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Fishery Landings and Catch-at-Age Revisions for Atlantic Herring (*Clupea harengus*) in NAFO Divisions 4RSw Over the 1973-2021 Period

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Foreword

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

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ABSTRACT

This document presents a revision of commercial fishery landings and catch-at-age estimates for Atlantic herring (*Clupea harengus*) in NAFO division 4R and unit area 4Sw over the 1973-2021 period. Landings were re-extracted from original data sources to build continuous historical series and identify discrepancies with values used in previous assessments. A standardized and reproducible algorithm was developed to assign biological samples to landings based on spatial, temporal, and gear-type proximity. This approach was then applied to update annual catch-at-age estimates for spring- and fall-spawning components. Results indicate only minor changes in landings data and catch-at-age estimates relative to the original approach, with more noticeable differences at younger ages. Nevertheless, comparisons with earlier assessments suggest minimal impact on overall age composition and cohort tracking. These revised inputs aim to enhance the transparency and reproducibility of catch-at-age estimates for future stock assessments of herring in 4RSw.

1. INTRODUCTION

Estimating the total catch and catch-at-age of commercial fish populations is an important step in the process of determining sustainable exploitation limits and regulations. Fishery landings for most Canadian fish species are monitored and sampled by the Department of Fisheries and Oceans Canada (DFO) to obtain this information. Since biological characteristics can be influenced by a variety of environmental and sampling-related processes acting simultaneously on populations, disaggregating landings by age requires a careful analysis of the correspondence between landings and available samples over time periods, regions and gear types.

The Atlantic herring (*Clupea harengus*) in the northern Gulf of St. Lawrence (nGSL) are managed and assessed as two discrete stocks; one along the west coast of Newfoundland (NAFO division 4R) and another on Quebec's North Shore (NAFO division 4S). The spatial limits for each stock were originally defined on the basis of tagging experiments conducted in the 1970s and early 1980s (Moores and Winters 1984) and the evidence, within each region, for ecologically and genetically distinct spring and fall spawning components (Melvin et al. 2009; Lamichhaney et al. 2017). However, the preliminary results of an ongoing acoustic tagging experiment in the nGSL (Émond and Nilo 2025) indicate that herring in division 4R and the adjacent unit area 4Sw may not or may no longer be considered biologically independent. Given this new evidence, and because landings in division 4S have been dominated by 4Sw since the late 2000s (DFO 2021), the present revision is applicable to 4RSw as a whole.

Catch-at-age for 4RS Atlantic herring have historically been estimated with the CATCH.AWS software, written in STSC APL language (Anonymous 1986), and later rewritten in the more modern Visual Basic language and renamed as CATCH (Doniol-Valcroze et al. 2018). Apart from the lack of appropriate documentation on the software's inner workings and source code, which have been discussed elsewhere for Atlantic cod (*Gadus morhua*) in divisions 3Pn4RS (Ouellette-Plante et al. 2022), the software has been criticized for requiring the user to make subjective manual decisions regarding, for example, the choice of biological samples to be associated with fishery landings each year. This lack of reproducibility is particularly problematic in data-poor situations, where the need to impute samples from neighbouring locations, times of year or another gear type may be greater.

The present document provides updated estimates of commercial fishery catch-at-age for Atlantic herring in the combined NAFO divisions 4RSw. We begin by re-extracting fishery landings from all original data sources over the 1973-2021 (division 4R) and 1985-2021 (unit area 4Sw) periods. Then, we present a standardized selection algorithm for the estimation of numbers-at-age, using biological samples from increasingly dissimilar locations, times of year, and gear types. Lastly, we integrate these data inputs into catch-at-age estimates for spring and fall spawners and compare results with the values presented in previous assessments.

2. METHODS

All methods were implemented in the R statistical software version 4.1.1 (R Core Team 2020).

2.1. LANDINGS DATA

Landings were extracted from original data sources for comparison with the values employed in the last published assessment reports (Émond et al. 2024; DFO 2021). The landings for division 4R were obtained from (1) Zonal Interchange File Format (ZIFF) data files which focused on landings by Canadian fleet over 1985-2021; (2) historical DFO research documents covering the assessment period from 1973 to 1996, which appeared to constitute the main source of landings for many previous assessments of the stock; and (3) NAFO's STATLANT 21B dataset which include herring landings from both Canadian and non-Canadian fleet over 1960-2018. For periods with overlap between the datasets, we decided on the most precise combination of sources to be retained based on comparisons of values by gear, NAFO unit area and year. Landings for division 4S were available over the same years in the ZIFF and NAFO B databases, but only the ZIFF were retained for 4Sw given the inability to subset this unit area in NAFO B. The main characteristics of each dataset are summarized below, along with the steps taken to create and standardize each variable (i.e. year, month, NAFO unit area, gear type and gear sector).

2.1.1. ZIFF Database (1985-2021)

ZIFF data were extracted on December 19, 2022 over the full range of NAFO unit areas in 4RS. These files include all fisheries landings reported by Canadian fishing vessels since 1985 and are regularly updated to ensure the highest quality possible (see the dates of last modifications in Figure 1). At the time of the present revision, the landings for the 2019 to 2021 fishing seasons were still being compiled or validated in some locations and, thus, are regarded as preliminary.

We ensured that each record in the ZIFF had an associated year, month, NAFO unit area and gear type to match the resolution available in historical DFO documents (see subsection 2.1.2). No particular issues were found for either year or month. There were 611 records with either missing or unspecified NAFO unit area (e.g. 4R, 4Ru, 4S, 4SU), of which 5 could be recovered from the geographic coordinates and 390 could be assigned based on the landing port identification number. The remaining records with unknown NAFO unit area were removed from the dataset. Gear type was defined from the following six categories: large seiner (vessel length ≥ 65 feet), small seiner (vessel length < 65 feet), gillnet, tuck (bar) seine, trap, and an 'other' category combining the less frequently employed gear types (< 0.5% of annual landings), including beach seine, baited hand line, longline, drift gillnet, pot, bottom otter trawl (stern), midwater trawl (stern), midwater trawl (side) and jigger (Table A1). The mode of capture was further defined with respect to gear sector – either mobile (large seiner, small seiner, tuck seine), fixed (gillnet, trap), or other (all other gear types) – to improve the sample selection process in the algorithm. Note that tuck seines are categorized as fixed gear for fisheries management purposes but that they were treated as mobile gear in the index as they operate in essentially the same manner as purse seines. The aggregated dataset contained 2,827 combinations of year, month, NAFO unit area and gear type.

2.1.2. Historical DFO documents (1973-1996)

Historical landings for NAFO division 4R were obtained from past DFO research documents covering the years 1973-1983 (McQuinn 1987[1]), 1984-1989 (McQuinn and Lefebvre 1993[2]), and 1990-1996 (McQuinn et al. 1999). These data were available in non-electronic, pre-tabulated format only, i.e. the values were summarized by year, month, NAFO unit area and gear type, with each document reporting on Canadian landings made over the last 10-15 years

[1] Landings for 1973-1981 originated from Statistics Branch, Newfoundland region, whereas gillnet landings for 1982-1986 originated from Statistics Branch, Newfoundland and Gulf regions.

[2] Original source not specified.

from the date of publication. As in the ZIFF, the last three years of data in each assessment are considered preliminary as modifications were still expected.

Since the landings were pre-aggregated by year, month, NAFO unit area and gear type, no modifications were made for any of the original variables in the dataset. However, misreporting by the large-seiner industry between 1982 and 1985 – when the total allowable catch (TAC) was lowered from 16,000 to 10,000 t – has led to significant underestimation of the total landings in McQuinn's (1987) Table 3. For 1982-1983, the 'industry-corrected' numbers in McQuinn's (1987) Table 2 (9,548 and 7,279 t) were allocated to the same proportions by year, month and NAFO unit area as in the original table to match the resolution available for other years. The same corrections were not needed for 1984-1985 as the updated values were available in McQuinn and Lefebvre (1993). The full historical dataset comprised landings from 1,216 distinct combinations of year, month, NAFO unit area and gear type.

Historical data extractions did not cover the period from 1965 to 1972 because the corresponding research documents (or some equivalent data source) for these years could not be recovered in our archives. Furthermore, the original sources for the landings presented in Émond et al.'s (2024) annually resolved summary Table 2 could not be validated against the detailed inputs employed in the CATCH software.

2.1.3. NAFO's STATLANT 21B database (1960-2018)

Fisheries landings compiled in NAFO's STATLANT 21B database were retrieved on December 22, 2022 from the online statistics repository, using the *read.nafoB* function developed in the CatchR package (Ouellette-Plante et al. 2022). These data report on commercial landings made by all Canadian and non-Canadian fishing vessels over the period from 1960 to 2018 (the last year available), but are thought as being largely equivalent to the (Canadian-only) ZIFF landings since Canada implemented the 200-nautical mile Exclusive Economic Zone (EEZ) in 1977. At the time of this revision, herring records from 2014 were not available whereas data for all other years had an unknown degree of overlap with the ZIFF (see Figure 3).

We edited each variable in NAFO's 21B database to match the definitions employed in the historical DFO documents and ZIFF. All records had an associated year and NAFO division (4R or 4S). Month of capture was reported in all years except, for division 4R, in 1960, 1986 and 1997 when the landings were presented as yearly totals. The specific NAFO unit area was unknown as it could not be inferred from the dataset or any other source of information. Gear type was defined in most instances but on a coarser resolution than in the ZIFF; for example, all seiners were categorized as large seiners (vessel length ≥ 65 ft) because information on vessel length was generally not available (this category was comparable to the combined landings of large and small seiners in other datasets). There was a total of 1,495 combinations of year, month (when available), NAFO division and gear type in the dataset.

The fact that NAFO 21B data included both Canadian and foreign fishing vessels is not expected to affect the comparison with the (Canadian-only) ZIFF database in a meaningful way. Indeed, the only reported landings that could be ascribed to non-Canadian fishing vessels since 1960 have been made by France (mainland) in 1975 (division 4S) and 1979 (division 4R) in a bottom otter trawl fishery targeting Atlantic cod.

2.2. SAMPLE SELECTION

Biological samples were obtained from various landing ports via DFO's commercial sampling program and attributed to strata k $(k = 1,2, \dots, K)$ defined by unique combinations of *year* (1973-2021), *month* (1-12), *NAFO unit area* (4Ra-d; 4Sw), *gear type* (large seiner, small seiner, tuck seine, gillnet, trap, other) and *gear sector* (mobile, fixed, other). For some stratum-specific landings W_k, one or more random samples of approximately 55 fish (range: 30-295) were selected and sent to the Maurice Lamontagne Institute for assignment of spawning group (spring or fall), sex (male, female, unknown), total length (± 1 mm), total mass (± 1 g), gonad mass (± 0.1 g), stage of gonadal development (categories 1-8), and age class (0-11+). These biological characteristics were then paired with landings of corresponding or similar strata for catch-at-age calculations.

The assignment of M biological samples to landings W_k followed a standardized algorithm to ensure the replicability of results from one iteration to the next. The initial scheme based on the year, month, NAFO unit area, gear type and gear sector of capture was developed by McQuinn (1987). The algorithm is based on a 14-level hierarchy wherein samples collected at level 1 originate from the same year, month, NAFO unit area and gear type as the landings W_k and levels 2-14 employed imputation using values from increasingly dissimilar strata:

$$m = \begin{cases} 1 & = \text{year + month + NAFO + gear type} = \text{if } M \geq 2\text{, else} \downarrow \\ 2 & = \text{year + month + NAFO + gear sector} = \text{if } M \geq 2\text{, else} \downarrow \\ 3 & = \text{year + adj. months + NAFO + gear type} = \text{if } M \geq 2\text{, else} \downarrow \\ 4 & = \text{year + adj. months + NAFO + gear sector} = \text{if } M \geq 2\text{, else} \downarrow \\ 5 & = \text{year + adj. months + NAFO} = \text{if } M \geq 2\text{, else} \downarrow \\ 6 & = \text{year + month + adj. NAFO + gear type} = \text{if } M \geq 2\text{, else} \downarrow \\ 7 & = \text{year + month + adj. NAFO + gear sector} = \text{if } M \geq 2\text{, else} \downarrow \\ 8 & = \text{year + adj. months + adj. NAFO + gear type} = \text{if } M \geq 2\text{, else} \downarrow \\ 9 & = \text{year + adj. months + adj. NAFO + gear sector} = \text{if } M \geq 2\text{, else} \downarrow \\ 10 & = \text{year + adj. months + adj. NAFO} = \text{if } M \geq 2\text{, else} \downarrow \\ 11 & = \text{year + adj. NAFO + gear type} = \text{if } M \geq 2\text{, else} \downarrow \\ 12 & = \text{year + adj. NAFO + gear sector} = \text{if } M \geq 2\text{, else} \downarrow \\ 13 & = \text{year + adj. NAFO} = \text{if } M \geq 2\text{, else} \downarrow \\ 14 & = \text{year} \end{cases} \quad (1)$$

Samples from adjacent (adj.) months were prioritized over samples from adjacent locations to reflect the observation by McQuinn (1987) that proportions of spring and fall spawners tend to be more similar in time than in space in division 4R. Although evidence supporting this assertion was not consistently observed for our study system (e.g. see Figure A1 for comparisons across months and across NAFO unit areas), we still maintained this manner of doing because preliminary explorations indicated very little incidence of the specific sequence of selection on the outcomes of the catch-at-age estimation procedure.

The search for samples was set to progress to higher levels of aggregations until at least two independent samples could be assigned per given landing W_k. As in Ouellette-Plante et al. (2022), the search was not constrained by a maximum number of samples.

The algorithm's behavior and output were evaluated by estimating the total number of strata and combined landings assigned to each of the 14 aggregation levels. We also examined how the selections evolved over time via the comparison of mean and landings-weighted mean aggregation levels across years.

2.3. CATCH-AT-AGE

Catch-at-age for spring and fall spawning herring was estimated by implementing the equations given below in the R environment, which were largely inspired from Gavaris and Gavaris (1983) and Ouellette-Plante et al. (2022). Before combining the M samples (m = 1, 2, ..., M) associated with each stratum k ($k = 1, 2, \ldots, K$), the proportion of fish of age a and of spawning component s in sample m was calculated as:

$$p_{kmsa} = \frac{n_{kmsa}}{n_{kms}} \tag{2}$$

where n_{kmsa} is the number of fish of age a and spawning component s in sample m.

The proportion of age a and of spawning component s at the stratum level, p_{ksa}, was:

$$p_{ksa} = \frac{\sum_{m=1}^{M} p_{kmsa}}{M} \tag{3}$$

The landed weight of fish of age a and spawning component s in stratum k, W_{ksa}, was therefore calculated as:

$$W_{ksa} = W_k \cdot p_{ksa} \tag{4}$$

The corresponding number of specimens, N_{ksa}, was obtained by:

$$N_{ksa} = \frac{W_{ksa}}{\overline{w}_{ksa}} \tag{5}$$

where $\overline{w}_{ksa}$ is the mean total weight of fish of age a and spawning component s in stratum k and was calculated as:

$$\overline{w}_{ksa} = \frac{\sum_{i=1}^{n} w_{ksai}}{n_{ksa}} \tag{6}$$

where w_{ksai} is the total weight of fish i of age a and spawning component s in stratum k and n_{ksa} is the number of fish of age a and spawning component s in stratum k. Then, catch-at-age in numbers by spawning component and age-class ($caan_{sa}$) was calculated by year as:

$$caan_{sa} = \sum_{k}^{K} N_{ksa} \tag{7}$$

Lastly, the proportions of each spawning component s in the commercial catches in each year y ($y = 1, 2, \ldots, Y$), p_{ys}, was obtained from:

$$p_{ys} = \frac{\sum_{a=1}^{A} caan_{ysa}}{\sum_{s=1}^{S} \sum_{a=1}^{A} caan_{ysa}} \tag{8}$$

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

The above equations differ from the approach developed for Atlantic cod in 3Pn4RS (Ouellette-Plante et al. 2022) in two important ways. First, calculations for Atlantic herring must account for the presence of two co-occurring spawning components (fall and spring spawners) whose relative contribution to the landings can only be determined through biological sampling. Second, biological samples are not subsampled for age determination, allowing numbers-at-age to be estimated directly, without relying on traditional age-length keys.

Major trends in the data were summarized by estimating the standardized proportions by age and year (SPAY) for each spawning component and NAFO division. Numbers at age were first converted to annual proportions at age by:

$$p_{ysa} = \frac{caan_{ysa}}{\sum_{a=1}^{A} caan_{ysa}} \tag{9}$$

p_{ysa} was then standardized ($spay_{ysa}$) by subtracting the mean proportion at each age $\bar{p}_{sa}$:

$$\bar{p}_{sa} = \frac{\sum_{y}^{Y} p_{ysa}}{Y} \tag{10}$$

and dividing by the standard deviation σ_{sa} of the proportions computed across years:

$$spay_{ysa} = \frac{p_{ysa} - \bar{p}_{sa}}{\sigma_{sa}} \tag{11}$$

where standard deviation is:

$$\sigma_{sa} = \sqrt{\frac{\sum_{y}^{Y}(p_{ysa} - \bar{p}_{sa})^2}{Y}} \tag{12}$$

To identify and visualize the differences between the original and revised catch-at-age estimates, we calculated the log-ratio (log[new/old]) of the two non-standardized datasets, which provides values that are symmetric around zero.

3. RESULTS

3.1. LANDINGS DATA

3.1.1. Continuous landings series for division 4R (1973-2021)

Despite having been updated in December 2009, we were surprised to find that ZIFF data files compiled over 1985-1992 have not been consistently employed in any recent stock assessment for division 4R (Figure 1). Instead, the original landings series for this period was more closely aligned with the values published in McQuinn (1987), McQuinn and Lefebvre (1987) and McQuinn et al. (1999).

To identify which of these two datasets provided the most plausible values for 1985-1992, ZIFF landings for division 4R were aggregated by year, NAFO unit area and gear type to match the resolution in the historical DFO dataset (Figure 2). Landings by large seiners ranged from 13,171 to 25,598 t, with the estimates presented in McQuinn and Lefebvre (1993) and McQuinn et al. (1999) exceeding ZIFF values by as much as 8,787 t. These elevated values in DFO documents are known to have coincided with a peak in herring sales to Asian and European countries, the development of an over-the-side sale agreement with Russia from 1988 to sometime in the 1990s, and a degree of quota sharing between NAFO unit areas 4Rc and the adjacent 4TVn (McQuinn and Lefebvre 1993). Landings estimated for small seiners and gillnets were highly consistent across sources whereas equivalent comparisons for tuck seine and trap gear were not possible given that these have only been introduced in the late 1990s and 2000s, respectively. Based on the evidence presented in Figure 2, therefore, we subsetted the ZIFF dataset for 1993-2021 and extended that series with the similarly resolved, but presumably more conservative historical DFO landings compiled over 1973-1993.

We investigated whether historical DFO landings for 1973-1993 could be replaced with the more recently updated NAFO B database for division 4R (Figure 3). Although the vast majority of pre-2000 records in NAFO B were last modified in the mid to late 1990s, comparisons for the combined large and small seiners indicated that specific records in this dataset were not up to date for herring. A notable discrepancy was observed for 1982 and 1983, where the NAFO B landings corresponded to the industry-misreported values in McQuinn's (1987) Table 3 (5,586 and 4,616 t) rather than the *a posteriori* corrections presented in the same document's Table 2 (9,548 and 7,278 t; see Methods subsection 2.1.2). Another key example is for year 1984; in that year, the landings in NAFO B corresponded to the (then) preliminary value of 4.78 t in

McQuinn (1987) rather than the final estimate of 7.20 t in McQuinn and Lefebvre (1993). Although the correspondence between sources was relatively high for gillnets and other gear types combined, except perhaps after 2000, we concluded that NAFO B estimates were incomplete over 1973-1993. Thus, historical DFO documents were deemed to provide more up-to-date information than NAFO B for the 1973-1992 period.

The data sources employed for the landings in each year from 1973 to 2021 are summarized for each NAFO unit area in division 4R (Figure 4: left panels). These included McQuinn (1987) from 1973 to 1984, McQuinn and Lefebvre (1993) from 1984 to 1990, McQuinn et al. (1999) from 1990 to 1993, and ZIFF data from 1993 to 2021.

3.1.2. Continuous landings series for unit area 4Sw (1985-2021)

For NAFO unit area 4Sw, we used ZIFF data over 1985-2021 in correspondence to the last assessment (DFO 2021) as there were no known issues with the data prior to 1993 or in any given year (Figure 4: right panel). The series was not extended further back in time because it was not possible to subset NAFO B data by unit area as in other databases and landings up to the late-2000s were spread among both west and east sides of division 4S.

3.1.3. Summary of trends by gear type and NAFO unit area

Landings by gear type and NAFO unit area are presented for each year in Tables 1 and 2 for division 4R and in Table 3 for 4Sw(see the equivalent Table 2 in Émond et al. 2024, for detailed comparisons for 4R). Landings in division 4R have exhibited sustained increases during the 1970s, 1990s and 2010s, with values peaking in 1973 and 1991 at 26,684 and 26,381 t, respectively. Landings in unit area 4Sw were comparatively lower in magnitude, but they consistently exceeded 3,000 t annually in the years from 2012 to 2017, with a maximum value of 4,378 t recorded in 2012. The TAC for NAFO division 4R has been established at 20,000 t annually since 2003 whereas the TAC for the entire division 4S has been set at a combined total of 4,500 t since 2019 – this includes a maximum of 4,000 t in unit area 4Sw as well as an optional 500 t in all other unit areas (i.e. 4Sivxyz), once the limit of 4,000 t has been reached (the measure was implemented to encourage fishing in unit areas other than 4Sw).

The revised landings did not deviate much from the most recent stock assessments for either division 4R (Émond et al. 2024) or unit area 4Sw (DFO 2021), as revealed by the comparison of trends by gear type (large seiner, small seiner, tuck seine, gillnet, trap) and NAFO unit area (4Sw, 4Ra, 4Rb, 4Rc, 4Rd) in Figure 5. Notably, the revised landings series have allowed the confirmation of two major trends in the data since 1973. The first one is the historical dominance of the mobile gear sector across all unit areas in 4RSw, with large and small seiners having accounted for 63.2% and 17.0% of all landings recorded since 1973, respectively, and the fixed gear sector more active in the (shallow) coastal spawning and overwintering grounds. The second pattern of interest has been a sustained shift, since 2010, in the proportion of landings from the southern unit areas 4Rc and 4Rd towards the northerly located unit areas 4Rb, 4Ra and 4Sw, a pattern that has been previously attributed to an underlying change in stock distribution (e.g. Chamberland et al. 2021). Equivalent comparisons by month of capture could not be drawn given that the original landings in Émond et al. (2024) were only available at the annual temporal resolution.

3.2. SAMPLE SELECTION

Trends in the number of commercial samples available for selection followed landing trends until the mid to late-1990s, following which sample availability sharply decreased to ≤ 50 samples annually (Figure 6). The proportions of samples collected by each gear type were in general accordance with the amounts landed, except in the 1985-2000 period when gillnets were over-represented in the sampling (range: 26.8 – 68.3%) relative to their contributions to the landings (range: 1.43 – 23.1%). Comparisons by NAFO unit area revealed a tendency for lower sampling in the southern portion of 4R, notably in 1973 and during the late 1980s and early 1990s when the contribution of 4Rd was greater in the landings (range: 13.5 – 72.8%) than in the samples (range: 13.4 – 30.9%), as well as an over-representation of the northern unit areas 4Ra and 4Sw. Temporally, the sampling coverage was the most consistent in the later months of the year (10-12) but was somewhat deficient in the spring months (4-6).

Out of 2,576 combinations of year, month, NAFO unit area and gear type, 526 (20.4%) had the required minimum of 2 independent samples at level 1, representing 65.0% of total landings made between 1973 and 2021 (Table 4). The vast majority of strata attained this requirement at or before aggregation level 5 (n_k = 1,671; 64.9%), implying that most landings W_k could be associated with biological samples originating from the same NAFO unit area. Accounting for samples collected in NAFO unit areas adjacent to W_k, but sharing the same gear type or sector (levels 6-9) resulted in a cumulative total of 2,096 strata (81.4%) being associated to nearly all landings (96.3%). Associations made at levels ≥ 10 were relatively rare and overall did not account for much of the landings.

The mean aggregation level of strata remained stable at values between 3 and 5 until the early 2000s, with overall very similar degrees of variability between years (Figure 7). Then, in accordance with the gaps in sample availability identified in Figure 6, the mean aggregation level increased to 7-8 in the mid-2000s, declined during the 2010s and showed another increase in the late 2010s. Although the mean aggregation levels were lower when accounting for the amounts landed in each stratum (reflecting the higher proportions of landings ascribed to low aggregation levels; see the red line in Figure 7), an increase in the mean aggregation level over time was still observed.

3.3. CATCH-AT-AGE

Catch-at-age estimates for fall spawners in division 4R were, overall, very similar to the original estimates in Émond et al. (2024), with most of the short-term variability replicated for ages ≥ 5 years (Figures 8 and 9). Larger differences with the original series were noted at ages ≤ 4 years, which is perhaps unsurprising given that herring are not fully recruited to the commercial fishery until the age of three or four years old (Figure 10). Year 1988 provides a good example of the method’s sensitivity to these rarer age classes, where landed numbers at ages 2, 3 and 4 years were estimated at 484, 207 and 511 thousand individuals in the previous assessments, and only 0, 0, and 567 with the revised approach. The more pronounced difference observed in 2021 between the two series is attributable to the updated landing data and the greater availability of samples for that year during the revision of the catch-at-age estimates.

Catch-at-age for spring spawners in division 4R were slightly more variable than for fall spawners, as reflected by more frequent peaks and dips in abundance over the time period investigated (Figures 11 and 12). During the 1980s, the revised estimates for ages 2-3 years – the least frequently observed categories that could be compared – were considerably lower than in the original assessment, which may reflect the greater sensitivity of results to the sampling algorithm (Figure 13). This deviation was largely reduced in the subsequent years, when the abundance of spring spawners appeared to have been uniformly low across the entire study area.

Catch-at-age trends for fall and spring spawners in unit area 4Sw were largely consistent with those in division 4R (Figures 8 and 11). However, they did not reflect the dominant cohorts as clearly as the catch-at-age from division 4R (Figures 14 and 15). The fishery in 4Sw contributed little to the overall catch in 4RSw, representing only 9.40% of strata with non-zero landings (n_k= 236) and just 5.42% of total landings. Thus, although over half of the strata in this unit area had been assigned samples collected in 4Sw (levels 1-5; n_k= 152), it remains unclear to what extent these observations reflect a shared dynamic between 4R and 4Sw.

The revisions made to catch-at-age estimation in NAFO division 4R did not have any major impact on perceptions of the stock's spawning group composition over the common period from 1973 to 2021 (Figure 16). In both the original and revised series, catch-at-age for division 4R was dominated by spring spawners until the early to mid-1990s, by fall spawners until the early to mid-2010s, and exhibited a rapid increase in the proportions of spring spawners over the remainder of the time period. The perceived recovery of this spawning group in the (preliminary) year 2021, driven in large part by the availability of a strong 2017 cohort to the fishing gear, was proportionally less important according to the revised than to the original series, though we note that this trend is likely to evolve as additional landings data for the past three calendar years become available.

4. DISCUSSION

Our revisions of data inputs and calculation methods for herring catch-at-age in NAFO divisions 4RSw have resulted in a number of improvements. First, we have identified the likely sources of the landings employed in previous research documents for years up to 1973 (Émond et al. 2024; DFO 2021) and developed continuous landings series for both divisions 4R and 4Sw. Second, we have implemented a herring-specific algorithm to simplify and render reproducible the assignment of biological samples to each landing, thus allowing catch-at-age estimates to be updated during each new assessment cycle. Third, we have implemented the (previously unknown) catch-at-age equations into the R statistical environment. The main conclusions gained from each component of this work are summarized below, along with possible next steps.

The re-extraction of fishery landings from original data sources was intended to ensure that only the most plausible values – which were not necessarily the most recent – would be employed for each assessment year. In contrast to what was initially believed for division 4R, the original landings series for 1985-2021 was composed of both ZIFF and historical DFO data, with the latter source deemed more reliable than ZIFF until 1992. Another surprising finding is that the NAFO B dataset – for which most values had been last updated in the mid to late 1990s – sometimes failed to capture important known updates in the herring landings (e.g. major revisions to the 1982-1983 landings by large seiners), leading us to conclude that historical DFO data were generally more reliable than this data source. These comparisons support the continued use of historical DFO data over 1973-1992 and the use of ZIFF data from 1993 to the present time, as in the past assessments.

Our revisions exposed a decreasing availability of commercial samples over time which has been particularly rapid since the early 2000s. This trend was not matched by a corresponding decrease in fishery landings, suggesting that catch-at-age estimation has become increasingly dependent upon the imputation of samples from neighbouring or similar months, locations and gear types. The weighted mean aggregation level provides an objective measure of the impact of such changes on the degree of correspondence between biological samples and landings.

The main advantages of an automated selection algorithm relates to the reproducibility and transparency of the outputs. Although most previous assessments are believed to have followed the guidelines proposed by McQuinn (1987) for the selection of samples, which prioritized biological samples from adjacent months within the same NAFO unit area as the landings W_k

over samples from the same month but adjacent NAFO areas, their past application could not be fully evaluated due to absent or incomplete records of the samples assigned in most strata k.

Another core benefit of automating the assignment of biological samples to landings is the possibility to expand or modify the algorithm to match new sources of knowledge or data constraints. In the present work, the variables defining each stratum k were established by the historical DFO documents as these provided the least precise degree of resolution of the combined ZIFF and DFO series. However, in the event that evidence in support of a different structure of data source (e.g. NAFO B) became available for 4RSw, it would be relatively straightforward and rapid to address via the algorithm. Automation also greatly facilitates sensitivity analyses, allowing users to assess how robust the results are to various assumptions made during the process, such as the minimum number of samples required per stratum.

The present document was developed in the context of considerable uncertainty about the stock affiliation of herring in unit area 4Sw to either division 4R or 4S. As noted previously, however, the decision to estimate catch-at-age for the combined NAFO divisions 4RSw was supported by the preliminary results of an ongoing tagging experiment suggesting a degree of exchange among NAFO divisions 4R and 4S (Émond and Nilo 2025). The analyses presented herein did not suggest any major differences between divisions 4R and 4Sw in terms of spawning group composition in the biological samples, and thus the landings, or the ability to identify and monitor the dominant cohorts across years. Therefore, unless factors not considered in the present work contradicted the notion of a single fall spawning unit and a single spring spawning stock unit for 4RSw, combining the two areas for assessment purposes appears to be a reasonable approach.

ACKNOWLEDGEMENTS

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REFERENCES CITED

Anon. 1986. CAFSAC Assessment Software Catalog. CAFSAC Res. Doc. 86/96: i + 24 p.

Chamberland, J.-M., Lehoux, C., Émond, K., Vanier, C., Paquet, F., Lacroix-Lepage, C., Benoît, H.P., Van Beveren, E., and Plourde, S. 2022. Atlantic herring (*Clupea harengus*) stocks of the west coast of Newfoundland (NAFO Division 4R) in 2019. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/076. v + 115 p.

DFO. 2021. Assessment of the Quebec North Shore (Division 4S) herring stocks in 2020. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/037.

Doniol-Valcroze, T., van Beveren, E., Légaré, B., Girard, L., and Castonguay, M. 2018. Atlantic mackerel (*Scomber scombrus* L.) in NAFO Subareas 3 and 4 in 2016. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/062: v + 51 p.

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

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

Gavaris, S., and Gavaris, C.A. 1983. Estimation of catch at age and its variance for groundfish stocks in the Newfoundland region. *In* Sampling commercial catches of marine fishes and invertebrates. *Edited by* W. G. Doubleday and D. Rivard. pp. 178–182.

Lamichhaney, S., Fuentes-Pardo, A. P., Rafati, N., Ryman, N., McCracken, G. R., Bourne, C., Singh, R., Ruzzante, D. E., and Andersson, L. 2017. Parallel adaptive evolution of geographically distant herring populations on both sides of the North Atlantic Ocean. Proc. Natl Acad. Sci. 114:E3452.

McQuinn. I. H. 1987. Revisions to the 4R herring catch-at-age matrices. Can. Atl. Fish. Sci. Adv. Com. Res. Doc. 87/68, 23p.

McQuinn, I. H., and Lefebvre, L. 1993. An assessment of the western Newfoundland (NAFO Division 4R) herring resource up to 1992. DFO Can. Sci. Advis. Sec. Res. Doc. 93/53. 48 p.

McQuinn, I. H., Hammil, M., and Lefebvre, L. 1999. An assessment and risk projections of the west coast of Newfoundland (NAFO Division 4R) herring stocks (1965 to 2000). DFO Can. Sci. Advis. Sec. Res. Doc. 99/119, 94pp.

Melvin, G. D., Stephenson, R. L., and Power, M. J. 2009. Oscillating reproductive strategies of herring in the western Atlantic in response to changing environmental conditions. ICES J. Mar. Sci., 66(8): 1784-1792.

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

Ouellette-Plante, J., van Beveren, E., Benoît, H. P., and Brassard, C. 2022. Details of `catchR`, an *R* package to estimate the age and length composition of fishery catches, with an application to 3Pn4RS Atlantic cod. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/015. iv + 69 p.

R Core Team. 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria

TABLES

Table 1. Annual landings (t) and Total Allowable Catch (TAC) of herring in NAFO division 4R per unit area from 1973 to 2021. Data for 2019, 2020 and 2021 are preliminary.

YEAR	Unit Area				TOTAL	TAC
	4Ra	4Rb	4Rc	4Rd		
1973	9,213	2,068	2,862	12,541	**26,684**	-
1974	3,043	918	858	2,624	**7,443**	-
1975	1,764	240	112	3,611	**5,727**	-
1976	2,327	226	2,067	6,566	**11,186**	-
1977	4,359	258	3,001	5,561	**13,179**	12,000
1978	6,431	288	1,968	6,774	**15,461**	12,500
1979	3,508	3,877	5,040	6,029	**18,454**	12,500
1980	4,224	2,881	6,928	5,058	**19,091**	18,000
1981	1,942	2,950	4,899	3,637	**13,428**	16,000
1982	1,695	4,492	7,147	1,463	**14,797**	10,000
1983	2,225	3,449	4,141	1,410	**11,225**	10,000
1984	824	4,720	3,925	1,006	**10,475**	10,000
1985	295	10,066	1,897	2,118	**14,376**	10,000
1986	337	16,298	2,655	2,127	**21,417**	17,000
1987	993	10,491	4,320	772	**16,576**	30,600
1988	552	1,350	13,789	2,453	**18,144**	30,600
1989	350	1,016	7,033	9,288	**17,687**	37,000
1990	322	4,178	7,434	5,203	**17,137**	35,000
1991	521	6,941	2,494	16,425	**26,381**	35,000
1992	787	4,146	1,392	8,898	**15,223**	35,000
1993	910	2,233	1,021	11,224	**15,389**	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	**15,131**	20,000
2004	712	252	6,162	7,574	**14,700**	20,000
2005	1,137	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	**20,742**	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	**20,470**	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	**19,419**	20,000
2016	3,195	14,253	2,211	273	**19,933**	20,000
2017	2,842	9,727	2,102	767	**15,438**	20,000
2018	1,566	4,360	607	885	**7,419**	20,000
2019	4,512	7,642	3,181	470	**15,806**	20,000
2020	3,053	921	618	271	**4,862**	20,000
2021	703	807	2,595	26	**4,131**	20,000
MEAN (1973-2021)	**2,081**	**4,807**	**4,465**	**4,175**	**15,528**	-

Table 2. Annual landings (t) of herring in NAFO division 4R per gear type in NAFO Division 4R from 1973 to 2021. Data for 2019, 2020 and 2021 are preliminary.

YEAR	Fishing gear						TOTAL
	Large seine	Small seine	Gillnet	Tuck seine	Trap	Other	
1973	20,068	0	6,616	0	0	0	**26,684**
1974	4,732	0	2,711	0	0	0	**7,443**
1975	3,495	0	2,232	0	0	0	**5,727**
1976	8,207	0	2,979	0	0	0	**11,186**
1977	9,728	0	3,451	0	0	0	**13,179**
1978	9,925	0	5,536	0	0	0	**15,461**
1979	10,239	0	8,215	0	0	0	**18,454**
1980	9,634	0	9,457	0	0	0	**19,091**
1981	7,925	0	5,503	0	0	0	**13,428**
1982	9,548	0	5,249	0	0	0	**14,797**
1983	7,278	0	3,947	0	0	0	**11,225**
1984	7,204	0	3,271	0	0	0	**10,475**
1985	13,171	0	1,205	0	0	0	**14,376**
1986	19,270	0	2,147	0	0	0	**21,417**
1987	13,733	0	2,843	0	0	0	**16,576**
1988	16,353	0	1,791	0	0	0	**18,144**
1989	16,660	0	1,027	0	0	0	**17,687**
1990	16,301	0	836	0	0	0	**17,137**
1991	25,598	0	783	0	0	0	**26,381**
1992	10,278	4,391	554	0	0	0	**15,223**
1993	11,822	3,254	190	0	111	13	**15,389**
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	4,219	0	233	4	**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	96	**13,224**
2002	8,392	3,383	1,256	0	73	13	**13,117**
2003	11,090	2,307	1,629	0	104	0	**15,131**
2004	11,099	2,973	499	0	127	2	**14,700**
2005	11,006	3,918	1,031	909	528	535	**17,927**
2006	11,102	3,942	703	2,300	498	53	**18,597**
2007	10,954	2,660	132	1,545	706	8	**16,005**
2008	11,184	4,357	3	4,498	700	0	**20,742**
2009	11,170	4,415	0	3,778	872	0	**20,235**
2010	10,217	4,950	525	2,953	560	0	**19,205**
2011	10,259	5,428	2,107	1,883	626	167	**20,470**
2012	10,047	5,171	1,790	1,342	862	138	**19,351**
2013	9,986	4,905	915	2,337	1,230	0	**19,374**
2014	9,994	5,504	96	1,075	1,440	43	**18,152**
2015	11,167	4,470	680	2,029	928	143	**19,419**
2016	10,999	4,397	623	2,593	1,133	188	**19,933**
2017	9,628	3,313	547	1,167	746	37	**15,438**
2018	4,077	966	512	1,440	425	0	**7,419**
2019	7,676	3,758	681	3,402	289	0	**15,806**
2020	1,197	1,289	117	2,074	185	0	**4,862**
2021	2,844	283	33	801	170	0	**4,131**
MEAN (1973-2021)	**10,292**	**3,567**	**2,008**	**2,125**	**469**	**60**	**15,528**

Table 3. Annual landings (t) of herring in NAFO unit area 4Sw per gear type from 1985 to 2021, along with the Total Allowable Catch (TAC) for division 4S. Note that from 2019 to 2021, the 4,500 t TAC includes a maximum of 4,000 t in unit area 4Sw and an additional 500 t in other unit areas (4Sivxyz), to encourage fishing outside 4Sw once the 4,000 t is reached. Data for 2019, 2020 and 2021 are preliminary.

YEAR	4Sw							TAC
	Large seine	Small seine	Gillnet	Tuck seine	Trap	Other	Total	
1985	0	0	114	0	0	0	**114**	1,000
1986	0	0	191	0	6	1	**198**	1,000
1987	0	0	92	0	0	2	**94**	1,000
1988	0	11	35	0	0	0	**46**	1,000
1989	0	0	194	0	0	0	**194**	1,000
1990	0	0	39	0	0	0	**39**	1,000
1991	0	0	34	0	0	16	**50**	1,000
1992	0	0	70	0	0	0	**70**	4,000
1993	0	4	31	0	0	0	**34**	4,000
1994	0	0	139	0	0	0	**139**	4,000
1995	0	0	131	0	0	0	**131**	4,000
1996	0	0	164	0	0	0	**164**	4,000
1997	0	44	23	0	0	1	**69**	4,000
1998	0	0	42	0	13	0	**55**	4,000
1999	0	0	5	0	6	0	**10**	4,000
2000	0	0	20	0	43	0	**63**	4,000
2001	0	0	124	0	0	0	**124**	4,000
2002	0	0	50	0	32	0	**82**	4,000
2003	0	0	16	0	0	0	**16**	4,000
2004	0	0	24	0	0	0	**24**	4,000
2005	0	7	89	0	254	0	**351**	4,000
2006	0	22	24	0	5	0	**50**	4,000
2007	0	0	29	0	24	0	**53**	4,000
2008	0	4	41	0	307	20	**371**	4,000
2009	0	102	96	0	853	0	**1,051**	4,000
2010	0	79	77	0	259	0	**415**	4,000
2011	0	2,112	6	0	681	0	**2,799**	4,000
2012	0	2,771	30	0	1,576	0	**4,378**	4,000
2013	0	3,361	117	0	561	0	**4,038**	4,000
2014	0	2,445	80	0	760	0	**3,284**	4,000
2015	0	3,563	0	0	369	0	**3,932**	4,000
2016	0	3,981	0	0	39	0	**4,021**	4,000
2017	0	3,094	0	0	42	0	**3,136**	4,000
2018	0	2,468	0	0	37	0	**2,505**	4,000
2019	0	2,036	0	0	224	0	**2,259**	4,500
2020	0	1,393	0	0	89	0	**1482**	4,500
2021	0	589	30	0	40	0	**659**	4,500
MEAN (1985-2021)	**0**	**759**	**58**	**0**	**168**	**1**	**987**	**-**

Table 4. Number of strata (n_k) assigned per aggregation level and corresponding cumulative landings (W_k, in t) and percentage of total.

Level	**Number of strata**		**Combined landings**	
	$\boldsymbol{n_k}$ **(cumul.)**	**%** $\boldsymbol{n_k}$ **(cumul.)**	$\boldsymbol{W_k}$ **(cumul.)**	**%** $\boldsymbol{W_k}$ **(cumul.)**
1	526 (526)	0.204 (0.204)	513,794 (513,794)	0.65 (0.65)
2	211 (737)	0.082 (0.286)	54,327 (568,121)	0.069 (0.719)
3	370 (1,107)	0.144 (0.43)	79,277 (647,398)	0.1 (0.82)
4	142 (1,249)	0.055 (0.485)	15,848 (663,246)	0.02 (0.84)
5	422 (1,671)	0.164 (0.649)	42,331 (705,577)	0.054 (0.893)
6	180 (1,851)	0.07 (0.719)	26,512 (732,089)	0.034 (0.927)
7	74 (1,925)	0.029 (0.747)	9,833 (741,923)	0.012 (0.939)
8	122 (2,047)	0.047 (0.795)	14,061 (755,984)	0.018 (0.957)
9	49 (2,096)	0.019 (0.814)	4,993 (760,977)	0.006 (0.963)
10	144 (2,240)	0.056 (0.87)	5,328 (766,305)	0.007 (0.97)
11	179 (2,419)	0.069 (0.939)	18,315 (784,620)	0.023 (0.993)
12	46 (2,465)	0.018 (0.957)	2,633 (787,253)	0.003 (0.997)
13	62 (2,527)	0.024 (0.981)	1,828 (789,082)	0.002 (0.999)
14	49 (2,576)	0.019 (1)	870 (789,952)	0.001 (1)

FIGURES

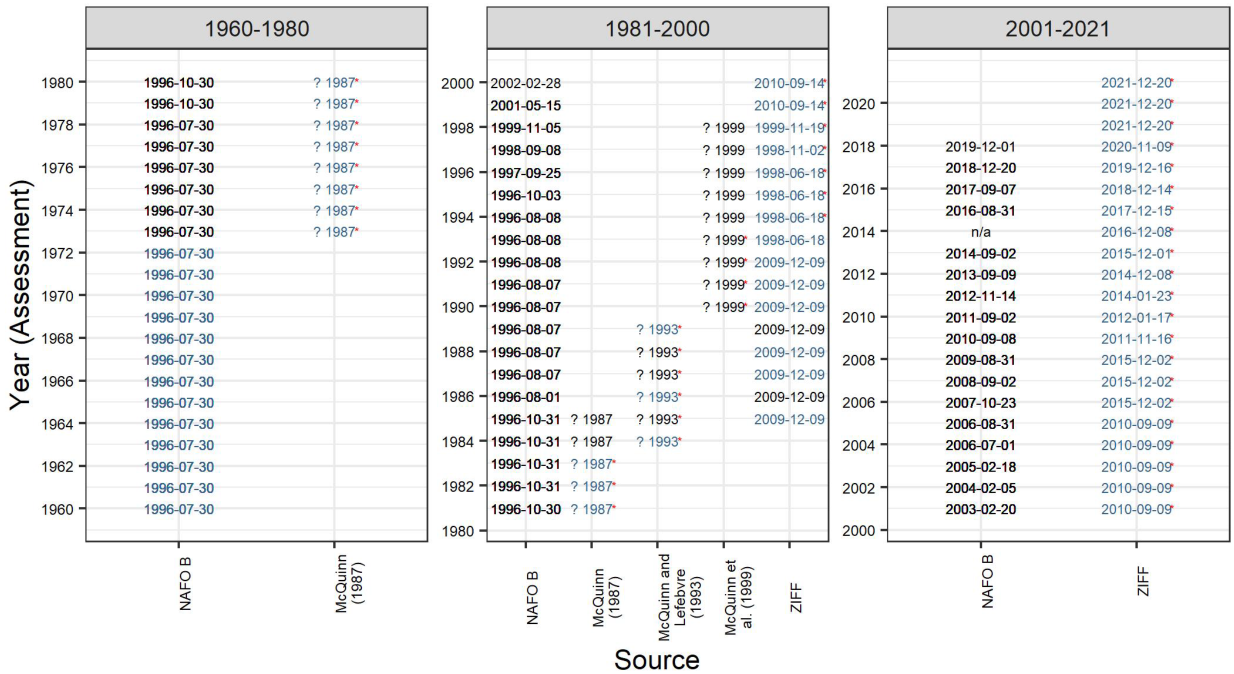

Figure 1. Dates of the most recent modifications for each landings dataset and assessment year over the 1960-2021 period. Data sources used in the present revision are shown in blue. Sources believed to have been used in the original assessment (based on point-by-point comparisons with Table 2 of Émond et al. (2024)) are marked with a red asterisk. A '?' symbol indicates missing values for the date and/or month variables.

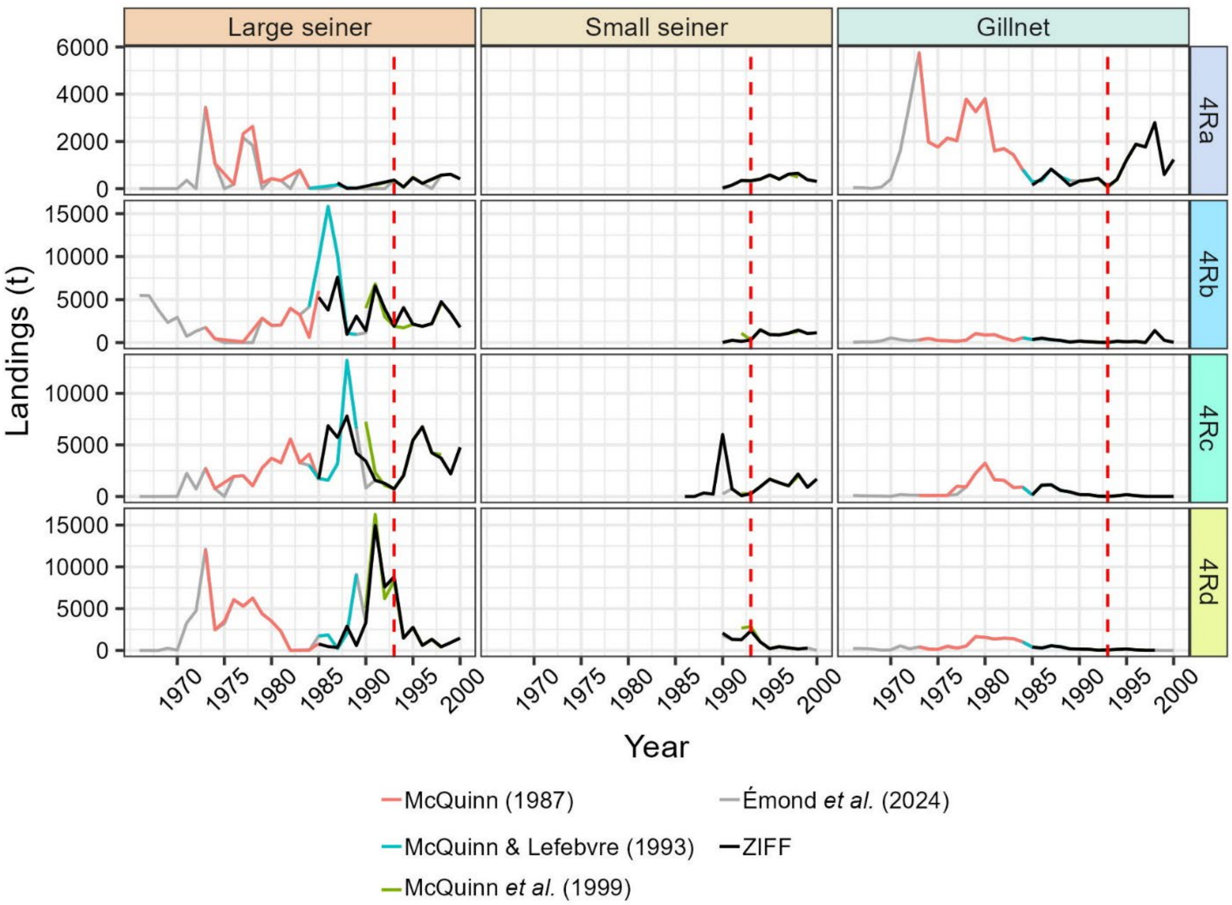

Figure 2. Comparison of total landings by gear type and NAFO unit area between three historical DFO documents (McQuinn 1987, McQuinn and Lefebvre 1993; McQuinn et al. 1999), the last published assessment report (Émond et al. 2024) and ZIFF data files extracted on December 19, 2022 in NAFO division 4R over the common period 1970-2000. The red dotted vertical line at year 1993 indicates the year in which the landings in Émond et al. (2024) began matching the corresponding ZIFF.

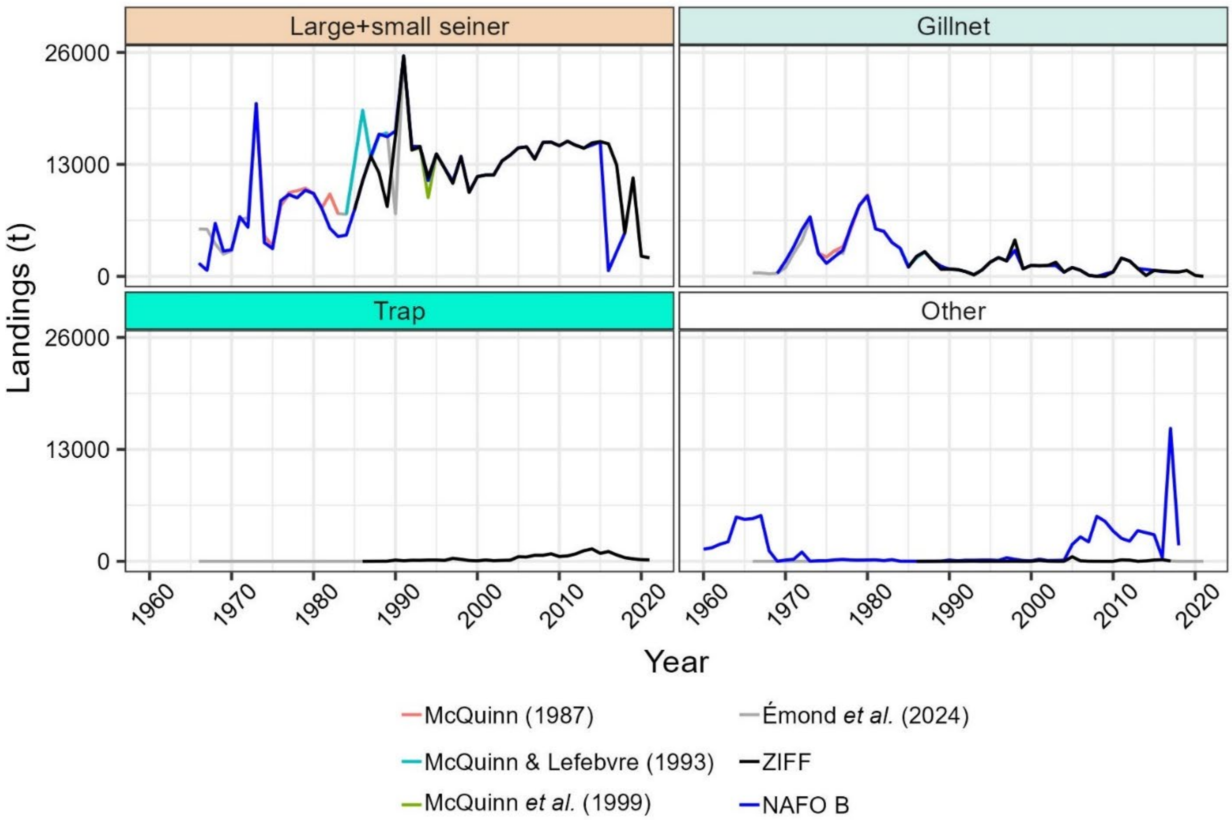

Figure 3. Comparison of total annual landings by gear type between three historical DFO documents (McQuinn 1987, McQuinn and Lefebvre 1993, McQuinn et al. 1999), the last published assessment report (Émond et al. 2024), ZIFF data files extracted on December 19, 2022 and NAFO B data extracted on December 22, 2022 in NAFO division 4R. Landings for purse seiners in DFO research documents and the ZIFF dataset were aggregated across vessels larger and smaller than 65 feet because information on vessel length was not available in the NAFO B database (i.e. large and small seiners were presumably combined).

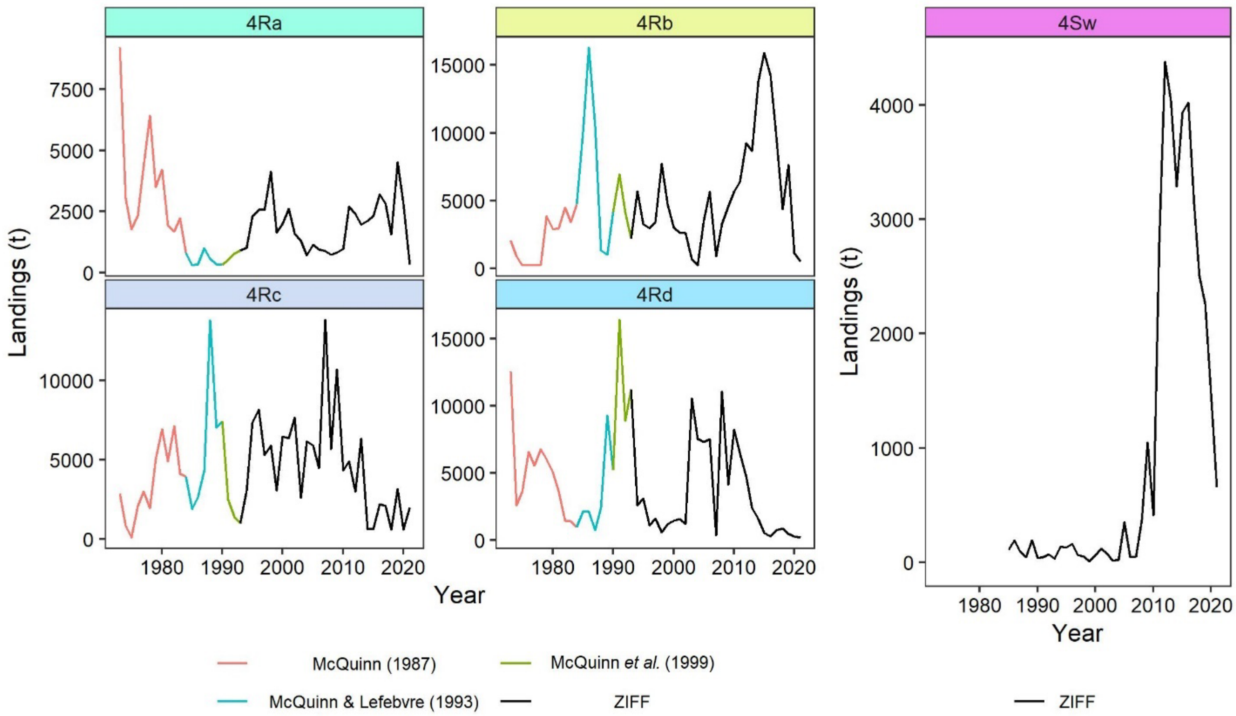

Figure 4. Data sources employed for the development of continuous landings series in NAFO divisions 4RSw over the 1973-2021 period. Landings in each year and NAFO unit area are combined across gear types and months.

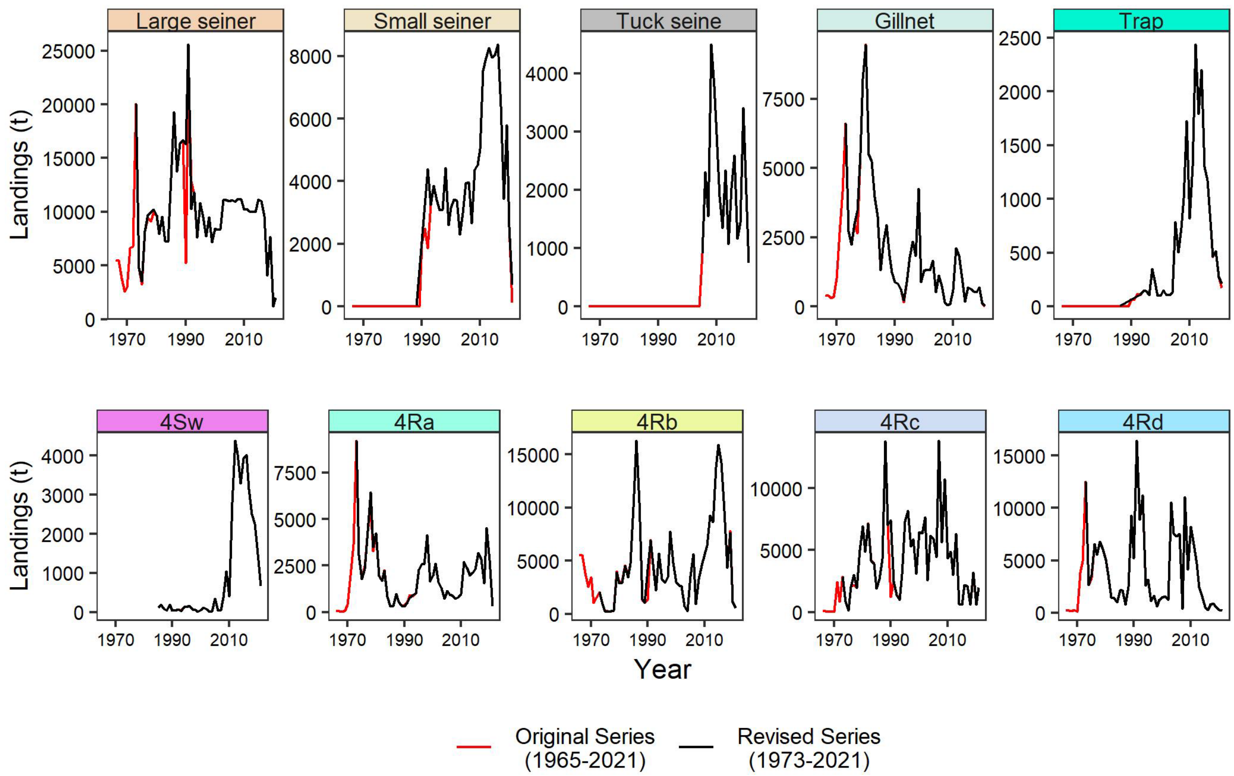

Figure 5. Trends in the total landings by gear type (excluded category: other) and NAFO unit area for herring in NAFO divisions 4RSw according to the original series over 1965-2021 (source: Table 2 in Émond et al. 2024) and the revised series over 1973-2021 (sources: see Figure 4). Note that some of the original data sources employed to construct the Émond et al. (2024) series are unknown for the period from 1966 to 1973.

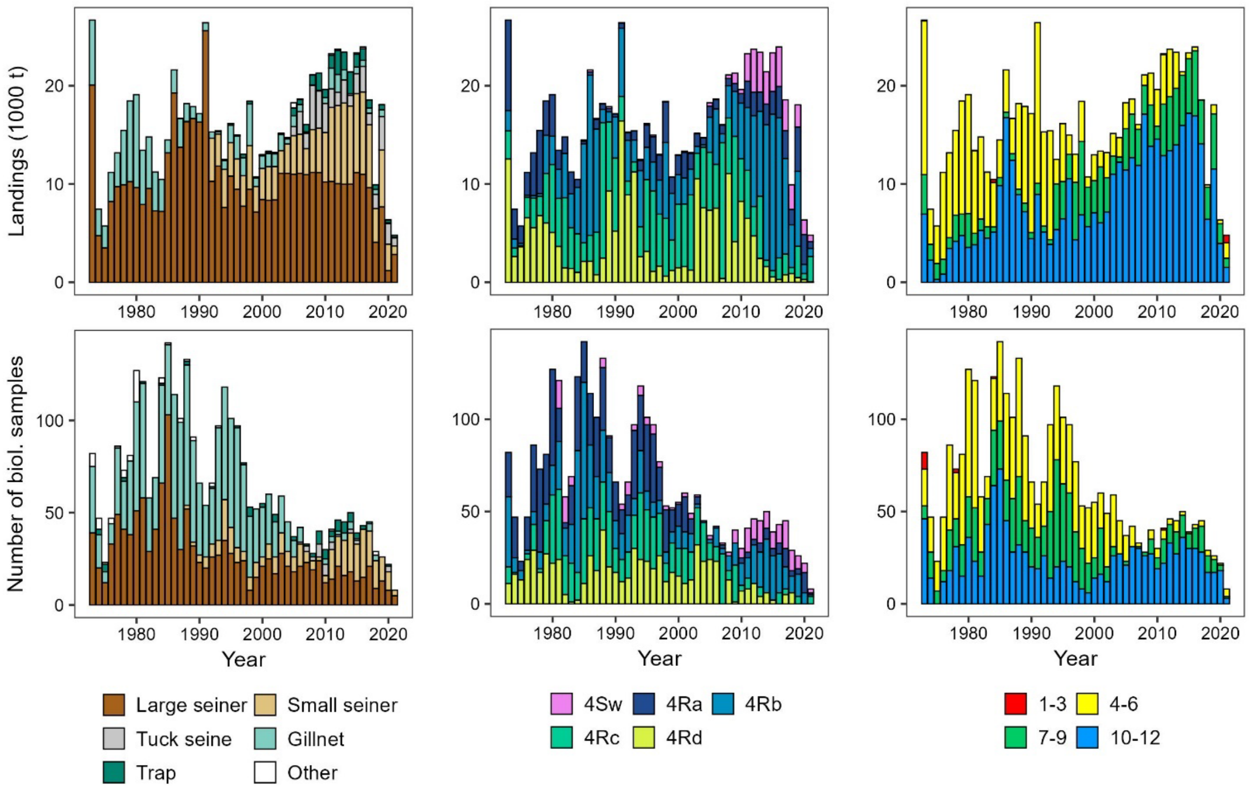

Figure 6. Trends in the total landings recorded in the various databases (top row; see Figure 4 for sources by year) and numbers of biological samples available to the catch-at-age algorithm (bottom row: number of distinct samples of 30 individuals or more), categorized by gear type, NAFO unit area and three-month period (i.e. quarter).

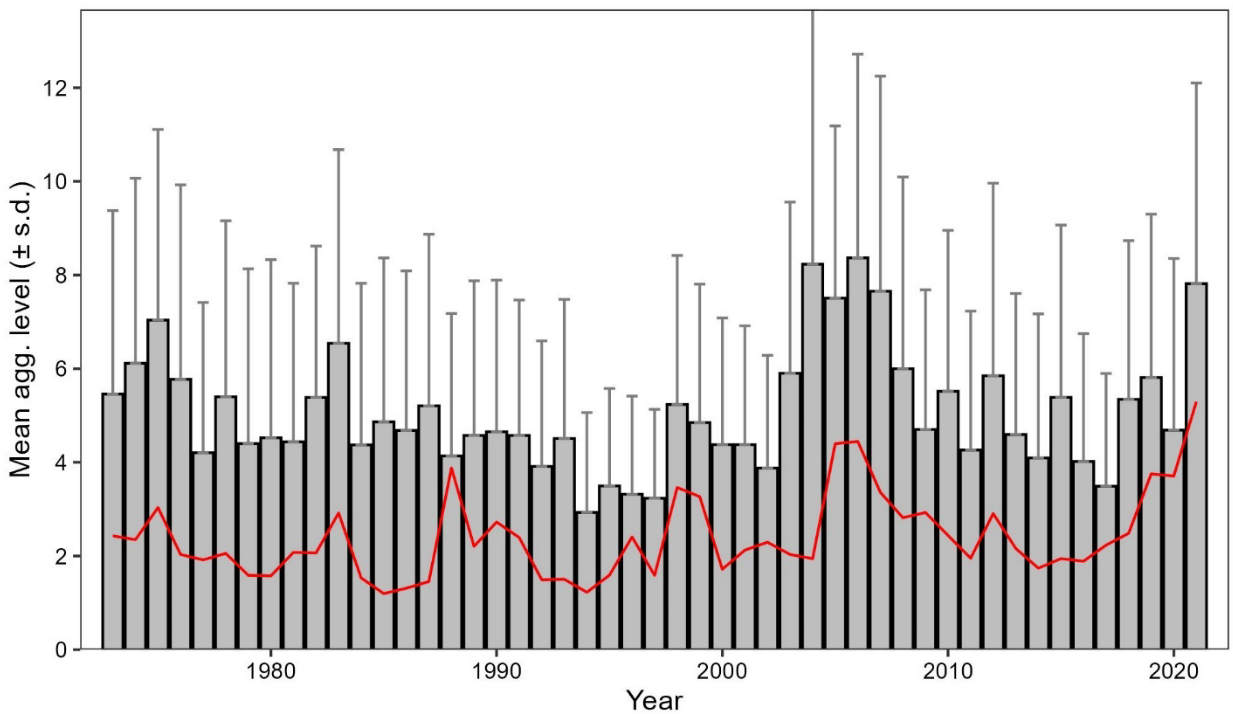

Figure 7. Trends over time in the mean aggregation levels of the samples assigned to each stratum k and year, with their associated standard deviations (1973 to 2021). The red line shows the mean aggregation level weighted by the magnitude of the landings that they intend to represent (i.e. landings in each stratum, W_k).

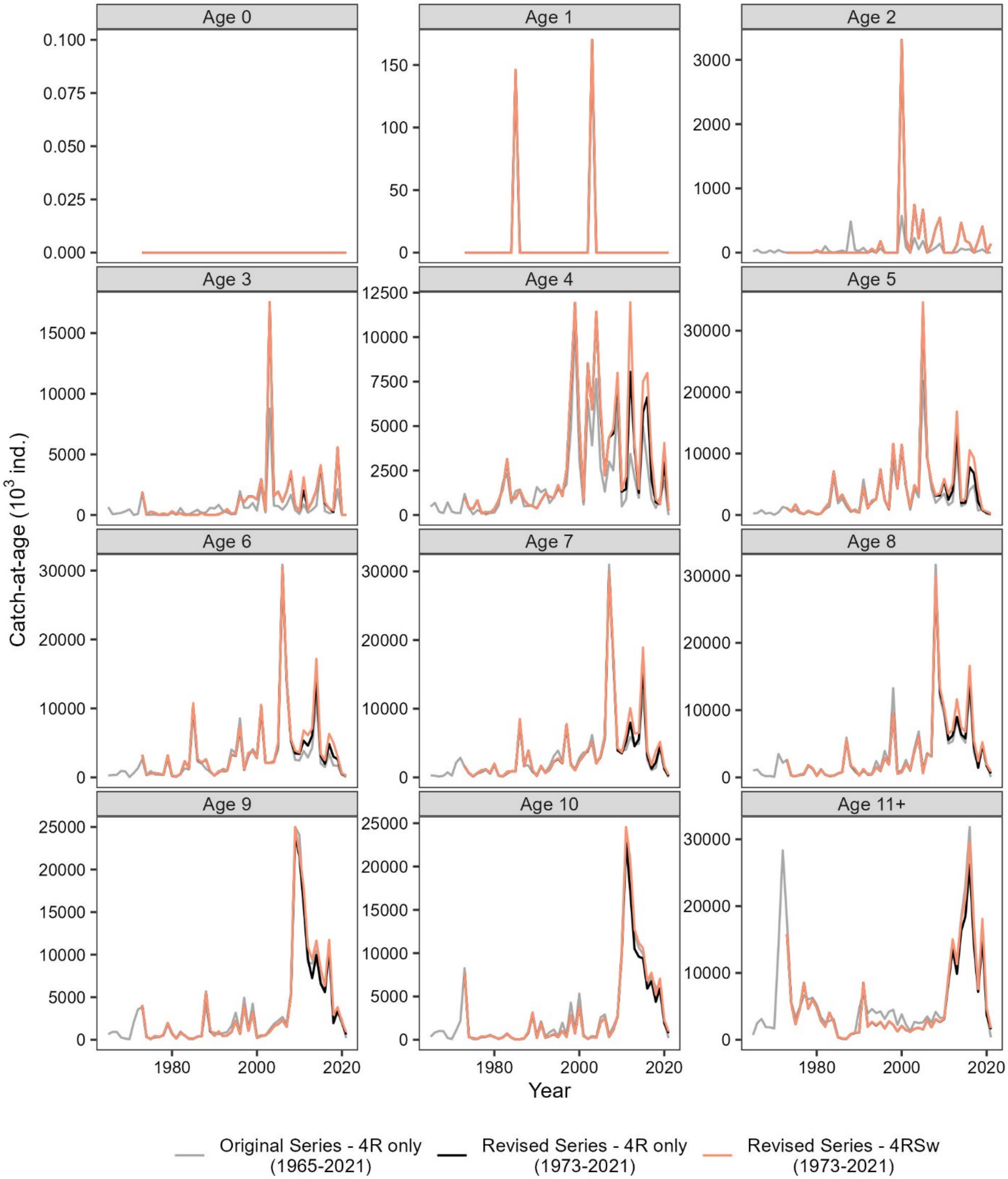

Figure 8. Comparison of catch-at-age estimates between the original approach (Émond et al. 2024) and the revised method presented in this document, by age group, for fall-spawning herring in NAFO division 4R or 4RSw over the period from 1965 to 2021. Note that only the years from 1973 onward were included in the revision.

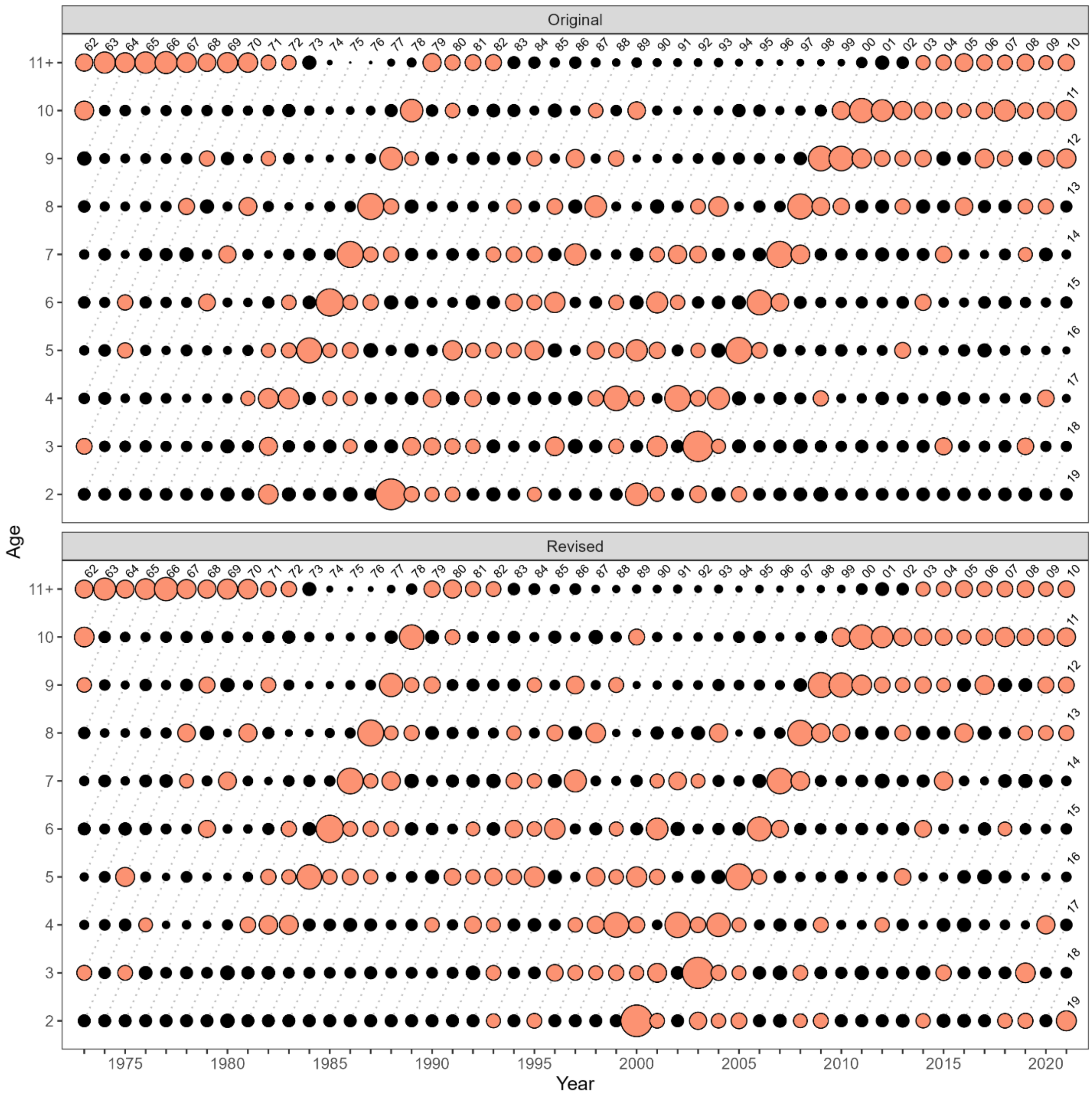

Figure 9. Standardized proportions at age and year (SPAY) from the original approach (Émond et al. 2024) and the revised method presented in this document for fall-spawning herring in NAFO division 4R over the period from 1973 to 2021. Red and black bubbles indicate above- and below-average values, respectively. Bubble size reflects the SPAY value. Cohort years (last two digits) are displayed above bubbles for the oldest ages and for those in the most recent year.

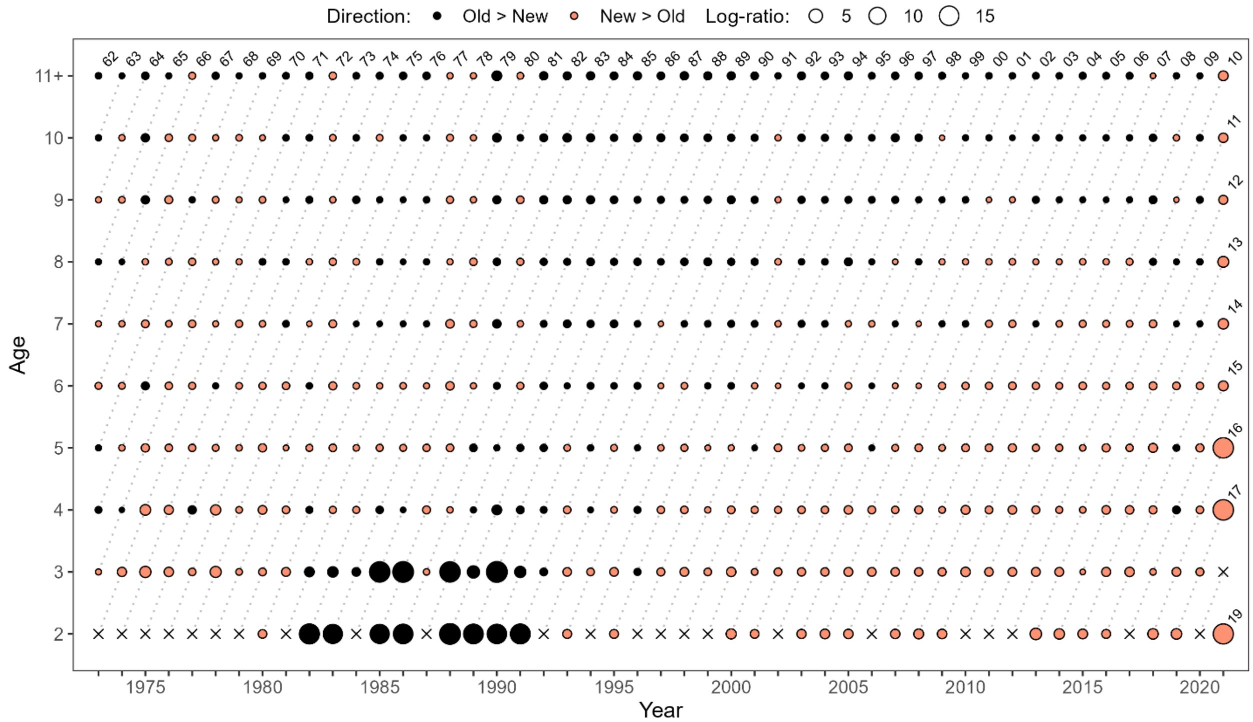

Figure 10. Differences in catch-at-age between the original approach (Émond et al. 2024) and the revised method presented in this document for fall-spawning herring in NAFO Division 4R (1973-2021). Log-ratios (log[new/old]) are represented by bubble size and color: red for positive and black for negative differences. An 'x' indicates cases with no difference. Cohort years (last two digits) are displayed above bubbles for the oldest ages and for those in the most recent year.

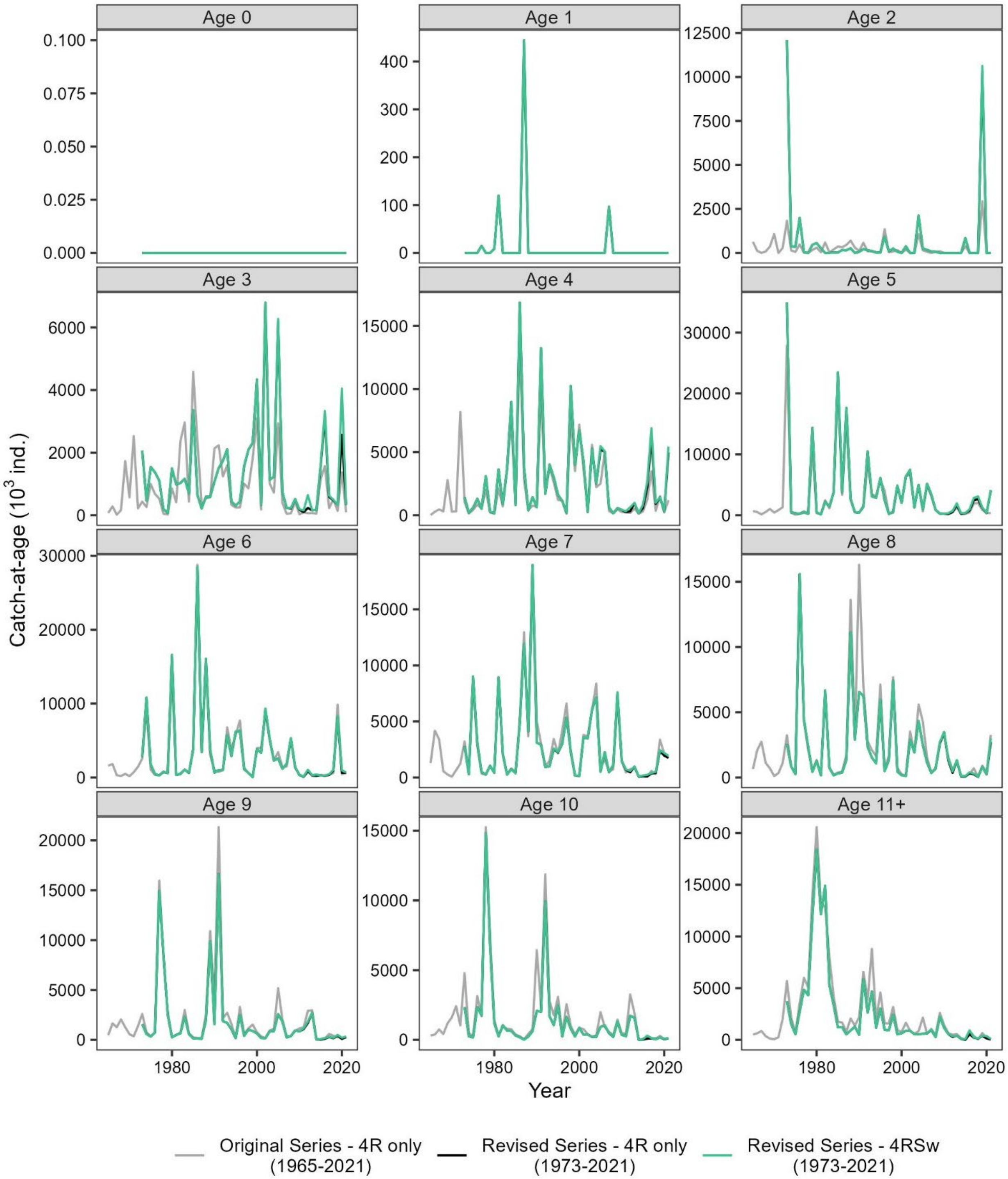

Figure 11. Comparison of catch-at-age estimates between the original approach (Émond et al. 2024) and the revised method presented in this document, by age group, for spring-spawning herring in NAFO division 4R or 4RSw over the period from 1965 to 2021. Note that only the years from 1973 onward were included in the revision.

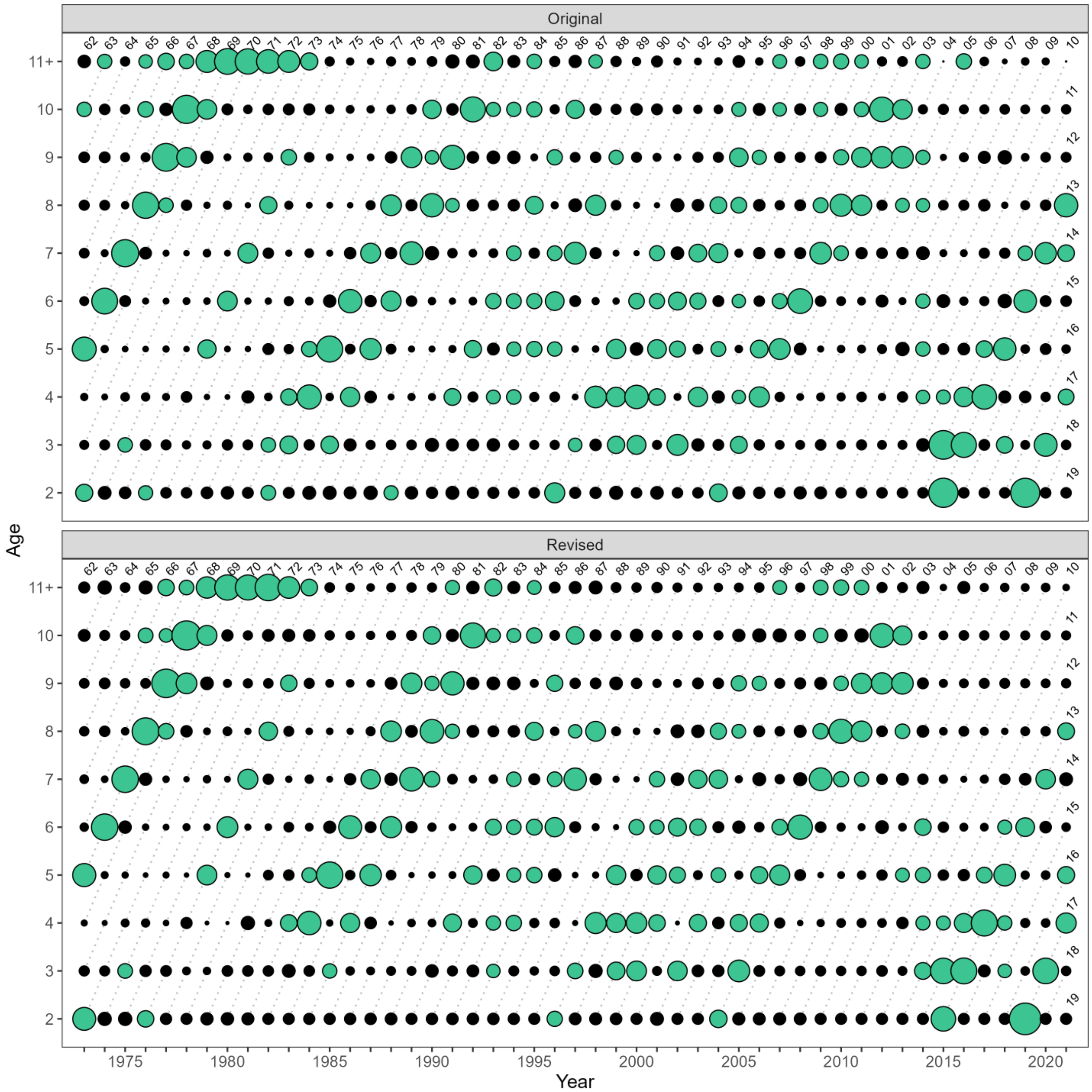

Figure 12. Standardized proportions at age and year (SPAY) from the original approach (Émond et al. 2024) and the revised method presented in this document for spring-spawning herring in NAFO division 4R over the period from 1973 to 2021. Red and black bubbles indicate above- and below-average values, respectively. Bubble size reflects the SPAY value. Cohort years (last two digits) are displayed above bubbles for the oldest ages and for those in the most recent year.

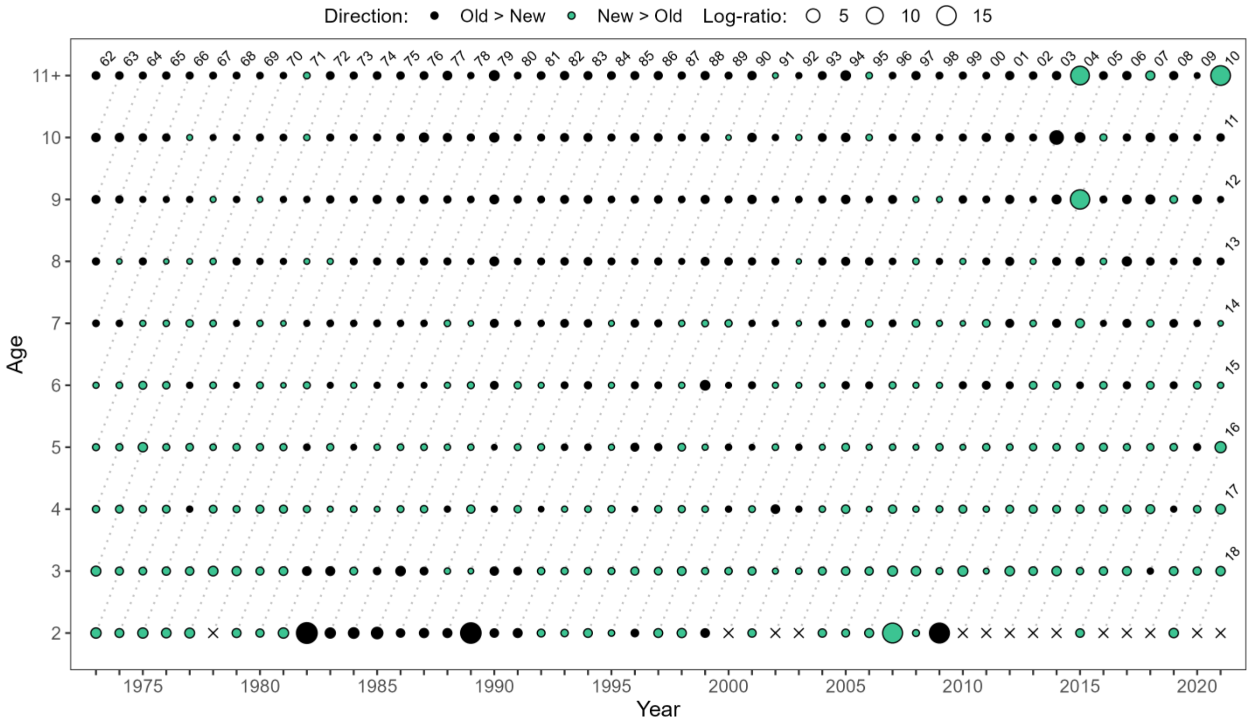

Figure 13. Differences in catch-at-age between the original approach (Émond et al. 2024) and the revised method presented in this document for spring-spawning herring in NAFO Division 4R (1973-2021). Log-ratios (log[new/old]) are represented by bubble size and color: red for positive and black for negative differences. An 'x' indicates cases with no difference. Cohort years (last two digits) are displayed above bubbles for the oldest ages and for those in the most recent year.

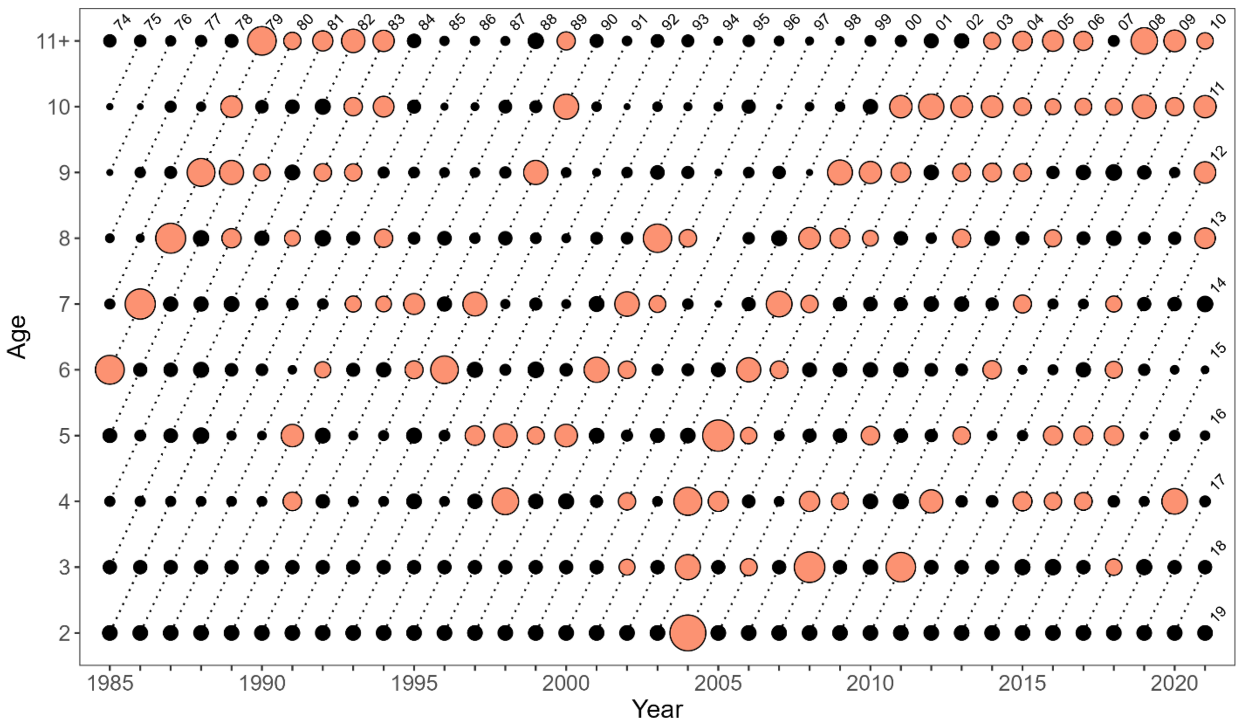

Figure 14. Standardized proportions at age and year (SPAY) the revised method presented in this document for fall-spawning herring in NAFO unit area 4Sw over the period from 1985 to 2021. Red and black bubbles indicate above- and below-average values, respectively. Bubble size reflects the SPAY value. Cohort years (last two digits) are displayed above bubbles for the oldest ages and for those in the most recent year.

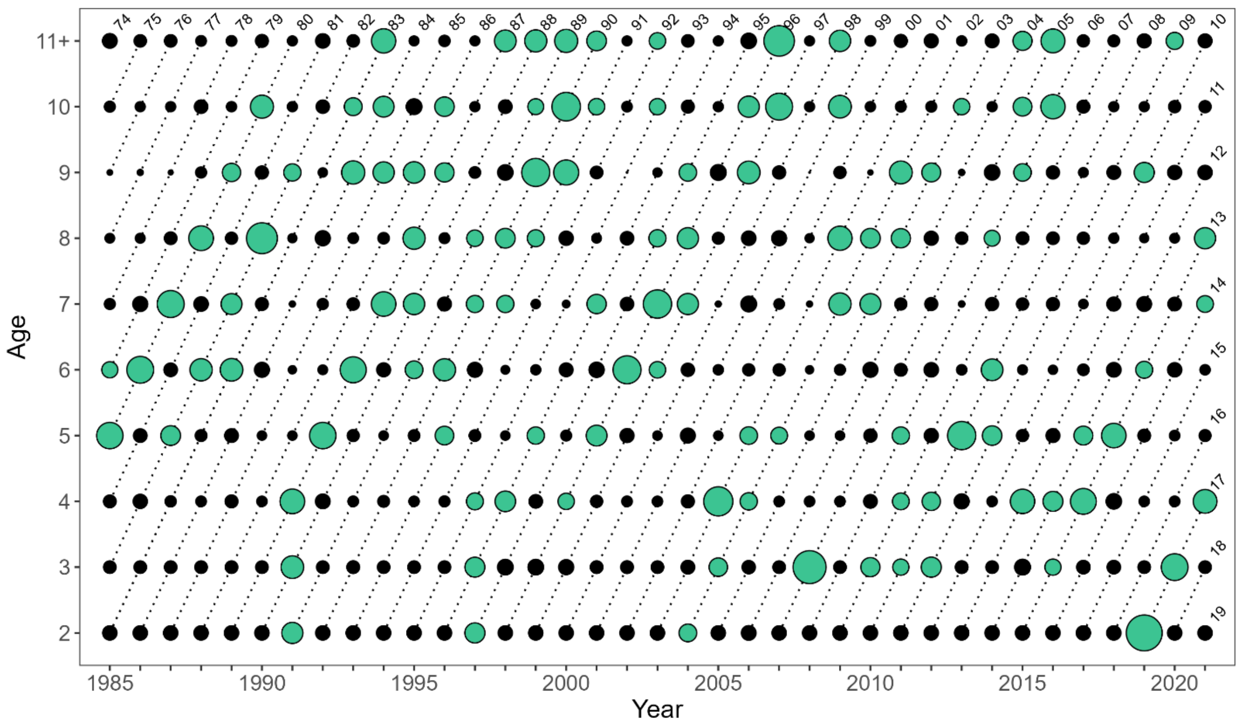

Figure 15. Standardized proportions at age and year (SPAY) the revised method presented in this document for spring-spawning herring in NAFO unit area 4Sw over the period from 1985 to 2021. Red and black bubbles indicate above- and below-average values, respectively. Bubble size reflects the SPAY value. Cohort years (last two digits) are displayed above bubbles for the oldest ages and for those in the most recent year.

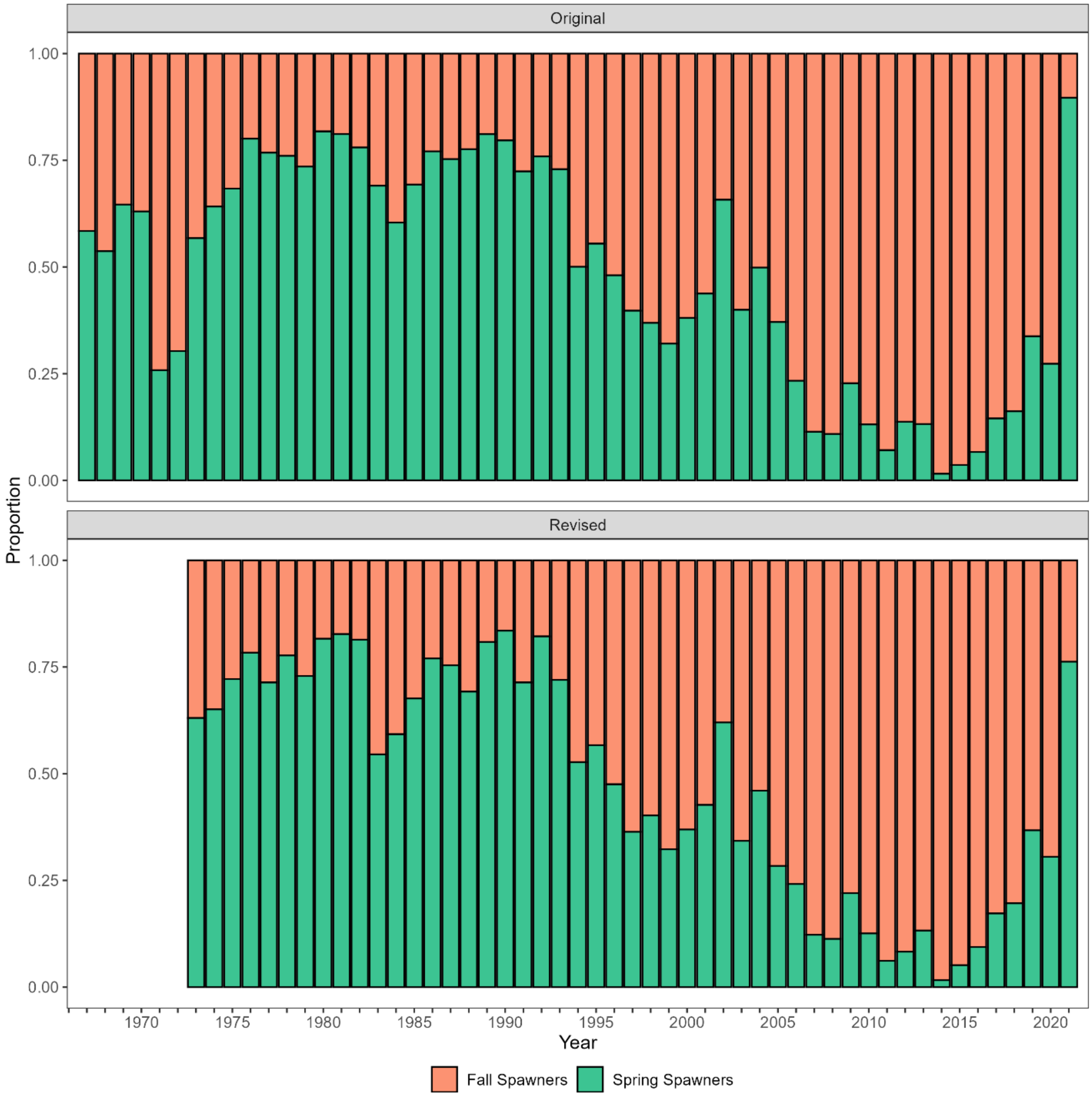

Figure 16. Estimated proportions of each spawning component in the catch-at-age for NAFO division 4R over the period from 1965 to 2021 (top panel: original series) or from 1973 to 2021 (bottom panel: revised series, subsetted for division 4R only).

APPENDIX

Table A1. Herring landings (t) from bycatch or less frequently employed fishing gear ('other' category, see Tables 2 and 3) in NAFO Divisions 4RSw from 1985 to 2021. Data for 2019, 2020 and 2021 are preliminary.

YEAR	Other gear								
	Bottom otter trawl	Midwater trawl	Shrimp trawl	Beach seine	Longline	Jigger	Hand line	Pot	Japanese trap
1985	0	0	0	0	0	0	0	0	0
1986	0.14	0	0	0.05	0.40	0	0	0	0
1987	0	0	0	0	0.93	0	0	0	0.54
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0
1991	0	0	0	1.15	2.71	2.65	10.77	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	13.06	0	0	0	0	0
1994	0	0.23	0	0	0	0	0.70	0	0
1995	0	0	0	0.17	0	0.06	1.82	0	0
1996	0	0	0	0	0	0	0.03	0.98	0
1997	0	0	0	1.63	1.31	0	1.85	0	0
1998	0	0.43	0	0	0.15	0	3.61	0	0
1999	0.13	0	0	0	0	0	0	0	0
2000	0.01	0	0	0	0.02	0	0	0	0
2001	0.08	0	0	96.37	0	0	0.01	0	0
2002	0.11	0	0	12.72	0.10	0	0	0	0
2003	0.04	0	0	0	0	0	0	0	0
2004	0	0	0	1.81	0	0	0.09	0	0
2005	0	0	0	529.55	0	0	5.47	0	0
2006	0	0	0	52.82	0	0	0.06	0	0
2007	0	0	0	8.05	0	0	0.03	0	0
2008	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0.02	0	0
2011	0	0	0	166.51	0.13	0	0.44	0	0
2012	0	0	0	133.79	3.74	0	0	0	0
2013	0	0	0	0	0	0	0	0	0
2014	0	0	0	39.39	3.62	0	0	0	0
2015	0	0	0	143.43	0	0	0	0	0
2016	0	0	0	187.52	0	0	0	0	0
2017	0	0	0	37.29	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	0
2019	0	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0

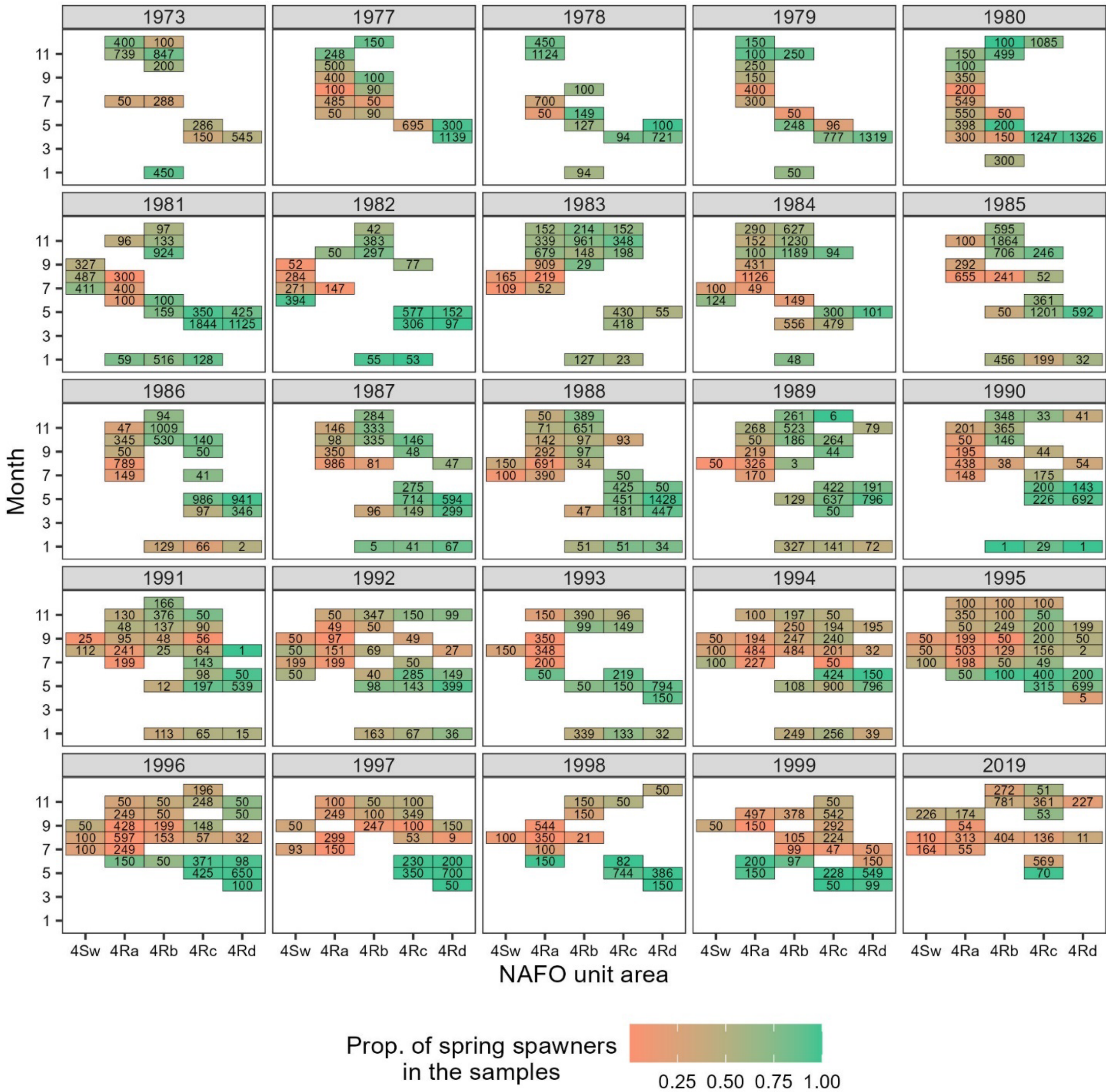

Figure A1. Relative importance of each spawning component in the biological samples collected in the twenty-five years associated with the highest total sampling (here, the years with ≥ 61 distinct samples). The numbers in the center of each tile give the total number of individuals (fall and spring spawners combined) represented by these proportions.