladykov (15 Oct – 25 Oct)	8 (442)	8 (441)	2 (110)	0	1 (48)	0	Commercial samples
2017	CCGS F. G. Creed (21 Oct – 06 Nov)	3 (166)	3 (255)	0	1 (93)	0	0	CCGS Leim, Chartered fishing vessel, Commercial samples
2019	CCGS Leim (27 Oct - 11 Nov)	0	1 (122)	0	15 (1,109)	0	0	Chartered fishing vessel
2020	CCGS Leim (19 Oct - 07 Nov)	0	2 (104)	0	12 (851)	0	0	Chartered fishing vessel, Commercial samples
2021	RV Novus (13 Oct - 29 Oct)	0	0	0	19 (1,557)	0	0	Chartered fishing vessel

Table 3. Atlantic herring target strength (TS, dB) to length (L, cm) relationships found in the literature published since 1990, and the study published by Foote (1987). Length range represents the range of lengths of herring individuals present in the biological samples used within each study. The in-situ method involves the use of acoustic data and biological samples collected at sea, while ex-situ experiments were conducted on individual fish in submerged cages.

TS-L relationship	Reference	Method	Length range (cm)	Location	Frequency (kHz)
$20\log_{10}(L) - 71.9$	Foote (1987)	*In-situ/ex-situ*	14.6-28.5	North sea/Baltic sea	38
$20\log_{10}(L) - 65.5$	Wheeler (1991)	*Ex-situ*	25-37	Trinity Bay, NF	120
$20\log_{10}(L) - 67.1$	Reynisson (1993)	*In-situ*	7-34	Icelandic fjords	38
$20\log_{10}(L) - 71.1$	Misund and Beltestad (1996)	*In-situ*	33	Norwegian sea	38
$20\log_{10}(L) - 67.3$	Ona (2003)	*In situ/ex-situ*	25-37	Norwegian sea	38
$20\log_{10}(L) - 67.8$	Didrikas and Hansson (2004)	*In-situ*	4.5-28.5	Baltic sea	38/70
$20\log_{10}(L) - 63.9$	Peltonen and Balk (2005)	*In-situ*	10-26.5	Baltic sea	38
$20\log_{10}(L) - 67.1$	Fassler et al. (2008)	Model	16-40	Norwegian sea	38
$20\log_{10}(L) - 64.8$	Fassler et al. (2008)	Model	9-25	Baltic sea	38

Table 4. Summary of the data inputs and results for the 2009 acoustic survey according to revised methods (Table 1), with their standard errors (S.E.) and coefficients of variation (C.V.). Strata 04 and 08 were not surveyed.

2009	Stratum				All herring backscattering coefficients (s_a)					Fall spawners				Spring spawners			
							Weighted mean s_a				Biomass				Biomass		
Name	Stratum	Area (km²)	Transect number	Transect average length (m)	Sampling density (km · km⁻²)	Total s_a (m²)	Mean (m² · m⁻²)	S.E.	C.V.	Biomass density (kg · m⁻²)	Total (t)	S.E.	C.V.	Biomass density (kg · m⁻²)	Total (t)	S.E.	C.V.
St. Georges S.	01	407.7	15	4,068	1.497e-01	4,437.6	1.088e-05	5.247e-06	48.2	0.0126	5,117.9	2,467.47	48.2	0.00116	471.8	227.45	48.2
St. Georges N.	02	187.7	8	4,124	1.757e-01	9,481.1	5.050e-05	3.671e-05	72.7	0.0582	10,934.6	7,948.59	72.7	0.00537	1,007.9	732.70	72.7
Port-au-port G.	03	1,983.0	17	18,865	1.617e-01	7,839.8	3.954e-06	1.412e-06	35.7	0.00456	9,041.6	3,229.60	35.7	0.00042	833.5	297.70	35.7
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	474.5	9	13,721	2.603e-01	10.5	2.211e-08	8.323e-09	37.6	2.55e-05	12.1	4.55	37.6	2.35e-06	1.1	0.42	37.6
Bonne Bay Bank	06	1,080.7	20	10,746	1.989e-01	2,035.9	1.884e-06	7.048e-07	37.4	0.00217	2,348.0	878.51	37.4	0.0002	216.4	80.98	37.4
Bay of Islands	07	206.4	6	7,828	2.275e-01	181.2	8.778e-07	7.002e-07	79.8	0.00101	209.0	166.71	79.8	9.33e-05	19.3	15.37	79.8
Bras Nord	BN	31.1	2	2,823	1.816e-01	580.0	1.865e-05	2.236e-05	119.8	0.0216	672.1	805.49	119.8	0.00191	59.4	71.16	119.8
Bonne Bay	08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	09	499.8	4	8,261	6.611e-02	185.9	3.719e-07	1.248e-07	33.6	0.000437	218.3	73.24	33.6	3.75e-05	18.8	6.30	33.6
St. John Bay	10	1,437.0	14	19,628	1.912e-01	131.6	9.157e-08	7.622e-08	83.2	0.000106	151.8	126.32	83.2	9.73e-06	14.0	11.64	83.2
Basse-Côte-Nord	4Sw	2,741.3	23	15,515	1.302e-01	3,930.2	1.434e-06	5.449e-07	38.0	0.00145	3,971.6	1,509.40	38.0	0.000349	957.7	363.98	38.0
Average/Total	-	**9,049.3**	**118**	**12,461**	**1.625e-01**	**28,813.9**	**8.867e-05**	**4.334e-05**	**48.9**	**0.00361**	**32,675.2**	**9,134.39**	**28.0**	**0.000398**	**3,598.2**	**906.07**	**25.2**

Table 5. *Summary of the data inputs and results for the 2010 acoustic survey according to revised methods (Table 1), with their standard errors (S.E.) and coefficients of variation (C.V.). Stratum 04 was not surveyed.*

2010	Stratum				All herring backscattering coefficients (s_a)					Fall spawners				Spring spawners			
							Weighted mean s_a			Biomass density	Biomass			Biomass density	Biomass		
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km · km^{-2})	Total s_a (m^2)	Mean (m^2 · m^{-2})	S.E.	C.V.	(kg · m^{-2})	Total (t)	S.E.	C.V.	(kg · m^{-2})	Total (t)	S.E.	C.V.
St. Georges S.	01	407.7	13	4,442	1.416e-01	3,438.0	8.432e-06	6.188e-06	73.4	0.00947	3,863.3	2,835.2	73.4	0.00147	597.8	438.73	73.4
St. Georges N.	02	302.7	15	5,052	2.503e-01	4,074.3	1.346e-05	6.703e-06	49.8	0.0151	4,578.2	2,280.4	49.8	0.00234	708.5	352.88	49.8
Port-au-port G.	03	55.1	2	1739	6.317e-02	553.6	1.005e-05	3.426e-06	34.1	0.0113	622.0	211.9	34.1	0.00155	85.1	29.001	34.1
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	474.5	8	14,602	2.462e-01	7,106.7	1.498e-05	2.730e-06	18.2	0.0168	7,985.7	1,455.6	18.2	0.0026	1,235.7	225.25	18.2
Bonne Bay Bank	06	638.3	10	8,410	1.318e-01	6,899.5	1.081e-05	2.318e-06	21.4	0.0121	7,752.8	1,663.0	21.4	0.00188	1,199.7	257.34	21.4
Bay of Islands	07	245.4	3	15,221	1.861e-01	2,075.8	8.459e-06	3.498e-06	41.4	0.0095	2,332.5	964.6	41.4	0.00147	361.0	149.26	41.4
Bras Nord	BN	31.0	3	2991	2.895e-01	14.9	4.821e-07	8.318e-08	17.3	0.000542	16.8	2.9	17.3	7.41e-05	2.3	0.396	17.3
Bonne Bay	08	35.3	3	3,470	2.948e-01	31.6	8.949e-07	2.656e-07	29.7	0.00101	35.5	10.5	29.7	0.000156	5.5	1.63	29.7
Hawk's Bay	09	412.8	10	8,268	2.003e-01	1,945.9	4.713e-06	4.450e-06	94.4	0.0053	2,186.5	2,064.3	94.4	0.00082	338.4	319.44	94.4
St. John Bay	10	945.3	12	13,177	1.673e-01	27,229.6	2.880e-05	8.404e-06	29.2	0.0324	30,597.5	8,927.1	29.2	0.00501	4,734.8	1,381.43	29.2
Basse-Côte-Nord	4Sw	625.5	11	7,447	1.310e-01	6,482.1	1.036e-05	4.449e-06	42.9	0.0128	7,989.7	3,430.0	42.9	0.000714	446.6	191.71	42.9
Average/Total	-	**4,173.8**	**90**	**8,063**	**1.739e-01**	**59,852.0**	**1.114e-04**	**1.518e-05**	**13.6**	**0.0163**	**67,909.6**	**10,707.2**	**15.8**	**0.00233**	**9,711.4**	**1,581.84**	**16.3**

Table 6. *Summary of the data inputs and results for the 2011 acoustic survey according to revised methods (Table 1), with their standard errors (S.E.) and coefficients of variation (C.V.). Stratum 04 was not surveyed.*

2011	Stratum				All herring 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})	S.E.	C.V.	Biomass density (kg · m^{-2})	Biomass Total (t)	S.E.	C.V.	Biomass density (kg · m^{-2})	Biomass Total (t)	S.E.	C.V.
St. Georges S.	01	386.5	17	3,856	1.696e-01	617.6	1.598e-06	4.522e-07	28.3	0.00183	708.3	200.4	28.3	0.000159	61.5	17.41	28.3
St. Georges N.	02	299.4	14	5,744	2.686e-01	929.8	3.105e-06	1.897e-06	61.1	0.00356	1,066.2	651.3	61.1	0.000309	92.6	56.59	61.1
Port-au-port G.	03	802.9	16	8,060	1.606e-01	2,805.1	3.494e-06	8.264e-07	23.7	0.00401	3,216.8	760.9	23.7	0.000348	279.5	66.11	23.7
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	474.5	8	14,223	2.398e-01	944.5	1.991e-06	5.659e-07	28.4	0.00234	1,110.4	315.6	28.4	0.000112	53.1	15.10	28.4
Bonne Bay Bank	06	1,148.1	23	11,184	2.241e-01	6,368.1	5.547e-06	2.521e-06	45.4	0.00652	7,486.3	3,402.4	45.4	0.000312	358.2	162.79	45.4
Bay of Islands	07	198.2	3	13,081	1.980e-01	101.4	5.114e-07	5.617e-08	11.0	0.000601	119.2	13.1	11.0	2.88e-05	5.7	0.63	11.0
Bras Nord	BN	31.0	3	3329	3.222e-01	25.1	8.108e-07	2.865e-07	35.3	0.000934	29.0	10.2	35.3	7.32e-05	2.3	0.802	35.3
Bonne Bay	08	54.5	3	3,750	2.063e-01	98.9	1.814e-06	1.231e-06	67.9	0.00213	116.3	78.9	67.9	0.000102	5.6	3.78	67.9
Hawk's Bay	09	499.8	12	8,543	2.051e-01	546.7	1.094e-06	2.672e-07	24.4	0.00113	563.4	137.7	24.4	0.000125	62.6	15.31	24.4
St. John Bay	10	728.1	14	12,619	2.427e-01	17,100.3	2.349e-05	7.050e-06	30.0	0.0242	17,624.4	5,290.1	30.0	0.00269	1,959.4	588.15	30.0
Basse-Côte-Nord	4Sw	1,601.7	24	9,861	1.478e-01	3,277.8	2.047e-06	7.920e-07	38.7	0.00209	3,353.5	1,297.8	38.7	0.000164	263.1	101.82	38.7
Average/Total	-	**6,224.7**	**137**	**8,922**	**1.964e-01**	**32,815.4**	**4.550e-05**	**7.947e-06**	**17.5**	**0.00568**	**35,358.0**	**6,505.9**	**18.4**	**0.000504**	**3,136.2**	**623.89**	**19.9**

Table 7. *Summary of the data inputs and results for the 2013 acoustic survey according to revised methods (Table 1), with their standard errors (S.E.) and coefficients of variation (C.V.). Stratum 04 was not surveyed.*

2013	**Stratum**				**All herring 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	407.7	17	3,995	1.666e-01	1,473.06	3.613e-06	3.253e-06	90.0	0.00453	1,848.0	1 663.96	90.0	3.9e-05	15.9	14.33	90.0
St. Georges N.	02	302.7	15	5,391	2.672e-01	1,282.39	4.236e-06	2.082e-06	49.1	0.00531	1,608.8	790.62	49.1	4.58e-05	13.9	6.81	49.1
Port-au-port G.	03	802.9	17	8,863	1.877e-01	536.38	6.681e-07	5.709e-07	85.5	0.000807	648.3	554.02	85.5	6.52e-06	5.2	4.47	85.5
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	474.5	9	13,382	2.538e-01	739.78	1.559e-06	7.757e-07	49.8	0.00188	894.2	444.88	49.8	1.52e-05	7.2	3.59	49.8
Bonne Bay Bank	06	1,148.1	23	11,322	2.268e-01	36,658.02	3.193e-05	1.741e-05	54.5	0.0387	44,407.7	24,218.84	54.5	0.000194	222.6	121.40	54.5
Bay of Islands	07	281.5	4	14,508	2.061e-01	959.02	3.406e-06	2.212e-06	64.9	0.00412	1,159.2	752.67	64.9	3.32e-05	9.4	6.07	64.9
Bras Nord	BN	31.0	3	2,897	2.803e-01	8.05	2.597e-07	1.730e-07	66.6	0.000314	9.7	6.49	66.6	2.54e-06	0.1	0.0526	66.6
Bonne Bay	08	35.4	3	3,123	2.647e-01	3.98	1.123e-07	1.839e-08	16.4	0.000136	4.8	0.79	16.4	6.82e-07	0.0	0.004	16.4
Hawk’s Bay	09	499.8	12	8,752	2.101e-01	700.93	1.402e-06	4.890e-07	34.9	0.0017	849.1	296.07	34.9	8.51e-06	4.3	1.48	34.9
St. John Bay	10	799.5	17	11,103	2.361e-01	3,661.84	4.580e-06	4.275e-06	93.3	0.00555	4,436.0	4,140.12	93.3	2.78e-05	22.2	20.75	93.3
Basse-Côte-Nord	4Sw	1,601.7	24	9,885	1.481e-01	883.93	5.519e-07	1.551e-07	28.1	0.00064	1,024.5	288.0	28.1	0	-	-	-
Average/Total	-	**6,384.9**	**144**	**8,940**	**2.016e-01**	**46,907.36**	**5.232e-05**	**1.851e-05**	**35.4**	**0.00892**	**56,948.0**	**24,689.29**	**43.4**	**4.74e-05**	**302.4**	**125.22**	**41.4**

Table 8. Summary of the data inputs and results for the 2015 acoustic survey according to revised methods (Table 1), with their standard errors (S.E.) and coefficients of variation (C.V.). Strata 03, 04, 07, BN, 08, 09 and 4Sw were not surveyed.

2015	Stratum				All herring backscattering coefficients (s_a)					Fall spawners				Spring spawners			
							Weighted mean s_a				Biomass				Biomass		
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km · km^{-2})	Total s_a (m^2)	Mean (m^2 · m^{-2})	S.E.	C.V.	Biomass density (kg · m^{-2})	Total (t)	S.E.	C.V.	Biomass density (kg · m^{-2})	Total (t)	S.E.	C.V.
St. Georges S.	01	407.7	17	4,283	1.786e-01	284	6.957e-07	5.542e-07	79.7	0.000833	339.7	270.60	79.7	3.4e-05	13.9	11.05	79.7
St. Georges N.	02	299.0	14	6,036	2.826e-01	482	1.613e-06	1.384e-06	85.8	0.00193	577.6	495.50	85.8	7.89e-05	23.6	20.23	85.8
Port-au-port G.	03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	464.5	8	14,424	2.484e-01	13,427	2.890e-05	8.305e-06	28.7	0.0356	16,558.6	4,758.27	28.7	0.000581	270.0	77.60	28.7
Bonne Bay Bank	06	1,132.5	11	11,324	1.100e-01	10,556	9.321e-06	2.877e-06	30.9	0.0115	13,018.4	4,018.17	30.9	0.000187	212.3	65.53	30.9
Bay of Islands	07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bras Nord	BN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
St. John Bay	10	876.7	7	15,575	1.244e-01	1,967	2.244e-06	9.578e-07	42.7	0.00259	2,266.5	967.32	42.7	8.96e-05	78.6	33.53	42.7
Basse-Côte-Nord	4Sw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average/Total	-	**3,180.5**	**57**	**8,882**	**1.592e-01**	**26,716**	**4.278e-05**	**8.966e-06**	**21.0**	**0.0103**	**32,760.8**	**6,327.82**	**19.3**	**0.000188**	**598.4**	**109.41**	**18.3**

Table 9. Summary of the data inputs and results for the 2017 acoustic survey according to revised methods (Table 1), with their standard errors (S.E.) and coefficients of variation (C.V.). Stratum 04 was not surveyed.

2017	Stratum				All herring backscattering coefficients (s_a)					Fall spawners				Spring spawners			
					Sampling density	Total s_a	Weighted mean s_a			Biomass density	Biomass			Biomass density	Biomass		
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	(km · km^{-2})	(m^2)	Mean (m^2 · m^{-2})	S.E.	C.V.	(kg · m^{-2})	Total (t)	S.E.	C.V.	(kg · m^{-2})	Total (t)	S.E.	C.V.
St. Georges S.	01	126.6	4	5,623	1.777e-01	43.8	3.461e-07	7.777e-08	22.5	0.000355	45.0	10.1	22.5	4.98e-05	6.3	1.42	22.5
St. Georges N.	02	303.7	15	5,280	2.608e-01	1,763.9	5.808e-06	4.821e-06	83.0	0.00596	1,810.9	1,503.1	83.0	0.000836	253.9	210.71	83.0
Port-au-port G.	03	802.9	17	8,261	1.749e-01	2,799.1	3.486e-06	1.369e-06	39.3	0.00358	2,873.8	1,128.4	39.3	0.000502	402.9	158.19	39.3
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	474.5	9	13,294	2.522e-01	381.7	8.044e-07	2.758e-07	34.3	0.000919	436.1	149.5	34.3	4.47e-05	21.2	7.28	34.3
Bonne Bay Bank	06	1,148.1	23	10,915	2.187e-01	3,353.5	2.921e-06	7.499e-07	25.7	0.00334	3,832.1	983.8	25.7	0.000162	186.5	47.89	25.7
Bay of Islands	07	192.7	3	12,026	1.873e-01	144.4	7.496e-07	6.336e-07	84.5	0.000857	165.0	139.5	84.5	4.17e-05	8.0	6.79	84.5
Bras Nord	BN	31.0	3	2,978	2.882e-01	2.05	6.609e-08	2.803e-08	42.4	5.01e-05	1.6	0.659	42.4	2.26e-05	0.7	0.30	42.4
Bonne Bay	08	54.5	3	2,930	1.612e-01	27.5	5.050e-07	1.694e-07	33.5	0.000577	31.5	10.6	33.5	2.81e-05	1.5	0.51	33.5
Hawk's Bay	09	499.8	11	9,055	1.993e-01	719.5	1.439e-06	1.244e-06	86.4	0.00164	822.2	710.3	86.4	8.01e-05	40.0	34.57	86.4
St. John Bay	10	743.2	16	10,331	2.224e-01	6,956.4	9.360e-06	3.540e-06	37.8	0.0101	7,470.4	2,825.5	37.8	0.00139	1,033.8	391.03	37.8
Basse-Côte-Nord	4Sw	297.4	5	9,741	1.638e-01	46.85	1.575e-07	2.197e-08	14.0	0.000168	50.1	6.99	14.0	1.36e-05	4.0	0.564	14.0
Average/Total	-	**4,674.4**	**109**	**8,993**	**2.097e-01**	**16,238.7**	**2.564e-05**	**6.346e-06**	**24.7**	**0.00376**	**17,588.8**	**3,620.64**	**20.6**	**0.000416**	**1,943.3**	**471.20**	**24.2**

Table 10. Summary of the data inputs and results for 2019 acoustic survey according to revised methods (Table 1), with their standard errors (S.E.) and coefficients of variation (C.V.). Strata 01, 02, 04, BN, BI01 and BI02 were not surveyed.

2019	**Stratum**				**All herring backscattering coefficients (s_a)**					**Fall spawners**				**Spring spawners**			
							Weighted mean s_a				**Biomass**				**Biomass**		
Name	**Stratum**	**Area (km^2)**	**Transect number**	**Transect average length (m)**	**Sampling density ($km \cdot km^{-2}$)**	**Total s_a (m^2)**	**Mean ($m^2 \cdot m^{-2}$)**	**S.E.**	**C.V.**	**Biomass density ($kg \cdot m^{-2}$)**	**Total (t)**	**S.E.**	**C.V.**	**Biomass density ($kg \cdot m^{-2}$)**	**Total (t)**	**S.E.**	**C.V.**
St. Georges S.	01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
St. Georges N.	02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-port G.	03	730.0	3	11,034	4.535e-02	3,185	4.363e-06	1.716e-06	39.3	0.00413	3,013.8	1,185.4	39.3	0.00145	1,059.8	416.8	39.3
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	474.5	1	1780	3.753e-03	35.5	7.485e-08	0	0	5.31e-05	25.2	0	0	2.7e-05	12.8	0	0
Bonne Bay Bank	06	972.8	7	11,044	7.947e-02	13,827	1.421e-05	3.746e-06	26.4	0.00962	9,353.7	2,464.7	26.4	0.00534	5,195.7	1,369.1	26.4
Bay of Islands	07	299.9	3	16,569	1.658e-01	694	2.316e-06	6.125e-07	26.5	0.00164	492.9	130.4	26.5	0.000838	251.2	66.5	26.5
Bras Nord	BN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	08	58.5	4	2,677	1.831e-01	164	2.795e-06	7.699e-07	27.5	0.00189	110.6	30.5	27.5	0.00105	61.4	16.9	27.5
Hawk's Bay	09	499.8	5	9,878	9.882e-02	4,167	8.337e-06	4.638e-06	55.6	0.00301	1,503.3	836.3	55.6	0.00436	2,181.5	1,213.5	55.6
St. John Bay	10	996.9	6	15,033	9.048e-02	24,018	2.409e-05	3.356e-06	13.9	0.0122	12,123.6	1,689.0	13.9	0.00964	9,610.4	1,338.9	13.9
Basse-Côte-Nord	4Sw	2,194.9	13	12,821	7.594e-02	2,593	1.181e-06	5.561e-07	47.1	0.000596	1,308.7	616.1	47.1	0.000473	1,037.4	488.4	47.1
Belle Isle S.	BI01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Belle Isle N.	BI02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average/Total		**6,227.3**	**42**	**11,401**	**7.690e-02**	**48,684.0**	**5.737e-05**	**7.143e-06**	**12.5**	**0.00448**	**27,890.6**	**3,378.2**	**12.1**	**0.00311**	**19,342.6**	**2,349.3**	**12.1**

Table 11. *Summary of the data inputs and results for the 2020 acoustic survey according to revised methods (Table 1), with their standard errors (S.E.) and coefficients of variation (C.V.). Strata 04, BN, 08, BI01 and BI02 were not surveyed.*

2020	Stratum				All herring 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	407.7	7	4,556	7.822e-02	138	3.390e-07	1.583e-07	46.7	0.000288	117.4	54.8	46.7	8.07e-05	32.9	15.4	46.7
St. Georges N.	02	302.7	4	7,026	9.283e-02	509	1.681e-06	7.636e-07	45.4	0.00143	432.3	196.4	45.4	0.0004	121.1	55.0	45.4
Port-au-port G.	03	802.9	7	9,270	8.083e-02	1,205	1.501e-06	5.433e-07	36.2	0.000877	704.0	254.8	36.2	0.000517	415.1	150.3	36.2
Port-au-port	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	05	474.5	3	14,772	9.340e-02	291	6.143e-07	2.521e-07	41.0	0.000379	179.7	73.7	41.0	0.000199	94.2	38.7	41.0
Bonne Bay Bank	06	1,148.1	7	12,089	7.371e-02	1,700	1.481e-06	4.103e-07	27.7	0.000965	1,107.4	306.8	27.7	0.000523	600.9	166.5	27.7
Bay of Islands	07	286.2	4	17,867	2.497e-01	1,523	5.321e-06	9.215e-07	17.3	0.00323	925.4	160.3	17.3	0.00187	536.0	92.8	17.3
Bras Nord	BN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	09	499.8	4	7,794	6.238e-02	373	7.465e-07	2.756e-07	36.9	0.000468	233.9	86.3	36.9	0.000271	135.5	50.0	36.9
St. John Bay	10	967.8	8	13,288	1.098e-01	2,557	2.642e-06	9.835e-07	37.2	0.00198	1,920.1	714.8	37.2	0.00081	783.6	291.7	37.2
Basse-Côte-Nord	4Sw	2,169.6	10	11,956	5.511e-02	17,664	8.142e-06	4.622e-06	56.8	0.00611	13,265.7	7,530.0	56.8	0.0025	5,413.8	3,073.0	56.8
Belle Isle S.	BI01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Belle Isle N.	BI02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average/Total	-	**7,059.3**	**54**	**10,784**	**8.250e-02**	**25,961**	**2.247e-05**	**4.938e-06**	**22.0**	**0.00268**	**18,885.7**	**7,579.7**	**40.1**	**0.00115**	**8,133.1**	**3,097.5**	**38.1**

Table 12. Summary of the data inputs and results for the 2021 acoustic survey according to revised methods (Table 1), with their standard errors (S.E.) and coefficients of variation (C.V.). Strata 07, BN and 08 were not surveyed.

2021	Stratum				All herring 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: Mean ($m^2 \cdot m^{-2}$)	Weighted mean s_a: S.E.	Weighted mean s_a: C.V.	Biomass density ($kg \cdot m^{-2}$)	Biomass: Total (t)	Biomass: S.E.	Biomass: C.V.	Biomass density ($kg \cdot m^{-2}$)	Biomass: Total (t)	Biomass: S.E.	Biomass: C.V.
St. Georges S.	01	407.7	10	4,188	1.027e-01	729	1.788e-06	6.358e-07	35.6	0.000391	159.6	56.8	35.6	0.00133	540.4	192.2	35.6
St. Georges N.	02	302.7	6	6,283	1.245e-01	489	1.616e-06	6.106e-07	37.8	0.000471	142.7	53.9	37.8	0.00108	328.0	123.9	37.8
Port-au-port G.	03	796.3	9	9,232	1.043e-01	1,909	2.398e-06	9.388e-07	39.2	0.000474	377.4	147.7	39.2	0.00181	1,441.5	564.4	39.2
Port-au-port	04	352.5	6	10,015	1.705e-01	1,469	4.168e-06	2.248e-06	53.9	0.00131	461.7	249.0	53.9	0.00268	943.2	508.8	53.9
Bay of Islands G.	05	477.9	4	14,650	1.226e-01	1,195	2.500e-06	5.473e-07	21.9	0.000938	448.1	98.1	21.9	0.00156	743.9	162.8	21.9
Bonne Bay Bank	06	1,157.3	11	12,061	1.146e-01	3,187	2.754e-06	8.738e-07	31.7	0.00224	2,593.8	823.0	31.7	0.000994	1,150.9	365.2	31.7
Bay of Islands	07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bras Nord	BN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	09	499.7	7	8,158	1.143e-01	695	1.392e-06	1.014e-06	72.9	0.00113	566.0	412.5	72.9	0.000503	251.1	183.0	72.9
St. John Bay	10	983.3	8	11,935	9.710e-02	1,318	1.341e-06	4.848e-07	36.2	0.000885	869.8	314.5	36.2	0.000569	559.6	202.4	36.2
Basse-Côte-Nord	4Sw	2,194.9	18	12,330	1.011e-01	6,843	3.118e-06	8.113e-07	26.0	0.00116	2,538.0	660.4	26.0	0.00166	3,649.1	949.5	26.0
Belle Isle S.	BI01	1,092.2	12	9,123	1.002e-01	31,796	2.911e-05	1.135e-05	39.0	0.00607	6,634.3	2,586.5	39.0	0.022	24,073.9	9,385.6	39.0
Belle Isle N.	BI02	626.8	9	7,550	1.084e-01	14,064	2.244e-05	9.737e-06	43.4	0.00396	2,479.5	1,076.0	43.4	0.013	8,139.7	3,532.2	43.4
Average/Total (without BI)	-	**7,172.6**	**79**	**9,982**	**1.099e-01**	**17,836**	**2.107e-05**	**3.114e-06**	**14.8**	**0.00114**	**8,156.9**	**1,217.4**	**14.9**	**0.00134**	**9,607.8**	**1,328.7**	**13.8**
Average/Total (with BI)	-	**8,891.6**	**100**	**9,660**	**1.086e-01**	**63,696**	**7.262e-05**	**1.527e-05**	**21.0**	**0.00194**	**17,270.8**	**3,054.5**	**17.7**	**0.0047**	**41,821.3**	**10,116.2**	**24.2**

FIGURES

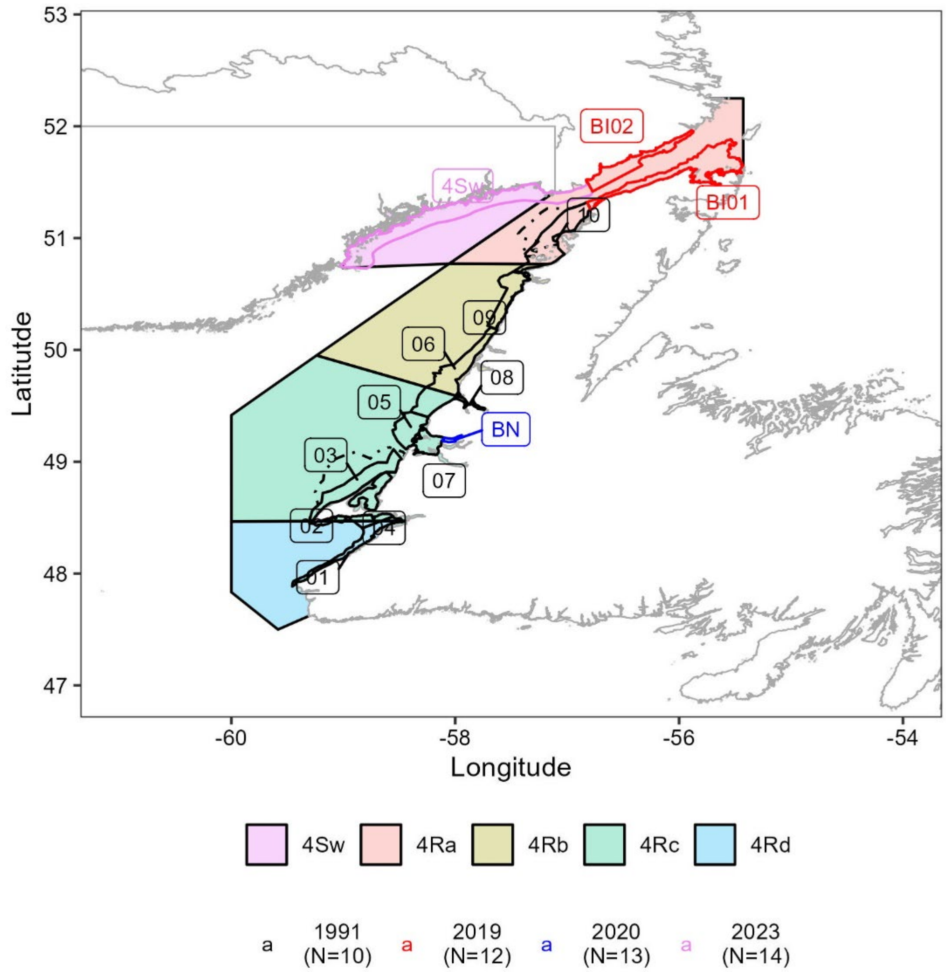

Figure 1. Evolution of the number and identity of acoustic-survey strata from the original survey design proposed in 1991 (surface areas in km^2: 01=407.7, 02=302.7, 03=796.3, 04=352.5, 05=477.9, 06=1,157.3, 07=306.2, 08=58.5, 09=499.7, 10=983.3) to the versions that were presented in 2019 (1991 version plus BI01=1,163 and BI02=626.8), 2020 (2019 version plus BN=32.90 km^2) and 2023 (2020 version plus 4Sw=2,194.9 km^2). Strata 03 and 10 before area reduction in 2010 are represented with a black dashed line. Note that the BN and 4Sw strata were sampled from 2009, while the BI01 and BI02 strata were sampled from 2019 only.

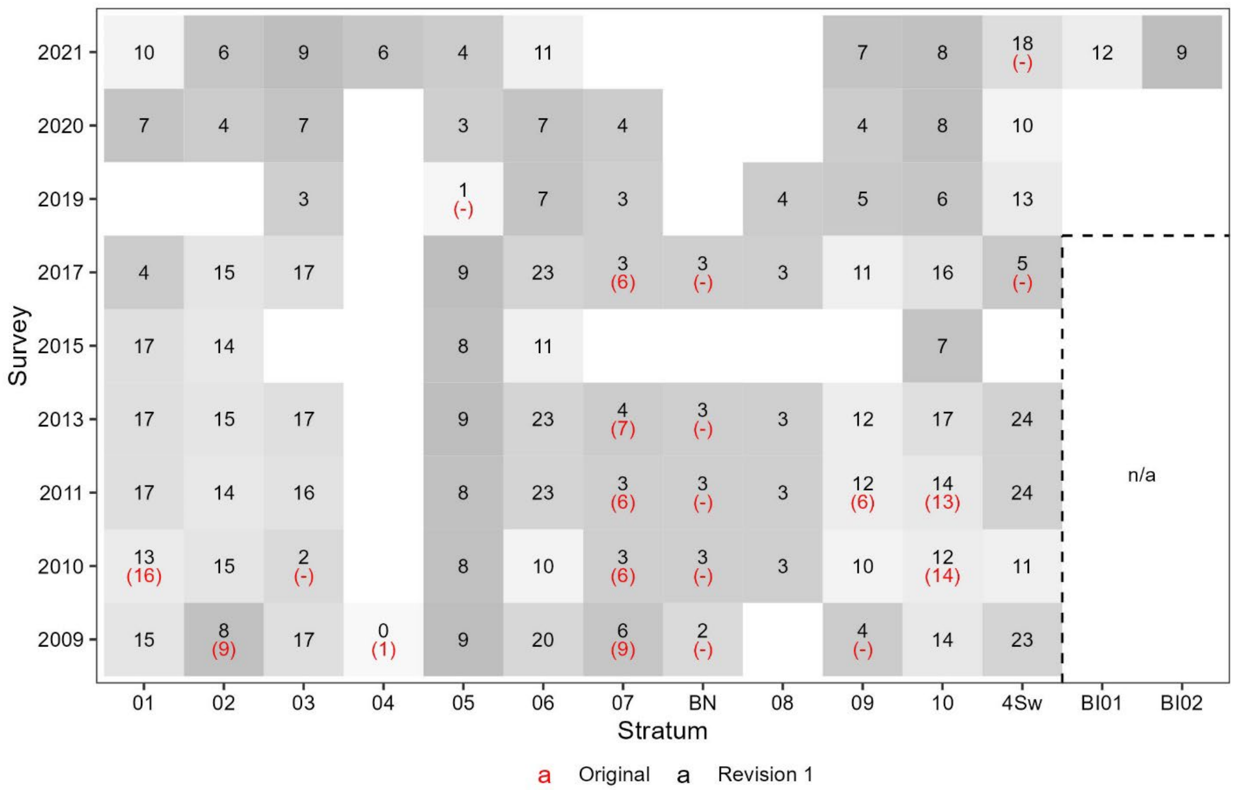

Figure 2. Numbers of transects surveyed by stratum and survey according to Revision 1 and, when different, the Original methods. Empty cells identify the strata that have not been surveyed (zero transect) whereas the dash symbol identifies the strata that have been surveyed but for which the results have not been reported in the assessment report for either division 4R (Émond et al. 2024) or 4Sw (DFO 2021b). The blank 'n/a' rectangle illustrates that the BI01 and BI02 strata were not part of the theoretical survey design until 2019.

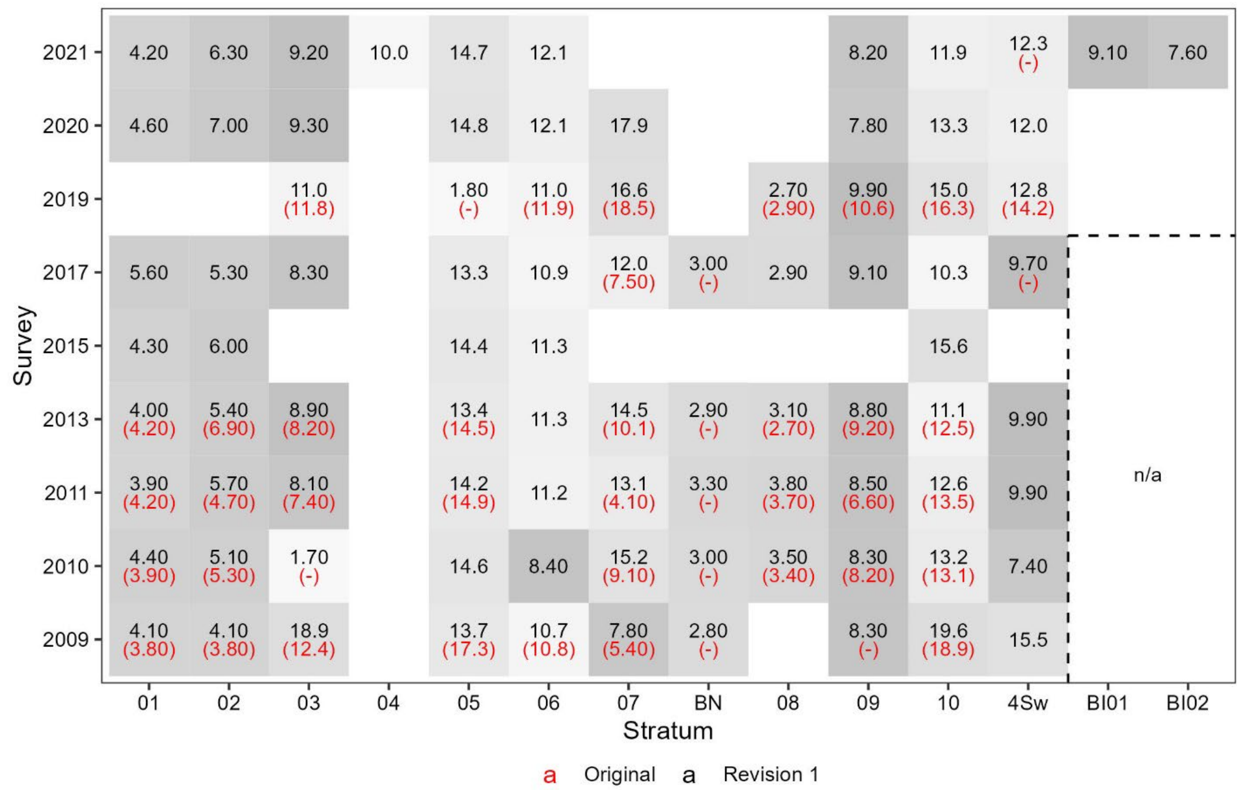

Figure 3. Average length of transects by stratum and survey (unit: km) according to Revision 1 and, when different, the Original methods. Empty cells identify the strata that have not been surveyed (zero transect) whereas the dash symbol identifies the strata that have been surveyed but for which the results have not been reported in the assessment report for either division 4R (Émond et al. 2024) or 4Sw (DFO 2021b). The blank 'n/a' rectangle illustrates that the BI01 and BI02 strata were not part of the theoretical survey design until 2019.

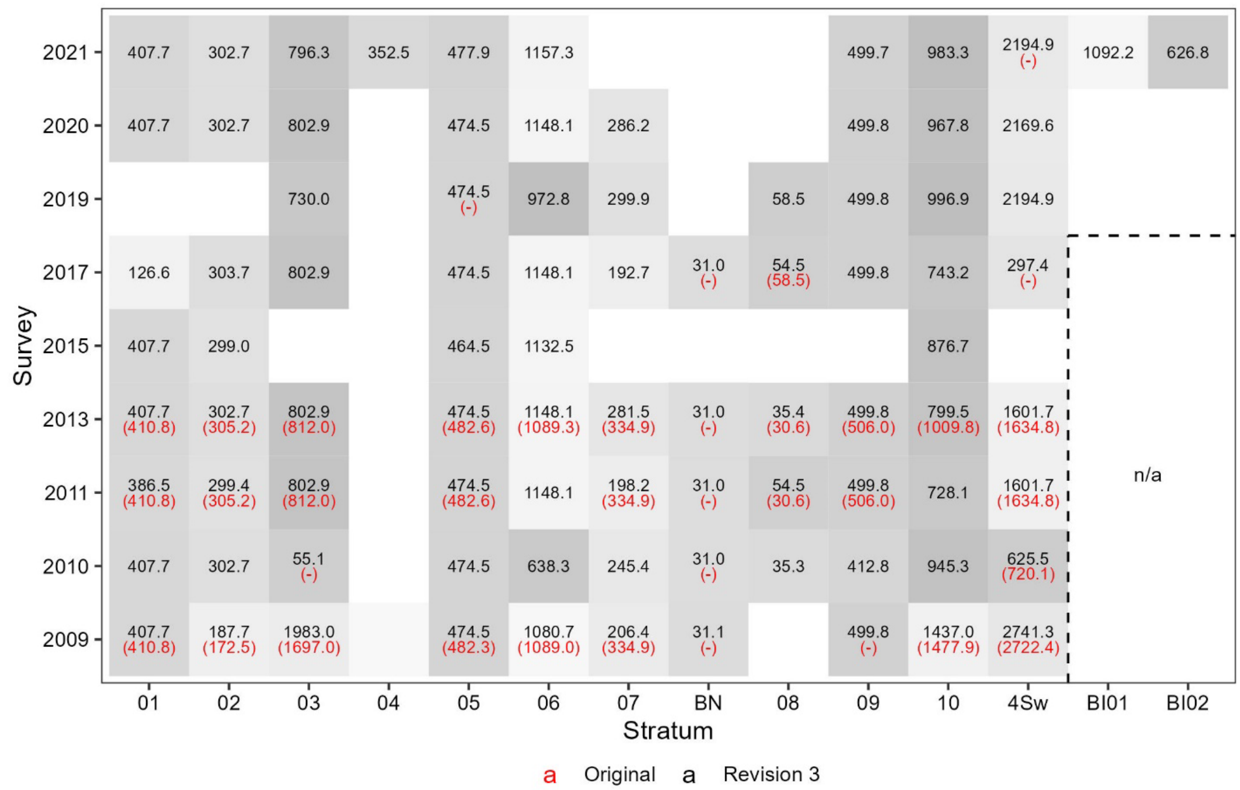

Figure 4. Estimated surface area of the strata surveyed in km2 within each stratum and survey according to revised methods (Revision 3) and, when different, the original assessment values. Empty cells identify the strata that have not been surveyed (zero transect) whereas the dash symbol identifies the strata that have been surveyed but for which the results have not been reported in the assessment report for either division 4R (Émond et al. 2024) or 4Sw (DFO 2021b). The blank 'n/a' rectangle illustrates that the BI01 and BI02 strata were not part of the theoretical survey design until 2019.

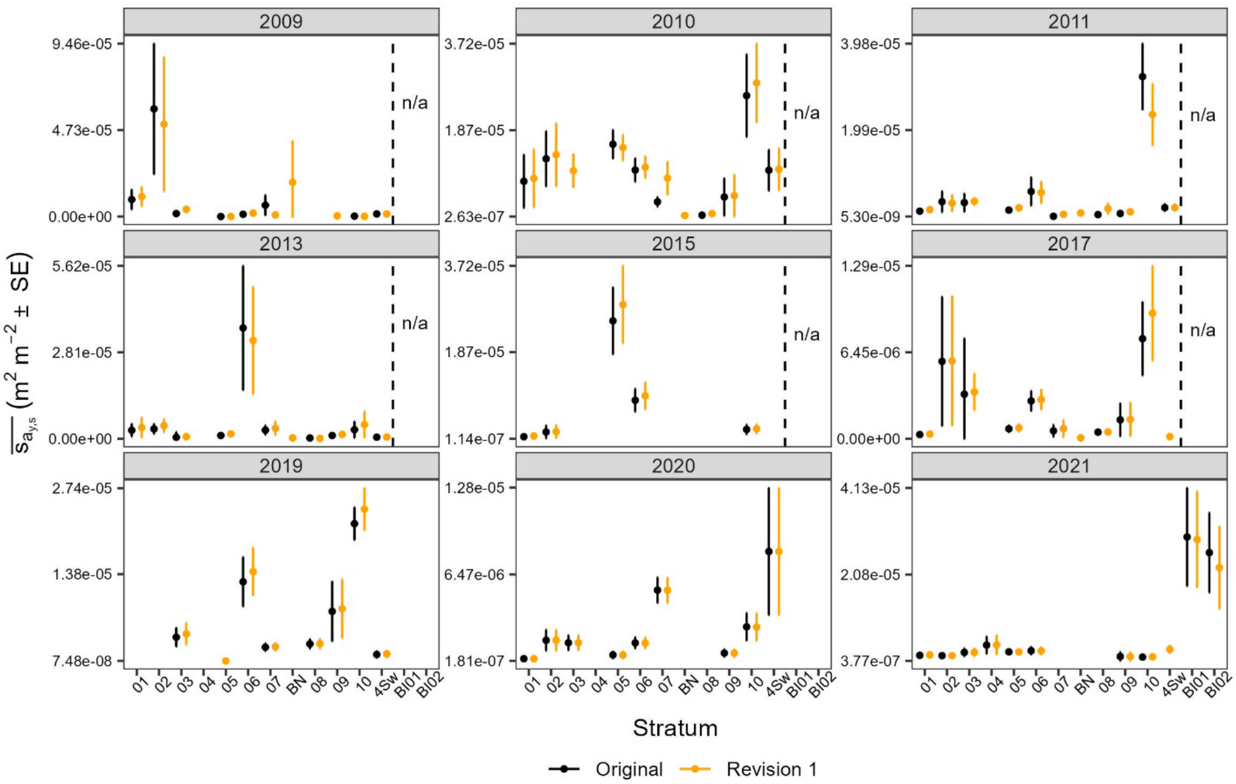

Figure 5. Comparison of the $\overline{s_{a_{y,s}}}$ *and standard error (SE,* $\sqrt{\sigma^2_{\overline{s_{a_{y,s}}}}}$*) presented in the last published assessment (Original) and the estimations incorporating the standardized acoustic inputs and methods (Revision 1). The blank 'n/a' rectangles illustrate that the BI01 and BI02 strata were not part of the theoretical survey design until 2019.*

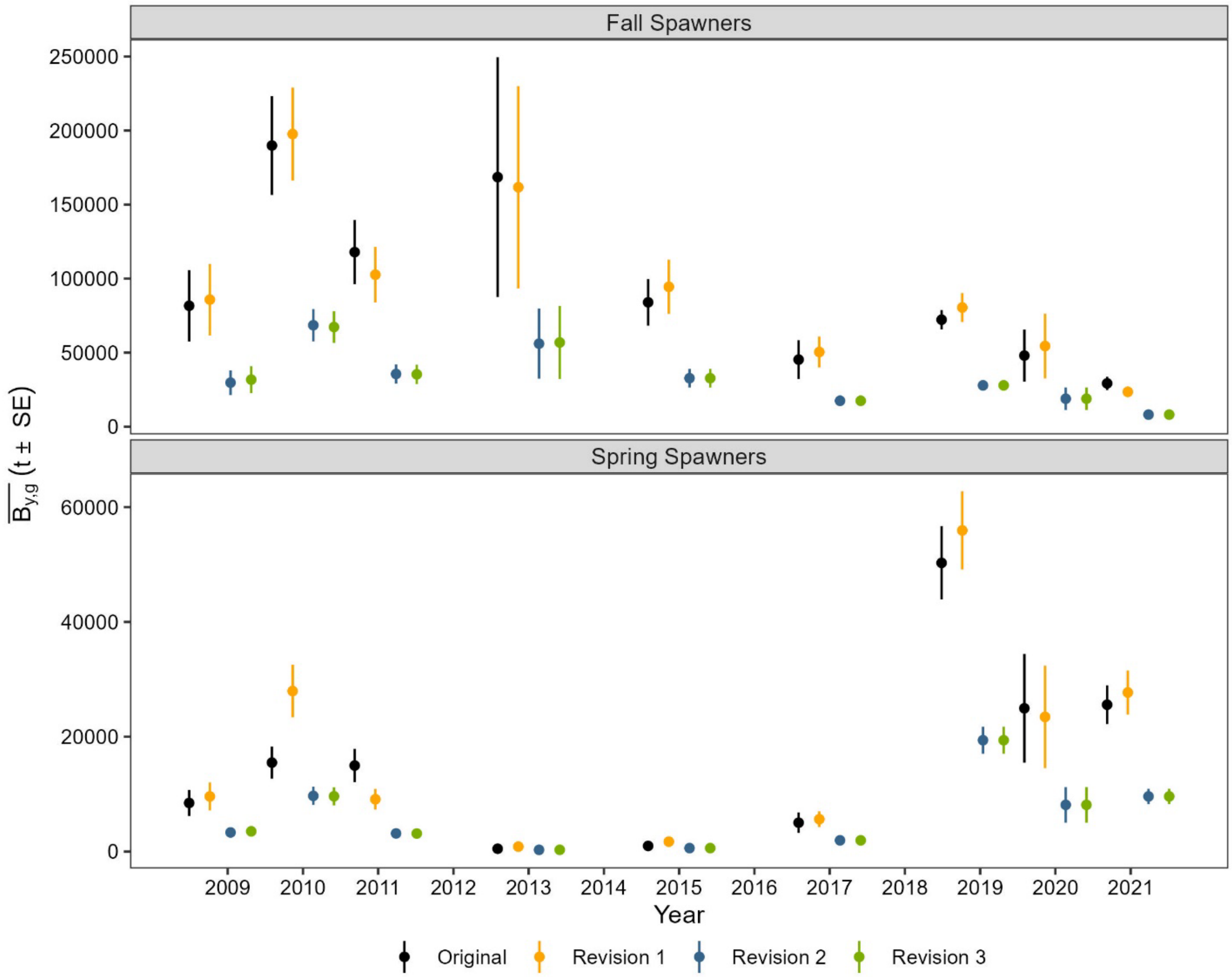

Figure 6. Evolution of the $\overline{B_{y,g}}$ and their standard error (SE, $\sqrt{\sigma^2_{\overline{B_{y,g}}}}$) from the last published assessment (Original) to the revisions incorporating, in a step-wise manner, the standardized acoustic data inputs (Revision 1), the change of target strength (Revision 2), and the revised strata surface areas (Revision 3).

APPENDIX A. SUPPLEMENTARY INFORMATION ON ACOUSTIC SURVEYS

Table A13. Hydroacoustic vessels employed for the estimation of herring biomass between 2009 and 2021 (CCGS: Canadian Coast Guard Ship; RV: Research Vessel) and their associated calibration parameters. Transducer's depth and half-beam angle apply to the 38 kHz transducer. The numbers in black indicate the parameters that were extracted from the header of revised HEI files whereas the numbers in red provide the values applied in the original assessments (when different).

Survey	Vessel	Transducer's depth (td; m)	Half-beam angle ($\emptyset$; °)
2009	CCGS F. G. Creed	2.400 (3.000)	3.450
2010	CCGS F. G. Creed	2.400 (3.000)	3.450
2011	CCGS F. G. Creed	2.400	3.450
2013	CCGS F. G. Creed	2.400	3.450
2015	CCGS Vladykov	3.500 (2.400)	3.475 (3.450)
2017	CCGS F. G. Creed	2.400	3.550 (3.450)
2019	CCGS Leim	3.000	3.450
2020	CCGS Leim	3.000	3.475
2021	RV Novus (Leeway Marine)	2.700 (2.400)	3.310 (3.500)

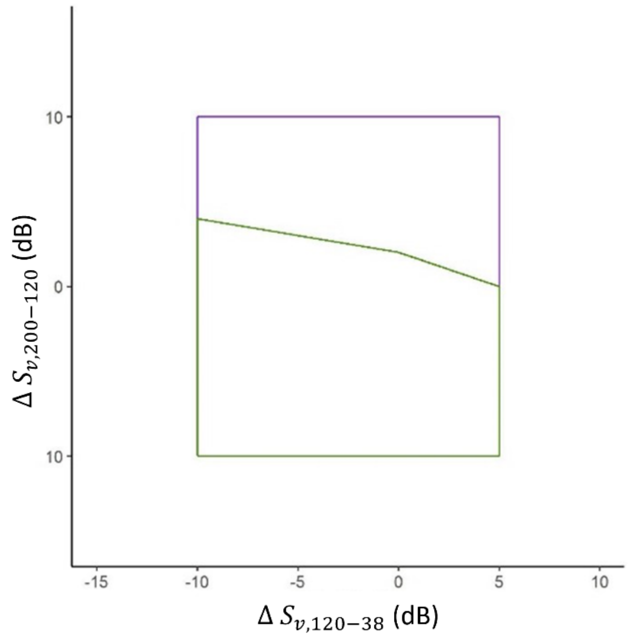

Figure A7. Polygons used in the multi-frequency classification of swimbladder (green) and non swimbladder (purple) fish , according to McQuinn (pers. comm.). Both axes represent pairwise frequency differences of volume backscattering strength S_v (dB re 1 m^{-1}), i.e., Δ$S_{v,i-j}$ = $S_{v,i}$ – $S_{v,j}$, where i and j are indices denoting frequency in kHz.