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Assessment of the West Coast of Newfoundland (NAFO Division 4R) Atlantic Herring (*Clupea harengus*) Stocks in 2021

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Canada

Foreword

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

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ABSTRACT

This document details the data and analyses used to assess the status of the west coast of Newfoundland (NAFO Division 4R) spring- and fall-spawning herring stocks. The present stock assessment took place on March 1-2, 2022 and provides advice for the 2022-2023 fishing seasons. The data and knowledge available are insufficient to quantitatively assess the status of the resource. However, the main results of this assessment indicate that maintaining the TAC at status quo should not pose any significant risk to the two herring spawning stocks in Division 4R in the short term. Maximum exploitation rates in 2020-2021, estimated as the ratio of the TAC over the highest biomass index estimated in the acoustic survey, were low (<15%). The abundance of young fish observed in the 2020-2021 acoustic surveys and commercial catches for both spring and fall spawners is an encouraging sign for the future of these stocks. Landings have been trending downward since 2017, and the recent decrease of 81% since 2019 can be explained by the high incidence of fish under the legal size that prevented harvesters from landing their quotas. After a period of low stock status in the 2000s and 2010s, there are signs of increase for the spring-spawning stock since 2019. This conclusion will need to be reconsidered following the review of the assessment framework in 2024-2025.

1. INTRODUCTION

Atlantic herring (*Clupea harengus*) is a schooling pelagic fish distributed throughout the North Atlantic Ocean and adjacent waters (Brunel and Dickey-Collas 2010). In Canada, its distribution extends from the coasts of Nova Scotia to those of Labrador. Herring stocks have a complex structure that remains largely unknown. Each stock consists of several populations that use temporally and spatially distinct spawning areas (Melvin et al. 2009, Stephenson et al. 2009). Every year, herring undertake extensive migrations between their feeding, spawning and overwintering areas. During these migrations, different populations (either from the same or adjacent stocks) mix during the feeding and overwintering periods, only to separate again into their individual components in the spawning season. The same herring return to the same spawning sites year after year. This homing phenomenon is attributed to a learning behaviour with the recruitment of young year-classes in a population (McQuinn 1997).

In many of the Northwest Atlantic ecosystems, herring populations are characterized by the presence of two spawning groups or stocks. Spring spawners (SS) generally spawn in April-May and fall spawners (FS) in August and September. Historically, southern areas were dominated by FS and northern areas by SS, although the trends of both spawning components have varied over time (Melvin et al. 2009). On the west coast of Newfoundland (NAFO division 4R; Figure 1A), SS and FS herring are considered separate stocks and are assessed separately. Recent genetic studies have confirmed the genetic differentiation between these two spawning groups (Lamichhaney et al. 2017, Chen et al. 2021).

In NAFO Division 4R, the herring fishery is managed by a total allowable catch (TAC) without distinction between the two spawning stocks. The current TAC of 20,000 t was established following scientific advice in the early 2000s (DFO 2003). The TAC is sub-divided into three allocation categories: mobile gear (purse seine) greater than or equal to 19.8 m (55% of the TAC: 11,000 t), mobile gear less than 19.8 m (22% of the TAC: 4,400 t), and fixed gear including modified bar seine known as “tuck seine” (23% of the TAC: 4,600 t). The greater than 19.8m mobile gear fishery operates under an individual transferable quota (ITQ) regime, whereas the less than 19.8 m mobile gear fishery operates under an individual quota (IQ) regime. The fixed gear fishery is fully competitive with separate quotas for herring fishing areas 13 and 14 (Figure 1B). The 4R herring stock is also a bait fishery in which harvesters are permitted to use gillnets to catch herring for use in commercial fisheries requiring bait such as lobster and snow crab. Since 2018, an annual allocation of 50 t for the bait fishery has been taken in the fixed gear allocation. Up until 2017, the minimum size limit for herring was established at a fork length of 26.5 cm, based on the mean length at 50% maturity, and a maximum of 10% undersized herring fishing trip was allowed. In 2017-2018, the minimum size limit for herring was decreased to 24.76 cm following an update of the mean length at 50% maturity, and the tolerance for undersized fish was increased to 20% (DFO 2018).

A first series of acoustic surveys was carried out in the fall (October-November) between 1991 and 2002 in division 4R to derive an estimate of herring abundance. A second series of surveys was initiated in the fall of 2009 and continued until 2021. The objective of these surveys was to estimate the abundance of SS and FS as they gather near the coast to feed before beginning their migration to overwintering areas. A summer (August) acoustic survey was also initiated in 2019 to target FS aggregations during their spawning season. The data collected from these surveys were used to calculate biomass indices for the two spawning stocks. These biomass indices are, along with commercial fishery data, the main source of information used to assess herring stock status in division 4R. During the last peer-review meeting in 2020, concerns related to some aspects of the acoustic survey index led to the rejection of the assessment model (virtual population analysis) as the basis for the science advice, resulting in the rejection of the reference points and the precautionary approach (Chamberland et al. 2022). A review of the assessment framework will be carried out in 2023-2025.

A peer-review meeting was conducted on March 1-2, 2022 to provide the regional fisheries management with advice on the status of herring stocks on the west coast of Newfoundland, published in the ensuing science advisory report (DFO 2022). This document details the data and analyses underlying the scientific advice. This includes the evaluation of the status of the herring stocks based on 1) commercial fishery data following the 2020 and 2021 seasons (broken down by NAFO subdivision, fishing gear and month); 2) the updated biological indicators resulting from the commercial fishery sampling program; 3) the biological characterization of the catches from Fisheries and Oceans Canada’s (DFO) annual northern Gulf of St. Lawrence (nGSL) multi-species bottom-trawl survey, and 4) results of the 2020 and 2021 summer and fall acoustic surveys. Analyses conducted on the effects of the environment on stock productivity indices (relative condition and recruitment) are also presented.

2. METHODS

2.1. LANDINGS

Data from the Atlantic herring commercial fishery in NAFO division 4R (Figure 1A) were extracted in January 2022 from the Zonal Interchange File Format (ZIFF) files produced by DFO’s regional statistics bureau for the years 2000-2021. At the time of this assessment, landing data for the 2019-2021 fishing seasons were considered preliminary as landings were still being compiled or validated for some fisheries. Landings for the period 1965-1999 were compiled from different archived databases and reports (McQuinn 1987*a*, McQuinn and Lefebvre 1995a, McQuinn et al. 1999).

Landings data were tabulated by NAFO subdivision (Figure 1A) and fishing gear. Large seiners are defined as seiners with a vessel length greater than or equal to 19.8 m (or 65 ft), whereas small seiners have a vessel length less than 19.8 m (or 65 ft). Infrequently used gear types were grouped as ‘other’ and included the beach and bar seine, hand line (baited), longline, gillnet (drift), pot, bottom otter trawl (stern), midwater trawl (stern), midwater trawl (side) and jigger.

Landings data by fishing fleet (large and small purse seiners and fixed gear) were compared to allocations for the period 1985-2021. Cumulative frequency distributions of the catch were used to describe seasonal patterns in landings in individual years or blocks of years for the period 1985-2021. Finally, the yearly spatial distributions of the catch for the three types of seine (large, small and "tuck") were mapped. Although harvesters are required to record information about fishing locations (i.e. geographic coordinates), missing data are common. Consequently, the data upon which the maps were based are incomplete and include only landings for which latitude and longitude were provided.

Prior to 2017, the herring bait fishery was not included in landing statistics, as no data before the implementation of mandatory logbooks (in 2017) were available. From 2017 to 2019, catches from the herring bait fishery were estimated using the logbooks that were returned by harvesters, although return rates of these logbooks were low (Chamberland et al. 2022). Bait removals were however excluded from this assessment, as the data from logbooks for 2020 and 2021 were not compiled at the time of this assessment. This fishery most likely contributes only a minor fraction of the total catch (0.04–0.20% of total landings, Chamberland et al. 2022).

2.2. COMMERCIAL AND BIOLOGICAL SAMPLING

Biological samples were collected from main landing ports through DFO's commercial fishery sampling program since 1965. For a given landing, 150 herring were randomly selected and measured to the nearest 0.5 cm (total length) to obtain length-frequency information. Then, another sample of 55 fish was randomly selected and sent to the Maurice Lamontagne Institute (MLI) for determination of the spawning component (spring or fall), total length (± 1 mm), total weight (± 1 g), sex, gonad weight (± 0.1 g), stage of gonad maturation, and age via the extraction and examination of otolith structure.

Individual herring were assigned a spawning component using the method established by McQuinn (1987b, 1989). Gonad maturity stages 1, 2, 6, and 7 were determined by visual examination following the criteria established by Landry and McQuinn (1988), while maturity stages 3, 4, 5 and 8 were identified using a discriminant analysis based on a gonadosomatic index (McQuinn 1989). Immature herring (maturity stages 1 and 2) were assigned to a spawning component based on the visual examination of their otoliths (Messieh 1972, Cleary et al. 1982). Mature individuals (maturity stages 3 to 8) were assigned to a spawning component based on gonad maturity stage and month of capture (McQuinn 1987b).

Total (W_t) and gonad (W_g) weight of frozen (W_{frozen}) samples were converted to fresh weight (W_{fresh}) using the following equations for males:

$$W_{t,fresh} = 1.2258 \cdot W_{t,frozen}{}^{0.96916}$$

$$W_{g,fresh} = 1.253 \cdot W_{g,frozen}{}^{0.977}$$

and females:

$$W_{t,fresh} = 1.626 \cdot W_{t,frozen}{}^{0.97851}$$

$$W_{g,fresh} = 1.365 \cdot W_{g,frozen}{}^{0.916}$$

When required, fork length (FL) was converted to total length (TL) as:

$$TL = (1.0866 \cdot FL) + 9.5632$$

Finally, frozen total length (TL_{frozen}) was converted to fresh total length (TL_{fresh}) as:

$$TL_{fresh} = 1.02 \cdot TL_{frozen}$$

Only the length frequencies of the purse seine fishery (large and small) were presented, because this gear represents the largest proportion of the total catch (~80% of total catch over the 2000-2021 period). Frequency distributions included fish from all subdivisions and months.

Since 2018, herring samples were collected during DFO's annual nGSL multispecies bottom-trawl survey conducted in August in order to estimate the length and age composition of those fish vulnerable to the gear, as well as to increase sample size for length and age at maturity estimations. For all tows in division 4R with a minimum of 30 herring, a random sample of up to 55 fish was frozen and sent to MLI for determination of biological characteristics. In 2018-2020, all fish captured in division 4R with a total length less then 200 mm were also added to the samples.

2.3. COMMERCIAL CATCH-AT-AGE COMPOSITION

The age composition of commercial catches was calculated using an application written in Visual Basic developed at MLI and last updated in 2014. The equations used in this application were taken from the APL functions of CATCH (Rivard 1982) and are based on the methods and equations detailed in Gavaris and Gavaris (1983) and McQuinn (1987a). Briefly, for every year, commercial fishery landings were summarized by month, NAFO subdivision and fishing gear (hereafter strata) for pairing with the corresponding biological samples. Where there was no biological sample for a given stratum, the landings were paired with the sample(s) judged to have the best representability. The following hierarchy was used to attribute biological samples to strata with insufficient samples (McQuinn 1987a):

1. Across months within a subdivisions, and quarter (April to June, July to September and October to December).
2. Across subdivisions within a month.
3. Across months and subdivisions within a quarter.
4. Across months and quarters within the northern (4Ra) and southern zone (4Rb, 4Rc, 4Rd).

Based on the attributed biological samples, the stratum-specific catch proportion, age composition and mean weight were calculated for each spawning component. The total catch per stratum could hence be separated by spawning component, and transformed into catch-at-age (in numbers) for both the SS and FS components. The annual 4R commercial fishery catch-at-age by spawning component was then obtained by summing over all strata. The proportions of each spawning component in the commercial catches in each year, p_{ys}, was obtained by:

$$p_{ys} = \sum_{a=1}^{A} N_{ysa} \,/ \sum_{s}^{S} \sum_{a=1}^{A} N_{ysa}$$

where N_{ysa} is the numbers of age a and of spawning component s in year y.

2.4. BIOLOGICAL INDICATORS

2.4.1. Recruitment index

A relative index of recruitment was calculated for each spawning component from the age composition of commercial fishery catches, providing a rough estimate of relative year-class strength. Numbers at age were first converted to annual proportions at age by:

$$p_{ysa} = \frac{N_{ysa}}{\sum_{a=1}^{A} N_{ysa}}$$

p_{ysa} was then standardized ($spay_s$) by subtracting the mean proportion at each age $\bar{p}_{sa}$ and dividing by the standard deviation σ_{sa} of the proportions computed across years:

$$\bar{p}_{sa} = \frac{\sum_{y}^{Y} p_{ysa}}{Y}$$

$$\sigma_{sa} = \sqrt{\frac{\sum_{y}^{Y} (p_{ysa} - \bar{p}_{sa})^2}{Y}}$$

$$spay_s = \frac{p_{ysa} - \bar{p}_{sa}}{\sigma_{sa}}$$

The recruitment index was calculated by averaging the standardized proportions of ages 3 and 4 for years y and $y+1$, respectively, except for the 2018 cohort where only age 3 of year y was used. The resulting recruitment index was lagged 3 years to match with the year of birth.

2.4.2. Length and age at 50% maturity

Length and age at maturity are generally considered to be the length (L_{50}) and age (A_{50}) at which 50% of individuals are sexually mature. L_{50} and A_{50} are biological indicators that may reflect fishery-induced changes in maturation schedules (Lappalainen et al. 2016), changes in environmental conditions, as well as density-dependent mechanisms such as drastic increases or decreases in biomass (Cardinale et Modin 1999, Coutré et al. 2013). L_{50} can also be used to establish minimal legal sizes in commercial fisheries to avoid growth overfishing.

L_{50} and A_{50} were estimated per spawning component and cohort year (birth year). The estimation by cohort year (longitudinal estimates) was preferred over year (cross-sectional estimates), because the maturation schedule reflects the conditions experienced by the cohorts (Enberg et al. 2012) and because the results are used as a biological index (i.e., not in a stock assessment model). All available biological data (commercial landings, acoustic – see section 2.5 – and nGSL multispecies bottom-trawl survey, hereafter commercial and research samples) were used in the calculations. Due to issues with the high incidence of undersized herring in recent years, a request was made for Science to determine the current L_{50} of both SS and FS herring stocks. These L_{50} values were also compared to the commercial size limit. L_{50} was expressed as fork length in centimeters for easier comparison with the legal size limit.

A maturity ogive by spawning component and cohort year was first estimated using a generalized linear model (GLM) with a binomial error distribution and a logit link function, with maturity stage (mature or immature) as the response variable and length or age as the explanatory variable. Month of capture was also included as an explanatory variable in the estimation of L_{50} in order to correct for seasonal growth. Month of capture was however not included for SS because of the insufficient availability of juveniles in the biological samples. The GLMs were then used to predict the L_{50} and A_{50} values of each cohort of the two spawning components. L_{50} of FS was calculated as the predicted L_{50} in November.

To account for the maturation of juvenile herring throughout the year of their first reproduction, age was calculated using the month of capture with the following equations:

$$a'_{SS} = \frac{8 + (mcapt - 1) + (a - 1) \cdot 12}{12}$$

$$a'_{FS} = \frac{5 + (mcapt - 1) + (a - 1) \cdot 12}{12}$$

where a'_{SS} and a'_{FS} are respectively the SS and FS ages used in the GLM, $mcapt$ is the month of capture, and a is the age determined by otolith reading. In doing so, it was assumed that all SS and FS herring hatched May 1st and August 1st, respectively.

For SS, A_{50} could not be estimated for some year-classes due to insufficient numbers of immature herring in the samples. Hence, for each year-class, data from the two neighbouring year-classes were included in order to obtain sufficient sample sizes. The 95% confidence intervals around L_{50} and A_{50} were obtained by bootstrap (number of iterations=999). For each replicate or sample generated, a GLM was fit and used to estimate L_{50} and A_{50} values. The confidence intervals were obtained by calculating the 2.5% and 97.5% quantiles of the simulated L_{50} and A_{50} values. Cohorts whose total number of juveniles was less than 5 (including data from two neighbouring year-classes) were excluded from the analysis.

2.4.3. Length and weight-at-age

The length and weight-at-age were estimated by fitting a GLM by spawning component and age-class, with a Gaussian error distribution and an identity link function. To take into account the temporal, spatial and fishing gear variability in samples, the lengths and weights-at-age were standardized by including NAFO subdivision, month of capture, and fishing gear as explanatory variables in the models. For SS, the standardized lengths and weights-at-age were produced using the values predicted by the GLMs for the following levels of the standardization factors: NAFO subdivision 4Rd, month of August and small purse seiners (vessels < 65 ft). For FS, reference levels were NAFO subdivision 4Ra, month of November and small purse seiners. These reference levels were chosen to maximize the number of years of length and weight-at-age that can be predicted. The 95% confidence intervals around the predicted lengths and weights-at-age were calculated using the *interval* function of the *HH* library (Heiberger 2020) of the R software (R Core Team 2021). The mean lengths and weights-at-age were estimated using all available biological data (commercial and research samples).

2.4.4. Relative condition index

Le Cren's (1951) relative condition factor (Kn) was estimated separately for the SS and FS herring using the following formula:

$$Kn = \frac{W}{aL^b}$$

where W is the somatic weight (g), L the total length (mm), and a and b the parameters of the logarithmic weight-length relationship. Values of Kn < 1 indicate that the fish's weight is below average for fish of the same length. K_n was standardized to account for seasonal, spatial and gear variability among samples. To do this, a GLM with a Gaussian error structure and an identity link function, with NAFO subdivision, month of capture and fishing gear as independent variables, was fitted to the Kn data of each spawning component. For SS, the standardized Kn were produced using the values predicted by the GLMs for the following levels of the standardization factors: NAFO subdivision 4Rd, August and small purse seiners. For FS, reference levels were NAFO subdivision 4Ra, November and small purse seiners. Only fish between 4 and 9 years old were included in the estimation of Kn. The Kn of SS and FS aged 4 to 9 varied similarly over the entire time series and were therefore averaged annually for each of the two spawning components. The 95% confidence intervals around the predicted Kn were calculated using the *interval* function of the *HH* package of the R software.

2.4.5. Cumulative stock productivity index

A cumulative index combining three stock productivity indicators was developed to integrate available information of the two herring spawning stocks on the west coast of Newfoundland and to describe their respective temporal patterns in productivity. Three annual indicators were included: the recruitment index (1970-2018; see section 2.4.1), the mean total length at age 6 (1970-2021; see section 2.4.3), and the relative condition index (1970-2021; see section 2.4.4). Each indicator was transformed into standardized anomalies by subtracting the series mean and then dividing by the standard deviation of the series. The productivity index was defined as the sum of the annual standardized anomalies.

Each indicator reflects different aspects of productivity. The recruitment index was considered a rough proxy of when annual peaks in recruitment might have occurred, but cannot be used to detect long-term trends. The variations in mean length at age 6 were interpreted as a proxy of long-term changes in individual growth rates. Individual growth is often related to other vital rates, including survival and fecundity, and may be influenced by population density, prey availability, predation risk and temperature (Smoliński 2019, Becker et al. 2020). Condition is a particularly important attribute of individual fish which can affect stock productivity through its influence on growth, reproduction, and survival (ICES 2017). Condition of a fish reflects the physical and biological circumstances experienced during some previous period, and is affected by interactions among food availability, environmental and habitat characteristics, and the physiology of the individual (e.g. reproductive status, overwintering).

2.5. ACOUSTIC SURVEY

A first series of acoustic surveys off the west coast of Newfoundland, aimed at estimating herring biomass during the fall commercial fishery targeting pre-wintering aggregations, was completed in October and November of 1991, 1993, 1995, 1997, 1999, and in September 2002. A second series of surveys began in the fall of 2009 following recommendations from the Fisheries Resource Conservation Council (FRCC 2009) and was conducted in October and November of 2009, 2010, 2011, 2013, 2015, 2017, 2019, 2020 and 2021. This survey covers a larger area as it always included the northern strata (subdivision 4Ra), which were previously skipped on occasion, as well as the Lower North Shore of Quebec (subdivision 4Sw, not included in this assessment). In 2019, 2020 and 2021, acoustic surveys were conducted in August in addition to the fall survey to target FS aggregations during their spawning season. The details and results of the first series of acoustic surveys (1991-2002) are presented in McQuinn and Lefebvre (1999) as well as in Appendix A and will not be further discussed. The following sections describe the methodology used for the 2009-2021 surveys.

2.5.1. Survey design

The survey covered the entire west coast of Newfoundland, from Cape Anguille to the southern portion of the Strait of Belle Isle, generally covering the 20 to 60 m isobaths. The study area was stratified (strata 1-10, BN) according to the major physical characteristics of the environment, the spatial distribution of commercial catches and the population distribution as observed in past surveys (McQuinn and Lefebvre 1999) (Figure 2). In 2019, two new strata were added on the northern and southern sides of the Strait of Belle Isle (strata BI1 and BI2, see Figure 2), which is considered an important summer-fall feeding area for herring (Moores and Winters 1984, McQuinn and Lefebvre 1995b). Transects surveyed by the hydroacoustic vessel were parallel, equidistant, and oriented perpendicular to the coast within each stratum (Figure 2). The distance between transects varied annually due to logistic reasons. For every survey, the first transect within each stratum was placed randomly. The total number of transects for all strata were determined based on the allocated vessel time minus 30%, as a margin for bad weather and mechanical breakdowns. There was nevertheless among year variation in the number of transects surveyed per stratum (Figure A51). The transects were surveyed at night time only (17:00-07:00) because of the diurnal behavior of herring as it generally migrates off the bottom at night, thus making them more distinct from the bottom echoes and reducing the “deadzone” problem (Mitson 1983, McQuinn and Lefebvre 1999).

2.5.2. Data acquisition and analysis

From 2009 to 2020, a Simrad EK60 echosounder (Kongsberg Maritime AS, Horten, Norway) was used to transmit and collect the acoustic signals. Up to five frequencies (38, 70, 120, 200, and 333 kHz) were used simultaneously, depending on the vessel performing the survey (Table A17). All data were saved in real time on a computer using Simrad's ER60 software. In 2021, the more advanced Simrad EK80 echosounder operating simultaneously at three frequencies (38, 120 and 200 kHz) was used. Laboratory and field experiments confirmed that EK60 and EK80 provide similar measures of backscattering coefficients (Demer et al. 2017, Macaulay et al. 2018). Therefore, a change from the EK60 to the EK80 should not introduce a significant change in the survey time-series biomass estimate. The echosounder was calibrated each year before the survey using the standard target or sphere method (Demer et al. 2015).

For the 2009-2020 surveys, the acoustic data was transformed into the HAC format (HydroACoustics, McQuinn et al. 2005) using ER60. The HAC files were subsequently scrutinized and integrated in 2 m (depth) by 25 m (horizontal distance) cells using CH2 software developed at MLI (Simard et al. 2000). For the 2021 surveys, the acoustic data analyses were conducted in Echoview 12 (Myriax Pty, Ltd., Hobart, Tasmania, Australia) and the R software for statistical computing (version 4.0.2) with RStudio (version 1.3.1056, RStudio Team 2020). The echograms were similarly scrutinized and then integrated in 2 m (depth) by 25 m (horizontal distance) cells as .csv files. The exported files were transformed into the HEI file format (Hydroacoustic EchoIntergration, Simard et al. 2000) using R.

Schools were classified as fish species with swimbladders fish by comparing the mean backscattering volume strength (S_V) of the 38, 120 and 200 kHz frequencies. Most fish schools were considered to be herring as very few other fish species with swimbladders are present in the survey area in the fall (McQuinn and Lefebvre 1999). The conversion of backscatter to biomass was accomplished by using target strength estimates per unit length (TS_{cm}) determined from the equation suggested by Foote (1987) for clupeoids at 38 kHz:

$$TS_{cm} = 20(\log_{10} \cdot L) - 71.9$$

where L is the mean fish length (cm), and by converting to target strength per unit weight (TS_{kg}):

$$TS_{kg} = TS_{cm} + 10(\log_{10} W^{-1})$$

where W is the mean fish weight in kg (McQuinn and Lefebvre 1999). The mean lengths and weights were calculated for each transect from the samples most closely associated with each school. Total biomass of SS and FS was calculated using an estimate of the percent weight of each spawning component corresponding to each sample. The vessel and fishing gear used to capture the samples, the number of samples, as well as the size of each sample, varied between surveys (Table A18). For some years, samples from the commercial fishery were used to convert acoustic signals to biomass due to the impossibility of obtaining fishery-independent samples (e.g. 2013, 2015, 2017 and 2020).

Total biomass estimates and variance per stratum were obtained following the equations described in O'Boyle and Atkinson (1989) for surveys with varying transect lengths. Although the application of classical statistics for a random-stratified design to a systematic-stratified survey may lead to a bias in the strata variance estimates, the variance should theoretically be overestimated (Cochran 1977). The variance estimates and corresponding standard errors presented in the results section are therefore considered conservative in terms of acoustic data. Note also that the variance defined herein does not quantify the statistical uncertainty in biomass estimates but, rather, the inter-transect variability in the abundance of herring within each stratum.

The total biomass per spawning component per stratum was transformed into numbers-at-age using the same methodology as used for the commercial catch-at-age (see section 2.3). The age-disaggregated abundance index was then obtained by summing over all the strata covered by the survey during a given year. However, some strata were not surveyed every year and the survey biomass estimates are limited to those that were, resulting in total stock biomass being underestimated in those years with missing survey strata (Figure A51).

2.5.3. Summer and fall acoustic surveys of 2020-2021

The acoustic survey implies the estimation of numbers-at-age independent from the commercial fishery and, therefore, relies on biological samples collected with an accompanying fishing vessel for herring spawning stock composition, length and weight information. Over the 2009-2013 period, the hydroacoustic survey vessel has been accompanied by a chartered fishing vessel (Gemini II) equipped with a purse seine (Table A18). In 2015 and 2017, due to the impossibility to charter a fishing vessel, the demographic composition of the stocks was mostly inferred from commercial fishery samples corresponding to the closest spatiotemporal match (i.e. closest day and distance between the survey and commercial samples). The consequence of this shortcoming was that these samples now classified as “research samples” were excluded from the commercial fishery catch-at-age calculation to avoid inducing a correlation between the two sources of data. The samples used in the subsequent calculations thus originate from various gear types, as it was not possible to select only one gear type to fulfill the condition of closest spatiotemporal match (Table A18). In the acoustic surveys of 2019-2021, the chartering of a fishing vessel allowed the collection of a larger number of fishery-independent samples (Table A18). The chartered vessel was equipped with a pelagic trawl with minimal size-selectivity (50 mm codend) and was instructed to sample fish in areas of high acoustic signals so that samples could be collected with the closest spatiotemporal match. Up to 100 randomly collected herring per tow were frozen *in situ* and sent to MLI for biological analysis.

Since at least 2009, the 4R commercial fishery, which targets pre-overwintering herring aggregations, generally occurred later in the year relative to previous years, suggesting a potential delay in the timing of herring migration in the late fall (DFO 2018). This change resulted in a temporal mismatch between the acoustic survey and the commercial fishery, a deviation from the initial acoustic survey design (McQuinn and Lefebvre 1999, DFO 2018). Because of logistical constraints associated with the deployment of DFO’s small research vessels later in the fall, three additional acoustic surveys were conducted in August of 2019-2021 (hereafter summer survey) in order to target spawning aggregations of fall herring which were deemed to occur in a more consistent manner over time. This survey is considered as the start of a new time series. The summer acoustic surveys were conducted with the CCGS Frederick G. Creed (August 11-23, 2019), CCGS Leim (August 8-30, 2020), and Research Vessel (RV) Novus (August 8-18, 2021) in the strata defined in the original survey design as well as in the Strait of Belle Isle (Figure 2), an area where herring landings have been reported to increase in recent years.

2.6. ENVIRONMENTAL DRIVERS OF CONDITION AND RECRUITMENT

A previous study examining the links between 4T and 4R herring recruitment and environmental variability using multivariate environmental indices suggested that environmental conditions did not seem to act uniformly on the recruitment of either herring stocks or their respective spawning components (Brosset et al. 2019). Moreover, high recruitment in 4R SS herring was associated with cooler conditions (temperature, zooplankton species composition and phenology), whereas high recruitment in 4R FS herring was associated with warmer conditions. In this context, we assessed the relationships between recruitment, body condition, and environmental conditions using standard discrete environmental indices produced as part of DFO’s Gulf of St. Lawrence (GSL) ecosystem approach (Duplisea et al. 2020). We used generalized additive models (GAMs) to assess the effect of variations in physical (surface temperature, timing of surface water warming and cooling) and biological (spring bloom dynamics, abundance and phenology of key zooplankton taxa) environmental conditions known to be mechanistically linked with small pelagic fish species recruitment, growth, and condition (Brosset et al. 2019, Ljungström et al. 2020). *Calanus* spp. and *Pseudocalanus* spp. were considered as key zooplankton taxa due to their importance in larval, juvenile and adult herring diets (Darbyson et al. 2003, Wilson et al. 2018).

We hypothesized that body condition (Kn) would respond positively to warmer conditions/earlier timing of plankton and a greater availability of preferred/important prey for both spawning components. Likewise, we hypothesized that recruitment would be favored under conditions that would promote a faster growth (and improved survival) of larval herring.

2.6.1. Environmental indices

Environmental indices were extracted from the GSL Ecosystem Matrix (Duplisea et al. 2020). They were chosen according to their potential role in herring feeding success and net energy gain and in recruitment. Predictors were classified into three categories: (1) physical indices, (2) spring bloom dynamics indices, and (3) key zooplankton taxa abundance and phenology indices (Table 1).

Physical indices (1982-2021) were sea surface temperature (SST), the week of the year when SST warms up to 10°C, the week of the year when SST cools down to 10°C, and the last day of ice occurrence. For each spawning component, SST of the month used to standardize Kn or averaged over the months between spawning and the month used to standardize Kn were included in the analyses. Thus, for the SS component, SST in August and SST averaged over May to August were considered, while SST in November and averaged over August to November were considered for the FS herring stock. Spring bloom dynamics indices (1999-2019) included the onset and the duration of the bloom. Zooplankton indices (2001-2019) included the abundance of *C. finmarchicus*, *C. hyperboreus*, *Pseudocalanus* spp. and small Calanoida (dominated by *Pseudocalanus* spp.) in early summer and fall, the phenology of *C. finmarchicus* (ratio between stages C1-C4 and other copepodites stages) in early summer and fall, and the phenology of *C. hyperboreus* (ratio of stage C4 on stages C1-C4) in early summer (used for SS herring only*). C. hyperboreus* abundance and phenology were not considered as predictors of recruitment, because it is unlikely to be a prey of herring larvae. The ratio of the abundance of large calanoids over small calanoids was used to reflect changes in the average size of zooplankton taxa prey.

All the environmental indices listed above were extracted for regions 2 (Mecatina), 3 (Centre) and 4 (Northeast) of the ecosystem approach which correspond to the 4R region, and the annual averages were weighted by the area of each region (Duplisea et al. 2020).

2.6.2. Generalized additive models (GAMs)

The effect of the environment on the interannual variability of K_n was evaluated with GAMs assuming a Gamma error distribution. We used quantile GAMs (Fasiolo et al. 2021) to verify the effect of the environment on recruitment using quantile 0.5 and 0.75 because of the high variability in recruitment data. We adopted a stepwise approach when considering environmental predictors of different categories:

1. physical indices representing the longest time series (1982-2021),
2. physical and spring bloom indices (1999-2019),
3. physical, spring bloom and zooplankton indices corresponding to the shortest time series (2001-2019).

Correlations and relationships among predictors were verified and correlated predictors ($r > 0.6$) were not included in the same models. Outliers were investigated using dotplots. All the models that were tested considered a maximum of three predictor variables in order to minimize potential of overfitting and were ordered according to their Akaike Information Criterion corrected for small sample size (AICc). The basis dimension (k) was set to a maximum of 3 to avoid multi-modal relationships. The variance explained (R^2) between predictions and observations and the deviance explained were calculated, and each model was evaluated using a bootstrap simulation and leave-one-out cross-validation (jackknife).

The bootstrap consisted of resampling predictors and refitting the model 1000 times. The deviance explained was calculated for each iteration and the deviance explained by the model was compared to the distribution of the explained deviance obtained in the bootstrap simulations. Models were retained if their respective explained deviances were above the 95th percentile threshold of the simulated datasets. Each model was also tested using a jackknife procedure. For each model, we removed one year at a time, refitted the model and predicted the value. The predicted values were then compared to the observed values by calculating Pearson's correlation coefficient (r). The final selected model had the lowest AICc ($\Delta < 2$), the highest R^2 ($\Delta < 0.05$), was significant in the bootstrap simulations (i.e. explained deviance of the model was above the 95th percentile of the distribution of the explained deviance obtained in the bootstrap simulations), and was robust against missing years (jackknife R^2 $\Delta < 0.1$). When two models had similar performances on all indicators, the most parsimonious model was selected. Model residuals were inspected for temporal autocorrelation using the *acf* function in R. All analyses were done in R version 4.0.2, GAMs were fitted using the *mgcv* package (Wood 2017) and quantile GAMS were calculated using the *qgam* package (Fasiolo et al. 2021).

3. RESULTS AND DISCUSSION

3.1. LANDINGS

During the 1980s and 1990s, Atlantic herring landings on the west coast of Newfoundland were variable and averaged approximately 15,405 t per year, with a high of 26,437 t in 1991 and a low of 8,164 t in 1990 (Table 2, Figure 3). Landings increased slowly but regularly between 2000-2008 and stabilized at around 20,000 t until 2016, limited by the TAC for those years. Landings have not reached the TAC since 2017 and totaled 4,863 t in 2020 and 3,075 t in 2021 (preliminary data; Table 2, Figure 3). In 2020, harvesters in 4R reported that a significant amount of herring below the legal size of 24.76 cm has impeded their ability to harvest the available quota, and this continued to be an issue for the 2021 fishing season. Since 2012, most landings were reported from NAFO subdivision 4Rb, except in 2020 and 2021 where most landings were reported from subdivisions 4Ra and 4Rc, respectively (Table 2, Figure 3).

The majority of the herring was landed by the large seiner fleet (Table 3, Figure 4). In 2020 and 2021, the large seiners landed only 1,198 t and 2,044 t (preliminary data), respectively, much lower than the 1966-2019 average of 9,651 t (Table 3). The small seiner fleet landed less biomass in 2021 (110 t) than in 2020 (1,148 t), while the 1990-2019 average (no landings prior to 1990) was 3,580 t (Table 3, Figure 4). The biomass landed with the tuck seine totaled 2,215 t in 2020 and 749 t in 2021, while the other fixed gears (gillnet and trap) landed 302 t and 172 t in 2020 and 2021, respectively (Table 3). In 2020, less than a quarter of the small and large seiners quotas were caught (Figure 5). In 2021, less than 20% of the large seiner quota was caught, and the small seiners and fixed gears landed less than 5% of their quota (Figure 5).

Fishing activities in the spring by the large and small purse seiner fleets declined at the end of the 1990s following the implementation of management measures to protect the main spawning grounds of the SS herring stock (DFO 2017). Since then, these fisheries, as well as the tuck seine fishery, are mostly practiced in the fall (Figure 6). Cumulative landings of large and small seiners indicate that these fisheries have been starting and running later since the 2010s, except in 2021 where landings of the large and small purse seine fleets mainly occurred before July 1st (Figures 6-7). Landings by the fixed gear fleet generally occur throughout the season, however, the 2020 season had the slowest start since 2010 with landings occurring mostly in November and December (Figure 7).

Landings by large and small purse seiners were concentrated near the coast and within large bays, mainly in the southern and mid portions of 4R (Bonne Bay (4Rb), Bay of Islands (4Rc), Port au Port Bay (4Rc) and Bay St. George (4Rd); Table 4, Figures 8-9). Landings by the tuck seine began in 2005 in subdivision 4Ra and Bonne Bay (Table 4, Figure 10). They then extended to the large bays located further south (the entry of fishing coordinates is incomplete for 2020 and 2021). The proportion of missing geographic coordinate values in the ZIFF files was less than 20% and often zero for the large seiners up until 2019, and between 25 to 63% for small seiners in the early 2000s, then below 10% until 2015 when the percentage increased again (Figure 11). The tuck seine data has the most missing coordinates, with percentages decreasing from 2005 to 2016 but increasing recently and reaching 100% in 2021. The high occurrence of missing values in 2020 and 2021 is probably due to the fact that these data were still preliminary. Interpretation of the spatial distribution of the landings for the tuck seine in 2020 and 2021, and to a lesser extent the large and small seine fleets, are therefore uncertain.

3.2. COMMERCIAL AND BIOLOGICAL SAMPLING

Atlantic herring commercial fishery samples were generally collected according to the distribution of the fishery in space and time (Table 5). In 2020, samples were collected only in the fall, and most samples came from the more larger mobile gear fishery. In 2021, no samples were collected from the fixed gear fishery in the spring nor in the fall, and only four samples (three in the spring and one in the fall) were collected from the mobile gear fishery. The number of samples collected in 2021 was low due to the very low landings in the small purse seine and tuck seine fisheries (Table 3). Samples in 2020 were collected in NAFO subdivisions 4Ra and 4Rb, whereas those in 2021 were collected in 4Ra, 4Rb and 4Rc (Table 5).

The length frequency distributions of SS and FS herring caught by the purse seine fleet (small and large) are presented in Figure 12. The length frequency distributions of both spawning components are characterized by the presence of prominent modes which are associated to strong year-classes (Figure 12). These dominant year-classes can be tracked through time from age 4 onward, and may support the fishery for several years. For SS, the length frequencies between 2006 and 2011 were dominated by the 2002 year-class (according to age readings from otoliths). The more recent strong mode in the length frequencies between 2015 and 2021 was caused by the 2013 year-class, while the mode at smaller sizes between 2019 and 2021 was generated by the new 2017 year-class (Figure 12). For FS, age readings from otoliths confirmed that the strong mode between 2003 and 2013 was caused by the 2000 and 2001 year-classes. Since 2013, the FS length frequencies are dominated by the 2008 year-class and older individuals (Figure 12). In 2019-2021, smaller individuals, that most likely belong to the more recent 2016 year-class, were also apparent in the length frequencies.

The most recent strong year-classes identified in the purse seine length frequencies were also observed in the length frequencies of the samples collected during DFO's nGSL multi-species bottom trawl survey from 2018 to 2021 (Figure 13). For SS, length frequencies were dominated by the 2013 year-class, and to a lesser extent, by the 2017 year-class in 2020-2021. For FS, length frequencies were mostly dominated by older individuals. The mode of the 2016 year-class was also discernible, particularly in 2020.

Location and proportion of SS and FS in the samples collected during DFO's nGSL multi-species bottom-trawl survey from 2018 to 2021 are presented in Figure 14. Samples in 2018 and 2019 were concentrated in the northern portion of NAFO Division 4R (subdivisions 4Ra and 4Rb), while the samples collected in 2020 and 2021 were better distributed over the entire area. On average, the SS component represented 24.0% and 14.8% of all the herring sampled in 2018 and 2019, respectively, and these proportions increased to 40.2% and 48.1% in 2020 and

2021, respectively. In 2020 and 2021, the proportion of SS was higher in the southern portion of NAFO division 4R, whereas FS were generally more dominant in the north (Figure 14).

3.3. SUMMER AND FALL ACOUSTIC SURVEYS OF 2020-2021

The spatial coverage of the acoustic survey has varied considerably within and among years, with the number of transects surveyed per stratum (i.e. transect density) exhibiting an overall decline over the 1991-2021 period (Figure A51). As in 2019, the acoustic surveys of 2020 and 2021 were conducted both in the summer (August) and fall (October-November). The summer surveys covered all the original strata with the exceptions of stratum 1 in 2020, and strata 2 and 8 in 2021, whereas the fall surveys excluded strata 4 and 8 in 2020, as well as strata 7 and 8 in 2021 (refer to Figure 2 for strata names). In some instances, strata in the Strait of Belle-Isle were excluded or only partially covered due to mechanical issues, adverse weather conditions or time constraints/vessel availability (Figures 15 and A51).

The spatial distribution of herring biomass during the summer and fall 2020-2021 acoustic surveys is shown in Figure 15. Whereas in the summer of 2020 the highest biomass values were observed in strata 5 and 7 (Bay of Islands), in the fall of 2020, the highest values were observed in stratum 4Sw, near the southern edge of stratum BI2 (Tables 7-8). In 2021, the highest biomass values were observed in the northern portion of Division 4R (strata 10, BI1, BI2 and 4Sw) for both the summer and fall surveys (Tables 9-10, Figure 15).

The biological samples used to estimate the 2020-2021 acoustic survey index comprised between 12 and 17 distinct samples, with total sample sizes ranging from 606 to 1268 individuals (Table A18). Most samples were collected by a chartered pelagic trawler, though we note that the 2020-2021 summer surveys also included samples collected during the multi-species bottom trawl survey by the CCGS Teleost. The fall 2020 acoustic survey index also included two commercial fishery samples, as samples collected by the chartered pelagic trawler did not adequately cover the entire survey area. The dominance of pelagic trawl samples in 2019-2021 contrasted with the surveys in previous years (2009-2017), wherein purse seiners accounted for approximately 90% of all samples collected.

The proportion of SS and FS in the samples used to estimate the biomass index in 2020 and 2021, as well as their spatial distribution, are illustrated in Figure 16. The proportion of SS in these samples increased in comparison to previous years. Overall, the SS component represented 42.4% of the herring sampled in August 2020 and 42.5% of those sampled in October-November 2020. In 2021, this spawning component comprised 39.0% and 67.4% of the individuals sampled during the summer and fall acoustic survey, respectively.

The length frequency distributions of SS and FS herring used in the estimation of the fall 2009 to 2021 acoustic index, as well as the samples from the 2019 to 2021 summer surveys, are shown in Figure 17. For SS, the expected progression of modes from 2009 to 2017 associated with different year-classes was hardly discernible due to the very low occurrence of SS herring in some biological samples between 2010 and 2017 where total number of SS herring varied from none to 76. This situation changed in recent years, when modes observed at around 200-225 mm and 300-325 mm in 2019 shifted to the 225-250 and 325-350 mm length-classes, respectively, in the summer and fall acoustic surveys of 2020 and 2021 (Figure 17A). For FS, the dominant mode of the length frequency distribution from 2009 to 2017, which occurred within the 325-350 mm length category, did not seem to follow the growth of cohorts over time (Figure 17B). More recently, however, the mode observed at 175-225 mm in 2019 shifted to the 250-275 mm category in 2020-2021, a pattern consistent with expected cohort dynamics over time.

3.4. SPRING SPAWNER COMPONENT ASSESSMENT

3.4.1. Commercial catch-at-age composition

The annual proportion of SS herring in the commercial landings varied between 25.8% and 81.7% over the 1965-2005 period (Figure 18). The proportion of SS decreased rapidly from around 2005 onwards and reached the lowest value of the time series (1.6%) in 2014. Since then, the proportion of SS in the fishery has been increasing and accounted for 89.6% of the landings in 2021, the highest value of the time series (Figure 18).

The age composition of SS herring landed in the commercial fishery in 2020 and 2021 was characterized by the dominance of the 2013 year-class (age 7 in 2020 and age 8 in 2021), and to a lesser extent of the 2017 year-class (age 3 in 2020 and age 4 in 2021) (Table 6, Figure 19). The 2013 year-class accounted for 39.9% and 42.7% of all SS landings (in numbers) in 2020 and 2021, respectively, while the 2017 year-class accounted for 25.8% in 2020 and 15.6% in 2021. The estimated number of fish at age 2 in the commercial fishery in 2019 (2017 year-class) was the highest for that age group since 1965 (Table 6, Figure 19). This may reflect an abundant year-class, changes in management measures which permitted the catch of smaller herring, or a combination of both. In 2017-2018, the regulated minimum size was decreased from 26.5 cm to 24.76 cm (fork length), based on a review of age at maturity, and the tolerance level for landing small herring was increased from 10% to 20% (DFO 2018). We will be able to assess the importance of the 2017 year-class at the next assessment, when it has completely recruited to the fishery. Other dominant year-classes were those of 1968, 1974, 1980, 1982, 1990, 1996, 1997, 1999 and 2002 (Figure 19).

3.4.2. Acoustic biomass index

In 2020, the biomass index of SS herring was estimated at 103,564 t (95% CI: ± 9,316 t) in the summer survey, while the biomass in the fall survey was estimated at a much lower value of 7,877 t (95% CI: ± 921 t; Tables 7-8). In 2021, the biomass was estimated at 45,580 t (95% CI: ± 4,659 t) and 112,145 t (95% CI: ± 20,803 t) in the summer and fall, respectively (Tables 9-10). The fall acoustic survey of 2021 estimated the highest biomass index of SS since the beginning of the survey (Figure 20). The proportion of SS in the acoustic surveys increased substantially in recent years (Figure 21), jumping from an average of 7.3% for the 2009-2017 period to an average of 42.4% in 2019 (summer: 23.7%, fall: 53.8%), 44.6% in 2020 (summer: 44.8%, fall: 40.6%), and 51.5% in 2021 (summer: 22.9%, fall: 75.4%). Recent higher prevalence of SS was also observed in the commercial catches (Figure 18).

During the summer surveys, 5.2%, 25.6% and 1.1% of the biomass of SS was observed in the Strait of Belle Isle in 2019, 2020 and 2021, respectively, while the majority of the biomass (84.6%) was found in this same area during the fall 2021 survey (the 2019 and 2020 fall surveys did not cover the Strait of Belle Isle). Except for 2019, more biomass was observed in the survey during the summer than in the fall, without considering the Strait of Belle Isle strata (Figure 20). However, if the biomass found in the Strait is accounted for, more biomass was observed during the fall survey in 2021 also.

Although changes in survey catchability and coverage hinder inter-annual comparisons and assessment of long-term trends in biomass, the biomass indices estimated are considered to represent minimum estimates of the amount of fish available at the time of the survey. The ratio of the biomass fished over the highest biomass index estimated in the acoustic surveys was considered to be a proxy for the maximum exploitation rate. In 2020 and 2021, the maximum exploitation rates were 1.1% and 2.4%, respectively (Table 11). If the 20,000 t TAC had been taken, the maximum exploitation rates would have resulted in 4.5% in 2020 and 15.6% in 2021.

These exploitation rates are lower than commonly used biological reference points for species with similar life history characteristics (e.g. $E_{0.1}$=29.5%, Turcotte et al. 2021).

The age-disaggregated acoustic survey index for SS herring did not follow the most dominant cohorts observed in the commercial fishery catch-at-age, except for the most recent 2017 year-class (Figure 22). This discrepancy with the commercial catch-at-age could be explained by low sample sizes for SS herring in the acoustic samples, time-varying survey catchability, partial survey coverage and/or change in sampling gear. The acoustic survey biomass estimates of SS herring were mainly composed of fish of the 2017 year-class in 2019 (summer: 65.0%, fall: 64.0%) and 2020 (summer: 88.4%, fall: 68.1%) (Table 12, Figure 22). The 2017 year-class also dominated the 2021 fall acoustic survey (91.1%), but not the 2021 summer acoustic survey (23.9%), which was dominated by older individuals of ages 6-8 (68.1%). This disparity could be explained by the samples used to convert the acoustic biomass into numbers-at-age. Due to the low availability of acoustic samples for this survey, most of the samples used to divide the acoustic biomass into numbers-at-age were taken from DFO's nGSL multi-species bottom-trawl survey, which had a lower selectivity at younger ages/smaller lengths then the survey conducted with the pelagic trawl (Table A18, Figure 23).

3.4.3. Recruitment index

The recruitment index of SS herring, which represents the proportion of ages 3 and 4 in commercial catches with a 3-year lag, is shown in Figure 24. This index provides a very rough estimate of relative year-class strength. Large year-classes occurred irregularly (every ~5-15 years) over the 1965-2021 period, and were interspersed with moderate to low year-classes. The most recent strong recruitment events occurred in 2012-2013 and 2017. This index should however be interpreted with caution, especially when comparing the index from one year to another, as the selectivity of ages 3 and 4 varied over time. Changes to the management of the commercial fishery (e.g. no minimum legal catch size prior to 1985, decrease in the minimum legal size in 2018) have most likely affected the selectivity of ages 3 and 4 in the fishery. The decline observed in the average length of these age-classes since the 1990s could also have reduced their selectivity over time (see section 3.4.5).

3.4.4. Length and age at 50% maturity

The L_{50} for SS herring declined over the 1962 to 1993 year-classes, increased towards the overall mean (24.19 cm fork length) until the 1997 year-class, and then exhibited more variable trends from the 1999 year-class onwards (Figure 25). Specifically, the L_{50} for the 2000-2004 year-classes varied near the overall mean and then decreased below the mean for the 2005-2012 year-classes. Since then, the L_{50} has been increasing, such that the most recent estimate available (2017 year-class) was slightly above the time series average. The current L_{50} (2017 year-class) was estimated at 24.52 cm (fork length), which is near the current minimum size limit of 24.76 cm in the commercial fishery (Figure 26). It was not possible to estimate L_{50} for the 1998, 2007 and 2010 year-classes, because less than 5 immature fish were sampled. Large bootstrapped confidence intervals for some year-classes were associated with small sample sizes (Figure 25).

The A_{50} declined over the 1961-2000 year-classes, increased above the time series average of 3.38 years in the early 2000 year-classes, and then decreased by approximately one year until the 2011 year-class (Figure 27). The A_{50} has been increasing since then, reaching the highest values of the series for the 2015 (4.32 years), 2016 (4.76 years) and 2017 year-classes (4.85 years; Figure 28). The 95% bootstrapped confidence intervals are larger between the 2004 and 2011 year-classes, which was related to the smaller sample sizes (Figure 27).

3.4.5. Length and weight-at-age

After an increase from the mid-1970s to the mid-1980s, the average length and weight of SS herring on the west coast of Newfoundland declined throughout the 1990s and 2000s in all age-classes, and then remained relatively stable and below long-term averages since the early 2010s (Figures 29-30). Except for age 2 (which were not well represented in samples), the decline was more severe for weight-at-age than for length-at-age. On average, length-at-age declined by 4.3% (age 10) to 12.0% (age 4) between 1990 and 2021, whereas mean weight-at-age declined by 24.5% (age 10) to 40.4% (age 4) over the 1990-2021 period. A decrease in the average length- and weight-at-age was also observed in the other Northwest Atlantic SS herring stocks, including those on Quebec's North Shore (Division 4S; DFO 2021a), east and south coasts of Newfoundland (Division 3KLPs; Bourne et al. 2018), and southern Gulf of St. Lawrence (Division 4TVn; Turcotte et al. 2021).

3.4.6. Relative condition index

The relative condition index (Kn) of SS was low in the early 1970s, started to increase at the end of the 1970s and remained relatively high until the 2010s (Figure 31). Since then, Kn has been decreasing and is below the series average since 2014. The minimum values of 0.98 and 0.99 were reached in 2016 and 2021, respectively, for this stock.

3.4.7. Cumulative stock productivity index

The cumulative stock productivity index suggests that the SS herring stock has been shifting between low and high productivity regimes. During the 1970s, anomalies in the cumulative stock productivity index were predominantly negative (Figure 32). Following a period of positive anomalies in the 1980s, the productivity of the SS stock fluctuated between positive and negative anomalies throughout the 1990s. Since the mid-2000s, anomalies remained predominantly negative, except for years where notable recruitment events were observed (e.g. 2012-2013). Although there are signs of recent increase for this stock, this suggests that SS herring on the west coast of Newfoundland is in a lower productivity state (i.e. reduced growth and condition) since the mid-2000s, as observed for the SS herring stock in NAFO Division 4TVn (Turcotte et al. 2022).

3.5. FALL SPAWNER COMPONENT ASSESSMENT

3.5.1. Commercial catch-at-age composition

Commercial landings of FS herring landed in 2020 and 2021 were mainly composed of fish aged 9 years and over (Table 13, Figure 33). These age groups made up 60.0% and 85.3% of all fall spawner catches in 2020 and 2021, respectively. The last relatively abundant year-class in the fishery was observed in 2008 (age 12 in 2020 and age 13 in 2021). A new year-class (2016) seemed to have emerged in the fishery for fall spawners in 2019 (DFO 2021b). Although relatively abundant in 2019 and 2020 (catches at age 3 in 2019 and age 4 in 2020 were among the highest in the series), this year-class was absent from the catches in 2021 (Table 13, Figure 33). Other dominant year-classes were those of 1979, 1990, 1995, 2000, and 2001 (Figure 33).

Interestingly, the increasing prevalence of FS herring from the early 2000s to mid-2010s was predicted to some degree by Melvin et al. (2009) based on their conceptual model of environmentally-driven reproductive success and the expected increasing mean water temperatures. It is worth nothing however that proportions of FS in the samples (Figure 18) are representative of the proportions in the fishery (as opposed to stock relative abundance) and consequently are influenced by the management measures implemented in 1999 that aim at protecting the SS stock, as well as fishery selectivity.

3.5.2. Acoustic biomass index

The biomass index of FS herring in NAFO division 4R was estimated at 226,005 t (95% CI: ± 35,507 t) in the summer survey of 2020, while the biomass in the fall survey was estimated at only 16,283 t (95% CI: ± 2,053 t) (Tables 7-8). In 2021, the biomass was estimated at 210,121 t (95% CI: ± 36,845 t) and 43,170 t (95% CI: ± 6,154 t) in the summer and fall surveys, respectively (Tables 9-10). The summer acoustic survey of 2020 estimated the highest biomass index of FS since the beginning of the survey (Figure 34). The proportion of FS in the acoustic surveys increased gradually from 45.1% in 1991 to 70.4% in 2002, remained high from 2009 to 2017 (87.4%-98.1%), and then decreased from 2019 onwards (Figure 21). The proportions of the FS component in the summer surveys (55.2%-77.1%) were however greater than or equal to the proportions estimated in the fall surveys (24.6%-59.4%), which can be attributed to the spawning season occurring at the same time than the summer survey. As observed for the SS stock, the biomass of FS found in the Strait of Belle Isle represented an important amount of the biomass estimated in the whole study area (41.0%-48.5%), except in the summer survey of 2019 where it represented only 8.8% of the biomass (Figure 34). More biomass of FS was observed during the summer than in the fall surveys, including or not the biomass estimated in the Strait of Belle Isle. However, the difference between the biomass estimated during the two surveys (summer and fall) was greater in 2020 and 2021 compared to 2019.

Although changes in survey catchability and coverage hinder inter-annual comparisons and assessment of long-term trends in biomass, the biomass indices estimated in 2020 and 2021 were considered to represent minimum estimates of the amount of fish available at the time of the survey. The ratio of the biomass fished over the highest biomass index estimated in the acoustic surveys was considered to be a proxy for the maximum exploitation rate. In 2020 and 2021, the maximum exploitation rates were 1.7% and 0.2%, respectively (Table 11). If the 20,000 t TAC had been taken, the maximum exploitation rates would have resulted in 6.8% in 2020 and 1.2% in 2021. These exploitation rates are lower than commonly used biological reference points for species with similar life history characteristics (e.g. $E_{0.1}$=27.4%, Turcotte et al. 2021).

The age-disaggregated survey index for FS herring seemed to follow some of the earlier dominant year-classes present in the commercial fishery catch-at-age (e.g. 2000-2001 and 2008; Figures 33 and 35), but patterns in the acoustic survey numbers-at-age after 2008 are more inconsistent and include year effects in which abundance was high across a range of ages (e.g. 2010 and 2013). The acoustic survey biomass estimates of FS herring in 2020 were dominated by fish aged 4 year from the 2016 year-class (summer: 60.5%, fall: 52.6%). The 2020 age-disaggregated summer survey index showed the highest number of age 4 (2016 year-class) since the beginning of the survey (Table 14 and Figure 35). Although this high contribution of young fish could be an indication of a strong 2016 year-class, its high value could at least be partly associated to a change in survey catchability based on samples independent from the commercial fishery. The 2016 year-class also dominated the 2021 fall acoustic survey (40.6%), but not the 2021 summer acoustic survey (10.4%), which was dominated by fish aged 8 years and over (70.1%). Contrary to what was observed for SS herring, both acoustic and Teleost samples were dominated by older individuals in 2021 (Figure 36).

3.5.3. Recruitment index

The recruitment index of FS herring is shown in Figure 37. As for SS herring, large year-classes in the fishery occurred irregularly (every ~3-16 years) over the 1965-2021 period. The last strong recruitment events occurred in 2000 and more recently in 2016, but to a much lesser extent. This index should however be interpreted with caution, as the selectivity of ages 3 and 4 has most likely decreased over time (see further explanations in section 3.4.3).

3.5.4. Length and age at 50% maturity

The L_{50} for FS herring was stable for the 1960s year-classes, declined until the early 1990s year-classes, and then increased towards the time series average of 24.51 cm fork length (Figure 38). The L_{50} has been varying without trend around the long-term average since the 2000 year-class. The current L_{50} (2017 year-class) was estimated at 25.46 cm (fork length), which is over the current minimum size limit of 24.76 cm in the commercial fishery (Figure 39). The L_{50} for the 1963, 1964, 1971, 1975, 1976, 1983, and 1984 cohorts could not be estimated for November, because there were no samples available for that month. The large bootstrapped 95% confidence intervals for some year-classes between 1972 and 1985 were associated with small sample sizes of juvenile fish.

The A_{50} for FS varied between 3.13 and 5.87 years of age between the 1961 and 2017 year-classes (Figure 40). The A_{50} declined from year-class 1965 to 1981, fluctuated below the time series average of 4.08 years until the mid-2000s year-classes, and has since increased to the highest values of the series in 2015 (5.59 years), 2016 (5.87 years) and 2017 year-classes (5.29 years; Figure 41). The large bootstrapped 95% confidence intervals for some year-classes were associated with small number of juvenile fish in samples.

3.5.5. Length and weight-at-age

Following a decline throughout the 1980s and 1990s for all age-classes (2 to 11+), mean lengths and weights at age of the FS herring stock either continued to decrease or remained relatively stable and below the long-term average throughout the 2000s and 2010s (Figures 42-43). As observed for the SS stock, the decline was more severe for weight-at-age than for length-at-age, except for age 2 (which were not well represented in samples). On average, length-at-age decreased by 3.4% (age 10) to 18.3% (age 3) between 1990 and 2021, whereas mean weight-at-age declined by 21.5% (age 10) to 36.7% (age 5). A decrease in the average weight-at-age was also observed in the other fall-spawning herring stocks in the northwest Atlantic, including those on Quebec's North Shore (Division 4S; DFO 2021a), southern Gulf of St. Lawrence (Division 4TVn; Turcotte et al. 2021), and southwest Nova Scotia and the Bay of Fundy (Division 4VWX; Singh et al. 2020).

3.5.6. Relative condition index

Trends in the relative condition index (Kn) of FS herring closely followed observations for SS herring (Figure 44). At any point in the time series, however, condition for FS was approximately 0.1 point smaller than for SS. Kn of FS has been decreasing and is below the series average since 2006, and attained a minimum value of 0.92 in 2012.

3.5.7. Cumulative stock productivity index

Following a period of positive anomalies in the 1980s, the productivity of the FS stock fluctuated between positive and negative anomalies throughout the 1990s and early 2000, with the strong positive anomalies mostly associated with strong recruitment events (e.g. 1995, 1998 and 2000; Figure 45). The stock productivity has remained largely negative since 2003, which suggests that the FS herring stock on the west coast of Newfoundland has been in a lower productivity state over the last two decades.

3.6. ENVIRONMENTAL DRIVERS OF CONDITION AND RECRUITMENT

Indices describing the physical environment and the spring bloom showed high interannual variations without clear trends, except for SST which showed a warming trend over the study period (Figures 46-47). Indices related to zooplankton dynamics, on the other hand, exhibited clear trends over the 2001-2019 period (Figure 48). *Calanus* abundance was generally higher in the early summer than in the fall. *C. finmarchicus* abundance decreased in the fall over the 2000s and then remained relatively stable although highly variable since, with peaks in 2008, 2012 and 2017 (Figure 48). *C. hyperboreus* abundance remained relatively stable over the 2002-1019 period and was higher in 2003, 2009 and 2014. *Pseudocalanus* spp. and the small calanoids category started to increase around 2010, which led to a decrease in the ratio of large and small calanoids (Figure 48). The index of phenology for *C. finmarchicus* in the early summer and fall increased over the 2001-2019 period, while *C. hyperboreus* phenology varied without trend and was highest during the 2004-2013 period (Figure 48).

For the Kn of SS herring, the best model considering only the physical environmental indices was rejected because it showed temporal autocorrelation (Table 15). The best model considering the physical and spring bloom dynamics indices explained a lower deviance in Kn than the 95th percentile of the distribution of deviance explained by resampled values and was rejected (Table 15). The best model considering zooplankton abundance and phenology indices explained 83% of deviance in Kn. The model was robust against missing years, i.e. the *r* between observed and predicted Kn (0.83) during the jackknife was deemed similar to the r^2 obtained with all data (0.7). According to this model, Kn of SS was higher when the spring phytoplankton bloom duration was longer, when *C. hyperboreus* phenology was earlier (i.e. more advanced development as indicated by a higher proportion of stage CIV relative to stages CI-CIV), and when the abundance of *Pseudocalanus* ssp. was lower (Figure 49). *Pseudocalanus* abundance is the predictor with the largest effect on the Kn of SS herring (Figures 49B and 49D). *Pseudocalanus* are small calanoids that provide less energy per unit than large Calanoids, which could favor a lower net energy gain by herring during years of greater abundance of these small Calanoids (Ljungström et al. 2020). Small Calanoids are becoming more abundant in the GSL since 2014 (Blais et al. 2019), suggesting that herring may acquire less energy in recent years for the same foraging effort, which is consistent with the lower values of Kn observed in recent years (Figure 31).

For the Kn of FS herring, the best model considering only physical indices showed strong temporal autocorrelation in residuals and was therefore rejected (Table 15). The best model included average SST from August to November, *C. finmarchicus* abundance in the fall and *C. finmarchicus* phenology in the fall, and explained 66% of the deviance in Kn (Table 15, Figure 50). The model was robust against missing years (i.e. the *r* between observed and predicted Kn (0.68) during the jackknife procedure was similar to the r^2 obtained with all data (0.61)). Kn of FS herring was greater when SST was colder, when *C. finmarchicus* was more abundant, and when *C. finmarchicus* phenology occurred earlier (i.e. lower C1-C4/C1-C6 ratio) (Figure 50). The condition of both herring spawning stocks was thus favoured by the high abundance of large energy-rich Calanoid copepods, which is consistent with the results obtained for the herring stocks in Division 4S (DFO 2021a).

For the recruitment index, all models were rejected because the deviance explained was not superior to the 95th percentile of the distribution of the explained deviance obtained in the bootstrap simulations (Table 16).

4. SOURCES OF UNCERTAINTY

Changes in catchability of the acoustic survey represent a major source of uncertainty for the assessment of the spring- and fall-spawning herring stocks on the west coast of Newfoundland. Several factors may explain the variations observed in the catchability of the survey. Survey dates (mid-October to early November) have remained relatively constant, while the commercial fishery has shifted in time (late September to early-late December), which may indicate a change in fish behaviour and availability of herring for the survey. Interannual variations in acoustic sampling effort and spatial coverage of the survey may also influence catchability and add important uncertainty to the time series. Lastly, biological samples used to divide the acoustic biomass between spring- and fall-spawning herring and convert it into numbers-at-age were generally limited and were collected using fishing gear that varies from year to year. Occasionally, they came from the commercial fishery or other DFO surveys (e.g. Teleost). The use of commercial samples compromises the statistical independence of acoustic samples in relation to fishing data and adds uncertainty to the survey results.

The lack of information on herring population structure in the nGSL is another important source of uncertainty in this assessment. In the nGSL, herring are managed and assessed as two discrete stocks; one along the west coast of Newfoundland (division 4R) and another on the north coast of Quebec (division 4S). However, there is some evidence from capture-mark-recapture studies and commercial fishery data that mixing occurs between the herring stocks in 4R and eastern 4S during their feeding and overwintering migrations (Moores and Winters 1984; McQuinn and Lefebvre 1995b). More specifically, McQuinn and Lefebvre (1995b) suspected that herring which spawned along the Quebec Lower North Shore (NAFO subdivision 4Sw) were subsequently caught along the west coast of Newfoundland during the fall commercial fishery, and suggested that the definition of 4R as a management unit be revised to include 4Sw. However, the migration and mixing patterns of herring stocks in the nGSL are still poorly understood. Until more detailed information becomes available, the herring stocks in Divisions 4R and 4S are considered distinct populations and assessed separately.

5. CONCLUSION AND ADVICE

The data and knowledge available are insufficient to quantitatively assess the status of the resource. However, evidence available as recently as 2021 indicates that maintaining the TAC at status quo should not pose any significant risk to the two herring spawning stocks in Division 4R in the short term. Although the acoustic survey has uncertainties, which adversely affect the interpretation of temporal trends and absolute values of abundance, the calculated biomass represents a minimum estimate of the amount of fish available at the time of the survey. The maximum exploitation rates estimated from these biomasses and the commercial fishery for 2020-2021 were low (< 15%). These exploitation rates are lower than commonly used biological reference points for species with similar life history characteristics (Patterson et al. 1992).

After a period of low stock status in the mid-2000s and 2010s, the SS herring stock in NAFO division 4R is showing recent signs of increase. The proportion of SS has increased significantly since 2019 in the commercial catches and in the acoustic survey. The 2020 and 2021 acoustic surveys also estimated the highest SS biomass since the beginning of the survey.

The acoustic survey biomass estimates in 2020 and 2021 were mainly composed of SS of the 2017 year-class (age 3-4) and of FS of the 2016 year-class (age 4-5). The abundance of 3- and 4-year-olds for SS was the highest observed since the beginning of the survey. The abundance of young fish observed in the 2020-2021 acoustic surveys for both spawning stocks is an encouraging sign for the future of these stocks. Landings have been trending downward since

2017, and the recent decrease of 81% since 2019 can be explained by the high incidence of fish under the legal size that prevented harvesters from landing their quotas.

Catch-at-age in the commercial fishery followed the progression of year-classes up to age 11+ for the two spawning stocks, indicating low overall mortality. Catch-at-age was also dominated by older individuals (9 years and over) for the FS stock, which accounted for the majority of landings. The dominance of older year-classes in catches suggests that this stock is not overfished (Berkeley et al. 2004). Furthermore, excessive fishing pressure would have been expected to reduce the L_{50} and A_{50} over time which is not the case for SS and FS stocks.

During the last peer-review meeting in 2020, concerns related to some aspects of the fall acoustic survey led to the rejection of the assessment model as the basis for the science advice, resulting in the rejection of the reference points and the precautionary approach (DFO 2021b). A review of the assessment framework will be carried out in 2023-2025.

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TABLES

Table 1. Physical and biological variables used in the GAM analyses to assess the effects of the environment on the condition (Kn) and recruitment (R) of spring (SS) and fall spawners (FS). Fall-spawning herring models did not include variables related to the spring bloom. For spring-spawning herring, the abundance and phenology of zooplankton in early summer (June) was used, whereas the abundance and phenology of zooplankton in fall (October) was used for fall spawning herring. SST: sea surface temperature. The spring timing represents the first week of the year when the surface water temperature is above 10°C and the fall timing represents the last week of the year when the surface water temperature is below 10°C.

Period	Variable	Reference	Kn		R	
			SS	FS	SS	FS
	SST May-June		x	-	x	
	SST May-August		x	-	x	-
	SST May-November		-	-	x	x
	SST August		x	-	-	-
1982-2021	SST August-November	Galbraith et al. 2022	-	x	-	x
	SST November		-	x	-	-
	Spring timing (SST > 10°C)		x	-	x	-
	Fall timing (SST < 10°C)		-	x	-	x
	Timing of the last appearance of ice		x	-	x	-
1999-2019	Bloom timing	Blais et al. 2019	x	-	x	-
	Bloom duration		x	-	x	-
	Abundance of *C. finmarchicus*		x	x	x	x
	Abundance of *C. hyperboreus*		x	x	-	-
	Abundance of *Pseudocalanus* spp.		x	x	x	x
2001-2019	Abundance of small calanoids	Blais et al. 2019	x	x	x	x
	Large calanoids / small calanoids		x	x	x	x
	Phenology of *C. finmarchicus*		x	x	x	x
	Phenology de *C. hyperboreus*		x	-	-	-

Table 2. Annual landings (t) and Total Allowable Catch (TAC) of herring per subdivision in NAFO Division 4R from 1966 to 2021. 2019, 2020 and 2021 data are preliminary.

YEAR	SUBDIVISION				TOTAL	TAC
	4Ra	4Rb	4Rc	4Rd		
1966	45	5,530	103	216	**5,894**	-
1967	40	5,540	66	215	**5,861**	-
1968	11	3,843	59	156	**4,069**	-
1969	68	2,545	46	277	**2,936**	-
1970	407	3,473	27	79	**3,986**	-
1971	1,954	1,063	2,424	3,830	**9,271**	-
1972	3,628	1,544	862	4,921	**10,955**	-
1973	9,213	2,068	2,862	12,541	**26,684**	-
1974	3,043	918	857	2,624	**7,442**	-
1975	1,786	266	128	3,340	**5,520**	-
1976	2,467	246	2,069	6,569	**11,351**	-
1977	4,366	189	2,205	5,568	**12,328**	12,000
1978	5,651	369	1,984	6,807	**14,811**	12,500
1979	3,265	3,998	5,043	6,032	**18,338**	12,500
1980	4,243	2,969	6,944	5,098	**19,254**	18,000
1981	1,969	3,090	4,899	3,639	**13,597**	16,000
1982	1,696	4,550	7,158	1,466	**14,870**	10,000
1983	2,259	3,557	4,188	1,412	**11,416**	10,000
1984	809	4,722	3,925	1,007	**10,463**	10,000
1985	301	10,070	1,897	2,118	**14,386**	10,000
1986	337	16,298	2,655	2,127	**21,417**	17,000
1987	993	10,496	4,320	772	**16,581**	30,600
1988	553	1,349	13,789	2,454	**18,145**	30,600
1989	350	1,016	7,033	9,288	**17,687**	37,000
1990	377	1,332	1,259	5,196	**8,164**	35,000
1991	576	6,947	2,494	16,420	**26,437**	35,000
1992	902	4,147	1,391	8,896	**15,336**	35,000
1993	852	2,198	1,029	11,022	**15,100**	35,000
1994	1,017	5,711	3,053	2,599	**12,380**	35,000
1995	2,284	3,273	7,321	3,134	**16,012**	22,000
1996	2,584	2,951	8,173	1,114	**14,823**	22,000
1997	2,571	3,451	5,300	1,638	**12,960**	22,000
1998	4,129	7,729	5,891	609	**18,359**	22,000
1999	1,653	4,766	3,087	1,201	**10,707**	13,000
2000	1,981	2,995	6,469	1,470	**12,916**	15,000
2001	2,613	2,643	6,379	1,589	**13,224**	15,000
2002	1,604	2,621	7,660	1,232	**13,117**	15,000
2003	1,290	714	2,593	10,533	**15,130**	20,000
2004	712	252	6,162	7,574	**14,700**	20,000
2005	1,138	3,574	5,889	7,326	**17,927**	20,000
2006	957	5,645	4,457	7,538	**18,597**	20,000
2007	884	915	13,831	375	**16,005**	20,000
2008	731	3,286	5,668	11,058	**20,743**	20,000
2009	821	4,573	10,707	4,134	**20,235**	20,000
2010	984	5,651	4,342	8,228	**19,205**	20,000
2011	2,694	6,389	4,899	6,489	**20,471**	20,000
2012	2,396	9,249	2,994	4,712	**19,351**	20,000
2013	1,977	8,651	6,322	2,424	**19,374**	20,000
2014	2,129	13,798	640	1,585	**18,152**	20,000
2015	2,322	15,915	637	546	**19,420**	20,000
2016	3,195	14,253	2,211	273	**19,932**	20,000
2017	2,842	9,727	2,102	767	**15,438**	20,000
2018	1,566	4,360	607	885	**7,418**	20,000
2019	4,512	7,642	3,182	470	**15,806**	20,000
2020	2,803	1,154	618	288	**4,863**	20,000
2021	316	530	2,018	211	**3,075**	20,000
MEAN (1966-2019)	**1,921**	**4,723**	**3,931**	**3,955**	**14,531**	-

Table 3. Annual landings (t) of herring per fishing gear in NAFO Division 4R from 1966 to 2021. 2019, 2020 and 2021 data are preliminary.

YEAR	FISHING GEAR						TOTAL
	Large seine	Small seine	Gillnet	Tuck seine	Trap	Other	
1966	5,491	0	403	0	0	0	**5,894**
1967	5,464	0	397	0	0	0	**5,861**
1968	3,776	0	293	0	0	0	**4,069**
1969	2,585	0	351	0	0	0	**2,936**
1970	2,979	0	1,007	0	0	0	**3,986**
1971	6,607	0	2,664	0	0	0	**9,271**
1972	6,800	0	4,155	0	0	0	**10,955**
1973	20,068	0	6,616	0	0	0	**26,684**
1974	4,731	0	2,711	0	0	0	**7,442**
1975	3,221	0	2,232	0	0	67	**5,520**
1976	8,207	0	2,979	0	0	165	**11,351**
1977	9,453	0	2,651	0	0	224	**12,328**
1978	9,123	0	5,536	0	0	152	**14,811**
1979	9,990	0	8,215	0	0	133	**18,338**
1980	9,632	0	9,471	0	0	151	**19,254**
1981	7,925	0	5,503	0	0	169	**13,597**
1982	9,548	0	5,249	0	0	73	**14,870**
1983	7,279	0	3,947	0	0	190	**11,416**
1984	7,204	0	3,252	0	0	7	**10,463**
1985	13,171	0	1,205	0	0	10	**14,386**
1986	19,270	0	2,147	0	0	0	**21,417**
1987	13,733	0	2,843	0	0	5	**16,581**
1988	16,353	0	1,792	0	0	0	**18,145**
1989	16,660	0	1,027	0	0	0	**17,687**
1990	5,245	2,016	836	0	66	0	**8,164**
1991	23,106	2,488	779	0	62	1	**26,437**
1992	12,815	1,853	552	0	117	0	**15,336**
1993	11,634	3,240	119	0	103	4	**15,100**
1994	7,634	3,854	747	0	145	1	**12,380**
1995	10,815	3,392	1,658	0	145	2	**16,012**
1996	9,472	3,072	2,175	0	102	1	**14,823**
1997	7,751	3,052	1,803	0	350	3	**12,960**
1998	9,468	4,434	4,217	0	233	6	**18,359**
1999	7,146	2,599	869	0	92	0	**10,707**
2000	8,427	3,153	1,277	0	59	0	**12,916**
2001	8,344	3,418	1,215	0	150	97	**13,224**
2002	8,392	3,383	1,256	0	73	13	**13,117**
2003	11,090	2,307	1,630	0	104	0	**15,131**
2004	11,099	2,974	499	0	127	2	**14,701**
2005	11,005	3,918	1,031	908	529	535	**17,926**
2006	11,101	3,941	702	2,300	499	53	**18,596**
2007	10,954	2,659	132	1,546	706	8	**16,005**
2008	11,185	4,357	3	4,498	700	0	**20,743**
2009	11,171	4,416	0	3,778	872	0	**20,237**
2010	10,218	4,950	525	2,953	560	0	**19,206**
2011	10,260	5,429	2,108	1,883	625	166	**20,471**
2012	10,047	5,172	1,790	1,342	862	137	**19,350**
2013	9,985	4,905	915	2,337	1,231	0	**19,373**
2014	9,994	5,504	96	1,075	1,440	43	**18,152**
2015	11,168	4,471	680	2,030	928	144	**19,421**
2016	10,999	4,397	623	2,594	1,132	188	**19,933**
2017	9,628	3,312	546	1,167	746	37	**15,436**
2018	4,076	966	512	1,439	424	0	**7,417**
2019	7,677	3,758	680	3,401	289	0	**15,806**
2020	1,198	1,148	117	2,215	185	0	**4,863**
2021	2,044	110	2	749	170	0	**3,075**
MEAN (1966-2019)	**9,651**	**1,989**	**1,974**	**616**	**249**	**52**	**14,531**

Table 4. Annual landings (t) of herring per fishing gear and subdivision in NAFO Division 4R from 1966 to 2021. 2019, 2020 and 2021 data are preliminary.

YEAR	4Ra							4Rb						
	Large seine	Small seine	Gillnet	Tuck seine	Trap	Other	TOTAL	Large seine	Small seine	Gillnet	Tuck seine	Trap	Other	TOTAL
1966	0	-	45	-	-	-	**45**	5,491	-	39	-	-	-	**5,530**
1967	0	-	40	-	-	-	**40**	5,464	-	76	-	-	-	**5,540**
1968	0	-	11	-	-	-	**11**	3,776	-	67	-	-	-	**3,843**
1969	0	-	68	-	-	-	**68**	2,344	-	201	-	-	-	**2,545**
1970	0	-	407	-	-	-	**407**	2,939	-	534	-	-	-	**3,473**
1971	356	-	1,598	-	-	-	**1,954**	725	-	338	-	-	-	**1,063**
1972	0	-	3,628	-	-	-	**3,628**	1,330	-	214	-	-	-	**1,544**
1973	3,453	-	5,760	-	-	-	**9,213**	1,763	-	305	-	-	-	**2,068**
1974	1,071	-	1,972	-	-	-	**3,043**	439	-	479	-	-	-	**918**
1975	0	-	1,764	-	-	22	**1,786**	0	-	240	-	-	26	**266**
1976	184	-	2,143	-	-	140	**2,467**	0	-	226	-	-	20	**246**
1977	2,155	-	2,028	-	-	183	**4,366**	0	-	158	-	-	31	**189**
1978	1,834	-	3,795	-	-	22	**5,651**	0	-	288	-	-	81	**369**
1979	0	-	3,258	-	-	7	**3,265**	2,829	-	1,048	-	-	121	**3,998**
1980	428	-	3,810	-	-	5	**4,243**	2,002	-	879	-	-	88	**2,969**
1981	342	-	1,600	-	-	27	**1,969**	2,037	-	913	-	-	140	**3,090**
1982	0	-	1,695	-	-	1	**1,696**	3,973	-	519	-	-	58	**4,550**
1983	787	-	1,438	-	-	34	**2,259**	3,223	-	226	-	-	108	**3,557**
1984	15	-	790	-	-	4	**809**	4,166	-	554	-	-	2	**4,722**
1985	0	-	295	-	-	6	**301**	9,718	-	348	-	-	4	**10,070**
1986	0	-	337	-	-	0	**337**	15,830	-	468	-	-	0	**16,298**
1987	164	-	829	-	-	0	**993**	10,164	-	327	-	-	5	**10,496**
1988	44	-	509	-	-	0	**553**	1,093	-	256	-	-	0	**1,349**
1989	13	-	337	-	-	0	**350**	947	-	69	-	-	0	**1,016**
1990	0	0	323	0	54	0	**377**	1,145	0	174	-	13	0	**1,332**
1991	0	151	368	-	56	1	**576**	6,567	270	103	-	7	0	**6,947**
1992	0	347	440	-	115	-	**902**	3,954	145	47	-	1	0	**4,147**
1993	362	332	55	-	103	-	**852**	1,899	299	0	-	0	0	**2,198**
1994	72	406	394	-	145	1	**1,017**	4,063	1,487	161	-	0	0	**5,711**
1995	464	580	1,215	-	24	0	**2,284**	2,138	930	101	-	104	0	**3,273**
1996	226	404	1,883	-	70	0	**2,584**	1,896	886	143	-	27	0	**2,951**
1997	0	617	1,765	-	189	1	**2,571**	2,192	1,097	8	-	154	0	**3,451**
1998	577	647	2,793	-	110	2	**4,129**	4,750	1,455	1,398	-	123	3	**7,729**
1999	610	379	600	-	64	-	**1,653**	3,409	1,060	269	-	28	0	**4,766**
2000	414	307	1,231	-	29	0	**1,981**	1,776	1,149	40	-	30	0	**2,995**
2001	1,228	223	1,157	-	5	0	**2,613**	1,076	1,360	58	-	145	4	**2,643**
2002	247	233	1,103	-	9	13	**1,604**	1,407	1,029	121	-	64	-	**2,621**
2003	-	23	1,193	-	74	-	**1,290**	110	148	426	-	30	-	**714**
2004	-	185	429	-	99	0	**712**	-	169	53	-	28	2	**252**
2005	-	110	537	72	329	90	**1 137**	733	1,340	467	502	191	340	**3,574**
2006	18	81	446	12	400	0	**957**	1,830	1,841	171	1,673	99	31	**5,645**
2007	14	148	43	0	680	0	**884**	106	322	78	382	26	-	**915**
2008	-	31	-	0	700	-	**731**	2,679	523	1	83	-	-	**3,286**
2009	-	97	0	-	725	0	**821**	1,516	732	-	2,179	147	0	**4,573**
2010	-	-	451	-	533	0	**984**	3,310	838	69	1,411	23	-	**5,651**
2011	-	51	2,017	-	625	0	**2 694**	5,486	469	89	345	0	0	**6,389**
2012	-	103	1,362	65	862	4	**2 396**	5,150	3,509	421	169	-	0	**9,249**
2013	-	86	718	87	1,087	-	**1 977**	5,051	2,663	145	648	144	0	**8,651**
2014	-	445	92	135	1,414	43	**2 129**	9,171	4,226	4	371	26	0	**13,798**
2015	140	500	680	75	928	-	**2 322**	10,936	3,738	0	1,241	-	-	**15,915**
2016	742	522	623	179	1,129	-	**3 195**	9,576	3,473	-	1,103	3	99	**14,253**
2017	852	447	545	252	746	-	**2 842**	7,048	2,375	1	265	-	37	**9,727**
2018	-	117	511	514	423	-	**1 566**	3,551	526	1	281	1	-	**4,360**
2019	1,362	645	671	1 544	289	-	**4 511**	5,278	1,758	9	597	-	-	**7,642**
2020	74	940	117	1487	185	-	**2 803**	506	124	-	524	-	-	**1,154**
2021	-	-	2	144	170	-	**316**	125	11	-	394	-	-	**530**
MEAN (1966-2019)							**1,921**							**4,723**

Table 4. (continued).

YEAR	4Rc							4Rd						
	Large seine	Small seine	Gillnet	Tuck seine	Trap	Other	TOTAL	Large seine	Small seine	Gillnet	Tuck seine	Trap	Other	TOTAL
1966	0	-	103	-	-	-	**103**	0	-	216	-	-	-	**216**
1967	0	-	66	-	-	-	**66**	0	-	215	-	-	-	**215**
1968	0	-	59	-	-	-	**59**	0	-	156	-	-	-	**156**
1969	0	-	46	-	-	-	**46**	241	-	36	-	-	-	**277**
1970	12	-	15	-	-	-	**27**	28	-	51	-	-	-	**79**
1971	2,239	-	185	-	-	-	**2,424**	3,287	-	543	-	-	-	**3,830**
1972	727	-	135	-	-	-	**862**	4,743	-	178	-	-	-	**4,921**
1973	2,740	-	122	-	-	-	**2,862**	12,112	-	429	-	-	-	**12,541**
1974	756	-	101	-	-	-	**857**	2,465	-	159	-	-	-	**2,624**
1975	0	-	112	-	-	16	**128**	3,221	-	116	-	-	3	**3,340**
1976	1,956	-	111	-	-	2	**2,069**	6,067	-	499	-	-	3	**6,569**
1977	2,009	-	193	-	-	3	**2,205**	5,289	-	272	-	-	7	**5,568**
1978	1,037	-	931	-	-	16	**1,984**	6,252	-	522	-	-	33	**6,807**
1979	2,774	-	2,267	-	-	2	**5,043**	4,387	-	1,642	-	-	3	**6,032**
1980	3,703	-	3,224	-	-	17	**6,944**	3,499	-	1,558	-	-	41	**5,098**
1981	3,277	-	1,622	-	-	0	**4,899**	2,269	-	1,368	-	-	2	**3,639**
1982	5,575	-	1,572	-	-	11	**7,158**	0	-	1,463	-	-	3	**1,466**
1983	3,269	-	873	-	-	46	**4,188**	0	-	1,410	-	-	2	**1,412**
1984	3,023	-	902	-	-	0	**3,925**	0	-	1,006	-	-	1	**1,007**
1985	1,733	-	164	-	-	0	**1,897**	1,720	-	398	-	-	0	**2,118**
1986	1,586	-	1,069	-	-	0	**2,655**	1,854	-	273	-	-	0	**2,127**
1987	3,183	-	1,137	-	-	0	**4,320**	222	-	550	-	-	0	**772**
1988	13,197	-	592	-	-	0	**13,789**	2,019	-	435	-	-	0	**2,454**
1989	6,589	-	444	-	-	0	**7,033**	9,111	-	177	-	-	0	**9,288**
1990	824	248	187	-	0	0	**1,259**	3,275	1,768	152	-	0	0	**5,196**
1991	1,577	741	175	-	0	0	**2,494**	14,961	1,326	133	-	0	0	**16,420**
1992	1,271	82	37	-	0	0	**1,391**	7,589	1,279	27	-	1	0	**8,896**
1993	740	276	9	-	0	4	**1,029**	8,634	2,333	55	-	0	0	**11,022**
1994	2,026	951	75	-	0	0	**3,053**	1,472	1,010	117	-	0	0	**2,599**
1995	5,457	1,680	179	-	5	1	**7,321**	2,755	201	163	-	12	1	**3,134**
1996	6,751	1,332	84	-	5	1	**8,173**	600	450	65	-	0	0	**1,114**
1997	4,237	1,042	11	-	7	2	**5,300**	1,322	296	19	-	0	0	**1,638**
1998	3,712	2,173	5	-	0	1	**5,891**	428	160	21	-	0	0	**609**
1999	2,195	891	0	-	0	0	**3,087**	932	269	0	-	0	0	**1,201**
2000	4,766	1,697	5	-	0	0	**6,469**	1,470	0	0	-	0	0	**1,470**
2001	4,708	1,578	-	-	-	93	**6,379**	1,332	257	-	-	-	-	**1,589**
2002	5,929	1,721	9	-	-	-	**7,660**	809	400	23	-	-	0	**1,232**
2003	2,192	401	1	-	-	0	**2,593**	8,788	1,735	10	-	-	0	**10,533**
2004	5,673	489	-	-	-	-	**6,162**	5,426	2,131	17	-	-	-	**7,574**
2005	4,693	925	-	269	-	2	**5,889**	5,579	1,543	27	65	9	103	**7,326**
2006	3,029	991	3	433	-	-	**4,457**	6,224	1,028	82	182	-	22	**7,538**
2007	10,834	1,866	4	1,119	-	8	**13,831**	1	323	7	45	-	-	**375**
2008	4,165	666	-	837	-	-	**5,668**	4,341	3,137	2	3,578	-	-	**11,058**
2009	8,306	1,839	-	562	-	-	**10,707**	1,349	1,748	-	1,037	-	-	**4,134**
2010	3,352	715	3	272	-	-	**4,342**	3,556	3,397	2	1,270	4	-	**8,228**
2011	2,770	1,399	2	609	-	120	**4,899**	2,004	3,510	-	929	-	46	**6,489**
2012	1,821	866	7	280	-	19	**2,994**	3,076	694	-	828	-	114	**4,712**
2013	2,643	2,063	51	1,564	-	-	**6,322**	2,291	93	1	38	-	-	**2,424**
2014	303	287	-	49	-	-	**640**	520	546	-	520	-	-	**1,585**
2015	92	170	-	358	-	17	**637**	-	63	-	356	-	127	**546**
2016	681	336	-	1,105	-	89	**2,211**	-	66	-	207	-	-	**273**
2017	1,272	350	-	480	-	-	**2,102**	456	140	-	170	-	-	**767**
2018	275	238	-	94	-	-	**607**	250	86	-	550	-	-	**885**
2019	1,037	1,264	-	881	-	-	**3,182**	-	91	-	380	-	-	**470**
2020	618	-	-	-	-	-	**618**	-	84	-	204	-	-	**288**
2021	1,919	99	-	-	-	-	**2,018**	-	-	-	211	-	-	**211**
MEAN (1966-2019)							**3,931**							**3,955**

Table 5. Number of Atlantic herring sampled by year, season, fleet (mobile and fixed) and NAFO subdivision from the commercial port sampling program and sent to MLI for further inspection of their biological characteristics. Fish sampled before and after August 1st are considered to issue from the spring and fall fishery, respectively.

	Spring fishery								Fall fishery									
YEAR	**Fixed**				**Mobile**				**Fixed**					**Mobile**				**TOTAL**
	4Ra	**4Rb**	**4Rc**	**4Rd**	**4Ra**	**4Rb**	**4Rc**	**4Rd**	**4Ra**	**4Rb**	**4Rc**	**4Rd**	**4R**	**4Ra**	**4Rb**	**4Rc**	**4Rd**	
1965	0	0	0	0	0	0	0	0	0	100	0	0	0	0	465	0	0	**565**
1966	0	0	0	0	0	0	0	0	0	48	48	0	0	0	252	0	250	**598**
1967	0	100	0	94	0	163	0	88	50	277	78	0	0	0	545	0	0	**1,395**
1968	0	0	0	0	0	50	26	300	0	0	0	24	0	0	350	0	0	**750**
1969	0	0	0	0	0	0	0	50	0	50	0	0	0	0	496	0	0	**596**
1970	100	0	0	0	0	0	0	200	248	350	0	0	0	0	149	0	0	**1,047**
1971	200	0	0	0	0	0	300	150	0	550	0	0	0	50	150	0	0	**1,400**
1972	150	50	0	100	0	0	97	350	400	400	0	0	0	0	1,375	150	0	**3,072**
1973	50	288	0	0	0	450	436	545	739	697	0	0	0	400	450	0	0	**4,055**
1974	30	100	0	0	0	0	50	797	745	150	0	0	0	300	300	0	0	**2,472**
1975	199	250	0	50	48	0	0	600	0	0	0	0	0	0	0	0	0	**1,147**
1976	350	100	19	29	0	0	150	1,190	150	0	0	0	0	447	0	0	0	**2,435**
1977	535	140	0	0	0	0	695	1,439	1,048	50	0	0	0	200	290	0	0	**4,397**
1978	750	276	0	100	0	94	94	721	350	0	0	0	0	1,224	100	0	0	**3,709**
1979	300	100	499	250	0	248	374	1,069	750	100	0	0	0	300	150	0	0	**4,140**
1980	1,149	200	900	477	648	500	347	849	800	99	0	0	0	0	500	1,085	0	**7,554**
1981	500	259	1,499	175	59	516	823	1,375	396	37	0	0	0	0	1,117	0	0	**6,756**
1982	149	0	344	47	0	55	592	210	0	154	0	0	0	50	582	150	0	**2,333**
1983	53	0	0	56	0	127	889	0	2,099	343	0	0	0	274	1,082	793	0	**5,716**
1984	50	0	302	101	0	798	494	0	2,006	247	100	0	0	106	2,918	0	0	**7,122**
1985	0	0	543	352	0	506	1,328	282	1,049	0	0	0	0	0	3,747	349	0	**8,156**
1986	149	0	845	890	0	129	364	401	1,237	90	150	0	0	0	1,650	50	0	**5,955**
1987	0	0	943	795	0	105	241	167	1,535	92	0	0	0	58	971	204	47	**5,158**
1988	344	0	1,061	699	50	101	101	1,267	1,253	220	0	0	0	57	1,137	102	0	**6,392**
1989	178	0	1,071	448	0	462	191	622	755	194	0	0	0	118	838	358	81	**5,316**
1990	148	0	513	338	0	2	159	508	883	50	0	0	0	2	1,045	85	97	**3,830**
1991	200	0	299	296	0	127	216	315	440	50	0	0	0	93	831	278	1	**3,146**
1992	200	0	329	399	0	313	218	185	247	0	0	0	0	155	948	203	177	**3,374**
1993	422	0	745	500	0	389	133	1,010	1,312	0	0	0	0	200	597	246	0	**5,554**
1994	337	0	730	600	0	358	1,207	636	1,119	69	0	0	0	187	1,250	757	232	**7,482**
1995	420	50	399	699	0	100	366	255	1,236	0	0	0	190	254	515	765	264	**5,513**
1996	300	50	346	848	100	0	450	0	1,259	250	0	0	192	200	100	600	100	**4,795**
1997	150	0	578	900	0	0	150	250	633	0	0	0	68	250	400	600	150	**4,129**
1998	200	0	197	486	50	0	649	50	800	50	0	0	100	100	250	50	50	**3,032**
1999	200	0	278	848	150	315	67	0	100	0	0	0	339	732	380	1,151	0	**4,560**
2000	250	0	278	650	50	0	250	100	200	50	0	0	88	100	550	250	0	**2,816**
2001	350	0	395	400	200	50	100	50	50	50	0	0	0	350	349	450	99	**2,893**
2002	150	50	287	497	150	208	250	150	0	50	0	0	47	250	484	349	183	**3,105**
2003	150	0	310	399	100	125	550	0	0	0	0	0	0	0	100	50	1,199	**2,983**
2004	50	0	345	399	0	0	100	0	0	0	0	0	0	0	0	600	750	**2,244**
2005	0	0	164	247	0	0	192	0	0	0	0	0	0	0	93	49	901	**1,646**
2006	0	0	264	109	50	0	50	50	0	50	0	0	0	0	450	50	1,000	**2,073**
2007	0	0	0	0	100	0	0	0	0	50	99	0	0	0	98	1,252	0	**1,599**
2008	0	0	0	0	0	0	0	0	0	0	0	100	0	0	428	250	578	**1,356**
2009	0	0	0	0	0	0	349	0	0	350	0	0	0	0	919	1,482	441	**3,541**
2010	150	0	0	0	0	0	150	0	0	298	0	0	182	0	299	443	350	**1,872**
2011	150	0	0	0	0	50	199	0	0	198	0	0	0	231	299	208	785	**2,120**
2012	107	0	0	0	0	0	0	0	0	53	0	0	0	55	1,104	0	603	**1,922**
2013	220	0	0	0	0	0	110	0	0	0	0	0	0	67	1,331	479	359	**2,566**
2014	218	0	0	0	0	0	0	0	110	55	0	0	0	0	1,537	0	330	**2,250**
2015	0	0	0	0	0	0	0	0	110	48	0	0	0	111	1,265	0	110	**1,644**
2016	0	0	0	0	55	0	0	0	0	0	0	0	0	275	1154	317	0	**1,801**
2017	164	0	0	0	110	0	0	0	0	0	0	0	0	277	759	165	276	**1,751**
2018	165	0	0	0	0	0	0	0	0	0	0	0	0	0	220	0	495	**880**
2019	0	0	0	0	55	0	140	0	0	0	0	0	0	110	710	55	0	**1,070**
2020	0	0	0	0	0	0	0	0	110	55	0	0	0	587	255	0	0	**1,007**
2021	0	0	0	0	55	0	110	0	0	0	0	0	0	0	54	0	0	**219**

Table 6. Commercial catch-at-age (000's) of the spring-spawning herring stock on the west coast of Newfoundland (NAFO Division 4R) from 1965 to 2021.

YEAR	AGE									
	2	3	4	5	6	7	8	9	10	11+
1965	630	73	13	693	1,602	1,293	651	461	305	509
1966	115	283	276	520	1,822	4,176	2,090	1,652	382	638
1967	0	18	459	139	318	3,403	2,745	1,265	742	847
1968	84	163	302	549	203	569	1,120	2,049	420	358
1969	366	1,730	2,778	1,026	500	264	703	1,259	1,185	117
1970	1,067	570	297	435	182	75	116	565	1,615	61
1971	0	2,527	303	841	720	651	340	350	2,412	255
1972	284	220	8,189	1,308	1,461	1,245	1,115	1,377	1,034	2,013
1973	1,833	435	1,063	27,872	2,570	3,222	3,232	2,598	4,789	5,696
1974	141	261	130	371	9,445	318	851	774	490	2,175
1975	57	996	420	100	1,063	8,431	317	336	244	665
1976	484	680	846	201	350	2,802	15,567	759	3,136	3,588
1977	10	534	541	409	304	348	4,362	15,959	1,694	6,003
1978	0	47	1,987	207	679	241	2,162	8,208	15,260	5,062
1979	167	25	214	10,828	617	1,075	547	2,772	7,404	14,032
1980	300	854	106	355	13,872	407	1,344	247	1,427	20,574
1981	40	417	2,114	129	354	8,872	188	515	283	13,181
1982	594	2,374	693	2,452	421	2,153	6,488	704	950	12,863
1983	34	2,965	3,562	1,131	1,091	293	713	2,990	798	7,975
1984	198	433	7,773	3,809	595	814	209	672	755	4,226
1985	362	4,587	787	21,642	3,993	445	381	255	380	1,764
1986	323	2,348	13,762	3,349	28,781	5,241	465	167	260	1,661
1987	455	329	2,781	15,257	3,507	12,952	1,736	182	37	806
1988	702	539	402	2,461	15,064	3,677	13,616	2,527	423	2,060
1989	305	574	763	461	3,036	18,704	3,072	10,910	779	1,380
1990	114	2,136	670	405	997	5,010	16,296	3,773	6,432	2,187
1991	577	2,233	9,849	1,285	768	3,018	6,955	21,327	2,366	6,579
1992	90	1,243	1,707	8,538	998	998	2,781	2,168	11,879	3,902
1993	79	1,592	3,802	3,409	6,784	1,509	2,102	2,727	2,800	8,804
1994	14	332	2,597	3,183	3,762	3,434	1,642	1,589	1,757	1,945
1995	12	247	1,219	5,750	5,807	2,152	7,126	185	3,083	4,577
1996	1,347	248	1,156	4,056	7,712	4,211	551	3,291	419	1,597
1997	36	1,006	131	259	1,303	6,598	1,684	580	2,554	1,588
1998	80	859	7,836	393	579	2,143	7,683	1,146	994	3,174
1999	152	1,815	3,501	4,583	202	156	749	1,532	378	943
2000	0	3,106	7,182	2,207	3,971	108	248	765	857	773
2001	189	184	3,627	6,440	4,045	3,794	146	338	766	1,651
2002	0	6,545	515	6,643	8,770	3,672	3,525	179	411	869
2003	0	1,016	5,576	1,367	5,085	6,021	1,924	931	204	569
2004	1,048	722	2,224	4,829	2,307	8,375	5,591	1,113	320	841
2005	149	2,935	2,504	653	3,439	809	4,282	5,182	1,984	2,155
2006	63	391	4,973	4,891	1,402	1,643	1,529	2,011	919	575
2007	0	45	332	3,055	1,492	527	385	381	574	1,060
2008	57	62	141	857	5,078	740	635	361	345	475
2009	94	422	469	206	1,339	7,141	2,735	908	1,453	2,612
2010	0	32	248	232	404	1,473	3,301	1,143	445	1,437
2011	0	95	222	161	159	449	1,570	1,256	463	642
2012	0	63	195	462	1,018	748	591	2,918	3,259	499
2013	0	69	520	1,300	207	871	1,259	2,961	1,905	564
2014	0	50	111	169	172	124	126	113	17	150
2015	377	1,150	308	210	333	55	138	0	72	0
2016	0	1,569	1,232	476	188	99	290	131	71	851
2017	0	228	3,484	1,941	442	585	702	596	134	375
2018	0	506	346	1,980	614	306	65	406	93	41
2019	2,937	141	1,501	865	9,857	3,374	913	275	282	657
2020	0	1,369	222	413	443	2,119	355	187	60	146
2021	0	96	1,187	314	605	1,742	3,267	288	146	0

Table 7. Herring biomass densities and estimates by stratum from the acoustic survey conducted on August 8-30, 2020. Standard error (S.E.) and coefficient of variation (C.V.) of the biomass estimates were computed based on the variance of transect biomass by stratum (O'Boyle and Atkinson 1989). N.S.= Not sampled.

Summer 2020	Stratum				All herring area backscattering coefficients (s_a)					Fall-spawning herring				Spring-spawning herring			
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km/km^2)	Total sa (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.	1	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
St. Georges N.	2	302.7	4	6,465.4	0.085	2,637.6	8.71E-06	2.1E-06	24.1	0.019	5,856.0	1,410.1	24.1	0.004	1,330.0	320.2	24.1
Port-au-Port G.	3	795.8	4	8,857.1	0.045	12,881.9	1.62E-05	2.57E-06	15.9	0.024	18,756.7	2,977.2	15.9	0.015	11,991.3	1,903.4	15.9
Port-au-Port	4	352.0	3	10,925.9	0.093	5,203.3	1.48E-05	4.38E-06	29.7	0.02	7,080.8	2,102.1	29.7	0.015	5,237.7	1,555.0	29.7
Bay of Islands G.	5	477.9	5	14,939.1	0.156	11,078.2	2.32E-05	5.61E-06	24.2	0.028	13,369.0	3,231.9	24.2	0.026	12,466.9	3,013.9	24.2
Bonne Bay Bank	6	1,157.2	3	13,552.2	0.035	25,134.8	2.17E-05	3.16E-06	14.5	0.028	32,033.6	4,657.6	14.5	0.025	29,484.5	4,287.0	14.5
Bay of Islands	7	293.2	4	15,980.9	0.218	8,596.9	2.93E-05	4.35E-06	14.8	0.04	11,688.3	1,734.1	14.8	0.029	8,646.0	1,282.8	14.8
Bonne Bay	8	58.5	6	2,989.9	0.307	627.2	1.07E-05	2.36E-06	22	0.023	1,327.2	292.6	22.0	0.008	466.4	102.8	22.0
Hawk's Bay	9	499.7	3	10,107.1	0.061	1,445.8	2.89E-06	1.12E-06	38.8	0.005	2,288.3	888.9	38.8	0.003	1,437.0	558.2	38.8
St. John Bay	10	959.1	9	11,765.7	0.11	10,100.8	1.05E-05	2.54E-06	24.1	0.025	23,699.5	5,708.4	24.1	0.006	5,738.1	1,382.1	24.1
Belle-Isle S.	BI1	774	8	7,472.8	0.077	44,087.6	5.7E-05	3.04E-05	53.3	0.134	103,996.0	55,674.7	53.5	0.033	25,179.5	13,480.0	53.5
Belle-Isle N.	BI2	603.7	5	8,401.8	0.07	2,387.7	3.95E-06	1.31E-06	33.1	0.009	5,596.3	1,855.7	33.2	0.002	1,355.0	449.3	33.2
Bras Nord	BN	32.9	3	3,249.4	0.296	230.8	7.01E-06	6.66E-07	9.5	0.01	313.8	29.8	9.5	0.007	232.1	22.0	9.5
Average / Total:	-	6,714.6	57	9,558.9	0.08	124,412.7	0.000206	3.21e-05	15.6	0.034	226,005.3	56,453.5	25.0	0.015	103,564.5	14,812.0	14.3

Table 8. Herring biomass densities and estimates by stratum from the acoustic survey conducted on October 18 to November 5, 2020. Standard error (S.E.) and coefficient of variation (C.V.) of the biomass estimates were computed based on the variance of transect biomass by stratum (O'Boyle and Atkinson 1989). N.S.= Not sampled.

Fall 2020	Stratum				All herring area backscattering coefficients (s_a)					Fall-spawning herring				Spring-spawning herring			
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km/km^2)	Total sa (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.	1	407.7	7	4,556.3	0.078	138.5	3.4E-07	1.58E-07	46.6	0.001	339.3	158.2	46.6	0	95.0	44.3	46.6
St. Georges N.	2	302.7	4	7,026.1	0.093	507.9	1.68E-06	7.54E-07	45.0	0.004	1,244.4	559.4	45.0	0.001	348.6	156.7	45.0
Port-au-Port G.	3	802.9	7	9,270.8	0.081	1,205.5	1.5E-06	5.43E-07	36.2	0.003	2,031.2	734.9	36.2	0.001	1,197.7	433.4	36.2
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	474.5	3	14,772.3	0.093	292.1	6.16E-07	2.52E-07	41.0	0.001	519.2	212.7	41.0	0.001	272.2	111.5	41.0
Bonne Bay Bank	6	1,148.1	7	12,089.7	0.074	1,708.9	1.49E-06	4.12E-07	27.7	0.003	3,211.6	890.6	27.7	0.002	1,742.8	483.3	27.7
Bay of Islands	7	286.2	4	17,867.9	0.25	1,525.5	5.33E-06	9.22E-07	17.3	0.009	2,675.0	462.0	17.3	0.005	1,549.4	267.6	17.3
Bonne Bay	8	*N.S*			-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	9	499.8	4	7,794.6	0.062	374.2	7.49E-07	2.75E-07	36.7	0.001	676.4	248.5	36.7	0.001	392.0	144.0	36.7
St. John Bay	10	967.8	8	13,288.7	0.11	2,578.7	2.66E-06	9.95E-07	37.3	0.006	5,585.6	2,085.2	37.3	0.002	2,279.5	851.0	37.3
Belle-Isle S.	BI1	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Belle-Isle N.	BI2	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bras Nord	BN	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Average / Total:		7,413.7	44	10,833.3	0.062	8,331.3	1.44e-05	1.74E-06	12.1	0.002	16,282.7	2,517.9	15.5	0.001	7,877.2	1130	14.3

Table 9. Herring biomass densities and estimates by stratum from the acoustic survey conducted in August 8-18, 2021. Standard error (S.E.) and coefficient of variation (C.V.) of the biomass estimates were computed based on the variance of transects biomass by stratum (O'Boyle and Atkinson 1989). N.S.= Not sampled.

Summer 2021	Stratum				All herring area backscattering coefficients (s_a)					Fall-spawning herring				Spring-spawning herring			
							Weighted mean s_a				Biomass				Biomass		
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km/km^2)	Total sa (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.	1	302.9	8	3,794.7	0.1	1,214.2	4.01E-06	3.02E-06	75.3	0.001	396.4	298.6	75.3	0.013	4,002.6	3,015.1	75.3
St. Georges N.	2	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-Port G.	3	796.3	5	10,428.6	0.065	3,956.4	4.97E-06	1.47E-06	29.6	0.006	4,762.7	1,409.7	29.6	0.006	4,664.8	1,380.7	29.6
Port-au-Port	4	352.5	5	9,906.9	0.141	2,141.4	6.07E-06	2.7E-06	44.5	0.008	2,904.4	1,147.3	39.5	0.008	2,844.7	1,123.7	39.5
Bay of Islands G.	5	477.9	4	12,878.8	0.108	2,527.5	5.29E-06	2.38E-06	45.0	0.006	3,042.6	1,369.7	45.0	0.006	2,980.1	1,341.6	45.0
Bonne Bay Bank	6	1,157.3	10	11,945.8	0.103	10,397.4	8.98E-06	2.07E-06	23.0	0.017	20,221.7	4,656.5	23.0	0.015	17,325.1	3,989.5	23.0
Bay of Islands	7	306.2	7	10,907.8	0.249	2,544.3	8.31E-06	1.81E-06	21.8	0.011	3,353.4	667.4	19.9	0.011	3,284.5	653.6	19.9
Bonne Bay	8	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	9	499.7	6	9,462.3	0.114	5,700.1	1.14E-05	3.33E-06	29.2	0.022	11,086.1	3,237.3	29.2	0.019	9,498.1	2,773.6	29.2
St. John Bay	10	983.3	11	10,739.5	0.12	18,509.7	1.88E-05	7.19E-06	38.2	0.080	78,226.8	29,156.9	37.3	0	466.3	173.8	37.3
Belle-Isle S.	BI1	301.6	7	3,908.2	0.091	20,896.2	6.93E-05	3.12E-05	45.0	0.286	86,127.2	38,723.8	45.0	0.002	513.4	230.8	45.0
Belle-Isle N.	BI2	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bras Nord	BN	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Average / Total:		6,198.7	63	9,330.3	0.094	67,887.2	0.000137	3.26E-05	23.8	0.034	210,121.3	48,862.4	23.3	0.007	45,579.6	6,178.9	13.6

Table 10. Herring biomass densities and estimates by stratum from the acoustic survey conducted on October 13-28, 2021. Standard error (S.E.) and coefficient of variation (C.V.) of the biomass estimates were computed based on the variance of transects biomass by stratum (O'Boyle and Atkinson 1989). N.S.= Not sampled.

Fall 2021	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km^2)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km^2)**	**Total sa (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.	1	407.7	11	4,028.4	0.109	693.6	1.7E-06	6.07eE07	35.7	0.001	462.3	156.3	33.8	0.004	1564.9	529.0	33.8
St. Georges N.	2	302.7	6	6,283.9	0.125	490.2	1.62E-06	6.11E-07	37.8	0.001	412.3	155.7	37.8	0.003	947.7	357.9	37.8
Port-au-Port G.	3	796.3	9	9,232.9	0.104	1,912.9	2.4E-06	9.4E-07	39.1	0.001	1090.3	426.8	39.1	0.005	4164.8	1630.3	39.1
Port-au-Port	4	352.5	7	9,464.9	0.188	1452.2	4.12E-06	2.01E-06	48.7	0.004	1344.2	641.2	47.7	0.008	2746	1309.9	47.7
Bay of Islands G.	5	477.9	4	14,650.5	0.123	1206.3	2.52E-06	5.55E-07	22.0	0.003	1304.7	286.7	22.0	0.005	2166.1	475.9	22.0
Bonne Bay Bank	6	1,157.3	11	12,061.3	0.115	3234.0	2.79E-06	8.91E-07	31.9	0.007	7590.4	2419.2	31.9	0.003	3368.1	1073.5	31.9
Bay of Islands	7	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	8	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	9	499.7	7	8,158.2	0.114	710.2	1.42E-06	1.04E-06	73.0	0.003	1666.8	1216.4	73	0.001	739.6	539.8	73.0
St. John Bay	10	983.3	9	10,926.1	0.100	1258.6	1.28E-06	5.07E-07	39.6	0.003	2461.4	948.9	38.6	0.002	1583.8	610.6	38.6
Belle-Isle S.	BI1	1,092.2	12	9,123.8	0.100	32491.4	2.97E-05	1.16E-05	39.1	0.018	19552.4	7636.4	39.1	0.065	70949.4	27710.0	39.1
Belle-Isle N.	BI2	626.8	10	7,642.2	0.122	16299.5	2.6E-05	9.42E-06	36.2	0.012	7284.9	3000.6	41.2	0.038	23914.8	9850.1	41.2
Bras Nord	BN	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Average / Total:		7,094.2	86	9,157.2	0.108	59748.9	7.36E-05	1.52E-05	20.7	0.006	43169.8	8733.5	20.2	0.016	112145.2	29524.4	26.3

Table 11. Exploitation rates (%) for the spring- and fall-spawning herring stocks in NAFO Division 4R in 2020-2021. The exploitation rates are estimated as the ratio of the landings (t) over the highest biomass index (t) estimated in the acoustic surveys. Presumed landings of each spawning component if the TAC of 20,000 t had been taken are based on the proportions of the two spawning stocks in the 2020-2021 commercial catch-at-age composition.

Year	**Spawning stock**	**Landings (t)**	**Acoustic biomass index (t)**	**Exploitation rate (%)**
Based on 2020-2021 preliminary landings:				
2020	Spring	1,143	103,565 (± 9,316)	1.10 (1.01-1.21)
	Fall	3,719	226,005 (± 35,507)	1.65 (1.42-1.95)
2021	Spring	2,682	112,145 (± 20,803)	2.39 (2.02-2.94)
	Fall	342	210,121 (± 36,845)	0.16 (0.14-0.20)
If the 20,000 t had been taken:				
2020	Spring	4,702	103,565 (± 9,316)	4.54 (4.17-4.99)
	Fall	17,448	226,005 (± 35,507)	6.77 (5.85-8.03)
2021	Spring	15,298	112,145 (± 20,803)	15.56 (13.12-19.10)
	Fall	2,552	210,121 (± 36,845)	1.21 (1.03-1.47)

Table 12. Spring-spawning herring numbers-at-age (000's) from the summer and fall acoustic surveys conducted on the west coast of Newfoundland (NAFO division 4R) from 1991 to 2021.

SURVEY	AGE									
	2	3	4	5	6	7	8	9	10	11+
Fall 1991	5,252	14,241	78,462	216	13,484	43,972	26,318	48,683	8,773	44,080
Fall 1993	15,591	36,865	32,008	26,686	41,341	1,567	6,965	6,965	5,398	12,879
Fall 1995	1,000	4,627	5,587	32,838	12,184	6,786	18,560	5,301	12,356	14,334
Fall 1997	128	18,951	2,380	4,341	17,636	29,299	12,529	343	27,038	5,618
Fall 1999	4,597	44,622	24,176	29,285	725	0	988	8,243	1,786	8,323
Fall 2002	1,217	8,112	909	16,287	33,965	23,812	19,822	238	4,709	1,190
Fall 2009	0	1,346	0	485	3,769	10,014	2,423	1,938	969	3,284
Fall 2010	2,900	5,996	62,616	920	1,518	12,254	17,779	4,280	1,311	1,047
Fall 2011	0	8,839	3,086	3,364	3,225	279	5,951	5,952	5,923	5,255
Fall 2013	0	0	16,396	3,560	848	3,392	3,110	0	173	0
Fall 2015	0	508	3,962	1,321	0	0	0	0	364	0
Fall 2017	0	0	4,879	18,292	0	0	0	1,424	0	1,424
Summer 2019	85,247	5,760	11,520	2,304	16,128	9,216	0	0	1,152	0
Fall 2019	314,759	37,518	4,450	7,082	90,861	10,034	24,389	153	0	2,695
Summer 2020	2,055	974,302	57,554	6,166	20,555	36,999	2,055	2,055	0	0
Fall 2020	484	44,068	10,977	1,937	1,291	3,874	1,453	323	323	0
Summer 2021	0	916	49,447	5,494	31,133	77,834	32,049	6,410	1,831	1,831
Fall 2021	895	16,118	740,535	15,223	9,850	8,954	15,223	5,373	895	0

Table 13. Commercial catch-at-age (000's) of the fall-spawning herring stock on the west coast of Newfoundland (NAFO Division 4R) from 1965 to 2021.

YEAR	AGE									
	2	3	4	5	6	7	8	9	10	11+
1965	17	655	476	235	271	303	1,010	653	355	722
1966	44	76	682	318	348	232	1,181	931	845	2,517
1967	0	112	181	790	369	124	433	934	1,011	3,108
1968	0	170	108	209	935	223	174	284	998	1,913
1969	34	299	711	364	876	736	200	142	214	1,859
1970	0	466	187	33	51	251	90	71	89	1,688
1971	40	0	112	440	638	2,150	3,485	2,071	1,073	14,138
1972	10	96	115	1,310	1,345	2,852	2,165	3,577	2,173	28,342
1973	0	1,798	1,180	1,114	2,626	1,527	2,631	3,830	8,265	17,653
1974	0	20	393	530	325	592	258	308	313	5,610
1975	0	19	40	865	925	107	157	147	218	3,371
1976	0	48	272	290	422	561	325	253	88	4,818
1977	0	3	169	134	404	721	405	342	293	6,646
1978	0	10	27	545	393	1,108	1,689	503	341	6,051
1979	0	7	116	345	2,689	520	1,287	1,847	468	6,286
1980	15	181	136	86	176	1,729	250	675	308	5,243
1981	0	33	524	245	90	295	1,234	153	124	3,369
1982	101	567	1,824	956	509	140	377	972	315	2,609
1983	15	83	2,330	1,356	1,309	506	159	467	618	2,824
1984	0	55	668	6,259	1,147	908	220	146	268	3,091
1985	15	235	1,340	1,907	9,678	902	622	115	36	468
1986	35	426	1,431	2,671	2,292	8,421	794	384	66	227
1987	0	156	487	1,354	2,009	1,728	5,927	474	163	196
1988	484	207	511	481	1,240	1,740	1,667	4,165	705	777
1989	43	599	539	923	807	749	828	961	2,873	983
1990	27	530	1,568	424	306	429	384	839	481	4,718
1991	73	832	1,278	5,763	674	1,501	919	649	2,144	7,124
1992	0	337	1,446	1,448	1,236	775	543	779	390	3,928
1993	21	210	672	1,957	1,015	1,661	558	911	877	4,608
1994	0	61	994	2,777	4,032	3,104	2,435	1,630	1,179	3,999
1995	65	91	1,419	6,159	3,512	3,905	1,211	3,189	411	4,246
1996	0	1,969	1,358	2,531	8,573	2,304	3,927	828	1,968	3,130
1997	0	593	1,726	877	1,086	7,649	2,193	4,949	562	4,200
1998	0	597	4,802	8,820	2,995	2,029	13,268	1,251	4,289	4,493
1999	0	989	10,785	4,245	4,103	1,178	858	4,238	1,096	2,222
2000	572	359	3,154	10,673	3,175	2,854	998	352	5,329	3,807
2001	83	2,503	589	4,829	9,608	3,647	2,607	532	546	2,265
2002	0	216	6,476	831	2,147	3,660	958	502	110	1,305
2003	227	8,782	3,910	4,227	2,130	6,168	4,305	1,212	441	2,674
2004	51	776	7,653	2,889	2,368	2,252	6,841	1,859	318	2,510
2005	181	734	2,668	21,815	4,036	2,825	1,113	2,252	2,577	2,610
2006	0	440	1,318	9,622	30,865	5,447	3,620	2,673	2,925	3,509
2007	34	871	3,007	4,355	13,677	30,979	3,083	1,928	577	2,594
2008	76	1,666	2,503	1,978	5,327	17,332	31,643	5,561	1,535	4,184
2009	139	402	6,271	2,710	2,530	4,146	11,850	24,999	2,685	3,274
2010	0	86	481	3,491	2,463	3,877	9,354	24,053	10,584	3,304
2011	0	871	883	1,596	3,837	4,047	5,040	15,725	24,198	9,639
2012	0	194	3,435	2,140	2,886	5,905	5,398	9,070	17,350	14,875
2013	6	421	2,106	10,581	4,307	4,768	8,565	8,951	12,192	11,657
2014	63	769	960	1,445	11,580	4,894	6,104	10,515	10,642	18,242
2015	42	3,961	4,967	1,782	2,037	12,376	5,151	6,817	9,913	23,145
2016	52	325	2,878	4,069	1,488	2,559	13,341	5,678	6,366	31,838
2017	0	152	899	4,809	3,428	1,061	3,697	11,233	7,280	17,404
2018	23	222	395	733	1,718	1,391	1,769	3,129	6,059	7,114
2019	49	2,125	979	921	1,696	4,699	4,994	3,378	5,308	16,661
2020	0	16	1,933	196	358	1,292	1,858	2,380	2,195	3,894
2021	0	0	0	0	52	26	52	208	208	338

Table 14. Fall-spawning herring numbers-at-age (000's) from the summer and fall acoustic surveys conducted on the west coast of Newfoundland (NAFO division 4R) from 1991 to 2021.

YEAR	AGE									
	2	3	4	5	6	7	8	9	10	11+
Fall 1991	0	8,841	37,546	29,664	12,515	4,207	12,515	16,616	4,101	106,938
Fall 1993	3,054	42,610	25,955	33,590	14,213	36,785	9,533	5,601	8,996	31,228
Fall 1995	0	7,365	15,411	59,905	12,296	20,719	8,609	16,702	5,713	36,515
Fall 1997	119	3,334	29,209	12,209	13,805	69,256	7,892	17,097	1,849	36,207
Fall 1999	838	19,431	83,377	42,889	44,183	10,165	4,585	52,314	7,335	26,596
Fall 2002	1,422	4,451	66,684	4,943	24,607	85,516	32,926	20,979	3,156	17,721
Fall 2009	2,986	673	21,474	8,761	9,336	26,564	82,666	77,087	4,429	20,410
Fall 2010	0	20,190	18,109	97,164	61,536	36,405	89,921	142,890	90,500	41,651
Fall 2011	0	54,138	27,071	19,456	37,160	23,192	31,018	86,786	134,727	40,555
Fall 2013	2,889	18,088	49,418	91,576	86,103	42,062	67,059	62,379	67,008	158,837
Fall 2015	0	7,980	13,717	5,862	14,624	40,698	15,915	28,025	48,126	137,759
Fall 2017	0	0	1,598	10,201	25,127	8,303	13,970	39,303	31,859	50,105
Summer 2019	7,406	89,927	6,348	25,391	28,565	70,884	33,855	12,696	21,159	126,956
Fall 2019	1,872	137,301	12,790	93,318	57,651	18,335	27,253	4,261	8,471	61,928
Summer 2020	0	29,867	821,346	70,934	35,467	87,735	104,535	52,267	56,001	98,935
Fall 2020	345	2,072	49,736	6,735	2,763	3,799	4,490	7,081	4,835	12,779
Summer 2021	26,688	1,906	11,438	72,440	24,782	70,534	148,693	81,972	83,878	173,475
Fall 2021	45,499	3,981	15,925	107,491	8,531	5,119	11,375	15,356	13,081	38,674

Table 15. Summary results of generalized additive models evaluating the effect of the environment on the variability of Kn for each time series available and spawning component. phys: physical indices, phyto: spring bloom + physical indices, zoo: zooplankton + spring bloom + physical indices. The effect of each selected predictor on the response variable can be positive (+) or negative (-). Non-significant effects are noted with n.s. Model performance was evaluated with the R² between observed and predicted values, % of deviance explained (%DEV), the comparison of deviance explained with bootstrap (for significantly higher than the distribution obtained by bootstrap and n.s. otherwise) and the Pearson's correlation coefficient between predicted and observed values during the Jackknife procedure. The status of the models is either selected or rejected. In case of rejection, the reason is given. Selected models are in bold.*

Component	Series	Selected predictors	Effect	R^2	%DEV	Bootstrap	Jackknife	Status
Spring	phys.	SST August	-	0.14	15	*	0.31	rejected: temporal autocorrelation
	phyto.	Last ice SST May-August Bloom duration	- + n.s. +	0.37	45	n.s.	0.45	rejected: failed bootstrap
	zoo.	**Bloom duration** ***C. hyperboreus* phenology (early summer)** ***Pseudocalanus* (early summer)**	**+ n.s.** **+** **-**	**0.70**	**83**	*****	**0.83**	**selected**
Fall	phys.	SST August-November	-	0.25	27	*	0.45	rejected: temporal autocorrelation
	zoo.	**SST August-November** ***C. finmarchicus* abundance (fall)** ***C. finmarchicus* phenology (fall)**	**-** **+** **-**	**0.61**	**66**	*****	**0.68**	**selected**

Table 16. Summary results of generalized additive models (quantile 0.5) evaluating the effect of the environment on recruitment for each time series available and spawning component. Phys: physical indices, phyto: spring bloom + physical indices, zoo: zooplankton + spring bloom + physical indices. Non-significant effects are noted with n.s. Model performance is evaluated with the R^2 between observed and predicted values, % of deviance explained (%DEV), the comparison of deviance explained with bootstrap (for significantly higher than the distribution obtained by bootstrap and n.s. otherwise) and the Pearson's correlation coefficient between predicted and observed values during the Jackknife procedure. The status of the models is either selected or rejected. In case of rejection, the reason is given.*

Component	Series	Selected predictors	Effect	R^2	%DEV	Bootstrap	Jackknife	Status
Spring	phys.	Last ice	n.s.	-0.04	11	n.s.	-0.65	rejected: failed bootstrap
	phyto.	Spring timing	n.s.	-0.06	17	n.s.	-0.30	rejected: failed bootstrap
	zoo.	Onset of bloom	n.s.	-0.12	23	n.s.	-0.32	rejected: failed bootstrap
Fall	phys.	SST May-November	n.s.	-0.02	10	n.s.	-0.16	rejected: failed bootstrap
	zoo.	SST May-November	n.s.	-0.04	18	n.s.	-0.14	rejected: failed bootstrap

FIGURES

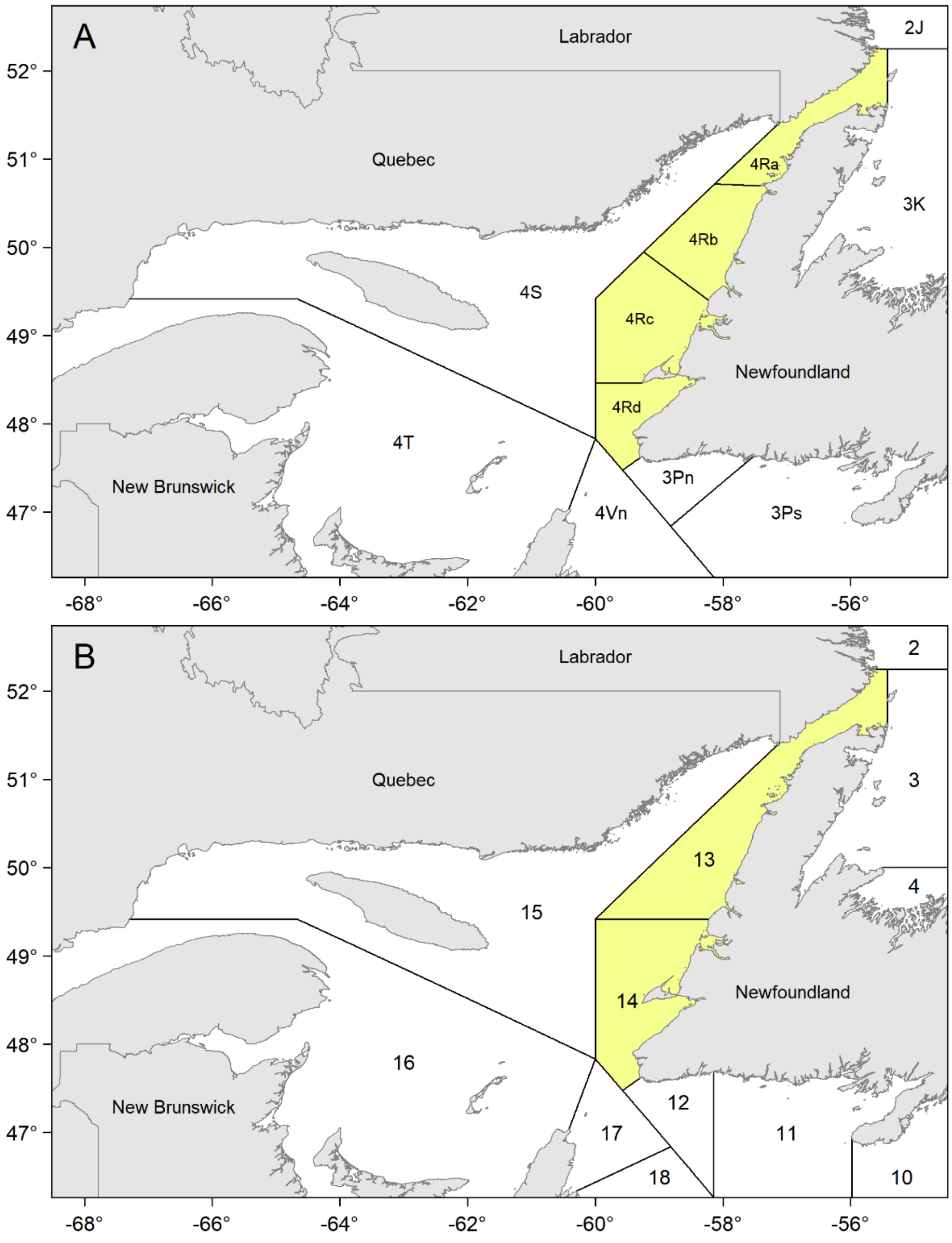

Figure 1. (A) Map of subdivisions of NAFO Division 4R. (B) Map of herring fishing areas (HFA) 13 and 14.

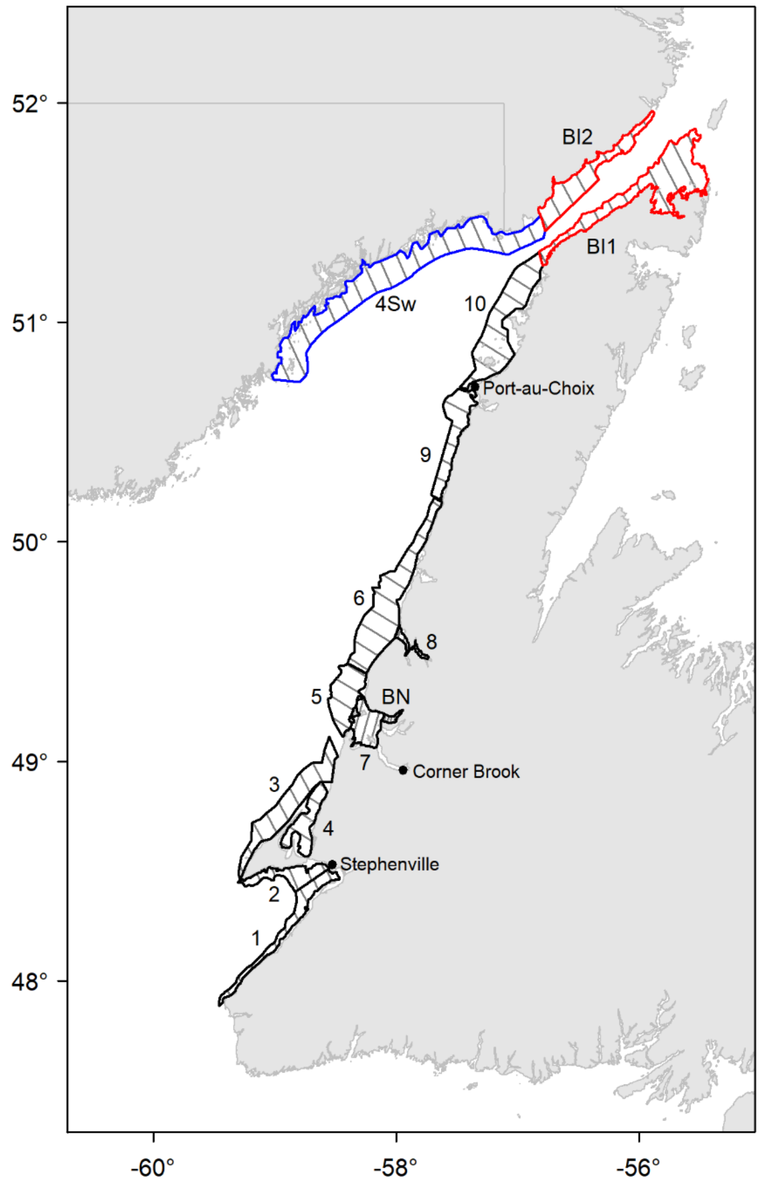

Figure 2. Map of the acoustic survey stratification scheme. Red polygons are strata added to the survey area in 2019 in the Strait of Belle Isle. The blue polygon is the stratum that covers subdivision 4Sw from NAFO division 4S (not included in this assessment). The gray lines within each stratum are the transects surveyed by the hydroacoustic vessel in the fall of 2021.

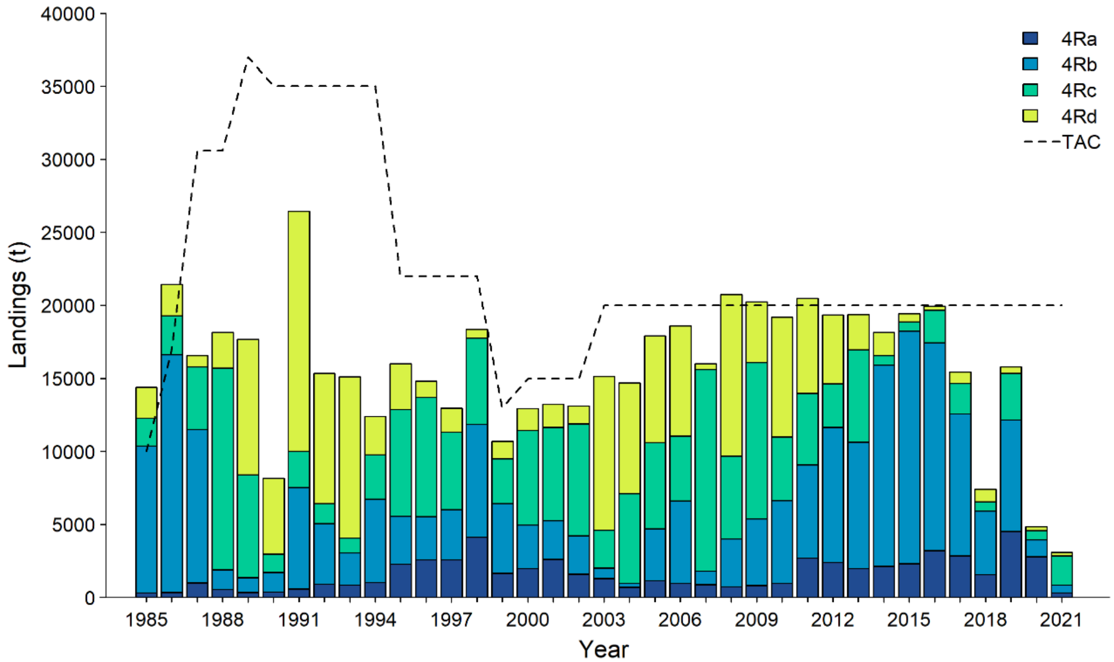

Figure 3. Herring cumulative commercial landings (t) per subdivision and total allowable catch (TAC) of the west coast of Newfoundland (NAFO Division 4R), from 1985 to 2021. Landings for 2019, 2020 and 2021 are preliminary.

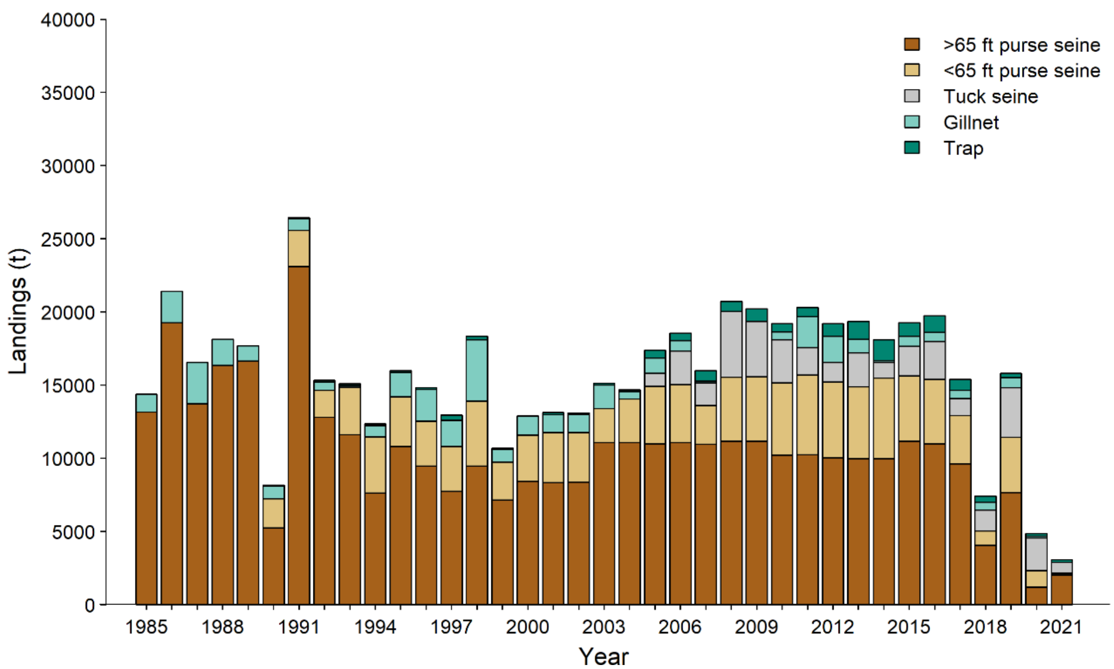

Figure 4. Herring cumulative commercial landings (t) per fishing gear of the west coast of Newfoundland (NAFO Division 4R), from 1985 to 2021. Landings for 2019, 2020 and 2021 are preliminary.

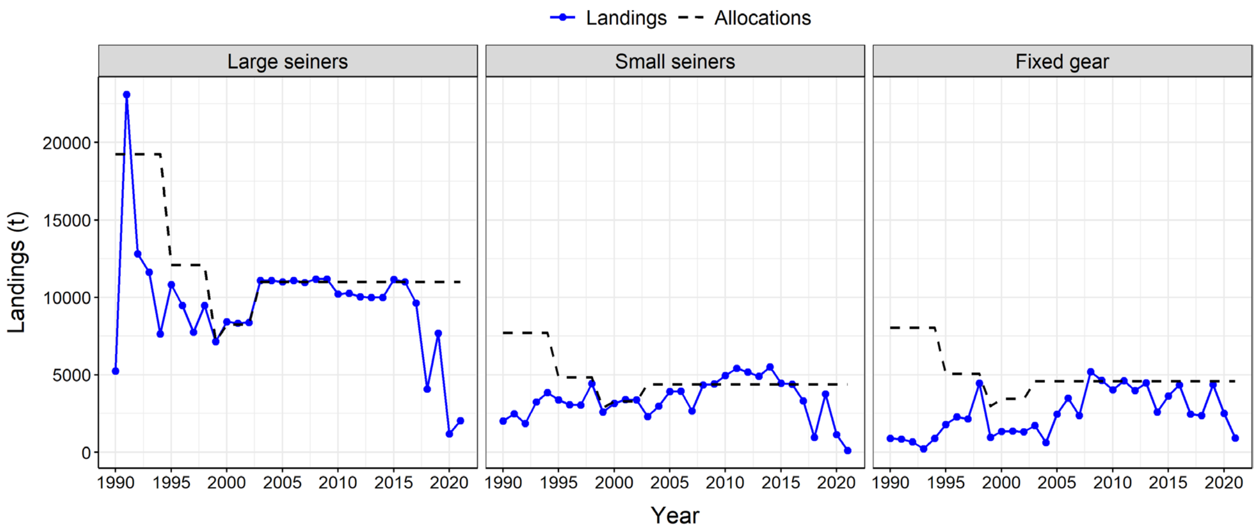

Figure 5. Herring commercial landings (t; solid blue line) and allocations (t; dashed black line) per fishing fleet (large seiner ≥ 65', small seiner < 65', and fixed gear) in NAFO Division 4R from 1990 to 2021. Landings for 2019, 2020 and 2021 are preliminary.

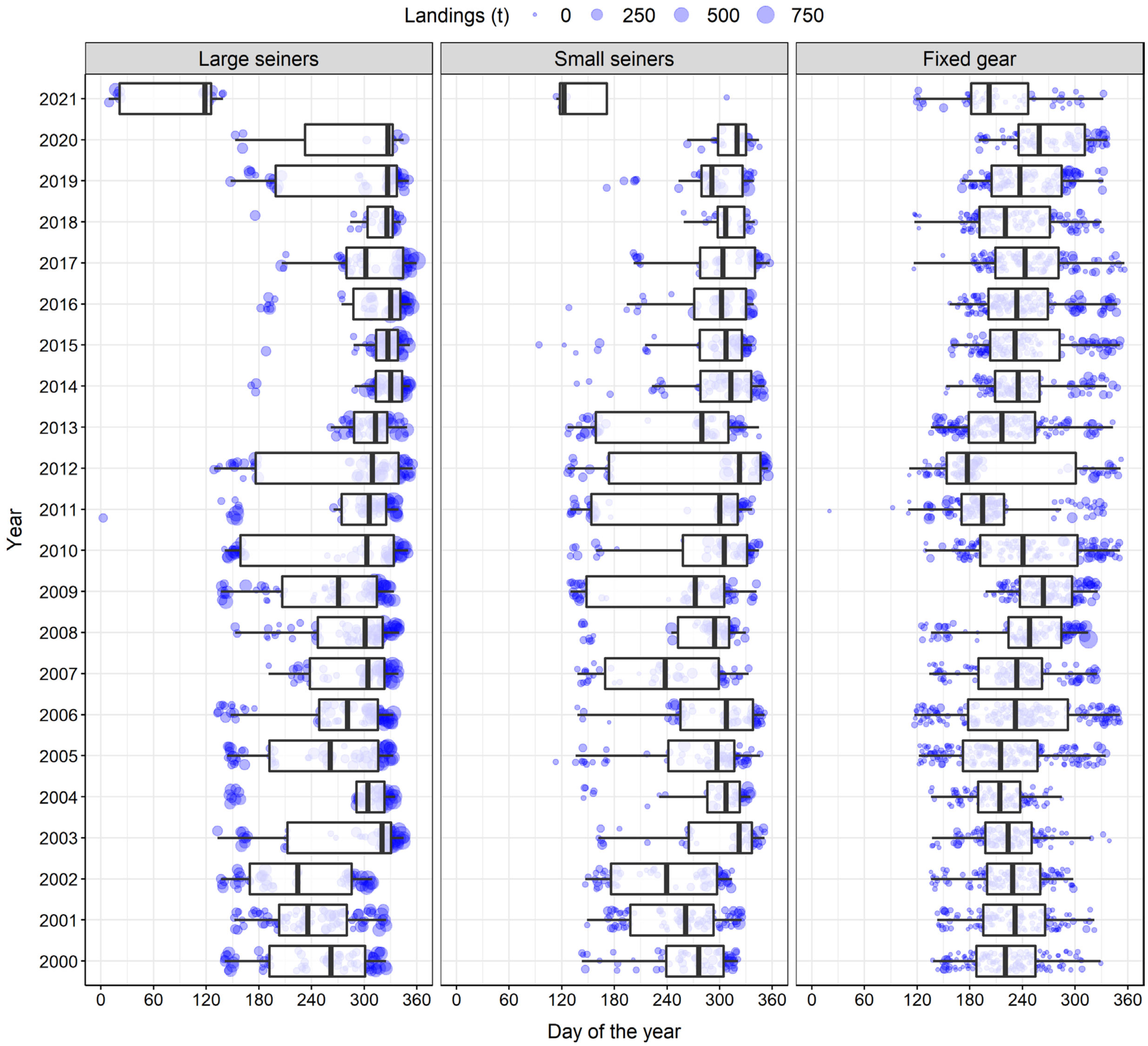

Figure 6. Boxplot representing commercial herring landings (t) per year and Julian day for large seiners (≥ 65'), small seiners (< 65') and fixed gear from 2000 to 2021 in NAFO Division 4R. Individual landings are plotted with circle size proportional to landed weight and jittered for visual representation. Landings for 2019, 2020 and 2021 are preliminary.

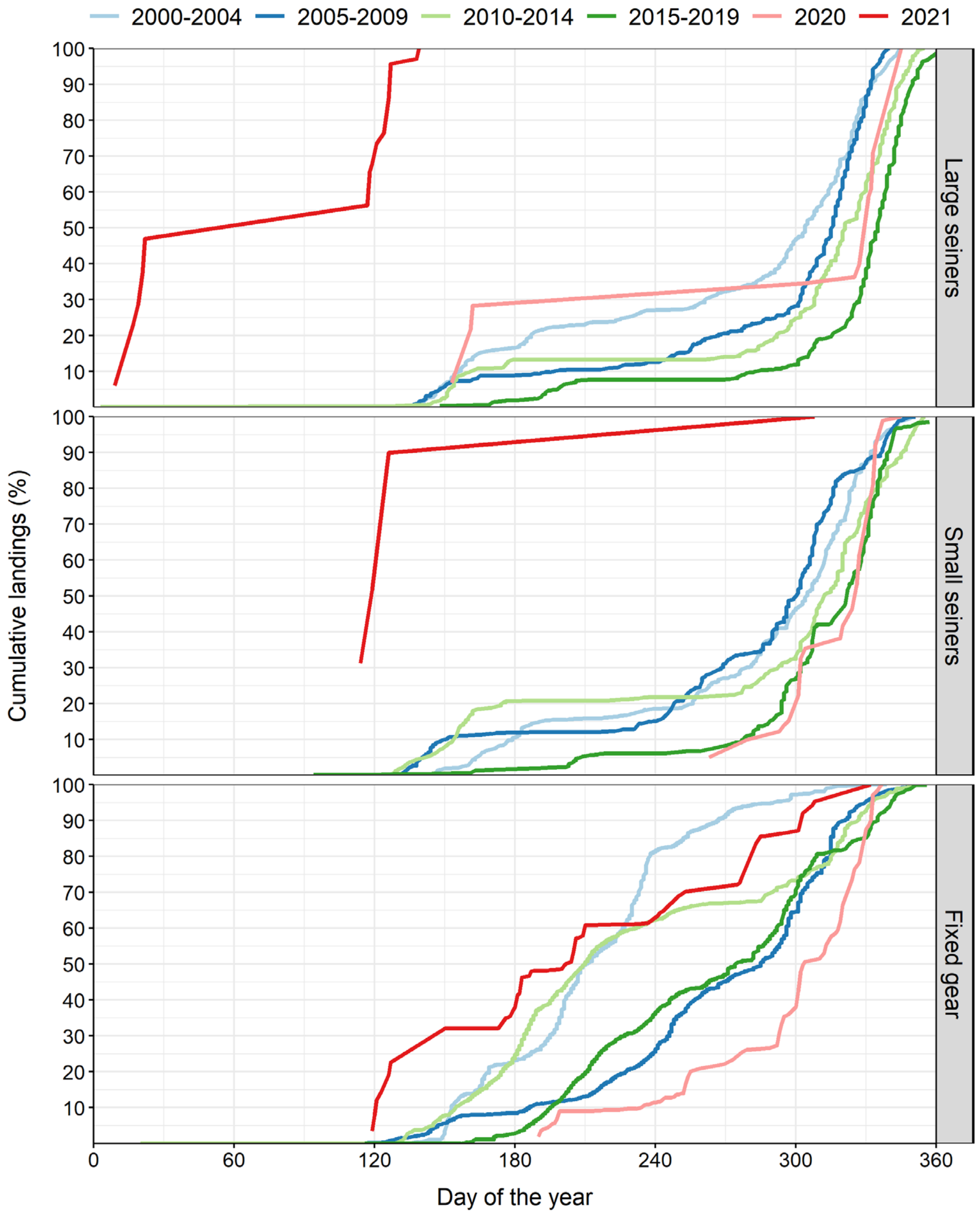

Figure 7. Cumulative commercial herring landings (%) over the fishing season by 5 year periods according to the day of the year and by fishing fleet (large seiner ≥ 65', small seiner < 65', and fixed gear) in NAFO Division 4R. The last 2 years of available data are plotted individually. Landings for 2019, 2020 and 2021 are preliminary.

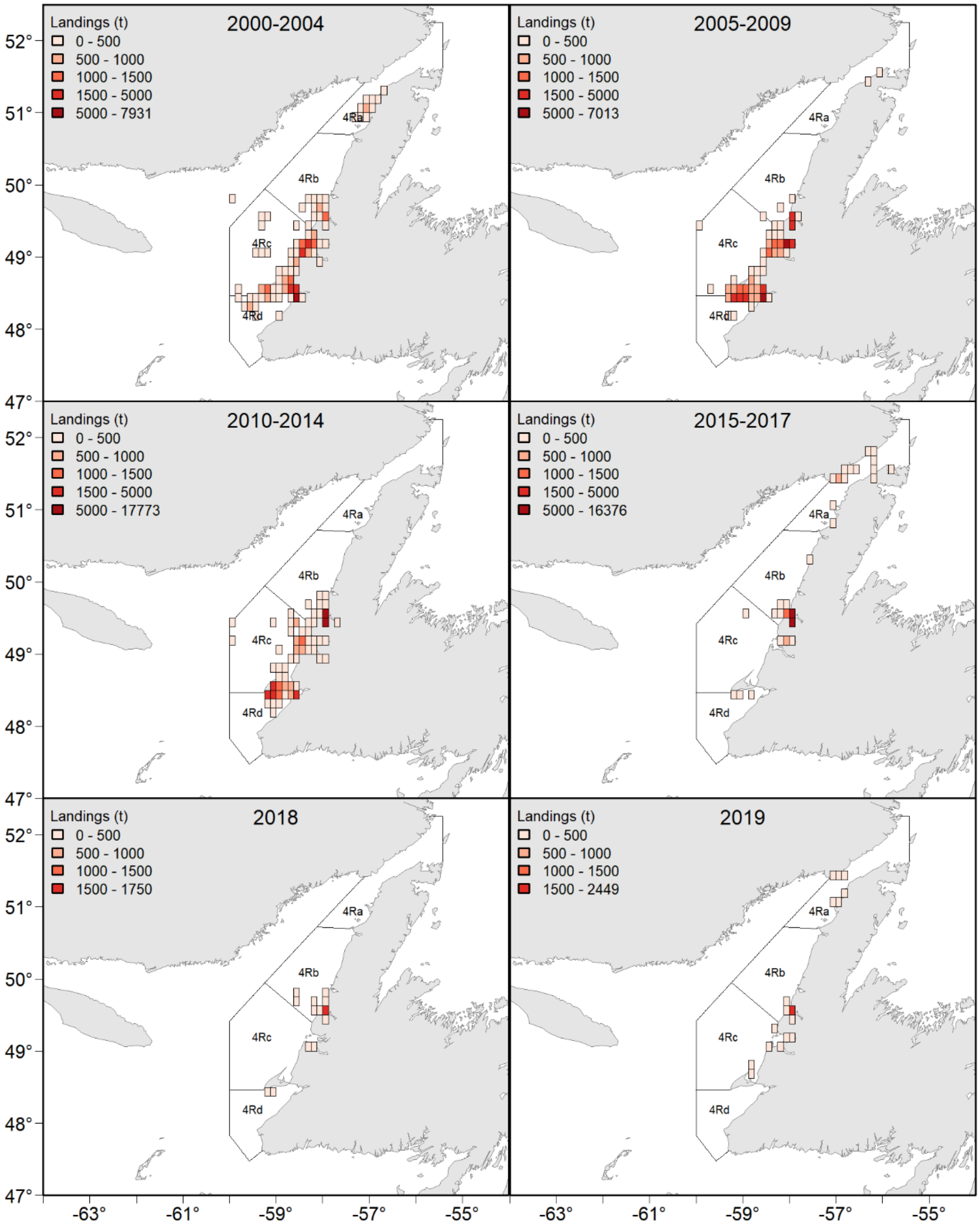

Figure 8. Location of commercial herring landings (t) by the large purse seiner fleet (> 65') in NAFO Division 4R from 2000 to 2021. Landings for 2019, 2020 and 2021 are preliminary.

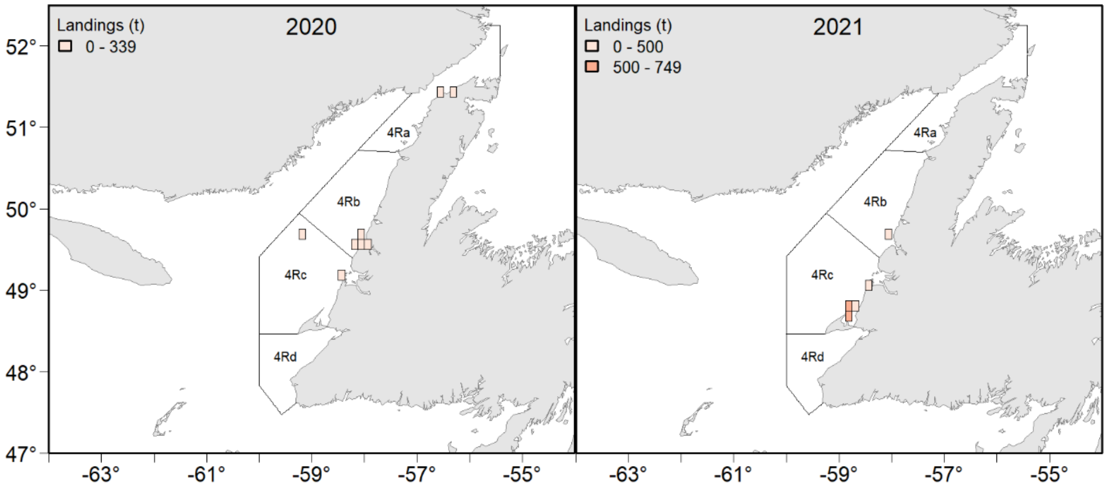

Figure 8. (continued).

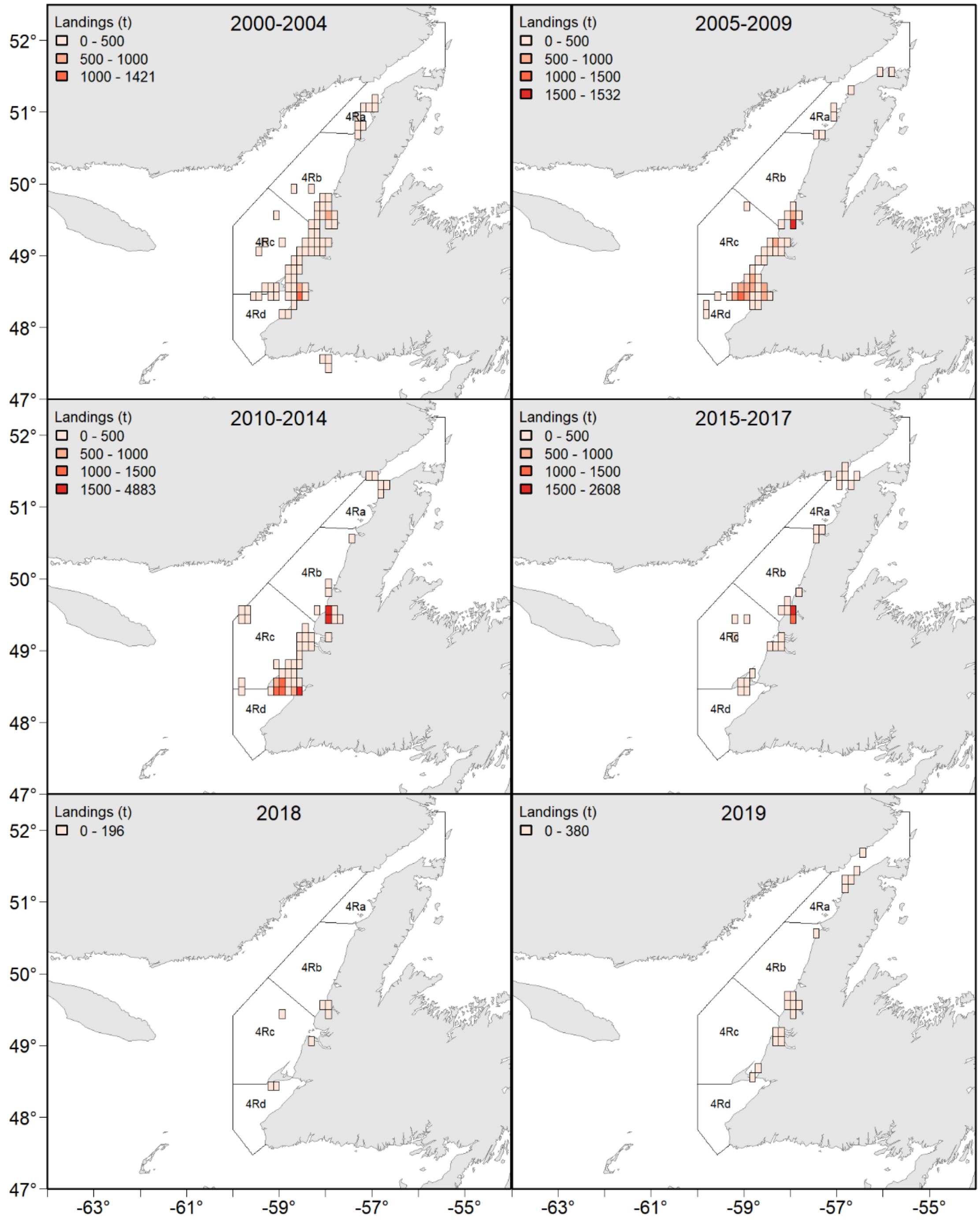

Figure 9. Location of commercial herring landings (t) by the small purse seiner fleet (< 65') in NAFO Division 4R from 2000 to 2021. Landings for 2019, 2020 and 2021 are preliminary.

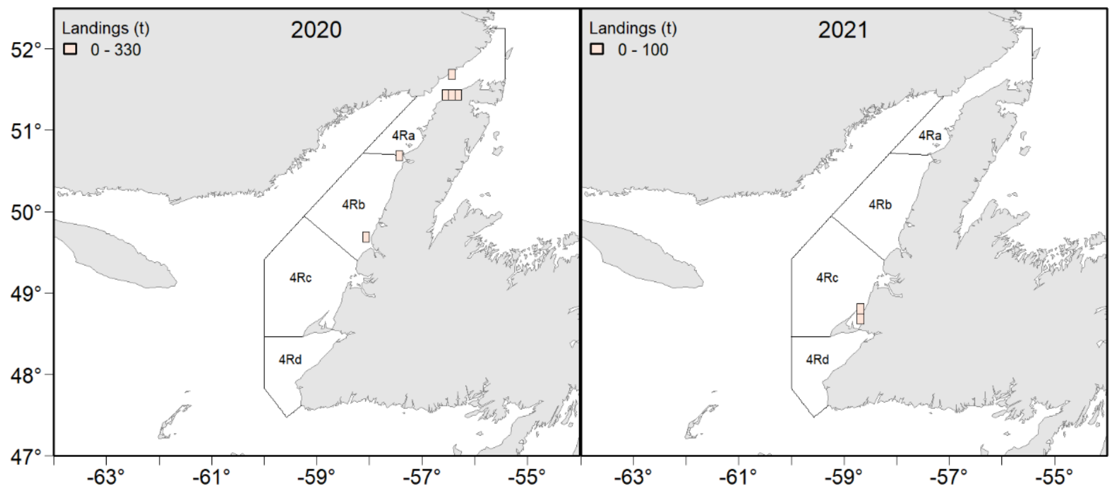

Figure 9. (continued)

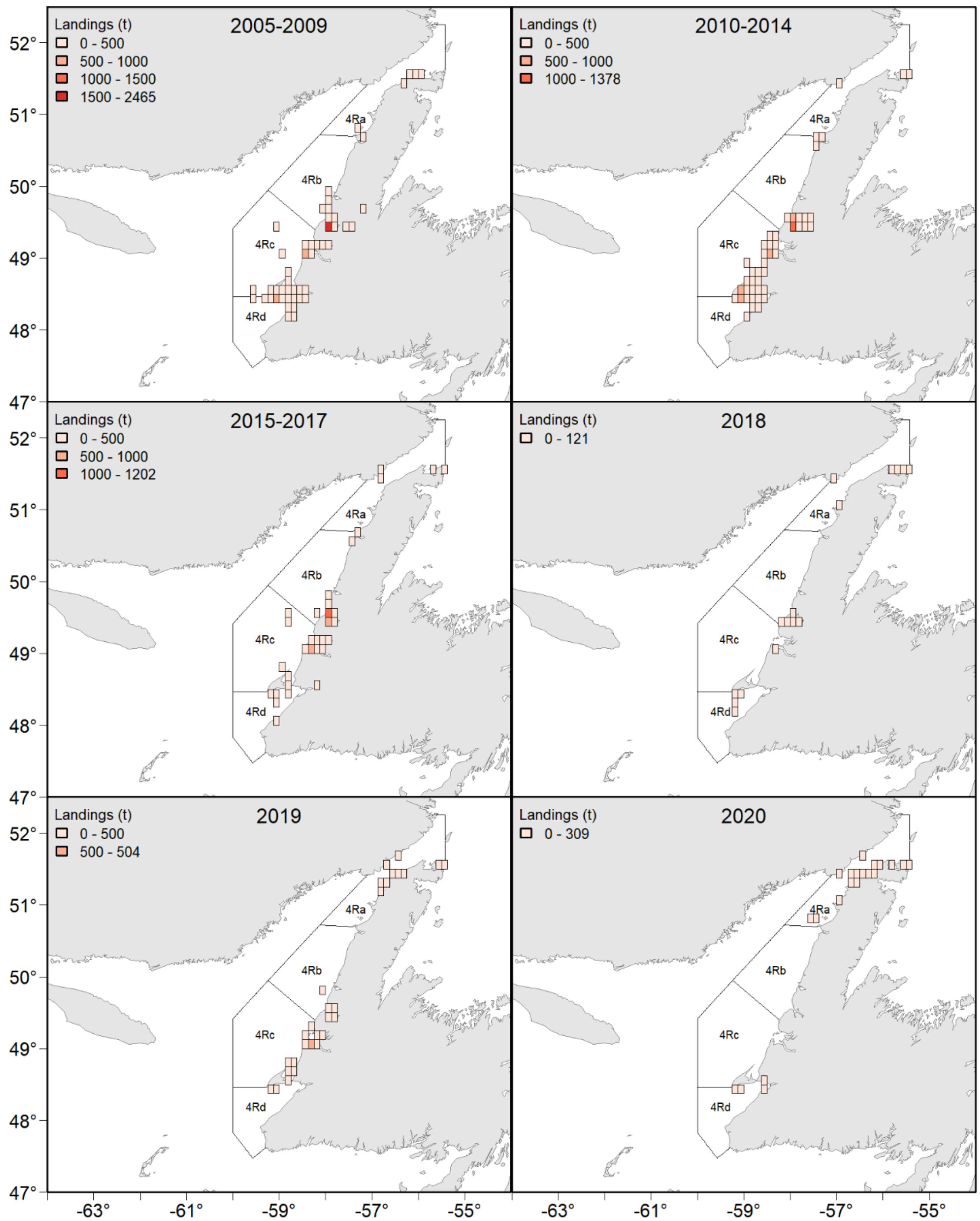

Figure 10. Location of commercial herring landings (t) by tuck seiners (fixed gear) in NAFO Division 4R from 2005 to 2020. Landings for 2019 and 2020 are preliminary.

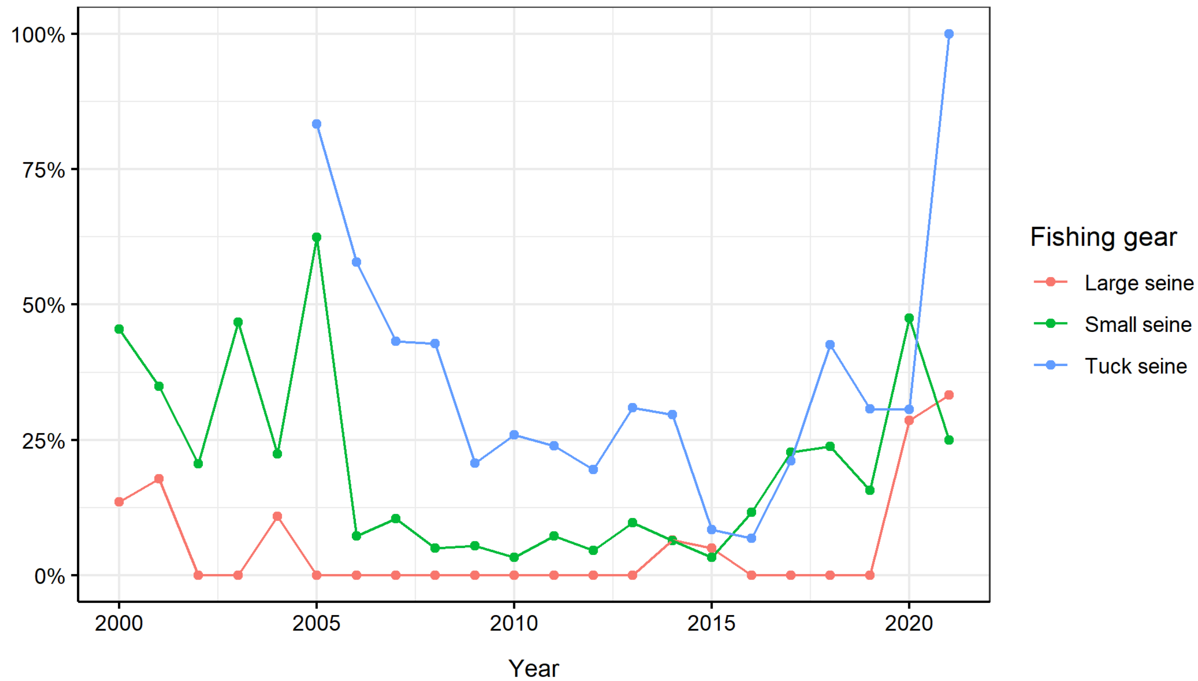

Figure 11. Percent of missing latitude and longitude in the NAFO Division 4R herring ZIFF files for large, small, and tuck seiners. 2019, 2020 and 2021 data are preliminary.

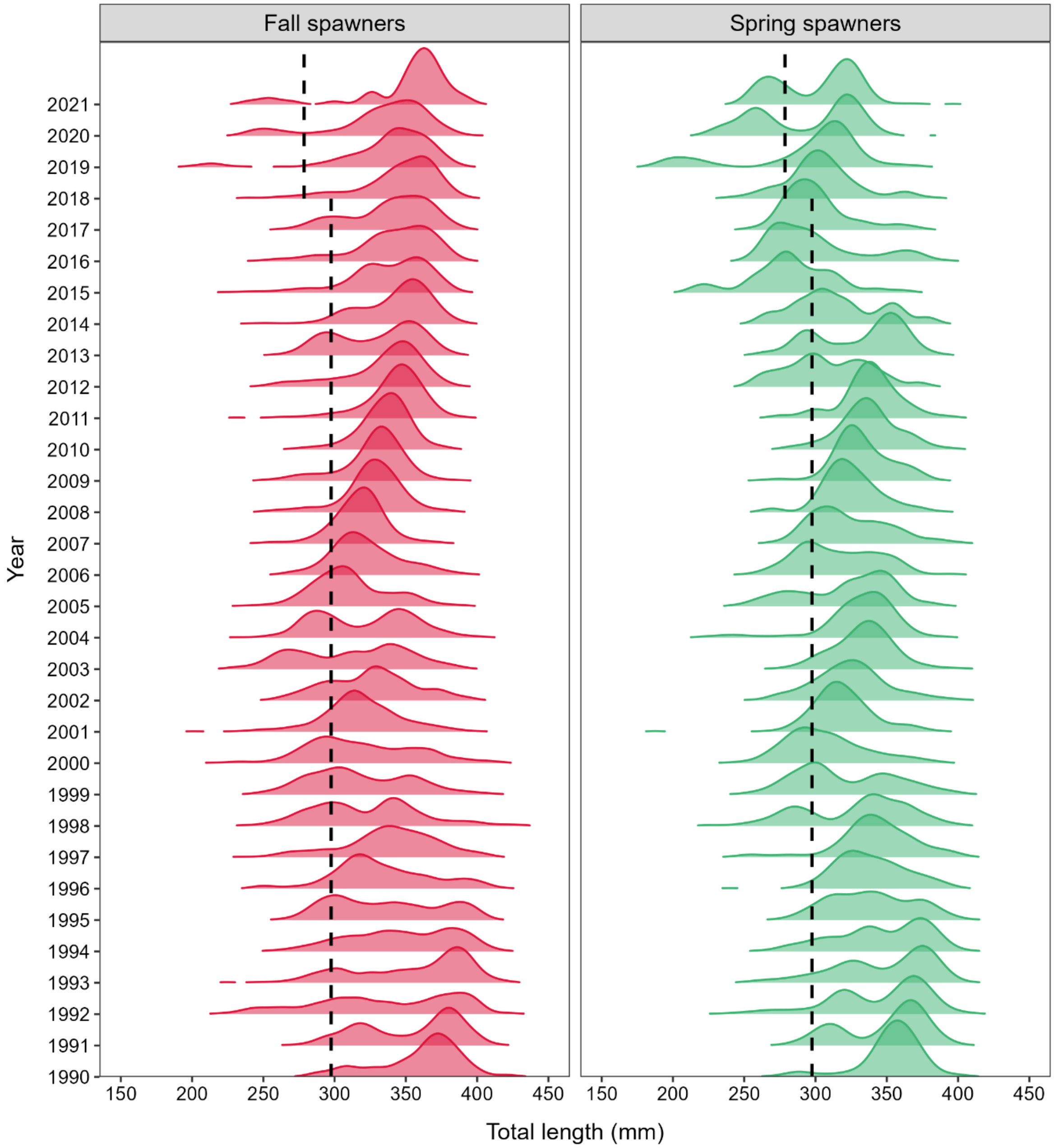

Figure 12. Relative length frequency distributions of spring- and fall-spawning herring caught by the purse seine fleet (large and small) in NAFO Division 4R from 1990 to 2021. The black dashed vertical lines represent the minimum size limit (1990-2017: 26.5 cm fork length, 2018-2021: 24.76 cm fork length).

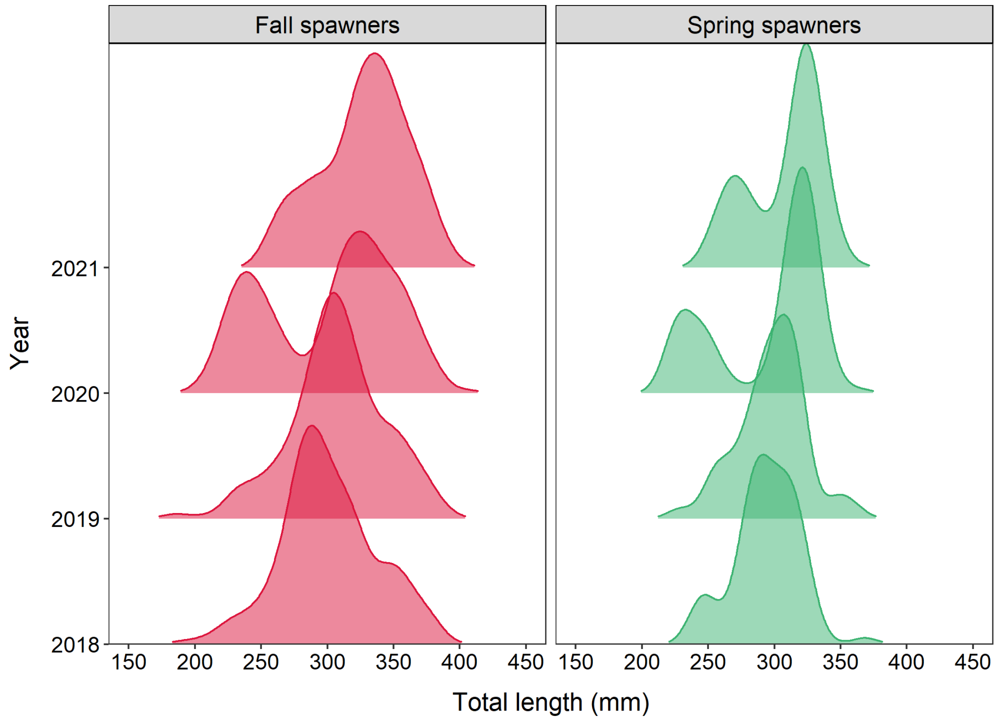

Figure 13. Relative length frequency distributions of spring- and fall-spawning herring in the samples collected during DFO's nGSL multi-species bottom trawl survey from 2018 to 2021.

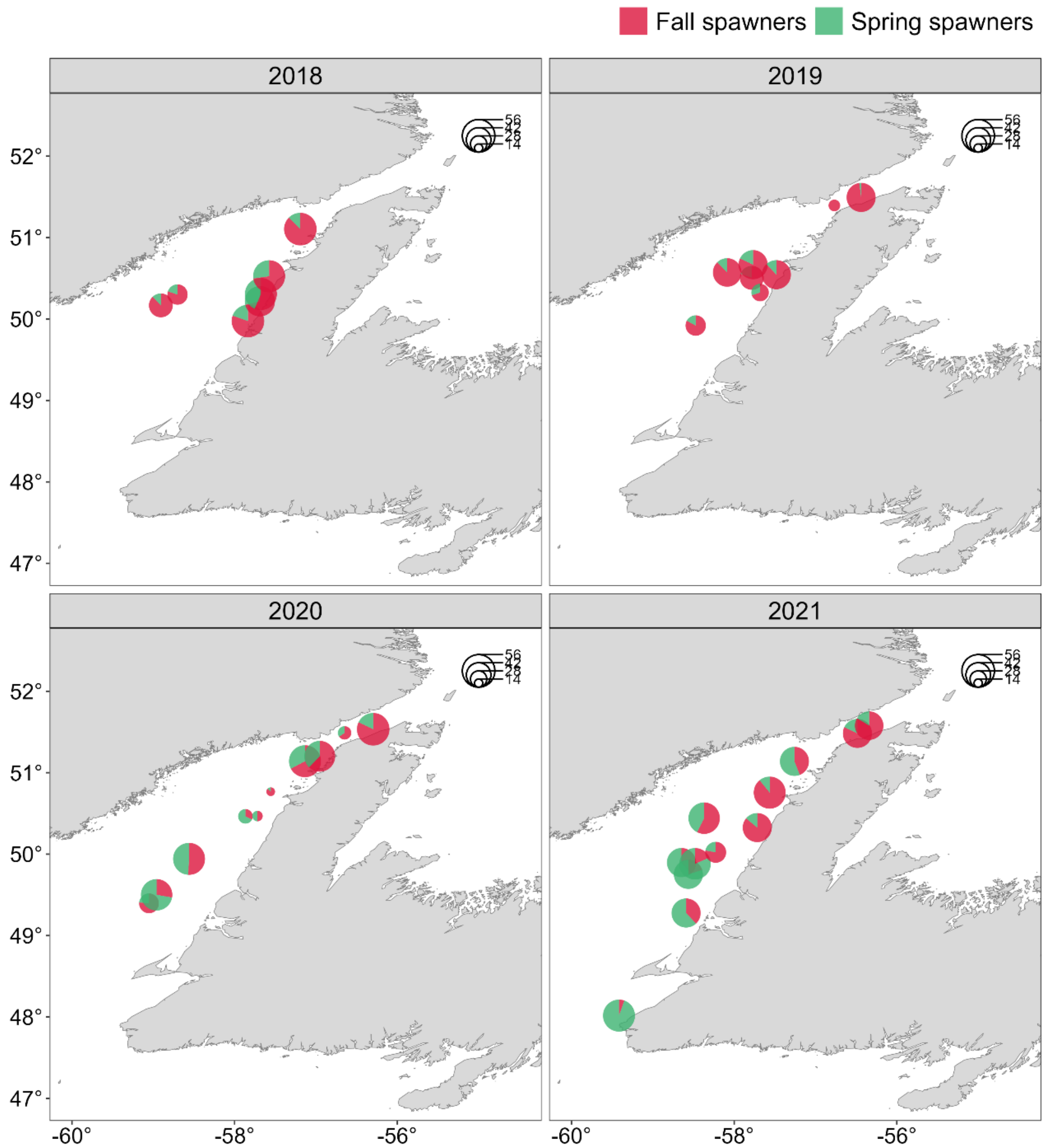

Figure 14. Pie charts representing the proportion (in number of individuals) of spring- and fall-spawning herring in the biological samples collected during DFO's nGSL multi-species bottom trawl survey from 2018 to 2021 and sent to Maurice-Lamontagne Institute for detailed biological characterization. Circle radius is proportional to sample size.

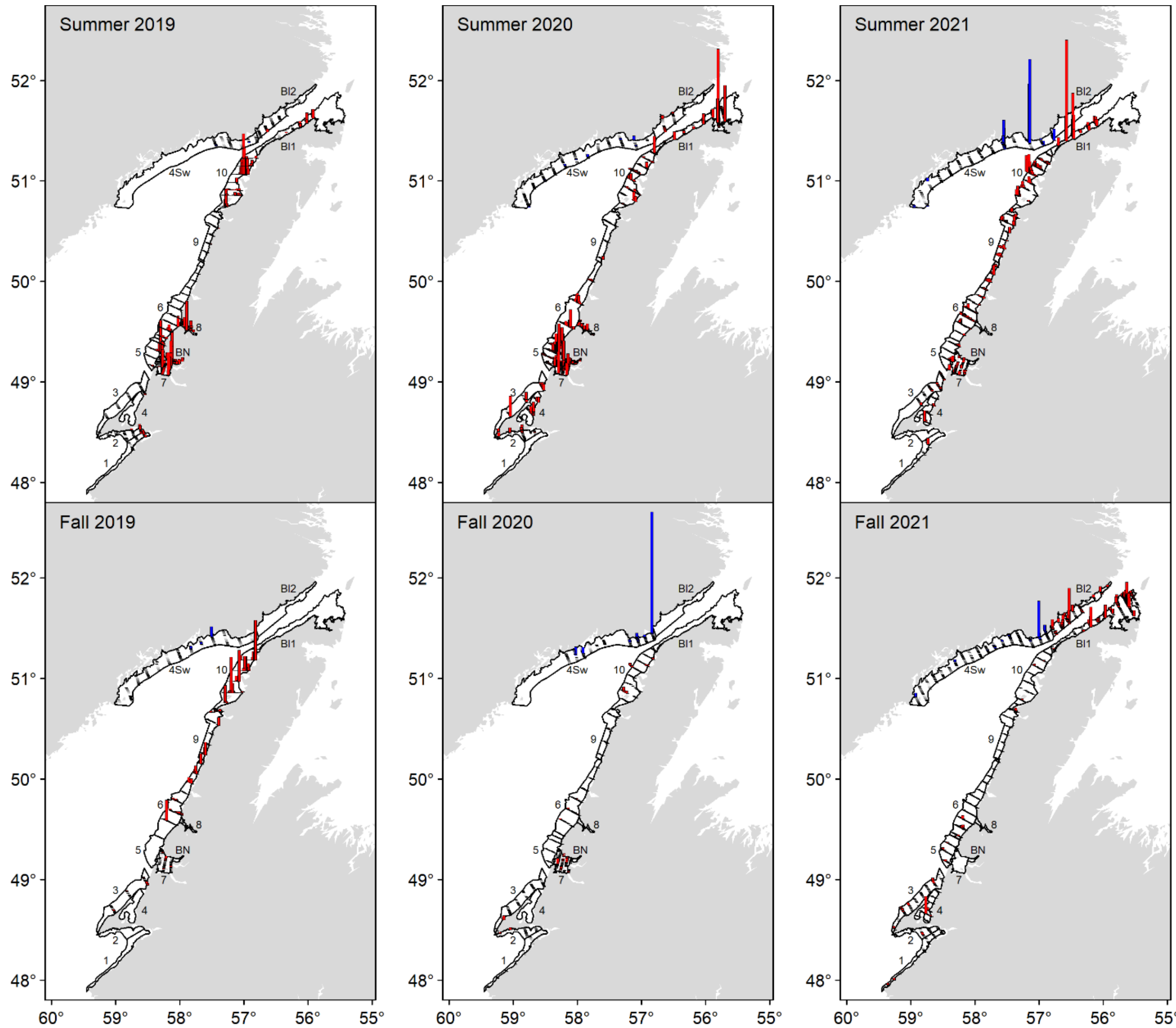

Figure 15. Distribution of herring biomass measured during the summer (August) and fall (October-November) hydroacoustic surveys from 2019 to 2021. Biomass is proportional to the height of the bars. The biomass measured in subdivision 4Sw of NAFO division 4S is represented in blue, but is not included in this assessment.

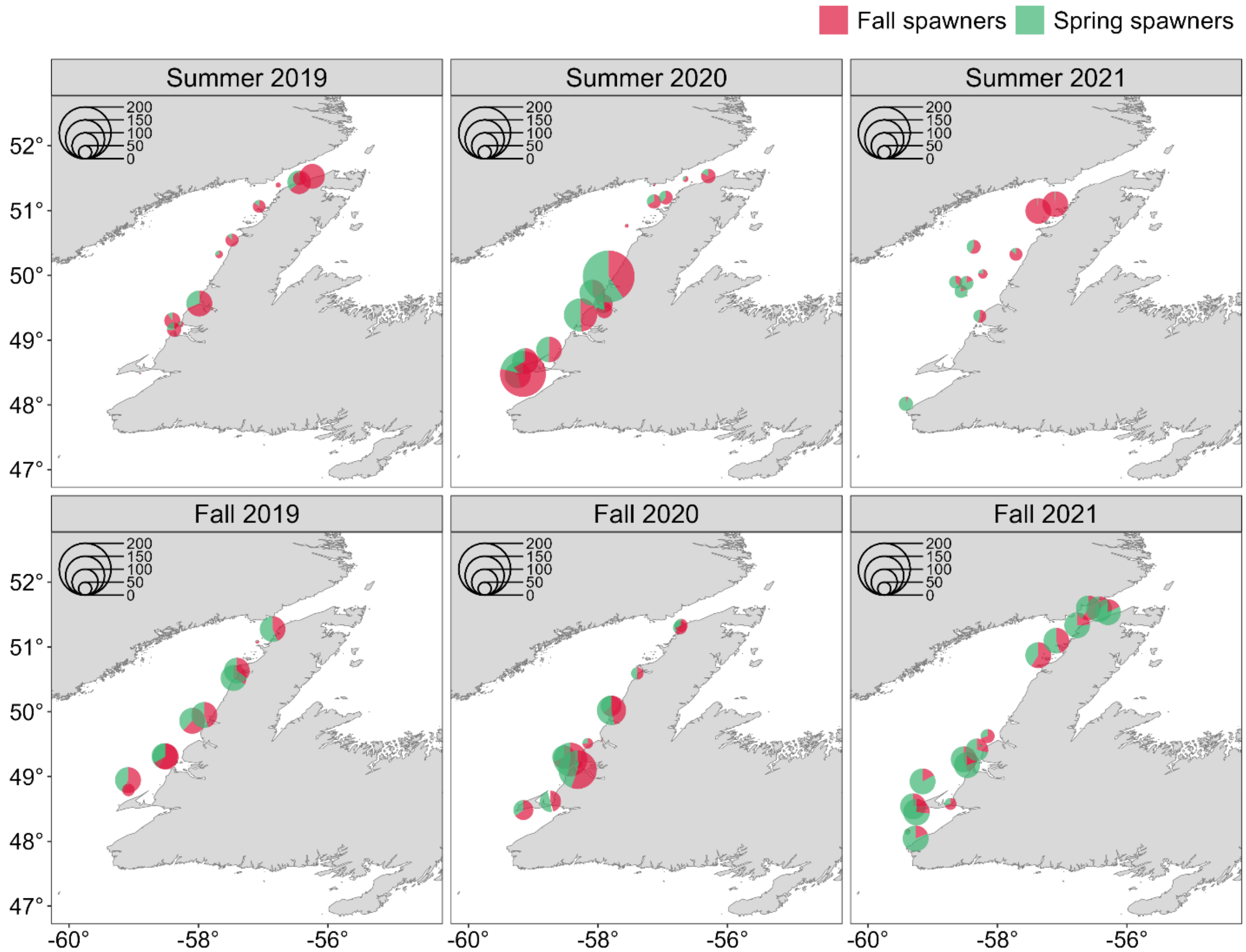

Figure 16. Pie charts representing the proportion (in number of individuals) of spring- and fall-spawning herring in the biological samples used to estimate the biomass measured during the 2019, 2020 and 2021 summer (August) and fall (October-November) acoustic surveys in NAFO Division 4R. Circle radius is proportional to sample size.

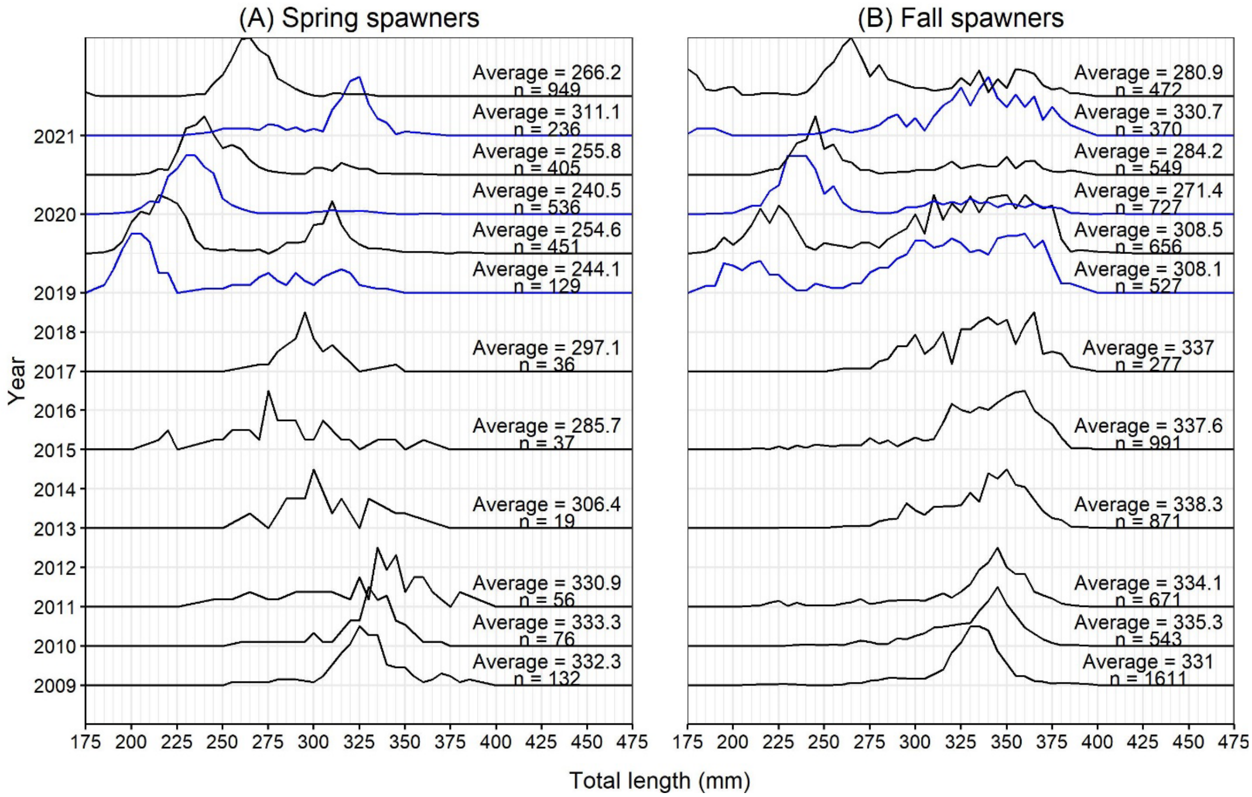

Figure 17. Total length relative frequency distributions of spring- (A) and fall-spawning (B) herring used in the computation of the age-disaggregated acoustic index in the summer (blue lines) and fall surveys (black lines) conducted from 2009 to 2021 (n= number of fish, average= average length).

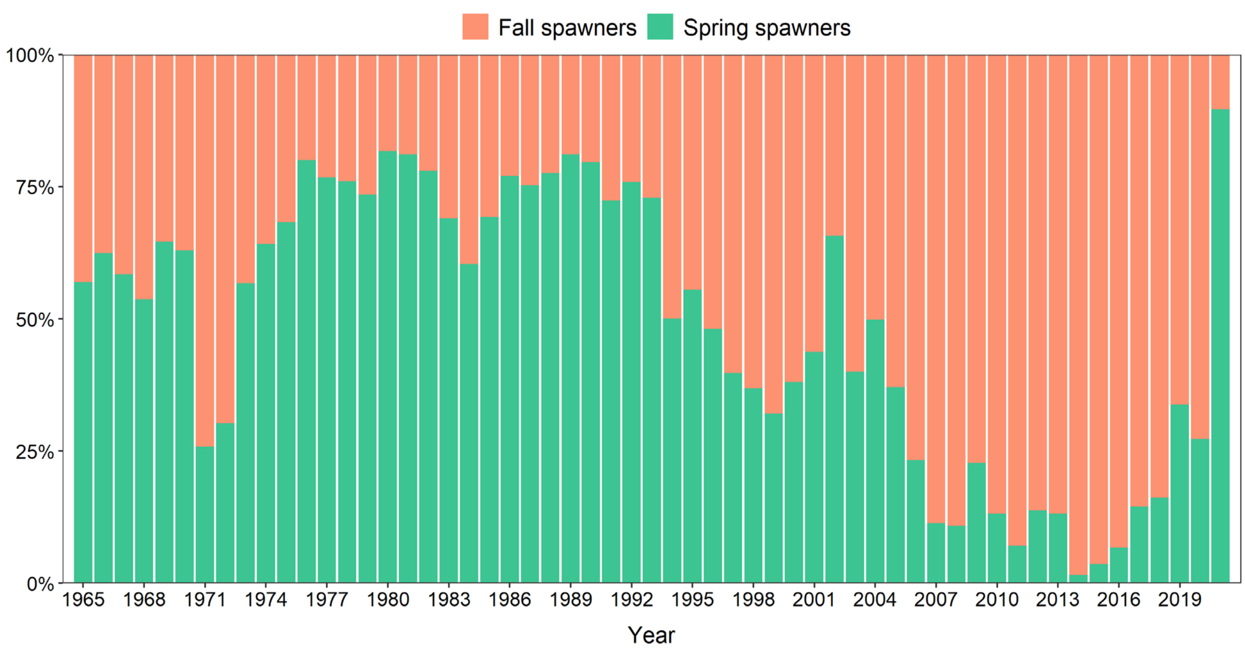

Figure 18. Annual proportion of spring- and fall-spawning herring (number of individuals) in NAFO Division 4R commercial landings from 1965 to 2021.

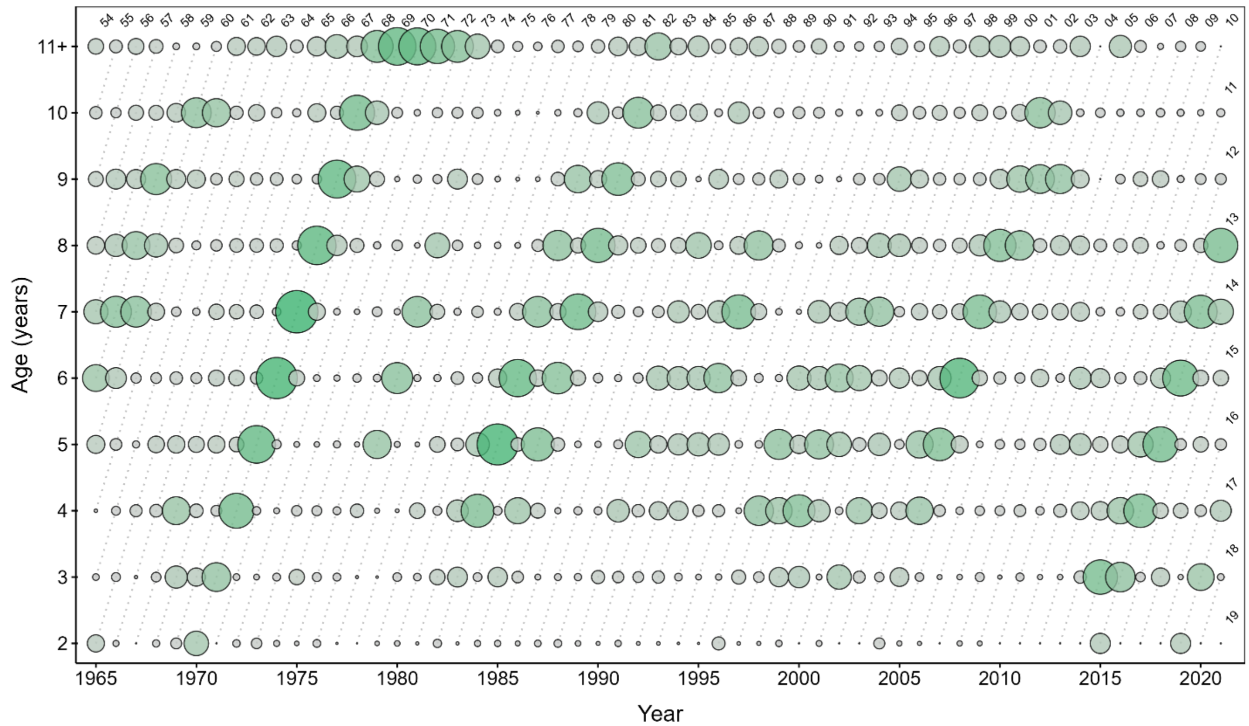

Figure 19. Annual catch-at-age composition (%) of spring-spawning herring in NAFO Division 4R from 1965 to 2021. The circle area is proportional to the proportion of the number of fish at each age. Cohort years' last two digits are indicated above bubbles.

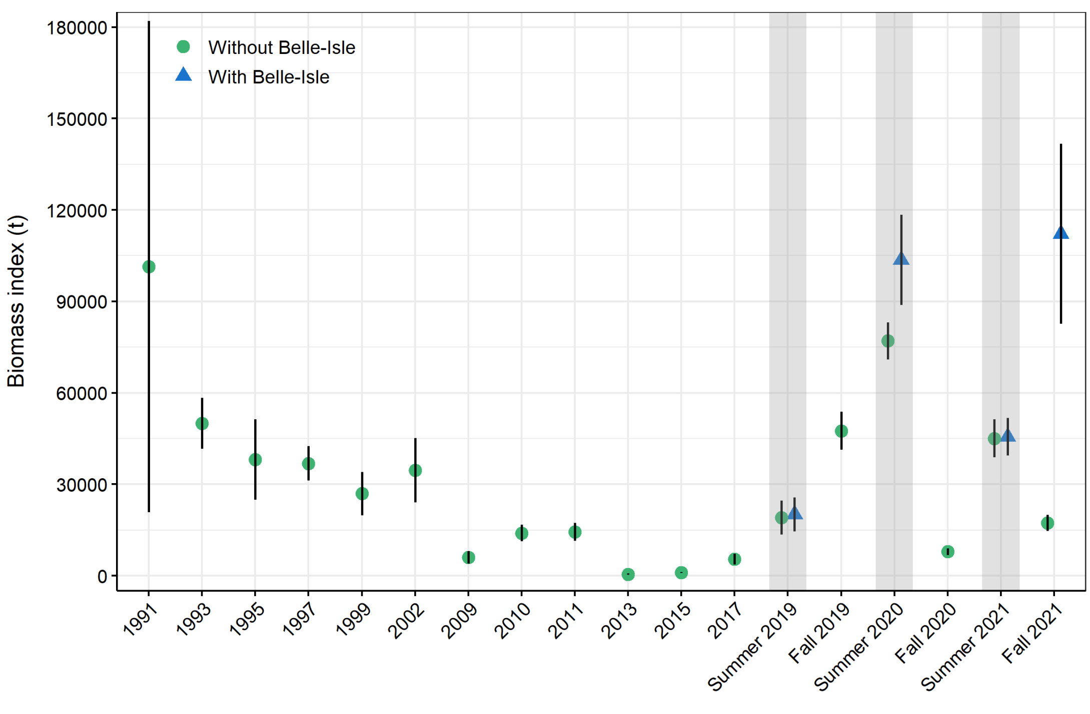

Figure 20. Fall (1991-2021) and summer (gray-shaded areas, 2019-2021) acoustic survey biomass indices for spring-spawning herring, with and without consideration of the Belle Isle transects. Error bars represent standard errors.

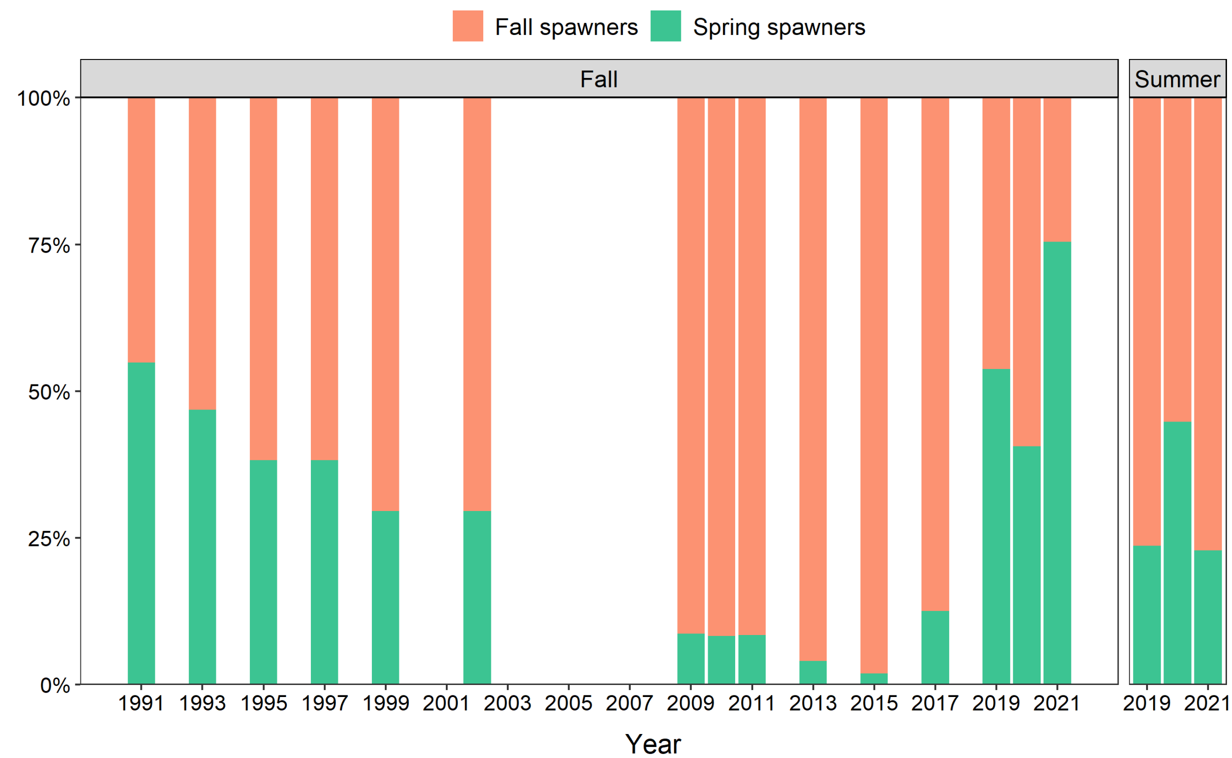

Figure 21. Proportion of spring- and fall-spawning herring (number of individuals) estimated from the summer and fall acoustic surveys from 1991 to 2021.

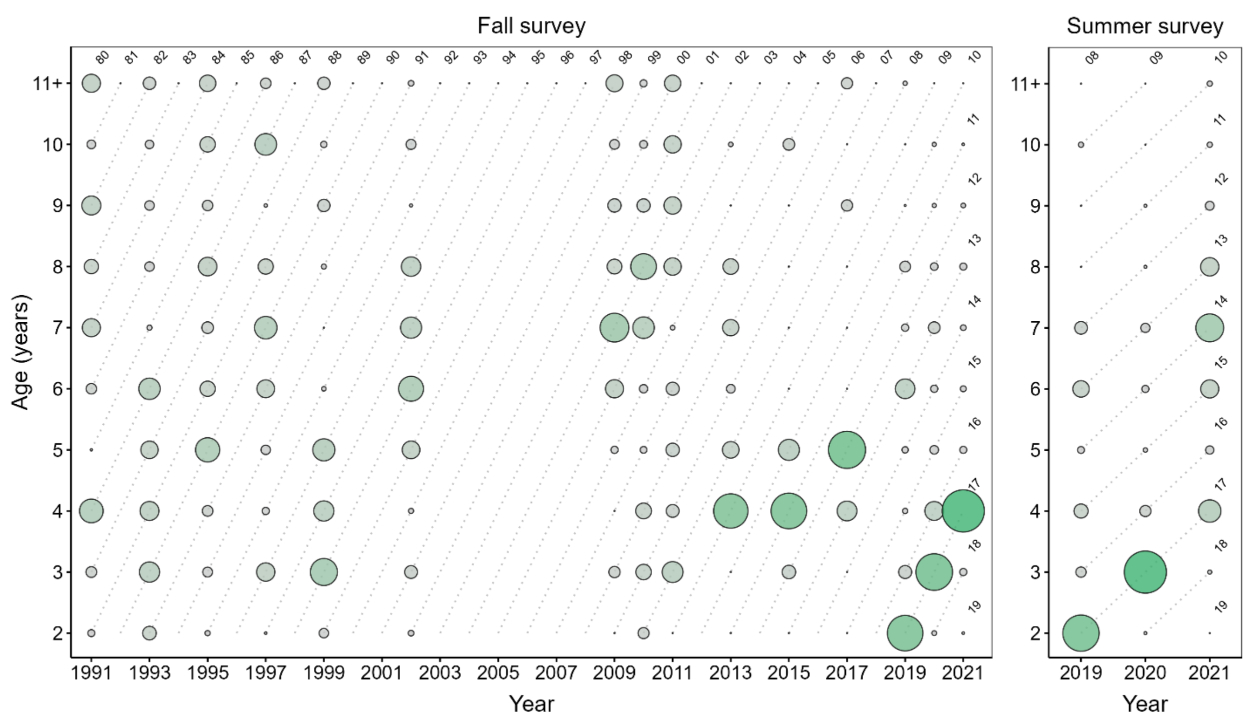

Figure 22. Annual numbers-at-age composition (%) of spring-spawning herring from the summer (August) and fall (October-November) acoustic surveys conducted in NAFO Division 4R between 1991 and 2021. The circle area is proportional to the proportion of the number of fish at each age. Cohort years' last two digits are indicated above bubbles.

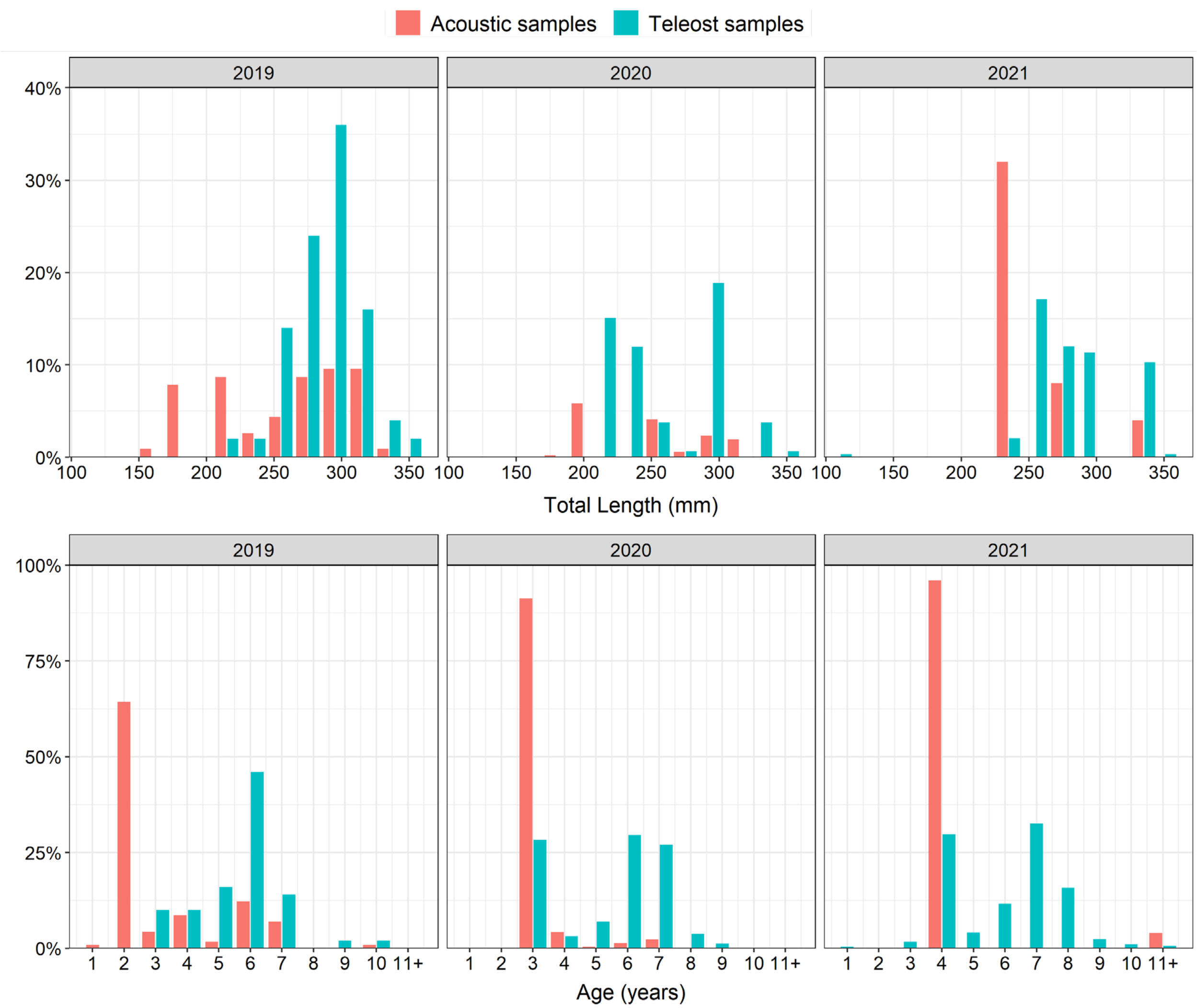

Figure 23. Length (top panel) and age (bottom panel) frequencies distribution of spring-spawning herring from samples collected during the summer acoustic survey (pelagic trawl) and DFO's annual nGSL multispecies survey (bottom trawl, CCGS Teleost) in NAFO division 4R from 2019 to 2021.

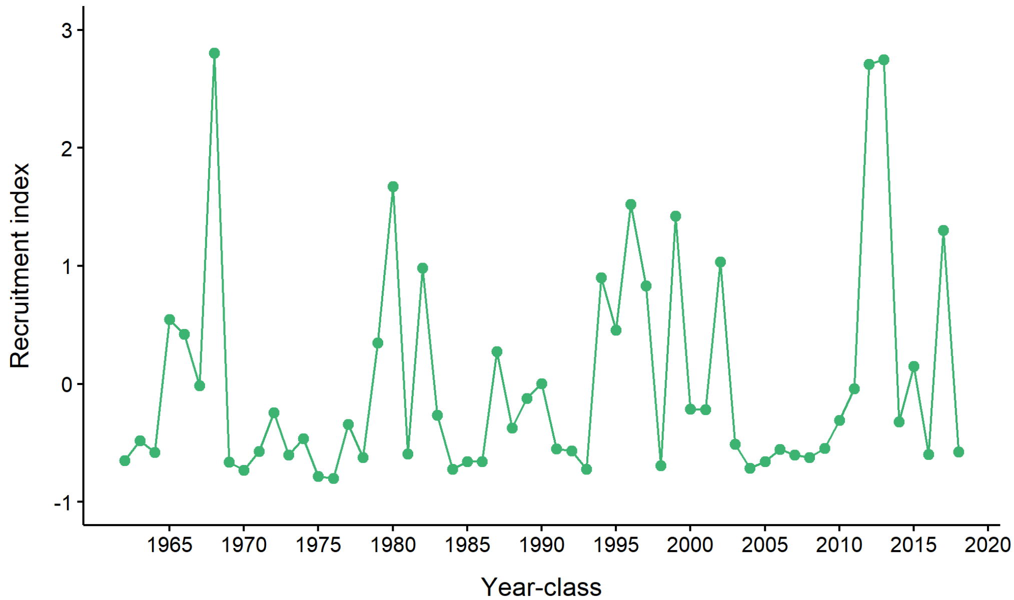

Figure 24. Recruitment index of spring-spawning herring in commercial catches in NAFO Division 4R for the 1962 to 2018 year-classes. The index was obtained by averaging the standardized proportions of ages 3 and 4 for years y and y+1 excluding the 2018 cohort for which age 3 for year y was used.

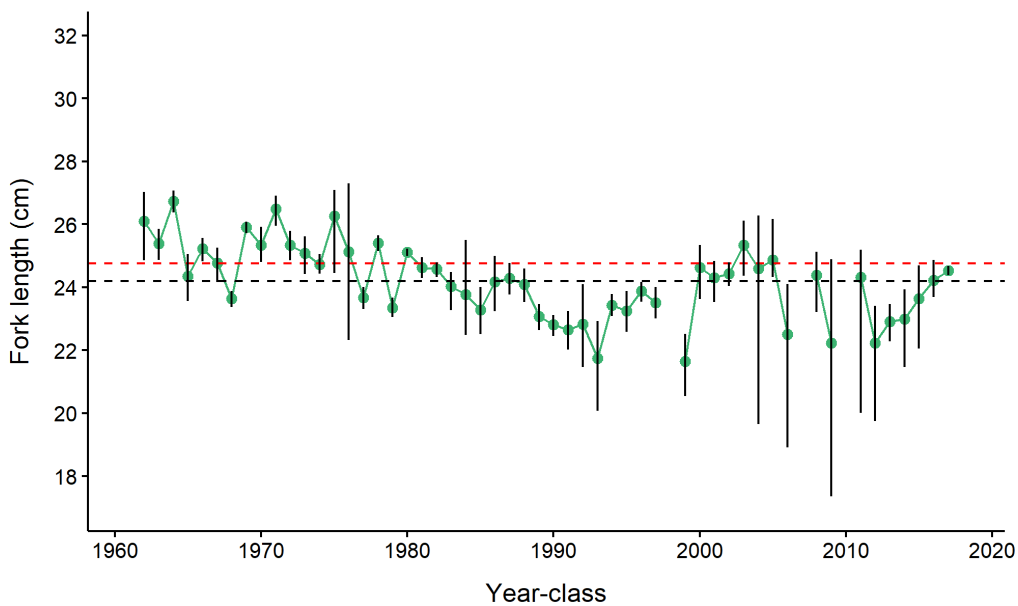

Figure 25. Fork length at 50% maturity (L_{50}) by year-class for spring-spawning herring in NAFO Division 4R. Error bars represent bootstrapped 95% confidence intervals. The horizontal dashed black line is the series average (24.19 cm) and the red dashed line is the legal catch size (24.76 cm).

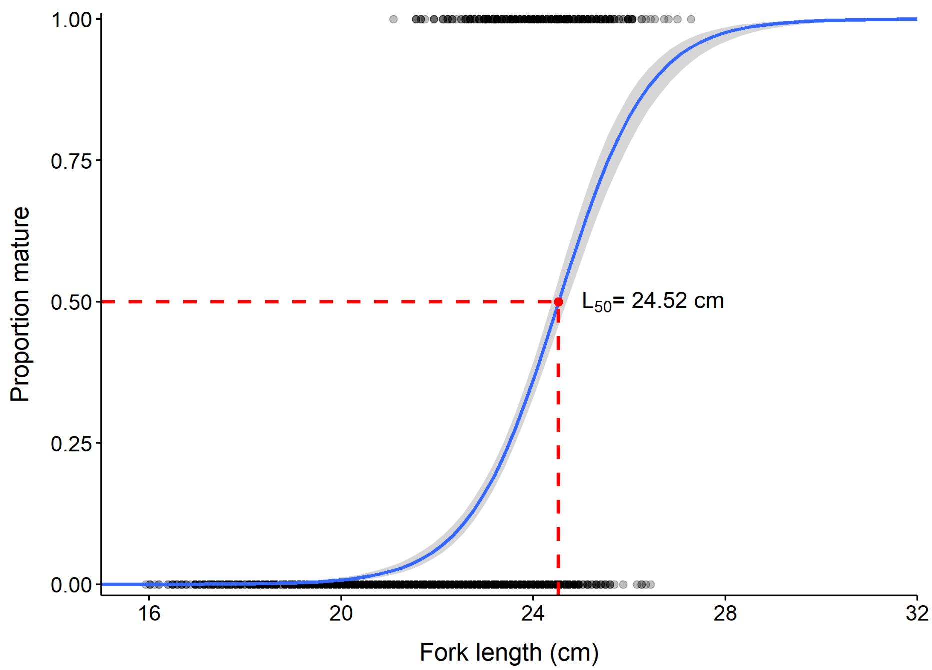

Figure 26. Maturity ogive (blue line) by length for the spring spawner 2017 year-class. The L_{50} was estimated at 24.52 cm fork length. The grey shaded area represents the 95% confidence interval. Black dots represent observed mature (1) and immature (0) herrings.

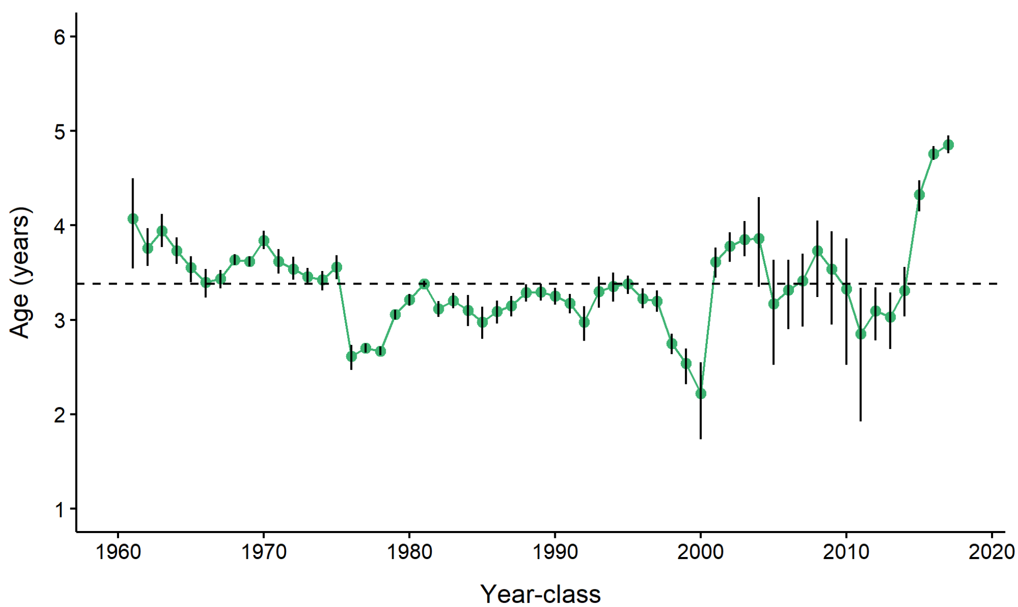

Figure 27. Age at 50% maturity (A_{50}) by year-class in NAFO Division 4R for spring-spawning herring. Error bars represent bootstrapped 95% confidence intervals. For each year-class, data were pooled with the 2 neighboring year-classes because of insufficient number of immature fish. The horizontal dashed black line is the series average (3.38 years).

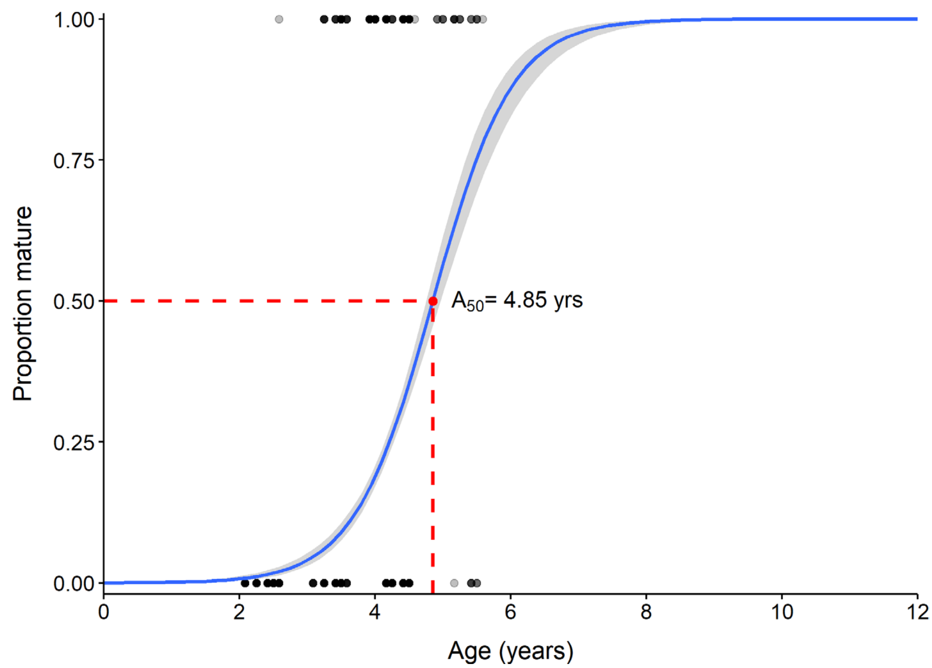

Figure 28. Maturity ogive (blue line) by age for the spring spawner 2017 year-class. The A_{50} was estimated at 4.85 years. The grey shaded area represents the 95% confidence interval. Black dots represent observed mature (1) and immature (0) herrings.

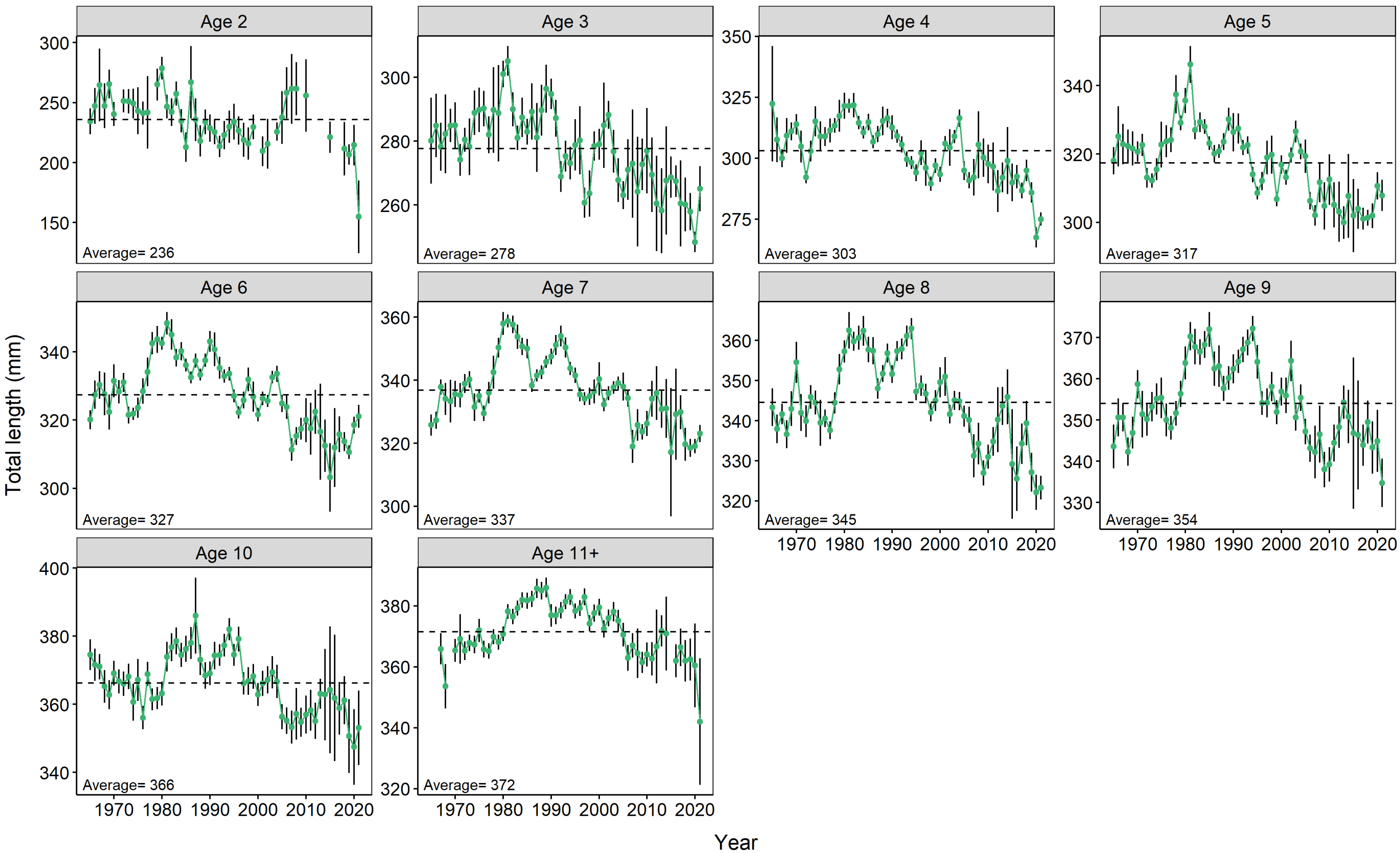

Figure 29. Total length (mm) at ages 2 to 11⁺ of spring spawners in NAFO Division 4R from 1965 to 2021. The series were standardized to take into account the NAFO subdivision, fishing gear and month of capture. The horizontal dashed black line is the series average.

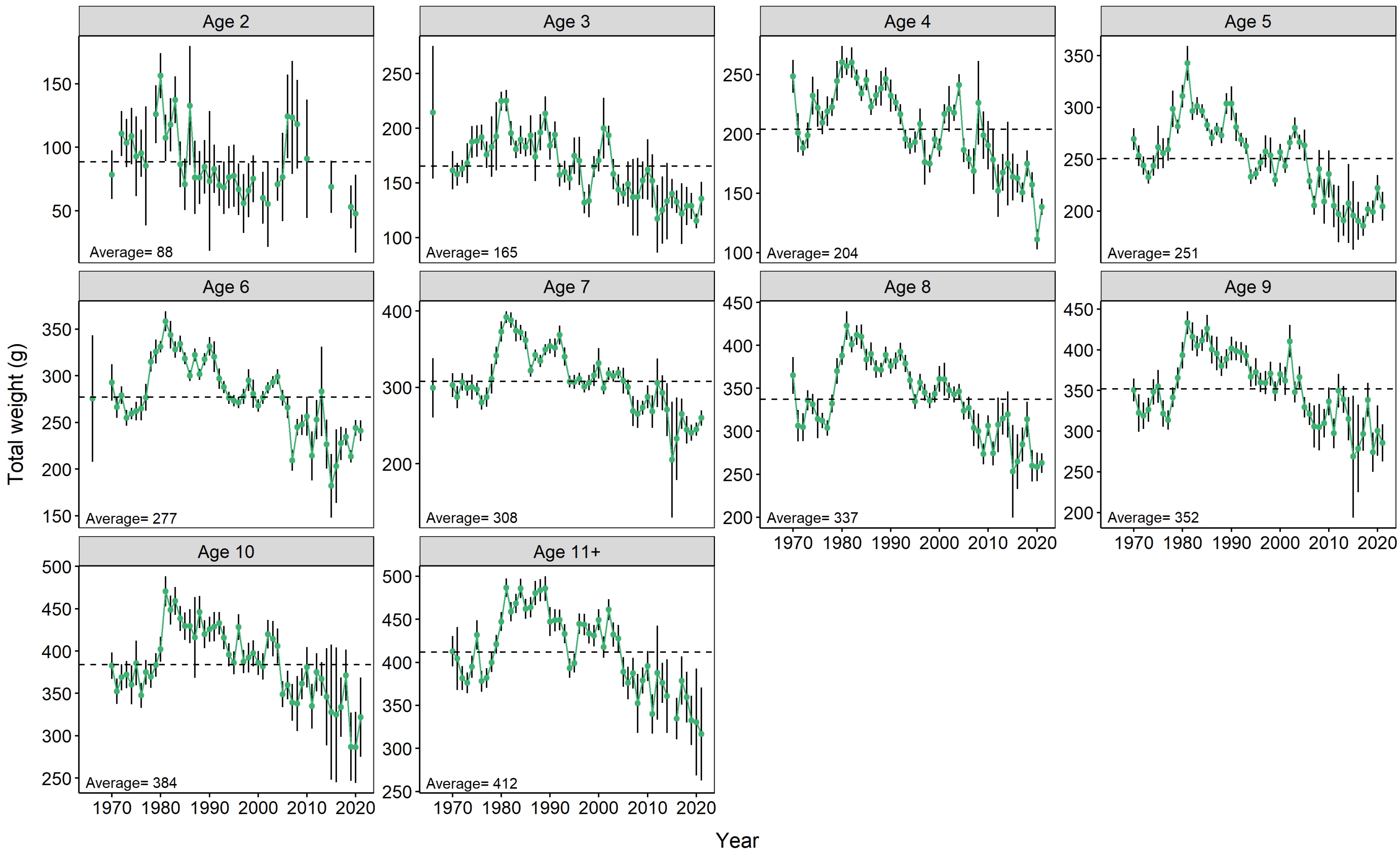

Figure 30. Total weight (g) at ages 2 to 11⁺ of spring spawners in NAFO Division 4R from 1965 to 2021. The series were standardized to take into account the NAFO subdivision, fishing gear and month of capture. The horizontal dashed black line is the series average.

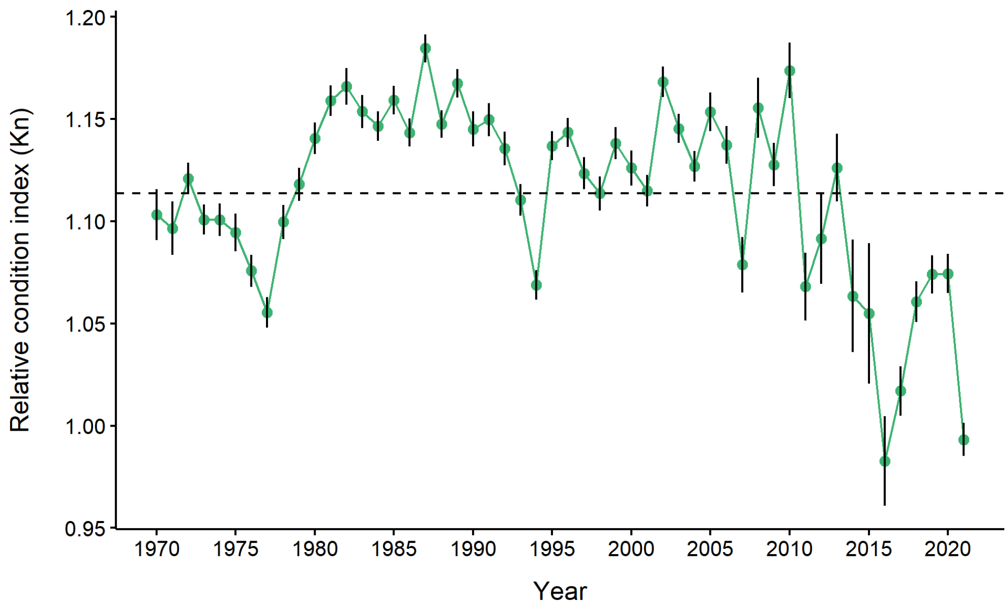

Figure 31. Standardized relative condition index (with a 95% confidence interval) for spring spawner herring in NAFO division 4R from 1970 to 2021. The series were standardized to take into account the NAFO subdivision, fishing gear and month of capture. The horizontal dashed black line is the series average (1.11).

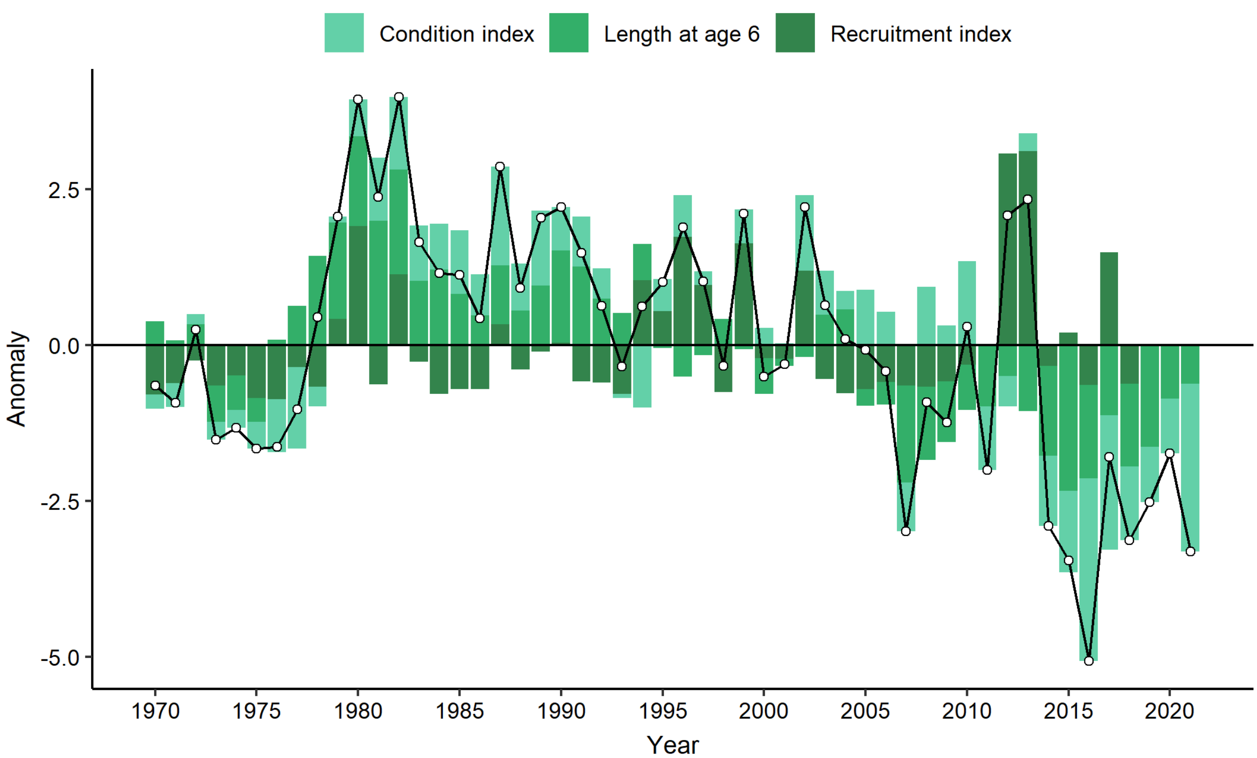

Figure 32. Cumulative stock productivity index based on the sum (white dot) of annual standardized anomalies of key stock productivity indicators (relative condition index, average total length at age 6 and recruitment index) of spring-spawning herring in NAFO division 4R from 1970 to 2021.

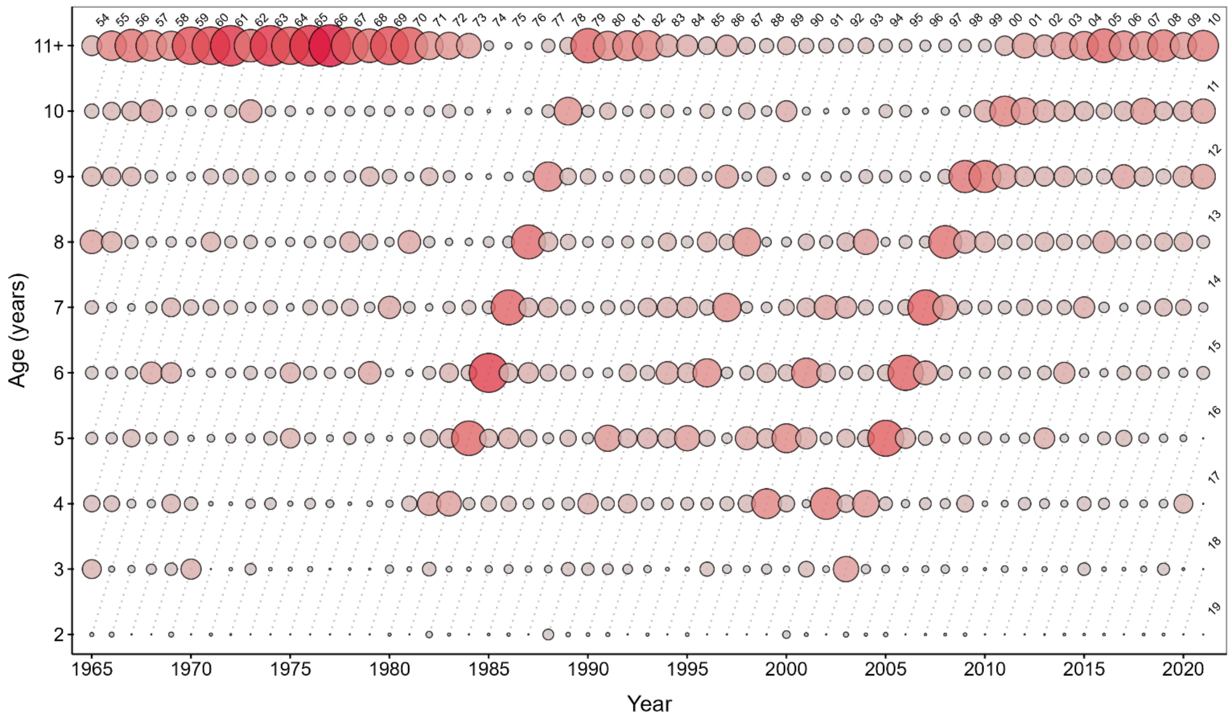

Figure 33. Annual catch-at-age composition (%) of fall-spawning herring in NAFO Division 4R from 1965 to 2021. The circle area is proportional to the proportion of fish at each age. Cohort years' last two digits are indicated above bubbles.

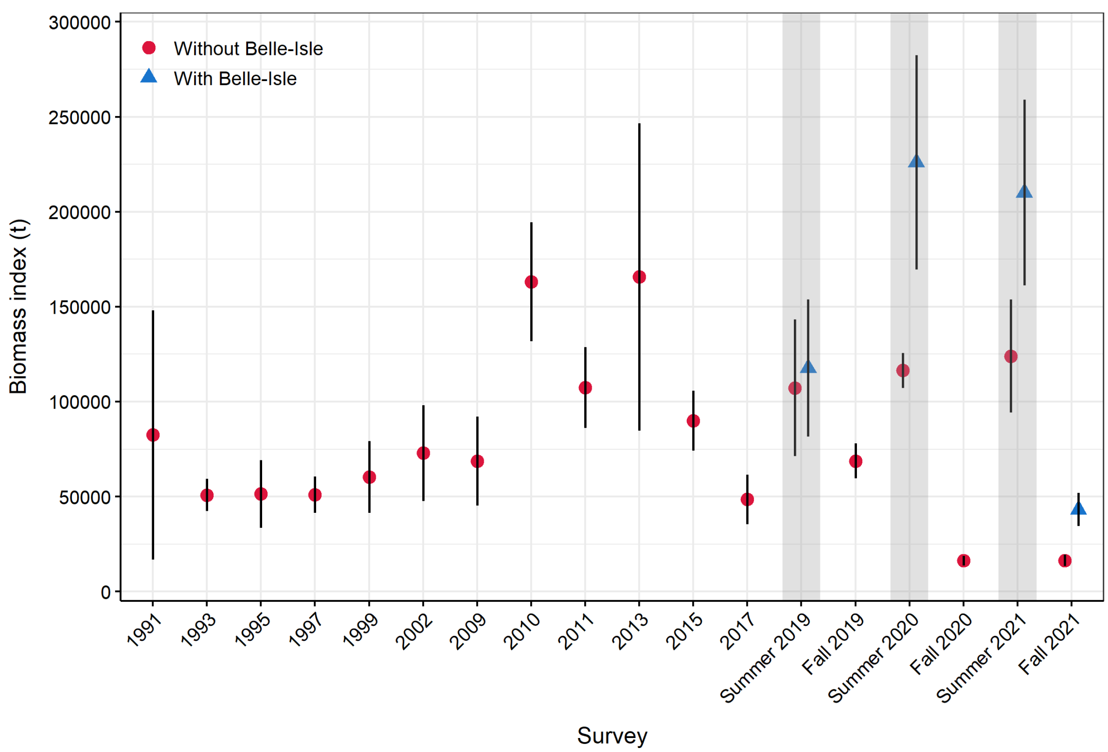

Figure 34. Fall (1991-2021) and summer (2019-2021, gray-shaded areas) acoustic survey biomass indices for fall-spawning herring, with and without consideration of the Belle Isle transects. Error bars represent standard errors.

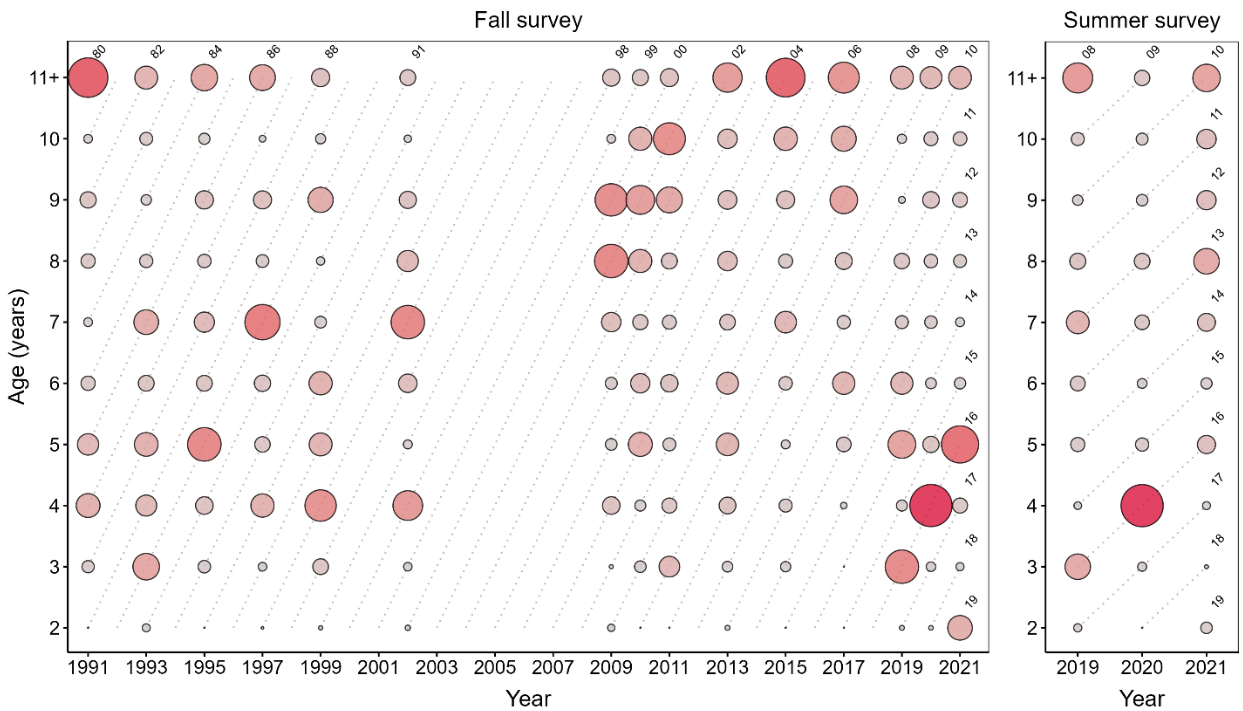

Figure 35. Annual numbers-at-age composition (%) of fall-spawning herring from the summer (August) and fall (October-November) acoustic surveys conducted in NAFO Division 4R between 1991 and 2021. The circle area is proportional to the proportion of fish at each age. Cohort years' last two digits are indicated above bubbles.

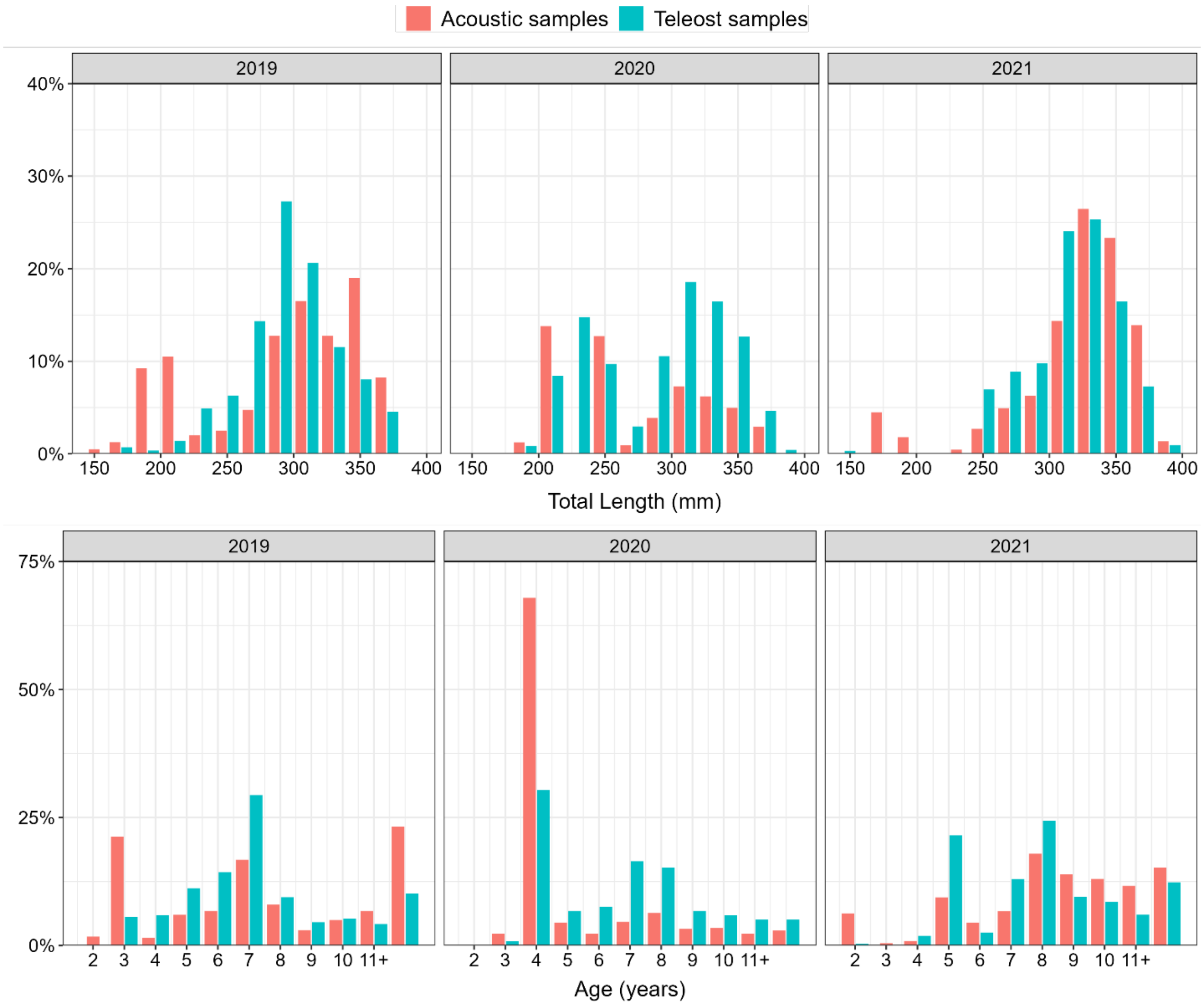

Figure 36. Length (top panel) and age (bottom panel) frequency distributions of fall spawners herring from samples collected during the summer acoustic survey (pelagic trawl) and DFO's annual nGSL multispecies survey (bottom trawl) in NAFO division 4R from 2019 to 2021.

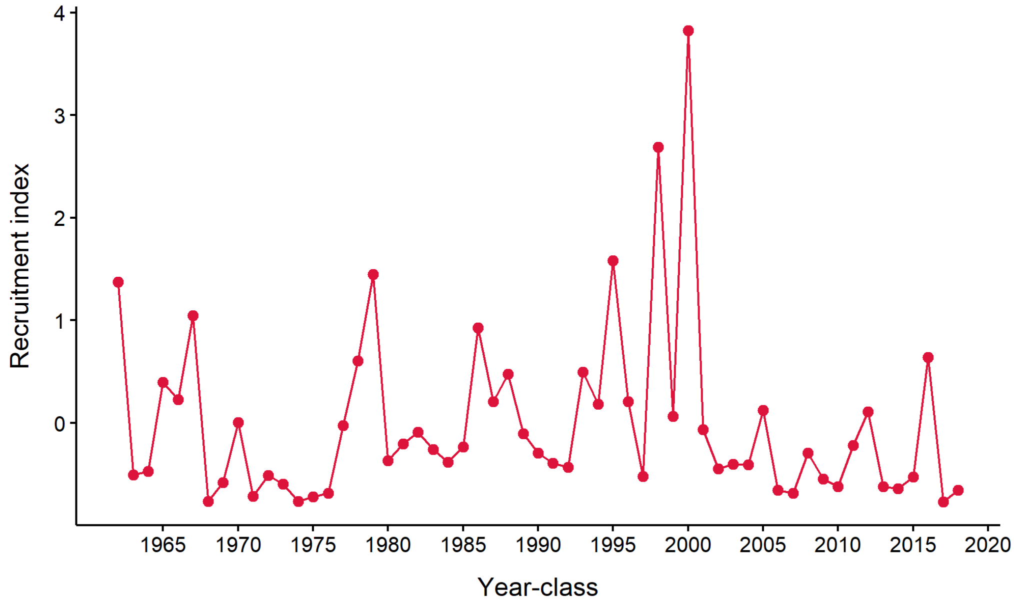

Figure 37. Recruitment index of fall-spawning herring in commercial catches in NAFO Division 4R for the 1962 to 2017 year-classes. The index was obtained by averaging the standardized proportions of ages 3 and 4 for years y and y+1, excluding the 2017 cohort for which age 3 for year y was used.

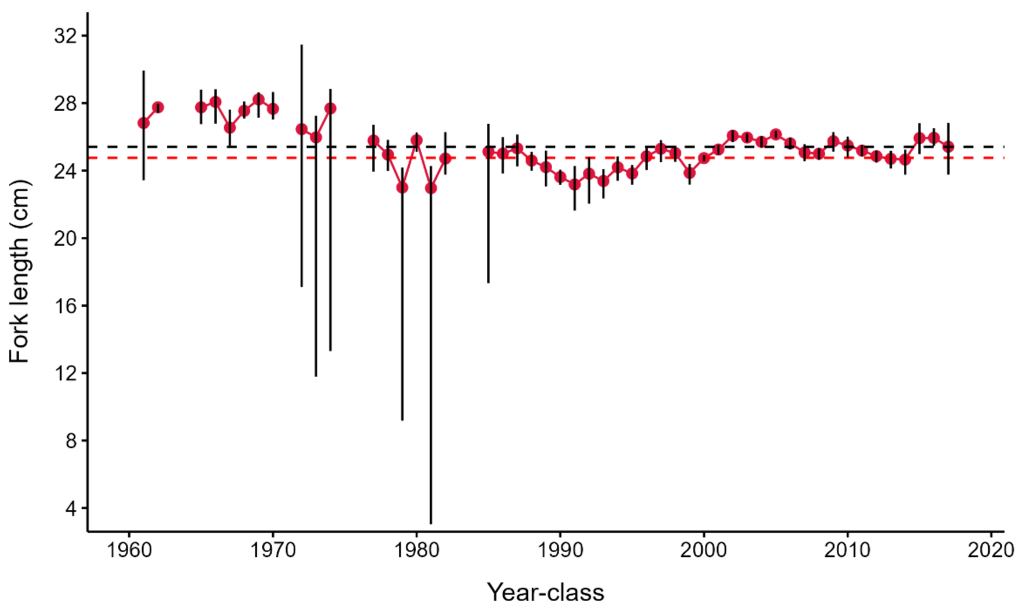

Figure 38. Fork length at 50% maturity (L_{50}) by year-class for fall-spawning herring in NAFO Division 4R. Error bars represent bootstrapped 95% confidence intervals. The horizontal dashed black line is the series average (25.41 cm) and the red dashed line is the legal catch size (24.76 cm).

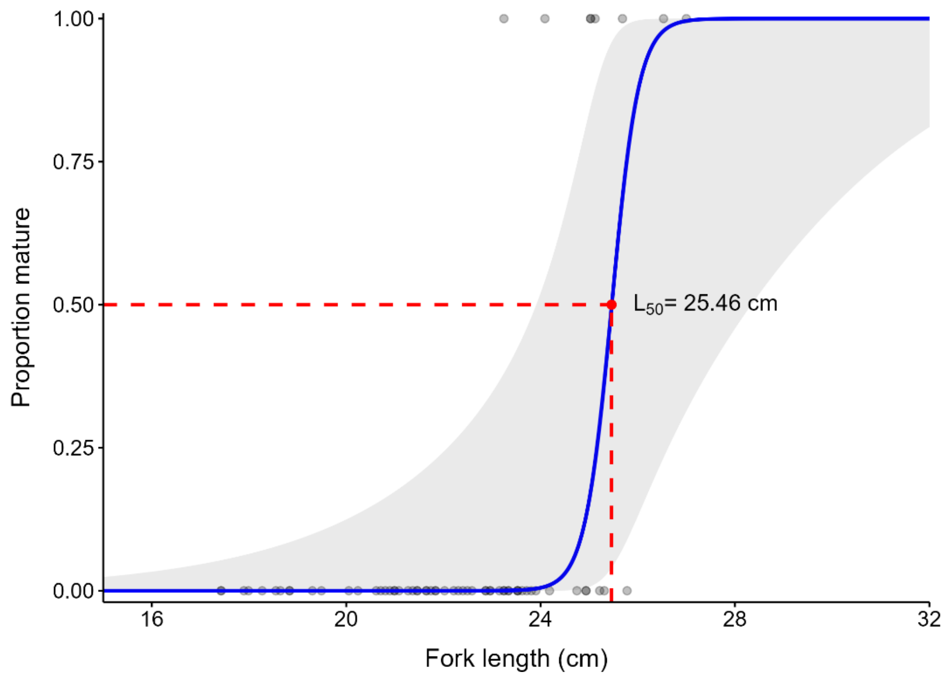

Figure 39. Maturity ogive (blue line) by length for the fall spawner 2017 year-class. The L_{50} was estimated at 25.46 cm fork length. The grey shaded area represents the 95% confidence interval. Black dots represent observed mature (1) and immature (0) herrings.

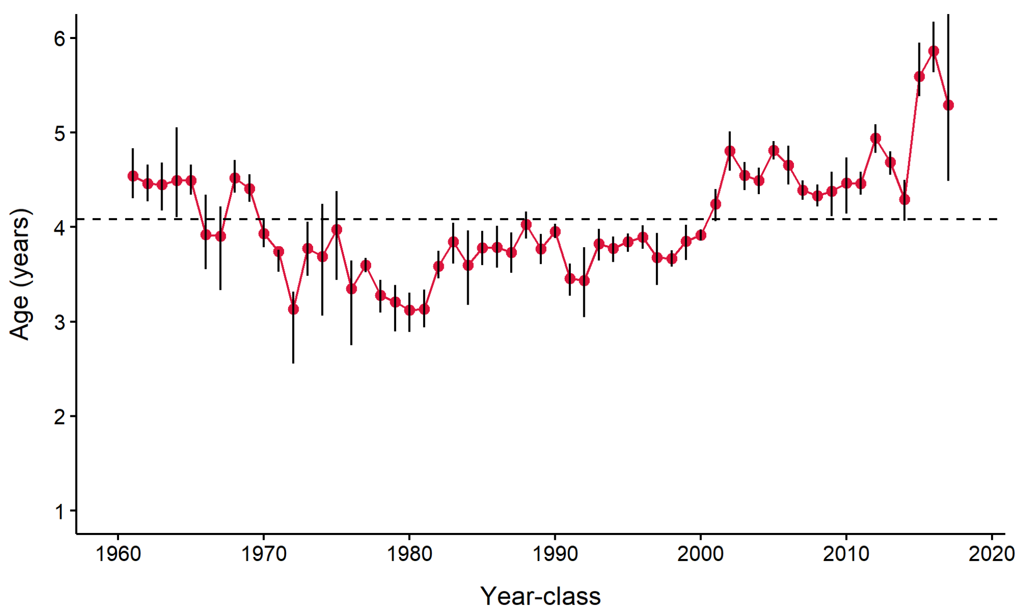

Figure 40. Age at 50% maturity (A_{50}) by year-class in NAFO Division 4R for fall-spawning herring. Error bars represent bootstrapped 95% confidence intervals. The horizontal dashed black line is the series average (4.08 years).

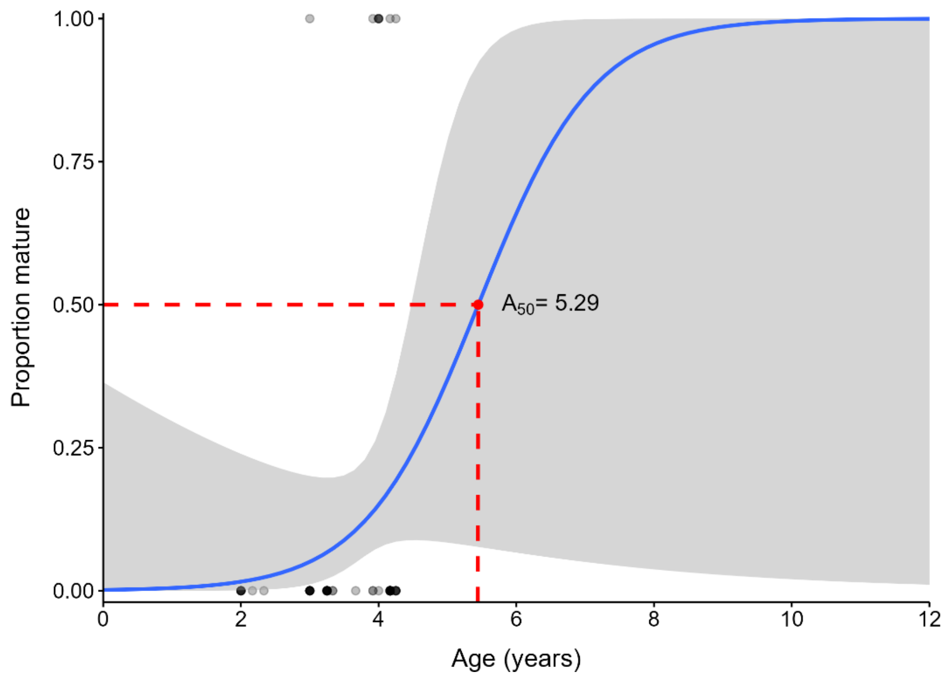

Figure 41. Maturity ogive (blue line) by age for the fall spawner 2017 year-class. The A_{50} was estimated at 5.29 years. The grey shaded area represents the 95% confidence interval. Black dots represent observed mature (1) and immature (0) herrings.

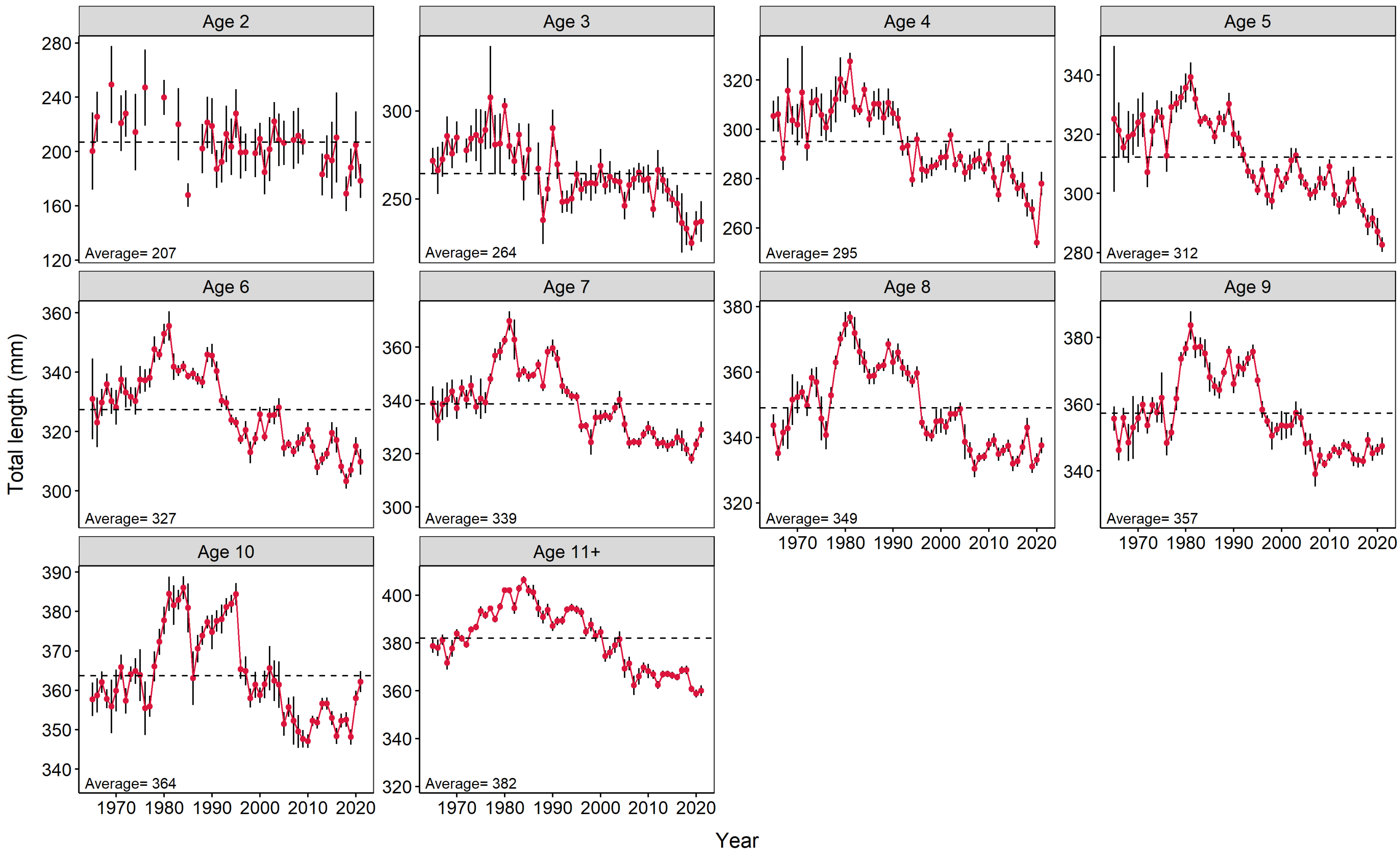

Figure 42. Total length (mm) at ages 2 to 11+ of fall spawners herring in NAFO Division 4R from 1965 to 2021. The series were standardized to take into account the NAFO subdivision, fishing gear and month of capture. The horizontal dashed black line is the series average.

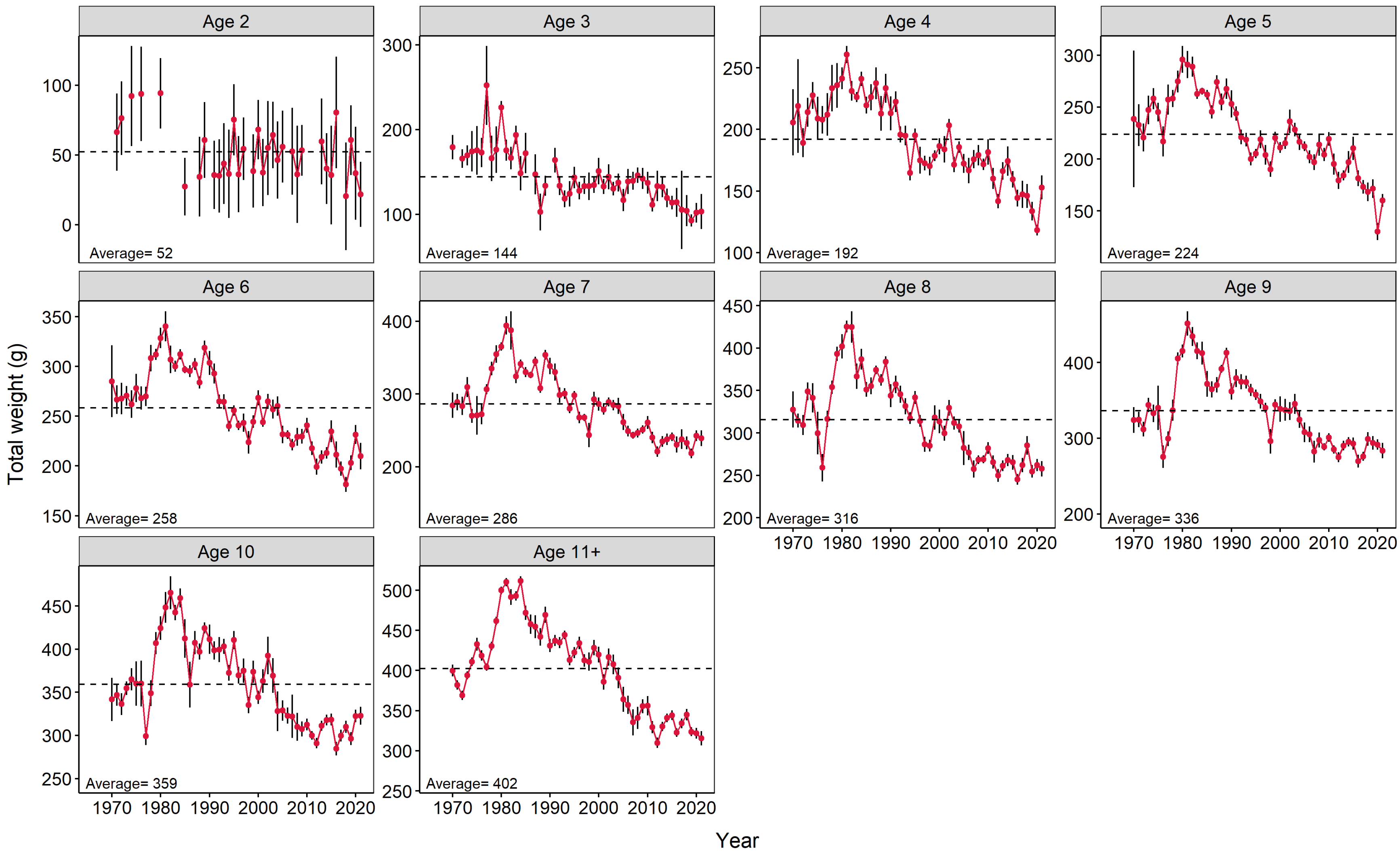

Figure 43. Total weight (g) at ages 2 to 11+ of fall spawners herring in NAFO Division 4R from 1965 to 2021. The series were standardized to take into account the NAFO subdivision, fishing gear and month of capture. The horizontal dashed black line is the series average.

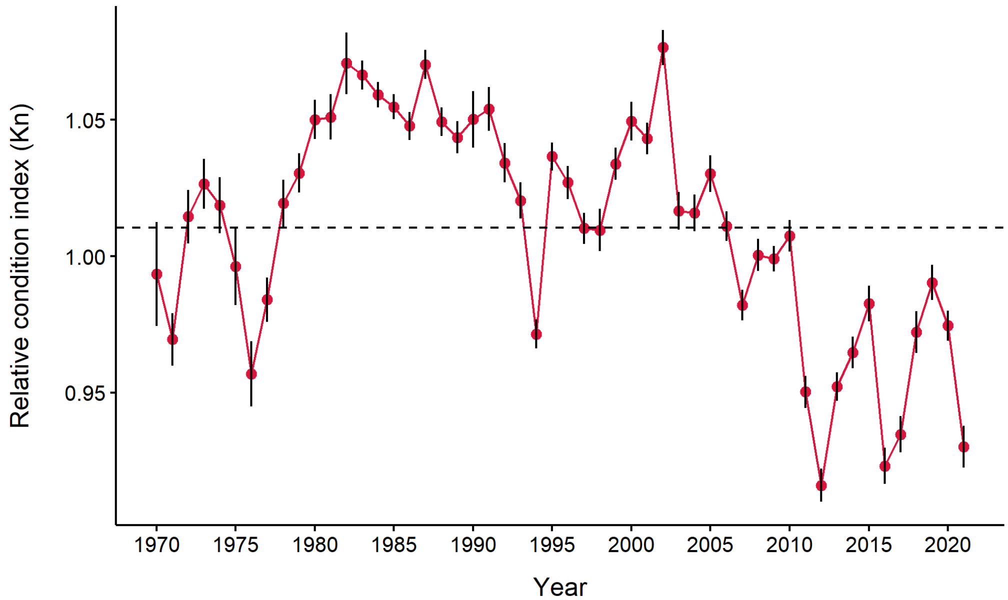

Figure 44. Standardized relative condition index (with a 95% confidence interval) for fall herring spawners in NAFO division 4R from 1970 to 2021. The series were standardized to take into account the NAFO subdivision, fishing gear and month of capture. The horizontal dashed black line is the series average (1.01).

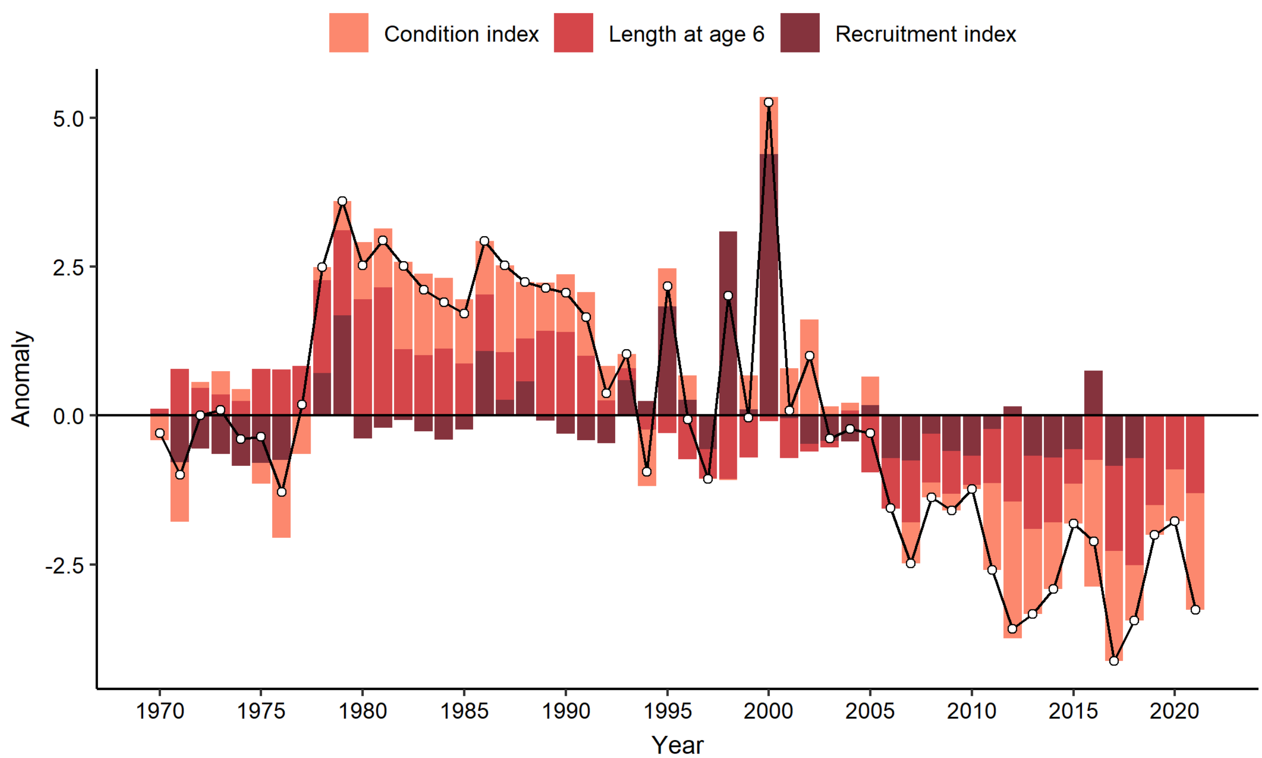

Figure 45. Cumulative stock productivity index based on the sum (white dot) of annual standardized anomalies of key stock productivity indicators (relative condition index, average total length at age 6 and recruitment index) of fall-spawning herring in NAFO division 4R from 1970 to 2021.

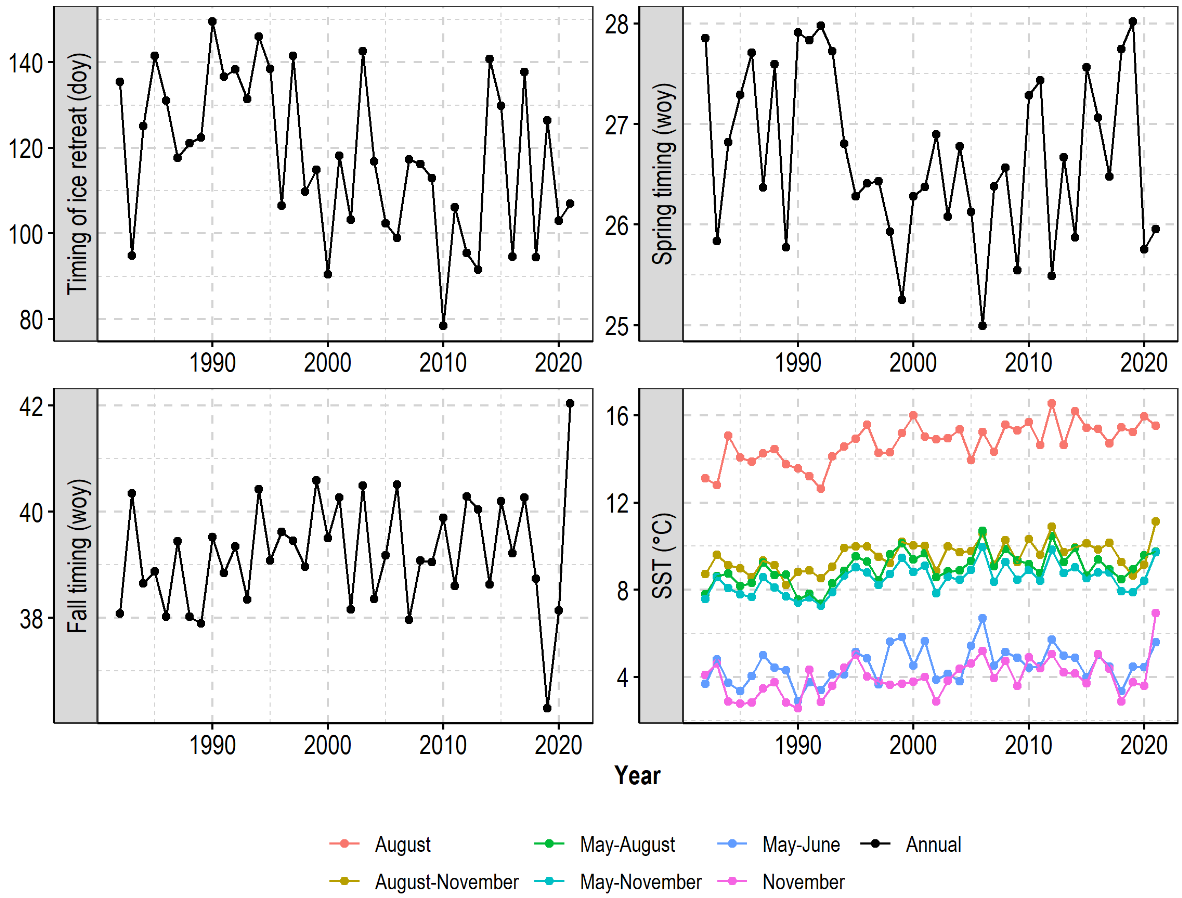

Figure 46. Interannual variability of the physical environment predictors included in generalize additive model evaluating the effect of the environment on herring condition and recruitment averaged for region 2, 3 and 4 of the ecosystem approach. Spring timing represents the first week of the year when the surface water temperature is above 10°C and fall timing represents the last week of the year when the surface water temperature is below 10°C (doy= day of year, woy= week of year). SST represents Sea Surface Temperature.

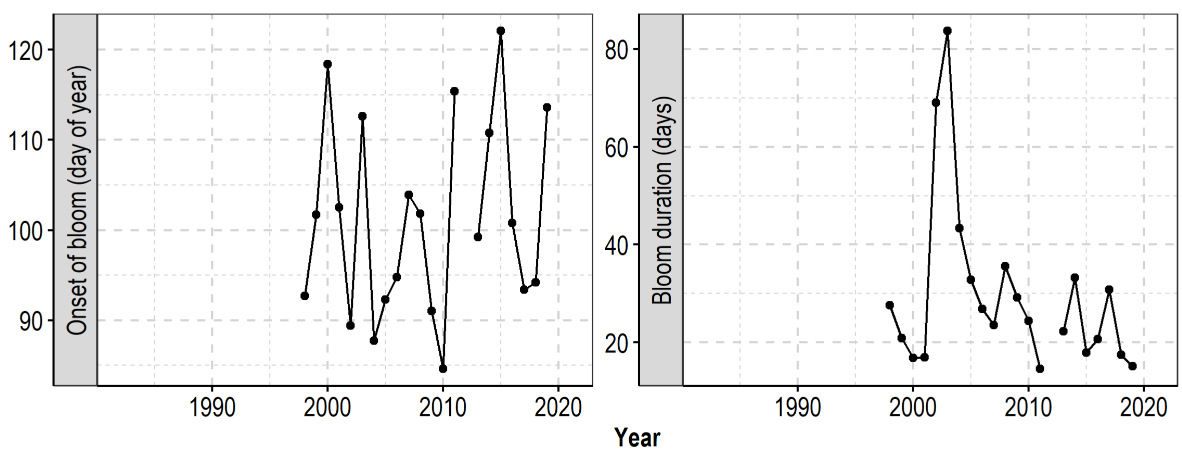

Figure 47. Interannual variability of phytoplankton productivity predictors included in generalize additive model evaluating the effect of the environment on herring condition and recruitment averaged for regions 2, 3 and 4 of the ecosystem approach.

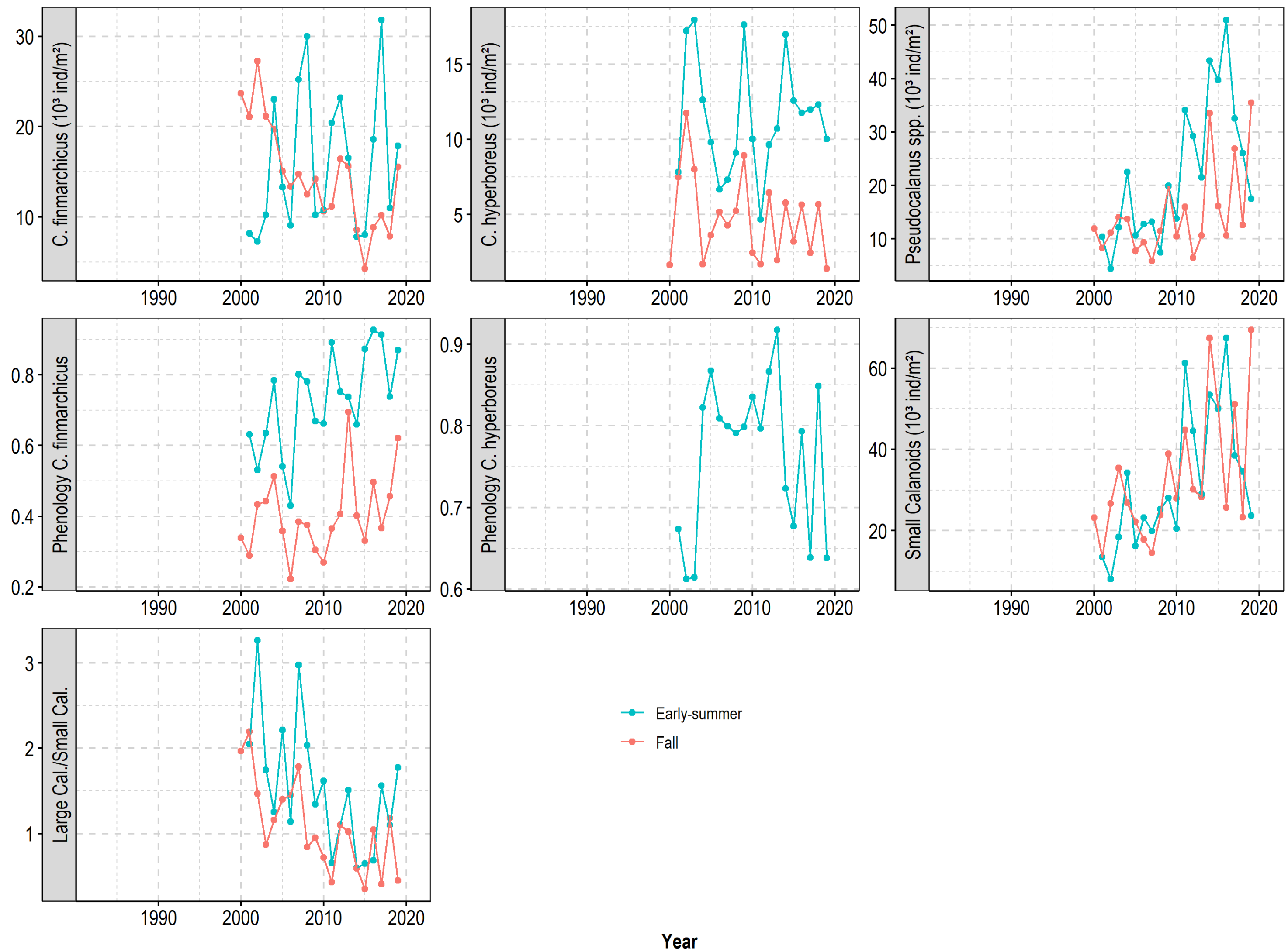

Figure 48. Interannual variability of zooplankton productivity predictors included in generalize additive model evaluating the effect of the environment on herring condition and recruitment averaged for region 2, 3 and 4 of the ecosystem approach.

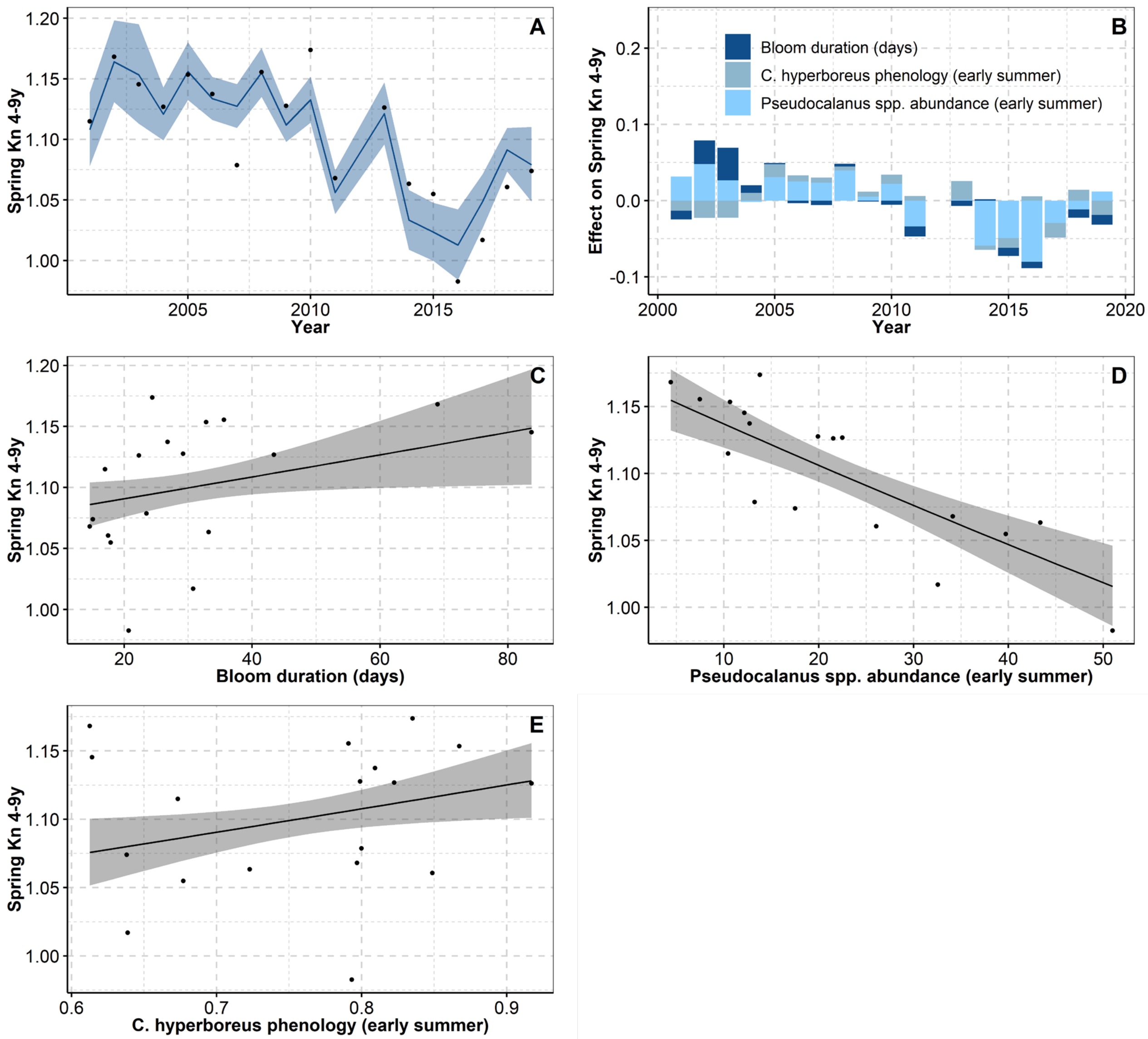

Figure 49. Selected GAM for the Kn of 4-9 years spring-spawning herring. A) Observed Kn (black circles) are plotted against GAM predictions (blue line) and the 95% confidence intervals on the predictions (shaded blue area), B) Contribution of each variable to the predicted Kn each year, C) Effect of bloom duration, D) Effect of Pseudocalanus spp. abundance in early summer, E) Effect of C. hyperboreus phenology in early summer.

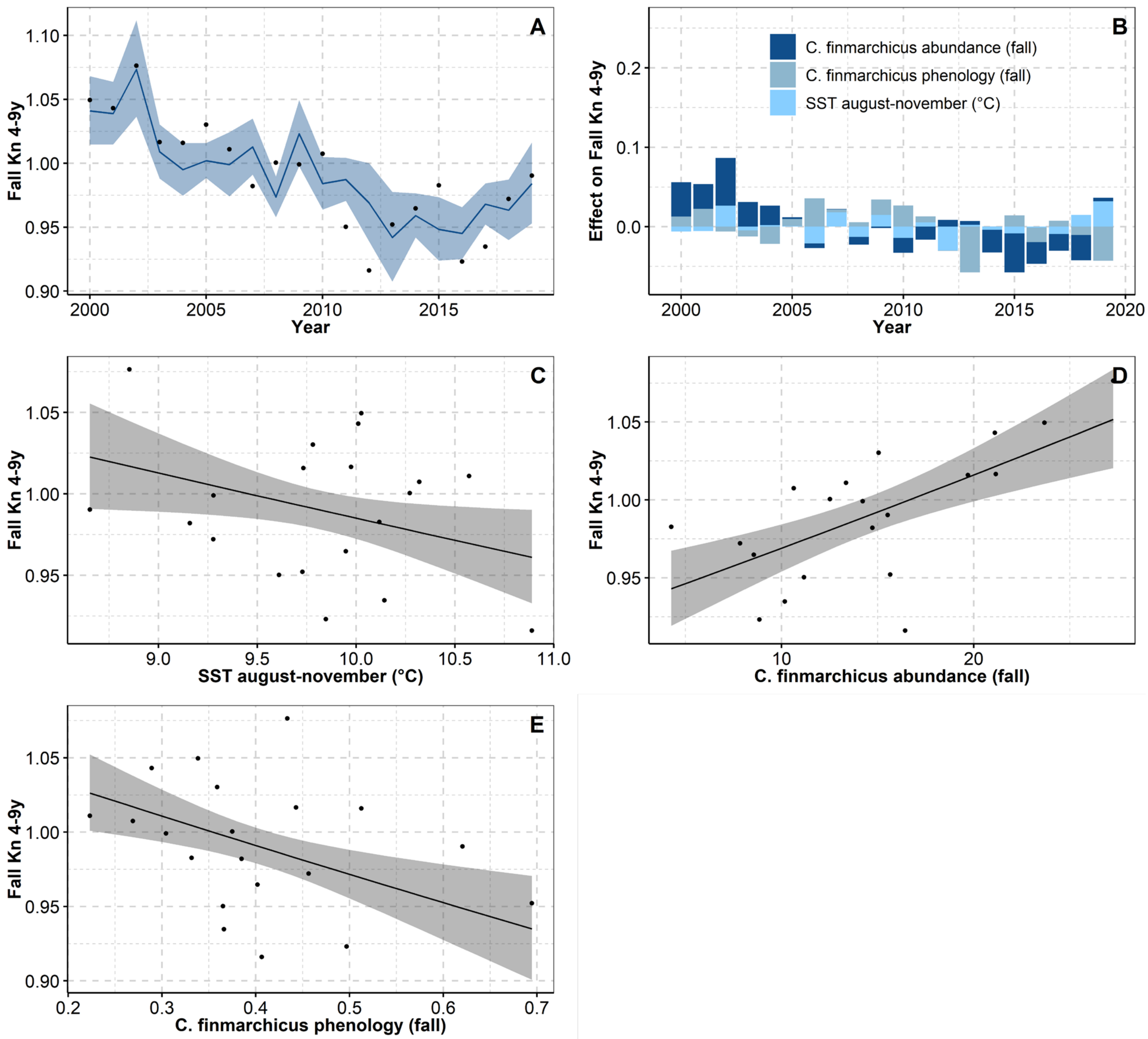

Figure 50. Selected GAM for the Kn of 4-9 years fall-spawning herring. A) Observed Kn (black circles) are plotted against GAM predictions (blue line) and the 95% confidence intervals on the predictions (shaded blue area), B) Contribution of each variable to the predicted Kn each year, C) Effect of average Sea Surface Temperature (SST) from August to November, D) Effect of C. finmarchicus abundance in the fall, E) Effect of C. finmarchicus phenology in the fall.

APPENDIX A: ADDITIONAL INFORMATION ON ACOUSTIC SURVEYS CONDUCTED IN NAFO DIVISION 4R FROM 1991 TO 2021

Here we present: 1-hydroacoustic vessels used to perform the acoustic survey from 1991 to 2021 (Table A17), 2-summary of the biological samples applied in the estimation of the 2009-2021 abundance indices (Table A18), 3- sampling effort (number of transects per stratum) over the 1991-2021 period (Figure A51), 4-biomass estimates per stratum and spawning component for the 1991-2002 (Table A19) and 2009-2021 (Table A20) periods, and 5-spatial distribution of herring biomass measured during the 2009 to 2017 acoustic surveys (Figure A52). The 1991 to 2002 biomass estimates come from previous stock assessment documents (McQuinn and Lefebvre 1999, Grégoire et al. 2012, Légaré et al. 2014).

Table A17. Start and end dates and vessels used to perform the herring acoustic surveys from 1991 to 2021. All vessels listed are part of the Canadian Coast Guard (CCG) fleet, except the RV Novus which is a chartered vessel from the company Leeway Marine.

Survey	Start	End	Vessel
1991	23-Nov	02-Dec	E.E. Prince (CCG)
1993	11-Nov	24-Nov	Frederick G. Creed (CCG)
1995	20-Oct	02-Nov	Frederick G. Creed (CCG)
1997	16-Oct	31-Oct	Frederick G. Creed (CCG)
1999	10-Oct	21-Oct	Frederick G. Creed (CCG)
2002	15-Sep	26-Sep	Frederick G. Creed (CCG)
2009	21-Oct	06-Nov	Frederick G. Creed (CCG)
2010	21-Oct	02-Nov	Frederick G. Creed (CCG)
2011	20-Oct	01-Nov	Frederick G. Creed (CCG)
2013	13-Oct	22-Oct	Frederick G. Creed (CCG)
2015	15-Oct	25-Oct	Vladykov (CCG)
2017	21-Oct	06-Nov	Frederick G. Creed (CCG)
Summer 2019	11-Aug	23-Aug	Frederick G. Creed (CCG)
Fall 2019	26-Oct	06-Nov	Leim (CCG)
Summer 2020	08-Aug	30-Aug	Leim (CCG)
Fall 2020	19-Oct	06-Nov	Leim (CCG)
Summer 2021	04-Aug	18-Aug	RV Novus (Leeway Marine)
Fall 2021	13-Oct	28-Oct	RV Novus (Leeway Marine)

Table A18. Number of samples of Atlantic herring by survey and fishing gear used for the estimation of the acoustic biomass index from 2009 to 2021. In some years, samples from the commercial fishery were used to fill gaps in sampling (in bold). The total number of herring are indicated in parentheses.

Survey	Pelagic trawl	Bottom trawl	Tuck seine	Purse seine (> 65’)	Purse seine (< 65’)	Gillnet	Vessel
2009	0	0	0	8 (1,743)	0	0	Chartered fishing vessel
2010	0	0	0	3 (625)	0	0	Chartered fishing vessel
2011	0	0	0	3 (728)	0	0	Chartered fishing vessel
2013	0	0	0	4 (566)	**4 (324)**	0	Chartered fishing vessel & Commercial samples
2015	0	0	**2 (110)**	**8 (442)**	**8 (441)**	**1 (48)**	Commercial samples
2017	1 (93)	0	0	**3 (166)**	**1 (55)**	0	CCGS Leim & Commercial samples
Summer 2019	12 (505)	0	0	0	0	0	Chartered fishing vessel
Fall 2019	11 (868)	0	0	0	0	0	Chartered fishing vessel
Summer 2020	12 (1,061)	5 (202)	0	0	0	0	CCGS Teleost & Chartered fishing vessel
Fall 2020	12 (850)	0	0	0	**2 (104)**	0	Chartered fishing vessel & Commercial samples
Summer 2021	3 (248)	9 (358)	0	0	0	0	CCGS Teleost & Chartered fishing vessel
Fall 2021	16 (1,268)	0	0	0	0	0	Chartered fishing vessel

Table A19. Herring biomass densities and estimates by stratum from the acoustic surveys conducted in the fall of 1991 (November 23-December 2), 1993 (November 11-24), 1995 (October 20-November 2), 1997 (October 16-31), 1999 (October 10-21) and 2002 (September 15-26). Standard errors (S.E.) and coefficients of variation (C.V.) of the biomass estimates were computed based on the variance of transect biomass by stratum (O'Boyle and Atkinson 1989). N.S.= Not sampled.

1991	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km^2)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km^2)**	**Total sa (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.	1	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
St. Georges N.	2	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-Port G.	3	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-Port	4	437.4	6	10,518.7	0.144	0	0	-	-	0	0	-	-	0	0	-	-
Bay of Islands G.	5	707.6	11	11,898.6	0.185	1,016.8	1.44E-06	1.41E-06	97.9	0.004	3,014.0	2,950.7	97.9	0.004	3,683.0	3,605.7	97.9
Bonne Bay Bank	6	682.5	29	12,992.7	0.552	26,307.3	3.85E-05	3.25E-05	84.4	0.114	77,970.0	65,650.7	84.2	0.099	95,297.0	80,240.1	84.2
Bay of Islands	7	295.7	6	14,526.2	0.295	198.4	6.71E-07	6.92E-07	103.1	0.002	588.0	606.2	103.1	0.002	719.0	741.3	103.1
Bonne Bay	8	53.2	14	2,158.5	0.568	451.1	8.47E-06	7.89E-06	93.2	0.017	877.0	816.5	93.1	0.019	1,718.0	1,599.5	93.1
Hawk's Bay	9	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
St. John Bay	10	1,640.3	21	14,503.1	0.186	0	0	-	-	0	0	-	-	0.000	0	-	-
Average / Total:	-	3,816.8	87	11,410.7	0.260	27,973.6	4.91E-05	3.35E-05	68.2	0.022	82,449.0	65,547.0	79.5	0.019	101,417.0	80,626.5	79.5
1993	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km^2)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km^2)**	**Total sa (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.	1	1,157.4	17	10,929.8	0.161	333.9	2.89E-07	2.77E-07	95.8	0.001	788.0	757.3	96.1	0.001	778.0	747.7	96.1
St. Georges N.	2	665.8	10	10,732.0	0.161	0	0	-	-	0.000	0	-	-	0.000	0	-	-
Port-au-Port G.	3	850.6	13	11,531.0	0.176	933.6	1.10E-06	7.67E-07	69.7	0.003	2,203.0	1,539.9	69.9	0.002	2,176.0	1,521.0	69.9
Port-au-Port	4	437.4	11	7,524.4	0.189	2.8	6.48E-09	6.43E-09	99.2	0.000	7.0	7.0	99.3	0.000	7.0	7.0	99.3
Bay of Islands G.	5	707.6	16	10,237.8	0.231	3,141.8	4.44E-06	1.59E-06	35.8	0.010	7,413.0	2,653.9	35.8	0.008	7,324.0	2,622.0	35.8
Bonne Bay Bank	6	1,035.5	44	10,350.2	0.440	13,206.5	1.28E-05	2.64E-06	20.6	0.038	39,017.0	7,725.4	19.8	0.029	38,337.0	7,590.7	19.8
Bay of Islands	7	295.7	4	14,401.7	0.195	534.2	1.81E-06	1.73E-06	95.6	0.004	1,260.0	1,208.3	95.9	0.003	1,245.0	1,194.0	95.9
Bonne Bay	8	53.2	11	2,200.5	0.455	51.2	9.62E-07	5.61E-07	58.3	0.003	159.0	92.7	58.3	0.002	125.0	72.9	58.3
Hawk's Bay	9	*N.S.*															
St. John Bay	10	*N.S.*															
Average / Total:		5,203.3	126	9,736.7	0.236	18,204.0	2.14E-05	3.67E-06	17.1	0.010	50,846.0	8,440.4	16.6	0.008	49,993.0	8,298.8	16.6

Table A19. (continued).

1995	Stratum				All herring area backscattering coefficients (s_a)					Fall-spawning herring				Spring-spawning herring			
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km/km^2)	Total sa (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.	1	1,156.7	14	10,952.6	0.133	0	0	-	-	0.000	0	-	-	0	0	-	-
St. Georges N.	2	666.5	8	10,911.8	0.131	0	0	-	-	0.000	0	-	-	0	0	-	-
Port-au-Port G.	3	866.8	10	1,557.3	0.018	1,640.6	1.89E-06	1.49E-06	78.8	0.002	1,965.0	1,548.4	78.8	0.003	4,586.0	3,613.8	78.8
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	0.000	-	-	-
Bay of Islands G.	5	766.3	25	11,957.9	0.390	2,447.9	3.19E-06	1.38E-06	43.3	0.006	4,573.0	1,971.0	43.1	0.005	5,312.0	2,289.5	43.1
Bonne Bay Bank	6	1,044.5	33	12,481.3	0.394	3,563.3	3.41E-06	7.67E-07	22.5	0.009	8,942.0	2,012.0	22.5	0.005	5,717.0	1,286.3	22.5
Bay of Islands	7	296.6	10	10,005.6	0.337	0	0	-	-	0.000	0	-	-	0.000	0.0	0.0	0.0
Bonne Bay	8	53.0	9	2,404.3	0.408	11.9	2.24E-07	1.61E-07	71.9	0.000	10.0	7.5	74.5	0.000	39.0	29.1	74.5
Hawk's Bay	9	487.1	11	9,065.9	0.205	1,029.0	2.11E-06	1.21E-06	57.3	0.005	2,607.0	1,496.4	57.4	0.003	1,650.0	947.1	57.4
St. John Bay	10	1,786.5	20	17,441.1	0.195	13,028.9	7.29E-06	4.04E-06	55.4	0.019	33,301.0	18,448.8	55.4	0.012	20,847.0	11,549.2	55.4
Average / Total:		7,124.0	140	10,753.1	0.216	21,721.6	1.81E-05	4.75E-06	26.2	0.007	51,398.0	17,783.7	34.6	0.005	38,151.0	13,200.2	34.6

1997	Stratum				All herring area backscattering coefficients (s_a)					Fall-spawning herring				Spring-spawning herring			
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km/km^2)	Total sa (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.	1	328.0	39	5,066.5	0.602	6,885.3	2.10E-05	5.62E-06	26.8	0.026	8,648.1	1,944.2	22.5	0.061	20,083.1	4,515.0	22.5
St. Georges N.	2	305.0	29	5,202.1	0.495	361.3	1.19E-06	8.06E-07	68.1	0.001	453.8	296.2	65.3	0.003	1,053.9	687.9	65.3
Port-au-Port G.	3	1,324.8	26	18,525.9	0.364	64.2	4.85E-08	3.61E-08	74.5	0.000	102.3	73.1	71.4	0.000	78.8	56.3	71.4
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	850.4	21	13,496.7	0.333	1,070.0	1.26E-06	6.09E-07	48.4	0.003	2,167.6	1,047.4	48.3	0.002	1,969.5	931.6	47.3
Bonne Bay Bank	6	1,156.2	35	11,202.4	0.339	561.7	4.86E-07	1.77E-07	36.5	0.001	1,135.8	390.0	34.3	0.001	1,065.3	365.8	34.3
Bay of Islands	7	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	8	52.0	8	2,839.1	0.437	46.4	8.92E-07	5.67E-07	63.6	0.002	97.4	54.1	55.5	0.001	67.7	37.6	55.5
Hawk's Bay	9	550.3	24	8,349.8	0.364	43.0	7.82E-08	7.03E-08	89.9	0.000	117.2	102.8	87.7	0.000	38.2	33.5	87.7
St. John Bay	10	1,339.8	25	17,821.4	0.333	14,052.8	1.05E-05	2.59E-06	24.7	0.029	38,276.1	9,383.8	24.5	0.009	12,488.0	3,061.6	24.5
Average / Total:		5,906.5	207	10,503.8	0.368	23,084.7	3.54E-05	6.30E-06	17.8	0.009	50,998.0	9,653.6	18.9	0.006	36,844.0	5,589.2	15.2

Table A19. (continued).

1999	Stratum				All herring area backscattering coefficients (s_a)					Fall-spawning herring				Spring-spawning herring			
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km/km^2)	Total sa (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.	1	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
St. Georges N.	2	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-Port G.	3	1,004.4	20	13,863.9	0.276	3,296.6	3.28E-06	9.86E-07	30.0	0.005	4,856.1	1,232.9	25.4	0.006	6,213.7	1,836.3	29.6
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	850.4	20	12,547.3	0.295	2,443.1	2.87E-06	9.73E-07	33.9	0.005	4,068.6	1,246.2	30.6	0.005	3,859.6	1,174.7	30.4
Bonne Bay Bank	6	910.3	10	15,935.3	0.175	11,557.9	1.27E-05	7.35E-06	57.9	0.037	33,948.2	18,332.8	54.0	0.014	12,541.4	6,677.8	53.2
Bay of Islands	7	292.3	5	16,727.3	0.286	71.7	2.45E-07	1.48E-07	60.5	0.000	96.4	49.9	51.7	0.000	0.0	0.0	-
Bonne Bay	8	52.0	8	1,997.8	0.307	7.5	1.44E-07	1.36E-07	94.0	0.000	21.9	19.1	87.4	0.000	8.8	7.7	87.4
Hawk's Bay	9	320.4	8	7,535.3	0.188	281.3	8.78E-07	8.29E-07	94.4	0.001	337.3	295.5	87.6	0.001	393.0	344.2	87.6
St. John Bay	10	1,203.6	19	16,720.3	0.264	8,252.6	6.86E-06	1.62E-06	23.7	0.014	17,034.4	3,950.3	23.2	0.003	3,912.4	674.6	17.2
Average / Total:		4,633.4	90	12,946.3	0.251	25910.8	2.70E-05	7.70E-06	28.5	0.013	60,363.0	18,837.7	31.2	0.006	26,929.0	7,065.3	26.2

2002	Stratum				All herring area backscattering coefficients (s_a)					Fall-spawning herring				Spring-spawning herring			
Name	Stratum	Area (km^2)	Transect number	Transect average length (m)	Sampling density (km/km^2)	Total sa (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.	1	410.8	25	4,331.2	0.264	876.5	2.13E-06	1.08E-06	50.8	0.006	2,421.9	1,162.8	48.0	0.003	1,226.5	588.9	48.0
St. Georges N.	2	305.2	15	6,059.0	0.298	1,575.0	5.16E-06	4.77E-06	92.4	0.010	3,048.9	2,709.4	88.9	0.011	3,364.1	2,989.5	88.9
Port-au-Port G.	3	1,697.0	17	18,177.7	0.182	669.1	3.94E-07	3.00E-07	76.2	0.001	1,222.1	893.0	73.1	0.001	1,384.6	999.3	72.2
Port-au-Port	4	362.3	6	10,516.5	0.174	4,251.2	1.17E-05	1.04E-05	88.4	0.028	10,199.3	8,468.2	83.0	0.019	6,743.0	5,598.6	83.0
Bay of Islands G.	5	482.3	9	13,317.8	0.249	1,576.1	3.27E-06	2.80E-06	85.7	0.007	3,403.6	2,750.5	80.8	0.005	2,455.1	1984.0	80.8
Bonne Bay Bank	6	1,089.0	26	11,497.3	0.274	460.7	4.23E-07	3.02E-07	71.3	0.001	994.9	678.5	68.2	0.001	717.6	489.4	68.2
Bay of Islands	7	301.9	4	14,287.0	0.189	1,673.9	5.55E-06	3.76E-06	67.8	0.009	2,655.6	1,675.0	63.1	0.013	4,043.0	2,092.1	51.7
Bonne Bay	8	59.1	6	2,918.7	0.296	37.8	6.40E-07	2.70E-07	42.1	0.001	79.1	27.8	35.1	0.001	68.6	24.1	35.1
Hawk's Bay	9	506.0	15	8,643.0	0.256	25.6	5.07E-08	4.73E-08	93.3	0.000	79.6	71.5	89.8	0.000	24.0	21.5	89.8
St. John Bay	10	1,477.6	16	20,540.0	0.222	15,657.5	1.06E-05	5.52E-06	52.1	0.033	48,810.9	23,293.2	47.7	0.010	14,523.6	7,841.7	54.0
Cape Ray	13	97.7	6	2,932.3	0.180	0	0	-	-	0	0	-	-	0	0	-	-
Average / Total:		6,788.9	145	10,624.9	0.211	26,803.5	4.00E-05	1.36E-05	34.0	0.011	72,916.0	25,191.5	34.5	0.005	34,550.1	10,567.6	30.6

Table A20. Herring biomass densities and estimates by stratum from the fishery-independent acoustic survey conducted in the fall of 2009 (October 21-November 6), 2010 (October 21-November 2), 2011 (October 20-November 1), 2013 (October 13-22), 2015 (October 15-25), 2017 (October 21-November 6) and 2019 (October 26-November 6), and in the summer of 2019 (August 11-23). Standard error (S.E.) and coefficient of variation (C.V.) of the biomass estimates were computed based on the variance of transects biomass by stratum (O'Boyle and Atkinson 1989). N.S.= Not sampled.

2009	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km^2)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km^2)**	**Total sa (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.	1	410.8	15	3,776.9	0.138	3,819.36	9.30E-06	5.43E-06	58.4	0.031	12,821.1	7,490.2	58.4	0.003	1,123.3	656.2	58.4
St. Georges N.	2	172.5	9	3,787.4	0.198	10,159.38	5.89E-05	3.57E-05	60.6	0.198	34,103.7	20,655.3	60.6	0.017	2,987.9	1,809.7	60.6
Port-au-Port G.	3	1,697.0	17	12,426.2	0.124	2,746.33	1.62E-06	9.11E-07	56.3	0.005	9,219.1	5,189.9	56.3	0.0005	807.7	454.7	56.3
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	482.3	9	17,262.3	0.322	6.89	1.43E-08	1.35E-08	94.3	0.00005	23.1	21.8	94.3	0.000004	2.0	1.9	94.3
Bonne Bay Bank	6	1,089.0	20	10,848.0	0.199	1,331.37	1.22E-06	5.92E-07	48.4	0.004	4,469.2	2,163.1	48.4	0.0004	391.6	189.5	48.4
Bay of Islands	7	334.9	9	5,414.1	0.145	2,071.82	6.19E-06	5.57E-06	90.1	0.021	6,954.8	6,267.3	90.1	0.002	609.3	549.1	90.1
Bonne Bay	8	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	9	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
St. John Bay	10	1,477.9	14	18,871.1	0.179	324.80	2.20E-07	1.26E-07	57.2	0.001	1,090.3	623.6	57.2	0.0001	95.5	54.6	57.2
Average / Total:		6,170.4	99	9,972.0	0.160	20,459.95	7.75E-05	3.65E-05	47.2	0.011	68,681.4	23,537.8	34.3	0.001	6,017.4	2,062.2	34.3

2010	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km^2)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km^2)**	**Total sa (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.	1	407.7	16	3,944.1	0.155	3,178.34	7.79E-06	5.68E-06	72.9	0.024	9,789.7	7134.1	72.9	0.005	1,945.2	1,417.6	72.9
St. Georges N.	2	302.7	15	5,305.0	0.263	3,807.99	1.26E-05	5.88E-06	46.7	0.041	12,321.5	5758.0	46.7	0.008	2,329.6	1,088.7	46.7
Port-au-Port G.	3	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	474.5	8	14,578.1	0.246	7,436.34	1.57E-05	3.05E-06	19.5	0.054	25,397.8	4,939.9	19.5	0.004	1,745.0	339.4	19.5
Bonne Bay Bank	6	638.3	10	8,390.4	0.131	6,538.65	1.02E-05	2.49E-06	24.3	0.035	22,331.9	5,418.4	24.3	0.002	1,534.4	372.3	24.3
Bay of Islands	7	245.4	6	9,077.1	0.222	834.17	3.40E-06	1.01E-06	29.9	0.012	2,849.0	850.7	29.9	0.001	195.7	58.4	29.9
Bonne Bay	8	35.3	3	3,446.1	0.293	19.75	5.59E-07	2.25E-07	40.3	0.002	67.5	27.2	40.3	0.000	4.6	1.9	40.3
Hawk's Bay	9	412.8	10	8,248.5	0.200	1,832.98	4.44E-06	3.99E-06	89.9	0.015	6,260.3	5,627.7	89.9	0.001	430.1	386.7	89.9
St. John Bay	10	945.3	14	13,079.0	0.194	24,632.85	2.61E-05	8.82E-06	33.9	0.089	84,130.3	28,488.4	33.9	0.006	5,780.4	1,957.4	33.9
Average / Total:		3,462.2	99	75,61.1	0.195	48,281.07	9.14E-05	1.33E-05	14.6	0.047	163,147.9	31,333.6	19.2	0.004	13,965.1	2,726.3	19.5

Table A20 (continued).

2011	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km²)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km²)**	**Total sa (m²)**	**Weighted mean s_a**			**Biomass density (kg/m²)**	**Biomass**			**Biomass density (kg/m²)**	**Biomass**		
							Mean (m²/m²)	**S.E.**	**C.V.**		**Total (t)**	**S.E.**	**C.V.**		**Total (t)**	**S.E.**	**C.V.**
St. Georges S.	1	410.8	17	4,212.3	0.174	508.07	1.24E-06	4.58E-07	37.0	0.004	1,709.7	632.5	37.0	0.000	146.4	54.2	37.0
St. Georges N.	2	305.2	14	4,717.6	0.216	1,040.63	3.41E-06	2.39E-06	70.2	0.011	3,501.8	2,457.1	70.2	0.001	299.9	210.4	70.2
Port-au-Port G.	3	812.0	16	7,352.8	0.145	2,603.19	3.21E-06	2.09E-06	65.3	0.011	8,760.1	5,718.5	65.3	0.001	750.3	489.8	65.3
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	482.6	8	14,926.8	0.247	712.19	1.48E-06	6.22E-07	42.1	0.005	2,450.0	1,032.4	42.1	0.000	119.4	50.3	42.1
Bonne Bay Bank	6	1,148.1	23	11,186.5	0.224	6,623.12	5.77E-06	3.24E-06	56.1	0.020	22,784.0	12,780.9	56.1	0.001	1,110.1	622.7	56.1
Bay of Islands	7	334.9	6	4,134.5	0.074	20.50	6.12E-08	5.59E-08	91.3	0.000	70.5	64.4	91.3	0.000	3.4	3.1	91.3
Bonne Bay	8	30.6	3	3,747.9	0.368	13.52	4.42E-07	2.46E-07	55.5	0.002	46.5	25.8	55.5	0.000	2.3	1.3	55.5
Hawk's Bay	9	506.0	6	6,564.3	0.078	357.32	7.06E-07	2.66E-07	37.6	0.002	1,022.6	384.7	37.6	0.000	179.5	67.5	37.6
St. John Bay	10	728.1	13	13,477.1	0.241	23,415.87	3.22E-05	7.60E-06	23.6	0.092	67,013.7	15,833.9	23.6	0.016	11,761.3	2,778.9	23.6
Average / Total:		4,758.3	106	8,326.8	0.185	35,294.41	4.85E-05	8.89E-06	18.3	0.023	107,359.0	21,317.2	19.9	0.003	14,372.6	2,899.1	20.2

2013	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km²)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km²)**	**Total sa (m²)**	**Weighted mean s_a**			**Biomass density (kg/m²)**	**Biomass**			**Biomass density (kg/m²)**	**Biomass**		
							Mean (m²/m²)	**S.E.**	**C.V.**		**Total (t)**	**S.E.**	**C.V.**		**Total (t)**	**S.E.**	**C.V.**
St. Georges S.	1	407.7	17	4,208.6	0.175	1,123.15	2.75E-06	2.07E-06	75.2	0.009	3,842.9	2,891.3	75.2	0.00008	33.7	25.3	75.2
St. Georges N.	2	302.7	15	6,900.9	0.342	962.66	3.18E-06	1.65E-06	51.8	0.011	3,293.8	1,706.9	51.8	0.0001	28.9	15.0	51.8
Port-au-Port G.	3	802.9	17	8,214.5	0.174	362.95	4.52E-07	1.73E-06	382.1	0.001	1,176.2	4,753.0	404.1	0.00001	10.0	41.7	417.1
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	474.5	9	14,540.4	0.276	498.14	1.05E-06	5.43E-07	51.7	0.003	1,614.3	834.8	51.7	0.00003	13.7	7.1	51.7
Bonne Bay Bank	6	1,148.1	23	11,327.6	0.227	41,308.84	3.60E-05	2.02E-05	56.2	0.125	143,041.0	80,378.3	56.2	0.00031	356.6	200.4	56.2
Bay of Islands	7	299.9	7	10,057.7	0.235	839.27	2.80E-06	1.50E-06	53.7	0.009	2,719.9	1,460.8	53.7	0.0001	23.1	12.4	53.7
Bonne Bay	8	58.5	3	2,658.3	0.136	13.96	2.39E-07	1.84E-07	77.1	0.001	48.3	37.3	77.1	0.000002	0.1	0.1	77.1
Hawk's Bay	9	499.8	12	9,172.8	0.220	525.40	1.05E-06	3.14E-07	29.9	0.004	1,819.3	543.9	29.9	0.00001	4.5	1.4	29.9
St. John Bay	10	799.5	17	12,469.0	0.265	2,344.53	2.93E-06	2.66E-06	90.9	0.010	8,118.4	7,377.8	90.9	0.00003	20.2	18.4	90.9
Average / Total:		4,793.7	120	9,221.1	0.231	47,978.89	5.04E-05	2.07E-05	41.0	0.035	165,674.4	80,945.0	48.9	0.0001	490.8	208.1	42.4

Table A20. (continued).

2015	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km^2)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km^2)**	**Total sa (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.	1	407.7	17	4,285.5	0.179	223.91	5.49E-07	4.35E-07	79.3	0.002	763.4	605.3	79.3	0.00007	30.2	24.0	79.3
St. Georges N.	2	299.0	14	6,038.1	0.283	466.63	1.56E-06	1.38E-06	88.6	0.005	1,590.9	1,409.0	88.6	0.0002	63.0	55.8	88.6
Port-au-Port G.	3	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	464.5	8	14,434.8	0.249	11,794.07	2.54E-05	7.16E-06	28.2	0.090	41,909.6	11,812.2	28.2	0.0008	387.6	109.2	28.2
Bonne Bay Bank	6	1,132.5	11	11,335.1	0.110	9,470.43	8.36E-06	2.45E-06	29.3	0.030	33,652.7	9,875.1	29.3	0.0003	311.2	91.3	29.3
Bay of Islands	7	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay	8	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Hawk's Bay	9	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
St. John Bay	10	876.7	7	15,600.4	0.125	1,837.21	2.10E-06	1.03E-06	49.1	0.007	6,078.9	2,983.2	49.1	0.0002	190.9	93.7	49.1
Average / Total:		3,180.5	57	8,890.4	0.159	23,792.25	3.80E-05	7.77E-06	20.5	0.026	83,995.5	15,757.4	18.8	0.0003	983.0	180.9	18.4

2017	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km^2)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km^2)**	**Total sa (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.	1	126.6	4	5,623.7	0.178	39.07	3.09E-07	8.58E-08	27.8	0.001	116.9	32.5	27.8	0	0	-	-
St. Georges N.	2	303.7	15	5,280.6	0.261	1,752.33	5.77E-06	4.81E-06	83.4	0.017	5,243.7	4,373.8	83.4	0.002	725.7	605.3	83.4
Port-au-Port G.	3	802.9	17	8,261.2	0.175	2,665.20	3.32E-06	4.17E-06	125.6	0.010	7,975.4	10,019.9	125.6	0.001	1,103.7	1,386.7	125.6
Port-au-Port	4	*N.S.*			-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	474.5	9	13,294.8	0.252	350.72	7.39E-07	2.46E-07	33.3	0.002	1,163.1	386.8	33.3	0.0001	58.5	19.5	33.3
Bonne Bay Bank	6	1,148.1	23	10,915.4	0.219	3,240.25	2.82E-06	7.44E-07	26.4	0.009	10,745.8	2,834.2	26.4	0.0005	540.5	142.6	26.4
Bay of Islands	7	192.7	6	7,502.4	0.234	113.49	5.89E-07	4.50E-07	76.4	0.002	376.4	287.7	76.4	0.0001	18.9	14.5	76.4
Bonne Bay	8	58.5	3	2,930.6	0.150	28.62	4.89E-07	1.68E-07	34.4	0.002	94.9	32.7	34.4	0.0001	4.8	1.6	34.4
Hawk's Bay	9	499.8	11	9,055.1	0.199	705.54	1.41E-06	1.22E-06	86.6	0.005	2,339.8	2,026.1	86.6	0.0002	117.7	101.9	86.6
St. John Bay	10	743.2	16	10,331.2	0.222	5,543.26	7.46E-06	2.74E-06	36.7	0.023	17,257.5	6,331.4	36.7	0.003	2,459.6	902.4	36.7
Average / Total:		4,349.9	104	8,957.3	0.214	14,438.47	2.29E-05	7.10E-06	31.0	0.010	45,313.6	13,114.4	28.9	0.001	5,029.5	1,770.6	35.2

Table A20. (continued).

Summer 2019	Stratum				All herring area backscattering coefficients (s_a)					Fall-spawning herring				Spring-spawning herring			
Name	Stratum	Area (km²)	Transect number	Transect average length (m)	Sampling density (km/km²)	Total sa (m²)	Weighted mean s_a			Biomass density (kg/m²)	Biomass			Biomass density (kg/m²)	Biomass		
							Mean (m²/m²)	S.E.	C.V.		Total (t)	S.E.	C.V.		Total (t)	S.E.	C.V.
St. Georges S.	1	407.7	3	8,552.0	0.063	1,514.1	3.71E-06	3.76E-06	101.4	0.008	3,443.9	3,491.4	101.4	0.001	536.9	544.3	101.4
St. Georges N.	2	302.7	6	7,417.8	0.147	1,098.3	3.63E-06	2.89E-06	79.6	0.008	2,509.2	1,988.2	79.2	0.001	391.2	310.0	79.2
Port-au-Port G.	3	806.3	5	10,795.3	0.067	733.2	9.09E-07	5.58E-07	61.3	0.002	1,664.7	1,022.7	61.4	0.000	259.5	159.4	61.4
Port-au-Port	4	*N.S.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	474.5	4	16,250.8	0.137	4,973.1	1.05E-05	8.09E-06	77.2	0.031	14,521.7	11,204.1	77.2	0.003	1,370.4	1,057.3	77.2
Bonne Bay Bank	6	1,148.2	11	12,843.5	0.123	3,417.2	2.98E-06	1.10E-06	37.0	0.007	7,613.7	2,825.1	37.1	0.002	2,209.5	819.9	37.1
Bay of Islands	7	335.4	7	10,821.8	0.226	12,367.5	3.69E-05	1.49E-05	40.3	0.067	22,563.3	9,382.7	41.6	0.017	5,774.5	2,401.3	41.6
Bonne Bay	8	58.5	6	3,328.6	0.341	965.5	1.65E-05	5.29E-06	32.0	0.035	2,045.1	656.1	32.1	0.010	612.1	196.4	32.1
Hawk's Bay	9	499.8	6	9,672.9	0.116	454.2	9.09E-07	2.24E-07	24.7	0.002	1,120.9	276.8	24.7	0.001	261.4	64.5	24.7
St. John Bay	10	996.9	7	17,100.8	0.120	19,479.2	1.95E-05	1.22E-05	62.6	0.052	51,768.9	32,401.4	62.6	0.008	7,668.6	4,799.7	62.6
Belle-Isle S.	BI1	312.0	7	5,885.9	0.132	3,419.8	1.10E-05	4.95E-06	45.1	0.028	8,653.3	3,911.0	45.2	0.003	865.7	391.3	45.2
Belle-Isle N.	BI2	626.8	7	9,748.5	0.109	690.9	1.10E-06	4.84E-07	43.9	0.003	1,751.3	768.7	43.9	0.000	175.2	76.9	43.9
Average / Total:		5,968.8	69	10,338.1	0.120	49,113.0	1.08E-04	2.27E-05	21.1	0.020	117,656.0	36,124.6	30.7	0.003	20,125.1	5,586.8	27.8
Fall 2019	**Stratum**				**All herring area backscattering coefficients (s_a)**					**Fall-spawning herring**				**Spring-spawning herring**			
Name	**Stratum**	**Area (km²)**	**Transect number**	**Transect average length (m)**	**Sampling density (km/km²)**	**Total sa (m²)**	**Weighted mean s_a**			**Biomass density (kg/m²)**	**Biomass**			**Biomass density (kg/m²)**	**Biomass**		
							Mean (m²/m²)	**S.E.**	**C.V.**		**Total (t)**	**S.E.**	**C.V.**		**Total (t)**	**S.E.**	**C.V.**
St. Georges S.	1	*N.S.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
St. Georges N.	2	*N.S.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port-au-Port G.	3	730.0	3	11,777.4	0.048	2,792.9	3.83E-06	1.49E-06	39.0	0.010	7,568.0	998.4	38.8	0.004	2,573.9	998.4	38.8
Port-au-Port	4	*N.S.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay of Islands G.	5	*N.S.*		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bonne Bay Bank	6	972.8	7	11,869.2	0.085	12,230.8	1.26E-05	3.91E-06	31.1	0.025	23,866.1	4,044.9	31.1	0.013	13,021.7	4,044.9	31.1
Bay of Islands	7	299.9	3	18,479.7	0.185	672.9	2.24E-06	6.38E-07	28.4	0.005	1,417.4	191.1	27.7	0.002	689.7	191.1	27.7
Bonne Bay	8	58.5	4	2,867.0	0.196	161.8	2.77E-06	7.77E-07	28.1	0.005	315.8	48.4	28.1	0.003	172.3	48.4	28.1
Hawk's Bay	9	499.9	5	10,602.4	0.106	3,954.8	7.91E-06	4.72E-06	59.7	0.008	4,097.0	3,574.2	59.8	0.012	5,977.2	3,574.2	59.8
St. John Bay	10	996.9	6	16,279.4	0.098	21,733.0	2.18E-05	2.59E-06	11.9	0.032	31,531.2	2,987.1	11.9	0.025	25,087.9	2,987.1	11.9
Belle-Isle S.	BI1	*N.S.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Belle-Isle N.	BI2	*N.S.*		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average / Total:		3,557.9	28	12,000.4	0.094	41,546.2	5.11E-05	6.90E-06	13.5	0.019	68,795.5	6,252.5	13.2	0.013	47,522.7	6,252.5	13.2

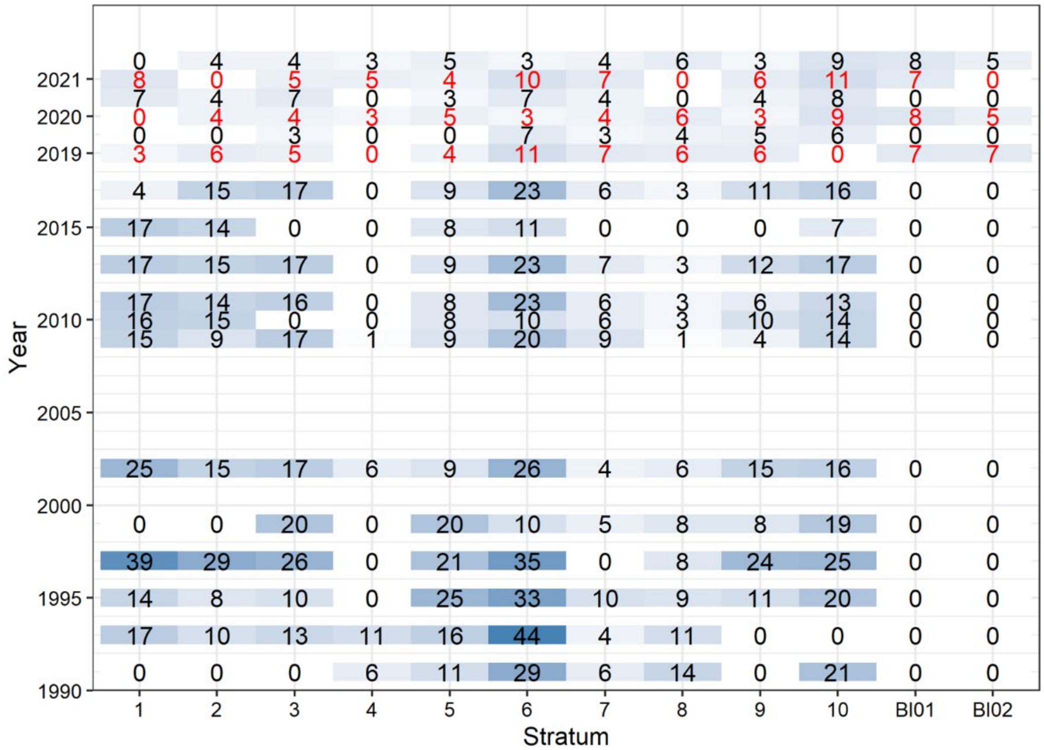

Figure A51. Number of transects surveyed per stratum over the 1991-2021 fall acoustic surveys (black) and the 2019-2021 summer acoustic surveys (red).

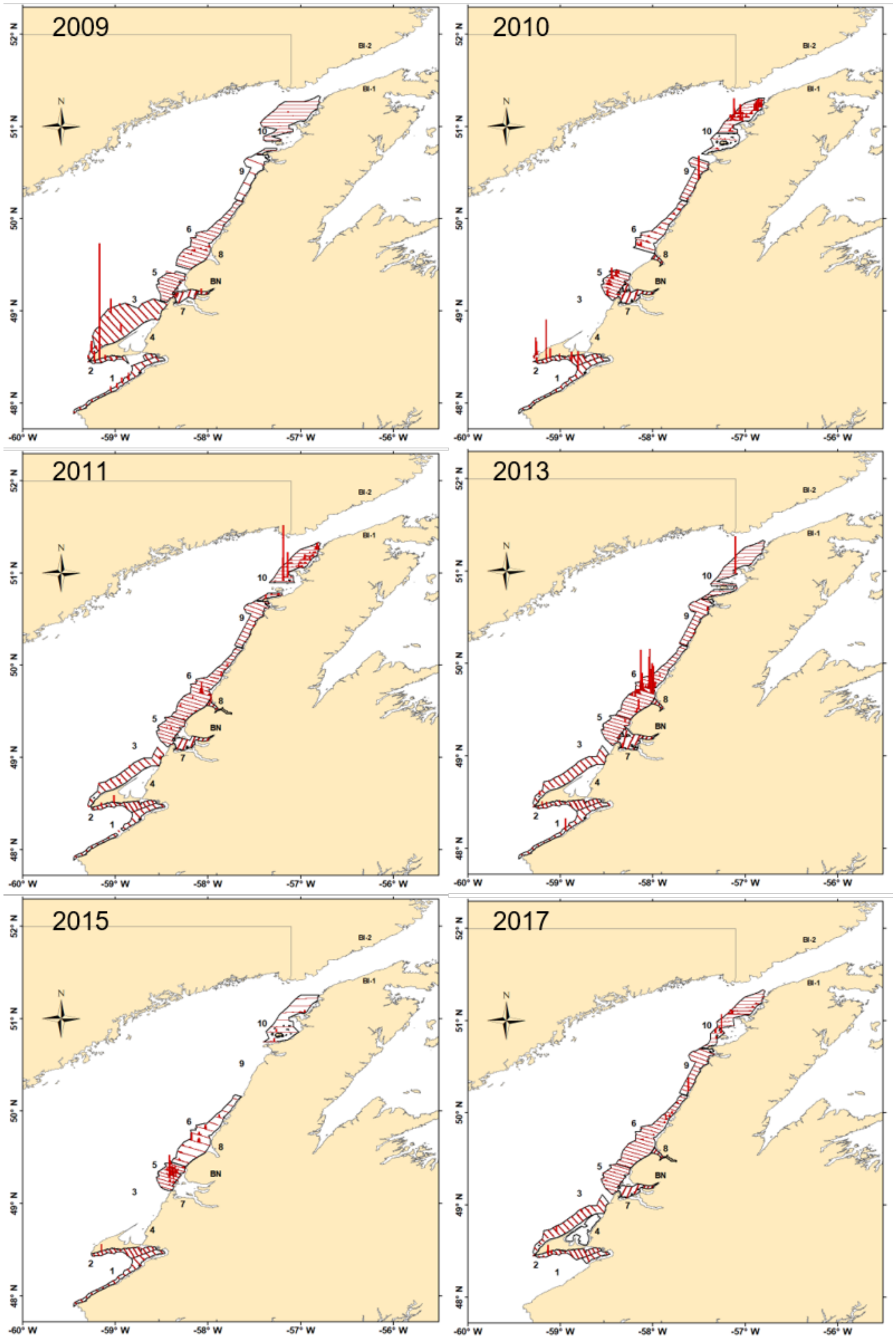

Figure A52. Distribution of herring biomass measured during the 2009 to 2017 hydroacoustic surveys. Biomass is proportional to the height of the red bars. Survey strata names are identified by numbers. The 2009 to 2013 and 2017 surveys were performed with the CCGS F.G. Creed and in 2015 the CCGS Vladykov was the designated platform. BN: Bras Nord.