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Revision of Catch- and Maturity- at Age Used to Assess the Northern Contingent of Atlantic Mackerel (*Scomber scombrus*)

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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

Catch- and maturity-at-age are two essential input matrices into the West-Atlantic mackerel stock assessment model. Here, we revise both estimation algorithms and provide a comparison with previously presented outcomes. Although the new matrices differed most notably from the old ones for the younger ages (1 and 2), the overall patterns were highly similar and thus resulted in the same perception of the stock's dynamics. The new methods were however preferred as they guarantee full interannual comparability, and in addition have several other desirable properties (flexibility, transparency, etc.). The 2023 final assessment model was run with the new input data presented in this document.

INTRODUCTION

Canada has provided assessments of West-Atlantic mackerel (*Scomber scombrus*) for about four decades (e.g., Maguire 1979). The types of input data used to determine stock state have however remained largely unchanged (an egg survey index, catch-at-age, commercial landings and biological information). Since the assessment became focussed on the northern contingent rather than the entire stock unit in 2001 (Grégoire et al. 2001), values of the input matrices or vectors have only rarely been modified. Even if (minor) changes in methodology or software were made, new values were typically computed only for the most recent years and merged with the existing time-series. The goal of this document is to review and update the catch-at-age and maturity-at-age matrices, to ensure methodological consistency between years, as well as transparency and reproducibility. Other input data are reviewed and updated in separate research documents (weight-at-age and fecundity-at-age, Boudreau et al.[1]; egg survey index, Lehoux et al.[2]).

The catch-at-age (CAA) time-series integrated into assessments of northern contingent mackerel prior to and including 2021 (Smith et al. 2022) spanned the period from 1968 to the terminal assessment year. For each assessment, the existing series was generally padded with new numbers for the most recent years (see Figure S1). Although terminal year landings are usually preliminary, and catch-at-age for these years should therefore ideally be re-estimated during the subsequent assessment, this was often not done (Figure S1). Updating CAA over a shifting window also generates additional challenges. For instance, the methods and data used to generate the early estimates are, to our knowledge, lost (e.g., from Maguire 1980). The CATCH software used since at least the 2012 stock assessment (Grégoire et al. 2013) also has several drawbacks, most of which are related to methodological transparency (applied algorithm unknown) and flexibility (possibility to perform sensitivity analyses or add improvements), as well as reproducibility (see Ouellette-Plante et al. 2022). During the last two assessments (Smith et al. 2020, 2022), R code was used to distribute landings over age, but again only for the most recent period (2015-2020).

The matrix of annual maturity-at-age (MAA) has likewise remained largely unchanged over at least the last decade (Figure S2). Different biologists applied different rules to define outliers, used different software (e.g., SAS by Grégoire and Beaudin (2014) vs R in more recent assessments), and it is unclear what underlying data was used (e.g., potential subsetting in terms of NAFO region and gear type). The second goal of the present analysis is therefore the re-estimate the full series.

Results were presented and reviewed during the 2023 stock assessment (Van Beveren et al. 2023).

[1] Boudreau et al. In preparation. Calculation of stock weight- and fecundity-at-age during the spawning season used to assess the northern contingent of Atlantic Mackerel (*Scomber scombrus*). DFO Can. Sci. Advis. Sec. Res. Doc.

[2] Lehoux et al. In preparation. Results of the mackerel (*Scomber scombrus* L.) egg surveys conducted in the southern Gulf of St. Lawrence from 1979 to 2022. DFO Can. Sci. Advis. Sec. Res. Doc.

METHODS

Code to conduct the stock assessment (input data calculation, modelling) was made available online (see iml-mackerel · GitHub).

CATCH-AT-AGE

Data

Landings

Landings data from 1968-1994 were downloaded from the NAFO landings database (STATLANT 21B) and data from 1995 to 2022 were from the most recent ZIFF files (Zonal Interchange File Format) produced by DFO's regional statistics bureaus. For 2022, recorded landings were supplemented with the landings associated with sample collection (using S52 fishing licenses, see Van Beveren et al. 2023).

Samples

Fisheries and Oceans Canada has a systematic port sampling program that was designed specifically to estimate the catch composition of commercial landings. For mackerel, it is also the most important source of data to determine biological characteristics.

Each year, a request is submitted for a certain number of samples per region, period and gear type (referred to as a stratum), in function of the expected importance of that stratum in terms of total landings. For mackerel, a sample consists of about 150 randomly selected fish of which the fork length (measured to the nearest 0.5 cm) is measured. A length-stratified subsample (two fish per length bin) is usually sent to the Maurice Lamontagne Institute (IML) for the determination of age (standardized to January 1st) and additional biological characteristics (e.g., weight; ± 0.1 g). Biological data (age, fish and gonad weight, etc.) from the port sampling program can be supplemented by samples collected for other purposes (e.g., specific research projects) and from other sources (e.g., research surveys, opportunistically collected small by-catch samples). The length-frequencies and biological ('bio') data are entered into two separate Oracle databases and were accessed with the DFOdata package (version 0.1.1). Note that raw length-frequency data is only available from 1976 onwards, whereas the bio database has raw information available from 1973 onwards. We were unable to retrieve older data (absent from paper archives at IML and digital databases at IML and Maritimes region, where mackerel has historically been assessed).

Details on samples collected in 2022 are given by Van Beveren et al. 2023.

Calculations

We use the specifically developed R package catchR to perform the analyses (version 0.1.1). All details on the package and applied algorithm can be found in Ouellette-Plante et al. (2022), who used it to estimate CAA for 3Pn-4RS cod.

Landings were distributed over length and age classes (1 to 10+) by year, trimester, large-scale region and gear type (see Table S1; identical to prior assessments), the combination of which is referred to as a stratum (*k*). Specifically, landings were totaled per stratum and samples were attributed to strata as defined in Table S1, before all data was fed to the catchR automated algorithm for sample attribution. The get.samples function uses a decision scheme comprising 12 aggregation levels g_k, where option one corresponds to the stratum level (i.e., there is a perfect match between the sample and the catch) and the remaining options represent the landings progressively less;

$$g_k = \begin{cases} 1 \ = year + period + region + gear & (if\ N \geq 2, else\ \downarrow) \\ 2 \ = year + neighboring\ periods + region + gear & (if\ N \geq 2, else\ \downarrow) \\ 3 \ = year + period + gear & (if\ N \geq 2, else\ \downarrow) \\ 4 \ = \ year + neighboring\ periods + gear & (if\ N \geq 2, else\ \downarrow) \\ 5 \ = year + gear & (if\ N \geq 2, else\ \downarrow) \\ 6 \ = year & (if\ N \geq 2, else\ \downarrow) \\ 7 \ = neighboring\ years + period + area + gear & (if\ N \geq 2, else\ \downarrow) \\ 8 \ = neighboring\ years + neigboring\ periods + region + gear & (if\ N \geq 2, else\ \downarrow) \\ 9 \ = neigboring\ years + period + gear & (if\ N \geq 2, else\ \downarrow) \\ 10 = neighboring\ years + neigboring\ periods + gear & (if\ N \geq 2, else\ \downarrow) \\ 11 = neigboring\ years + period & (if\ N \geq 2, else\ \downarrow) \\ 12 = neigboring\ years & (if\ N \geq 2, else\ \downarrow) \end{cases}$$

For each stratum, we searched for at least two samples (*N)* to determine the length-frequency distribution, and likewise two samples (not necessarily subsamples of the selected length-frequencies) to determine an age-length key (arguments min.lf.samples and min.al.samples in the get.samples function). A lower limit of 12 fish was set to construct an age-length key (min.al.fish argument), so that when this number was not attained the algorithm would search for additional samples. Such a minimum threshold was necessary because of the existence of extremely small samples often collected for research purposes. Age-length samples can also be small when not all ages of a subsample could be read (e.g., because of poor otolith state). Despite the minimum of two samples to construct an age-length key, we still forced the estimation algorithm to continue looking for biological samples if there was a 75% (prob.al argument) chance that a given length in the stratum-specific length-frequency distribution is of an age not yet in the age-length key. This can occur if for instance length-frequencies were used for which no specific subsample existed, or a subsample was poorly representative of the length-frequency sample. The latter can happen if for instance not all ages of the subsample could be read. Before the start of calculations, we removed all length-frequency samples with less than 70 fish from the database (1% of all samples) as well as age-length outliers. Details on the number of samples used within the calculations are provided in Table S2 and the composition of samples by gear, region and period relative to the landings are visualized in Figure S3.

Once samples were attributed, catch-at-age was calculated using the get.caa function (equations in Ouellette-Plante et al. 2022).

To transform the total landed weight of fish by length- or age-class into numbers, the average weight of a fish of that length or age class needs to be known. Individual average fish weights associated with each length of a length-frequency sample were predicted using annual trimester-specific length-weight relationships. These were produced by fitting robust linear regressions (R-package Robust; Wang et al. 2022) on a log scale through all appropriate data in the bio database (Figure S4). Exceptionally, less than 50 datapoints were available to fit the relationship, in which case datapoints of the neighboring trimesters were added (once for a first trimester and three times for a 4^{th} trimester, across all years).

Additional runs

The CAA for 2022, estimated using the default approach, might represent an abrupt change with prior values, as both the samples (e.g., change in harvester behavior) and the pattern in landings differed substantially because of the fishery closure (e.g., most landings were from the Maritimes region). To better understand the impact of this change, we performed additional runs.

Our first goal was to gain a better appreciation of how changes in fishing period, gear and region could affect the CAA matrix. Differences in selectivity between all levels (e.g., the second versus the third trimester) are hard to determine, as we rarely have samples that only differ in one level (e.g., to compare selectivity of two different gear categories, we ideally have samples from those gears from the same period, region and year). Here, we present overall estimates of CAA for a given gear class, region or period. Specifically, we applied the above described algorithm to disaggregate the landings of each category by age, using only samples (length-frequency and biological) available for that category.

CAA of 2022 has issues because of the new approach to collect samples and the change in the distribution of landings (different dominant gear type, region and period). Although we could currently not address the potential difference in selectivity associated with the new sampling approach, it is possible to simulate a situation in which the pattern in landings remained unaltered. To do so, we averaged the landings of the last 5 years prior to the closure (2017-2021) for each stratum, and scaled those landings to the total of 2022. In this simulation, total landings of 2022 thus remain the same, but the typically important strata are again dominant. These landings were then disaggregated by age using the described algorithm.

MATURITY-AT-AGE

Maturity-at-age (MAA), or the proportion of mature fish at a given age, is used within the assessment model to convert biomass into spawning stock biomass and to link stock abundance to egg production. Calculations were based on the available biological data ("bio" database including commercial as well as any other samples, see section "port sampling program"). Outliers were excluded (data from 1974, extreme age-length combinations) as well as years with 30 fish or less of age class 1 and 2 combined. Only June-July data was used, which corresponds to the approach used in the previous assessment (Smith et al. 2020). We fitted year-specific Generalized Linear Models (GLMs) with a Bernouilli distribution and a logit link function, in which age is the numeric explanatory variable and maturity group is the binary response variable. Immature fish correspond to maturity stages 1 and 2 and mature fish correspond to maturity stages 3 to 8 (Maguire 1981). Gear type or region were not consistently significant and were therefore not further considered. The assessment is not sex-specific and therefore this factor was likewise excluded. For the early years (1968-1973) no maturity estimates are available and the average of the five subsequent years was used (1974-1979; previously the values for 1974 were applied; Grégoire and Beaudin 2014). Once a cohort reaches 100% maturity, in the absence of evidence for skip spawning, this percentage cannot decrease anymore in subsequent years and estimates indicating such a decline must be biased. The proportion of mature fish of age 5+ was therefore systematically set to 1.

The predicted MAA is noisy and therefore a cubic spline smoother (smooth.spline R function, smoothing parameter set to 0.5) was applied over each age-specific time-series, in correspondence with the last assessment. Although for other assessment model input, a mixed model was applied to reduce noise and fill in gaps (see Boudreau et al.[1]), this was not done here because 1) maturity-at-age is already the result of annual models making specific assumptions about the relationship between maturity and age and 2) the mixed model used elsewhere for smoothing currently does not have the option to apply the appropriate logit transformation to the variable of interest (rather than log). Future work might focus on combining prediction, smoothing and gap filling.

RESULTS AND DISCUSSION

CATCH-AT-AGE

Quality

The quality of age decomposition of the given landings, assuming biological measurements (e.g., age determination) are precise, is determined by the number as well as the appropriateness of the length-frequency and biological samples used to characterize the catch of all individual strata. The catchR algorithm uses a multi-step hierarchical approach that starts by searching for samples that match the catch stratum perfectly (step 1), but that if insufficient samples are available will search for consecutively less suitable samples, if necessary up to the point where all samples of a given year are considered (step 6). For mackerel, the catch of the majority of strata is diffused into length- or age classes based on samples from the appropriate gear type and trimester, but are not region-specific (Figure S5). Because there are frequently no stratum-specific samples, many samples from a higher aggregation level are often accumulated, and the number of samples or fish used to define the length and age composition of the stratum-specific catch is considerably higher than the requested minimum (i.e., often up to 25 samples are combined).

Strata with larger landings are of higher importance. Across all years, 63% of the landings are characterized by at least two stratum-specific length-frequency samples, and 59% by at least two stratum-specific age-length keys (Figure S6). Adding samples from neighboring trimesters (step 2) was done for 9% of the landings in the case of length-frequencies and 14% of the landings in the case of age-length keys. Step 3 (borrowing samples from any other region, but from the appropriate year, period and gear) was used to determine the length-frequency of 16% of the landings and the age-length key of 14% of all landings. There is nonetheless variability over time (Figure S7 and Figure 8). Until 1993, the majority of landings were usually not characterized by stratum-specific samples (length-frequency or bio), despite a relatively important sampling effort. Coverage was best in the years 2000, when the number of samples was relatively high compared to other years, and strata that were dominant in terms of landings were well-sampled (e.g., Newfoundland seiner fleet). Sample coverage declined over the last decade, in parallel with the decrease in overall number of samples collected. The above results should be seen in light of the relatively broad stratum levels used (e.g., by trimester instead of month, as used to for instance assess 3Pn–4RS Atlantic cod; Ouellette-Plante et al. 2022). It should also be noted that to assess the quality of CAA, we did not consider the number of samples used per stratum relative to its landings (e.g., for the largest stratum-specific landings a minimum of two samples was still assumed sufficient).

Despite sometimes suboptimal coverage, cohorts are easily trackable (Figure 1) and there is no “smudging” (i.e., if age-determination is imprecise the strength of cohorts neighboring a strong cohort should be overestimated, resulting in less distinct cohorts and a smoother estimate of the recruitment pattern).

Comparison with previous estimates

The newly estimated CAA proportions do not differ meaningfully from the previously used values (Figure 1). There is no significant change in our perception of strong cohorts nor the overall evolution of the population’s age structure. New and old values diverge mainly prior to 1997; the proportion of age 1 fish in the new CAA matrix is typically higher, whereas the proportional availability of older fish in the landings is lower for most years. Correlations between the old and new values indeed indicate that the largest differences are observed in the landed proportions of age 1 fish (Figure S9). This is unsurprising as age 1 fish are rare and small changes in the methodology could therefore result in a somewhat different outcome. Note that within the assessment model, a larger observation error is estimated for this age class, and that the presented analyses support this practice (Van Beveren et al. 2023).

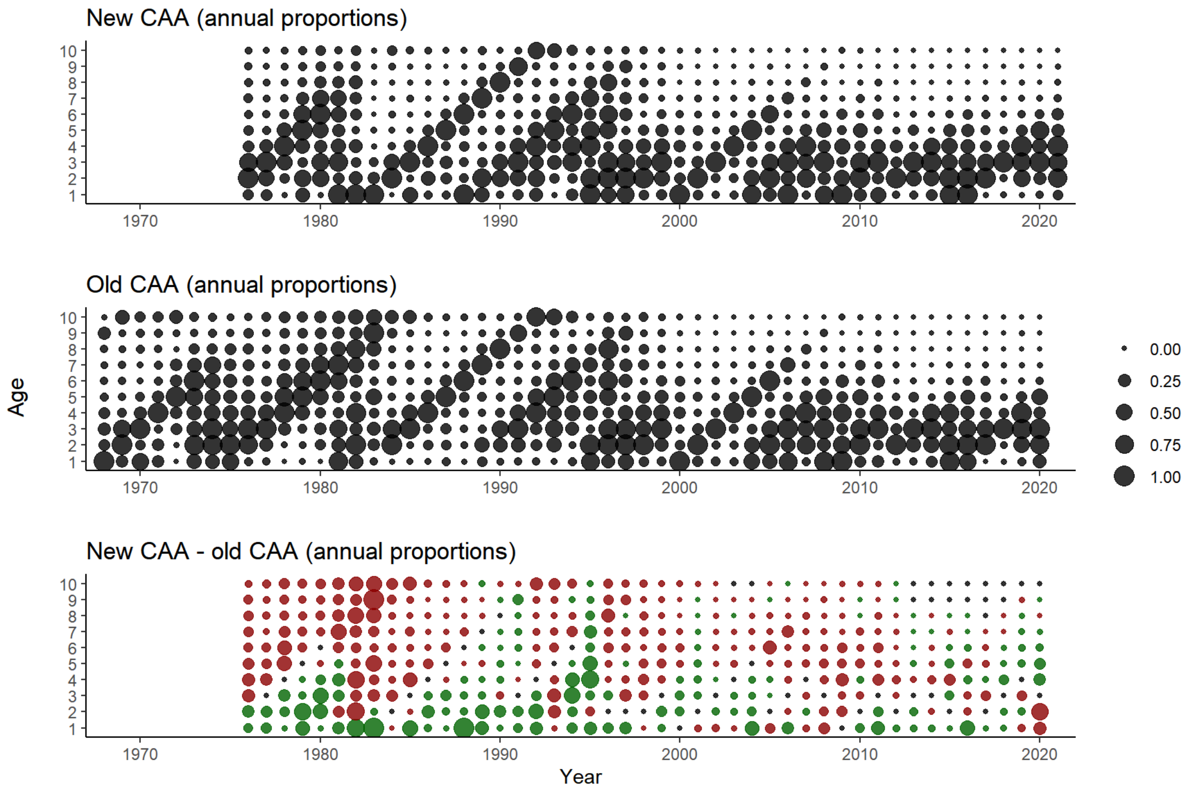

Figure 1. Comparison of catch-at-age (annual proportions) used during the 2021 assessment (old) and the new values estimated for the 2023 assessment (new). The bottom panel shows the difference between the upper two panels (red = new values are lower, green = new values are higher). The year of the fishery closure (2022) was removed from the top panel because of its distinctness from the rest of the time-series.

The weight-at-age of fish in the landings estimated with catchR does likewise to the CAA not diverge meaningfully from previous values (Figure S10, Figure S11). The largest discrepancy exists for the earliest year of data availability (1976). During previous assessments catch WAA was assumed to be much lower during this year. The largest differences are again observed for age 1 fish (Figure S12).

Note that we could not estimate CAA or WAA for 1968-1975 because of the lost length-frequency data for this period. Different solutions are proposed within the assessment to deal with this gap (Van Beveren et al. 2023).

Additional runs

The age composition of landings from the various regions (Figure S13 and S14), gear groups (Figure S15 and S16) or periods (Figure S17 and S18) showed overall similar patterns. The same strong cohorts were always detectable and a truncation of the age structure in the recent years was consistently visible. This indicates that the overall patterns should be robust to shifts in landings (true changes in selectivity) or samples (perceived changes in selectivity) across time, space and gear.

There can however be clear differences on a finer scale. For instance, the age composition of landings in western Newfoundland (NAFO 4R) was generally characterised by a lower proportion of age 1 mackerel, relative to the southern Gulf (NAFO 4T) and the Scotian Shelf (NAFO 4VWXY5). Older fish were often also proportionally more abundant in these landings (e.g., age 10+ from the 1982 cohort). On the Scotian Shelf, younger fish were more frequently present in the landings. Comparisons between other regions (e.g., eastern and southern Newfoundland, the northern Gulf) were restricted by the lack of samples or landings in some years (Figure S13). Gear type likewise had a clear effect on age composition. For instance, younger fish were proportionally much less present in the landings made using gillnets, relative to those from lines and the gear group including seiners, nets, traps and weirs (Figure S16). Because over the last decades, landing composition by gear, period and region visibly varied (Figure S13, S15 and S17), this indicates that fishery selectivity likely changed gradually over time, and more abruptly in 2022.

The estimated proportion-at-age landed in 2021 and 2022 is shown in Figure 2. In 2021, the landings were dominated by mackerel of ages 2 to 4, and few age 1 mackerel were present. Cohorts could not be tracked into 2022, when age 2 appeared dominant. Estimated proportions for 2022 did not differ greatly between the base run ("default" run) and the simulation in which landings were assumed to follow the same pattern as prior to the fishery closure ("prior landings" run). In this second scenario, more weight was for example given to samples from the southern gulf and Newfoundland, collected later in the year (rather than to Maritimes region early in the year). Under both approaches for 2022, samples matched poorly with the landings (Figure S7 and S8 for the default approach, Figure S19 and S20 for the corrected approach).

Although the above results demonstrated that estimates for 2022 should be associated with a clear change in selectivity and are likely imprecise, the overall pattern appeared robust. Specifically, a large part of the 73 length-frequency samples of 2022 (spanning multiple major regions and periods, although not gear types) was dominated by age 2 fish. A calculation of the proportion-at-age across all samples (giving each sample equal weight, without any information on landings), also showed that this conclusion is region-independent (Figure S21). On the Scotian Shelf, samples contained a high proportion of age 1 fish, but the majority was of age 2, and ages 4+ were extremely rare. Regions further along mackerel's main migratory route were progressively more likely to contain older fish. East-Newfoundland samples differed most from those from the Scotian Shelf, as the proportion of older fish was highest. Mackerel of age class 2 were nonetheless again dominant.

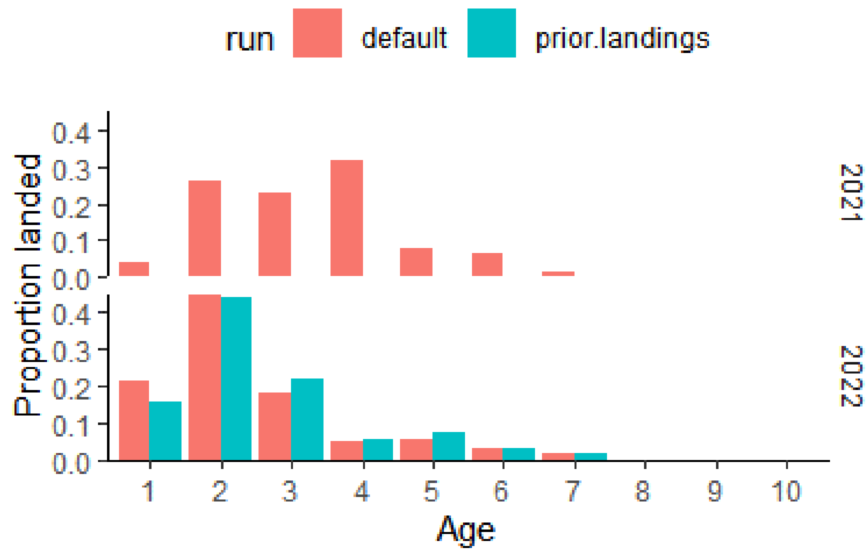

Figure 2. Catch-at-age (annual proportions) for 2021 (top) and 2022 (bottom). For 2022, two different approaches were used (see text).

MATURITY-AT-AGE

MAA of age 1 and 2 fish is highly uncertain. The number of fish sampled of these two age classes, and thus the number of immature fish, varied significantly from one year to the next, and is often very low. Although we used a threshold of at least 30 immature fish to determine MAA, higher numbers would result in less uncertainty and variability within the estimates.

Because values in the early years were extrapolated (1968-1974), they were more stable compared to those used in prior assessments (Figure 3). The pattern for ages 3+ did not otherwise differ meaningfully; by age 3, the large majority of fish have reached maturity each year. The variability in the proportion mature fish of age 1 and 2 is too uncertain and dependent on the smoothing approach used to merit discussion. That is, there is insufficient information in the estimates (large coefficients of variation) to assess true interannual variability (or temporal autocorrelation). The difference with previous values also demonstrates the sensitivity of the values to various assumptions.

The uncertainty in the proportions of mature fish of age 1 and 2 should warrant an evaluation of the impact of subjective choices (e.g., related to smoothing and gap filling) on the final assessment result. During the 2021 assessment, sensitivity analyses showed that there is no significant impact. Likewise, for the 2023 assessment, it was demonstrated that differences in interannual variability of age 1 and 2 maturity did not noticeably impact results.

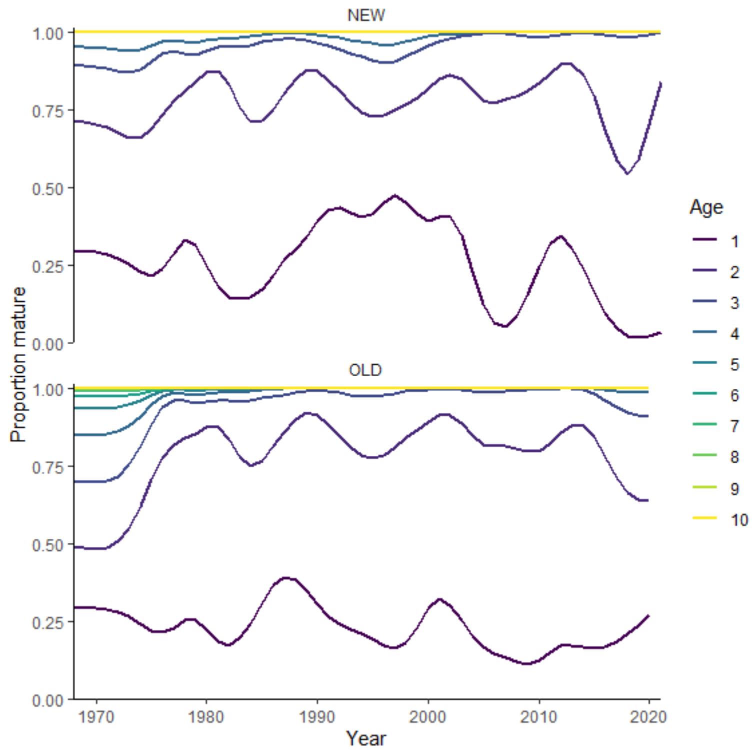

Figure 3. Comparison of the proportion mature-at-age data used during the 2021 assessment (old) and the 2023 assessment (new) for 1968-2020.

CONCLUSIONS

The presented CAA and MAA matrices are considered superior to ones previously used because of their consistency over time. The new CAA estimation, through the use of catchR, is also fully transparent and allowed for fast sensitivity testing (related to the minimum number of samples or fish required, the use of different strata, etc.) and visualisation of the (partial) quality of the results. Both matrices were used in the 2023 assessment and it is recommended that this method be used going forward.

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SUPPLEMENTARY INFORMATION

TABLES

Table S1. Strata used to determine catch-at-age.

Period	**Month**
Trimester 1	Jan, Feb, Mar
Trimester 2	Apr, May, Jun
Trimester 3	Jul, Aug, Sep
Trimester 4	Oct, Nov, Dec
Gear	**Gear type**
Seines, Nets, Traps, Weirs	FPN, FWR, LA, PS, SB, SDN, SPR
Gillnets	GN, GND, GNS
Lines, jiggers	LHM, LHP, LLS, LMP, LX
Miscellaneous	Any other category
Region	**NAFO divisions**
Eastern Newfoundland	2GJ3KL
Southern Newfoundland	3NOP
Western Newfoundland	4R
Northern GSL	4S
Southern GSL	4T
Scotian Shelf	4VWXY5Z

Table S2. Details of the length-frequency (≥70 fish) and biological samples (N = number of samples, n = number of fish, $\bar{n}$ = mean number of fish per sample, n_{min} = minimum number of fish per sample, n_{max} = maximum number of fish per sample). Samples for 2022 were collected under a new scientific sampling program.

	Length-frequency samples					Biological samples				
Year	**N**	**N**	$\bar{n}$	n_{min}	n_{max}	**N**	**N**	$\bar{n}$	n_{min}	n_{max}
1973	0	0	0	0	0	97	3504	36	11	99
1974	0	0	0	0	0	45	1860	41	20	100
1975	0	0	0	0	0	58	2179	38	22	65
1976	100	14219	142	80	229	89	2980	33	20	56
1977	95	12458	131	76	319	91	3262	36	13	100
1978	98	11280	115	83	178	74	1962	27	13	100
1979	115	13359	116	77	191	107	2850	27	12	112
1980	101	11940	118	80	209	71	1864	26	14	39
1981	78	10006	128	100	206	68	1635	24	7	50
1982	81	9621	119	76	211	54	1441	27	14	54
1983	13	1608	124	95	160	116	3647	31	5	58
1984	85	19637	231	78	351	123	4117	33	5	68
1985	64	13932	218	78	282	103	3532	34	15	78
1986	48	10903	227	74	295	85	2910	34	15	65
1987	94	17828	190	73	391	81	2449	30	12	51
1988	118	23780	202	100	338	62	2004	32	18	70
1989	94	20860	222	91	283	85	2810	33	6	144
1990	42	10295	245	155	314	58	1934	33	11	48
1991	54	12549	232	114	274	57	2015	35	15	50
1992	46	11256	245	147	318	57	2226	39	15	59
1993	47	11305	241	91	351	71	2435	34	15	50
1994	50	11750	235	141	311	40	1416	35	1	50
1995	72	16970	236	113	356	66	2276	34	17	69
1996	54	12808	237	107	341	48	1764	37	13	50
1997	51	12188	239	140	334	48	1866	39	16	50
1998	55	13213	240	111	443	52	1891	36	16	49
1999	59	13875	235	88	349	53	2151	41	29	68
2000	55	12779	232	156	330	52	1796	35	16	57
2001	78	19219	246	155	347	66	2426	37	19	50
2002	64	15694	245	151	283	58	1931	33	22	47
2003	80	18878	236	155	294	78	2553	33	15	50
2004	78	19175	246	180	295	71	2626	37	12	58
2005	87	14681	169	78	252	108	3975	37	14	91
2006	88	15586	177	148	329	128	4665	36	14	56
2007	76	14053	185	150	263	126	3871	31	15	49
2008	57	9948	175	145	241	73	2545	35	4	57
2009	75	12970	173	103	284	93	3215	35	10	69
2010	79	13635	173	138	255	134	4443	33	15	50
2011	49	8504	174	132	283	68	2424	36	8	56
2012	45	7401	164	148	206	60	2006	33	15	78
2013	36	5954	165	147	322	36	1083	30	17	48
2014	46	7495	163	149	254	46	1385	30	13	45
2015	43	7144	166	107	272	42	1322	31	18	61
2016	59	10456	177	146	263	57	2044	36	21	56
2017	63	11097	176	150	290	72	2271	32	1	50
2018	53	9109	172	116	271	62	2556	41	18	106
2019	48	8555	178	146	283	195	3643	19	1	100
2020	37	6138	166	110	275	149	2760	19	1	50
2021	48	8277	172	131	263	134	2724	20	1	54
2022	73	11453	157	71	488	126	2808	22	1	51

FIGURES

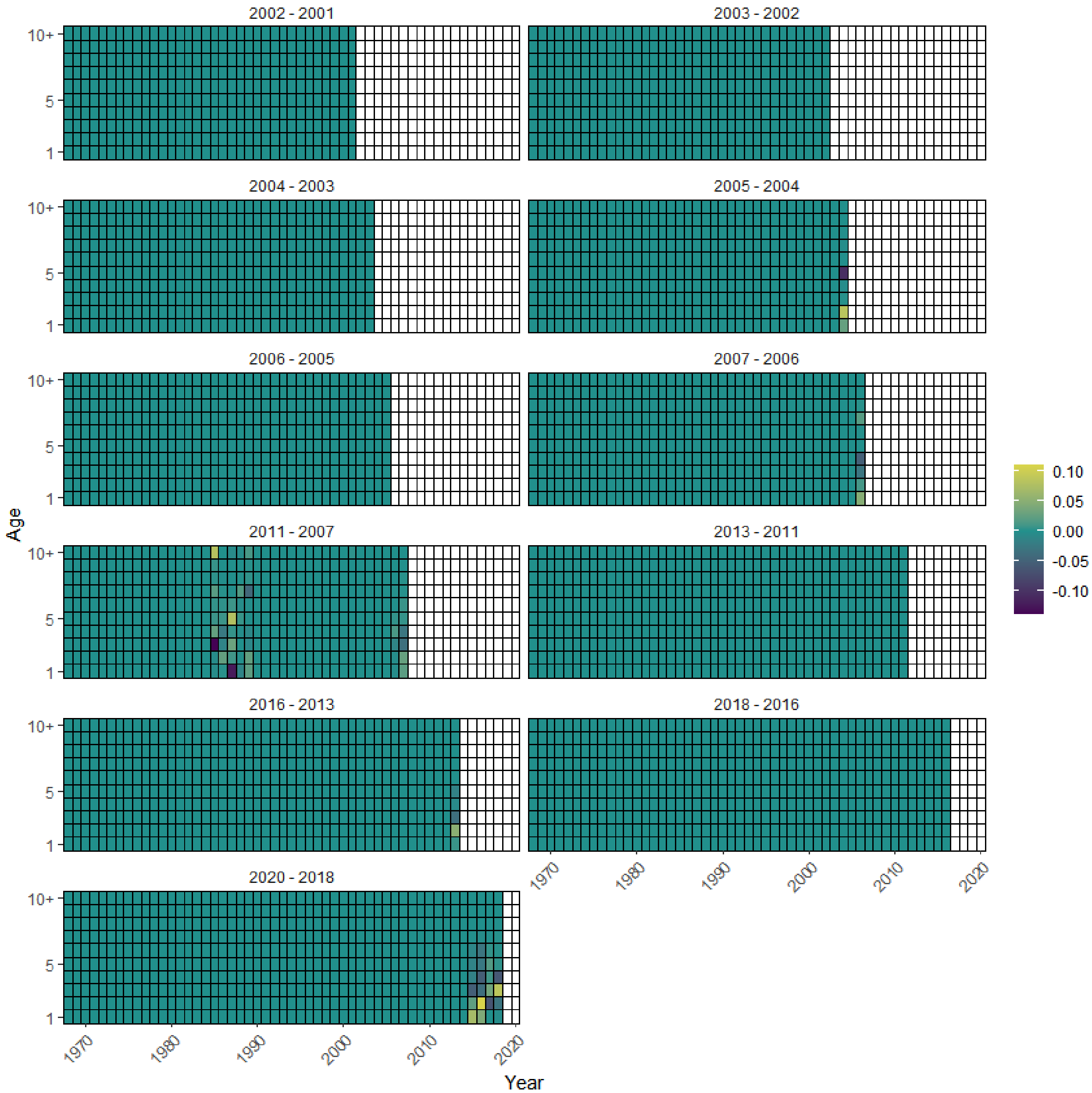

Figure S1. Comparison of catch-at-age values (annual proportions) across assessments. Each panel shows the absolute difference between the matrix used during a given assessment and the matrix used during the previous assessment (years indicated in the figure titles are the terminal years that where assessed rather than the assessment year itself). Yellow values indicate presented numbers were higher relative to before, purple values indicate the opposite and green values show there is no (or little) difference.

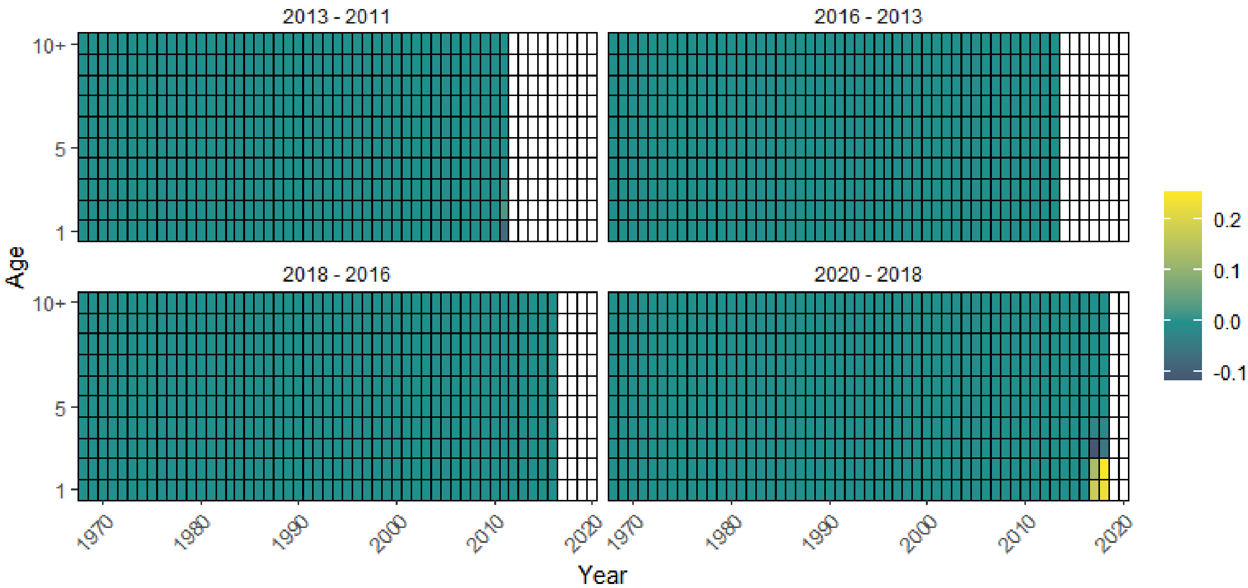

Figure S2. Comparison of maturity-at-age values across assessments. Each panel shows the absolute difference between the matrix used during a given assessment and the matrix used during the previous assessment (years indicated in the figure titles are the terminal years that where assessed rather than the assessment year itself). Yellow values indicate presented numbers were higher relative to before, purple values indicate the opposite and green values show there is no (or little) difference.

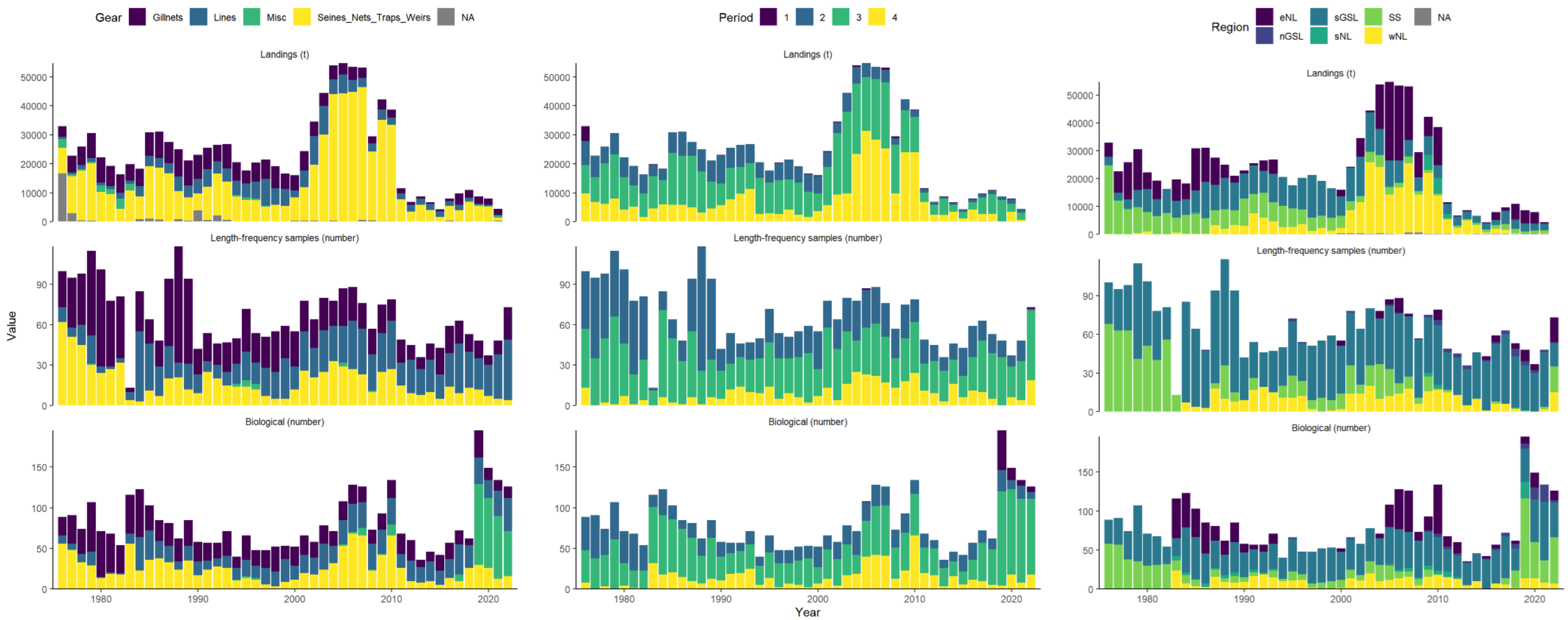

Figure S3. Landings (upper row), number of length-frequency samples (middle row, ~ 150 fish/sample) and number of biological samples (lower row, ~ 20-30 fish/sample), by gear (left panels), period (middle panels) and region (right panels). (NA = Not Available)

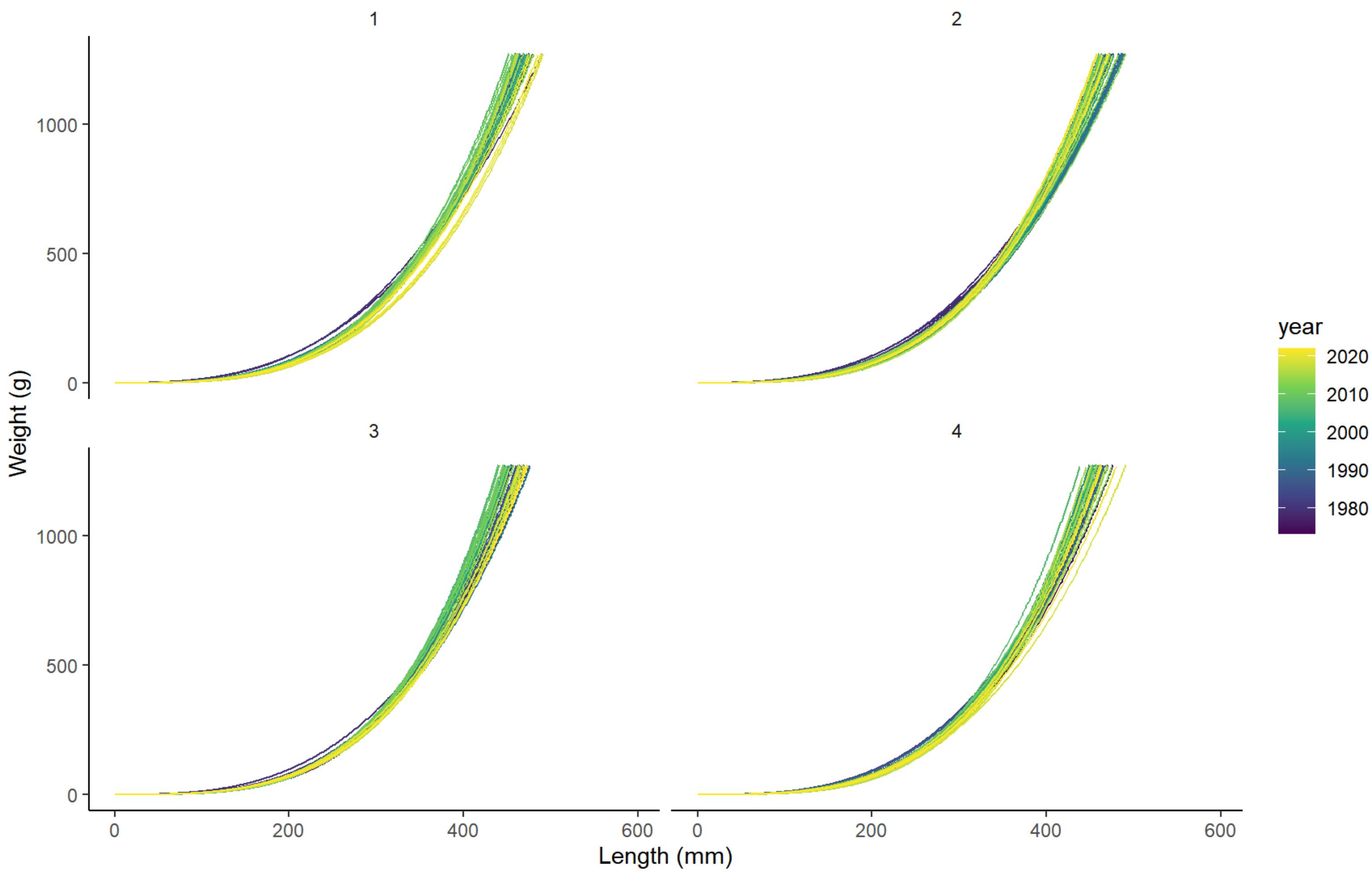

Figure S4. Predicted length-weight relationships by year (color) and trimester (panel).

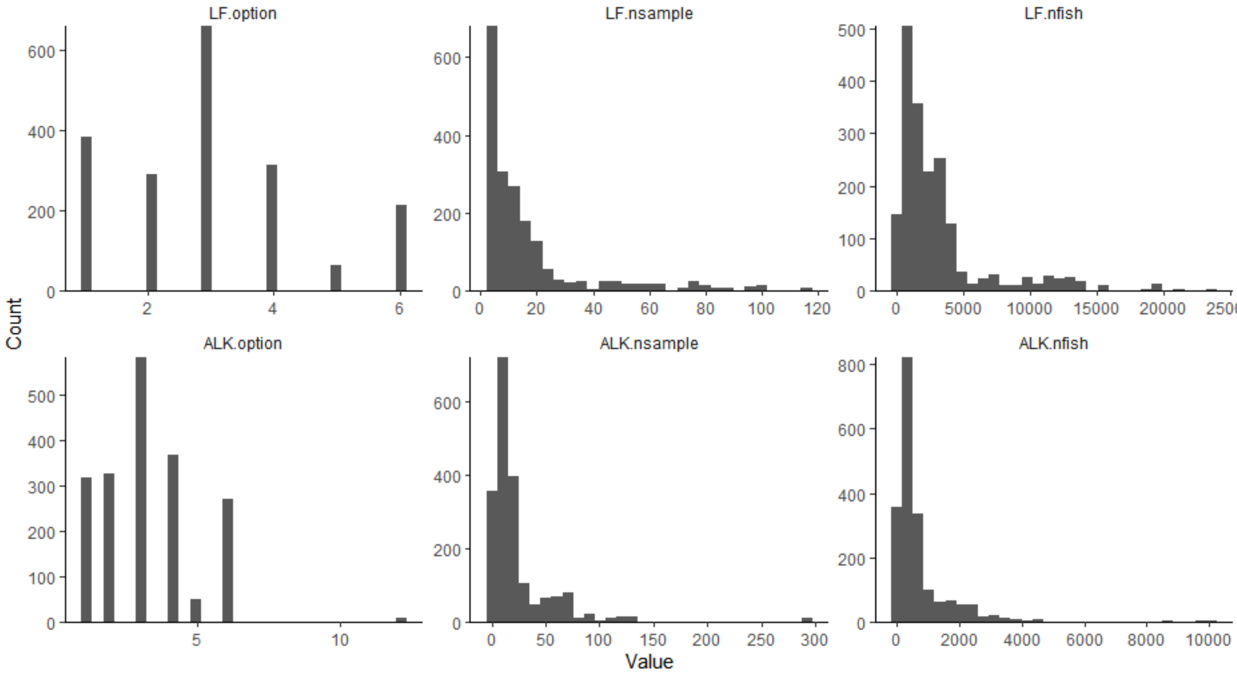

Figure S5. Counts of the number of times a hierarchical sample level (1 to 12) was used to attribute a sample (LF = length-frequency, ALK = age length key) to the landings of a given stratum. Higher levels indicate less adequate sampling (left panels). Number of samples associated with each strata (middle panels). Number of fish used to determine the length-frequency and age-length key of each strata (right panels). Figures are for all years combined.

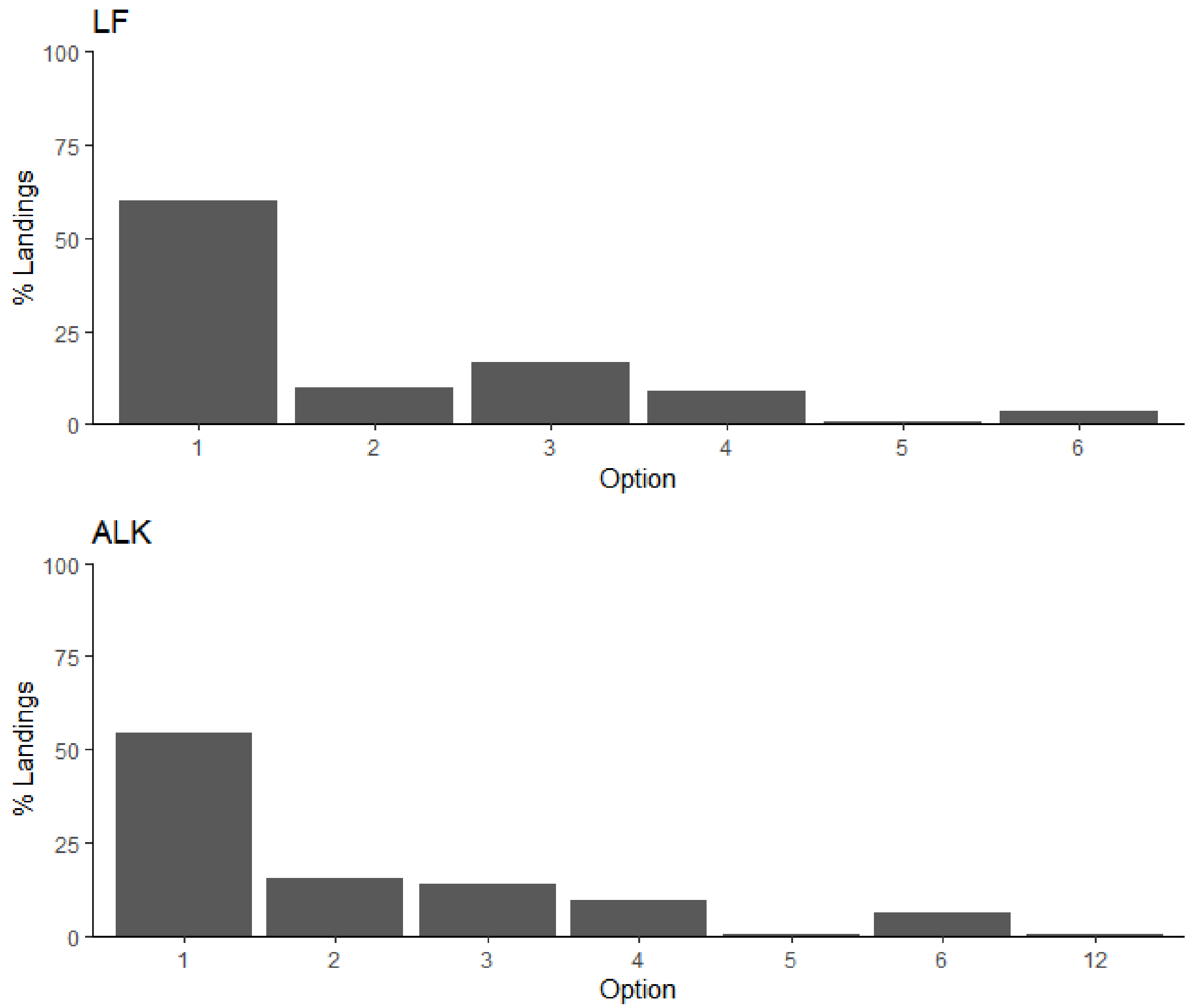

Figure S6. Percentage of landings overall all years (1976-2022) for which a certain hierarchical sample level (1 to 12, unused levels not shown) was used to attribute a sample (LF = length-frequency, ALK = age length key) to the landings of a given stratum. Higher levels indicate less adequate sampling.

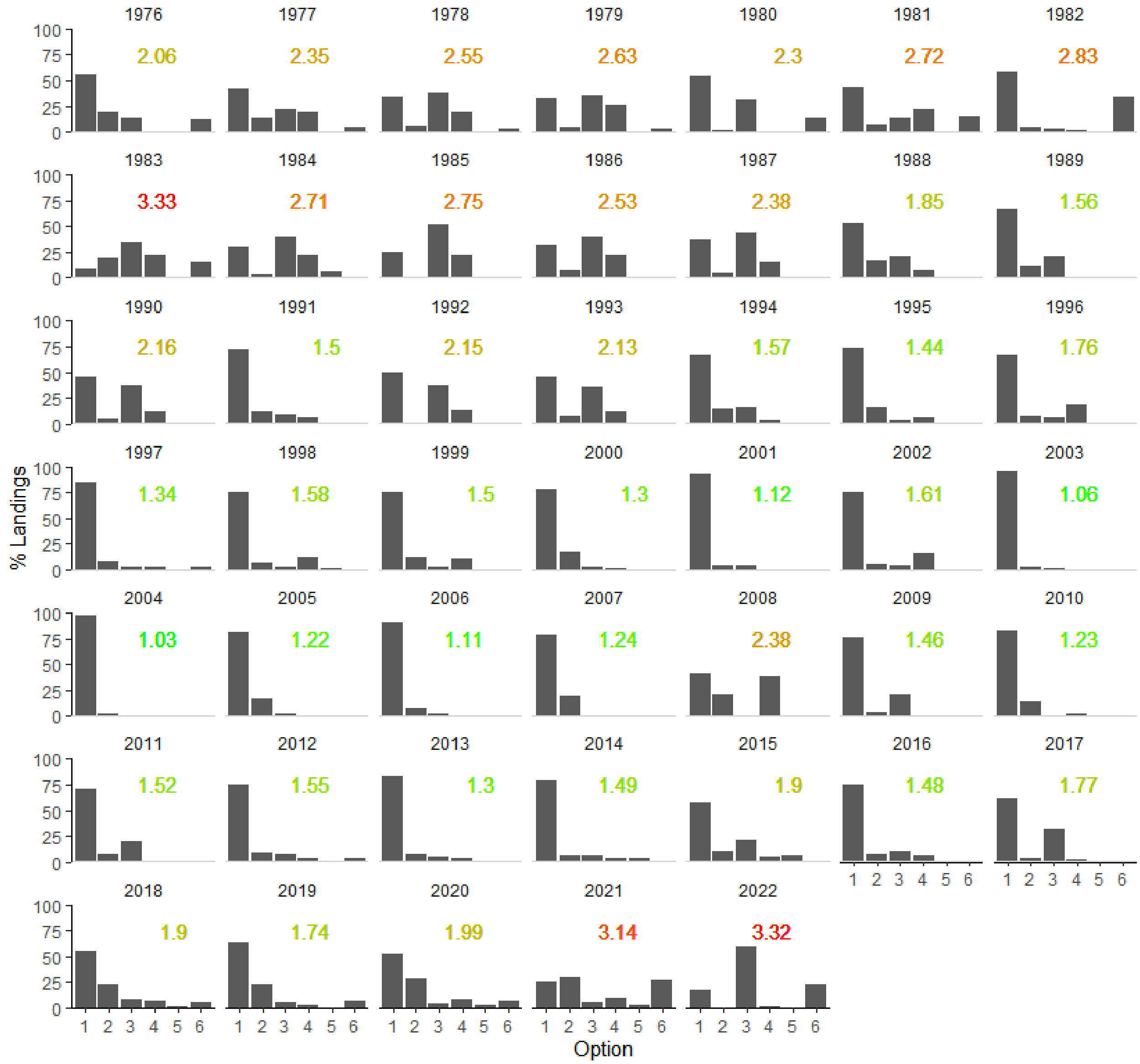

Figure S7. Percentage of landings, by year, for which a certain hierarchical sample level (1 to 12) was used to attribute length-frequency samples to the landings of a given stratum. Higher levels indicate less adequate sampling. If the first bar (option 1) is above the grey horizontal line, it indicates that for at least 50% of all landings an appropriate number and coverage of samples was present. The number indicated on top is a weighted average of all scores (1 = perfect sampling in green, 6 = poor sampling in red) and provides a simplistic indicator of sample quality. For 2022 the default approach was used.

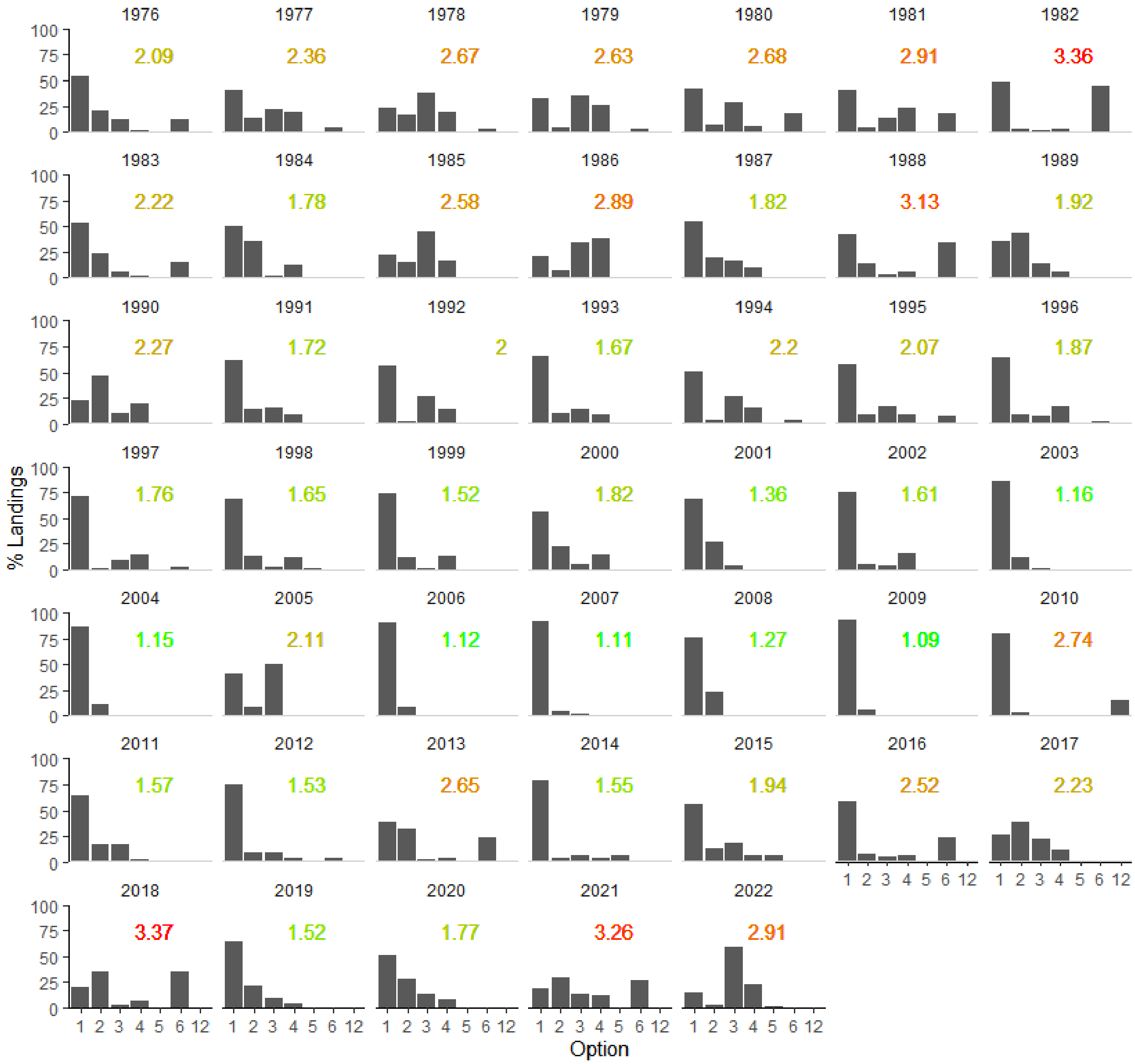

Figure S8. Percentage of landings, by year, for which a certain hierarchical sample level (1 to 12) was used to attribute age-length samples to the landings of a given stratum. Higher levels indicate less adequate sampling. If the first bar (option 1) is above the grey horizontal line, it indicates that for at least 50% of all landings an appropriate number and coverage of samples was present. The number indicated on top is a weighted average of all scores (1 = perfect sampling in green, 12 = poor sampling in red, >6 = samples from neighbouring years need to be used) and provides a simplistic indicator of sample quality. For 2022 the default approach was used.

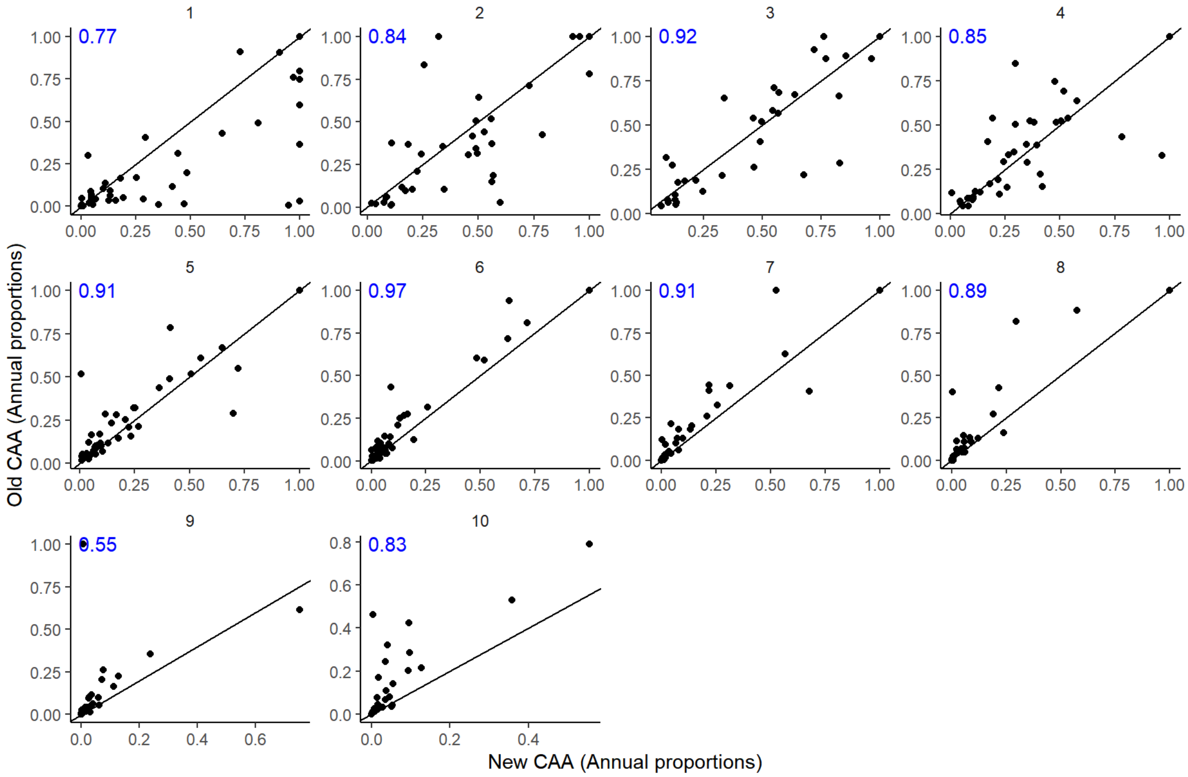

Figure S9. Correlation of CAA (annual proportions) between previous and new estimates by age (panels), with indication of Pearson's correlation coefficient (blue). Values on the black line are identical.

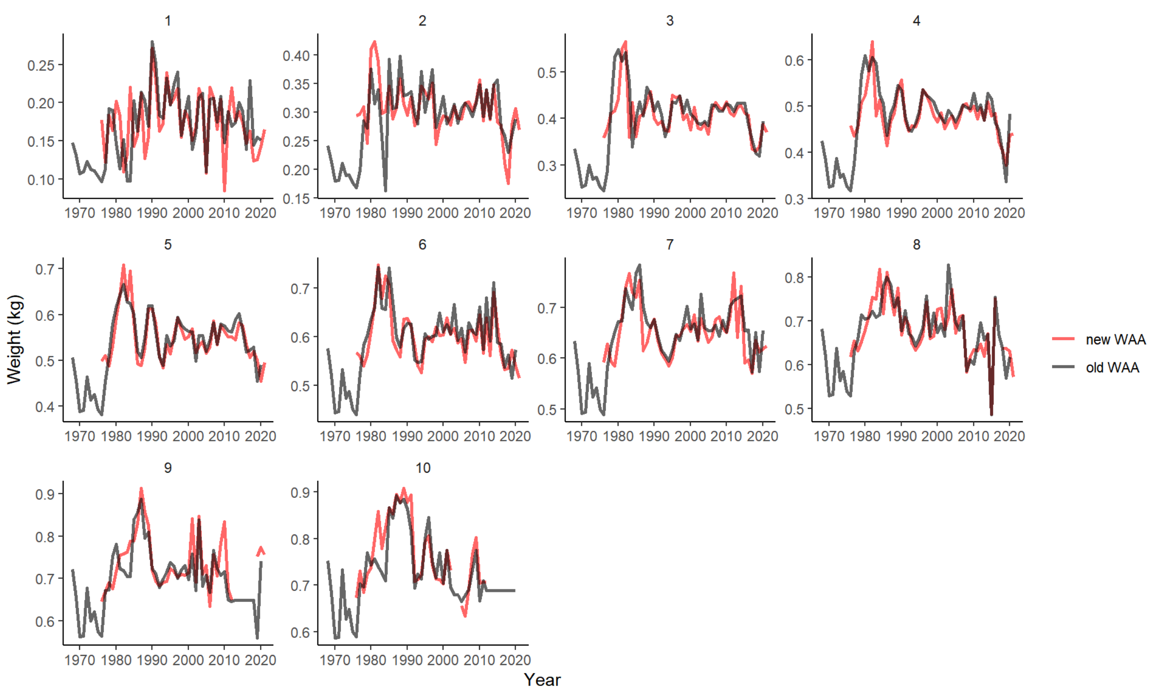

Figure S10. Comparison of the average weight of landed fish by age (WAA) used in the 2021 assessment (old) and the new values (new; without filled in gaps).

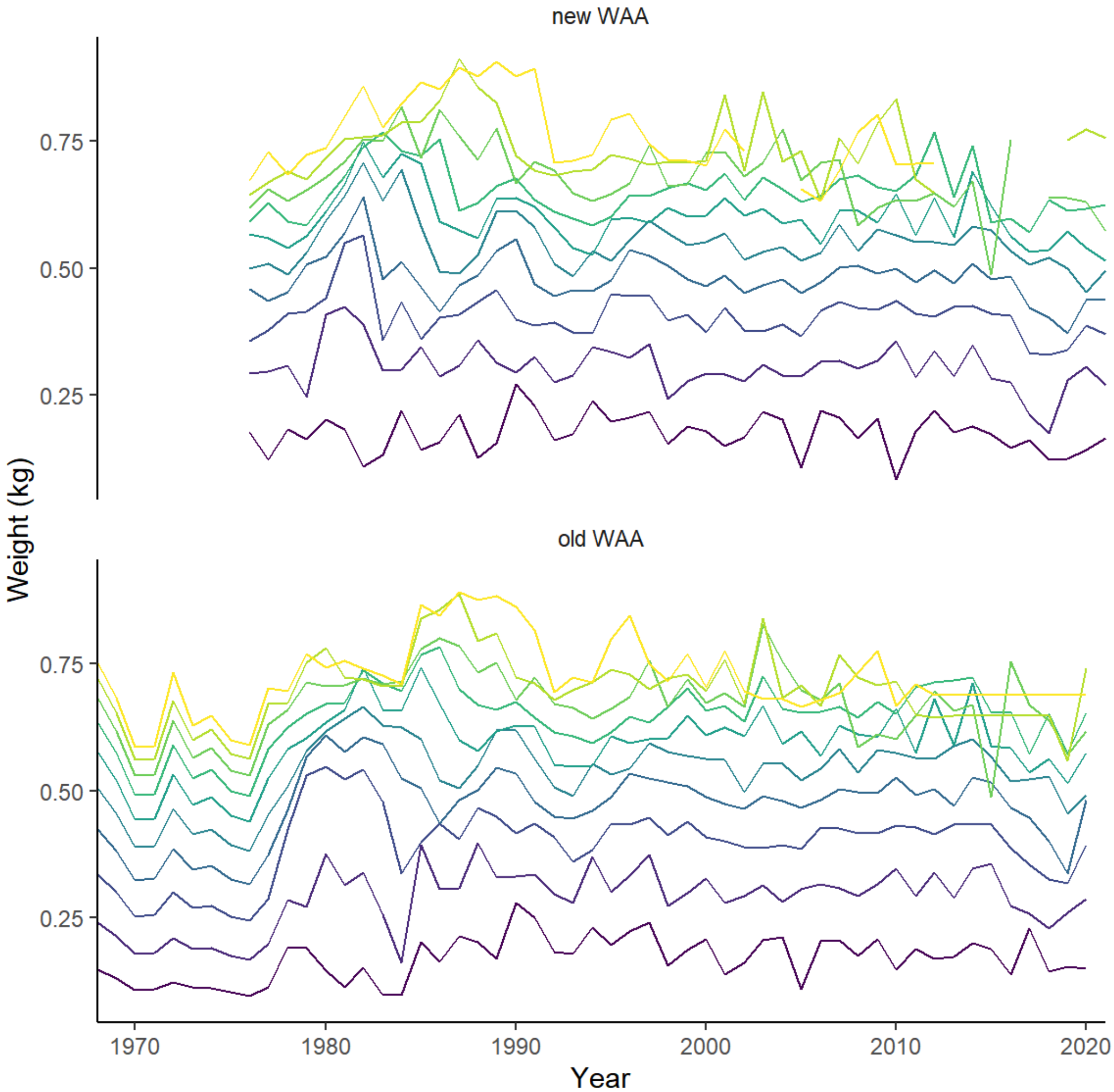

Figure S11. Comparison of weight-at-age matrices (landings) presented during the 2021 assessment (old) and the 2023 assessment (new) for 1968-2020.

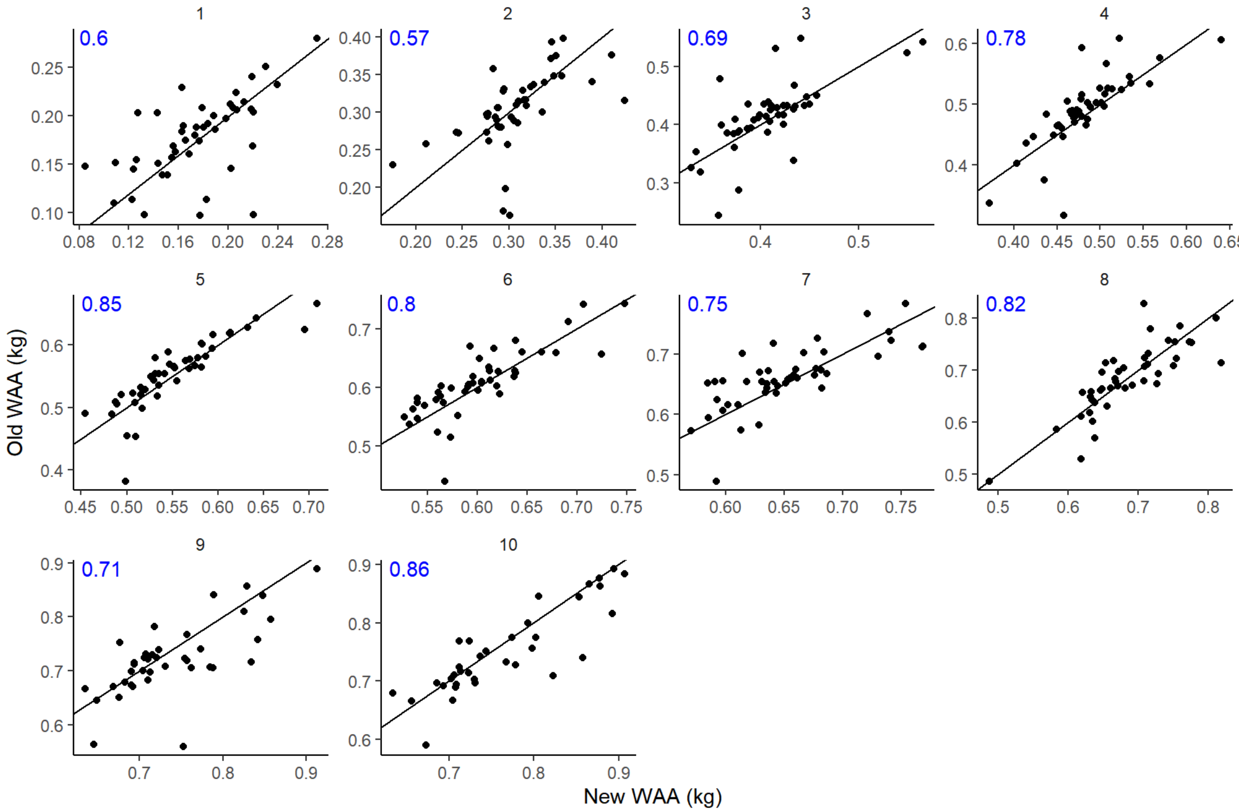

Figure S12. Correlation of WAA (kg) between previous and new estimates by age (panels), with indication of Pearson's correlation coefficient (blue). Values on the black line are identical.

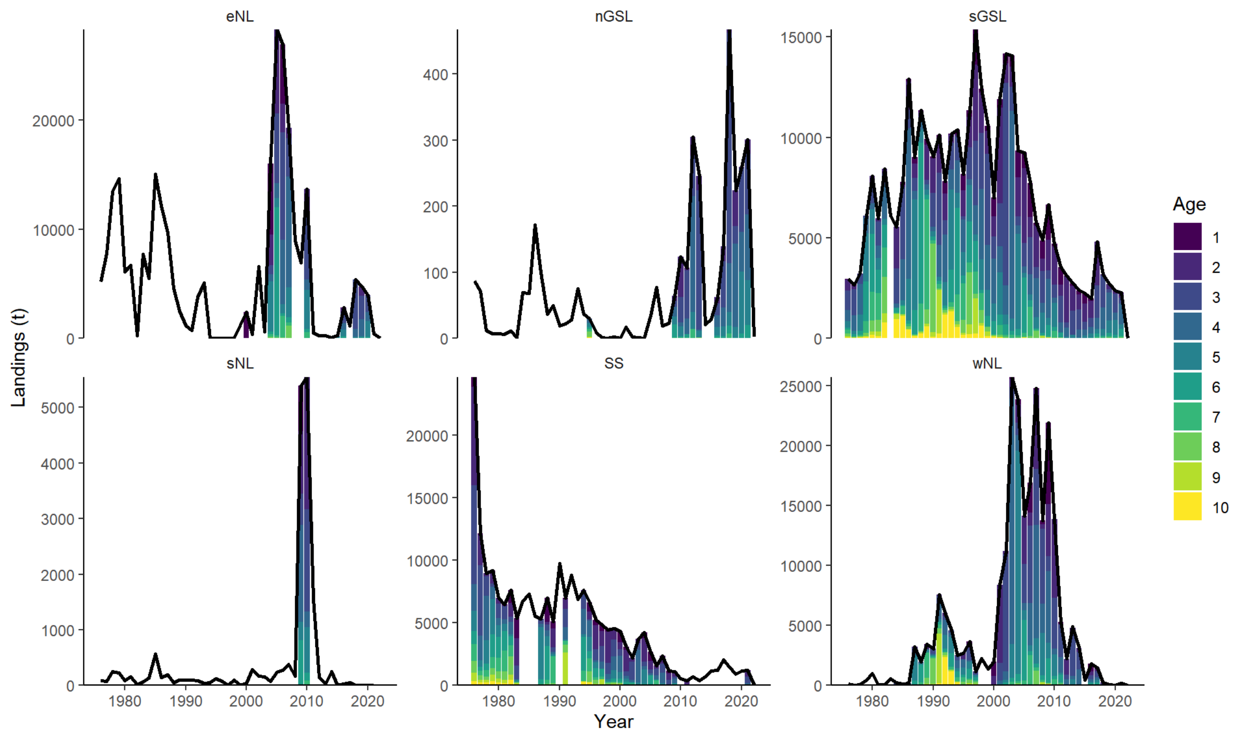

Figure S13. Landings (t) by region (see Table S1), decomposed by age. Age decomposition could not be done for years without samples (white area). (eNL = eastern Newfoundland, nGSL = northern Gulf of St-Lawrence, sGSL = southern Gulf of St.-Lawrence, sNL = southern Newfoundland, SS = Scotian Shelf, wNL = western Newfoundland)

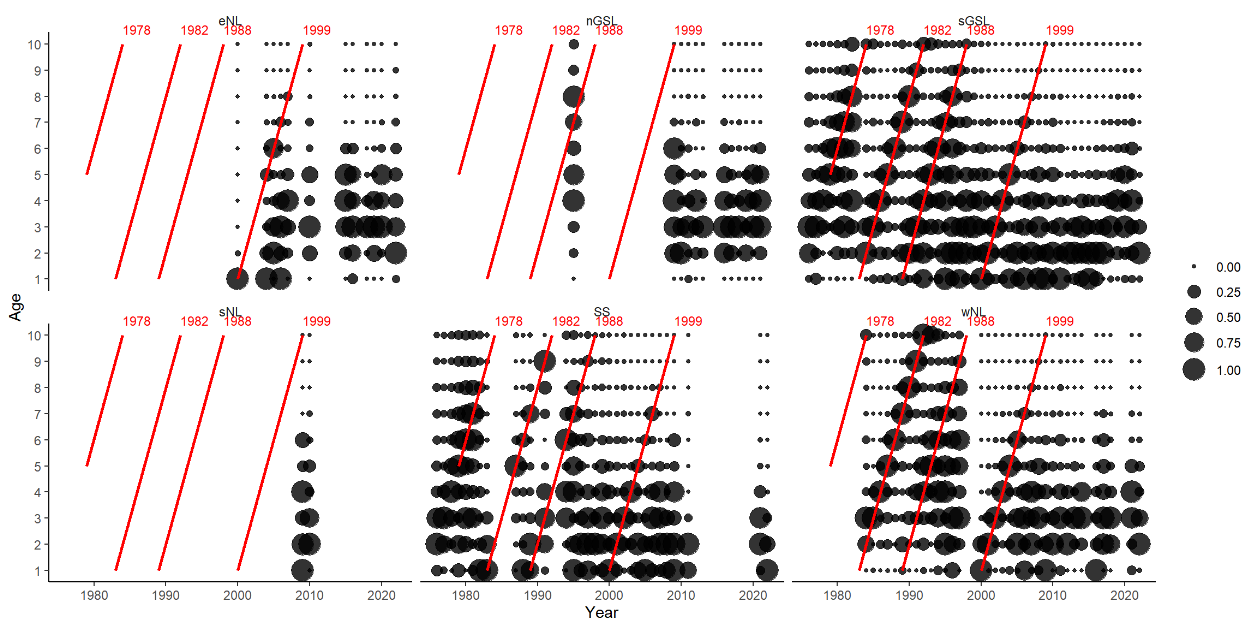

Figure S14. Catch-at-age by region (annual proportions). Strong cohorts are indicated with red lines to facilitate comparison of age-structure. (eNL = eastern Newfoundland, nGSL = northern Gulf of St-Lawrence, sGSL = southern Gulf of St.-Lawrence, sNL = southern Newfoundland, SS = Scotian Shelf, wNL = western Newfoundland)

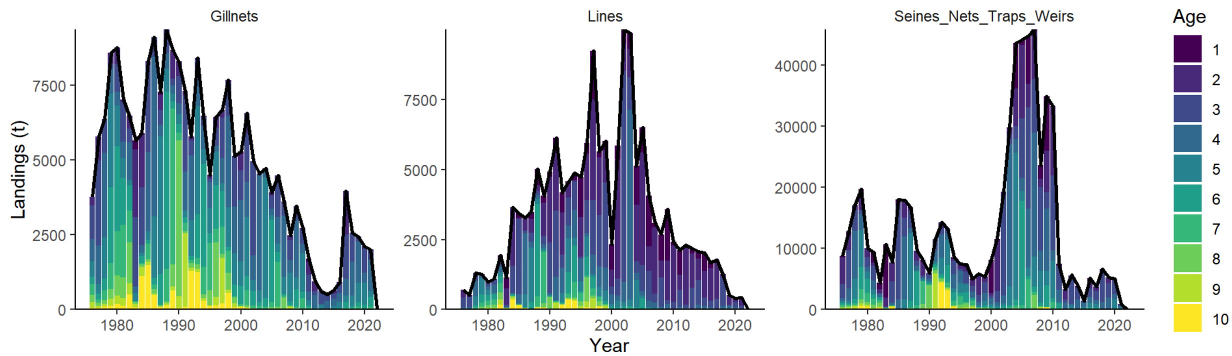

Figure S15. Landings (t) by gear class (see Table S1), decomposed by age. The "Miscellaneous category" is not shown because of a lack of landings and samples.

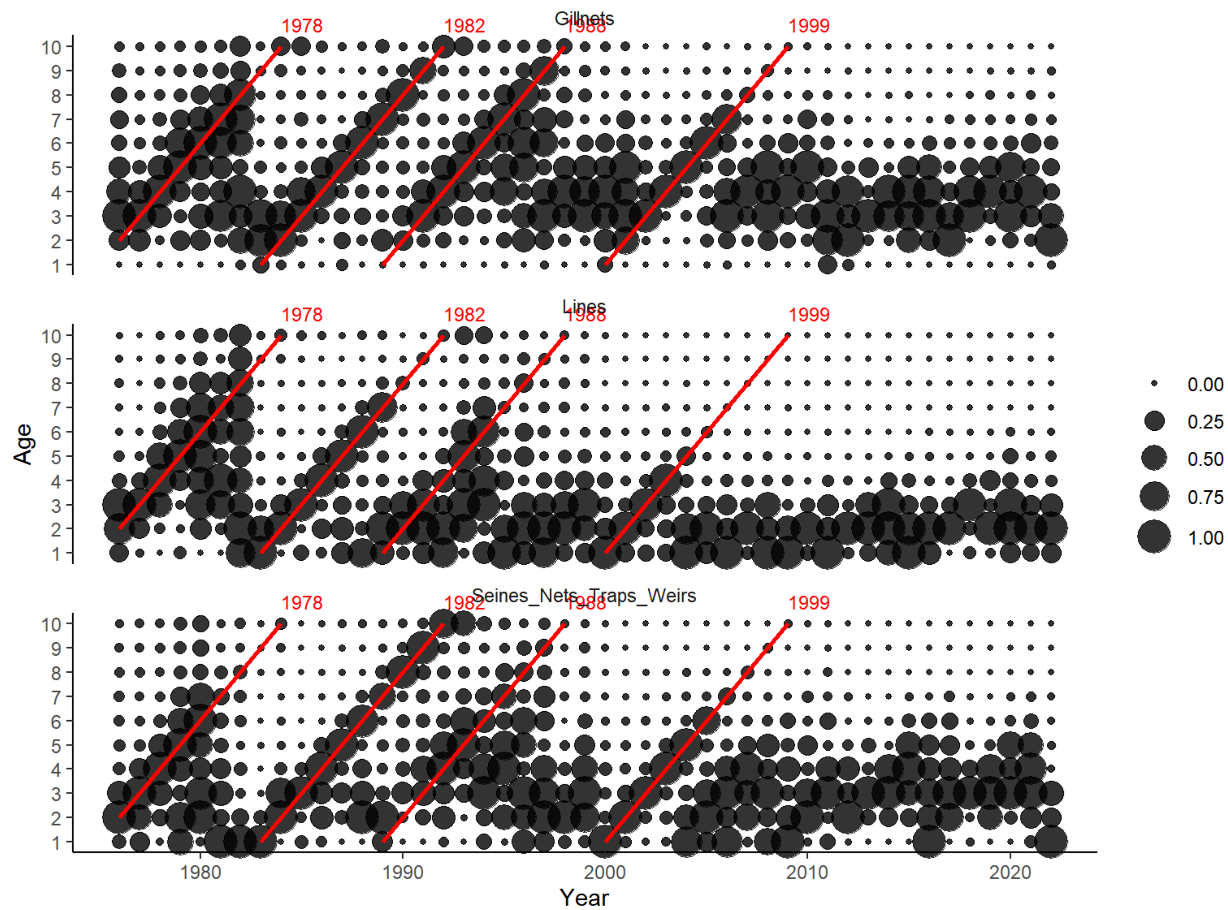

Figure S16. Catch-at-age by gear class (annual proportions). Strong cohorts are indicated with red lines to facilitate comparison of age-structure.

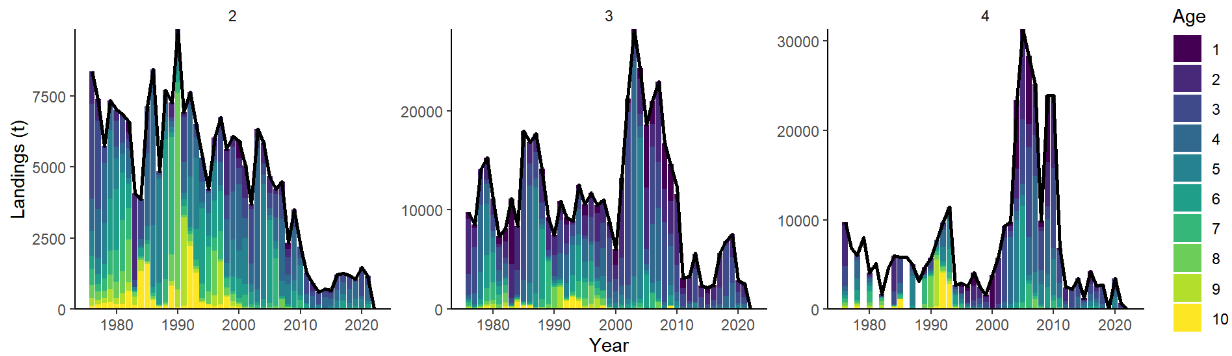

Figure S17. Landings (t) by period (trimester; see Table S1), decomposed by age. Age decomposition could not be done for years without samples (white area). Trimester 1 is not shown because of a lack of landings and samples.

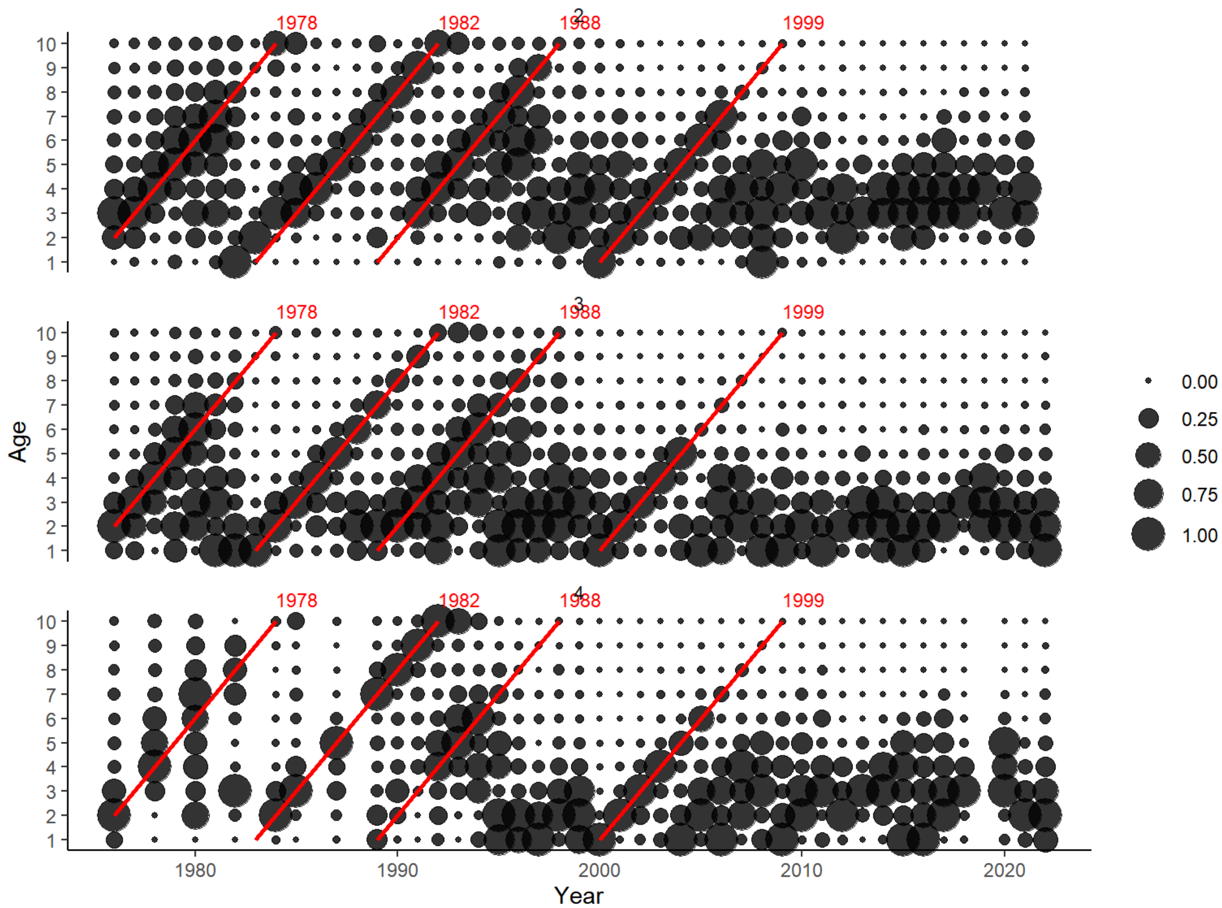

Figure S18. Catch-at-age by period (trimester, annual proportions). Strong cohorts are indicated with red lines to facilitate comparison of age-structure.

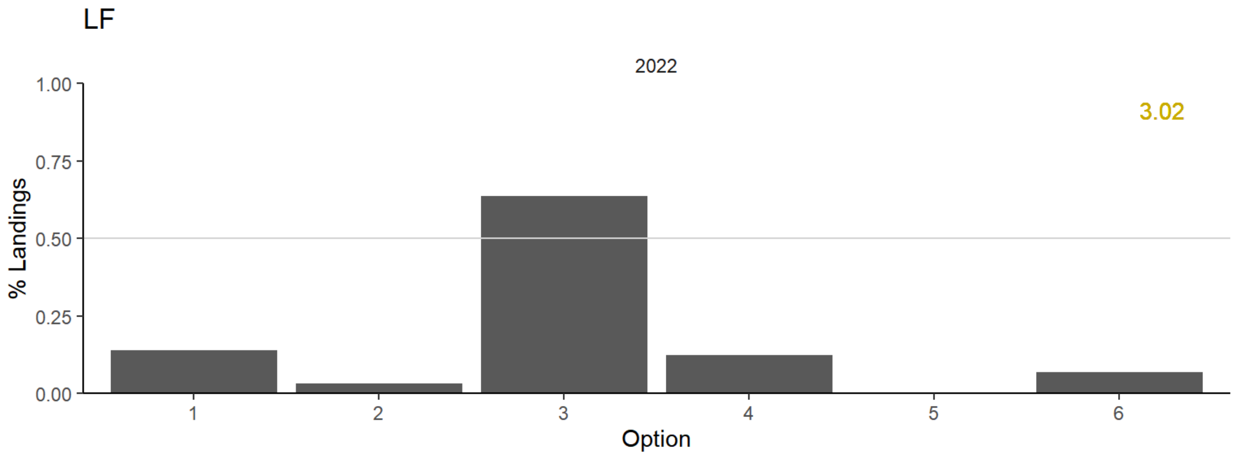

Figure S19. Percentage of 2022 landings (redistributed according to the pattern of 2017-2021) for which a certain hierarchical sample level (1 to 6) was used to attribute length-frequency samples to the landings of a given stratum. Higher levels indicate less adequate sampling. The number indicated on top is a weighted average of all scores (1 = perfect sampling, 6 = poor sampling) and provides a simplistic indicator of sample quality.

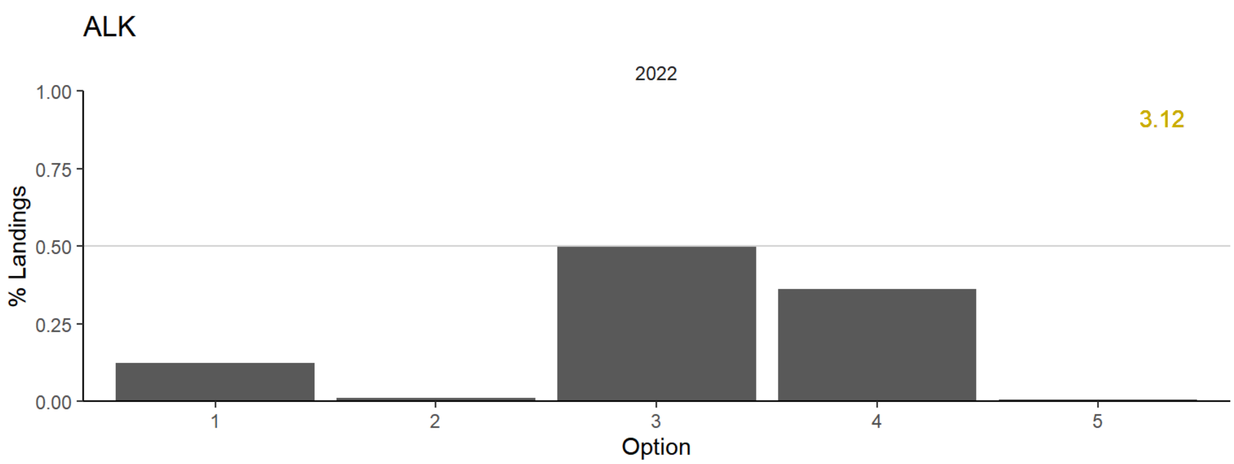

Figure S20. Percentage of 2022 landings (redistributed according to the pattern of 2017-2021) for which a certain hierarchical sample level (1 to 6) was used to attribute age-length key samples to the landings of a given stratum. Higher levels indicate less adequate sampling. The number indicated on top is a weighted average of all scores (1 = perfect sampling, 6 = poor sampling) and provides a simplistic indicator of sample quality.

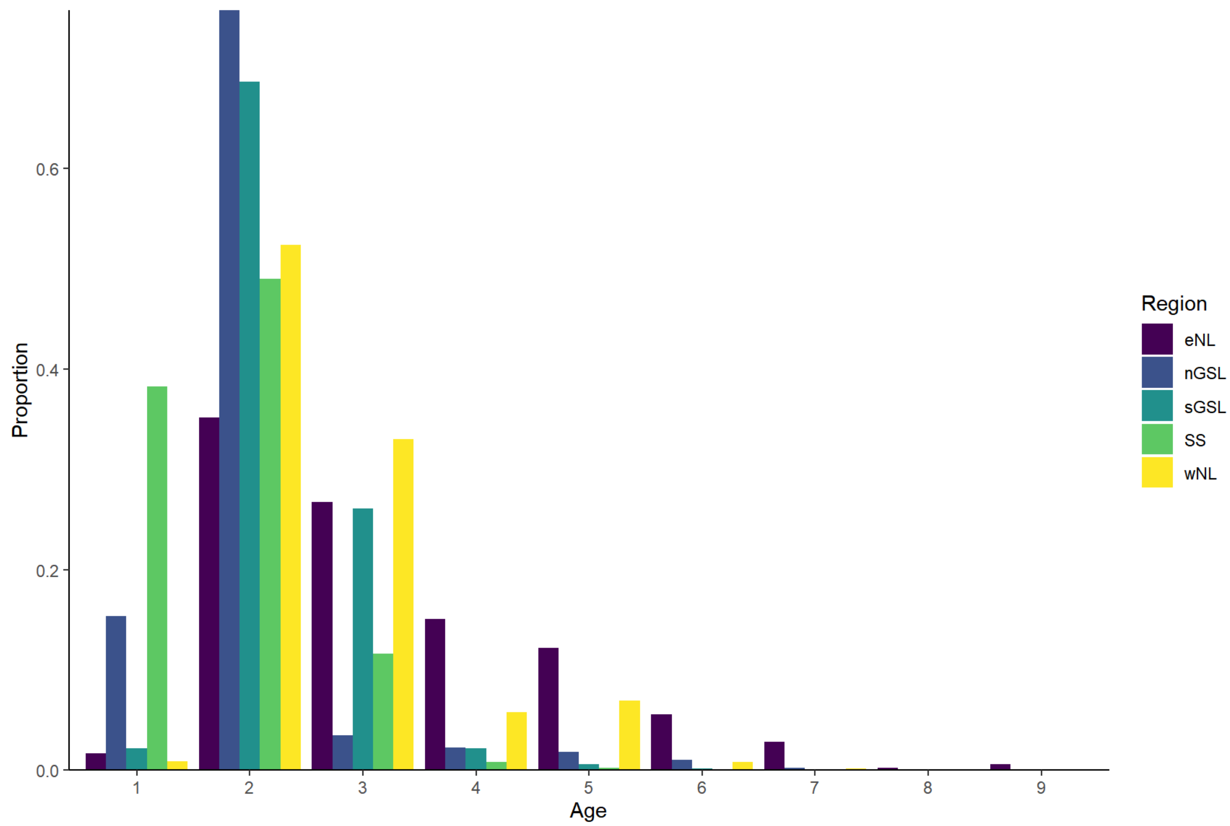

Figure S21. Proportions-at-age of mackerel in samples from each region.