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Northern Contingent Atlantic Mackerel (*Scomber scombrus*) Stock Assessment in 2024

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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 the data and methods used to assess the stock status of the northern contingent of Atlantic mackerel (*Scomber scombrus*) in the Northwest Atlantic. The presented and reviewed stock status indicators (February 26–27, 2025) were estimated with an age-structured stock assessment model that was fitted to landing data, landings-at-age, and an egg survey index. The estimated 2024 spawning stock biomass (SSB) was at 35% of the Limit Reference Point, placing the stock in the Critical Zone of the Precautionary Approach Framework. The stock has been in or near the Critical Zone since 2011. Recent average recruitment (2012–2024) has been low compared to the previous period (1969–2011) and the age structure of the stock was truncated with fish older than 6 years becoming rare. Short-term projections including continued recreational and U.S. fishing indicated that the probability of the SSB leaving the Critical Zone by 2027 varied around 30% for a TAC of 0 t and around 13% for a TAC of 8,000 t.

1. INTRODUCTION

This research document describes the data, methods, and supporting analyses contributing to the stock assessment of the northern contingent of Atlantic mackerel (*Scomber scombrus*, mackerel hereafter) in the Northwest Atlantic over 1969–2024. In the introduction, we provide background information on population structure, fisheries management, and a rationale for the assessment framework. For further information on this fish stock, see the Atlantic mackerel species page. The 2025 assessment meeting was carried out by the Department of Fisheries and Oceans Canada (DFO) at the Maurice Lamontagne Institute (IML) in Mont-Joli, Quebec, Canada on February 26–27, 2025.

1.1. POPULATION STRUCTURE

Mackerel occur on both sides of the North Atlantic. Individuals from each side are genetically distinct and there is no evidence for trans-Atlantic migration (Rodríguez-Ezpeleta et al. 2016; Gíslason et al. 2020; Bourret et al. 2023). In the Northwest Atlantic (NWA), there are two spawning contingents; a northern contingent which spawns predominantly in the southern Gulf of St. Lawrence (sGSL) in June-July (Van Beveren et al. 2023b), and a southern contingent which spawns mostly in the western Gulf of Maine and off southern New England, from mid-April to June (Studholme and Morse 1999). Both contingents mix in winter in deeper waters, in part on the U.S. shelf, where they are subject to the U.S. fishing fleet. The level of mixing during winter remains highly uncertain, but is likely large between years (Redding et al. 2020; Arai et al. 2021; Bourret et al. 2023).

1.2. FISHERIES MANAGEMENT

In 2022 and 2023, Fisheries Management division of DFO closed both the commercial and bait fisheries. In 2024, the bait fishery was reopened with a 470 t TAC. Mackerel were previously harvested commercially and for bait across the Atlantic Provinces and Quebec in an open competitive fishery using a variety of gear types (gillnets, mechanical jiggers, purse and tuck seines, weirs, and traps), the predominance of which varied by region and season. Mackerel are also harvested through a popular recreational fishery that remained open, but for which there has been a daily possession limit of 20 fish per person since May 2021. While each regional Fisheries Management sector implements its own license conditions and has its own catch monitoring system (a mixture of logbooks, purchase slips, and dockside monitoring), mackerel are managed on a national level. Although northern contingent mackerel is a transboundary stock that is also harvested by the U.S. fishing fleet, there is no joint management. The U.S. sets a NWA-wide allowable biological catch, which applies to both contingents, and then subtracts a projected Canadian catch, with the remainder set as the U.S. allowance for their commercial and recreational fishery.

The last assessment of mackerel in Canada took place in February 2023 (DFO 2023). The stock was estimated to be below its Limit Reference Point (LRP). Because the stock has been in or near the Critical Zone according to DFO's Precautionary Approach (DFO 2009) since 2011, a Rebuilding Plan was developed and first published in 2020. The main objectives of the Rebuilding Plan were to "limit the probability of Atlantic mackerel spawning stock biomass (SSB) declining from one year to the next (i.e., maintain a positive growth trajectory)" and "to rebuild Atlantic mackerel SSB above the LRP". The last assessment indicated these objectives were not attained (Van Beveren et al. 2023a). As the objectives of the Rebuilding Plan were not met, and because Atlantic mackerel has been prescribed under the Fish Stock Provisions of the revised Fisheries Act with new requirements for Rebuilding Plans, an updated plan for Atlantic mackerel was published in 2024 as requested by the Fisheries Resource Management Branch.

To document progress towards rebuilding and to inform strategic harvest decisions, the current document provides a new estimate of the time the stock would take to rebuild to a rebuilding target in the absence of all fishing and under prevailing conditions (Tmin), a summary of available knowledge on the ecosystem considerations (including how they are accounted for in the assessment and how they can affect rebuilding) and the effect of the fishery on spawning and stock trajectory.

1.3. ASSESSMENT FRAMEWORK

The northern contingent of Atlantic mackerel has historically been assessed based on three principal data sources: landings, landings-at-age and an egg survey index. Since the 2017 stock assessment (see Doniol-Valcroze et al. 2019), a custom state-space censored catch-at-age model (CCAM; Van Beveren et al. 2017) has been used to integrate the available information. State-space models can treat both biological stochasticity in population dynamics (referred to as process error) as well as observation error and are used to assess a broad range of stocks around the world (Aeberhard et al. 2018). A custom model was built to integrate the uncertainty in total removals (including discards, unreported, recreational and U.S. landings). Specifically, the model has a censored likelihood option to allow estimation of removals between an upper and lower bound (Van Beveren et al. 2017).

2. METHODS

All input data were revised during the 2023 assessment. The details of all methods, robustness tests and comparisons with previous estimates were presented in Lehoux et al. (2024), Van Beveren (2024) and Boudreau et al. (2025). The information below therefore only provides the details essential to understand the approaches used.

All data were collected and estimated for 1969–2024. Code to generate input data and run the assessment model is accessible online.

2.1. LANDINGS

Data on mackerel landings within Canadian waters for 1969–1994 were downloaded from the NAFO landings database (STATLANT 21B) and data from 1995 to 2024 were downloaded from the most recent ZIFF files (Zonal Interchange File Format) produced by DFO's regional statistics bureaus. Total commercial landings for the two terminal years (2023 and 2024) are considered preliminary (Table S 1and Table S 2). Removals associated with the 2022–2024 sample collection under a Section 52 fishing license (see commercial sampling) are not included in the ZIFF files but were added to the overall landings before their use within the assessment model.

In addition to the recorded landings, there are other sources of removals. Data from the U.S. commercial and recreational fisheries (1960–2022) were provided by the Northeast Fisheries Science Center (Kiersten Curti, NOAA, pers. comm.). U.S. catch statistics for 2023–2024 were not available at the time of the assessment. Therefore, we used the projected landings for the two terminal years which are thus considered preliminary (Table S 1).

A maximum amount of unaccounted-for catches in Canadian waters was estimated by Van Beveren et al. (2017). For more recent years, we assumed that the amount of unaccounted-for catches (recreational fishing, discards, illegal and unreported landings) was at most 140% of recorded landings, in correspondence with estimated maximum ratios since 2005. Because of the 2022 closure, the only unaccounted-for catches were assumed to be from recreational fishing. Because mackerel bycatch is small, discards from other fisheries are presumably minor. Precise estimates of the biomass caught by the recreational fishery are unavailable, but are

likely to be between 187 t and 680 t, based on a simple extrapolation of values provided by a federal survey on recreational fishing (Table S 3; DFO, 2015). The upper bound (680 t) corresponds roughly to the presence of 3 to 5 fishers per day (depending on average fish weight) that fish their daily quota (20 fish/day/person) in 300 different locations around Atlantic Canada, over a three-month period (July, August, September; when recreational fishing is commonly practiced). The lower bound (187 t) corresponds roughly to the presence of about 3 fishers per day each fishing their daily quota (20 fish/day/person) in 100 different locations around Atlantic Canada, over a three-month period (July, August, September; when recreational fishing is commonly practiced). Note that the aim of these estimates is to provide a reasonable lower and upper bound rather than a precise value, which cannot be determined with the information available.

2.2. COMMERCIAL SAMPLING

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

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 typically consists of at least 150 randomly selected fish of which the fork length is measured to the nearest 0.5 cm. A length-stratified subsample (two fish per length bin) is usually sent to IML for the determination of age (standardized to January 1st) and additional biological characteristics (fork length, ± 1 mm; weight, ± 0.1 g; gonad weight, ± 0.01 g; sex; maturity stage). Biological data (age, maturity, 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 or opportunistically collected small bycatch samples). The length frequencies and biological (“bio”) data are entered into two separate Oracle database tables and were accessed with the DFOdata package on github (version 0.1.1). Length-frequency data is only available from 1976 onwards, whereas the bio database has information available from 1973 onwards. We were unable to retrieve older data.

Since 2022, samples had to be collected outside the commercial port sampling program because of the commercial fishery closure. A license to fish for scientific purposes (Section 52 of the Fishery General Regulations) was issued to certain harvesters from each DFO region. License conditions, defined by each region, stipulated amongst other things that harvesters were allowed to keep 300 kg of mackerel for personal use and could fish only with gillnets or jiggers (e.g., no seining in Newfoundland). The standard rules around minimum fish size for retention (26.8 cm) were not applied from 2023 onwards. Contracted harvesters were asked to collect a certain number of samples. The initial intent in 2022 was to obtain samples similar to previous years in terms of quality, quantity and coverage to facilitate interannual comparison and secure continuity. Practical limitations imposed a more opportunistic approach (in function of gear types used, number of samples collected per region/period and overall spatio-temporal coverage). From 2023 onwards, a stratified survey design was used that balances the number of samples per region independent of their importance in terms of historical landings. With the exception of the Quebec region, where port samplers completed the sampling protocol as usual, samples were collected by harvesters or a technician from a fishery organization. Note that the total number of samples entered in the length-frequency and bio database and used within the assessment is not identical to the number of samples received, as some were merged upon arrival (because of sample size, identical date/location),lost during transportation, or consisted solely of a length-frequency distribution. Additional length frequencies were provided by port

samplers in the Quebec region. Details of 2022–2024 samples, as used within the assessment, are in Table S 4.

2.3. LANDINGS-AT-AGE

Landings-at-age (LAA) follow the method presented in Van Beveren (2024). In short, catches were decomposed by age with the help of length frequencies and age-length keys built with the commercial port sampling databases using the catchR package (see Ouellette-Plante et al. 2022 for details on the algorithm). Mackerel biomass caught under S52 licences was included in total landings but was not included in the LAA. Commercial and bait landings were first totalled by strata (a combination of trimester, gear type and region). For each stratum, the most representative samples were then automatically selected based on a hierarchical approach. If a minimum of two corresponding samples (length-frequency or age-length key) was not achieved, the catchR algorithm became gradually less restrictive in its sample search. Length frequencies and age-length samples attributed to a given strata were subsequently combined to obtain a stratum-specific length frequency (proportions) and a corresponding age-length key (proportions). Stratum-specific landings were divided into age classes by multiplying them by the proportions-at-length and the proportions-at-age for each length class. This separation, together with year and trimester-specific information on average fish weight by age obtained from length-weight relationships, permits estimation of total LAA in numbers. Weight-at-age from the first available year (1976) were applied to the early period (1969–1975) (Figure S 1).

Because of the fishery closure since 2022, there was likely an abrupt change in fishery selectivity associated with the recent years' LAA. Estimated LAA is a product of recorded total landings (which might have a true change in fishery selectivity) and samples that determine the age structure of those landings (which determine perceived changes in fishery selectivity). The distribution of the (small) reported 2022–2024 landings changed vastly across regions, gear types and time relative to years prior to the fishery closure, and was in 2022–2023 essentially limited to bycatch and catches associated with scientific sample collection. Sample distribution and selectivity was likewise atypical. A new sampling program had to be established, and the observed length- and age-compositions from 2022 to 2024 were therefore expected to have reduced comparability with previous years. For instance, a higher number of samples were obtained from Newfoundland, but none were from the usually important purse seine fishery. Because harvesters went out fishing with the specific aim of collecting a sample (and up to 300 kg of mackerel for personal use), a change in behaviour might also have affected results (e.g., more nearshore fishing, shorter trips at times when harvesters might otherwise not have gone out fishing). The majority of samples were also collected by harvesters themselves or technicians from harvester organizations rather than port samplers, with the exception of samples from the Quebec region.

The duration of the new sampling program (three years) was still considered too short to develop a new index. Time-varying selectivity is discussed in section 2.9.2.3.

We estimated a (partially) bias-corrected LAA and included it in the model (Van Beveren et al. 2023a). In this scenario, the average stratum-specific landings of 2017–2021 were used to determine LAA rather than the true landings distribution, and the resulting LAA was rescaled to the total landings of the corrected years. This simulates a situation where the fishery had stayed open, but it does not account for changes in sample collection. A partial correction can be justified because overall removals were very low. Because the fishery was partially opened in 2024, we considered two modified series:

1. 2022–2023 in which 2022 and 2023 were bias-corrected as described above and 2024 landings were calculated using the default approach (as done prior to 2022). When using

the default, LAA is estimated as usual. This can result in biased age composition and especially recruitment strength, as the expected abrupt change in fishing selectivity is unaccounted-for, and

2. 2022–2024 in which 2024 landings were assumed to have a biased age composition and were corrected as described above for 2022–2023.

Note that LAA within the assessment is always calculated for the commercial and bait fishery, and that the age-composition of unaccounted-for removals (recreational fishing, U.S. fishing, commercial discards, etc.) can only be assumed identical.

2.4. TOTAL EGG PRODUCTION

The mackerel egg survey, which covers the sGSL in June, has been conducted near-annually since 1979 and is the main indicator of stock trend. The basic concept of egg surveys is that if we know the number of eggs that have been spawned, then this can be used to determine the stock abundance or biomass as egg production and stock size are directly related through fecundity, the proportion of females in the stock and their proportion mature. Since the Management Strategy Evaluation (Van Beveren et al. 2020) and 2021 stock assessment (Smith et al. 2022), the assessment model is fitted directly to an index of Total Egg Production (TEP) rather than to the derived SSB index. The TEP index methodology was revised in the 2023 assessment and the details on the revised methodology can be found in Lehoux et al. (2024).

The mackerel egg survey consists of a 66 stations fixed grid, which is visited over about a 10-day period. At each station, a tow following a saw-tooth profile in the top 50 m of the water column is made with 61 cm bongo nets (333 µm mesh size) for about 10 minutes (less if there is clogging) while cruising at roughly 2.5 knots. For each year (y) and station (*i*), the volume of filtered seawater (V, m^3), depth sampled (D, m), and the mean temperature in the top 10 m of the water column (T10, °C) was calculated. Stage 1 and 5 eggs were counted (N1 and N5) from a subsample (Fr, fraction) of each station. Daily Egg Densities (DED, n/m^2) were calculated as follows:

$$DED_{y,i} = \frac{\left(\left(N1_{y,i} + N5_{y,i}\right)/Fr_{y,i}\right)}{V_{y,i}} * D_{y,i}$$

These values were subsequently corrected for variations in egg incubation time as a function of temperature, using the equation from Lockwood et al. (1977), giving Daily Egg Production (DEP, $n/m^2/day$):

$$DEP_{y,i} = \frac{DED_{y,i}}{e^{\left(-1.61*\log\left(T10_{y,i}\right)+7.76\right)}} * 24$$

DEP for missing stations was predicted with a spatial mixed model (R INLA). The average DEP across all stations was scaled to Total annual Egg Production (TEP, n) based on an estimate of the proportion of eggs spawned at the time of the survey (S) and the total survey area (A, 6.945^{10} m^2):

$$TEP_y = \frac{\left(\sum_{i=1}^{66} D\ EP_{y,i}/66\right) * A}{S_y}$$

The proportion of eggs spawned on the median survey date Sy, relative to the entire spawning period, is calculated based on the seasonal progression of female gonads. As eggs are released over the spawning season, the gonado-somatic index (GSI, percentage of fish weight

determined by the gonads) of female mackerel (NAFO areas 4T, 4V and 4W) reduces. This decrease is modelled with a logistic function:

$$f(GSI, Asym, scal, xmid) = \frac{Asyn}{1 + exp\left(\frac{xmid - x}{scal}\right)}$$

where *Asym* is the curve's maximum value, *scal* is the logistic growth or steepness of the curve (determining the spawning duration) and *xmid* is the sigmoid's midpoint (or the peak spawning day). A mixed model (R package nlme) is used with year as a random effect. The scaled slope of a logistic curve for a given year and day is equal to the proportion of eggs spawned at that moment. Sy is then defined as the proportion of eggs spawned at the median survey day. For certain years (1991, 1999 and 2022), there were difficulties with the logistic fit, and hence Sy was uncertain (see Lehoux et al. 2024 for details). For 1991 and 1999, there was independent evidence based on the proportion of larvae observed that Sy was indeed biased and both years were excluded. For 2022, no such evidence was detected.

The daily proportions of eggs spawned are also used to estimate spawning duration and seasonality. The latter information is important to validate the results; when the median survey date was outside the period when 70% of eggs were produced, the index value was assumed to be less precise (true for 2006, 2017, 2019 and 2024). It is currently impossible to feed (partially) estimated uncertainties into the assessment model or to downweigh the influence of certain data points, as the model assumes only one index-specific observation error.

During this assessment, we presented a default option but also considered progressively removing TEP values for which the uncertainty was assumed to be relatively large (see section 2.9.2.5.)

2.5. 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 SSB and to link observed with predicted egg production. The entire time series was updated in the 2023 assessment (Van Beveren 2024). In short, June-July data from the "bio" database was used to fit annual Generalized Linear Models (GLMs) that predict maturity as a function of age. Age-specific spline smoothers were subsequently used to reduce the noise in the predicted time series.

2.6. WEIGHT-AT-AGE

The stock assessment model requires three weight-at-age (WAA) matrices as inputs; WAA of the stock on January 1st (to estimate January 1st SSB, if of interest), WAA of the stock during spawning (to estimate June SSB, necessary within the stock-recruitment relationship and presented by default) and WAA of landed fish (to convert estimated numbers of landed fish into landed weight). Changes in the latter can reflect both fluctuations in the stock and shifts in the fishery (e.g., occurring later in the year when fish weigh more). Prior to 2023, biological WAA was not computed and WAA of landed fish was used as a substitute. Since the 2023 assessment, we estimated WAA of fish in June-July (also used as WAA on January 1st) not only to improve modelling of the stock dynamics, but also to provide an index that has more biological meaning (see Boudreau et al. 2025).

The WAA during spawning was determined as the average weight by age of fish in the "bio" database, sampled during June-July from the gillnet fishery in NAFO areas 4TVWX. Age-year combinations with fewer than 10 fish were discarded. A mixed model that assumes a first order

autoregressive (AR1) process over age, year and cohort was applied to reduce noise and fill in gaps (Cadigan 2022). The model is available in the catchR package.

2.7. FECUNDITY-AT-AGE

Fecundity is the intrinsic link between TEP and the abundance of spawning female fish. In the past, age-aggregated average annual values of fecundity were used to help transform TEP into an SSB index outside the model (Smith et al. 2020 and prior). Currently, a matrix of fecundity-at-age (FAA) is used by the model to perform the abundance-at-age to TEP conversion. Under the current approach, the model estimated age structure of the stock should determine overall stock fecundity and hence TEP.

The FAA model input matrix was reviewed and re-estimated in the 2023 assessment (see Boudreau et al. 2025). Pelletier (1986) determined potential fecundity of Atlantic mackerel sampled in Canadian waters. Potential fecundity estimates, in contrast to realized fecundity estimates, include oocytes that might not be spawned (follicular atresia) and exclude oocytes that might develop throughout the spawning period. Based on Pelletier's fecundity data, a robust linear regression (R package robust) between fecundity (fec), age (with fishes older than 9 years as a 10+ group), and the GSI was estimated:

$$log(fec) = 10.8 + 0.41 * log(age) + 0.71 * log(GSI)$$

The average GSI of stage 5 (i.e., ready to spawn) females was determined for each age class and year ("bio" database). Using the estimated robust linear regression, this GSI-at-age matrix was transformed into FAA. To reduce the amount of noise and fill in gaps, the previously mentioned mixed model used for WAA that assumes an AR1 process on age, year and cohort was again applied.

2.8. PROPORTION OF FEMALES-AT-AGE

The proportion of females in the population by age and year is used to transform TEP by spawning females to total spawning stock abundance. Prior to 2023 these values were computed based on the "bio" database and unsurprisingly fluctuated around 0.5 (95% within [0.48-0.54]; (Smith et al. 2022). Since 2023, we assumed that the true value was always 0.5 (typically within the confidence interval of computed values) and that any deviation was a result of observation error.

2.9. STOCK ASSESSMENT MODEL

2.9.1. Framework

The model (CCAM; Van Beveren et al. 2017) was developed using the Template Model Builder (TMB; Kristensen et al. 2016) package in R (R Core Team 2023) and is largely based upon SAM (stock assessment model; Nielsen and Berg 2014; Berg and Nielsen 2016) as well as elements from the Northern Cod Assessment Model (NCAM; Cadigan 2016). Model equations and parameter definitions are provided in Tables S 5 and S 6. In brief, instantaneous fishing mortality ($F_{a,y}$, with *a* = age and *y* = year) is modelled as a separable process, i.e., a product of fishing selectivity and annual fishing mortality. The instantaneous natural mortality rate ($M_{a,y}$) is provided as an input matrix to the model. The standard cohort equations are used to let a cohort evolve over time under the prevailing total mortality rate ($F_{a,y} + M_{a,y}$) and include a process error. A Beverton-Holt stock-recruitment relationship is applied. There are three observation equations that link stock state to the indices; one for the TEP index, one for the LAA proportions and one for the total landings.

The following settings were used:

- Age classes 1 to 10 with a plus group
- Time-invariant flat-topped fishery selectivity from age 5 onwards
- Relative TEP index (survey catchability estimated)
- Age-class dependent process errors (σ_{N1}^2 for *a* = 1 or recruitment, σ_{N2+}^2 for *a* = 2–10)
- Age-class dependent observation errors for LAA proportions (σ_{lp-A}^2 for *a*=1, σ_{lp-B}^2 for *a*= {2, 7–9}, σ_{lp-C}^2 for *a*={3–6}; note that there is no *a*=10 because of the continuation ratio logit transformation)
- Recruitment follows a 2-parameter Beverton-Holt stock-recruitment relationship.
- Annual fishing mortality (Fbar) is standardly presented as the average of fully selected age classes (5 to 10), which also corresponds to the value of F_y
- Relative timing of the survey/spawning (ts) set to 0.47 (June 21st)
- M = 0.28 (constant over time and age). This value was lower than used in the previous assessment (0.3 in Van Beveren et al. 2023a, see section 2.9.2.4 for details).

The following input data were used:

- Index data (with observation error):

1. Landings (Table S 7): the model is denoted “censored” as it uses an approach in which true removals are assumed to fall between a lower and an upper limit, where the lower limit is based on Canadian recorded landings and a minimum amount of U.S. landings (lower limit = recorded Canadian landings * 110% + 20% * U.S. landings) and the upper limit is based on an estimated ceiling for Canadian landings (Van Beveren et al. 2017); section “landings”) and a maximum amount of U.S. landings (upper limit = estimated Canadian upper limit + 80% * U.S. landings). As in the previous assessment, we assumed that the proportion of northern contingent fish within U.S. landings ranged from 20–80%. U.S. statistics included fish landed commercially, for recreational use, and discards.

   In 2023, U.S. recreational fishery projections exceeded commercial quotas for the first time. In the U.S., recreational fishing is most popular during summer when the northern contingent is absent. In contrast to previous assessments, we only included fish landed for recreational purposes in March-April and November-December (recreational landings * % of fish caught outside summer). Recreational fishing is not monitored during January-February but landings are assumed to be zero. US recreational fishery data were not available prior to 1981 and for 2022–2024. We applied the average of 2020–2021 to 2022–2024.
2. LAA (Table S 8)
3. TEP (Table S 9)

- Data to transform quantities (no observation error):

1. Stock weight-at-age on July 1st and January 1st (Table S 10)
2. Catch weight-at-age (Table S 11)
3. Maturity-at-age (Table S 12)
4. Fecundity-at-age (Table S 13)
5. Proportion of females-at-age: constant 0.5 since the 2023 assessment.

2.9.2. Key sensitivity runs

In this assessment we build on previous sensitivity runs and model selection. Based on the work of Van Beveren et al. (2023a), we start the model in 1969, used historic estimates of LAA for the period 1969–1975 and short-term interpolations of biological data for 1969–1972.

For this assessment, we evaluate the model's sensitivity to a set of assumptions described in this section. We compared AIC, trends in biomass, Fbar and recruitment and residuals when appropriate. Note that residuals were always very similar among runs and are only mentioned when noteworthy. Note that AIC cannot be used to compare among models with changes in data (i.e., egg survey, U.S. recreational fishery).

2.9.2.1. Upper and Lower catch limits

Because we reduced the U.S. recreational landings that could include northern contingent fish, relative to the last assessment, and acknowledge the remaining uncertainty, we verified the sensitivity of model outputs considering: 1) the adjusted time series of U.S. recreational landings (described above), 2) all U.S. recreational landings (March-December), and 3) no U.S. recreational landings. The model outputs were as expected similar up to 2022 when U.S. commercial landings were relatively higher. For 2023–2024, F was highest when considering all recreational US landings. Biomass and recruitment were, however, very similar among runs. The adjusted-for landings (1) are used within the stock assessment.

We further evaluated the sensitivity to the assumption that the proportion of the northern contingent in the US fishery is 20–80%. Additional runs were fitted with 25–50% as in Smith et al. (2022) and 50–75%, to ensure that this assumption does not meaningfully impact results.

2.9.2.2. Landings-at-age

1. Landings-at-age for 2022–2024 were set using 1) the default approach, 2) a modified estimate of LAA for 2022–2023 and 3) a modified estimate for all three years (2022–2024). The modified LAA decreased the proportion of age 2–3 fish and increased the proportion of age 4–10. For 2023, the proportion of age 3 fish increased along with the older age classes. The AIC was lowest for the default LAA while the modified 2022–2023 was preferred compared to the modified 2022–2024 approach. The modified version of LAA was thought to be the most realistic, as less weight was given to the large number of young fish caught in Maritimes region.
2. Various combinations of parameter sets for the variance of LAA proportions (σlp) were tested and presented in Figure S 2. The variance is allowed to be greatest for age 1 since these fish are rarely present in the catches. Ages that are not full selected by the fishery (2 or 2-3) or are rare because of the truncated age structure (5-9 or 7–9) likewise have separate variance. The lowest AIC suggested the use of σ^2_{lp-A} for a=1, σ^2_{lp-B} for a= {2,7–9}, σ^2_{lp-C} for a={3–6}.

2.9.2.3. Fishery selectivity

In the base model runs, selectivity-at-age follows a time-invariant flat-top curve where selectivity for ages 5–10 is 1. As mentioned earlier, fishery selectivity might have changed over time in part because of the 2022 closure. Since the scientific sampling program has been conducted for three years at the time of the assessment, we assigned blocks of years representing the major changes in selectivity, which was cross-evaluated with the use of the modified LAA (three selectivity assumptions x three LAA assumptions):

1. No time-varying selectivity, default LAA.
2. No time-varying selectivity, modified 2022–2023 LAA.

3. No time-varying selectivity, modified 2022–2024 LAA.
4. Time varying selectivity: block 1=1969-2021,2024 and block 2=2022–2023; default LAA.
5. Time varying selectivity: block 1=1969–2021 and block 2=2022–2024; default LAA.
6. Time varying selectivity: block 1=1969-2021,2024 and block 2=2022–2023; modified 2022–2023 LAA.
7. Time varying selectivity: block 1=1969–2021 and block 2=2022–2024; modified 2022–2024 LAA.

An 8th run building on run 5 that accounted for a change in selectivity starting around 2000 (increase of seiners and landings in Newfoundland; Figure 1) did not converge.

Run 2 was selected. AIC suggested that accounting for time-varying selectivity (runs 4 to 7) was no better than using the modified 2022–2023 LAA (runs 2–3). Further, run 2 was similar to runs 4 and 5 in terms of AIC and predicted time series, but the predicted selectivity for 2022–2024 (lower for ages 2–3) was contrary to expectations. The selected run predicted the lowest F and was midrange for SSB and recruitment.

2.9.2.4. Natural mortality

A range of instantaneous natural mortality rates between 0.15 and 0.3 were tested. The AIC was lowest for 0.28 with negligible differences in stock trends compared to the M=0.3 used in the 2023 assessment.

2.9.2.5. Egg index

A first set of sensitivity runs was performed to assess and demonstrate the impact of spawning activity outside the sGSL. Recent egg surveys in western and southern Newfoundland (2021–2024; Figure S 3) and Van Beveren et al. (2023b) evidenced that although eggs can be observed outside the sGSL, their densities are relatively minor compared to those within the sGSL. The presence of a relatively large biomass of mackerel along western and southern Newfoundland shores, during the spawning season, might be less likely given the low overall productivity of the surface layer in these areas; the abundance of the two main zooplankton preys (*Calanus finmarchicus* and *C. hyperboreus*) is at least one order of magnitude lower than in the sGSL (Figure S 4).

To assess the impact of incomplete egg survey coverage on the estimated stock state, we performed an extreme and unsupported simulation, where the proportion of eggs missed by the sGSL egg survey increased up to 100% over the entire time series. This was done using non-stationary random walks and a logit transformation. Missing TEP were added to the original series before running the assessment model. Out of 200 runs, only one predicted that the stock was above the LRP. Consequently, observations of spawning outside the sGSL do not change our general perception of stock state (Critical Zone).

A second set of sensitivity runs focused on the years of index data to include:

1. Without 2022: The estimation of Sy for 2022 showed larger uncertainty related to the absence of samples from early in the spawning period (without indication of bias; Figure S 5).
2. Without 2023: TEP in 2023 showed some indication of positive bias (Figure S 5 and Figure S 6) and a large positive model residual (Figure S 7). However, excluding 2023 resulted in a likely unrealistically low prediction of SSB in 2024. While the TEP in 2023 might have been slightly overestimated, this value was retained.

3. Without uncertain years: TEP for 2006, 2017, 2019 and 2024 were excluded because the timing of the survey was outside of the 70% intervals of the timing of spawning (Figure S 8). These estimates were retained to generate the final model fit, as despite the presence of larger uncertainties, there was no evidence of bias (Figure S 5 and Figure S 6). Specifically, the estimated proportion of eggs spawned by the time of the survey aligned with the percentage of larvae observed, and there were no red flags in the data, the logistic model fit or the predictions. Although the model residuals associated with these years were above average, they were not conspicuously different from several other years.

2.9.3. Projections

Short-term projections (3 years) for a range of different Total Allowable Catches (TACs) were performed as a basis for advice for the 2025–2026 fishing seasons. Projection specifications and equations are provided in the supplementary information of Van Beveren et al. (2020). Projections included stochastically projected unaccounted-for catches of both Canada and the U.S. separately (i.e., implementation error). The TAC was added to these estimated catches to calculate total removals and the resulting next years' stock biomass. The TAC includes all landings considered to be under control of Fisheries Management, including from commercial, bait and S52 Licenses, and mackerel caught to bait tuna.

Canadian unaccounted-for catches were assumed to be limited to the recreational fishery, as the amount of unaccounted-for removals from other sources (bycatch, discards) was considered to be negligible (see results "landings"). Because of a bag-limit put in place and no indication that recreational fishing will decrease in the near-future, we drew independent values for each year from a normal distribution (N(433.5,123.25), generating results mostly within the range of 187 to 680 t; see Table S 3). Importantly, we made the assumption that if the fishery reopens (projections with TAC > 0 t), there will be no extra implementation error as all bait, commercial and bycatch landings will be reported and counted under the TAC (with no additional mortality from discards or other). A baseline scenario was also provided, in which Canadian total removals were set to 0 t (fishery closure with no unaccounted-for removals except recreational). Such a scenario is informative but unrealistic, as a minimum amount of removals should always be expected (bycatch, S52 Licenses, illegal fishing activity).

Future U.S. removals were assumed to be aligned with their projected 2024 and 2025 specification (2024 and projected-2025 specifications for the Atlantic). The U.S. had not determined a TAC for 2025–2026 before the northern contingent assessment. There is no feedback between the Canadian TAC and U.S. removals in our projections; i.e., an increase in Canadian TAC does not result in lower U.S. landings, despite that the U.S. has historically subtracted Canadian landings from their Allowable Biological Catch (ABC; see section 1.2). Future U.S. recreational landings were set as 12% (fish caught outside summer) of the average reported recreational fishery during 2020–2021. The U.S. catches were set between the minimum of recreational fishing (2,143 t * 0.12) and the maximum ABC (3200 t) while being centred around the sum of commercial quota, discards and the recreational fishery (1,240 t).

$$UScatch_{2025-2027} \sim pert(257,1240,3200)$$

Between 20 and 80% of U.S. landings were assumed to be from the northern contingent ($unif$(0.2,0.8)). No temporal autocorrelation was included and changes in absolute numbers from one year to the next could be high.

Recruitment can be forecasted using various methods, which generate meaningful differences (e.g., Van Beveren et al. 2021). Two different methods were used and presented; under scenario 1, recruitment was projected using the estimated Beverton-Holt stock-recruitment relationship (autocorrelation estimated over full time-series) and under scenario 2, the average

recruitment since 2011 was used (autocorrelation set to 0.9). We averaged the results generated by each approach and provided the range between brackets.

2.9.4. Reference points

Stock status in terms of SSB was defined relative to the official LRP and Upper Stock Reference point (USR), which were set as 40% and 80% of the SSB reference, respectively, in correspondence with the default approach outlined in the Canadian Precautionary Approach policy (DFO 2009). The biomass reference point ($SSB_{F40\%}$) for mackerel was previously defined as the SSB corresponding to F40%, a proxy for FMSY. F40% is the fishing mortality rate that reduces the spawning biomass-per-recruit to 40% of its unfished levels (Goodyear 1977; Shepherd 1982). $SSB_{F40\%}$ was calculated based on the average biological WAA and MAA of the last 15 years, and recruitment of the full time series.

2.9.5. Tmin

Tmin relates to the objective of the rebuilding plan to rebuild the stock above the LRP by 2040. We recalculated Tmin to evaluate whether stock rebuilding is within the timeline originally planned. Van Beveren et al. (2023a) projected that the stock could get out of the Critical Zone with a 75% probability around 2029. The minimum time to rebuild was estimated by projecting the stock 10 years into the future, using either F=0 or TAC = 0 t. In the latter scenario, a small implementation error was added for U.S. catches, identical to the one used for short-term projections (i.e., future U.S. landings between 257 t and 3,200 t, with the highest likelihood at 1240 t). Forecasts over medium- to long-term periods can be highly sensitive to a range of model or data assumptions. We performed forecasts for Tmin using five different operating models (Table 1, which reflect key framework uncertainties already highlighted during the Management Strategy Evaluation; Van Beveren et al. 2020). Each model differed in one aspect from the base model, which was defined as the assessment model with recruitment projected using the Beverton-Holt stock-recruitment relationship (Table 1).

The SSB that corresponds to 75% probability of being above the LRP was calculated using a new approach. First, we obtained the average and coefficient of variation (CV) of all SSB estimates over the 1969–2024 period. A new fine-scale continuous sequence of SSB was then simulated, ranging between the minimum and maximum estimates of the time series, to which we applied the averaged CV ($\overline{CV}$) and its lower and higher 95% confidence intervals (CI; $\overline{CV} \pm 1.96 * \sigma_{\overline{CV}}$). For each simulated SSB, the probability of being above the LRP was calculated based on the three CVs (average, lower and upper value), back-transformed to standard error. The desired output corresponded to the biomass (average and 95% CI) associated with a 75% probability. All calculations were done on log-transformed values.

Table 1. Details of the operating models used to determine Tmin.

Operating model name	Details
OM.base	Assessment model (with Beverton-Holt recruitment projections)
OM.recmean	projections using average recruitment (2011–2024)
OM.M0.25	M = 0.25
OM.US25–50	25–50% of US landings
OM.US50–75	50–75% of US landings

2.10. ADDITIONAL BIOLOGICAL INFORMATION

2.10.1. Length at 50% maturity

Length at 50% maturity (L50) is not used within the assessment model but is presented as a biological indicator that can reflect fishery-induced changes in maturation (Lappalainen et al. 2016), changes in environmental conditions, and density-dependent mechanisms (Cardinale and Modin 1999; Meyer et al. 2003). Importantly, this information can also be used to help establish minimal legal fish sizes. Because of its use as a biological indicator, L50 was computed by cohort rather than annually, which has more biological meaning as it better reflects the life history of mackerel. One maturity ogive by cohort (1973–2021) was fitted to estimate L50, using a generalized linear model (GLM) with a binomial distribution and a logit link function and with maturity class as the binary response variable (immature = stages 1 and 2, mature = stages 3 to 8, following the staging key of Maguire 1981) and length as the explanatory variable. There was insufficient data to consistently use additional explanatory variables for all cohorts (e.g., month, gear, region). We instead subsetted commercial port sampling data for May-July, which corresponds to the early fishing season. Fitted models were bootstrapped over 999 iterations using the “car” package in R to produce 95% confidence intervals. Cohorts with fewer than 10 immature individuals, a poor model fit (i.e., 1990), or insufficient age classes (i.e., the most recent cohorts) were excluded.

2.10.2. Fishery impact during spawning

There is concern that fishing during the spawning season (June-July) is more harmful to the stock’s reproductive potential, relative to fishing that occurs after spawning. A temporal fishery closure has been suggested to limit such an effect. Fishery closures during spawning were, for example, implemented for herring (Molloy 1989), demersal fishes (Jaworski et al. 2006), cephalopods (Moltschaniwskyj et al. 2002), lobster (Ennis 2011), and reef fishes (Sadovy and Domeier 2005), with varied success. Overzee and Rijnsdorp (2015) reviewed the factors that affect the efficiency of these closures, which include 1) fishing mortality, 2) spawning disturbance, 3) spawning habitat and 4) population biology. We reviewed these factors for mackerel based on available evidence from the literature and fisheries data.

3. RESULTS

3.1. LANDINGS

Recorded commercial and bait landings of mackerel within Canadian waters ranged between 4.3 kt and 55 kt prior to the 2022 fishery closure (1968–2021; Figure 1). Earlier in the time series, most landings were recorded from the Scotian Shelf (NAFO 4VWX5YZ) but by the late 1990s, the sGSL (4T) became the dominant region for mackerel fishing. Annual landings increased substantially from 2000 to 2010, reaching record highs of around 53–55 kt between 2004 and 2007. This period of greater landings was due to a marked increase in fishing effort by small and large seiners off the coasts of Newfoundland (3KL and 4R), and coincided with the arrival of the large 1999 year class. This period was followed by a large decrease in landings that reached 4,272 t in 2015. The TAC was reached for the first time the year after (2016 TAC of 8,000 t) and has since limited total landings, with the exception of 2017. At the time of this assessment, recorded Canadian mackerel landings for 2023 and 2024 were 118 t (TAC 0 t) and 454 t (TAC 470 t), respectively. The bait fishery was closed in 2024 after reaching 440 t of bait landings. Mackerel caught and used for bait in the 2023–2024 tuna fishery (20 mackerel per day per fisher) were not included. The last two years’ landings were preliminary.

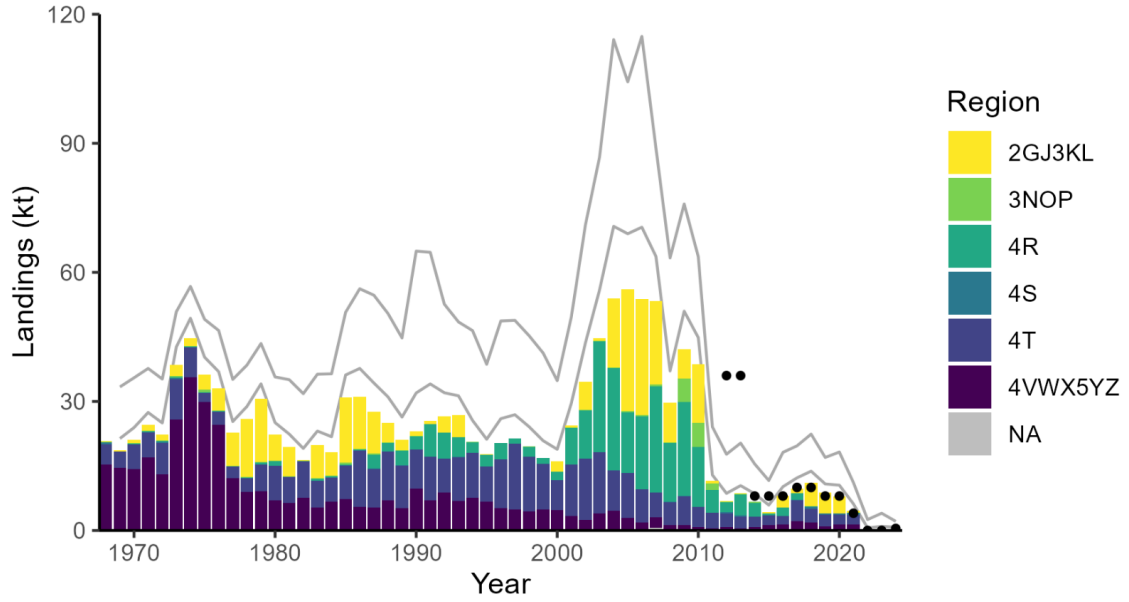

Figure 1. Mackerel landings (1968–2024) from Canadian waters (kt). Bars show recorded landings by NAFO division(s). Dots indicate the Total Allowable Catch (TAC; earlier TACs are not shown because they were set for the entire West-Atlantic mackerel stock). The grey lines represent the upper and lower bounds between which total removals are estimated in the stock assessment model.

Catches under Section 52 licenses totalled 19, 23 and 15 t in 2022, 2023 and 2024, respectively (maximum preliminary numbers used for certain samples). Catches were made by all regions and were, because of the higher number of samples requested in June and July, largest in July (Figure S 9).

3.2. LANDINGS-AT-AGE

Strong year classes (e.g., 1968, 1973, 1974, 1982, and 1999) were apparent in the annual landings-at-age data (Figure 2) and their progression from year to year could easily be tracked. Mackerel 10 years and older were more common prior to the late 1990s. Since then, the age structure of the catches became increasingly truncated. By the early 2010s, fish older than 6 years were uncommon in the catch. The last notable cohort that could be tracked in the catch was produced in 2015. In 2023–2024, landings were dominated by age classes 2 and 3. The combined proportion of ages 2 and 3 were estimated at 65 and 59% of landings for 2023 and 2024, respectively.

Because of the fishery closure in 2022 and 2023, the default estimated age composition of the landings for these years (bycatch and experimental fishing licenses) resulted from an abrupt change in fishery selectivity, hindering comparison with previous years. Below we present a partially corrected estimate of LAA (following Van Beveren 2024), which assumes that landings in 2022–2023 were made similarly to previous years (see Sensitivity analyses in section 2.9.2.2 for 2024). For instance, landings and thus samples from the sGSL and Newfoundland collected later in the year were assumed to be more important than in reality, to avoid major changes in fishery selectivity. There was no evidence that fish age 5+ represented or would have represented an important part of the landings. LAA excluded landings from the S52 licences.

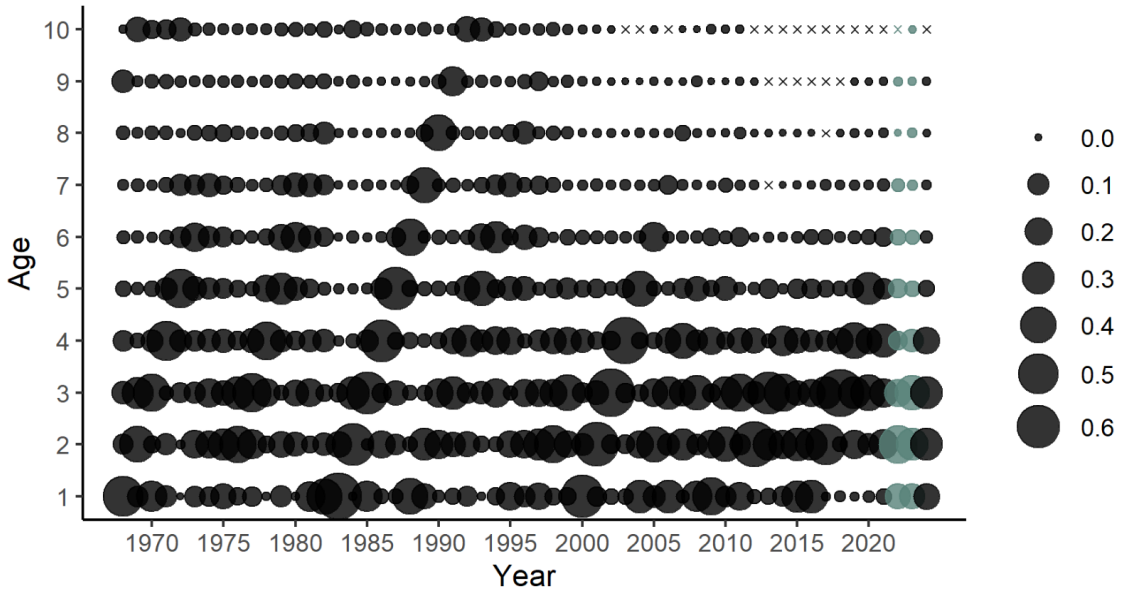

Figure 2. Bubble plot of mackerel landings-at-age (ages 1–10+) from 1968–2024 (annual proportions). Crosses represent zeros. The time series is a combination of historic (1968–1975) and revised (1976–2024) estimates. Note that 2022–2023 are distinct from previous years as estimates are based on a theoretical distribution of landings (green).

3.3. TOTAL EGG PRODUCTION

The time series of Total Egg Production (Figure 3) showed that despite large variability between some years, the total number of eggs produced has been declining to historic lows in the past decade. Prior to 1995, egg production was around 500 trillion eggs; TEP then dropped by about an order of magnitude over the period 1994–1999. Between 2002 and 2004, TEP was at higher levels again (average of 260 trillion eggs), corresponding with the strong 1999 cohort (see LAA). Since 2006, TEP has remained low (<100 trillion eggs). The estimated value for 2023 (76 trillion eggs) was the highest since 2019 (100 trillion). Nevertheless, the index decreased in 2024 to a level similar to 2021, thus becoming the second lowest of the time series after 2012 (11 trillion eggs). Measured egg densities are presented in Figure S 3 and Figure S 4.

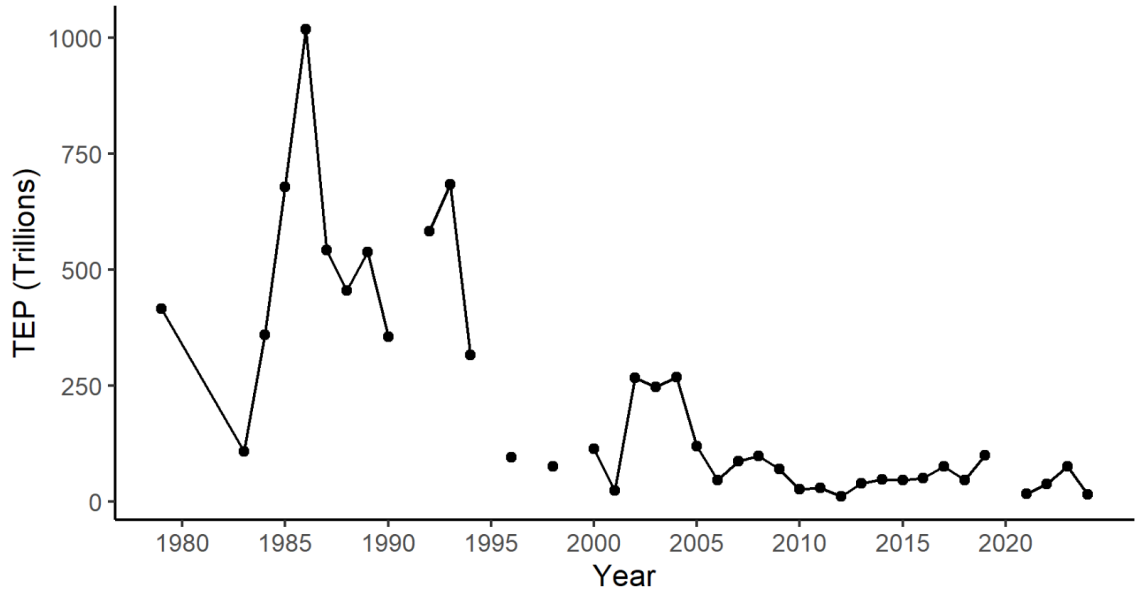

Figure 3. Total Egg Production derived from the annual mackerel egg survey in the southern Gulf of St. Lawrence (1991 and 1999 were removed because of bias).

3.4. MATURITY-, WEIGHT AND FECUNDITY-AT-AGE

Nearly all mackerel (>95%) are mature by age 3 (Figure 4A). The proportion of mackerel mature at age 2 was estimated to be around 0.77 (range: 0.56-0.90). Only about 1 out of 3 age-1 fish reach maturity each year (0.02-0.48). The interannual variability in the proportion of mature fish of age 1 and 2 cannot be precisely estimated and depends on the level of smoothing used. Weight-at-age of mackerel was lowest at the beginning of the time series (1968–1974; Figure 4B). The largest growth was observed in cohorts spawned in and around 1980. The average weight of fish for any given age class has since remained rather stable. On average, an age 1 mackerel weighs about 140 g, whereas by age 10+ they reach 750 g. Weight-at-age of fish in the landings follows a similar pattern (Figure S 1; unsmoothed to ensure the product of landed fish weights and numbers total reported landings). Fecundity-at-age has slightly increased from about 2000 to 2020, with a slight decrease after that (Figure 4C). An increase in fecundity indicates that for the same amount of TEP observed, less fish should be present in the water. This change is driven by the observed increase in the GSI of stage 5 females (ready to spawn), which is unrelated to sampling factors such as the collection date. The presented values are smoothed, and it should be noted that the exact level of interannual variability is again unknown.

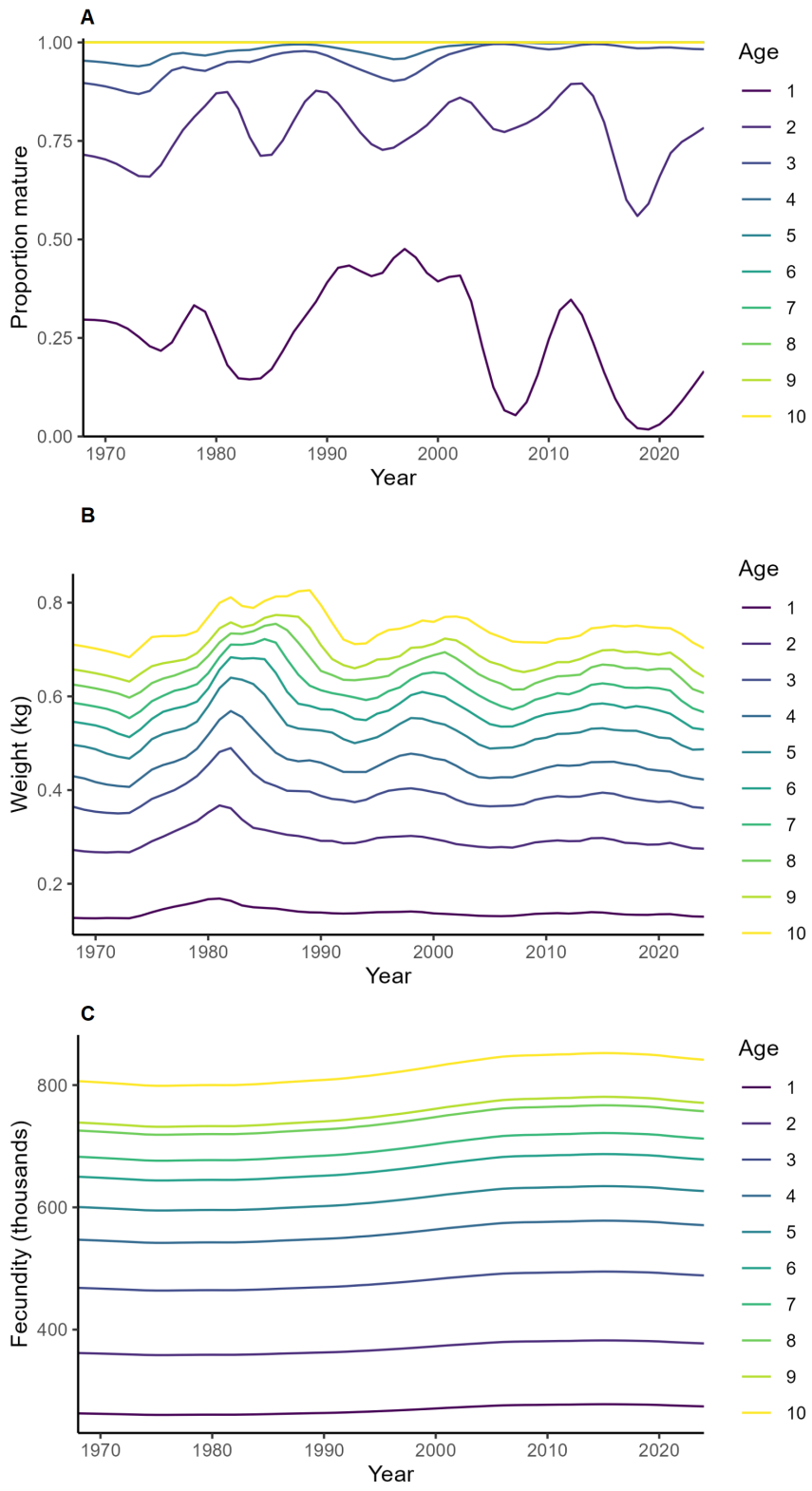

Figure 4. Maturity-(A), stock weight-(B) and fecundity-at-age (C) from 1968 to 2024. Age classes are indicated by different colours (age 1 = purple, age 10+ = yellow).

3.5. STOCK ASSESSMENT MODEL

3.5.1. Validation and robustness

Residual plots and retrospective patterns are shown in Figure S 7, Figure S 10, and Figure S 11. Retrospective peels with end years 2023 and 2019 did not converge. The largest pattern was for the 2020 peel, for which there was no egg index (due to COVID). Retrospective changes were considered acceptable as there was no consistent pattern over time (negative or positive), and peels where within the current confidence intervals. There were four outliers in the TEP index, suggesting that TEP in 2001, 2006, 2010 and 2012 were underestimated and the TEP in 2023 was overestimated. In some previous assessments, or with model runs with a lower M, there was a linear decrease over time in the residuals of Total Egg Production (e.g., Fig. S3 in Smith et al. 2022). This pattern was largely removed by increasing M, as under the assumption of a more productive stock, relatively fast changes in TEP can more easily be tracked (Van Beveren et al. 2023a). Sensitivity tests demonstrated that the model output was also robust against various assumptions (U.S. fishery, LAA, TEP, etc.; Figure S 12). Estimated model parameters are presented in Table S 6 and the derived estimates in Table S 15. Estimated annual numbers-at-age in the stock are presented in Table S 16 and annual age-specific fishing mortalities in Table S 17.

3.5.2. Output

Estimated SSB decreased below the LRP (40,921 t) in 2011 (Figure 5A, Figure S 13 and Table S 15, $SSB_{F40\%}$ = 102,303 t). With the arrival of the 2015 cohort, the ratio between SSB and the LRP increased to around 1 in 2017 and 2018 (0.92 and 0.96, respectively), but subsequently decreased to lower levels into the Critical Zone again. SSB was estimated to be at 32% and 35% of the LRP in 2023 and 2024, respectively. The last notable recruitment event was in 2015, but this cohort only represented a minor fraction (less than 0.2%) of the stock in 2023 and 2024 Figure 5B-C. There was no indication of substantial recruitment since 2015 (Table S 15). Fishing mortality rates (including catch uncertainty) are below the reference level (F40% = 0.59) since 2022 as a result of the fishery closure and low U.S. landings (Figure 5E-F, Table S 15). According to the model, the estimated fishing mortality rates on fully exploited mackerel (ages 5 to 10) in 2023 and 2024 were 0.52 (0.14-1.8 95%CI) and 0.33 (0.1-1.1 95%CI) respectively. Although exploitation rate is usually given for fish that are fully recruited to the fishery, these mackerel do not compose a large fraction of the population anymore (Figure 5B). The fishing mortality rate across all age classes, weighted by their abundance, was 0.17 and 0.12 for 2023 and 2024. Estimates of fishing mortality for the terminal assessment year showed a large confidence interval because of the explicitly acknowledged large uncertainty in total removals (censored approach). Fishing mortality in 2022–2024 could be somewhat overestimated because of the sharp decrease in overall removals in combination with the use of a random walk to track annual F and the imposed flexibility to estimate catch.

3.5.3. Projections

Projected short-term trends in SSB with respect to the LRP are provided in a decision table for different TACs and two recruitment scenarios (Table 2). The level of unaccounted-for catches for each TAC scenario is shown in the grey columns and the distribution of these values is plotted in Figure S 14. The probability of reaching the LRP (40,921 t) by 2027 with a TAC of 0 t (but with a recreational and U.S. fishery) was estimated to be around 30% (range shows values from each recruitment scenario). This probability decreased to 19% with a TAC of 4,000 t (TAC of 2021). With a TAC of 500 t, there was a high likelihood that the SSB will increase by 2027

(>75% probability). With a TAC between 1,000 t and 3,000 t, this likelihood was moderately high, whereas for higher TACs there was either a neutral or low probability of stock growth.

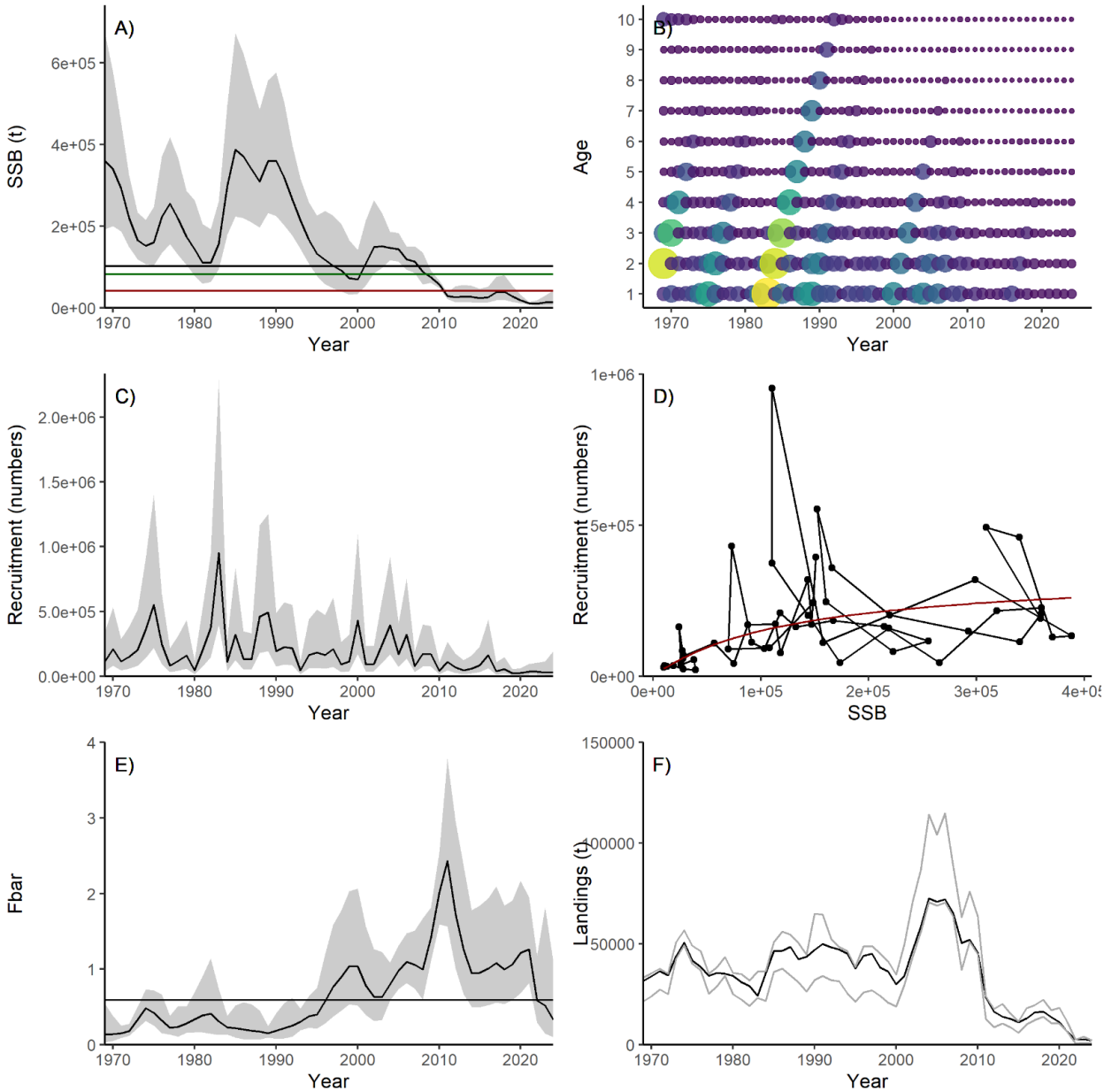

Figure 5. Model output: (A) Spawning Stock Biomass (SSB) in June (t) horizontal lines indicating the SSB reference point ($SSB_{F40\%}$; black), the Upper Stock Reference point ($80\%SSB_{F40\%}$; green) and the Limit Reference Point ($40\%SSBF_{40\%}$; red), (B) numbers-at-age in the stock (with the largest abundances indicated by large yellow bubbles), (C) recruitment (age 1, numbers), (D) stock-recruitment, (E) fishing mortality, Fbar (averaged over the fully selected age classes 5–10), (F) estimated catch (t, black) between the pre-determined bounds (grey).

Table 2. Three-year projections under different constant Total Allowable Catch (TAC). The TAC includes all landings considered to be under control of Fisheries Management, including from commercial, bait and S52 Licenses (~20t), and mackerel caught to bait tuna (~20t). Projections were performed under the assumption that mackerel will also be caught outside of the TAC, by both the Canadian (recreational fishing) and U.S. fleets (shaded columns; 95%CI, time invariant). Recruitment was projected using two different methods (individual values in grey), and the average of both is provided in black. For each TAC scenario, the probabilities of June spawning stock biomass (SSB) being greater than the Limit Reference Point (SSB/LRP) in 2026 and 2027 are provided. The probabilities of SSB growth from 2025 to 2027 are also provided ($SSB_{2027} > SSB_{2025}$). The ratios between SSB with respect to the LRP (SSB/LRP) for each scenario are likewise given for 2026 and 2027.

TAC (t)	Prob(SSB > LRP)		$SSB_{2027} > SSB_{2025}$	SSB/LRP		Unaccounted-for landings			
						Canada		U.S.	
	2026	2027		2026	2027	2.5%	97.5%	2.5%	97.5%
0	21% (21-21%)	30% (30-30%)	81% (78-84%)	0.56 (0.55-0.56)	0.66 (0.64-0.67)	192	674	154	1,678
250	20.50% (20–21%)	29% (29-29%)	78% (74-82%)	0.54 (0.54-0.55)	0.64 (0.62-0.65)	192	674	154	1,678
500	20.50% (20–21%)	28% (28-28%)	75% (71-79%)	0.54 (0.53-0.54)	0.62 (0.6-0.63)	192	674	154	1,678
750	19.50% (19–20%)	27% (27-27%)	72.50% (68-77%)	0.52 (0.52-0.53)	0.6 (0.58-0.61)	192	674	154	1,678
1,000	19.50% (19–20%)	27% (27-27%)	69.50% (65-74%)	0.52 (0.51-0.52)	0.58 (0.57-0.6)	192	674	154	1,678
2,000	18.50% (18–19%)	24% (24-24%)	59% (54-64%)	0.47 (0.47-0.47)	0.51 (0.5-0.52)	192	674	154	1,678
3,000	17% (17-17%)	21.50% (21–22%)	51% (46-56%)	0.42 (0.42-0.43)	0.44 (0.42-0.46)	192	674	154	1,678
4,000	16% (16-16%)	19% (19-19%)	44% (40-48%)	0.38 (0.38-0.38)	0.37 (0.35-0.39)	192	674	154	1,678
6,000	13% (13-13%)	16% (16-16%)	33% (29-37%)	0.3 (0.29-0.3)	0.24 (0.22-0.27)	192	674	154	1,678
8,000	12% (12-12%)	13% (13-13%)	27% (23-31%)	0.23 (0.23-0.24)	0.18 (0.16-0.2)	192	674	154	1,678

3.5.4. Tmin

The minimum time for the stock to get out of the Critical Zone (F=0) with a 75% likelihood was estimated at 7 to 10 years (9 years for the base model; Figure 6). Under a scenario in which the U.S. would remove up to 1,240 t annually (2025 projected removals, including discards and US recreational fishing), this rebuilding time would be between 8 and 11 years (11 years for the base model; Figure 6). The probability of getting out of the Critical Zone increased directly from 2025 onwards. Tmin was higher when mortality was lower which is consistent with a less productive stock (i.e. lower predicted recruitment). It was also higher if U.S. catches contained a lower percentage of Canadian catches for similar reasons. The Tmin estimated is slightly higher

compared to Van Beveren et al. (2023a). The rebuilding of the stock out of the Critical Zone, with a 75% probability, is pushed back from around 2028–2029 to around 2031–2033.

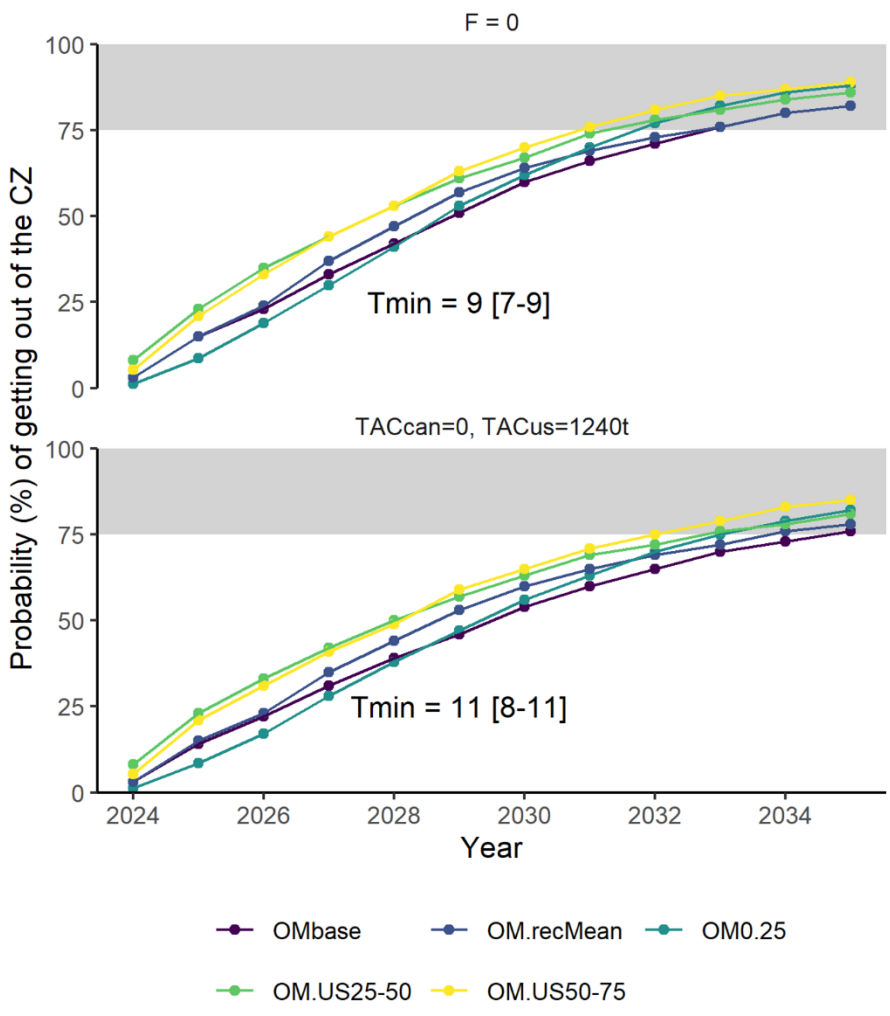

Figure 6. Probability (%) of getting out of the Critical zone (CZ) within the next 10 years, under F = 0 and TACcan = 0 t (no mackerel catches within Canadian waters, but some U.S. fishing). The minimum time to rebuild with a 75% probability under the base operating model (OMbase) is annotated and the range of values across operating models (OM; Table 1) is provided between square brackets.

There is no fixed SSB associated with a 75% probability of being above the LRP. The higher SSB and the lower the estimation error, the more likely this probability threshold will be reached. However, based on historical SSB estimates, which typically have less uncertainty associated with them than terminal year estimates, a 75% probability of being above the LRP is expected to correspond to a biomass roughly around 1.19 times the LRP (95%CI: 1.03-1.37; Figure S 13).

3.6. ADDITIONAL BIOLOGICAL INFORMATION

3.6.1. Length at 50% maturity

The L50 of the 1974–2021 cohorts has fluctuated between 243 mm and 298 mm, with a time-series mean of 265 mm (Figure 7). The L50 of the last two cohorts (2020 and 2021) was

255 mm (95%CI: 253–257 mm) and 246 mm (95%CI: 243–249 mm) respectively. Since the 2014 cohort, the L50 has been below or near the current minimum commercial length of 268 mm but has not reached a time series record.

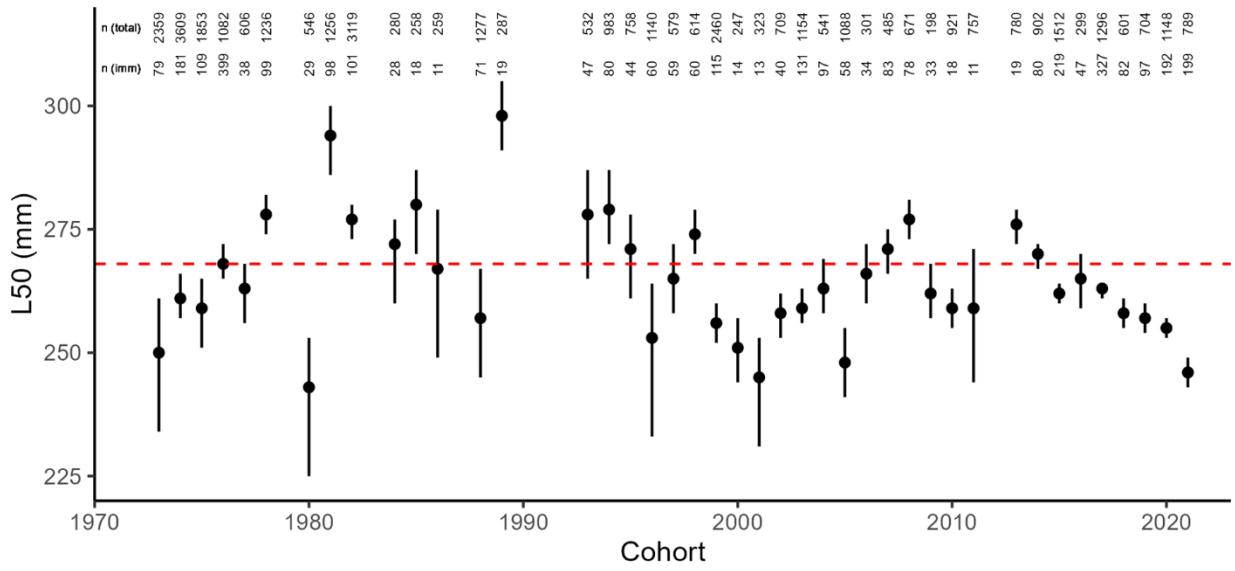

Figure 7. Length at 50% maturity (L50, mm) by cohort (1974–2021) with a 95% confidence interval. The horizontal red line indicates the current minimum commercial length of 268 mm. Numbers of individuals used to calculate the L50 of each cohort (n total) as well as the number of immature individuals (n imm.) are displayed at the top of the figure.

3.6.2. Fishery impact during spawning

3.6.2.1. Fishing mortality

An argument for closing the fishery during the spawning season (June-July) is that fishing during this particular period may be either more selective for specific groups or more efficient, resulting in higher fishing mortality. Fishing during the spawning period can induce different fishing pressure on age groups, sexes or maturity stages. For example, chances of catching older age classes may be higher during the spawning period as they gather on spawning grounds. Consequently, the selection of older age classes would enhance the truncation of the age and size structure.

In the sGSL, there is a switch in gear efficiency and usage around or after the peak of spawning. Gillnets are preferably used until July but harvesters prefer lines and hooks later in the season (Figure S 15). The shift in gear type is believed to reflect a change in mackerel ecology between pre-and post-spawning. We thus analyzed changes in fishery mortality in gillnetters landings. Landings were proportionally higher for gillnetters during the spawning season, as expected, but with the exception of ages 1–3, older fish were not targeted notably more during spawning (Figure S 16). Young mackerels were mostly caught after the spawning period (see Figure S 16 and Van Beveren et al. 2023b for more information on the timing of the fishery). We likewise found no evidence of differential pressure on each sex between fishing periods (spawning vs outside spawning) with the median of the sex ratio very close to 0.5 during or outside spawning (Figure S 17).

The average landed weight per trip by gillnetters is also similar during or after spawning (Figure S 18), indicating that fishing efficiency is not meaningfully higher during the spawning season.

Combined, the available evidence on temporal fishery selectivity and effectiveness suggests that fishing during the spawning period is not more harmful than outside of this period.

3.6.2.2. Spawning disturbance

Fishing activities may disturb the natural behaviour of fish during the spawning period and adversely affect the quantity or quality of the offspring produced (Mitcheson and Erisman 2012). For example, escaping the nets or vessel noise may generate a physiological response that may delay spawning or deteriorate the eggs.

Walsh and Johnstone (1992) observed that a small group of mackerel bursts away from the school when ready to spawn. Spawning probably occurs at the end of the speed burst away from the school after which the fish reintegrated the school. We found no evidence that fishing during spawning, usually with gillnets, may affect the physiological response of mackerel to the extent that it would impact its reproductive capacity. Mackerel uses a bet-hedging strategy when spawning; each female can spawn several times (i.e., batch spawning), and spawning can happen throughout the daily cycle. Therefore, spawning disturbance by fisheries is expected to be minimal.

3.6.2.3. Spawning habitat

The pelagic gears used for mackerel fishing are unlikely to cause damage to the pelagic spawning habitat.

3.6.2.4. Population biology

Fishing during the spawning period may impact 1) the number or quality of eggs which can affect recruitment, and 2) stock structure (genetics) because of selection on distinct stock components.

Harvesting a fish during the spawning season has the same demographic effect as removing it at any earlier point in its life, provided that earlier removal does not cause changes in subsequent natural mortality rates. Alternatively, removing a fish during spawning may directly reduce the reproductive output of the population similarly to removing a fish in the post-spawning period of the previous year. Additionally, the stock-recruitment relationship shows that a decrease in June-July biomass driven by the spawning season fishery is likely to have a limited impact on recruitment. This impact is also assumed to be much smaller than the effect of environmental stochasticity on recruitment (Brosset et al. 2020). There is therefore currently no evidence that fishing during the spawning season would have a direct and significant effect on the stock's reproductive potential.

Bourret et al. (2023) found no genetic differences among mackerel in Canada's NAFO divisions, suggesting that this contingent consists of one single population. Although mackerel can spawn outside the sGSL, the large majority share this single spawning area. Fishing pressure during the spawning season in the sGSL is thus unlikely to target a genetic subpopulation. Further, fishing pressure is not concentrated during the spawning season (Figure S 19). While the selection of larger (and older) individuals may induce evolutionary change, we found no evidence that older fish or other particular subcomponents of the population are heavily targeted during as opposed to outside the spawning period (see section 3.6.2.1).

There is currently no evidence that fishing on spawning grounds during the spawning period is more selective, more efficient or causes habitat or spawning disturbances that could negatively

4. DISCUSSION

4.1. ECOSYSTEM CONSIDERATIONS

No new evidence is available since the 2023 assessment. Therefore the information presented below is similar to that reported by Van Beveren et al. (2023a). Ecosystem considerations should be re-evaluated in the near-future considering the changes observed in the ecosystem since their effects on mackerel was last assessed (Brosset et al. 2020).

4.1.1. Ecosystem effects on the stock

This section summarizes available knowledge on how ecosystem factors affect three fundamental productivity processes (recruitment, natural mortality and growth) which determine the rate at which the mackerel stock will rebuild, and how this knowledge was integrated within the assessment.

The drivers of northern contingent mackerel recruitment variability have been analyzed several times (Runge et al. 1999; Castonguay et al. 2008; Plourde et al. 2015). The latest and most in-depth study demonstrated that mackerel recruitment is determined by stock state (including SSB and maternal body condition) and larval food conditions; the intensity of the spatial and temporal match between specific larval prey and egg production is correlated to recruitment strength (match- mismatch hypothesis; Brosset et al. 2020). Between-year changes and within-year gains in body condition, partially driving recruitment, also show correlation with plankton abundance and phenology (Plourde et al. 2015; Smith et al. 2020). This knowledge could theoretically be used to inform one-year ahead predictions of recruitment. However, projections are currently performed over a three-year period and although the first projected year is most influential, the demonstrated fine-scale nature of the recruitment process makes ecosystem-informed longer-term projections extremely hard. In the absence of directional trends in known environmental drivers, we acknowledge uncertainty in future recruitment by stochastically projecting this process under different statistical assumptions.

Natural mortality caused by a range of predators can be substantial, especially when SSB is low (Van Beveren et al. 2024). There is currently no evidence that natural mortality had a key role in causing the stock decline (no corresponding increase). Under lower SSB, predators are, however, likely to remove a relatively larger proportion of the stock and an increase in M will affect stock rebuilding. Although an effort was made to estimate a minimum biomass removed by predators, this information remains uncertain and this uncertainty, compounded with technical challenges, currently prevent its explicit incorporation into the assessment model.

The ecosystem factors affecting northern contingent mackerel growth have not yet been specifically investigated. Mackerel WAA, used as an assessment input, also does not display prominent patterns over time, and small-amplitude variations caused by changing environmental conditions do not significantly affect the assessment. Although ecosystem components associated with mackerel growth are currently unaccounted-for, they are considered to be of minor importance in determining stock productivity relative to recruitment and natural mortality.

Although environmental conditions drive the annual mackerel migration pattern (see Van Beveren et al. 2023b for a summary of available knowledge), there is currently no evidence that changes in spatial distribution have a direct impact on stock productivity and thus rebuilding.

4.1.2. Fishery Effects on the ecosystem

Atlantic mackerel is a forage fish species in the middle of the food web (e.g., Savenkoff et al. 2005). They play a key role in the ecosystem through the transfer of energy from lower trophic

levels to higher-order predators. The effect of fishery-induced changes in mackerel stock state on most predators is unknown, with the exception of northern gannets. This seabird species is the only predator known to feed predominantly on mackerel when they are available. The decline in breeding success of northern gannets in the sGSL has been associated with the decrease in mackerel SSB (Guillemette et al. 2018; d'Entremont et al. 2021 ; Pelletier and Guillemette 2022).

Bycatch of other species in the mackerel fishery is small and not known to significantly affect these stocks.

4.2. PROBABLE CAUSES OF STOCK DECLINE

This assessment supports the conclusion of the 2023 assessment that the fishing pressure is the most likely cause of decline. During the stock's decline into the Critical Zone (2005–2011), total landings were high and estimated fishing pressure was above the reference level. Age truncation typically results from overexploitation or increased natural mortality of older fish, as it cannot result from higher age-independent mortality or reduced recruitment. There is currently no evidence that natural mortality increased during that period (Van Beveren et al. 2024) or that recruitment was low (Figure 5). Habitat loss or degradation is of no known concern to this stock.

4.3. QUALITY OF THE ANALYTICAL ANALYSIS AND DATA GAPS

Many of the key uncertainties within the data that were highlighted in previous assessments (e.g., related to total removals), as well as our knowledge of stock dynamics, have in large part been accounted for through the use of the current stock assessment model. Although uncertainties remain (see next paragraph), stock status trends across different indices are consistent and large enough to consider stock status robust. Model robustness to multiple data assumptions was verified in the 2023 assessment (Lehoux et al. 2024; Van Beveren 2024; Van Beveren et al. 2024; Boudreau et al. 2025). The trends and derived conclusions were consistent across a wide range of model sensitivity analyses.

The two main uncertainties are considered to be (not in order of importance) 1) potential variations in the natural mortality rate and 2) the proportion of northern contingent mackerel caught in the U.S. mackerel fishery (see Redding et al. 2020; Arai et al. 2021; Bourret et al. 2023). An increased appreciation of the level of mixing should improve model estimates and projections.

5. CONCLUSIONS

The northern contingent of West-Atlantic mackerel is currently in the Critical Zone as defined by DFO's PA framework (DFO 2009) and has been in or around this zone since 2011. The age structure of the stock is truncated and average recruitment has been low, in relation with SSB. Stock projections provided in Table 2 will allow decision makers to weigh the trade-offs between SSB and different TACs over a period of three years.

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8. SUPPLEMENTARY TABLES

Table S 1. Recorded landings of Atlantic mackerel. The United States (U.S.) total used within the assessment does not include landings from the Foreign fleet. U.S. recreational landings exclude summer landings which likely do not contain the northern contingent. Landings for the last 2 years are preliminary.

Year	Canada	Canada Foreign	Total	U.S. Commercial	U.S. Recreational	U.S. Comm	U.S. Total	Other
1968	11,118	9,720	20,838	3,929	NA	NA	NA	65,747
1969	13,257	5,379	18,636	4,364	NA	NA	NA	114,189
1970	15,710	5,296	21,006	4,049	NA	NA	NA	210,864
1971	14,942	9,554	24,496	2,406	NA	NA	NA	355,892
1972	16,253	6,107	22,360	2,006	NA	NA	NA	391,464
1973	21,566	16,984	38,550	1,336	NA	NA	NA	396,759
1974	16,701	27,954	44,655	1,042	NA	NA	NA	321,837
1975	13,540	22,718	36,258	1,974	NA	NA	NA	271,719
1976	15,746	17,319	33,065	2,712	NA	NA	NA	223,275
1977	19,852	2,913	22,765	1,377	NA	NA	NA	56,067
1978	25,429	470	25,899	1,605	NA	NA	NA	841
1979	30,244	368	30,612	1,990	NA	NA	NA	440
1980	22,135	161	22,296	2,683	NA	NA	NA	566
1981	19,294	61	19,355	2,941	1,661	NA	NA	5,361
1982	16,380	3	16,383	3,330	358	NA	NA	6,647
1983	19,797	9	19,806	3,805	2,162	NA	NA	5,955
1984	17,320	913	18,233	5,954	1,470	NA	NA	15,045
1985	29,855	1,051	30,906	6,632	1,875	NA	NA	32,409
1986	30,325	772	31,097	9,637	2,175	NA	NA	26,507
1987	27,488	71	27,559	12,310	1,249	NA	NA	36,564
1988	24,060	956	25,016	12,309	1,454	NA	NA	42,858
1989	20,795	347	21,142	14,556	731	160	15,447	36,823
1990	19,190	3,857	23,047	31,261	975	827	33,063	30,678
1991	24,914	597	25,511	26,961	1,942	1,098	30,001	15,714
1992	24,307	2,255	26,562	11,761	145	2,072	13,978	0
1993	26,158	690	26,848	4,662	264	3,902	8,828	0
1994	20,564	49	20,613	8,917	128	5,409	14,454	0
1995	17,627	62	17,689	8,468	173	54	8,695	0
1996	20,282	76	20,358	15,728	150	2,053	17,930	0
1997	21,294	116	21,410	15,403	1,145	229	16,777	0
1998	19,503	10	19,513	14,525	492	97	15,115	0
1999	16,829	12	16,841	12,031	554	771	13,356	0
2000	16,070	26	16,096	5,649	67	153	5,869	0
2001	24,336	11	24,347	12,340	847	718	13,906	0
2002	34,616	7	34,623	26,530	1,029	155	27,714	0
2003	44,652	9	44,661	34,298	357	264	34,919	0
2004	53,896	14	53,910	54,990	56	2,141	57,187	0
2005	55,998	0	55,998	42,209	383	1,083	43,675	0
2006	53,756	3	53,759	56,640	1,392	135	58,167	0
2007	53,365	0	53,365	25,546	52	159	25,758	0
2008	29,636	4	29,640	21,734	794	747	23,275	0
2009	42,205	0	42,205	22,634	7	126	22,768	0
2010	38,646	0	38,646	9,877	1,648	97	11,622	0
2011	11,485	0	11,485	533	748	38	1,319	0
2012	6,843	0	6,843	5,333	147	33	5,513	0
2013	8,674	0	8,674	4,372	0	20	4,392	0
2014	6,680	0	6,680	5,905	0	51	5,957	0
2015	4,272	1	4,273	5,616	330	13	5,959	0
2016	8,052	0	8,052	5,687	894	18	6,599	0
2017	9,765	3	9,768	6,975	466	83	7,524	0
2018	11,051	0	11,051	8,717	3	177	8,897	0
2019	8,750	0	8,750	5,379	320	200	5,899	0
2020	7,957	0	7,957	8,306	363	192	8,861	0
2021	4,519	0	4,519	5,752	115	133	6,000	0
2022	161	0	161	1,908	157	44	2,109	0
2023	118	0	118	3,639	250	115	4,004	0
2024	391	0	454	868	250	115	1,233	0

Table S 2. Recorded landings (t) of Atlantic mackerel by DFO region. Landings for the last 2 years are preliminary.

Year	Gulf	Maritimes	Newfoundland	Quebec	Unknown
1968	0	0	193	0	20,645
1969	0	0	341	0	18,295
1970	0	0	922	0	20,084
1971	0	0	1,657	0	22,839
1972	0	0	1,759	0	20,601
1973	0	0	2,917	0	35,633
1974	0	0	1,934	0	42,721
1975	0	0	3,864	0	32,394
1976	0	0	5,354	0	27,711
1977	0	0	7,925	0	14,840
1978	0	0	13,724	0	12,175
1979	0	13,995	15,331	918	368
1980	0	13,379	7,206	1,550	161
1981	0	10,914	6,930	1,450	61
1982	0	12,588	308	3,484	3
1983	0	9,318	8,314	2,165	9
1984	0	9,222	5,867	2,231	913
1985	0	11,927	15,748	2,180	1,051
1986	0	14,882	12,445	2,998	772
1987	0	11,612	13,123	2,753	71
1988	0	13,780	6,614	3,666	956
1989	0	12,528	6,015	2,252	347
1990	0	12,965	4,255	1,970	3,857
1991	0	13,288	8,377	3,249	597
1992	0	10,935	9,893	3,479	2,255
1993	0	13,275	9,710	3,173	690
1994	0	14,442	2,583	3,539	49
1995	4,724	6,681	2,842	3,380	62
1996	6,702	5,517	3,755	4,308	76
1997	8,683	5,669	1,174	5,768	116
1998	8,545	4,562	2,239	4,065	102
1999	5,215	4,797	1,410	5,407	12
2000	5,106	4,547	4,396	2,022	26
2001	8,085	4,058	8,981	3,212	11
2002	8,270	3,989	17,936	4,421	7
2003	6,396	7,183	26,475	4,597	9
2004	6,292	5,635	39,990	1,979	14
2005	6,918	5,221	42,639	1,221	0
2006	5,028	2,587	44,111	2,031	3
2007	4,202	2,837	44,577	1,750	0
2008	2,807	1,959	23,007	1,863	4
2009	4,218	1,454	34,218	2,316	0
2010	3,158	668	33,110	1,709	0
2011	2,407	416	7,317	1,345	0
2012	2,264	683	2,618	1,278	0
2013	1,602	450	5,169	1,453	0
2014	975	770	3,432	1,502	0
2015	1,206	1,183	701	1,182	1
2016	1,020	1,435	4,631	966	0
2017	3,227	2,560	2,632	1,347	3
2018	2,361	1,640	5,623	1,426	0
2019	2,030	1,047	4,814	859	0
2020	1,818	1,336	4,015	788	0
2021	1,587	1,470	602	860	0
2022	1	59	10	91	0
2023	8	47	8	55	0
2024	219	106	27	39	63

Table S 3. Estimates of recreational mackerel fishing in Canada from DFO (2015). No data exists for Quebec and therefore the same numbers as for Nova Scotia were used.

Year	Newfoundland	Prince Edward Island	Nova Scotia	New Brunswick	Quebec	Total
2010	356,836	98,182	646,399	NA	NA	NA
2005	546,126	41,434	481,822	164,970	NA	NA
2000	477,720	43,069	NA	NA	NA	NA
1995	225,236	63,145	NA	157,169	NA	NA
1990	213,063	84,440	681,745	258,013	NA	NA
Max numbers	546,126	98,182	681,745	258,013	681,745.0	2,265,811
Max weight (kg)	0.3	0.3	0.3	0.3	0.3	NA
Max biomass (t)	164	29	205	77	205	680
Min numbers	213,063	41,434	481,822	157,169	41,434	934,922
Min weight (kg)	0.2	0.2	0.2	0.2	0.2	NA
Min biomass (t)	43	8	96	31	8	187

Table S 4. Length-Frequency samples for 2022-24 by NAFO area and month.

Year	Month	3K	3L	4R	4S	4T	4W	4X	Total
2022	6	0	0	0	0	1	0	0	1
2022	7	0	0	0	1	6	3	1	11
2022	8	4	1	5	0	6	3	2	21
2022	9	6	1	5	0	5	1	3	21
2022	10	4	1	3	0	0	1	3	12
2022	11	2	0	0	0	0	1	2	5
2022	total	16	3	13	1	18	9	11	71
2023	12	0	2	0	0	0	0	0	2
2023	6	0	0	0	0	6	2	3	11
2023	7	0	0	6	0	12	3	5	26
2023	8	0	0	10	0	7	3	1	21
2023	9	4	0	4	0	4	2	1	15
2023	10	4	0	0	0	1	2	1	8
2023	11	0	2	0	0	0	2	2	6
2023	total	8	4	20	0	30	14	13	89
2024	5	0	0	0	0	0	2	0	2
2024	6	0	0	2	0	9	0	3	14
2024	7	1	0	2	0	10	3	5	21
2024	8	1	1	5	0	3	2	2	14
2024	9	1	1	3	0	2	2	1	10
2024	10	0	0	3	0	2	2	1	8
2024	11	0	0	2	0	0	0	0	2
2024	total	3	2	17	0	26	11	12	71

Table S 5. Assessment model equations (a = age, y = year, SSB = spawning stock biomass (on January 1st and during spawning/survey time), Sel = selectivity, N = abundance, F = fishing mortality, M = natural mortality, W = mass, P = proportion mature, CU = upper catch limit, CL = lower catch limit, CT = total catch, LP = landings-at-age proportions, TEP = Total Egg Production, fec= fecundity, Fem = proportion of females, ts = timing of the survey, o = observed, MVN = multivariate normal, crl = continuation-ratio logit, q=survey index catchability).

Parameter	Formula
Cohort abundance	$N_{1,y} = \frac{\alpha SSB_{y-1}}{1+\beta SSB_{y-1}} e^{\varepsilon^N_{1,y}}$ $N_{a,y} = N_{a-1,y-1} e^{-Z_{a-1,y-1}+\varepsilon^N_{a,y}}$ $N_{A,y} = \left[N_{A-1,y-1} e^{-Z_{A-1,y-1}} + N_{A,y-1} e^{-Z_{A,y-1}}\right] + e^{\varepsilon^N_{A,y}}$ $\varepsilon^N_{a,y} \sim MVN(0, \alpha^2_{Na})$
Mortality rates	$F_{a,y} = Sel_a F_y$ $Z_{a,y} = F_{a,y} + M_{a,y}$ $F_y = F_{y-1} e^{\varepsilon^F_y}$ $\varepsilon^F_y \sim N\left(0, \sigma^2_{Fy}\right)$
Catch	$C_{a,y} = N_{a,y} \frac{F_{a,y}}{Z_{a,y}} [1 - e^{-Z_{a,y}}]$ $CT_y = \sum_{a=1}^{A} C_{a,y} W_{a,y}$ $LPa, y = \frac{C_{a,y}}{\sum_{a=1}^{A} C_{a,y}}$ $X_{a,y} = crl\left(LP_{a,y}\right)$ $l\left(C_{o1,\ldots,C_{oY}\mid\theta}\right) = \sum_{y-1}^{Y} l\,og\{\phi_N \left[\frac{log\left(CU_y/CT_y\right)}{0.01}\right] - \phi_N \left[\frac{log\left(CL_y/CT_y\right)}{0.01}\right]\}$ $l\left(X_{o_{a,y}}\mid\theta\right) = \sum_{a=1}^{A-1}\sum_{y=1}^{Y}\left[\varphi_N\left(\frac{X_{o_{a,y}} - X_{a,y}}{\sigma_{lp}}\right)\right]$
Survey index	$TEP_y = q \sum_{a=1}^{A} N_{a,y}\, e^{-Z_{a,y} t_s} fec_{a,y} Fem_{a,y} P_{a,y}$ $l\left(TEP_{o_y}\mid\theta\right) = \sum_{a=1}^{A}\sum_{Y=1}^{Y} l\,og\left[\varphi_N\left(\frac{TEP_{o_y} - TEP_y}{\sigma_s}\right)\right]$
Spawning Stock Biomass	$SSB^0_y = \sum_{a=1}^{A} N_{a,y}\, W^0_{a,y} P_{a,y}$ $SSB^{june}_y = \sum_{a=1}^{A} N_{a,y}\, e^{-Z_{a,y} t_s} W^{june}_{a,y} P_{a,y}$

Table S 6. Assessment model parameters.

Parameter	Definition	Effect
$N_{a,y}$	Stock abundance	Random
F_y	Fishing mortality	Random
α	Stock-recruitment coefficient	Fixed
β	Stock-recruitment coefficient	Fixed
Sel_a	Fishing selectivity	Fixed
q	Survey index catchability	Fixed
σ_N^2	Process error variance	Fixed
$\sigma_{F_y}^2$	Annual fishing mortality variance	Fixed
$\sigma_{lp_a}^2$	Landings-at-age proportions measurement error variance	Fixed
σ_s^2	Survey measurement error variance	Fixed

Table S 7. Catch limits (t), based on 20–80% of U.S. landings.

Estimate	Lower bound	Upper bound	Year
31,539	6,733	147,746	1969
33,860	11,916	96,219	1970
36,467	28,837	46,115	1971
34,361	31,447	37,545	1972
43,947	37,559	51,420	1973
50,605	45,795	55,921	1974
41,745	28,904	60,292	1975
38,515	19,653	75,482	1976
34,199	30,650	38,158	1977
35,565	16,970	74,537	1978
35,233	26,683	46,524	1979
34,149	14,773	78,938	1980
30,932	10,449	91,566	1981
29,077	9,322	90,695	1982
24,176	10,446	55,956	1983
35,441	31,451	39,938	1984
46,392	18,299	117,612	1985
46,567	15,521	139,713	1986
48,556	16,378	143,956	1987
42,417	16,891	106,518	1988
43,603	39,302	48,375	1989
46,958	19,423	113,524	1990
50,017	18,314	136,599	1991
48,280	20,120	115,857	1992
47,165	41,708	53,336	1993
45,084	38,227	53,171	1994
37,683	34,389	41,293	1995
44,034	19,035	101,861	1996
45,093	16,661	122,045	1997
38,321	13,792	106,474	1998
36,238	12,449	105,483	1999
29,860	10,643	83,776	2000
34,162	12,592	92,683	2001
47,069	18,088	122,483	2002
58,736	25,934	133,026	2003
72,609	64,868	81,274	2004
70,821	63,475	79,016	2005
72,173	66,526	78,299	2006
65,381	58,813	72,682	2007
50,354	25,261	100,370	2008
52,162	48,315	56,315	2009
45,835	42,713	49,185	2010
23,406	20,468	26,766	2011
16,392	7,010	38,330	2012
13,782	5,470	34,730	2013
12,813	5,219	31,457	2014
11,079	4,648	26,410	2015
13,115	5,455	31,533	2016
15,951	6,432	39,554	2017
16,513	6,585	41,407	2018
13,625	5,540	33,510	2019
11,029	4,841	25,127	2020
6,336	5,677	7,071	2021
2,475	2,317	2,643	2022
2,754	1,249	6,073	2023
2,069	1,896	2,258	2024

Table S 8. Landings-at-age ('000s of fish). Values from 1968–1975 were taken from previous assessments, values from 1976–2021 were re-estimated, and for 2022–2023 values were calculated under the assumption that landings were distributed similarly to 2017–2021. Note that LAA for 2024 were estimated using default methodology, based on preliminary landings data.

Year	1	2	3	4	5	6	7	8	9	10
1969	5,692	26,359	18,057	2,027	929	855	1,099	440	462	9,656
1970	20,277	3,654	33,584	8,047	2,496	451	425	1,578	1,645	4,335
1971	7,156	7,389	1,702	35,931	7,620	1,753	2,203	1,526	1,879	5,517
1972	1	136	4,401	5,541	24,826	4,975	5,248	77	546	6,833
1973	9,176	20,624	9,649	9,333	13,972	22,293	8,317	2,771	837	1,603
1974	8,618	24,340	26,703	14,602	12,594	12,417	15,377	4,053	1,714	1,749
1975	14,206	24,905	13,049	11,636	7,052	7,526	5,456	3,917	825	581
1976	5,080	37,835	28,806	6,419	4,401	2,359	2,919	2,008	1,341	636
1977	4,738	14,741	29,710	8,831	1,637	913	616	656	402	416
1978	78	2,801	12,088	25,956	10,683	2,357	1,153	545	685	448
1979	6,742	11,350	1,892	7,476	18,990	11,867	4,834	1,589	1,096	1,043
1980	55	5,644	6,818	2,593	5,096	10,051	5,681	1,925	1,120	949
1981	9,477	1,758	7,835	3,988	2,553	4,571	4,983	2,054	664	344
1982	13,994	4,498	1,633	4,177	598	2,335	3,065	4,116	1,068	1,346
1983	78,918	17,821	7,124	558	650	74	60	198	448	256
1984	42	26,081	14,354	1,190	279	628	136	180	708	2,526
1985	24,874	1,026	52,656	10,199	719	232	885	197	134	2,121
1986	2,405	15,674	5,864	45,165	7,578	535	217	245	76	751
1987	1,812	5,616	8,866	2,834	35,731	4,405	168	113	50	269
1988	25,187	1,981	1,896	2,716	2,635	26,505	3,466	180	96	417
1989	6,973	13,161	1,653	966	1,057	603	16,674	2,036	277	866
1990	668	10,057	9,736	1,870	1,336	1,142	790	17,874	1,097	173
1991	2,095	8,072	16,474	8,833	1,124	1,059	1,289	1,006	12,392	477
1992	4,773	9,503	5,505	16,736	9,205	1,357	552	978	655	9,294
1993	70	2,088	6,432	5,499	18,946	9,797	1,818	714	681	6,796
1994	2,311	1,315	9,949	9,355	2,683	11,969	3,754	550	338	1,523
1995	8,310	7,697	1,089	8,018	5,814	1,607	5,627	1,981	255	443
1996	3,950	8,875	8,578	1,027	5,772	6,352	1,234	5,106	1,140	337
1997	8,943	13,843	9,997	4,822	773	3,583	2,896	660	3,285	481
1998	2,309	22,532	10,384	8,602	3,293	268	1,603	1,272	246	1,041
1999	2,117	7,213	15,843	7,631	3,982	1,397	231	529	496	197
2000	34,934	6,038	4,677	7,604	2,545	1,499	268	52	197	150
2001	5,084	45,546	9,929	3,823	4,717	1,140	872	154	46	85
2002	3,257	6,208	71,875	6,277	1,869	1,652	309	147	15	25
2003	3,488	6,495	7,141	73,199	6,927	895	743	49	2	0
2004	43,886	28,441	7,049	5,617	54,033	2,144	805	421	7	0
2005	15,975	53,982	30,633	5,588	4,103	34,126	1,550	291	106	26
2006	44,178	15,490	45,343	22,877	3,229	1,633	9,884	275	20	0
2007	2,232	32,888	22,434	45,128	9,469	1,418	949	3,970	22	5
2008	21,028	7,034	28,852	7,699	11,794	1,102	303	130	681	2
2009	52,872	26,612	7,421	25,230	4,802	7,001	221	83	6	509
2010	8,928	34,960	29,991	4,794	12,722	1,543	2,312	98	1	60
2011	6,495	2,721	13,411	4,863	440	2,011	188	291	19	17
2012	475	12,219	2,079	2,988	266	26	55	4	2	0
2013	850	6,044	12,723	602	1,654	101	0	5	0	0
2014	1,278	3,465	7,058	4,072	83	63	1	1	0	0
2015	3,699	4,074	1,997	2,115	952	124	13	4	0	0
2016	7,803	7,457	4,990	2,740	1,930	757	30	1	0	0
2017	68	17,349	9,914	3,152	1,457	1,022	248	0	0	0
2018	272	895	23,828	5,348	962	205	110	11	0	0
2019	42	5,354	7,402	9,596	1,699	376	109	63	3	0
2020	173	1,948	7,562	3,215	5,714	573	77	6	4	0
2021	411	2,677	2,574	3,749	1,053	771	147	47	7	0
2022	79	224	99	32	34	17	8	0	1	0
2023	59	107	129	43	12	9	2	1	0	0
2024	258	459	446	279	61	23	6	0	1	0

Table S 9. Total Egg Production (TEP, in trillions of eggs, 10^12).

Year	TEP
1979	415.71
1980	NA
1981	NA
1982	NA
1983	108.18
1984	358.96
1985	678.28
1986	1,017.98
1987	542.55
1988	455.01
1989	538.02
1990	354.43
1991	NA
1992	583.21
1993	683.37
1994	315.62
1995	NA
1996	94.33
1997	NA
1998	74.67
1999	NA
2000	112.66
2001	24.03
2002	266.15
2003	246.17
2004	267.24
2005	119.17
2006	45.96
2007	87.15
2008	98.37
2009	69.77
2010	25.73
2011	29.51
2012	10.86
2013	38.41
2014	47.74
2015	45.64
2016	49.52
2017	75.59
2018	45.37
2019	99.62
2020	NA
2021	16.42
2022	37.17
2023	75.87
2024	15.11

Table S 10. Weight-at-age (kg) of the stock (June-July).

Year	1	2	3	4	5	6	7	8	9	10
1969	0.128	0.270	0.361	0.429	0.498	0.550	0.588	0.628	0.661	0.714
1970	0.127	0.268	0.356	0.420	0.491	0.545	0.583	0.623	0.656	0.709
1971	0.128	0.267	0.353	0.415	0.481	0.537	0.578	0.617	0.650	0.703
1972	0.128	0.268	0.352	0.411	0.474	0.526	0.569	0.610	0.643	0.696
1973	0.127	0.267	0.352	0.409	0.469	0.517	0.556	0.600	0.635	0.687
1974	0.132	0.277	0.365	0.426	0.486	0.533	0.569	0.611	0.651	0.707
1975	0.139	0.289	0.381	0.444	0.509	0.554	0.589	0.628	0.665	0.727
1976	0.146	0.299	0.390	0.454	0.520	0.569	0.601	0.638	0.671	0.729
1977	0.151	0.310	0.400	0.460	0.527	0.576	0.612	0.644	0.675	0.728
1978	0.156	0.321	0.413	0.470	0.533	0.582	0.617	0.654	0.679	0.730
1979	0.161	0.332	0.429	0.488	0.547	0.591	0.626	0.663	0.693	0.739
1980	0.167	0.350	0.454	0.518	0.579	0.619	0.649	0.686	0.717	0.769
1981	0.168	0.365	0.480	0.549	0.617	0.658	0.682	0.714	0.744	0.798
1982	0.163	0.359	0.488	0.568	0.639	0.685	0.709	0.733	0.757	0.810
1983	0.154	0.335	0.462	0.556	0.636	0.682	0.709	0.733	0.748	0.793
1984	0.150	0.317	0.435	0.530	0.627	0.684	0.713	0.739	0.753	0.789
1985	0.148	0.313	0.416	0.504	0.604	0.682	0.722	0.750	0.768	0.803
1986	0.147	0.308	0.408	0.479	0.570	0.652	0.715	0.755	0.774	0.813
1987	0.144	0.303	0.398	0.466	0.539	0.612	0.679	0.742	0.774	0.814
1988	0.141	0.301	0.398	0.461	0.531	0.586	0.646	0.715	0.772	0.825
1989	0.139	0.296	0.397	0.464	0.529	0.582	0.622	0.685	0.748	0.828
1990	0.139	0.290	0.387	0.459	0.527	0.575	0.613	0.654	0.710	0.796
1991	0.137	0.290	0.381	0.449	0.523	0.574	0.607	0.646	0.680	0.757
1992	0.137	0.286	0.379	0.439	0.510	0.567	0.603	0.636	0.667	0.722
1993	0.137	0.286	0.375	0.439	0.501	0.555	0.598	0.635	0.661	0.712
1994	0.139	0.291	0.380	0.440	0.507	0.552	0.592	0.638	0.668	0.713
1995	0.140	0.297	0.391	0.451	0.514	0.566	0.597	0.640	0.679	0.730
1996	0.140	0.299	0.399	0.464	0.527	0.572	0.611	0.643	0.680	0.741
1997	0.140	0.300	0.402	0.474	0.542	0.587	0.619	0.659	0.685	0.743
1998	0.141	0.301	0.404	0.478	0.554	0.604	0.636	0.668	0.703	0.749
1999	0.140	0.299	0.400	0.475	0.553	0.611	0.647	0.679	0.704	0.760
2000	0.137	0.295	0.396	0.468	0.545	0.606	0.651	0.687	0.711	0.757
2001	0.136	0.290	0.391	0.464	0.540	0.600	0.647	0.693	0.722	0.767
2002	0.135	0.284	0.379	0.452	0.528	0.586	0.632	0.680	0.719	0.769
2003	0.134	0.281	0.371	0.439	0.514	0.573	0.617	0.664	0.705	0.764
2004	0.132	0.278	0.367	0.428	0.498	0.558	0.602	0.647	0.688	0.749
2005	0.132	0.277	0.366	0.426	0.489	0.543	0.590	0.635	0.674	0.735
2006	0.131	0.278	0.367	0.428	0.491	0.538	0.579	0.627	0.667	0.726
2007	0.132	0.277	0.367	0.428	0.492	0.538	0.572	0.614	0.657	0.717
2008	0.134	0.282	0.370	0.435	0.498	0.546	0.579	0.614	0.651	0.714
2009	0.136	0.288	0.379	0.441	0.509	0.556	0.592	0.626	0.655	0.713
2010	0.137	0.290	0.384	0.448	0.512	0.564	0.598	0.635	0.663	0.712
2011	0.138	0.292	0.387	0.454	0.520	0.567	0.606	0.641	0.671	0.720
2012	0.137	0.290	0.386	0.453	0.521	0.571	0.604	0.643	0.672	0.722
2013	0.138	0.291	0.387	0.454	0.524	0.576	0.611	0.645	0.678	0.727
2014	0.140	0.297	0.391	0.460	0.531	0.585	0.624	0.661	0.688	0.742
2015	0.140	0.297	0.395	0.460	0.532	0.587	0.627	0.667	0.697	0.745
2016	0.138	0.294	0.393	0.461	0.529	0.584	0.624	0.665	0.698	0.749
2017	0.137	0.289	0.387	0.458	0.528	0.578	0.619	0.660	0.694	0.747
2018	0.137	0.289	0.384	0.455	0.529	0.583	0.618	0.660	0.695	0.750
2019	0.138	0.289	0.383	0.449	0.524	0.581	0.621	0.658	0.693	0.748
2020	0.140	0.293	0.385	0.451	0.520	0.578	0.622	0.663	0.693	0.749
2021	0.141	0.298	0.391	0.455	0.523	0.576	0.622	0.668	0.702	0.753
2022	0.141	0.298	0.395	0.457	0.523	0.574	0.613	0.660	0.699	0.755
2023	0.130	0.276	0.364	0.426	0.486	0.532	0.575	0.616	0.656	0.715
2024	0.130	0.275	0.362	0.423	0.487	0.529	0.566	0.607	0.642	0.702

Table S 11. Weight-at-age (kg) of landed fish.

Year	1	2	3	4	5	6	7	8	9	10
1969	0.177	0.294	0.358	0.458	0.499	0.568	0.592	0.618	0.645	0.673
1970	0.177	0.294	0.358	0.458	0.499	0.568	0.592	0.618	0.645	0.673
1971	0.177	0.294	0.358	0.458	0.499	0.568	0.592	0.618	0.645	0.673
1972	0.177	0.294	0.358	0.458	0.499	0.568	0.592	0.618	0.645	0.673
1973	0.177	0.294	0.358	0.458	0.499	0.568	0.592	0.618	0.645	0.673
1974	0.177	0.294	0.358	0.458	0.499	0.568	0.592	0.618	0.645	0.673
1975	0.177	0.294	0.358	0.458	0.499	0.568	0.592	0.618	0.645	0.673
1976	0.177	0.294	0.358	0.458	0.499	0.568	0.592	0.618	0.645	0.673
1977	0.123	0.297	0.378	0.435	0.510	0.560	0.628	0.655	0.668	0.730
1978	0.184	0.309	0.410	0.454	0.488	0.540	0.593	0.633	0.690	0.685
1979	0.164	0.246	0.415	0.507	0.531	0.564	0.584	0.654	0.676	0.724
1980	0.202	0.410	0.441	0.522	0.595	0.612	0.636	0.680	0.718	0.737
1981	0.183	0.424	0.549	0.569	0.642	0.665	0.682	0.710	0.754	0.798
1982	0.109	0.389	0.565	0.640	0.708	0.748	0.739	0.755	0.757	0.858
1983	0.133	0.298	0.359	0.479	0.633	0.679	0.768	0.750	0.762	0.778
1984	0.220	0.301	0.434	0.514	0.695	0.725	0.730	0.818	0.788	0.823
1985	0.143	0.346	0.361	0.462	0.583	0.707	0.721	0.717	0.789	0.865
1986	0.158	0.288	0.403	0.414	0.494	0.593	0.754	0.812	0.829	0.853
1987	0.212	0.308	0.410	0.467	0.489	0.574	0.614	0.760	0.913	0.895
1988	0.128	0.359	0.434	0.486	0.527	0.559	0.629	0.714	0.857	0.878
1989	0.156	0.315	0.457	0.534	0.612	0.637	0.661	0.776	0.826	0.907
1990	0.271	0.295	0.400	0.557	0.613	0.638	0.677	0.668	0.721	0.878
1991	0.230	0.327	0.387	0.469	0.582	0.621	0.635	0.709	0.693	0.893
1992	0.163	0.276	0.393	0.446	0.509	0.580	0.611	0.692	0.682	0.709
1993	0.173	0.290	0.374	0.458	0.484	0.540	0.598	0.648	0.690	0.712
1994	0.239	0.345	0.373	0.455	0.535	0.527	0.585	0.634	0.694	0.723
1995	0.198	0.336	0.450	0.476	0.515	0.595	0.602	0.647	0.723	0.793
1996	0.206	0.323	0.445	0.536	0.555	0.601	0.644	0.667	0.716	0.805
1997	0.219	0.351	0.447	0.525	0.593	0.591	0.643	0.743	0.704	0.744
1998	0.155	0.244	0.398	0.505	0.569	0.620	0.658	0.661	0.710	0.714
1999	0.190	0.278	0.408	0.478	0.547	0.602	0.667	0.665	0.708	0.712
2000	0.179	0.294	0.375	0.465	0.552	0.604	0.653	0.726	0.713	0.703
2001	0.151	0.291	0.423	0.486	0.569	0.639	0.686	0.729	0.842	0.774
2002	0.168	0.277	0.379	0.451	0.517	0.605	0.634	0.681	0.692	0.731
2003	0.218	0.311	0.377	0.468	0.532	0.617	0.678	0.709	0.848	0.706
2004	0.202	0.289	0.390	0.479	0.541	0.588	0.655	0.773	0.710	0.681
2005	0.108	0.288	0.366	0.452	0.516	0.596	0.631	0.672	0.730	0.656
2006	0.220	0.316	0.417	0.473	0.529	0.547	0.641	0.708	0.634	0.633
2007	0.207	0.318	0.434	0.502	0.587	0.613	0.676	0.714	0.757	0.693
2008	0.165	0.302	0.423	0.505	0.535	0.613	0.682	0.584	0.706	0.767
2009	0.204	0.318	0.418	0.489	0.578	0.591	0.660	0.619	0.784	0.803
2010	0.085	0.357	0.435	0.500	0.564	0.645	0.651	0.635	0.834	0.705
2011	0.180	0.285	0.412	0.473	0.552	0.566	0.684	0.632	0.676	0.706
2012	0.220	0.338	0.406	0.496	0.552	0.639	0.768	0.648	0.648	0.708
2013	0.176	0.287	0.424	0.470	0.545	0.561	0.641	0.620	0.663	0.708
2014	0.188	0.348	0.427	0.509	0.582	0.691	0.742	0.671	0.678	0.708
2015	0.174	0.283	0.411	0.479	0.575	0.623	0.591	0.487	0.693	0.708
2016	0.147	0.277	0.407	0.484	0.534	0.563	0.597	0.753	0.708	0.708
2017	0.163	0.211	0.334	0.423	0.507	0.532	0.570	0.696	0.722	0.708
2018	0.124	0.175	0.329	0.403	0.520	0.536	0.635	0.638	0.737	0.708
2019	0.126	0.279	0.339	0.372	0.500	0.573	0.613	0.638	0.752	0.708
2020	0.137	0.318	0.387	0.439	0.454	0.539	0.619	0.631	0.773	0.683
2021	0.166	0.273	0.380	0.445	0.494	0.515	0.629	0.573	0.758	0.680
2022	0.129	0.224	0.348	0.425	0.496	0.579	0.577	0.687	0.693	0.677
2023	0.118	0.190	0.291	0.385	0.480	0.553	0.629	0.660	0.663	0.677
2024	0.113	0.212	0.259	0.321	0.430	0.481	0.615	0.475	0.658	0.674

Table S 12. Maturity-at-age (proportions).

Year	1	2	3	4	5	6	7	8	9	10
1969	0.296	0.710	0.893	0.952	1	1	1	1	1	1
1970	0.293	0.703	0.888	0.949	1	1	1	1	1	1
1971	0.287	0.692	0.882	0.946	1	1	1	1	1	1
1972	0.274	0.676	0.874	0.942	1	1	1	1	1	1
1973	0.253	0.661	0.869	0.939	1	1	1	1	1	1
1974	0.229	0.659	0.877	0.944	1	1	1	1	1	1
1975	0.217	0.688	0.904	0.958	1	1	1	1	1	1
1976	0.238	0.734	0.929	0.970	1	1	1	1	1	1
1977	0.287	0.778	0.937	0.973	1	1	1	1	1	1
1978	0.333	0.810	0.931	0.969	1	1	1	1	1	1
1979	0.317	0.839	0.928	0.967	1	1	1	1	1	1
1980	0.250	0.871	0.939	0.972	1	1	1	1	1	1
1981	0.181	0.874	0.950	0.978	1	1	1	1	1	1
1982	0.147	0.831	0.951	0.980	1	1	1	1	1	1
1983	0.145	0.760	0.950	0.981	1	1	1	1	1	1
1984	0.147	0.712	0.957	0.985	1	1	1	1	1	1
1985	0.171	0.715	0.967	0.990	1	1	1	1	1	1
1986	0.217	0.751	0.973	0.993	1	1	1	1	1	1
1987	0.266	0.802	0.977	0.995	1	1	1	1	1	1
1988	0.304	0.850	0.978	0.995	1	1	1	1	1	1
1989	0.342	0.878	0.975	0.993	1	1	1	1	1	1
1990	0.391	0.873	0.967	0.990	1	1	1	1	1	1
1991	0.428	0.845	0.954	0.985	1	1	1	1	1	1
1992	0.434	0.808	0.942	0.980	1	1	1	1	1	1
1993	0.420	0.771	0.931	0.975	1	1	1	1	1	1
1994	0.406	0.742	0.920	0.970	1	1	1	1	1	1
1995	0.415	0.727	0.910	0.963	1	1	1	1	1	1
1996	0.453	0.733	0.902	0.957	1	1	1	1	1	1
1997	0.476	0.751	0.906	0.959	1	1	1	1	1	1
1998	0.454	0.769	0.920	0.968	1	1	1	1	1	1
1999	0.415	0.790	0.939	0.979	1	1	1	1	1	1
2000	0.393	0.819	0.957	0.987	1	1	1	1	1	1
2001	0.405	0.848	0.970	0.991	1	1	1	1	1	1
2002	0.409	0.860	0.978	0.993	1	1	1	1	1	1
2003	0.343	0.847	0.986	0.995	1	1	1	1	1	1
2004	0.228	0.813	0.992	0.998	1	1	1	1	1	1
2005	0.125	0.780	0.996	0.999	1	1	1	1	1	1
2006	0.066	0.772	0.996	1.000	1	1	1	1	1	1
2007	0.053	0.783	0.994	1.000	1	1	1	1	1	1
2008	0.087	0.795	0.990	0.999	1	1	1	1	1	1
2009	0.156	0.811	0.985	0.998	1	1	1	1	1	1
2010	0.246	0.834	0.982	0.998	1	1	1	1	1	1
2011	0.320	0.867	0.984	0.998	1	1	1	1	1	1
2012	0.347	0.895	0.989	0.999	1	1	1	1	1	1
2013	0.308	0.896	0.994	0.999	1	1	1	1	1	1
2014	0.238	0.864	0.996	1.000	1	1	1	1	1	1
2015	0.162	0.796	0.995	1.000	1	1	1	1	1	1
2016	0.096	0.696	0.992	1.000	1	1	1	1	1	1
2017	0.047	0.597	0.988	1.000	1	1	1	1	1	1
2018	0.022	0.555	0.985	1.000	1	1	1	1	1	1
2019	0.019	0.587	0.985	1.000	1	1	1	1	1	1
2020	0.031	0.662	0.988	1.000	1	1	1	1	1	1
2021	0.053	0.736	0.989	1.000	1	1	1	1	1	1
2022	0.081	0.789	0.989	1.000	1	1	1	1	1	1
2023	0.127	0.765	0.983	1.000	1	1	1	1	1	1
2024	0.166	0.783	0.983	1.000	1	1	1	1	1	1

Table S 13. Fecundity-at-age (numbers of eggs).

Year	1	2	3	4	5	6	7	8	9	10
1969	260,999	359,015	467,672	543,634	599,853	646,493	679,357	723,172	737,012	805,010
1970	260,618	358,490	466,989	542,840	598,976	645,549	678,364	722,115	735,935	803,834
1971	260,217	357,940	466,272	542,006	598,056	644,557	677,322	721,006	734,804	802,599
1972	259,797	357,362	465,519	541,131	597,090	643,516	676,229	719,842	733,618	801,304
1973	259,356	356,755	464,729	540,212	596,077	642,424	675,081	718,620	732,373	799,943
1974	258,893	356,119	463,900	539,249	595,013	641,278	673,876	717,338	731,066	798,516
1975	258,705	355,859	463,562	538,856	594,580	640,811	673,386	716,815	730,534	797,935
1976	258,727	355,890	463,602	538,903	594,632	640,866	673,444	716,877	730,597	798,004
1977	258,896	356,122	463,903	539,253	595,018	641,283	673,882	717,344	731,072	798,523
1978	259,017	356,289	464,121	539,506	595,298	641,584	674,199	717,680	731,415	798,898
1979	259,155	356,478	464,368	539,793	595,615	641,926	674,557	718,062	731,805	799,323
1980	259,196	356,534	464,441	539,878	595,708	642,026	674,663	718,175	731,919	799,448
1981	259,158	356,483	464,374	539,800	595,622	641,933	674,565	718,071	731,813	799,332
1982	259,176	356,508	464,406	539,837	595,663	641,978	674,612	718,121	731,864	799,388
1983	259,447	356,881	464,892	540,403	596,287	642,650	675,319	718,873	732,630	800,225
1984	259,737	357,280	465,412	541,007	596,953	643,369	676,074	719,677	733,450	801,120
1985	260,153	357,851	466,156	541,872	597,908	644,397	677,155	720,827	734,622	802,401
1986	260,682	358,579	467,104	542,974	599,124	645,708	678,532	722,293	736,116	804,032
1987	261,097	359,149	467,847	543,838	600,077	646,735	679,611	723,442	737,287	805,312
1988	261,500	359,704	468,571	544,678	601,005	647,735	680,662	724,560	738,427	806,556
1989	261,939	360,308	469,356	545,592	602,012	648,821	681,803	725,776	739,665	807,909
1990	262,294	360,796	469,993	546,332	602,829	649,701	682,728	726,760	740,669	809,005
1991	262,734	361,401	470,781	547,247	603,839	650,790	683,872	727,978	741,910	810,361
1992	263,322	362,210	471,835	548,472	605,191	652,247	685,403	729,608	743,571	812,175
1993	264,121	363,309	473,266	550,136	607,027	654,225	687,482	731,821	745,826	814,639
1994	264,780	364,216	474,448	551,510	608,543	655,859	689,199	733,648	747,689	816,673
1995	265,662	365,429	476,028	553,347	610,569	658,043	691,494	736,092	750,179	819,392
1996	266,565	366,671	477,646	555,227	612,645	660,280	693,845	738,594	752,729	822,178
1997	267,489	367,943	479,302	557,153	614,769	662,570	696,251	741,155	755,339	825,029
1998	268,514	369,353	481,139	559,288	617,126	665,109	698,919	743,996	758,234	828,191
1999	269,572	370,807	483,034	561,491	619,556	667,729	701,672	746,926	761,220	831,453
2000	270,690	372,345	485,037	563,820	622,126	670,498	704,582	750,024	764,377	834,901
2001	271,847	373,937	487,111	566,230	624,785	673,365	707,594	753,230	767,645	838,471
2002	272,812	375,264	488,839	568,239	627,002	675,753	710,105	755,902	770,369	841,445
2003	273,816	376,646	490,639	570,331	629,311	678,242	712,720	758,686	773,205	844,544
2004	274,758	377,941	492,327	572,293	631,475	680,575	715,171	761,295	775,865	847,448
2005	275,750	379,306	494,104	574,359	633,755	683,032	717,753	764,044	778,666	850,508
2006	276,590	380,462	495,610	576,110	635,686	685,113	719,940	766,372	781,039	853,100
2007	277,086	381,143	496,497	577,141	636,824	686,340	721,229	767,744	782,437	854,627
2008	277,414	381,595	497,086	577,825	637,580	687,154	722,084	768,655	783,365	855,641
2009	277,605	381,857	497,428	578,223	638,019	687,627	722,582	769,184	783,904	856,230
2010	277,916	382,285	497,985	578,871	638,733	688,397	723,391	770,045	784,782	857,189
2011	278,261	382,760	498,604	579,590	639,526	689,252	724,289	771,002	785,757	858,253
2012	278,442	383,009	498,929	579,967	639,943	689,701	724,761	771,504	786,269	858,812
2013	278,910	383,653	499,767	580,942	641,018	690,860	725,979	772,801	787,590	860,256
2014	279,235	384,099	500,348	581,618	641,764	691,663	726,823	773,699	788,506	861,256
2015	279,454	384,401	500,741	582,074	642,268	692,206	727,394	774,307	789,125	861,932
2016	279,492	384,453	500,809	582,153	642,355	692,300	727,493	774,412	789,233	862,049
2017	279,409	384,339	500,661	581,981	642,165	692,096	727,278	774,183	788,999	861,795
2018	279,251	384,121	500,377	581,651	641,801	691,703	726,865	773,744	788,552	861,306
2019	279,106	383,922	500,118	581,349	641,468	691,344	726,488	773,342	788,142	860,859
2020	278,741	383,420	499,464	580,589	640,629	690,440	725,538	772,331	787,112	859,733
2021	278,117	382,562	498,346	579,290	639,195	688,895	723,914	770,603	785,350	857,809
2022	277,643	381,910	497,497	578,303	638,107	687,722	722,681	769,290	784,013	856,348
2023	274,849	378,066	489,460	571,818	627,673	679,498	713,607	758,424	772,165	842,912
2024	274,391	377,437	488,646	570,866	626,628	678,367	712,419	757,162	770,880	841,510

Table S 14. Estimated model parameters (sd = standard deviation).

Parameter	Estimate	sd
$logq$	0.80	0.04
$log\sigma_{F_y}$	-0.70	0.09
$log\sigma_{N_1}$	-0.11	0.08
$log\sigma_{N_{2-10}}$	-1.03	0.08
$log\sigma_{lpa_1}$	0.57	0.09
$log\sigma_{lpa_{2,7-,9}}$	-0.11	0.07
$log\sigma_{lpa_{3-6}}$	-1.09	0.10
$log\sigma_s$	-0.30	0.11
$log\alpha$	0.97	0.33
$log\beta$	-11.79	0.56
$logitSel_1$	-2.37	0.20
$logitSel_2$	-0.74	0.13
$logitSel_3$	0.36	0.13
$logitSel_4$	1.24	0.26

Table S 15. Summary of model estimates showing spawning stock biomass (SSB) in tonnes on both January 1st (SSB0) and July 1st (SSB), age-1 recruitment (Recr.), mean instantaneous rate of fishing mortality of fully selected fish ($Fbar_{5\text{-}10}$ or F), the Limit Reference Point (LRP), and the SSB with respect to the LRP (SSB/LRP).

Year	LRP	SSB0	SSB	Recr.	F	SSB/LRP
1969	40,921	411,097	360,405	114,359	0.13	8.81
1970	40,921	387,779	339,962	208,522	0.14	8.31
1971	40,921	333,406	292,295	113,219	0.15	7.14
1972	40,921	250,405	219,528	149,362	0.18	5.36
1973	40,921	189,183	165,856	201,859	0.33	4.05
1974	40,921	173,478	152,087	359,294	0.48	3.72
1975	40,921	183,134	160,552	552,797	0.42	3.92
1976	40,921	254,209	222,863	246,256	0.32	5.45
1977	40,921	291,402	255,470	81,543	0.22	6.24
1978	40,921	249,573	218,799	116,314	0.23	5.35
1979	40,921	198,020	173,603	159,074	0.28	4.24
1980	40,921	164,230	143,979	45,239	0.34	3.52
1981	40,921	125,817	110,303	201,303	0.38	2.70
1982	40,921	125,904	110,379	373,813	0.41	2.70
1983	40,921	179,744	157,580	953,285	0.31	3.85
1984	40,921	340,735	298,720	110,911	0.23	7.30
1985	40,921	442,691	388,104	320,044	0.22	9.48
1986	40,921	422,565	370,459	133,727	0.20	9.05
1987	40,921	387,600	339,806	129,222	0.19	8.30
1988	40,921	352,562	309,088	459,998	0.17	7.55
1989	40,921	410,077	359,511	492,383	0.15	8.79
1990	40,921	410,848	360,187	191,479	0.18	8.80
1991	40,921	363,535	318,708	226,355	0.22	7.79
1992	40,921	302,804	265,466	215,892	0.25	6.49
1993	40,921	244,543	214,389	44,273	0.30	5.24
1994	40,921	190,518	167,025	163,768	0.38	4.08
1995	40,921	150,847	132,246	184,119	0.40	3.23
1996	40,921	134,230	117,678	163,589	0.57	2.88
1997	40,921	117,711	103,196	209,986	0.76	2.52
1998	40,921	104,421	91,545	91,082	0.89	2.24
1999	40,921	83,207	72,947	112,913	1.04	1.78
2000	40,921	79,634	69,814	430,186	1.03	1.71
2001	40,921	123,286	108,084	89,714	0.78	2.64
2002	40,921	169,570	148,661	94,324	0.63	3.63
2003	40,921	172,233	150,995	243,642	0.63	3.69
2004	40,921	167,914	147,209	394,477	0.80	3.60
2005	40,921	163,861	143,655	171,154	0.98	3.51
2006	40,921	135,095	118,436	319,884	1.10	2.89
2007	40,921	129,370	113,417	77,050	1.06	2.77
2008	40,921	100,400	88,020	173,110	1.00	2.15
2009	40,921	85,569	75,017	170,120	1.41	1.83
2010	40,921	64,655	56,683	42,426	2.02	1.39
2011	40,921	32,736	28,700	109,735	2.43	0.70
2012	40,921	29,570	25,924	66,979	1.73	0.63
2013	40,921	31,688	27,781	45,217	1.26	0.68
2014	40,921	30,939	27,124	57,885	0.94	0.66
2015	40,921	27,415	24,035	83,738	0.95	0.59
2016	40,921	29,852	26,171	162,698	1.01	0.64
2017	40,921	43,130	37,812	37,680	1.08	0.92
2018	40,921	44,982	39,435	54,982	0.99	0.96
2019	40,921	32,067	28,113	21,041	1.06	0.69
2020	40,921	21,394	18,756	24,207	1.21	0.46
2021	40,921	12,219	10,712	35,492	1.26	0.26
2022	40,921	11,367	9,965	34,367	0.58	0.24
2023	40,921	14,790	12,966	28,827	0.52	0.32
2024	40,921	16,386	14,365	32,337	0.33	0.35

Table S 16. Estimated numbers-at-age (thousands of fish).

Year	1	2	3	4	5	6	7	8	9	10
1969	114.36	890.13	297.96	38.98	12.22	12.60	26.01	14.07	5.58	116.69
1970	208.52	79.25	663.49	144.94	30.93	7.68	9.08	19.66	10.98	75.40
1971	113.22	135.88	48.90	452.04	77.82	20.39	5.90	7.03	14.52	65.26
1972	149.36	68.89	79.94	56.45	233.37	43.04	18.28	3.51	4.55	53.90
1973	201.86	139.18	64.38	57.37	54.16	103.74	27.19	11.78	2.61	19.69
1974	359.29	142.57	106.54	48.83	40.99	34.95	45.02	13.36	6.03	9.32
1975	552.80	289.29	81.86	54.54	26.82	26.23	17.01	18.08	5.69	5.79
1976	246.26	478.62	213.07	43.85	25.24	13.32	14.21	8.83	8.26	5.06
1977	81.54	189.00	391.11	126.77	25.17	13.38	7.99	8.17	4.73	6.38
1978	116.31	48.36	126.76	235.22	86.89	20.58	9.35	5.22	5.06	5.73
1979	159.07	87.14	26.12	65.14	123.18	59.03	17.49	6.60	3.50	6.06
1980	45.24	107.34	53.62	20.50	37.63	63.18	33.01	10.62	4.03	5.13
1981	201.30	29.10	66.81	22.51	15.31	25.69	32.82	15.48	5.96	4.56
1982	373.81	143.05	17.01	31.62	5.77	9.67	14.78	22.92	8.06	6.27
1983	953.29	298.26	99.17	10.54	14.30	2.57	3.72	6.80	12.04	7.28
1984	110.91	891.04	220.97	23.05	4.04	7.53	1.64	2.12	4.75	24.28
1985	320.04	85.73	799.69	130.22	9.25	2.39	4.99	1.13	1.28	20.03
1986	133.73	227.84	75.43	571.75	85.06	5.63	1.75	2.68	0.71	9.51
1987	129.22	87.07	136.16	47.08	444.37	62.90	3.21	1.24	1.48	5.49
1988	460.00	84.02	47.39	55.62	30.54	371.71	42.31	2.06	0.83	4.73
1989	492.38	345.11	52.91	27.74	26.79	15.61	352.08	25.13	1.34	3.92
1990	191.48	397.01	224.84	31.97	18.90	17.20	11.28	246.00	15.57	3.21
1991	226.36	140.14	308.14	142.09	17.76	12.34	11.79	7.93	153.45	10.69
1992	215.89	164.21	86.94	212.89	93.16	12.43	7.33	7.36	4.96	86.46
1993	44.27	151.10	103.49	49.99	151.16	61.75	8.20	4.43	4.23	43.02
1994	163.77	27.03	116.41	82.95	25.21	93.19	31.17	4.67	2.50	16.86
1995	184.12	113.79	14.86	72.69	51.00	13.32	46.92	15.63	2.44	7.25
1996	163.59	127.79	69.50	7.85	36.71	32.80	6.75	26.45	7.48	4.09
1997	209.99	117.00	77.83	32.03	3.74	17.04	14.83	2.86	12.04	4.18
1998	91.08	152.42	65.52	40.65	13.81	1.34	6.26	5.28	0.99	4.66
1999	112.91	60.08	86.81	31.39	15.84	4.54	0.52	1.87	1.56	1.34
2000	430.19	76.30	29.60	36.07	9.89	5.18	1.06	0.16	0.49	0.63
2001	89.71	351.46	43.22	12.80	12.49	2.59	1.47	0.25	0.05	0.23
2002	94.32	61.28	351.28	26.57	6.22	5.13	0.95	0.38	0.07	0.08
2003	243.64	61.98	37.27	274.40	17.95	3.08	2.31	0.40	0.10	0.05
2004	394.48	188.24	35.80	21.69	171.97	6.72	1.71	1.01	0.14	0.04
2005	171.15	297.06	113.13	17.29	9.95	75.92	2.67	0.62	0.23	0.06
2006	319.88	114.94	174.30	56.42	7.36	3.41	23.75	0.71	0.18	0.05
2007	77.05	228.44	63.76	96.45	16.59	2.14	0.89	7.81	0.14	0.05
2008	173.11	48.34	137.40	29.43	40.33	3.76	0.53	0.22	2.80	0.04
2009	170.12	116.21	23.85	68.07	11.32	15.79	0.96	0.12	0.05	1.04
2010	42.43	108.96	53.03	7.12	19.85	2.32	3.23	0.20	0.02	0.22
2011	109.74	22.17	40.24	10.04	0.88	2.74	0.26	0.32	0.02	0.02
2012	66.98	70.93	7.26	10.03	0.99	0.07	0.15	0.02	0.02	0.00
2013	45.22	50.51	37.22	1.66	2.68	0.18	0.01	0.01	0.00	0.00
2014	57.88	30.89	32.15	17.43	0.57	0.39	0.02	0.00	0.00	0.00
2015	83.74	40.58	17.18	13.86	4.82	0.32	0.06	0.01	0.00	0.00
2016	162.70	59.25	20.35	8.25	5.24	1.73	0.07	0.01	0.00	0.00
2017	37.68	133.87	34.19	8.45	2.94	1.77	0.43	0.01	0.00	0.00
2018	54.98	27.62	81.63	15.71	3.03	0.77	0.42	0.07	0.00	0.00
2019	21.04	39.56	21.30	31.04	4.84	0.93	0.25	0.12	0.02	0.00
2020	24.21	13.33	21.75	8.04	11.09	1.39	0.27	0.07	0.03	0.00
2021	35.49	15.52	6.60	7.85	2.33	1.70	0.24	0.09	0.02	0.01
2022	34.37	24.66	7.22	2.04	1.65	0.56	0.32	0.03	0.03	0.01
2023	28.83	26.64	16.46	4.08	1.09	0.64	0.17	0.12	0.02	0.01
2024	32.34	20.64	16.81	8.97	1.86	0.68	0.23	0.05	0.05	0.02

Table S 17. Estimated instantaneous fishing mortality-at-age.

Year	1	2	3	4	5	6	7	8	9	10
1969	0.01	0.04	0.08	0.10	0.13	0.13	0.13	0.13	0.13	0.13
1970	0.01	0.04	0.08	0.11	0.14	0.14	0.14	0.14	0.14	0.14
1971	0.01	0.05	0.09	0.12	0.15	0.15	0.15	0.15	0.15	0.15
1972	0.02	0.06	0.11	0.14	0.18	0.18	0.18	0.18	0.18	0.18
1973	0.03	0.11	0.19	0.26	0.33	0.33	0.33	0.33	0.33	0.33
1974	0.04	0.16	0.28	0.37	0.48	0.48	0.48	0.48	0.48	0.48
1975	0.04	0.14	0.25	0.33	0.42	0.42	0.42	0.42	0.42	0.42
1976	0.03	0.10	0.19	0.25	0.32	0.32	0.32	0.32	0.32	0.32
1977	0.02	0.07	0.13	0.17	0.22	0.22	0.22	0.22	0.22	0.22
1978	0.02	0.08	0.14	0.18	0.23	0.23	0.23	0.23	0.23	0.23
1979	0.02	0.09	0.17	0.22	0.28	0.28	0.28	0.28	0.28	0.28
1980	0.03	0.11	0.20	0.26	0.34	0.34	0.34	0.34	0.34	0.34
1981	0.03	0.12	0.23	0.30	0.38	0.38	0.38	0.38	0.38	0.38
1982	0.04	0.13	0.24	0.32	0.41	0.41	0.41	0.41	0.41	0.41
1983	0.03	0.10	0.18	0.24	0.31	0.31	0.31	0.31	0.31	0.31
1984	0.02	0.07	0.13	0.18	0.23	0.23	0.23	0.23	0.23	0.23
1985	0.02	0.07	0.13	0.17	0.22	0.22	0.22	0.22	0.22	0.22
1986	0.02	0.07	0.12	0.16	0.20	0.20	0.20	0.20	0.20	0.20
1987	0.02	0.06	0.11	0.14	0.19	0.19	0.19	0.19	0.19	0.19
1988	0.01	0.06	0.10	0.13	0.17	0.17	0.17	0.17	0.17	0.17
1989	0.01	0.05	0.09	0.12	0.15	0.15	0.15	0.15	0.15	0.15
1990	0.02	0.06	0.11	0.14	0.18	0.18	0.18	0.18	0.18	0.18
1991	0.02	0.07	0.13	0.17	0.22	0.22	0.22	0.22	0.22	0.22
1992	0.02	0.08	0.15	0.20	0.25	0.25	0.25	0.25	0.25	0.25
1993	0.03	0.10	0.18	0.23	0.30	0.30	0.30	0.30	0.30	0.30
1994	0.03	0.12	0.22	0.29	0.38	0.38	0.38	0.38	0.38	0.38
1995	0.03	0.13	0.24	0.31	0.40	0.40	0.40	0.40	0.40	0.40
1996	0.05	0.19	0.34	0.45	0.57	0.57	0.57	0.57	0.57	0.57
1997	0.07	0.25	0.45	0.59	0.76	0.76	0.76	0.76	0.76	0.76
1998	0.08	0.29	0.53	0.69	0.89	0.89	0.89	0.89	0.89	0.89
1999	0.09	0.34	0.61	0.81	1.04	1.04	1.04	1.04	1.04	1.04
2000	0.09	0.33	0.61	0.80	1.03	1.03	1.03	1.03	1.03	1.03
2001	0.07	0.25	0.46	0.61	0.78	0.78	0.78	0.78	0.78	0.78
2002	0.05	0.20	0.37	0.49	0.63	0.63	0.63	0.63	0.63	0.63
2003	0.05	0.20	0.37	0.49	0.63	0.63	0.63	0.63	0.63	0.63
2004	0.07	0.26	0.47	0.62	0.80	0.80	0.80	0.80	0.80	0.80
2005	0.08	0.32	0.58	0.76	0.98	0.98	0.98	0.98	0.98	0.98
2006	0.09	0.35	0.65	0.85	1.10	1.10	1.10	1.10	1.10	1.10
2007	0.09	0.34	0.63	0.82	1.06	1.06	1.06	1.06	1.06	1.06
2008	0.09	0.32	0.59	0.77	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.12	0.46	0.83	1.10	1.41	1.41	1.41	1.41	1.41	1.41
2010	0.17	0.65	1.19	1.56	2.02	2.02	2.02	2.02	2.02	2.02
2011	0.21	0.79	1.44	1.89	2.43	2.43	2.43	2.43	2.43	2.43
2012	0.15	0.56	1.02	1.34	1.73	1.73	1.73	1.73	1.73	1.73
2013	0.11	0.41	0.74	0.98	1.26	1.26	1.26	1.26	1.26	1.26
2014	0.08	0.30	0.56	0.73	0.94	0.94	0.94	0.94	0.94	0.94
2015	0.08	0.31	0.56	0.74	0.95	0.95	0.95	0.95	0.95	0.95
2016	0.09	0.33	0.59	0.78	1.01	1.01	1.01	1.01	1.01	1.01
2017	0.09	0.35	0.64	0.84	1.08	1.08	1.08	1.08	1.08	1.08
2018	0.09	0.32	0.59	0.77	0.99	0.99	0.99	0.99	0.99	0.99
2019	0.09	0.34	0.63	0.82	1.06	1.06	1.06	1.06	1.06	1.06
2020	0.10	0.39	0.72	0.94	1.21	1.21	1.21	1.21	1.21	1.21
2021	0.11	0.41	0.74	0.98	1.26	1.26	1.26	1.26	1.26	1.26
2022	0.05	0.19	0.34	0.45	0.58	0.58	0.58	0.58	0.58	0.58
2023	0.04	0.17	0.30	0.40	0.52	0.52	0.52	0.52	0.52	0.52
2024	0.03	0.11	0.20	0.26	0.33	0.33	0.33	0.33	0.33	0.33

9. SUPPLEMENTARY FIGURES

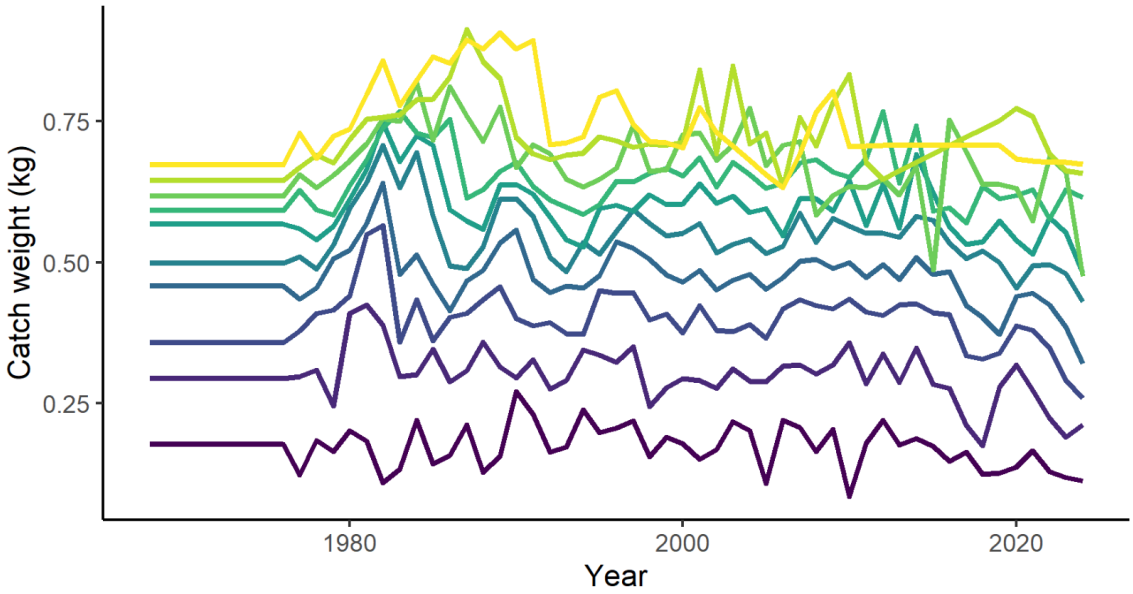

Figure S 1. Weight-at-age (kg) of fish in the landings. Ages 1 to 10 are indicated by violet to yellow.

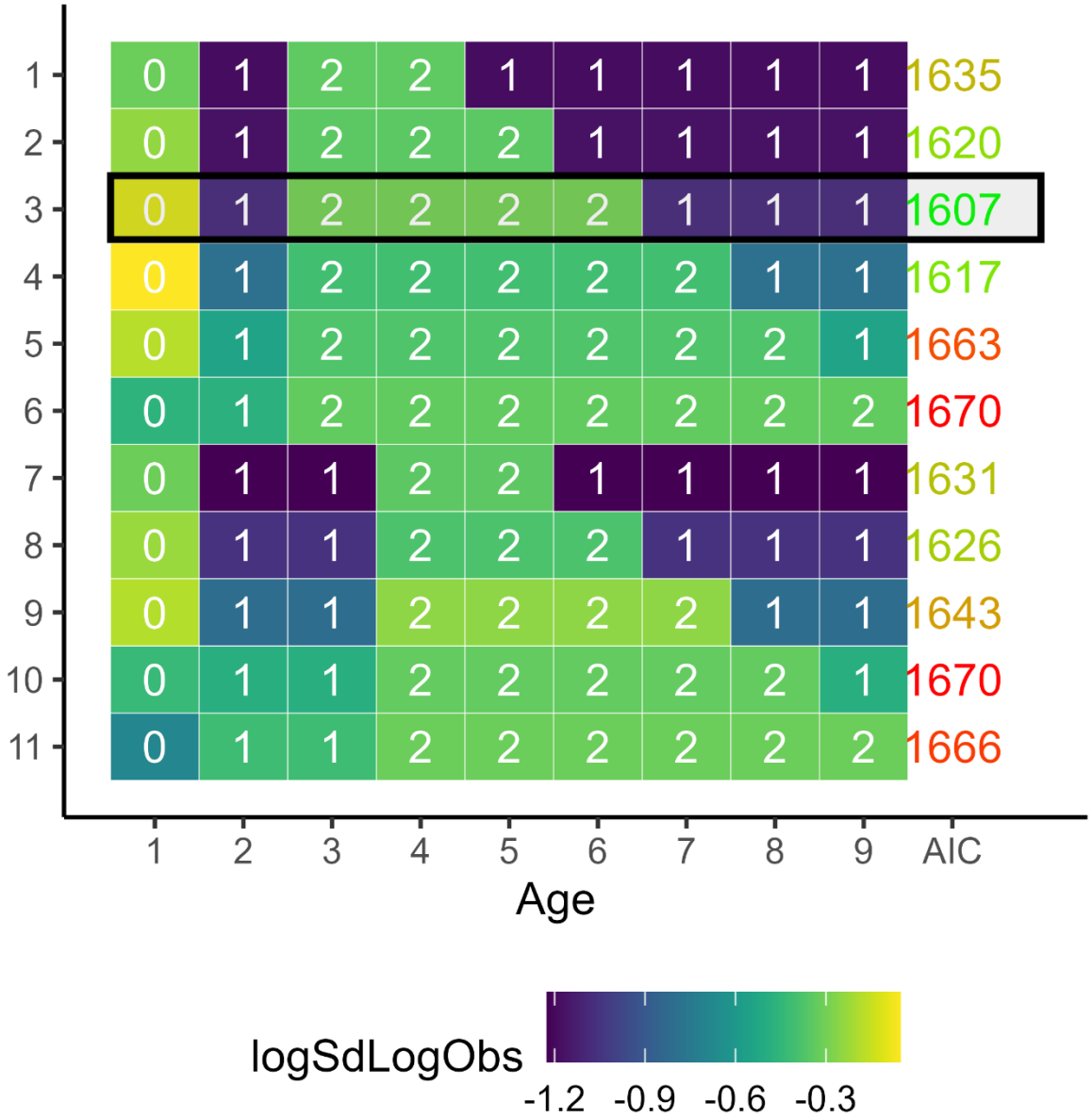

Figure S 2. Sensitivity runs tested for σ_{lp}. White numbers represent the identification of the parameters, square background colours are the estimated parameter values and AIC is indicated in the right column with text colours indicating AIC from low (green) to high (red). The selected run is indicated by the black rectangle.

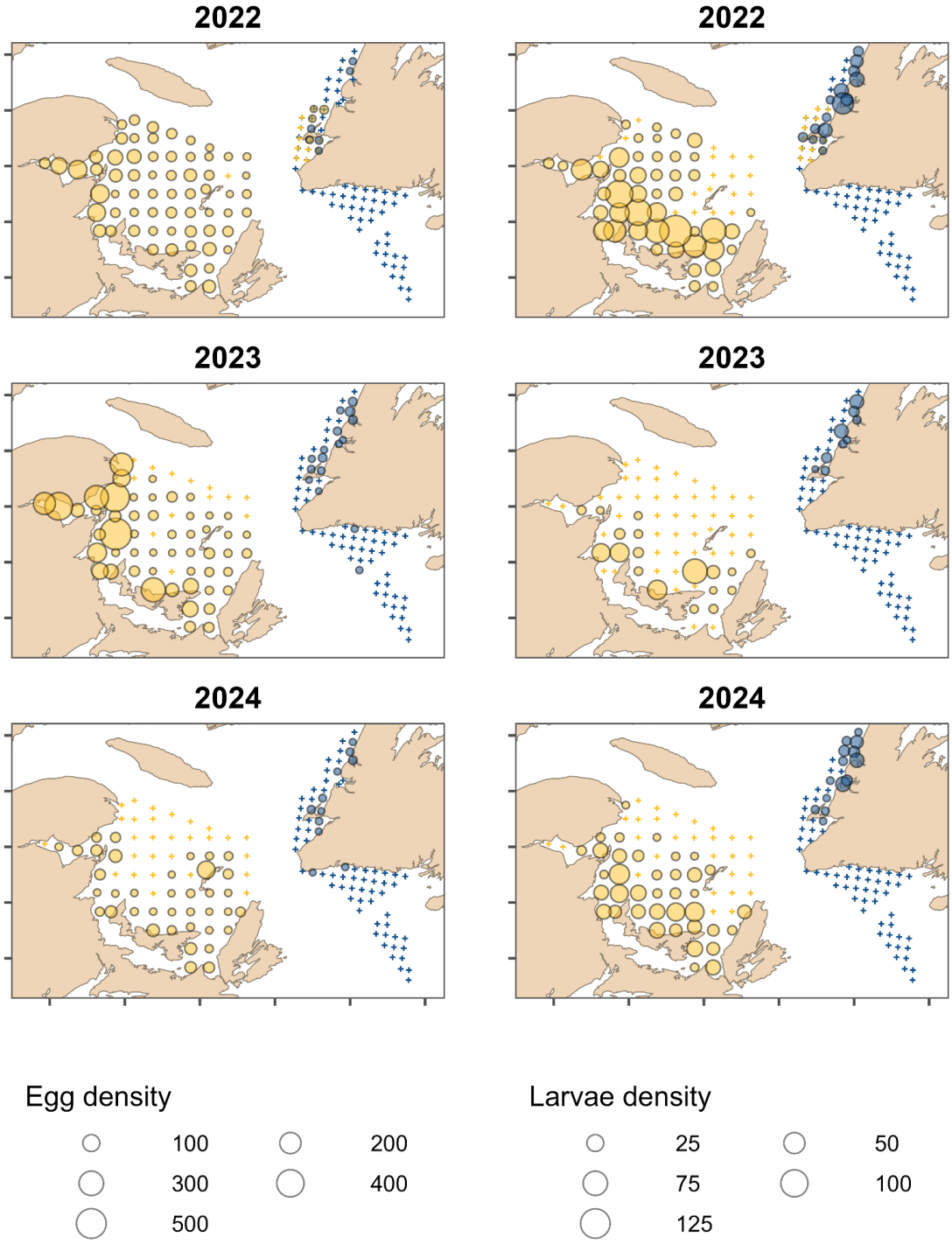

Figure S 3. Egg and larvae density (N/m²) for the sGSL egg survey in June and the Newfoundland egg survey in July during 2022–2024. Orange and blue circles indicate samples collected in June and July respectively. Crosses indicate absence of eggs or larvae. Note that 4R stations were additionally visited in June in 2022.

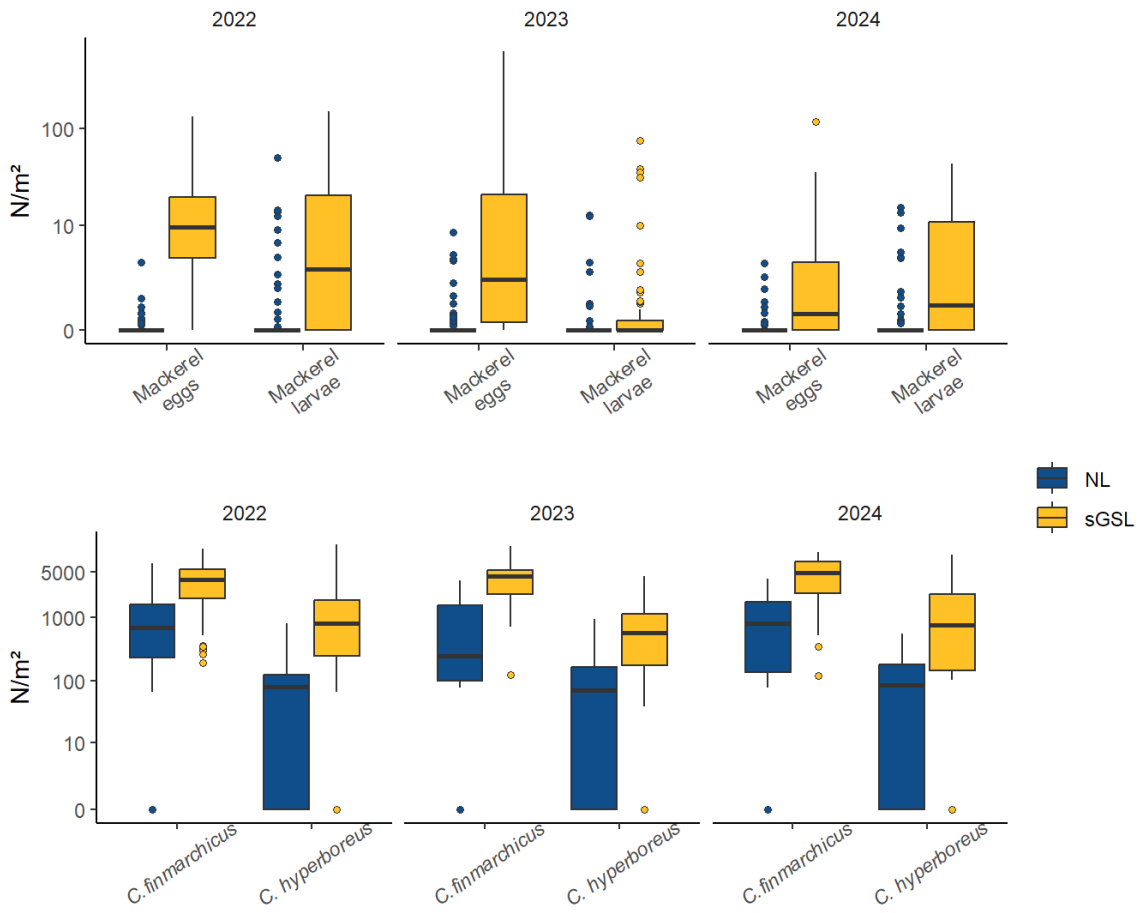

Figure S 4. Mackerel egg and larvae and copepod densities (N/m²) for the sGSL egg survey in June and the Newfoundland egg survey in July during 2022–2024. Note that the y-axis is on the log scale.

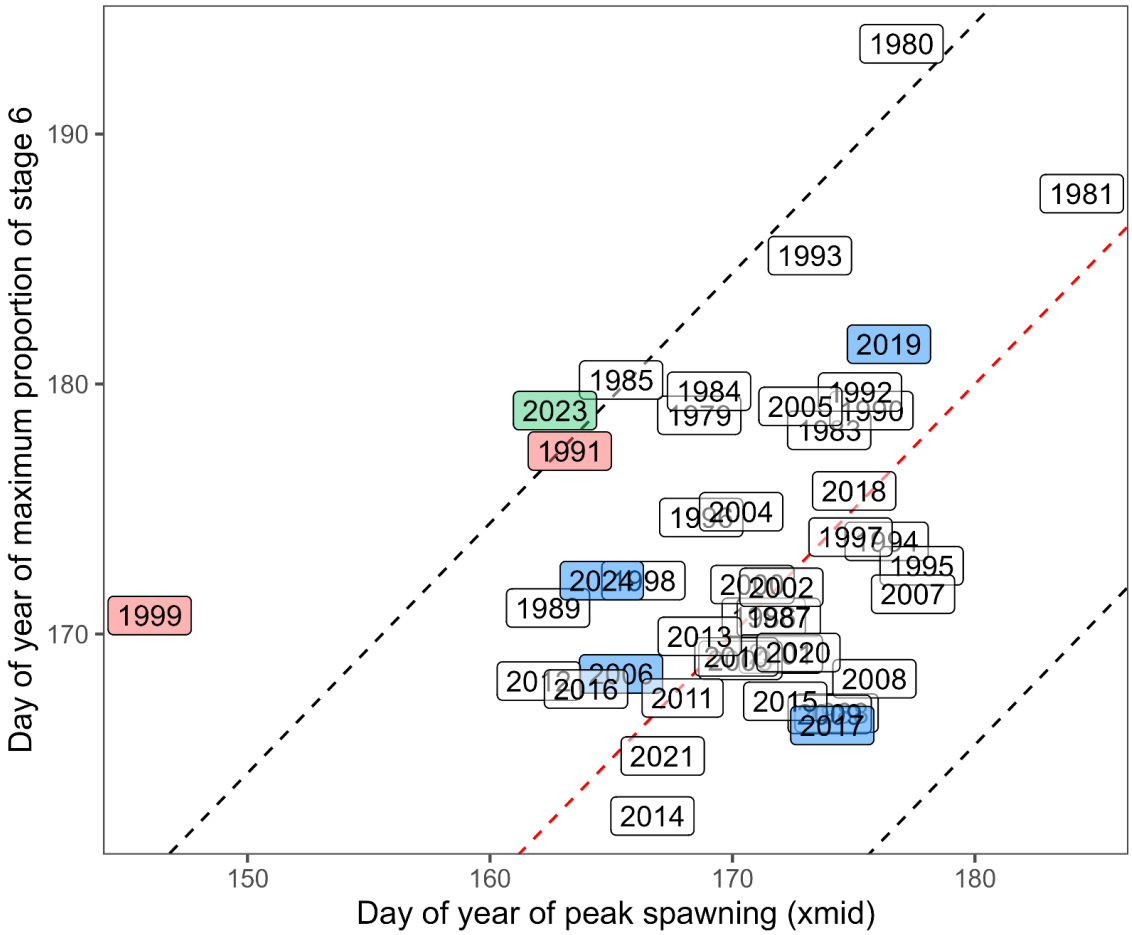

Figure S 5. TEP index bias indicator based on the proportion of stage 6 (spawning, Pelletier 1986) adult mackerel, independently calculated from the estimated peak spawning date. There is no bias if the estimated peak day of spawning is linearly related to the day the proportion of stage 6 mackerel was highest (red line with 95% confidence intervals in black). Years flagged as likely biased (inconsistency in logistic fit) and removed from the assessment are indicated in red. Years with larger uncertainty, but no indication of bias, because of the timing of the survey relative to the timing of spawning (outside the period when 70% of eggs are spawned) are indicated in blue. 2022 was excluded because the proportion of stage 6 could not be calculated on account of the poor sample coverage of the spawning season. 2023 (green) showed a small indication of bias that was further evaluated within the model.

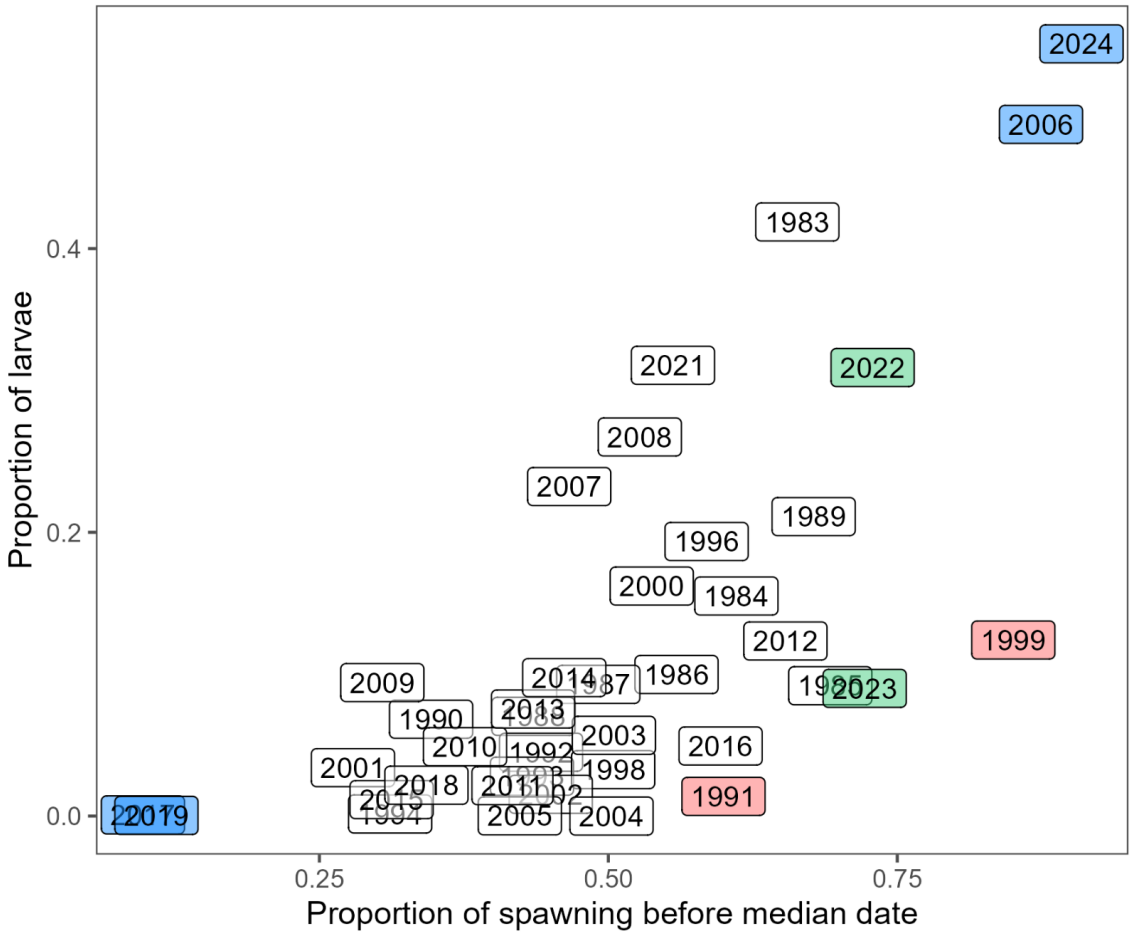

Figure S 6. TEP index bias indicator based on the proportion of larvae, independently calculated from the spawning season estimated by the logistic model. Years flagged as likely biased (inconsistency in logistic fit) and removed from the assessment are indicated in red. Years with larger uncertainty, but no indication of bias, because of the timing of the survey relative to the timing of spawning (outside the period when 70% of eggs are spawned) are indicated in blue. Years with larger uncertainty (2022), or small indication of bias (2023) are indicated in green and were further evaluated within the model.

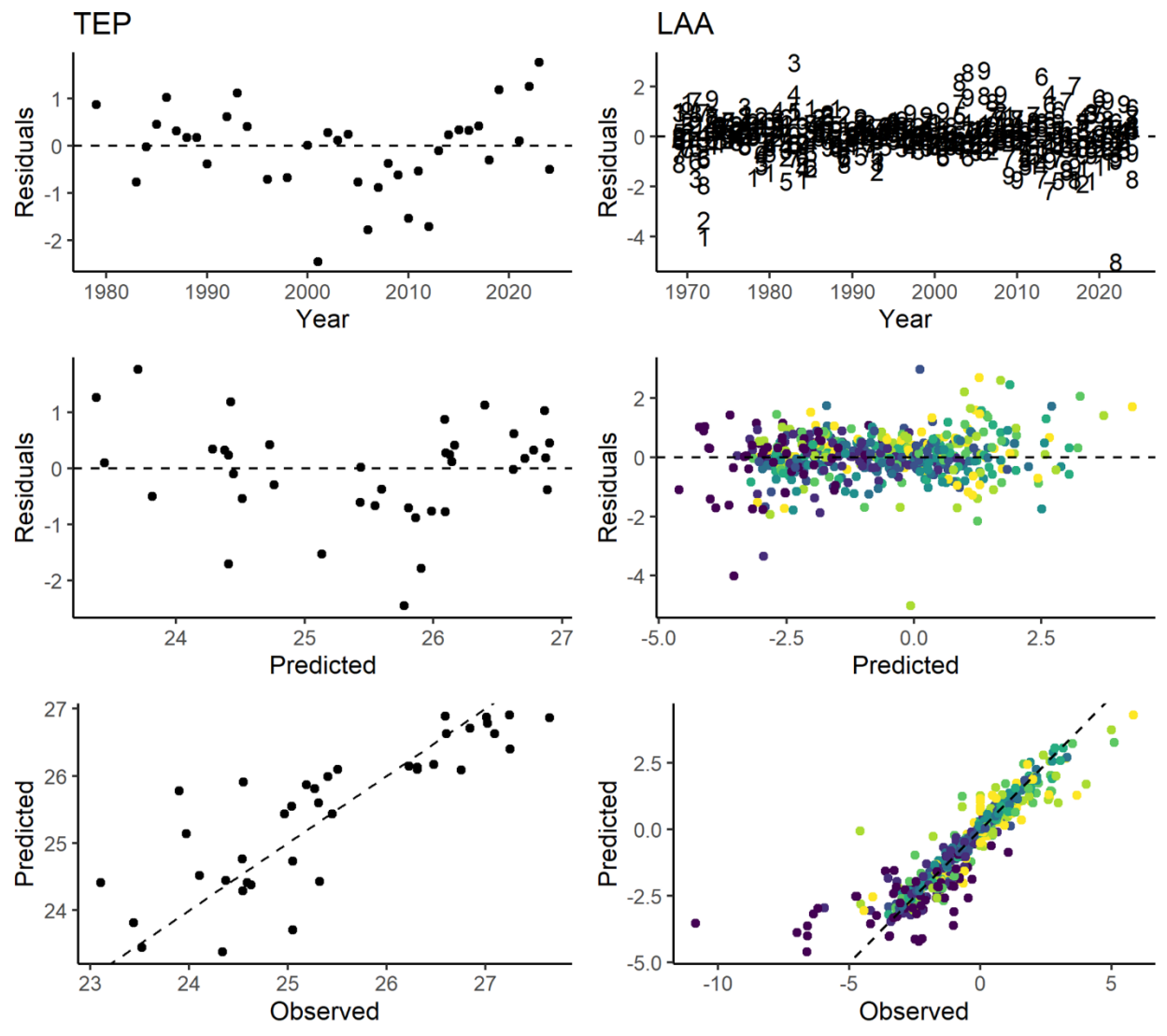

Figure S 7. Model residual plots for the index of Total Egg Production (left column) and landings-at-age (right column). The top row shows the standardized residuals plotted against year, the middle row shows the standardized residuals plotted against the predicted values, and the bottom row shows predicted values plotted against the observed values. The numbers and colours in the landings-at-age plots (right column) indicate the age classes from 1 to 10+ (young to old from violet to yellow).

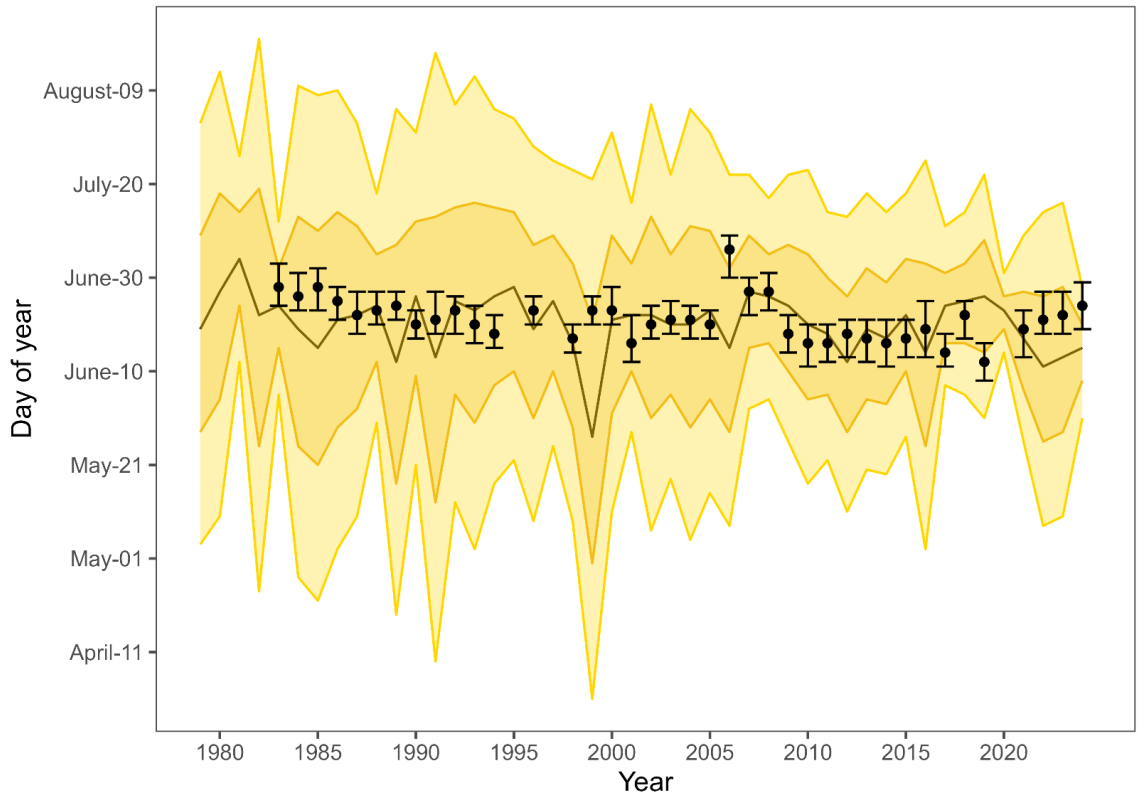

Figure S 8. Estimated spawning season. The black line indicates the peak day of spawning with dark yellow ribbons and pale yellow ribbons indicating 70 and 95% of spawning respectively. The median date of the surveys is indicated with black dots with the duration of the surveys indicated by the vertical bars.

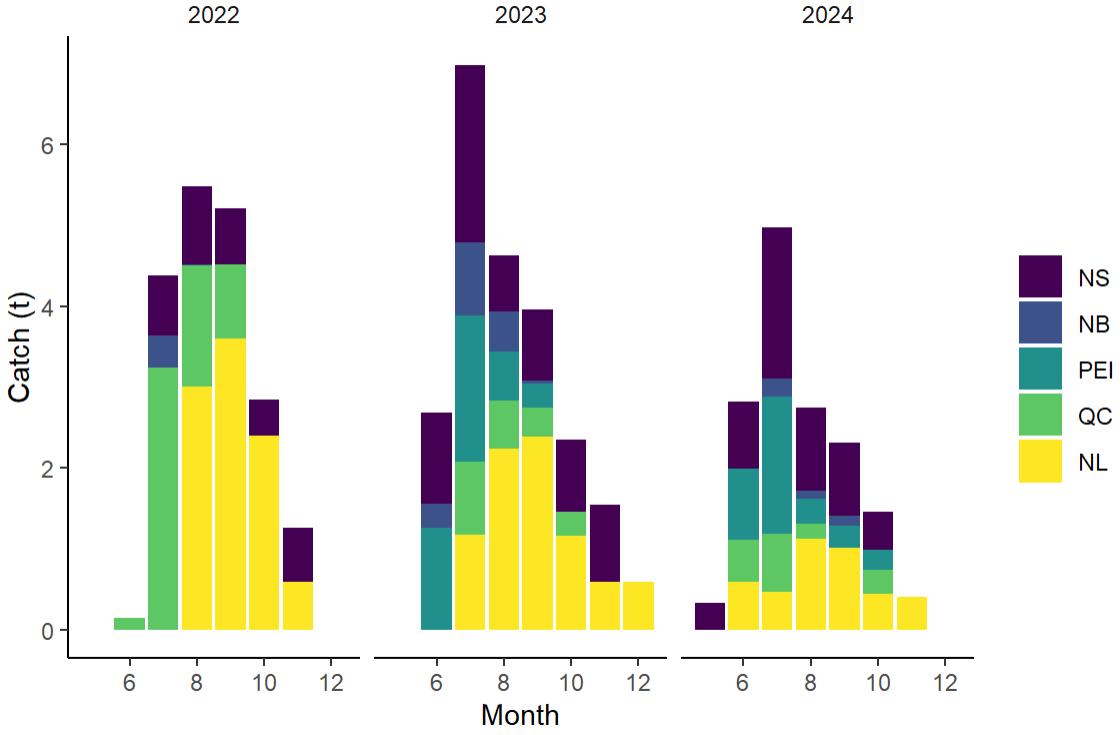

Figure S 9. Mackerel catches (t) under S52 licences. Bars show recorded landings by provinces (colours) by month. Catches totalled approximately 19 t, 22.7 t and 15 t in 2022, 2023 and 2024 respectively.

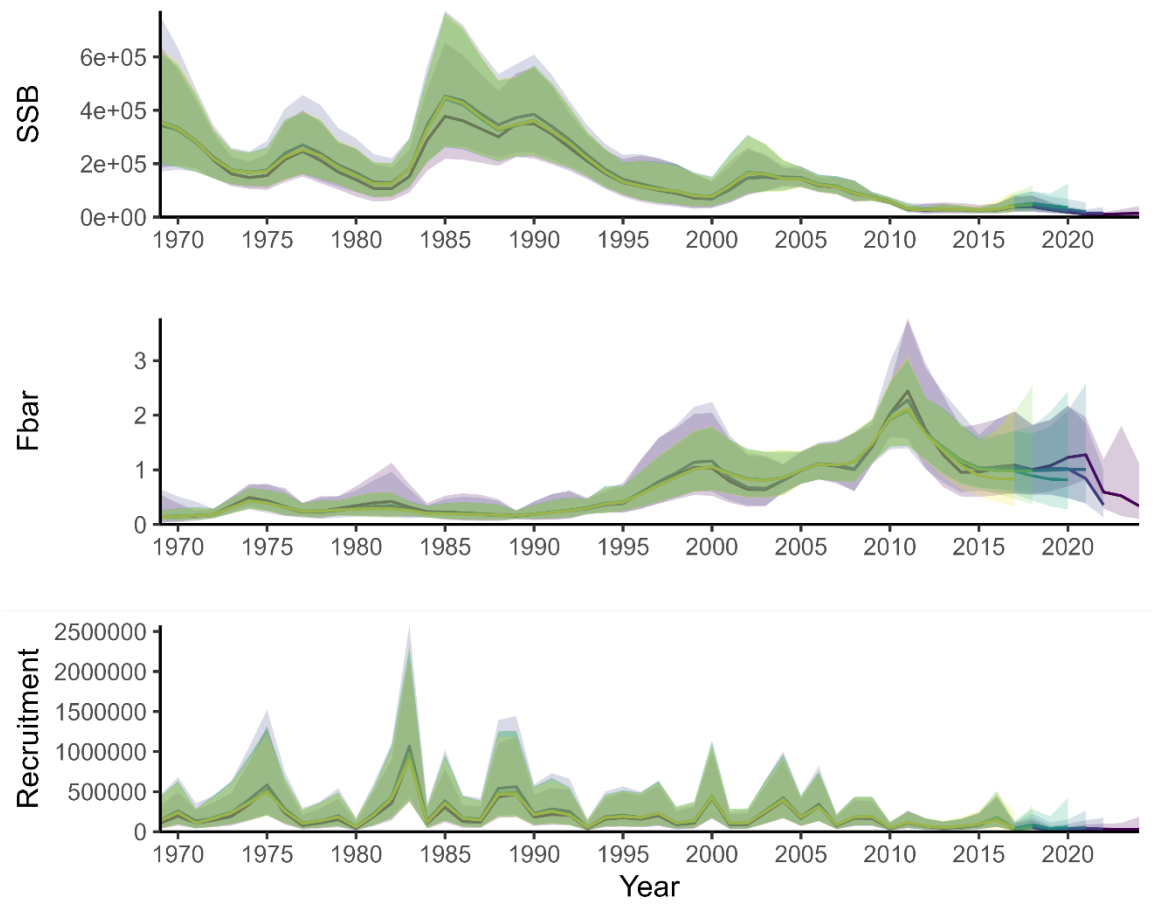

Figure S 10. Retrospective plots for the June Spawning Stock Biomass (SSB in kg; top row); the instantaneous fishing mortality rate Fbar ($F_{\overline{5-10}}$; middle row) and recruitment ('000s; bottom row). Each peel is in a different colour with the full model in violet.

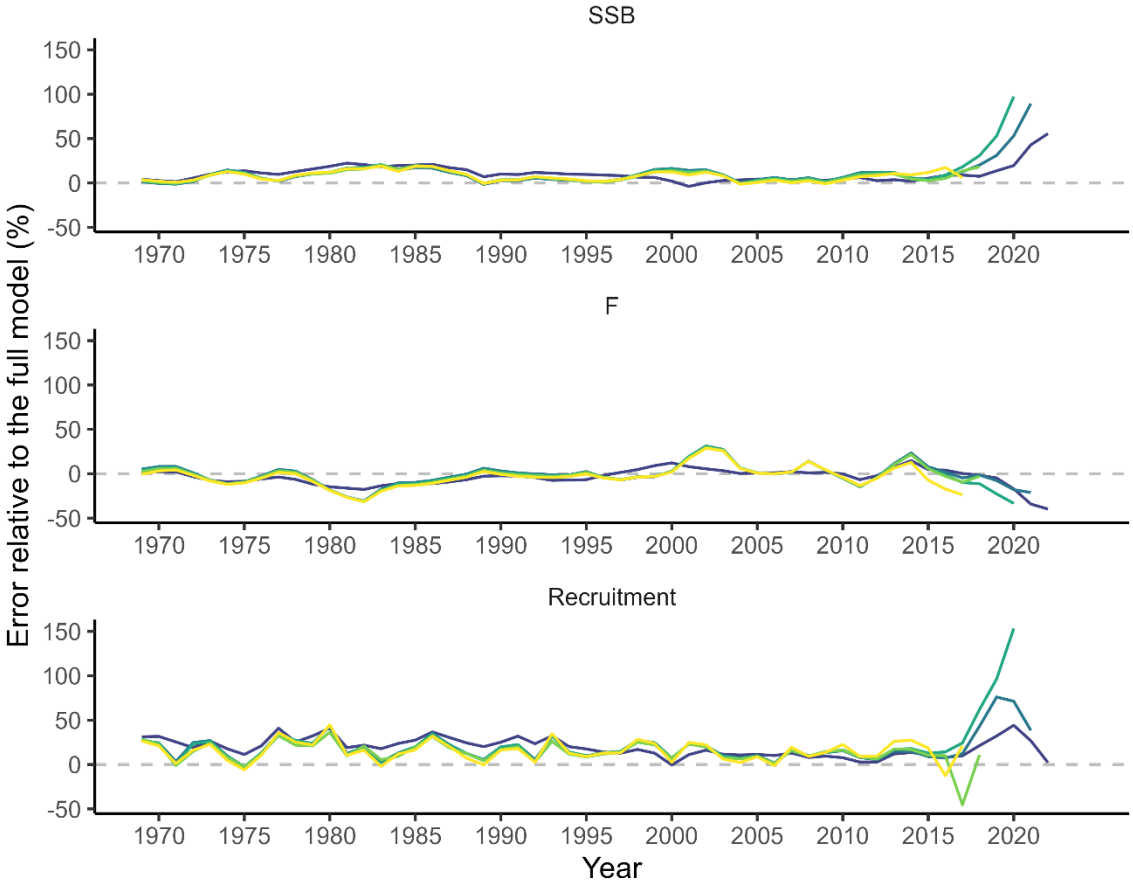

Figure S 11. Retrospective plots relative to the full model for the June Spawning Stock Biomass (SSB; top row); the instantaneous fishing mortality rate Fbar ($F_{\overline{5-10}}$; middle row) and recruitment (bottom row). Each peel is in a different colour.

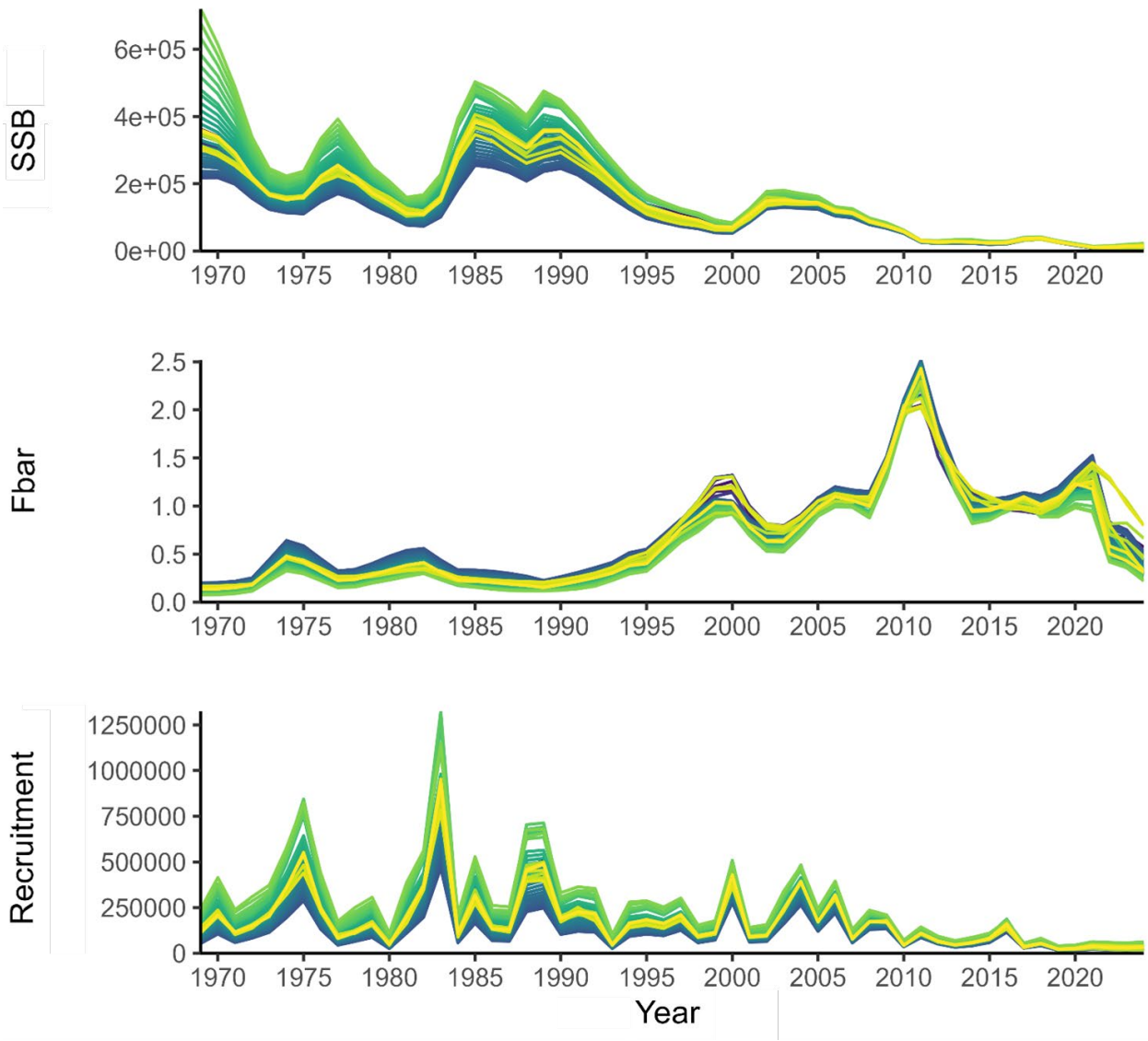

Figure S 12. Model estimates for each sensitivity analysis (see section 2.9.2) for the June Spawning Stock Biomass (SSB in kg; top row); the instantaneous fishing mortality rate Fbar ($F_{\overline{5-10}}$; middle row) and recruitment (bottom row). Sensitivity runs for spawning areas (200 simulations) are not represented.

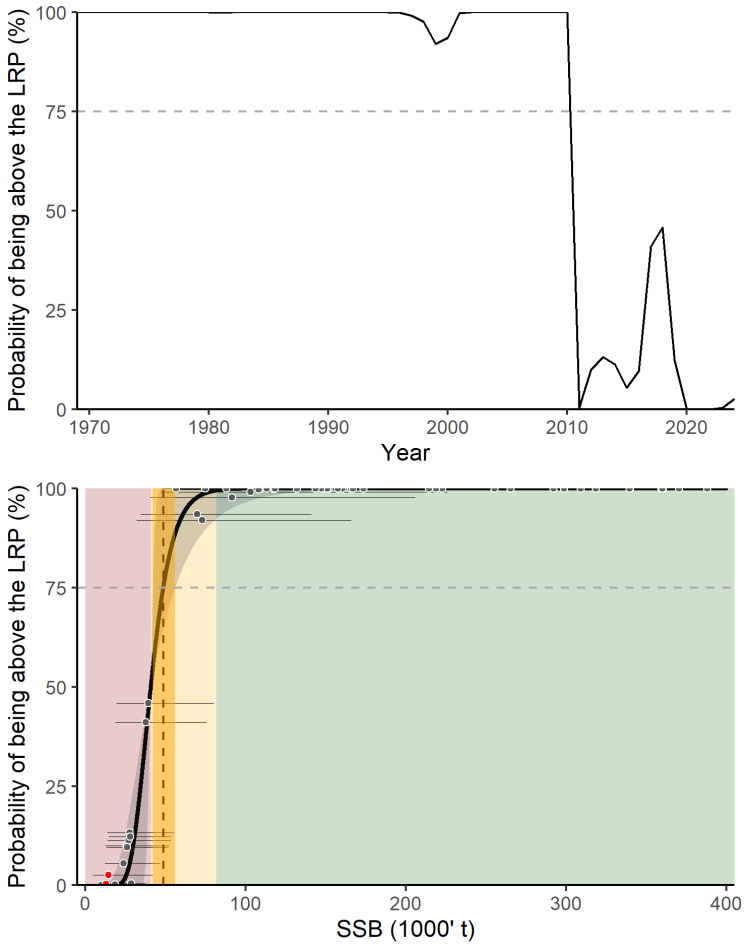

Figure S 13. Probability of being above the Limit Reference Points (LRP) over time (upper panel) and in function of estimated June spawning stock biomass (SSB, lower panel). The red, orange and green zone indicate the Critical, Cautious and Healthy Zone, respectively. The orange vertical line indicates the SSB associated with a 75% probability of being above the LRP with a 95% confidence interval (CI). Dots and associated horizontal lines indicate past SSB estimates with their 95% CI (1969–2024); 2023 and 2024 are shown in red.

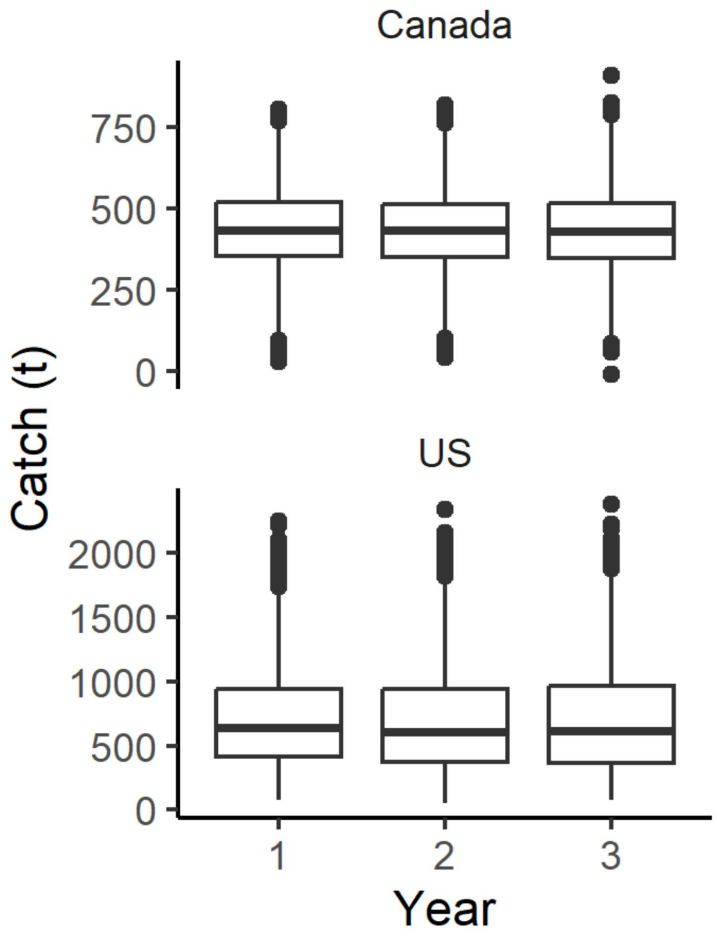

Figure S 14. Boxplots of the assumed unaccounted-for catch over the next 3 years (2025–2027), for Canada (upper panel, limited to recreational fishing) and the U.S. (lower panel).

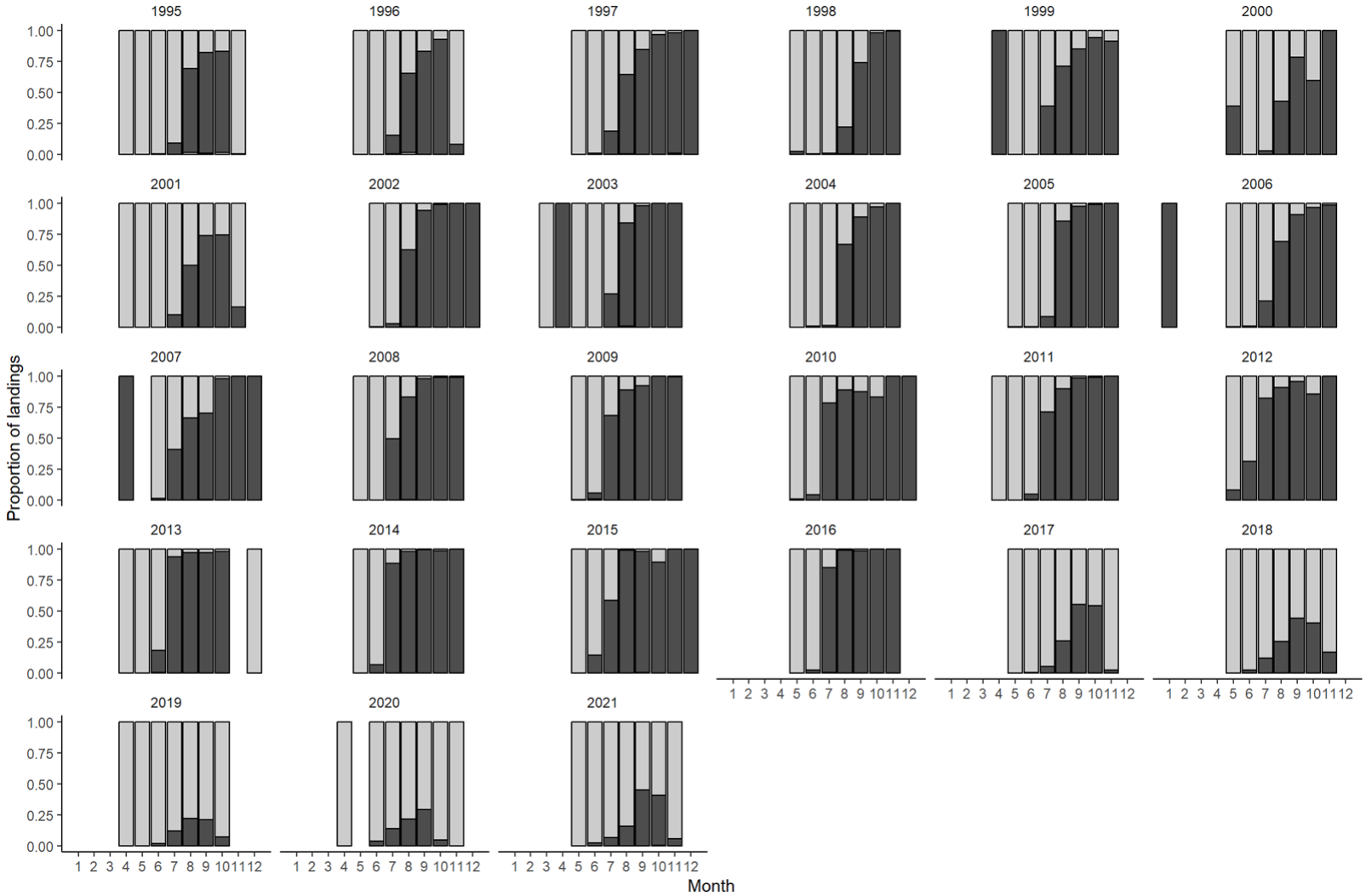

Figure S 15. Proportion of landings by gear in the main spawning area (sGSL: 4T). Gillnets (light grey) are used at the start of the spawning season. After the peak of the spawning season, hooks and lines (dark grey) are preferably used.

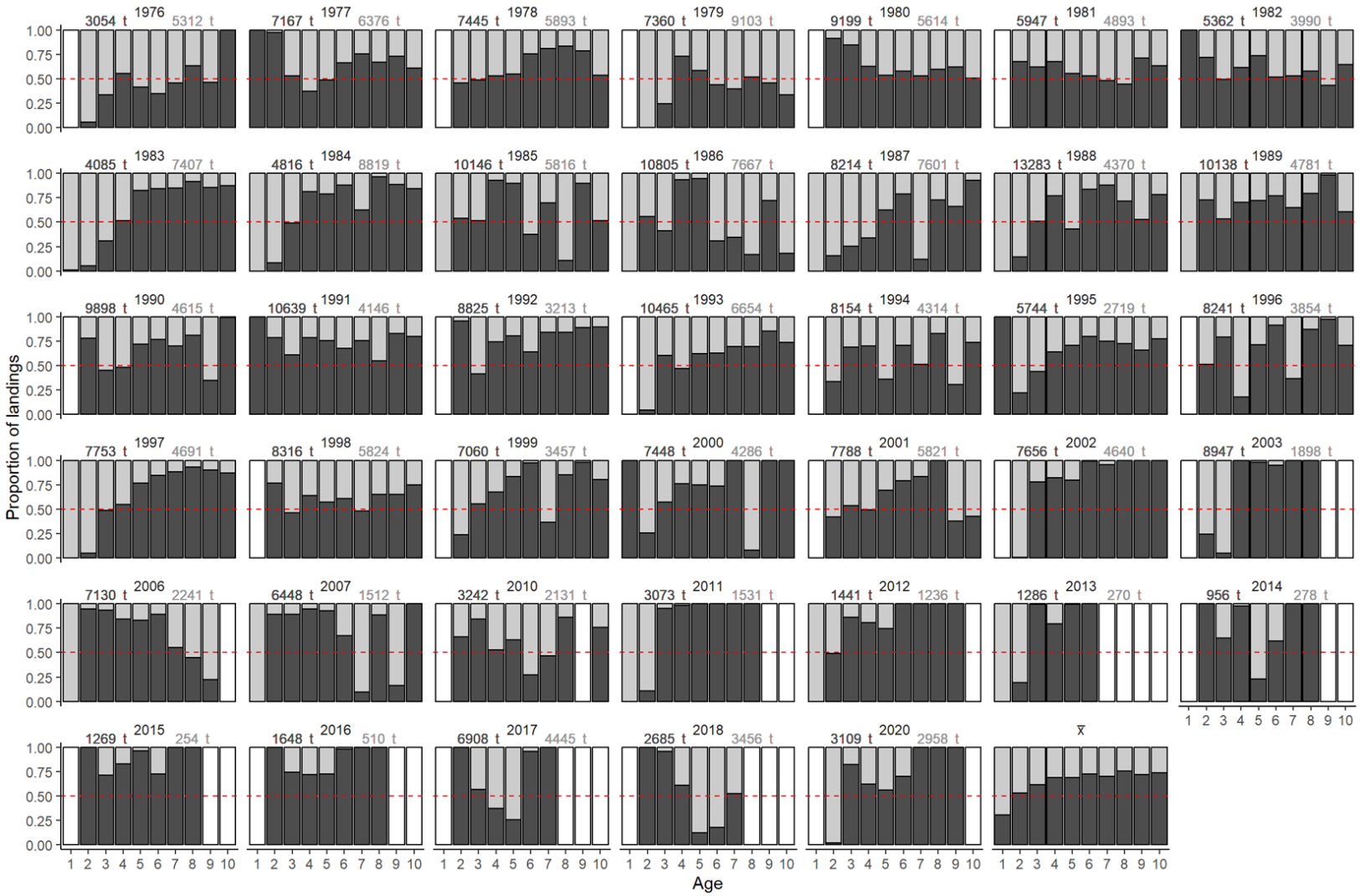

Figure S 16. Proportion of landings-at-age for gillnets during (dark grey) or outside (before or after, light grey) the spawning season (June-July). The last plot summarizes the mean proportion across all years. Some years (for example 2004–2005) were excluded because they failed to merge with samples (age not available). The horizontal red line shows the proportion of 0.5. White bars indicate months without catches. Dark grey and light grey text indicates the total catch by gillnetters for each year during (dark grey) or outside (light grey) the spawning season.

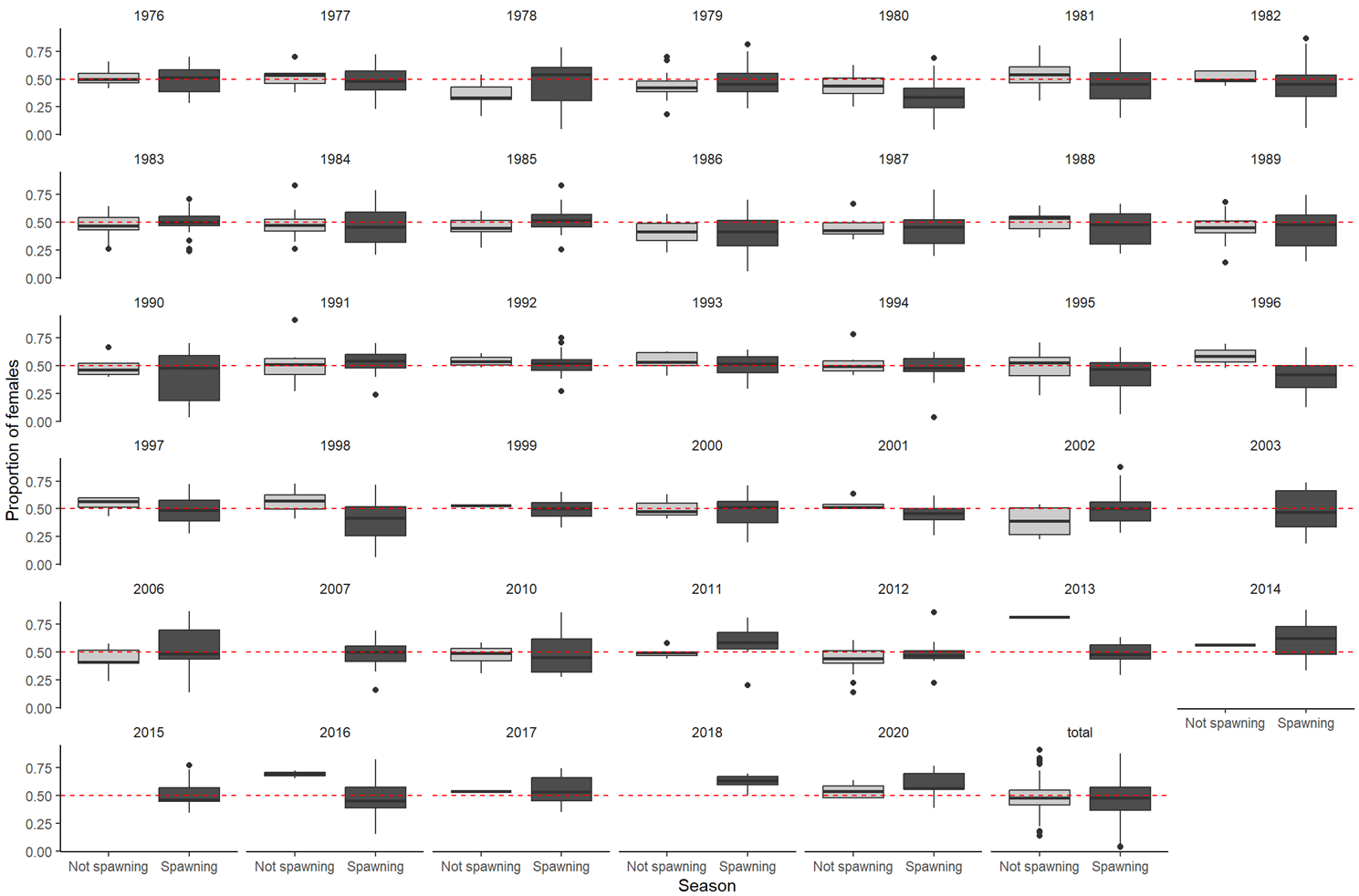

Figure S 17. Proportion of females in landings by gillnetters during (dark grey) or outside (before or after, light grey) the spawning season (June-July). The last plot summarizes the mean proportion across all years. Some years (for example 2004–2005) were excluded because they failed to merge with samples (age not available). The horizontal red line shows the proportion of 0.5.

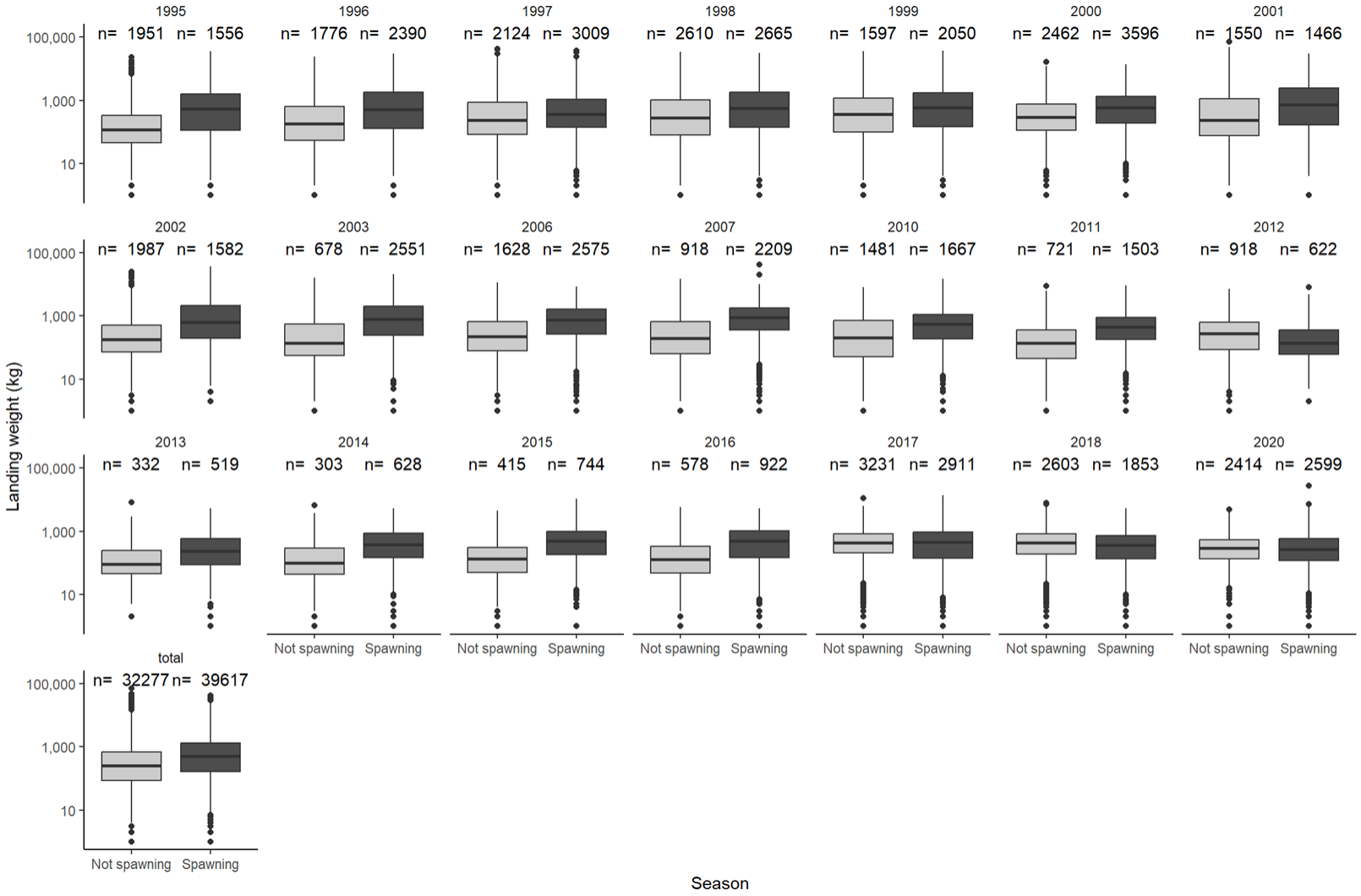

Figure S 18. Landed weight per fishing trip by gillnetters during (dark grey) or outside (before or after, light grey) the spawning season (June-July). The last plot combines the other years. Some years (for example 2004–2005) were excluded because they failed to merge with samples (age not available). Texts above each plot report the number of individual fishing trips by season.

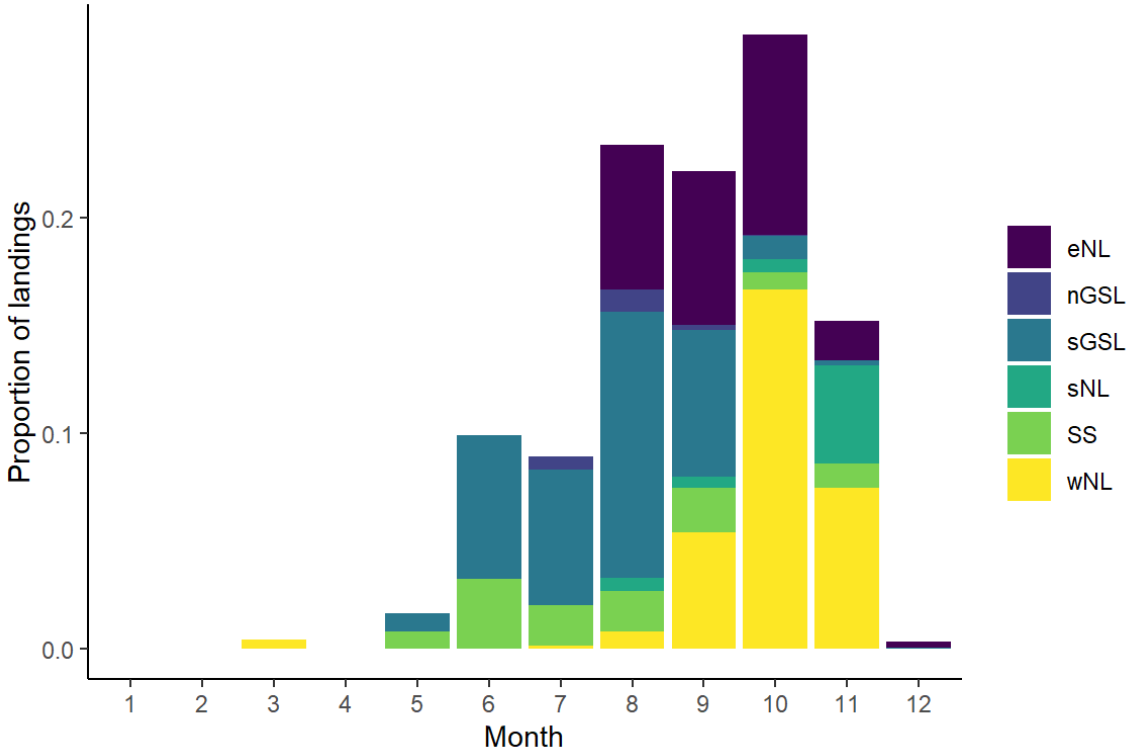

Figure S 19. Proportion of landings by month and regions during 2010–2019. Colours indicate regions of landings (eNL =eastern Newfoundland, nGSL= northern Gulf of St. Lawrence, sGSL= southern Gulf of St. Lawrence, sNL=southern Newfoundland, SS= Scotian Shelf, wNL= western Newfoundland and Labrador)