Report of the 2023 ICCAT Atlantic Albacore Stock Assessment Meeting (including MSE)
(Hybrid, 26-29 June 2023)

"*The results, conclusions and recommendations contained in this Report only reflect the view of the Albacore Species Group (ALBSG). Therefore, these should be considered preliminary until the SCRS adopts them at its annual Plenary meeting and the Commission revise them at its Annual meeting. Accordingly, ICCAT reserves the right to comment, object and endorse this Report, until it is finally adopted by the Commission*."

1. Opening, adoption of agenda and meeting arrangements

The hybrid meeting was held from 26 to 29 June 2023. The Atlantic Albacore rapporteur, Dr. Haritz Arrizabalaga (EU-Spain) and the meeting Chair, opened the meeting and welcomed participants. Mr. Camille Manel, ICCAT Executive Secretary, addressed the Group and welcomed the participants.

The Chair proceeded to review the Agenda which was adopted with a few changes (**Appendix 1**). The List of Participants is included in **Appendix 2**. The List of Documents and Presentations provided at the meeting is attached as **Appendix 3**. The abstracts of all SCRS documents and presentations are included in **Appendix 4**. The following participants served as Rapporteurs:

Sections	*Rapporteur*
Items 1 and 14	M. Ortiz and A. Kimoto
Item 2	P. Quelle, V. Zarate de Ortiz, and A. Kimoto
Item 3	M. Lauretta, A. Urtizberea, G. Moron, and G. Merino
Item 4	M. Lauretta, A. Urtizberea, G. Moron, and G. Merino
Item 5	M. Lauretta, A. Urtizberea, G. Moron, and G. Merino
Item 6	A. Kimoto, M. Ortiz, and M. Lauretta
Item 7	G. Merino
Item 8	G. Merino and H. Arrizabalaga
Item 9	S. Cass-Calay
Item 10	H. Arrizabalaga and G. Merino
Item 11	M. Ortiz and H. Arrizabalaga
Item 12	M.L. Araujo
Item 13	J. Ortiz de Urbina

2. Summary of input data for stock assessment and Management Procedure (MP) iteration

For further details please refer to the Report of the North Atlantic Albacore Data Preparatory Meeting (Anon. 2023).

2.1 Biology

A new natural morality at age vector was presented at the Data Preparatory meeting. The Group agreed with all the biological parameters that were discussed and adopted at the Data Preparatory meeting (Table 1 in Anon., 2023).

2.2 Catches

Based on the updated fleet structure agreed by the Group (Table 8 in Anon., 2023), the ICCAT Secretariat provided the updated catch by fleet using CATDIS as of 31 January 2023 after the Data Preparatory meeting. The Group was informed that after the Data Preparatory meeting (Anon., 2023), the ICCAT Secretariat received some minor catch updates for the period 2019-2021 for the North Atlantic albacore and that the differences between CATDIS (input data for the Stock Synthesis (SS)) and Task 1 (as of 26 June 2023) are minimal (< 0.1% in weight). There was no update on the 2022 catch. ICCAT The ICCAT Secretariat will provide the Group with 2022 catches at the September Species Group meeting in 2023.

2.3 Size

After the Data Preparatory meeting, the ICCAT Secretariat provided the updated length compositions by year, quarter, and fleet following the decisions of the Group (section 5.1 in Anon., 2023). Length data by year and fleet in a 2 cm bin with a minimum sample size of n= 90 fish (4.5 log scale) was provided for input in the SS model. The annual size input frequencies were weighted by the number of samples by quarter. The ICCAT Secretariat informed the Group that there were no updates to the North albacore size frequencies since the Data Preparatory meeting.

SCRS/2023/118 presented the spatial distribution of albacore size in the North Atlantic caught by the Chinese Taipei longline fishery. The size samples were collected in the main fishing ground between 15°N to 40°N from 2018 to 2022 and ranged mostly from 80 to 120 cm fork length (FL). It was noted that albacore smaller than 100 cm FL were observed north of 30°N, whereas individuals larger than 100 cm FL were caught mainly south of 30°N.

The Group noted that the information in this document was originally shared with the modeling team before the Data Preparatory meeting and thanked the authors for providing this useful document. The Group acknowledged that this document supports separating the longline fisheries into two areas, North and South of 30°N in the assessment model. The Group asked if the fishing methodology changed between the North and South of 30°N. The authors explained that the Chinese Taipei longline fishing operation targeting albacore has changed over time. The fleet targeting albacore operated both North and South of 30°N in the early period. However, during the 2010s the fleet operations shifted to target mostly large albacore South of 30°N. The author also indicated that this fleet still targets large albacore, but there was a big shift of its target species to bigeye tuna in the tropical area, compared to the early period before 2000.

The Group discussed that the difference in albacore size by area (i.e., larger albacore is observed in the South of 30°N) might have a biological basis. Although little is known about the basic life cycle, the feeding migration of juveniles occurs toward higher latitudes while spawning grounds are in the lower latitudes of the North Atlantic. That could explain the difference between the size compositions North and South of 30°N.

2.4 Indices of abundance

The Group did not receive any new information on abundance indices after the Data Preparatory meeting (section 4 in Anon., 2023).

The 2018-year point of the Venezuela longline index was excluded from the analysis based on the decision made at the 2020 Atlantic Albacore Stock Assessment Meeting (Anon., 2020) due to the low spatial and temporal sampling coverage in that year.

2.5 Fleet structure

The Group agreed to follow the decision regarding the fleet structure to use in the SS platform made at the data preparatory meeting (section 5.1 in Anon., 2023). The fleet structure can be found in Table 8 (Anon., 2023),hich contains 15 fleets.

3. Methods and Model Settings

3.1 Stock Synthesis Methods

The Group reviewed the preliminary SS (version 3.30.21, Methot and Wetzel, 2013) model assumptions, data configuration, model fits, and diagnostics presented in SCRS/2023/107. The SS model is a one-area, one-sex, annual time-step model for the North Atlantic albacore stock for the period 1930 to 2021. A total of 15 fleets (listed below and described in **Table 1**) and 8 abundance indices (Table 7, Anon. 2023, **Figure 1**) were included.

Fleet Structure: 15 fleets

- Baitboats (EU-Spain and EU-France), 1953-2021
- Baitboats – Islands seasons 1, 3, and 4 (EU-Portugal Madeira/Azores, EU-Spain, Canaries), 1958-2021
- Troll (EU-Spain and EU-France) + Gillnet (EU-France and EU-Ireland), 1930-2021
- Mid-water trawl (EU-France and EU-Ireland), 1987-2021
- Japan longline North (North of 30 degrees latitude), 1961-2021

- Japan longline South (South of 30 degrees latitude), 1961-2021
- Chinese Taipei longline North (North of 30 degrees latitude), 1968-2021
- Chinese Taipei longline South (South of 30 degrees latitude), 1968-2021
- U.S. and Canada longline North (North of 30 degrees latitude), 1980-2021
- U.S. longline South (South of 30 degrees latitude), 1980-2021
- Venezuela longline 1960-2021
- Korea, Panama and China longline, 1960-2021
- Other longlines, 1965-2021
- Other surface gears, 1978-2021
- Baitboats - Islands season 2, 1965-2021

Indices of Abundance: 8 CPUE

- Baitboats, 1981-2021(2020 no data)
- Japan longline North, 1988-2009 (2010 excluded)
- Japan longline South, 1988-2021 (2013 excluded)
- Chinese Taipei longline North, 1999-2021
- Chinese Taipei longline South, 1999-2021
- U.S. longline North, 1987-2021
- U.S. longline South, 1987-2021
- Venezuela longline, 1991-2017 (2018 excluded)

Each index series was normalized to a mean of one. The Group supported the decisions made at the Data Preparatory meeting and the 8 indices (5 indices for North of 30°N area, and 3 indices for South of 30°N area) introduced in the assessment were normalized to an average standard error of 0.2 for each series, preserving the interannual variability of the original index.

The Group noted the change in the time resolution from the initial model to the reference case from a quarterly to an annual timestep. This change greatly reduced the model complexity and led to an overall better fit to the different data series. Several diagnostics analyses were performed to evaluate the model specification and convergence. The Group requested some clarifications and additional analyses, which included an evaluation of the recent high recruitment deviations and what data are driving those estimates, an evaluation of growth with the addition of the length-at-age data and comparison with published growth models, a comparison of time series with prior assessment, data weighting assumptions, and model convergence. It was demonstrated that the recent high recruitments are primarily informed by the baitboat index (referencing ages 1 to 4, with peak selectivity for ages 2 and 3), which shows a sharp increase in CPUE during that period. Comparison of growth estimates to published studies (Bard *et al*., 1981, Santiago *et al*., 2005) showed good agreement and validated the growth estimates within the model. The Group commented that the addition of the length-at-age data greatly improved the model and allowed for the estimation of growth parameters directly in SS. A comparison of time series between the current SS model and the prior assessment indicated that differences in biomass time series are primarily due to the addition of the new data and that the results (scale and trend) are very similar when the data are truncated to the same period as the previous 2020 Atlantic Albacore Stock Assessment. Specifically, the updated CPUEs show an increasing trend since the last assessment across the data series.

The Group recommended exploring alternative data weighting, especially reweighting the length composition using the Francis method (Francis, 2011), as well as sensitivities with the CPUE and age data iteratively upweighted. It was shown that growth estimation varies depending on the weighting of the length-composition versus length-at-age data, and that the age data are important for improved estimation of growth. It was noted that additional age samples of larger fish (>100cm) would further improve growth estimates. Removal of each index series from the model (Jackknife analysis) showed the large influence of the bait boat CPUE on recent recruitment and biomass trends. Removal of other indices had less influence on the time series.

A brief description of the model inputs and revised model structure, based on the Group's recommendations for a base model configuration, is described below.

Growth and Natural Mortality

Growth was directly estimated in SS assuming a von Bertalanffy growth model (**Figure 2**). The natural mortality-at-age was scaled internally assuming a Lorenzen function (**Figure 3**) and base M of 0.36 at age 6, derived using the approach of Hamel and Cope (2022) and assuming a maximum age of 15 (Anon. 2023).

Length Compositions and Fleet Length-based Selectivities
Annual length composition data were input as straight fork lengths (cm) by fleet aggregated into 2 cm length bins across a range from 26 to 158 cm (**Figure 4**). Length composition data were modelled assuming a multinomial distribution with the effective sample size equal to the natural logarithm of numbers of measured fish. The Group discussed alternative effective sample size assumptions and recommended exploring alternative scaling approaches, to be explored intersessionally.

Length-based selectivity was estimated directly for fleets 1 to 12. The baitboat and mid-water trawler fleets showed a multimodal length composition and were modelled with a cubic spline function. For the cubic spline assumption, the number of nodes was set equal to 3 and 4 (respectively for each of both fleets), based on exploration of alternative parameterization and model fits. For nodes position, the SS auto-generation feature was used (Methot *et al*., 2020). The U.S. longline south and Venezuela longline were assumed to have logistic (asymptotic) selectivity. The remaining fleets, including the longlines and surface fisheries, were modelled with a double-normal function, with the exception of fleets 12, 13, and 14, which were mirrored to the U.S. longline south fleet. For the baitboat islands (fleets 2 and 15), troll and gillnets (fleet 3), and mid-water trawlers random walks were used to fit the interannual changes in the length distribution data which could be related to changes in the availability of fish between years. Time blocks were defined for Japanese and Chinese Taipei longline fleets to differentiate the changes in selectivity during the target, transition, and bycatch period: for the Japanese longline fleet until 1969 (as offset), 1970-1975, 1976-2021, and for the Chinese Taipei fleet until 1986 (as offset), 1987-1998,1999-2021.

Conditional Age-at-Lengths
The aging information was modelled as conditional age at length (CAAL) due to the relatively sparse age-length information across the time series and to not assume the data were representative of ages across the full range of sizes. The age-length pairs (3953 records from spine samples) are input as age frequency distributions by length bins (at 2 cm intervals) for each year and quarter, assumed collected by baitboats, trawl, and gillnets (**Figure 5**). Age information was input with an aging error vector calculated with data from 2011.

Initial F Assumptions
Previous to 1930, catch at equilibrium was assumed for fleet 3 to be equal to 10,000 t. Initial F was estimated directly in SS.

Length-weight relationship
The length-weight relationship used in the model was: W (kg) = 1.339e-4 * SFL (cm) $^{3.107}$ (Santiago, 1992).

Maturity
The age at 50% maturity was assumed to be age 5 and full maturity at age 6: 0 (ages 0-4), 0. 5 (age 5), 1 (ages 6-15).

Stock-recruitment relationship
A Beverton-Holt stock-recruitment relationship (with a flat top) was assumed with sigmaR fixed at 0.4, based on the FishLife life history database. R0 and steepness were freely estimated. Recruitment deviations were assumed to follow a lognormal distribution estimated on a log scale as N(0, sigmaR) variates with a min and max of -5 and 5, respectively. Zero recruitment deviations were assumed until the start of informative data about relative stock abundance beginning in 1960, and recruitment was not estimated for the terminal three years. The lognormal bias correction for the mean of the stock recruit relationship was applied following the method of Methot and Taylor (2011).

3.2 Surplus Production Models mpb

In 2016 and 2020, the North Atlantic albacore was assessed using the biodyn algorithm for a biomass dynamic production model based on Automatic Differentiation Model Builder (ADMB), which is available in the *mpb* package of the FLR project (www.flr-project.org) repository. The biodyn algorithm was validated against the surplus production model (ASPIC) in Kell *et al.,* 2017, by checking that it provided the same results using the 2013 Albacore Stock Assessment inputs and assumptions, and it is the algorithm that was used in the MSE framework (Merino and Arrizabalaga, 2016; Merino *et al.*, 2017). For the 2016 North and South Atlantic Albacore Stock Assessment, the Group selected five CPUE series for use in the production model and the same updated indices were used in the 2020 Atlantic Albacore Stock Assessment. The Group reviewed the data inputs and model settings and expressed no concerns with the decisions made at the Data Preparatory meeting. The ICCAT Secretariat noted the decision made following the Data Preparatory meeting to remove the last year of the Venezuelan longline CPUE index due to very limited observer coverage. The Group supported this decision. The selected indices showed an overall increasing trend since 2010 (**Figure 6**), which could reflect the increasing trend of the stock in the last decade when the catches have been below the adopted Total Allowable Catches (TACs).

Following document SCRS/2023/100 and the model configuration described in the *Recommendation by ICCAT on conservation and management measures, including a Management Procedure and Exceptional Circumstances Protocol, for North Atlantic albacore* Rec. 21-04) (**Tables 2 and 3**), the Group agreed to define the Reference Case including the 5 CPUE series, excluding the Japanese longline 2013 and the Venezuelan longline 2018 values.

4. Model diagnostics

4.1 Stock Synthesis

The SS reference case model converged (final gradient = 0.000847942) with a positive definite Hessian matrix. The estimated parameters included five growth model parameters, two stock-recruitment parameters (R_0 and steepness), one initial F parameter, 47 recruitment deviations, and the remaining parameters were fleet length-based selectivity parameters and selectivity random walk deviates. Parameter estimates, asymptotic standard errors, and assigned priors are provided in **Table 4**. In the reference case model, a prior was assigned to steepness, based on the estimate from the last assessment workshop (h=0.75), and the midwater trawl selectivity. The Group noted the model was able to estimate selectivity, demonstrated by a well-defined posterior that diverged noticeably from the prior and the likelihood profile analysis that showed a defined minimum. The Group recommended removing the prior on steepness and adding priors to particular selectivity parameters that showed very large standard deviations to improve the overall stability of the model (top logit parameters of fleets with double-normal selectivity, exclusively). These revisions to the reference case will be made intersessionally.

A jitter analysis was conducted to evaluate whether the model converged to a global solution, by applying a random deviation to starting values of 10%. None of the jitter runs indicated a lower negative log-likelihood than the reference case model (**Figure 7**), however, a fraction of trials failed to converge. The removal of prior on steepness from the initial model resulted in better convergence across trials (76% of trials converged compared to 50%, and the gradient was reduced), and the Group recommended the analytical team evaluate the performance of the model with the assigned priors on selectivity parameters. This work will also be conducted intersessionally, after all recommended revisions are incorporated.

Plots of the observed versus fit data and residual plots were examined to evaluate model fit to the indices (**Figure 8** and **Figure 9**) and length composition data (**Figure 10**). Overall, the model demonstrated an acceptable fit to some of the indices of abundance, but a general lack of fit was observed for the baitboat, U.S. longlines, and Venezuela longline indices. Runs tests were applied to the residual series of each index and length composition in order to quantitatively evaluate the randomness of the overall fit to the different time-series. There was evidence ($p < 0.05$) to reject the hypothesis of randomly distributed residuals for the baitboat, U.S. longline North and South, and the Venezuelan longline indices, supporting the conclusion of the model's lack of fit to those data (**Figure 11**).

Likelihood profiles were run on the estimated mean unfished equilibrium recruitment (R_0, log-scale), steepness (*h*), mean asymptotic length (L_{inf}), and growth rate (*k*) across a range of plausible values (**Figure 12**). The profile of R_0 by data component showed a well-estimated minimum, with general agreement across data components of an estimate between approximately 11.2 and 11.6 (natural log-scale). Similar to R_0, the profile on steepness indicated the parameter is estimable, although there was less agreement across data sources compared to R_0. The profiles on growth parameters (L_{inf} and *k*) also indicated that these parameters were well-determined, primarily informed by the conditional length-at-age data. The estimates of stock-recruitment R_0 and steepness were 11.4 and 0.67, respectively, and the estimates of growth L_{inf} and *k* were 125 and 0.19, respectively (**Table 4**). The *k* and steepness values were similar to the estimated median values of albacore species from the FishLife R package (h=0.64 and k=0.18).

The retrospective analysis of 5-year peel-off (**Figure 13**) indicated that spawning stock biomass and fishing mortality were consistently estimated across trials, with Mohn's rho estimates of 0.01 and 0.00, respectively. The capacity of the model to predict the CPUEs was analyzed with the hindcasting analysis and the performance was evaluated with the mean absolute scaled error (MASE) value (Carvalho *et al*., 2021) (**Figure 14**). The results indicate that the model could predict the JP LL North and South CPUEs. The influence of each CPUE on the estimated recruitment was evaluated with a Jackknife analysis, by running the model removing one index each time. The results indicated that the high recruitment of the last four years was mainly driven by the baitboat index.

The Group noted the set of diagnostics reviewed during the meeting were based on the initial model with recruitment estimated for the years 2019 and 2020. Following the Group's decision of not estimating recruitment for 2019-2021, it has been recommended that the full set of diagnostics be rerun for the reference case model where the last three years (2019-2021) recruitment are not estimated. This work will be conducted and reviewed intersessionally, after all recommended revisions are incorporated into the reference case model.

By comparison with the N-ALB assessment model of 2013 which used the Multifan-CL platform and different assumptions, the SS reference case estimated similar steepness and SSB value in 2011 (the terminal year of the 2013 Stock Assessment) as Multifan-CL, if only data until 2011 was considered in the reference case.

Sensitivity analysis
The sensitivity analyses suggest that the reference model is very robust in the results of the model, however, the Group suggested further analysis be done intersessionally, to optimize this reference model for the construction of the N-ALB MSE Operating Models (OMs), including 1) exploration of alternative data weighting, including Francis reweighting (Francis, 2011) of the length composition data, and sensitivity analyses that up weight individual data types (e.g. CPUEs, length composition, and conditional length-at-age by using the lambda's parameters in SS), 2) removal of the prior on steepness and addition of priors for fleets that use the double-normal selectivity (top logit parameters), 3) recalculation of effective sample sizes for the length composition and the age composition (rescaled on the natural scale versus log-transformed), and 4) remove the minimum sample size on the age at length data, to include the largest size fish samples.

During the Data Preparatory meeting, it was decided to conduct a sensitivity analysis including the historical Japanese abundance series to check whether productivity estimates improved. The sensitivity analysis including the JPNLL target (1959-1969) index as well as the early bycatch (1975-1987) periods indices estimated a similar steepness value (*h*=0.65) as the reference case (*h*=0.67).

4.2 Surplus Production models mpb

The Group discussed the model configuration and diagnostic analysis. In particular, the interpretation of bivariate residual plots that were developed for likelihood exploration (**Figure 15**) was discussed**.** It was clarified that the data sources that best inform model parameters are associated with the lowest penalties (i.e., the larger and darker symbols in **Figure 15**). This analysis shows that the longline indices of Chinese Taipei and to a lesser extent Japan, best inform the estimate of intrinsic growth rate *r*, and overall, corroborate that this model is largely driven by the Chinese Taipei longline CPUE (as in the 2016 and 2020 assessments). The other indices show larger penalties that are nearly constant across a wider range of *r*, implying that they are less informative. The Group agreed that the residual plots generally support the estimability of the surplus production model parameters (e.g., *r, K*), and noted that there was a strong positive linear relationship between *r* and F_{MSY}, which is to be expected given the limited parameters used in surplus production models. An additional analysis fitting the surplus production model removing one index at a time was provided and the Group noted that in the absence of Chinese Taipei CPUE, the model would be driven by the Japanese index. Overall, the model seemed robust to sequentially dropping one CPUE series.

Other model diagnostics examined residuals of fit (**Figures 16, 17, 18, 19, 20, 21**) and retrospective analyses (**Figure 22**). The Group discussed the retrospective pattern in B/B_{MSY} in the terminal years, and in B in the initial years. Smaller retrospective patterns were also present in the F/F_{MSY} estimates in the terminal years. The Group discussed if the retrospective pattern was sufficient evidence to reconsider the model that is the basis of the management procedure. However, the Group also noted that the peak biomass estimate in the model may be driven by the maximum values of the CPUE series that occurred 2-5 years prior to the terminal year, so the retrospective pattern could also be caused by simply removing the most recent years of data that reduce the increasing trends in CPUE observed until 2018. Overall, the Group agreed that diagnostics showed a good statistical performance of the model. The estimated biomass and catch trends were plotted against the estimated production function in **Figure 23.** This figure shows that in the early years, the catch exceeded the surplus production of the stock, but in recent years the surplus production has been larger than the catch, which probably explains the observed increases in CPUE and the estimated increase of biomass since 1992.

5. Model results

5.1 Stock Synthesis Model estimates

The time series of spawning stock biomass (SSB), fishing mortality (measured as biomass exploitation rate), and recruitment estimates are listed in **Table 5** and plotted in **Figures 24, 25,** and **26,** respectively**.** SSB showed a sharp decline between the mid-1950s and mid-1960s in response to the increased harvest (catches reached a maximum of 64,634 t Task 1 NC, in 1964) during this period. SSB remained at a lower and relatively stable level until 2006; since then, SSB has shown a steady increase until the end of the time series in 2021. Notably strong recruitments were estimated for the years 1963, 2016, 2017, and 2018. The latter three recruitment estimates have resulted in a sharp increase in biomass during the model terminal years. The Group noted that the initial model iteration estimated recruitment for 2019 and 2020, but it was recommended to not estimate those years, as there is little information to inform those estimates, as evidenced by a large associated standard error. Fishing mortality was estimated as harvest rate in proportion to biomass. In general, F estimates were low at the beginning of the time series but increased sharply during the 1950s, and remained high until 1980s when catches begin to decline notably. The estimates of F since 2008 have been consistently lower, with a terminal year harvest rate estimate in 2021 of 0.05 (**Table 5**).

The estimated benchmarks (MSY-based reference points) with their respective 95% confidence intervals from the SS reference case were: SSB_{MSY} = 93202 t, [51,136 – 135,269] F_{MSY} = 0.131 [0.095 – 0.167] (harvest rate), and MSY = 41,995 [38,860 – 45,130] t.

The trajectories of SSB/SSB_{MSY} and F/F_{MSY}, uncertainty, and stock status were estimated using the Multivariate Log-Normal method (ss3diags R package, Winker *et al.,* 2022) that uses the covariance matrix estimated within the SS reference case (**Figure 27**). The uncertainty and density plots were estimated from 10,000 iterations for SSB/SSB_{MSY} and F/F_{MSY}. The model estimated median values of SSB_{2021}/SSB_{MSY} = 2.19 (95% CI: 1.21-4.01) and F_{2021}/F_{MSY} = 0.45 (95% CI: 0.29-0.71), respectively. The median of the stock status trajectory was estimated within the green quadrant of the Kobe plot since 2008 (**Table 6**), while in the terminal year, 2021, 99.6% of the iterations fall within the green quadrant.

5.2 Surplus Production models mpb

The results of the Reference Case assessment for North Atlantic albacore using the surplus production model *mpb* are shown in **Table 7** and **Figure 28.** Results indicate a decreasing biomass trend between the 1930s and the 1990s and an increasing trend since then. Relative to MSY benchmarks, the Reference Case scenario estimates that the stock has been above B_{MSY} in the last decade and fishing mortality below F_{MSY} for a slightly longer period (**Figure 29** and **Table 8**). The Kobe phase plot shows a typical pattern of development, overexploitation, and recovery of the stock (**Figure 30**). The probability of the stock currently being in the green area of the Kobe plot (i.e., not overfished and not undergoing overfishing, $F<F_{MSY}$ and $B>B_{MSY}$) is 100 %. Therefore, the probability of being in the red (i.e., overfished and undergoing overfishing, $F>F_{MSY}$ and $B<B_{MSY}$) and yellow (overfished and not undergoing overfishing, $F<F_{MSY}$ and $B<B_{MSY}$, or not overfished but undergoing overfishing, $F>F_{MSY}$ and $B>B_{MSY}$) areas is 0%. Consistency with the 2016 and 2020 stock assessments was evaluated by comparing the biomass trend of this year's Reference Case with the 2016 and 2020 stock assessments' Base Case (**Figure 31**). The Group noted that the current estimate of absolute biomass is below that of the 2016 and 2020 stock assessments base case. This is driven by the larger intrinsic growth rate estimated. The estimated relative biomass and fishing mortality are very similar to the previous assessments which suggested a stability of the population at relatively large levels of biomass. In terms of estimated productivity (MSY), the estimated value in 2023 is larger (39 k tons) than the estimated values in 2020 (38 k tons) and 2016 (37 k tons).

The bootstrapped results are used to estimate uncertainty on parameters and reference points (**Figure 32**). The Group considered the probability density plots (**Figure 27** marginal distributions, **Figure 30**) and noted that some distributions deviated from the assumption of a normal distribution (i.e., high Biomass, low F_{MSY}). The Group recommended that these estimates be reviewed to ensure they were not the result of model runs that did not converge. This was checked and it was noted that they did converge but suggested a local minimum with lower *r* values, higher *K* (which are highly correlated as shown in the likelihood exploration), and lower F_{MSY} with higher B_{MSY}, also correlated. The density plots for MSY and current stock status developed from the posterior estimates of the bootstrapped model are normally distributed.

The Group also noted that the current surplus production model results appear to change the scale of biomass by about 30% relative to the previous assessment, which may indicate a need to reevaluate the model framework or the management procedure. However, it was noted that this was the result of the highly correlated parameters, with higher *r* and lower *K* compared to the previous assessments, but with similar estimates of productivity (MSY, 37K tons in 2016, 38 thousand tons in 2020 and 39 thousand tons in 2023). In cases where the scale of biomass is difficult to estimate, some species groups (e.g., bluefin tuna) have elected to use empirical management procedures rather than model-based. However, the Group also concluded that the evidence from all the models is consistent in that catches in recent years have been below the surplus production of the stock, which has allowed the biomass to increase.

In summary, the available information indicates that the stock biomass has continued to increase, as reflected in the observed CPUE values. The increase in stock biomass was likely facilitated by the recent catches below the adopted TACs, and the stock is now estimated to be in the green quadrant of the Kobe plot with a very high probability.

5.3 Synthesis of assessment results

The Group agreed to develop the best available scientific characterization of stock status based on the SS reference case and to use the model outputs to serve as a Status Check to confirm that stock status and catch projections are consistent with the results from the iteration of the management procedure (MP).

The Group noted that the SS reference case incorporated more detailed data (specifically length compositions and length-at-age data), age-specific biological functions, and time-varying selectivity patterns for the various fishing fleets compared to the surplus production model from the MP. Therefore, the results of SS are useful to compare the results of both models. Harvest rate, biomass, stock status, and MSY estimates, were relatively consistent with the updated *mpb* surplus production model. Both suggested that the stock is currently not overfished (B_{2021}/B_{MSY}: 2.19 by SS and 1.54 by *mpb*), and is not undergoing overfishing (F_{2021}/F_{MSY}: 0.45 by SS and 0.53 by *mpb*).

6. Stock Projections

It was discussed if the Group will conduct stock projections for the North Atlantic albacore. The Group was reminded that the management advice in 2023 will be based on the MP defined in Rec. 21-04, and the projection results will not be used to provide management advice to the Commission. Currently, the Group has been developing the new MSE Operating Model based on the SS platform, which is a new methodology for the North Atlantic albacore stock MSE. The Group highlighted the importance of a smooth transition to the new approach. For this purpose, the Group suggested comparing the outputs between the SS platform and the application of the MP of Rec. 21-04 by conducting a deterministic stock projection from SS.

The Group discussed the settings of the projection:

- Project five years (2022-2026),
- Project a future constant F scenario of 0.8*F_{MSY} (current reference mortality in the MP),
- Use the 2021 fleet selectivity,
- Future recruitment values (2019 and forward years) would be taken directly from the stock-recruitment relation estimated within the model.

The Group reviewed the results of the SS projections (**Figure 33**). It was noted that given the stock status in 2021 and that in recent years the total removals had been below the adopted TAC, the estimated catches for 2023 and the consecutive first 5-years are high (**Figure 33-b**). In addition, the model estimated relatively large recruitment inputs in 2015-2018 (e.g., exceptionally high positive recruitment deviations (**Figure 33-d**) that would be available to the fisheries during the start of the projection period (**Figure 33-a**). It was noted that these high recruitment levels have been only seen during the early 1960s in model history, and it was questioned if they were biologically plausible. Overall, it was noted that both the estimated *mpb* and SS stock status in 2021 indicated that the stock is not overfished nor undergoing overfishing (i.e., green quadrant of the Kobe plot) and the projected yield by SS (**Table 9**) is comparable to the TAC resulting from the application of the MP for the period 2024- 2026 (section 7).

7. Interaction of the Management Procedure

Document SCRS/2023/100 describes the application of the N-ALB MP, which includes the use of catch and five abundance indices to fit the surplus production model *mpb* and a decision rule (or Harvest Control Rule, HCR) to determine the TAC for the period 2024-2026. The median values of the *mpb* model output were used to estimate the TAC for 2024-2026. Noting that the biomass at the end of 2021 is estimated to be larger than B_{Thresh} = B_{MSY}, the TAC is calculated as follows:

$$TAC = F_{target}\ x\ B_{current}$$
$$= 0.8\ x\ Fmsy\ x\ B_{2021}$$
$$= 0.8\ x\ median(Fmsy)\ x\ median(B_{2021}) = \quad (0.8\ x\ 0.1146443\ x\ 519{,}799$$
$$= \mathbf{47{,}673.59}\ \boldsymbol{t}.$$

However, the stability clause in Recommendation 21-04 imposes that "*The maximum change in the catch limit (DMAX) shall not exceed 25% in case of increase or 20% in case of decrease of the previous recommended catch limit when $B_{CURR} \geq B_{THRESH}$.*". The TAC for the period 2021-2023 ($TAC_{2021-2023}$) was 37,801 t and the estimated TAC for 2024-2026 would exceed the allowed maximum change in TAC (1.25 x $TAC_{2021-2023}$ = 47,251 t). Therefore, the TAC advice for the period 2024-2026 is estimated at **47,251 t**.

8. Evaluation of Exceptional Circumstances

The documents SCRS/2023/P/075 and SCRS/2023/101 were presented to evaluate the potential existence of Exceptional Circumstances according to the available indicators. The natural mortality (M) at age vector adopted during the Data Preparatory meeting is not substantially different from the values of the OMs used in the MSE (**Figure 34**). Document SCRS/2023/101 evaluated the performance of the MP adopted in Recommendation 21-04 for a robustness grid of OM conditioned using the new natural mortality vector adopted by the Group during the Data Preparatory meeting. Results suggested that the productivity of the stock and the status of the stock at the start of the simulations were more optimistic than previously estimated. The MP applied to the robustness OMs resulted in a higher probability of being in the green quadrant of the Kobe plot and a higher catch in the long term than with the reference grid of OMs.

Document SCRS/2023/P/075 compares the trends for biomass (**Figure 35, Figure 36**), and fishing mortality (**Figure 37** and **Figure 38**) estimated in the MSE simulations (OMs and MPs) against the estimates of the *mpb* and the SS models in 2023, and recent observations of CPUE (**Figure 39**) and catch (**Figure 40**). This analysis is developed following the indicators described in Annex 2 of Recommendation 21-04. With regards to the estimated relative biomass (B/B_{MSY}), the Group noted that the values estimated by the SS model are larger than those in the MSE for the period 1930-1957, and this was attributed to the skewed production function estimated for the stock by the SS model and the higher depletion estimated for B_{MSY}. Although, according to the protocol this was identified as an exceptional circumstance, it was not considered an impediment for the application of the MP. The estimates of *mp*b fall within the values (95% CI) estimated in the MSE, both in the OMs and MPs. In addition, the CPUEs also fall within the values estimated in the MSE except for the year 2018 for the EU-Spain baitboat CPUE, which was slightly larger than the estimated for that year. Regarding the catches, the Group noted that they have been lower than the adopted TAC used in the HCR or MP for most years except for 2019, when it was exceeded by 3.5%.

In summary, the Group concluded that no exceptional circumstance(s) were identified that preclude the application of the MP to set the TAC for the period 2024-2026.

9. Discussion on the new MSE: steps and timeline

According to Rec. 21-04, the SCRS shall continue the development of a new MSE framework to support the possible adoption of a new MP by the Commission no later than 2026. Accordingly, the MSE roadmap reflects that the albacore species group and the SCRS should start this process in 2023. The recommendations of the Group for the new MSE are described below.

Potential Reference set
The Group recommended evaluating, at a minimum, the following axis of uncertainty for the new MSE and alternative approaches as indicated below.

- Uncertainty in natural mortality (M; e.g., CV = 20%).
- Uncertainty in recruitment variability (sigma R; e.g., mean = 0.4, CV 20%).
- Uncertainty in model component weighting (e.g., reference case and increase lambdas to 2 for size, age composition, and CPUEs; 4 levels)

Potential robustness set:

- Changes in unfished recruitment (e.g. R0; up and down 20%).
- Changes in recruitment variability (e.g. sigma R; mean = 0.6, 0.2)

Tuning
To facilitate the evaluation of management objectives tradeoffs, the Group agreed that there is added value in tuning the CMPs (e.g., to 60% probability of being in the green quadrant of the Kobe plot), especially when comparing a broader suite of both model-based and empirical CMPs.

Management Objectives/Performance Metrics: The Group recommended that pending further interactions with the Commission Panel 2, the current suite of management objectives should be retained. In addition, the Group noted that extending the CMPs to include empirical approaches may require the consideration of a maximum acceptable probability of falling below B_{lim}, but that the Group could use previously accepted performance metrics for safety until further guidance is available.

Observation Error Model (OEM) Improvements: The Group noted that the BFT OEM used the relevant CPUE statistical properties of each index to project predicted CPUE while the N-ALB OEM did not, instead only random error was considered. However, the BFT OEM did not consider uncertainty in the historical CPUE observations which was a feature of the N-ALB OEM. The Group saw advantages to both approaches. It is valuable to consider historical uncertainty in CPUE because changes in standardization approaches and other improvements often result in changes in the annual CPUE time-series and it is generally accepted that uncertainty in CPUE projections should include the appropriate statistical properties of the index (e.g. variation, autocorrelation). The Group recommended that both sources of observation error be considered when feasible.

Incorporation of Climate Change into the MSE
The Group reviewed a peer-reviewed publication that evaluated the robustness of the N-ALB HCR to potential changes induced by climate change (Merino *et al*., 2019). It was discussed that climate change can also cause, for example, shifts in distribution that results in mismatch between fisheries and the marine resources (changes in catchability), changes in habitat quality, fish behavior, and genetics/gene expression

that influence biological characteristics. The Group discussed whether to include these changes in the reference or robustness grids and decided to include potential changes in stock productivity (i.e., potential changes in R_0 and sigma-R) in the robustness grid to evaluate whether CMPs are resilient to future changes in the magnitude and variability in recruitment that could result from climate change. This approach is consistent with the guidance from the Working Group on Stock Assessment Methods (WGSAM). While there is still debate within the SCRS, the Group agreed not to include potential climate change effects in the reference grid until the underlying mechanisms are better understood but may be examined in the robustness tests.

Improving Documentation
The Group reviewed the most recent consolidated document (N-ALB_MSE_document_June2023.pdf) describing the current MSE approach and considered it complete. The new MSE approach will be described in a new, improved document. With regard to improving the documentation of the MSE process, the Group noted that it was difficult to keep the consolidated document updated as the MSE process evolved, that no instructions were available to guide that process, and that the final document might not be very useful in its current state because few are aware of it and it is difficult to find. The Group noted that the WGSAM recently recommended a unified approach to the organization and storage of these documents, and agreed that that is a useful and appropriate approach. In particular, WGSAM recommended that a live version of the ICCAT MSE documents and materials be made available on the ICCAT website. The Group also reviewed the current MSE webpages used for other groups (e.g., BFT, Commission for the Conservation of Southern Bluefin Tuna, CCSBT) and found them useful but noted that posting and maintaining this information requires resources from the ICCAT Secretariat.

The Group also discussed the need to better identify information needed by the Commission, including plain-language summaries to facilitate communication with non-technical audiences. Until the WGSAM guidance is finalized, the Group recommended two examples that are considered particularly effective, N-SWO and CCSBT. While the bluefin tuna example is extremely comprehensive, it was particularly time-consuming to prepare and maintain, and is also extremely technical in nature. To avoid overextending the available resources, the Group highly recommended a less onerous process.

MSE Roadmap/Timing
The Group agreed that it would be efficient to seek feedback from Panel 2 about the management objectives and performance metrics in order to focus the workload. A comprehensive MSE meeting with Panel 2 is recommended in 2025. During that meeting, the Group agreed to summarize the existing MSE approach and MP, highlight improvements made, and present the new CMPs and their performance relative to stated management objectives. It will also be necessary to highlight any decision points that require further Commission feedback.

10. Responses to the Commission

Rec. 21-04 requested to e*valuate the percentage by which catch data are underreported, that would trigger an occurrence of exceptional circumstance*.

Document SCRS/2023/101 evaluated scenarios of unreported catches consistently exceeding the TAC in the future. The study concluded that unreported catch of 10% or more above the TAC would result in NOT achieving the management objective of being in the green quadrant of the Kobe plot with at least a 60% probability. The Group noted that this should be interpreted as a percentage (%) of increase of unreported catch above the TAC that is not reported relative to historical levels.

The SCRS currently has no data or information to suggest that there is substantial underreporting of northern albacore catches.

11. Recommendations

11.1 Research and Statistics Recommendations

Due to the current limitations of the Mediterranean albacore stock assessment, the Group recommends a network of researchers be established to work intersessionally on the development of a comprehensive and coherent research plan for this stock to be integrated within the Albacore Year Programme (ALBYP), together with the North and South Atlantic stocks research plans.

The Group recommends that CPCs and the ICCAT Secretariat work together to complete the Task 1 NC data for the Mediterranean albacore before the next assessment. The Group has identified this as one of the main uncertainties in past assessments and recommended to consider methods developed by the WGSAM to estimate unreported catches.

The Group recommends the review and update of the fisheries statistics of Mediterranean albacore from the Egypt fleet(s) available in the ICCAT Secretariat databases.

The Group recommends that research should focus on identifying the main oceanographic factors that are associated with northern albacore migratory patterns, the size distribution of the population, and overall interaction with the different fleets to better understand the trends from fishery-dependent indicators.

The Group recommends that, when possible, indices of abundance be provided both in number and weight units for the different model platforms for evaluation of the Atlantic albacore.

The Group recommends that the reference SS model proposed for the new N-ALB MSE be optimized, as indicated in this report (Section 4.2).

The Group recommends that the WGSAM review and evaluate approaches to include in the assessment models the estimates of variability associated with indices of abundance. It was noted that different Species Groups have used different approaches for the same platform, and between platforms. The Group suggested that a comprehensive simulation study would allow for testing alternative configurations.

11.2 Management

The Group concluded that no Exceptional Circumstances were detected that would preclude the application of the MP. Therefore, the Group applied the MP to calculate the next TAC for the period 2024-2026. The resulting TAC is 47,251 t which represents a 25% increase with respect to the previous one.

12. Albacore Research Program: update on ongoing activities and future planning

12.1 Reproductive biology

SCRS/2023/117 provided an update on the reproductive biology study for South Atlantic albacore tuna. Samples from three capture areas and longline fleets, including Brazil and China Taipei were collected. The size range was 83-115 SFL cm. Larger sizes were observed at lower latitudes, and the estimated L_{50} values for males and females were 102.3 SFL cm and 96.3 SFL cm, respectively. The estimated L_{50}s are larger than in previous studies. Reproductive active females were mainly collected in the area where the Chinese Taipei fleet operates. Batch fecundity ranged from 0.14 to 1.7 million oocytes. Preliminary age analysis using spines, identified between 7 to 8 annual rings, however it is expected a higher total number of annual rings due to the non-visible rings in vascularization zones in the spine.

The Group congratulated the team for the work conducted and recommended to confirm the L50 estimates, which are higher than observed in other studies, as well as the sex-specific differences in maturity. In addition, the Group noted the importance of aging large fish (e.g., 200 fish larger than 100 cm) both for having a reliable estimate of Amax (used to derive estimates of natural mortality M) and to improve the growth estimation in SS. The Group considered that it could be interesting to validate growth through bomb radiocarbon techniques, although it was noted that other validation methods had been used to calibrate growth curves at least in the northern albacore stock. The Group also noted that a comparative study between hard parts (spines and otoliths) could be of interest in order to avoid aging large fish using spines only, as some rings are reabsorbed.

The consortium working on North Atlantic albacore reproductive studies informed that samples from Chinese Taipei collected in 2022 had arrived and would be processed in the following months.

12.2 E-tagging

SCRS/P/2023/028Rev reported an update of the electronic tagging activities conducted between 2019 and 2023, using different tagging platforms. So far 93 archival and 34 PSATs have been deployed in the Bay of Biscay and the Canary Islands. Results revealed some of the challenges as well as the main results obtained so far in relation to the main objective, which is to improve our knowledge of the lifecycle and habitat use by the North Atlantic albacore stock. Since the information provided during the Data Preparatory meeting, additional internal archival tags have been recovered, including one with more than one year at liberty that performs a very similar migration pattern compared to the previous long-term recovery available, visiting similar overwintering areas and showing site fidelity to the Bay of Biscay during consecutive summers.

The Group acknowledged that tracks already cover at least part of the albacore life cycle, however, the spawning migrations yet remain elusive and reminded the need to both improve tag retention and to try additional deployments in the West Atlantic areas. The Group noted that while accumulating a large dataset might be complex and expensive in the case of albacore, collecting a sufficient amount of e-tag data could allow to build realistic spatial distribution models that could be useful for a range of purposes including CPUE standardization, distribution shifts due to climate change, etc. Finally, it was requested that Group participants share and spread widely the posters announcing the rewards for recovered archival tags.

The Group confirmed the intention to continue research on reproductive biology and e-tagging within ALBYP in the coming years. The Group also noted that in case of budget reduction, a cost-benefit analysis of the different research lines (i.e., reproductive biology vs e-tagging) would be useful. However, the Group noted that this is a difficult exercise because different research lines inform about very different aspects of the biology of albacore, and while maturity is required for several stock assessment models, the population structure and stock ID are basic assumptions. In fact, it was noted that the evaluation of stock structure assumptions should have a higher priority within SCRS.

13. Other matters

The Presentation SCRS/P/2023/79 provided in-depth details regarding the Mediterranean albacore longline fishery in Egyptian waters. It covered various aspects such as the characteristics of the fishing gear, the level of recent catches, catch length composition and by-catch characterization. Information was also reported on the studies being carried out in relation to the biology of the species.

The Group acknowledged the information reported and stressed the importance of the information being included in the ICCAT database. As such, the ICCAT Secretariat noticed the need to corroborate Task 1 and Task 2 statistics for Egypt on the ICCAT database and agreed to contact authors directly on this issue. The Group also encouraged the participation of Egyptian scientists in upcoming Mediterranean albacore assessment sessions.
The Group noticed that since the last Intersessional meeting of the Albacore Species Group (including Med-ALB Stock Assessment) in 2021, the Executive Summary of this stock is kept separate from that of the Atlantic stocks. The Group agreed to keep them separate in the future.

14. Adoption of the Report and closure

The report was adopted during the meeting. The Chair of the Group thanked all the participants for their efforts. The meeting was adjourned.

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Table 1. North Atlantic albacore fleet structure used in the Stock Synthesis assessment model.

FL	Fishery ID	Description	Time	Gear	Catch (FlagName* or FleetCode*)	Size (FleetCode*)
1	1 BB	Baitboat (Spain, France)	1953-2021	BB	EU.ESP-ES-CANT_ALB, EU.FRA-FR	EU.ESP-ES-CANT_ALB, EU.FRA-FR
2	2 BB isl	Baitboat islands (Portugal Madeira/Azores, Spain Canary)	1958-2021 Quarters 1,3,4	BB	EU.PRT-PT-AZORES, EU.PRT-PT-MADEIRA, EU.ESP-ES-CANARY, EU.ESP-ES-CANT_ALBaz, EU.ESP-ES-CANT_ALBcd	EU.PRT-PT-AZORES, EU.PRT-PT-MADEIRA, EU.ESP-ES-CANARY
3	3 TR+GN	Troll (Spain, France) + Gillnets (France, Ireland)	1930-2021	TR+GN	TR: EU.ESP-ES-CANT_ALB, EU.FRA-FR, EU.IRL. GN: EU.FRA-FR, EU.IRL, GBR	TR: EU.ESP-ES-CANT_ALB, EU.FRA. GN: EU.IRL
4	4 MWT	Mid water trawl (France, Ireland)	1987-2021	TW	EU.FRA-FR, EU.IRL, GBR	EU.FRA, EU.IRL
5	5 JP LL T N	Japan LL target north30	1961-1969	LL	Japan (North of 30N)	JPN (North of 30N)
5	5 JP LL t N	Japan LL transition north30	1970-1975			
5	5 JP LL b N	Japan LL late north30	1976-2021			
6	6 JP LL T S	Japan LL target south30	1956-1969	LL	Japan (South of 30N)	JPN (South of 30N)
6	6 JP LL t S	Japan LL transition south30	1970-1975			
6	6 JP LL b S	Japan LL late south30	1976-2021			
7	7 TW LL e N	Taiwan LL early north30	1968-1986	LL	Chinese Taipei (North of 30N)	CTP (North of 30N)
7	7 TW LL t N	Taiwan LL transition north30	1987-1998			
7	7 TW LL l N	Taiwan LL late north30	1999-2021			
8	8 TW LL e S	Taiwan LL early south30	1962-1986	LL	Chinese Taipei (South of 30N)	CTP (South of 30N)
8	8 TW LL t S	Taiwan LL transition south30	1987-1998			
8	8 TW LL l S	Taiwan LL late south30	1999-2021			
9	9 US CAN LL N	US and Canada LL north30	1981-2021	LL	USA and Canada (North of 30N)	USA-US-Com, USA, Canada (North of 30N)
10	10 US LL S	US LL south30	1981-2021	LL	USA (South of 30N)	USA-US-Com, USA (South of 30N)
11	11 Ven LL	Venezuela LL	1960-2021	LL	Venezuela	VEN
12	12 MIX KR+PA	Mixed flags (KR+PA+CHN) LL	1964-2021	LL	Mixed flags (KR+PA), China PR, Korea Rep., Panama	Not included
13	13 Oth LL	Other LL	1965-2021	LL	all others	Not included
14	14 Oth Surf	Other surface	1978-2021		all others	Not included
15	15 BB isl Qt2	Baitboat islands (Portugal Madeira/Azores, Spain Canary)	1965-2021 Quarter 2	BB	EU.PRT-PT-AZORES, EU.PRT-PT-MADEIRA, EU.ESP-ES-CANARY, EU.ESP-ES-CANT_ALBaz, EU.ESP-ES-CANT_ALBcd	EU.PRT-PT-AZORES, EU.PRT-PT-MADEIRA, EU.ESP-ES-CANARY

Table 2. Abundance indices used in the biomass dynamic model *mpb*.

Index	First year	Final year	Reference
Chinese Taipei longline late	1999	2021	SCRS/2023/035
Japan bycatch longline	1988	2021	SCRS/2023/029
Spanish baitboat	1981	2021	SCRS/P/2023/012
US longline	1987	2021	SCRS/2023/036
Venezuelan longline	1991	2017	SCRS/2020/089

Table 3. Specifications of the biomass dynamic model.

Software	Catch series	Starting values
mpb	1930-2021	r=0.1 (search space, 0.01-1) K=1.26x10^6 (search space, 1.26x10^5-1.26x10^7) B0=1 (fixed) p(shape)=0.001 (Fox) (fixed)

Table 4. Stock Synthesis parameters estimated for North Atlantic albacore.

Parameter	Estimate	Phase	Parm_StDev	Gradient	Pr_type	Prior	Pr_SD
L_at_Amin_Fem_GP_1	41.992	2	0.535028	2.91E-05	No_prior	NA	NA
L_at_Amax_Fem_GP_1	125.464	2	2.26169	1.47E-05	No_prior	NA	NA
VonBert_K_Fem_GP_1	0.193517	3	0.0096568	6.38E-05	No_prior	NA	NA
SD_young_Fem_GP_1	3.32762	3	0.161824	2.21E-06	No_prior	NA	NA
SD_old_Fem_GP_1	5.57521	3	0.714884	3.36E-07	No_prior	NA	NA
SR_LN(R0)	11.4322	1	0.125226	4.47E-05	No_prior	NA	NA
SR_BH_steep	0.665474	2	0.0629336	2.11E-05	Normal	0.75	0.15
InitF_seas_1_flt_33_TR_GN	0.059876	1	0.0135089	-1.68E-06	No_prior	NA	NA
SizeSpline_GradLo_1_BB(1)	0.466903	5	0.119806	-2.98E-08	No_prior	NA	NA
SizeSpline_GradHi_1_BB(1)	-0.363604	5	0.0601401	-2.95E-07	No_prior	NA	NA
SizeSpline_Val_1_1_BB(1)	-3.6439	4	0.323398	-1.01E-06	No_prior	NA	NA
SizeSpline_Val_2_1_BB(1)	-1.49307	4	0.170136	-7.45E-07	No_prior	NA	NA
SizeSpline_Val_4_1_BB(1)	-1.80802	4	0.19697	4.85E-07	No_prior	NA	NA
Size_DblN_peak_2_BB_isl(2)	104.46	4	5.56114	-1.62E-07	No_prior	NA	NA
Size_DblN_ascend_se_2_BB_isl(2)	5.34952	4	0.162397	-9.42E-07	No_prior	NA	NA
Size_DblN_descend_se_2_BB_isl(2)	4.94446	5	0.55799	6.51E-07	No_prior	NA	NA
Size_DblN_peak_3_TR_GN(3)	63.8928	4	3.04209	-1.23E-06	No_prior	NA	NA
Size_DblN_top_logit_3_TR_GN(3)	-3.78791	5	2.09785	-2.22E-06	No_prior	NA	NA
Size_DblN_ascend_se_3_TR_GN(3)	3.57718	4	1.40545	6.42E-08	No_prior	NA	NA
Size_DblN_descend_se_3_TR_GN(3)	5.20451	5	0.398188	-6.48E-06	No_prior	NA	NA
SizeSpline_GradLo_4_MWT(4)	0.418331	3	0.0921375	-3.04E-07	Sym_Beta	0	0.001
SizeSpline_GradHi_4_MWT(4)	-0.230125	3	0.067359	-1.52E-06	Sym_Beta	0	0.001
SizeSpline_Val_1_4_MWT(4)	-3.97237	2	2.39716	-4.67E-07	Sym_Beta	0	0.001
SizeSpline_Val_3_4_MWT(4)	-3.95292	2	1.96706	2.90E-06	Sym_Beta	0	0.001
Size_DblN_peak_5_JPLL_N(5)	93.4134	4	3.00004	6.29E-07	No_prior	NA	NA
Size_DblN_top_logit_5_JPLL_N(5)	-13.5012	5	196.636	-1.66E-06	No_prior	NA	NA
Size_DblN_ascend_se_5_JPLL_N(5)	4.17725	4	0.532246	-1.23E-06	No_prior	NA	NA
Size_DblN_descend_se_5_JPLL_N(5)	5.34182	5	0.525206	-3.45E-06	No_prior	NA	NA
Size_DblN_peak_6_JPLL_S(6)	102.133	4	2.37625	-1.27E-07	No_prior	NA	NA
Size_DblN_top_logit_6_JPLL_S(6)	-13.5812	5	192.495	-9.25E-07	No_prior	NA	NA
Size_DblN_ascend_se_6_JPLL_S(6)	4.16375	4	0.429237	-1.84E-06	No_prior	NA	NA
Size_DblN_descend_se_6_JPLL_S(6)	5.13713	5	0.49451	-2.12E-06	No_prior	NA	NA
Size_DblN_peak_7_TAILL_N(7)	100.594	4	3.75581	6.39E-08	No_prior	NA	NA
Size_DblN_top_logit_7_TAILL_N(7)	-14.0435	5	172.74	9.59E-07	No_prior	NA	NA
Size_DblN_ascend_se_7_TAILL_N(7)	5.77672	4	0.250864	-3.58E-07	No_prior	NA	NA
Size_DblN_descend_se_7_TAILL_N(7)	5.20432	5	0.513966	1.09E-06	No_prior	NA	NA
Size_DblN_peak_8_TAILL_S(8)	120.832	4	8.20251	8.81E-07	No_prior	NA	NA
Size_DblN_top_logit_8_TAILL_S(8)	-13.8722	5	179.812	-2.35E-06	No_prior	NA	NA
Size_DblN_ascend_se_8_TAILL_S(8)	6.15683	4	0.298845	4.59E-07	No_prior	NA	NA
Size_DblN_descend_se_8_TAILL_S(8)	4.96731	5	0.559019	1.19E-06	No_prior	NA	NA
Size_DblN_peak_9_USLL_N(9)	104.18	4	1.982	2.00E-06	No_prior	NA	NA
Size_DblN_top_logit_9_USLL_N(9)	-12.3704	5	296.24	4.88E-06	No_prior	NA	NA
Size_DblN_ascend_se_9_USLL_N(9)	5.2323	4	0.185466	-1.76E-06	No_prior	NA	NA
Size_DblN_descend_se_9_USLL_N(9)	4.49751	5	0.573087	1.80E-07	No_prior	NA	NA
Size_inflection_10_USLL_S(10)	107.239	4	2.04849	2.71E-06	No_prior	NA	NA
Size_95%width_10_USLL_S(10)	12.661	5	1.40439	-7.85E-07	No_prior	NA	NA
Size_inflection_11_VENLL(11)	97.352	4	1.73116	1.83E-06	No_prior	NA	NA
Size_95%width_11_VENLL(11)	10.3651	5	1.68882	1.18E-06	No_prior	NA	NA
Size_DblN_peak_15_BBisl_s2(15)	83.7754	4	4.32897	-1.22E-06	No_prior	NA	NA
Size_DblN_top_logit_15_BBisl_s2(15)	-14.1019	5	170.468	2.25E-06	No_prior	NA	NA
Size_DblN_ascend_se_15_BBisl_s2(15)	5.10364	4	1.64994	-6.86E-07	No_prior	NA	NA
Size_DblN_descend_se_15_BBisl_s2(15)	5.70857	5	0.342074	3.45E-06	No_prior	NA	NA
Size_DblN_peak_5_JPLL_N(5)_BLK1repl_1970	101.913	6	5.58773	1.84E-06	No_prior	NA	NA
Size_DblN_peak_5_JPLL_N(5)_BLK1repl_1976	105.561	6	2.861	3.42E-06	No_prior	NA	NA
Size_DblN_ascend_se_5_JPLL_N(5)_BLK1repl_1970	5.66272	6	0.379253	-7.76E-06	No_prior	NA	NA
Size_DblN_ascend_se_5_JPLL_N(5)_BLK1repl_1976	6.19295	6	0.139581	-3.02E-07	No_prior	NA	NA
Size_DblN_peak_6_JPLL_S(6)_BLK1repl_1970	102.336	6	7.38359	-1.40E-07	No_prior	NA	NA
Size_DblN_peak_6_JPLL_S(6)_BLK1repl_1976	106.179	6	2.11257	2.62E-06	No_prior	NA	NA
Size_DblN_ascend_se_6_JPLL_S(6)_BLK1repl_1970	5.23035	6	0.707707	-2.12E-07	No_prior	NA	NA
Size_DblN_ascend_se_6_JPLL_S(6)_BLK1repl_1976	5.16637	6	0.201068	-2.75E-07	No_prior	NA	NA
Size_DblN_peak_7_TAILL_N(7)_BLK2repl_1987	93.7223	6	3.51605	8.62E-07	No_prior	NA	NA

Table 5. Stock Synthesis estimates of spawning stock biomass (t), recruitment at age-0, and harvest rate (fraction of total biomass).

	Spawning Stock Biomass		Recruitment		Harvest Rate	
	Estimate	StdDev	Estimate	StdDev	Estimate	StdDev
Initial	316576	44633	92241	11551	0.059876	0.0135089
1930	316576	44633	90760	11180	0.0183543	0.0024876
1931	316374	44638	90752	11179	0.0236145	0.00323454
1932	315434	44656	90714	11171	0.0196489	0.00270845
1933	313499	44671	90636	11153	0.017604	0.00242972
1934	311086	44654	90537	11130	0.0291062	0.00401145
1935	308358	44487	90423	11098	0.0324228	0.00451157
1936	304796	44256	90273	11055	0.0266551	0.00375184
1937	299799	44054	90056	10999	0.0215834	0.00304953
1938	294884	43820	89837	10942	0.0234062	0.00329826
1939	292144	43596	89712	10905	0.0274037	0.00385556
1940	291157	43422	89666	10888	0.0185425	0.00261398
1941	290674	43271	89644	10876	0.0213021	0.00298116
1942	290295	43101	89626	10865	0.026969	0.0037585
1943	290529	42923	89637	10859	0.0270744	0.00378016
1944	290316	42772	89627	10850	0.0275191	0.00384923
1945	288753	42631	89554	10828	0.0449458	0.00629889
1946	285782	42514	89414	10792	0.0387029	0.00552615
1947	281435	42427	89204	10744	0.0341334	0.00492279
1948	275690	42304	88918	10681	0.0408248	0.0059073
1949	270683	42154	88660	10623	0.0477269	0.00696356
1950	266919	42057	88461	10580	0.068983	0.0101982
1951	261457	42012	88163	10522	0.0615743	0.00939484
1952	253428	41924	87707	10436	0.0597772	0.00929619
1953	243746	41700	87123	10327	0.0565394	0.00890608
1954	234644	41396	86538	10220	0.0758736	0.0120207
1955	227006	41126	86018	10129	0.061297	0.00992489
1956	222059	40929	85666	10069	0.0805308	0.0130787
1957	216513	40720	85255	10003	0.0851249	0.0140972
1958	208896	40424	84663	9913	0.108812	0.0183774
1959	197756	40011	83731	9787	0.108269	0.0189897
1960	186111	39537	64140	19168	0.119227	0.0214788
1961	173972	39074	47753	15133	0.103685	0.0187188
1962	163856	38595	55166	20154	0.155105	0.0284789

1963	149848	37922	128197	37991	0.178941	0.0367279
1964	129343	36912	73523	26564	0.188601	0.0350921
1965	106189	34330	71260	22543	0.182871	0.0324777
1966	82949.2	30995	56649	17263	0.147832	0.0242172
1967	72271.8	28838	65841	18240	0.190358	0.0294456
1968	80292.1	27996	61478	16671	0.155308	0.0230835
1969	92112.7	27850	100013	19563	0.163424	0.0230051
1970	85858.3	24398	74637	16652	0.151386	0.0180928
1971	77413.2	21606	98677	16660	0.179939	0.0195018
1972	70760.7	19144	68638	13165	0.148054	0.0146376
1973	70625.7	17544	45949	10034	0.136951	0.0127604
1974	77467.1	16364	58987	10956	0.154425	0.0143471
1975	86852.8	16109	56665	11138	0.137541	0.0127319
1976	93283.1	15772	52405	10736	0.194744	0.0173781
1977	88640.7	15393	73642	11998	0.201083	0.0180781
1978	74794.4	14145	73364	11980	0.191423	0.0159662
1979	69511.4	12837	64615	11158	0.19494	0.0144604
1980	65776.2	11663	51964	9487	0.148806	0.00992659
1981	62698.2	10353	45556	8787	0.133323	0.00825834
1982	63413.7	9381	49591	8749	0.167892	0.0104009
1983	68082.4	8614	45957	8617	0.213728	0.0147555
1984	65949.5	7944	67600	10732	0.190465	0.0161603
1985	56544.3	7677	62085	10428	0.183105	0.0176287
1986	49277.1	7763	59619	9473	0.207123	0.0217396
1987	41658.9	8389	48008	7714	0.166397	0.0186046
1988	45568.1	9459	49716	8171	0.144349	0.0167727
1989	55984.2	11037	61887	9820	0.138932	0.0164493
1990	67185.6	12678	54480	9426	0.154647	0.0183202
1991	69422.6	13436	53284	9449	0.116985	0.0143352
1992	70639	13601	62082	10217	0.125157	0.0153719
1993	70779.2	13491	46912	9209	0.149825	0.0185124
1994	69831.2	13907	55649	9929	0.141861	0.0185071
1995	72049.3	14597	50113	9781	0.155492	0.0208779
1996	69941.7	14972	70514	11468	0.119393	0.016821
1997	74002.5	15674	67631	10928	0.11297	0.0155382
1998	77011.5	16129	52037	8881	0.0943512	0.0126345
1999	80730.2	16400	34021	6805	0.123087	0.0162197

2000	80152.4	16672	39537	7274	0.125321	0.017222
2001	84483.7	17348	47168	8285	0.106045	0.0152141
2002	91182.3	18470	64464	10036	0.0934907	0.0136784
2003	93291.7	18815	42446	7978	0.10075	0.0144756
2004	86945	17934	77100	11698	0.101883	0.0149741
2005	81526.4	16903	50458	9044	0.129404	0.0189753
2006	79084	16756	52651	9284	0.136389	0.0212556
2007	82318.2	17838	49625	9134	0.082918	0.0138456
2008	84953.2	18551	67708	11840	0.0754757	0.0128369
2009	92786.4	20105	69603	12330	0.0533678	0.00903422
2010	103028	21952	62920	11600	0.0619538	0.0102007
2011	107772	22686	73332	13118	0.0604497	0.00982949
2012	111869	23283	59807	12222	0.0725772	0.0115614
2013	118659	24493	56296	12302	0.06935	0.011087
2014	127193	26356	61357	13489	0.0747911	0.012004
2015	132657	27414	91673	17818	0.0718775	0.0116469
2016	136621	28306	124094	24325	0.0801821	0.0128641
2017	136404	28789	129218	30878	0.0670493	0.0105547
2018	132673	28358	100114	29266	0.0617034	0.00948556
2019	133780	28044	76211	6311	0.0669895	0.0102547
2020	144524	29542	77817	6384	0.0594128	0.009058
2021	171966	33869	81218	6832	0.0591337	0.00873726

Table 6. N-ALB Estimated median and 95% confidence intervals for B/B_{MSY} and F/F_{MSY} from the SS3 MVLN iterations.

Year	B/B_{MSY}	B/B_{MSY} LCI	B/B_{MSY} UCI	F/F_{MSY}	F/F_{MSY} LCI	F/F_{MSY} UCI
1931	3.38	2.81	4.08	0.18	0.15	0.22
1932	3.36	2.8	4.05	0.15	0.12	0.18
1933	3.33	2.78	4.01	0.13	0.11	0.16
1934	3.3	2.76	3.97	0.22	0.18	0.27
1935	3.26	2.73	3.92	0.25	0.21	0.3
1936	3.21	2.69	3.84	0.2	0.17	0.24
1937	3.16	2.66	3.77	0.16	0.14	0.2
1938	3.13	2.63	3.73	0.18	0.15	0.21
1939	3.12	2.62	3.72	0.21	0.18	0.25
1940	3.11	2.62	3.71	0.14	0.12	0.17
1941	3.11	2.61	3.71	0.16	0.14	0.19
1942	3.11	2.61	3.72	0.21	0.17	0.25
1943	3.11	2.61	3.72	0.21	0.17	0.25
1944	3.09	2.59	3.7	0.21	0.18	0.25
1945	3.06	2.57	3.65	0.34	0.29	0.41
1946	3.02	2.54	3.59	0.29	0.25	0.35
1947	2.95	2.5	3.5	0.26	0.22	0.31
1948	2.9	2.47	3.42	0.31	0.26	0.37
1949	2.86	2.44	3.36	0.36	0.31	0.43
1950	2.8	2.4	3.28	0.53	0.45	0.62
1951	2.72	2.34	3.16	0.47	0.4	0.55
1952	2.61	2.27	3.02	0.46	0.39	0.53
1953	2.52	2.2	2.88	0.43	0.38	0.49
1954	2.43	2.14	2.77	0.58	0.51	0.65
1955	2.38	2.11	2.7	0.47	0.42	0.52
1956	2.32	2.06	2.62	0.61	0.54	0.69
1957	2.24	2	2.51	0.65	0.57	0.73
1958	2.12	1.91	2.36	0.83	0.73	0.94
1959	2	1.81	2.21	0.83	0.72	0.95
1960	1.87	1.69	2.06	0.91	0.79	1.05
1961	1.76	1.59	1.94	0.79	0.68	0.92
1962	1.61	1.43	1.8	1.18	1	1.4
1963	1.39	1.18	1.63	1.36	1.1	1.69
1964	1.14	0.89	1.46	1.44	1.15	1.79
1965	0.89	0.62	1.28	1.39	1.11	1.76
1966	0.77	0.5	1.21	1.13	0.9	1.42
1967	0.86	0.55	1.34	1.45	1.15	1.83
1968	0.99	0.63	1.56	1.18	0.94	1.5
1969	0.92	0.59	1.44	1.25	0.98	1.59
1970	0.83	0.53	1.31	1.15	0.91	1.47
1971	0.76	0.48	1.2	1.37	1.07	1.75
1972	0.76	0.48	1.19	1.13	0.88	1.45
1973	0.83	0.53	1.29	1.04	0.81	1.34
1974	0.93	0.6	1.45	1.18	0.9	1.53
1975	1	0.64	1.56	1.05	0.78	1.4

1976	0.95	0.6	1.5	1.49	1.09	2
1977	0.8	0.5	1.29	1.53	1.11	2.1
1978	0.74	0.46	1.2	1.46	1.05	2.01
1979	0.7	0.44	1.14	1.49	1.08	2.04
1980	0.67	0.42	1.08	1.14	0.82	1.57
1981	0.68	0.42	1.09	1.02	0.73	1.41
1982	0.73	0.46	1.17	1.28	0.91	1.8
1983	0.71	0.44	1.14	1.63	1.13	2.33
1984	0.6	0.36	1	1.45	0.99	2.12
1985	0.53	0.31	0.91	1.4	0.93	2.09
1986	0.45	0.24	0.82	1.58	1.03	2.4
1987	0.49	0.26	0.91	1.27	0.81	1.98
1988	0.6	0.32	1.1	1.1	0.69	1.74
1989	0.72	0.39	1.31	1.06	0.67	1.67
1990	0.74	0.4	1.37	1.18	0.74	1.86
1991	0.76	0.41	1.39	0.89	0.56	1.42
1992	0.76	0.41	1.4	0.95	0.6	1.52
1993	0.75	0.4	1.39	1.14	0.71	1.82
1994	0.77	0.41	1.44	1.08	0.67	1.74
1995	0.75	0.39	1.42	1.19	0.73	1.91
1996	0.79	0.42	1.5	0.91	0.55	1.49
1997	0.83	0.44	1.56	0.86	0.53	1.4
1998	0.87	0.46	1.62	0.72	0.44	1.16
1999	0.86	0.45	1.62	0.94	0.58	1.51
2000	0.9	0.48	1.7	0.96	0.58	1.55
2001	0.98	0.52	1.82	0.81	0.49	1.32
2002	1	0.53	1.86	0.71	0.43	1.17
2003	0.93	0.49	1.74	0.77	0.47	1.25
2004	0.87	0.46	1.64	0.78	0.47	1.28
2005	0.85	0.45	1.6	0.99	0.6	1.62
2006	0.88	0.46	1.68	1.04	0.62	1.72
2007	0.91	0.48	1.73	0.63	0.38	1.06
2008	0.99	0.52	1.89	0.58	0.34	0.97
2009	1.1	0.58	2.09	0.41	0.24	0.69
2010	1.15	0.61	2.18	0.47	0.28	0.79
2011	1.2	0.63	2.26	0.46	0.28	0.77
2012	1.27	0.67	2.39	0.55	0.33	0.92
2013	1.36	0.72	2.56	0.53	0.32	0.88
2014	1.42	0.75	2.67	0.57	0.34	0.95
2015	1.46	0.78	2.75	0.55	0.33	0.91
2016	1.46	0.77	2.75	0.61	0.37	1.01
2017	1.42	0.75	2.69	0.51	0.31	0.84
2018	1.43	0.76	2.7	0.47	0.28	0.77
2019	1.55	0.83	2.89	0.51	0.31	0.83
2020	1.84	1	3.39	0.45	0.28	0.74
2021	2.19	1.21	4.01	0.45	0.29	0.71

Table 7. Estimated parameters and reference points for the *mpb* model reference case.

	Median	q05	q95
r	0.115	0.093	0.138
k	915,019	803,331	1,088,179
MSY	38,650	36,543	40,760
F_{MSY}	0.115	0.093	0.138
B_{MSY}	336,785	295,677	400,519

Table 8. Estimated annual parameters and reference points for the *mpb* model reference case.

Year	Biomass, median (t)	Biomass, q5% (t)	Biomass, q95% (t)	Fishing mortality, median	Fishing mortality, q5%	Fishing mortality, q95%	Relative biomass (B/Bmsy), median	Relative biomass (B/Bmsy), q5%	Relative biomass (B/Bmsy), q95%	Relative fishing mortality (F/Fmsy), median	Relative fishing mortality (F/Fmsy), q5%	Relative fishing mortality (F/Fmsy), q95%
1930	915019	803331	1088179	0.0123	0.0103	0.0140	2.7169	2.7169	2.7169	0.1071	0.1016	0.1133
1931	903769	792081	1076929	0.0173	0.0145	0.0197	2.6835	2.6789	2.6888	0.1504	0.1429	0.1588
1932	889443	778007	1062380	0.0144	0.0121	0.0165	2.6410	2.6313	2.6525	0.1259	0.1198	0.1326
1933	879465	768562	1051922	0.0130	0.0109	0.0149	2.6115	2.5994	2.6264	0.1134	0.1081	0.1194
1934	871984	761758	1043817	0.0217	0.0181	0.0248	2.5894	2.5766	2.6062	0.1887	0.1797	0.1984
1935	857888	748410	1029014	0.0242	0.0202	0.0277	2.5477	2.5315	2.5692	0.2108	0.2010	0.2212
1936	843438	734904	1013662	0.0199	0.0166	0.0229	2.5050	2.4860	2.5309	0.1737	0.1656	0.1819
1937	834481	727048	1003610	0.0162	0.0135	0.0186	2.4785	2.4596	2.5057	0.1410	0.1345	0.1477
1938	829799	723463	997729	0.0176	0.0147	0.0202	2.4646	2.4473	2.4910	0.1536	0.1464	0.1609
1939	824483	719197	991232	0.0207	0.0172	0.0237	2.4488	2.4330	2.4748	0.1806	0.1720	0.1892
1940	817260	712995	982834	0.0141	0.0117	0.0161	2.4274	2.4118	2.4538	0.1225	0.1167	0.1284
1941	816368	713134	980737	0.0162	0.0135	0.0186	2.4246	2.4119	2.4485	0.1414	0.1345	0.1483
1942	813810	711499	977060	0.0206	0.0172	0.0236	2.4170	2.4063	2.4393	0.1797	0.1709	0.1887
1943	807977	706580	970156	0.0207	0.0173	0.0237	2.3997	2.3893	2.4221	0.1809	0.1719	0.1899
1944	802749	702273	963843	0.0211	0.0176	0.0242	2.3842	2.3745	2.4063	0.1842	0.1750	0.1934
1945	797847	698284	957854	0.0346	0.0288	0.0395	2.3696	2.3605	2.3913	0.3014	0.2862	0.3166
1946	782810	684149	941734	0.0297	0.0247	0.0340	2.3250	2.3129	2.3510	0.2589	0.2463	0.2717
1947	773647	675994	931241	0.0262	0.0218	0.0300	2.2976	2.2850	2.3248	0.2283	0.2171	0.2394
1948	768420	671778	924582	0.0314	0.0261	0.0359	2.2815	2.2701	2.3082	0.2733	0.2598	0.2868
1949	759868	664210	914616	0.0367	0.0305	0.0420	2.2557	2.2441	2.2832	0.3196	0.3037	0.3354
1950	748374	653731	901664	0.0529	0.0439	0.0606	2.2212	2.2084	2.2509	0.4616	0.4388	0.4839
1951	726210	632657	877949	0.0470	0.0389	0.0540	2.1551	2.1374	2.1916	0.4099	0.3909	0.4289
1952	711559	619324	861485	0.0455	0.0376	0.0523	2.1111	2.0919	2.1505	0.3968	0.3789	0.4150
1953	699799	609127	847971	0.0430	0.0355	0.0494	2.0762	2.0569	2.1167	0.3751	0.3582	0.3921
1954	691207	602242	837699	0.0578	0.0477	0.0664	2.0507	2.0327	2.0910	0.5040	0.4809	0.5272
1955	673461	586179	818283	0.0467	0.0384	0.0536	1.9983	1.9779	2.0425	0.4064	0.3883	0.4248
1956	665694	580222	808745	0.0614	0.0506	0.0705	1.9754	1.9567	2.0187	0.5350	0.5106	0.5597
1957	649172	565350	790366	0.0649	0.0533	0.0745	1.9263	1.9062	1.9728	0.5647	0.5398	0.5908
1958	632758	550617	771957	0.0829	0.0679	0.0953	1.8773	1.8558	1.9269	0.7213	0.6899	0.7540
1959	607238	526853	744370	0.0822	0.0671	0.0947	1.8014	1.7752	1.8578	0.7151	0.6853	0.7454
1960	586257	507599	720948	0.0902	0.0733	0.1042	1.7382	1.7095	1.7993	0.7849	0.7534	0.8170
1961	563359	486879	695893	0.0758	0.0614	0.0878	1.6705	1.6389	1.7368	0.6604	0.6342	0.6858
1962	551931	477788	682314	0.1065	0.0862	0.1230	1.6368	1.6069	1.7032	0.9271	0.8891	0.9636
1963	525245	453257	653368	0.1149	0.0924	0.1331	1.5576	1.5235	1.6307	1.0002	0.9597	1.0373
1964	498313	428422	624253	0.1297	0.1035	0.1509	1.4780	1.4396	1.5580	1.1294	1.0811	1.1691
1965	468490	400530	592117	0.1295	0.1024	0.1514	1.3896	1.3466	1.4778	1.1268	1.0773	1.1666
1966	444342	377863	565213	0.1066	0.0838	0.1253	1.3165	1.2704	1.4106	0.9290	0.8841	0.9651
1967	433580	369313	552527	0.1364	0.1070	0.1601	1.2852	1.2406	1.3798	1.1879	1.1281	1.2360
1968	411301	349543	528456	0.1099	0.0856	0.1294	1.2199	1.1731	1.3199	0.9562	0.9043	0.9968
1969	404125	343959	518982	0.1156	0.0900	0.1359	1.1978	1.1528	1.2963	1.0066	0.9496	1.0520
1970	395784	337385	508235	0.1160	0.0903	0.1360	1.1726	1.1283	1.2697	1.0104	0.9514	1.0580
1971	387431	330894	498573	0.1467	0.1140	0.1717	1.1502	1.1066	1.2457	1.2760	1.1982	1.3385
1972	368233	313638	478192	0.1325	0.1020	0.1555	1.0952	1.0494	1.1949	1.1498	1.0744	1.2095
1973	357953	305512	466228	0.1277	0.0980	0.1496	1.0656	1.0181	1.1652	1.1079	1.0317	1.1690
1974	351231	299784	457568	0.1412	0.1084	0.1655	1.0448	0.9973	1.1436	1.2270	1.1397	1.2973
1975	340270	290138	445147	0.1231	0.0941	0.1444	1.0125	0.9627	1.1126	1.0691	0.9890	1.1352
1976	337240	288236	440545	0.1697	0.1299	0.1986	1.0038	0.9517	1.1012	1.4750	1.3609	1.5690
1977	318499	271207	420598	0.1696	0.1285	0.1992	0.9488	0.8935	1.0515	1.4720	1.3484	1.5777
1978	303032	257393	403988	0.1654	0.1241	0.1947	0.9031	0.8445	1.0103	1.4327	1.3040	1.5433
1979	291532	247026	391332	0.1762	0.1313	0.2080	0.8691	0.8073	0.9789	1.5245	1.3784	1.6553
1980	278359	235195	377415	0.1390	0.1025	0.1645	0.8302	0.7652	0.9443	1.2012	1.0775	1.3155
1981	277721	235529	376125	0.1243	0.0918	0.1466	0.8307	0.7633	0.9413	1.0749	0.9609	1.1808
1982	280911	239752	378987	0.1519	0.1126	0.1780	0.8414	0.7718	0.9493	1.3156	1.1710	1.4438
1983	276248	236135	373724	0.1864	0.1378	0.2181	0.8302	0.7560	0.9363	1.6128	1.4293	1.7829
1984	262398	222851	359612	0.1593	0.1162	0.1876	0.7908	0.7121	0.9013	1.3749	1.2051	1.5356
1985	258233	219293	355091	0.1581	0.1150	0.1862	0.7789	0.6967	0.8914	1.3648	1.1887	1.5346
1986	255234	216145	352511	0.1863	0.1349	0.2200	0.7709	0.6834	0.8851	1.6091	1.3930	1.8237
1987	246059	206314	342243	0.1549	0.1114	0.1847	0.7423	0.6486	0.8596	1.3425	1.1491	1.5412
1988	245256	204019	341273	0.1348	0.0969	0.1620	0.7405	0.6405	0.8575	1.1679	0.9929	1.3530
1989	250191	208404	345345	0.1282	0.0929	0.1539	0.7521	0.6478	0.8727	1.1157	0.9413	1.3007
1990	255698	212124	350464	0.1442	0.1052	0.1739	0.7681	0.6581	0.8913	1.2570	1.0575	1.4785
1991	256184	210679	350839	0.1090	0.0796	0.1326	0.7683	0.6523	0.8926	0.9495	0.7929	1.1253
1992	266570	218599	360166	0.1157	0.0857	0.1411	0.7935	0.6767	0.9220	1.0098	0.8405	1.2047
1993	273325	225128	366678	0.1395	0.1040	0.1694	0.8121	0.6916	0.9482	1.2175	1.0093	1.4630
1994	273045	224157	365965	0.1288	0.0961	0.1569	0.8113	0.6860	0.9529	1.1250	0.9255	1.3611
1995	277163	225506	368217	0.1385	0.1042	0.1702	0.8179	0.6894	0.9653	1.2179	0.9930	1.4808
1996	277331	223646	367274	0.1039	0.0784	0.1288	0.8171	0.6831	0.9729	0.9155	0.7402	1.1268
1997	286515	232036	375897	0.1013	0.0772	0.1251	0.8445	0.7010	1.0094	0.8925	0.7173	1.0967
1998	295819	240288	384361	0.0870	0.0670	0.1071	0.8722	0.7254	1.0373	0.7674	0.6114	0.9441
1999	309672	250619	396142	0.1116	0.0872	0.1379	0.9071	0.7483	1.0846	0.9847	0.7837	1.2119
2000	313598	253192	399148	0.1056	0.0830	0.1308	0.9182	0.7554	1.1042	0.9322	0.7410	1.1534
2001	319447	257323	403563	0.0822	0.0651	0.1020	0.9343	0.7656	1.1297	0.7265	0.5736	0.9018
2002	332289	268445	414819	0.0684	0.0548	0.0846	0.9707	0.8018	1.1763	0.6041	0.4776	0.7553
2003	347979	282460	429730	0.0735	0.0595	0.0905	1.0187	0.8424	1.2293	0.6481	0.5110	0.8102
2004	361411	293479	441620	0.0718	0.0588	0.0884	1.0576	0.8776	1.2747	0.6338	0.4991	0.7936
2005	374018	306799	453025	0.0944	0.0780	0.1151	1.0963	0.9102	1.3202	0.8337	0.6555	1.0459
2006	377103	309298	454949	0.0980	0.0812	0.1195	1.1056	0.9149	1.3327	0.8655	0.6796	1.0874
2007	378565	310140	455438	0.0581	0.0483	0.0709	1.1102	0.9152	1.3391	0.5134	0.4024	0.6472
2008	394465	326449	470630	0.0519	0.0435	0.0627	1.1588	0.9569	1.3954	0.4576	0.3599	0.5801
2009	412163	344310	487120	0.0373	0.0316	0.0447	1.2124	1.0031	1.4556	0.3296	0.2591	0.4147
2010	434230	367239	508599	0.0447	0.0382	0.0529	1.2759	1.0637	1.5287	0.3940	0.3109	0.4960
2011	451390	385928	525380	0.0443	0.0380	0.0518	1.3295	1.1079	1.5860	0.3898	0.3095	0.4900
2012	467817	403706	541186	0.0544	0.0470	0.0630	1.3770	1.1558	1.6351	0.4787	0.3822	0.6015
2013	478221	415623	551213	0.0516	0.0448	0.0594	1.4089	1.1853	1.6624	0.4544	0.3645	0.5704
2014	488680	426842	561601	0.0545	0.0474	0.0624	1.4417	1.2157	1.6904	0.4799	0.3868	0.5981
2015	495994	435988	569805	0.0517	0.0450	0.0588	1.4662	1.2392	1.7103	0.4541	0.3677	0.5648
2016	504635	446039	578746	0.0602	0.0525	0.0682	1.4927	1.2641	1.7328	0.5289	0.4304	0.6566
2017	507791	451197	582618	0.0561	0.0489	0.0631	1.5044	1.2763	1.7375	0.4914	0.4021	0.6092
2018	513268	458205	587988	0.0580	0.0507	0.0650	1.5209	1.2932	1.7483	0.5082	0.4180	0.6289
2019	517566	463793	592157	0.0675	0.0590	0.0753	1.5332	1.3110	1.7539	0.5916	0.4885	0.7278
2020	515732	464151	591039	0.0610	0.0533	0.0678	1.5298	1.3118	1.7417	0.5344	0.4434	0.6562
2021	517354	466777	593403	0.0607	0.0529	0.0673	1.5365	1.3207	1.7421	0.5306	0.4421	0.6502
2022	519799	470086	595769	NA	NA	NA	1.5432	1.3292	1.7427	NA	NA	NA

Table 9. Projected yield (t) at 0.8*F_{MSY} by the deterministic projection from the Stock Synthesis model.

Year	Mean	95%LCI	95%UCL
2024	50173	35671	64675
2025	49029	37080	60978
2026	47979	37959	57999

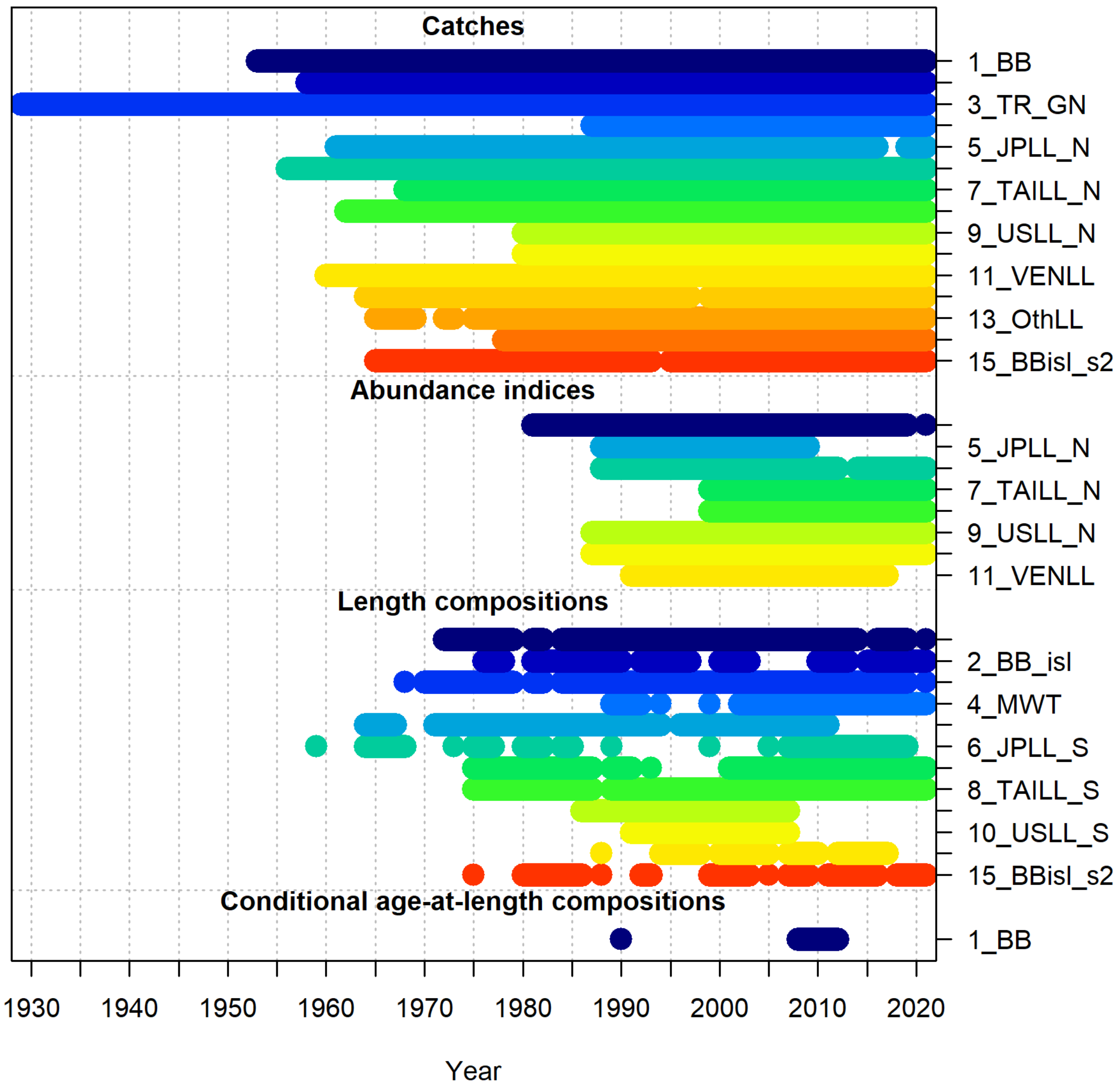

Figure 1. Summary of data time series modeled in Stock Synthesis.

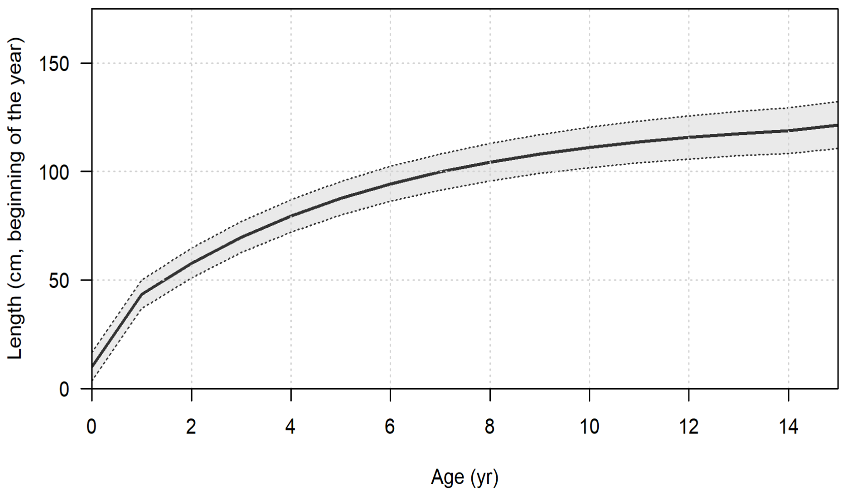

Figure 2. Estimated growth of North Atlantic albacore within the Stock Synthesis model.

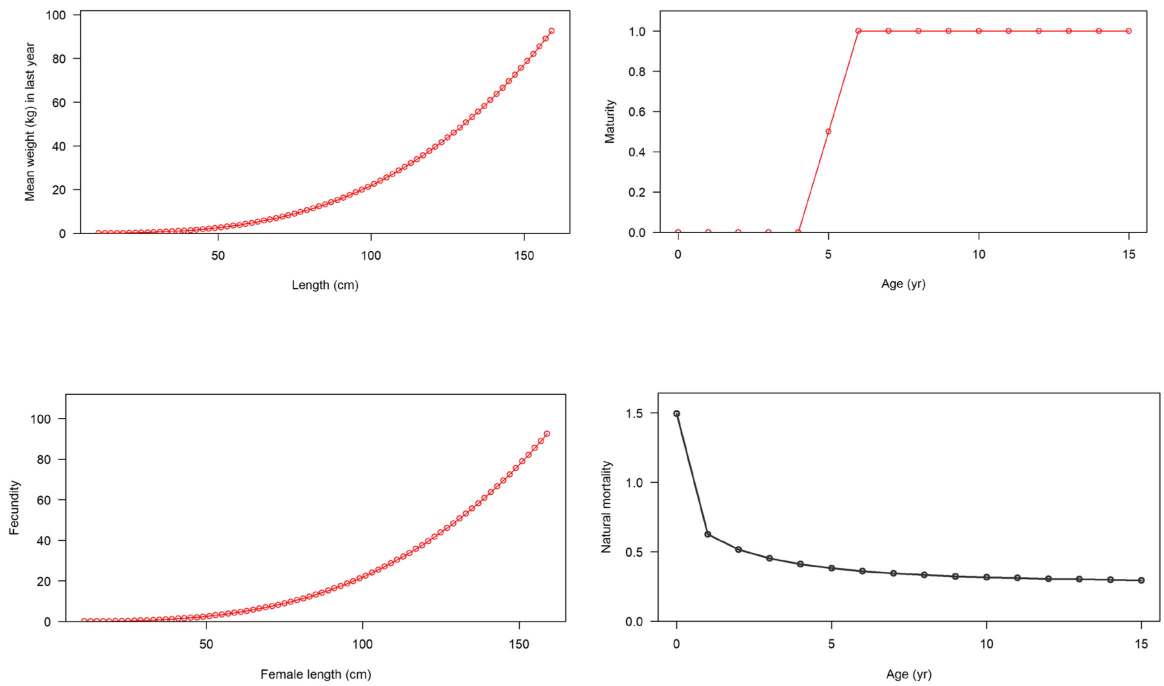

Figure 3. Summary of North Atlantic albacore biological assumptions in SS3, including length-weight (upper left panel), maturity-at-age (upper right panel), female fecundity-at-length (lower left panel), and natural mortality-at-age (lower right panel).

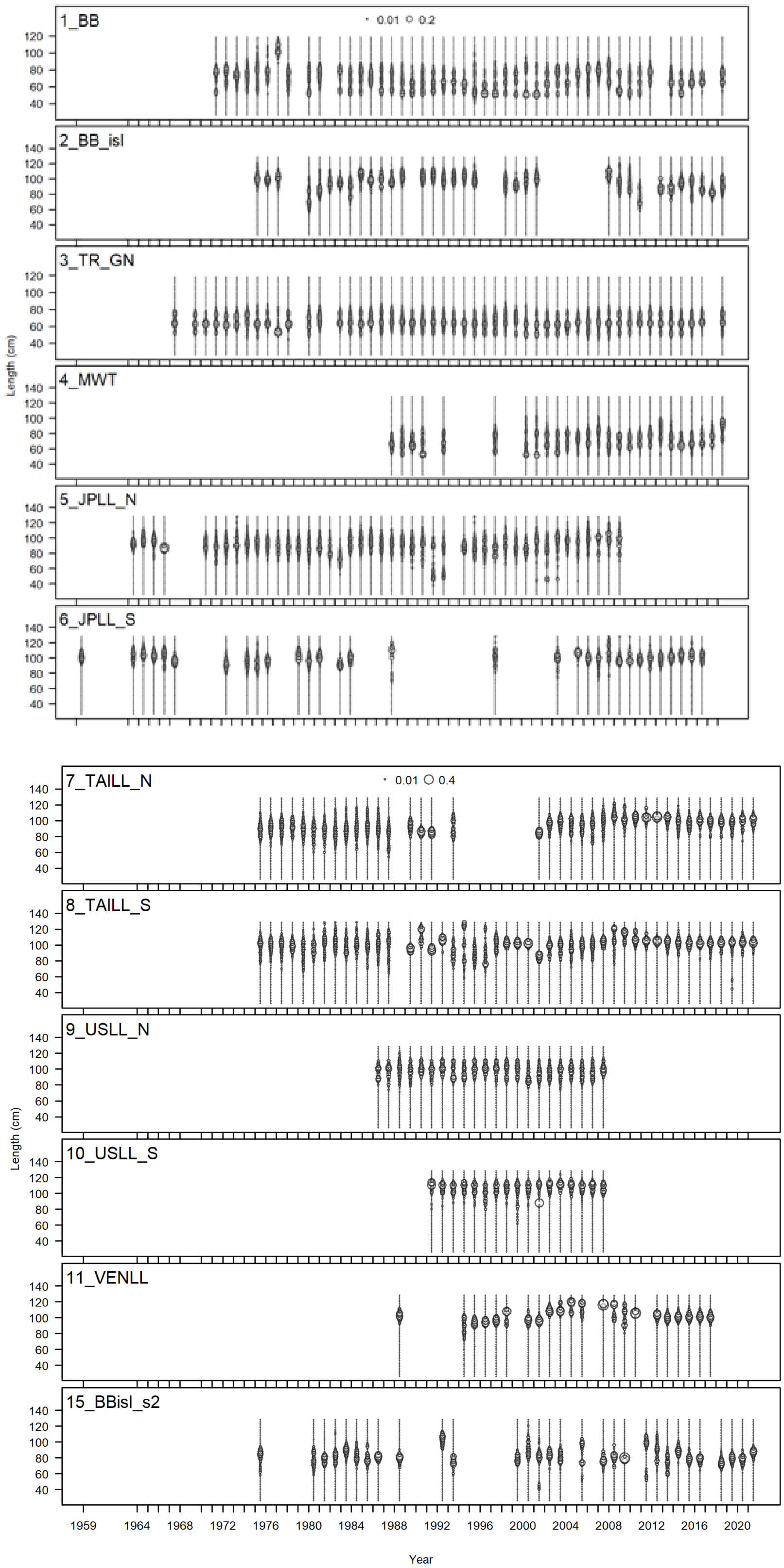

Figure 4. Time series of length composition by fleet used as input in Stock Synthesis.

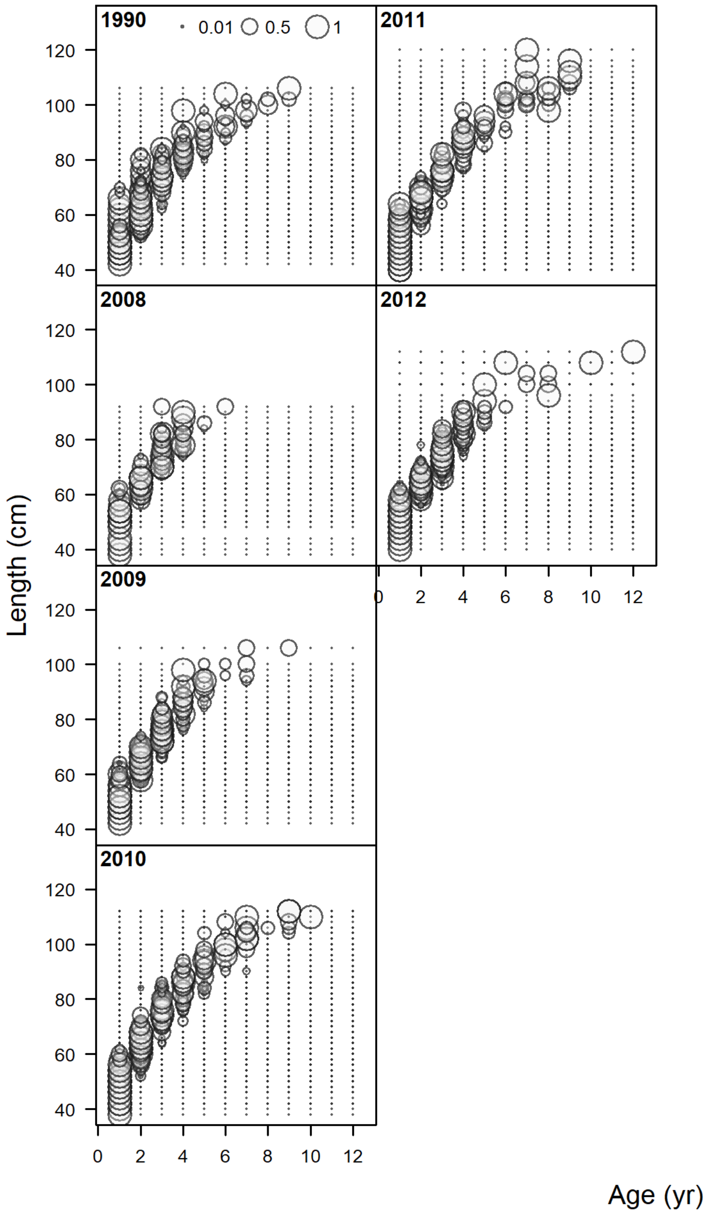

Figure 5. Summary of conditional age-at-length data by year, bubble size is scaled to the maximum sample size.

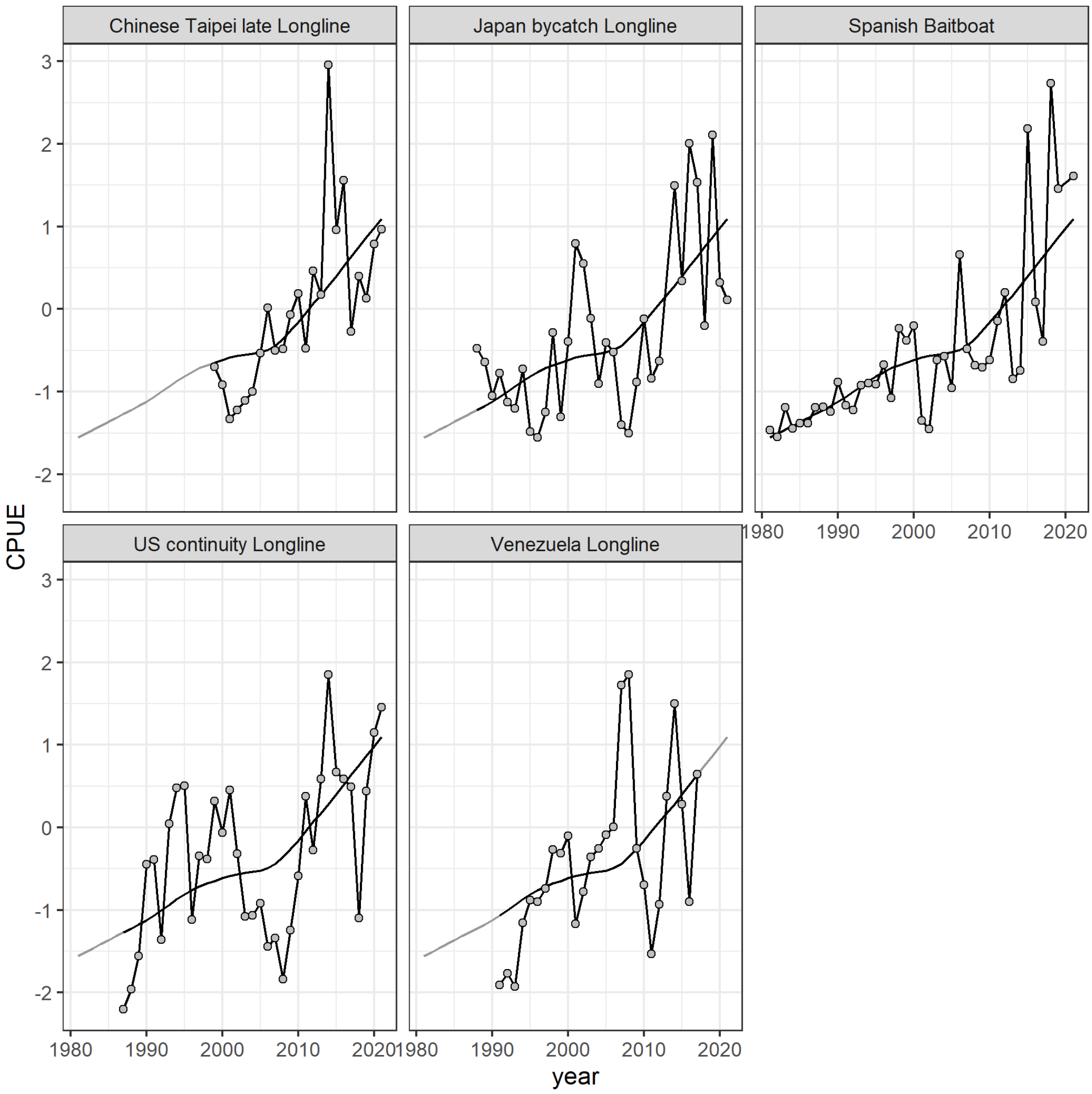

Figure 6. CPUE indices used in the stock assessment with *mpb*.

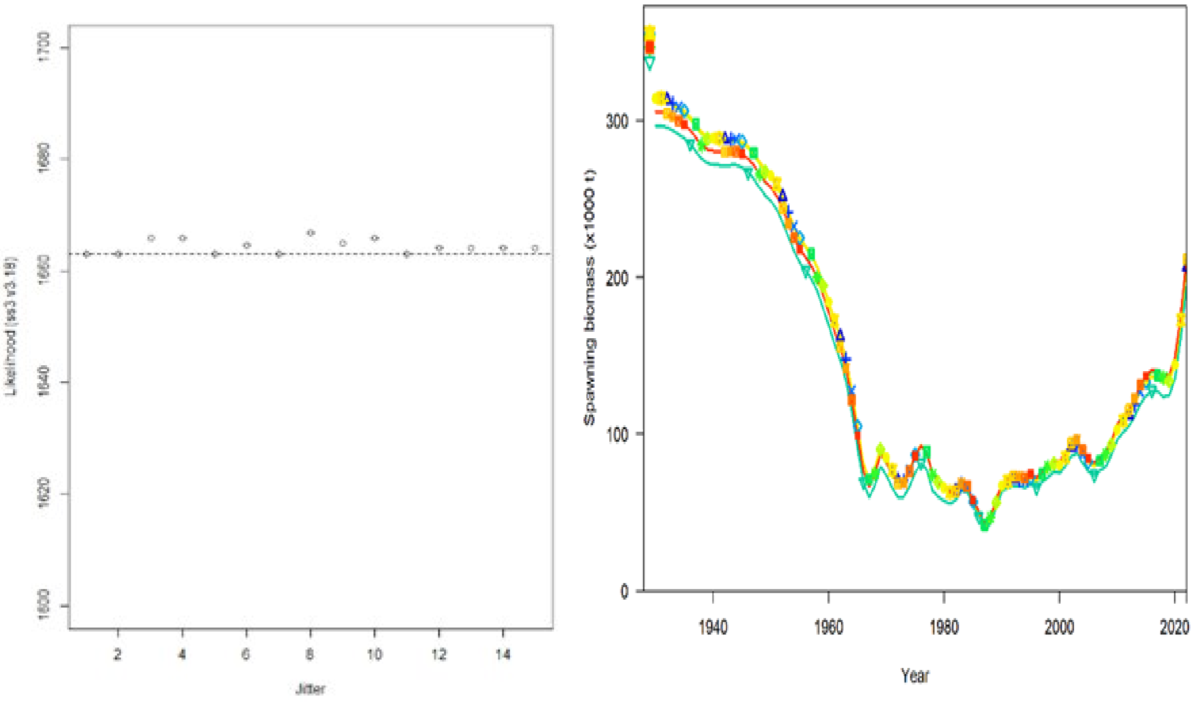

Figure 7. North Atlantic albacore Stock Synthesis jitter analysis results. Left panel shows the objective function values (negative log-likelihood) across model iterations with varied starting parameter values. The right panel shows the spawning biomass trajectory across trials.

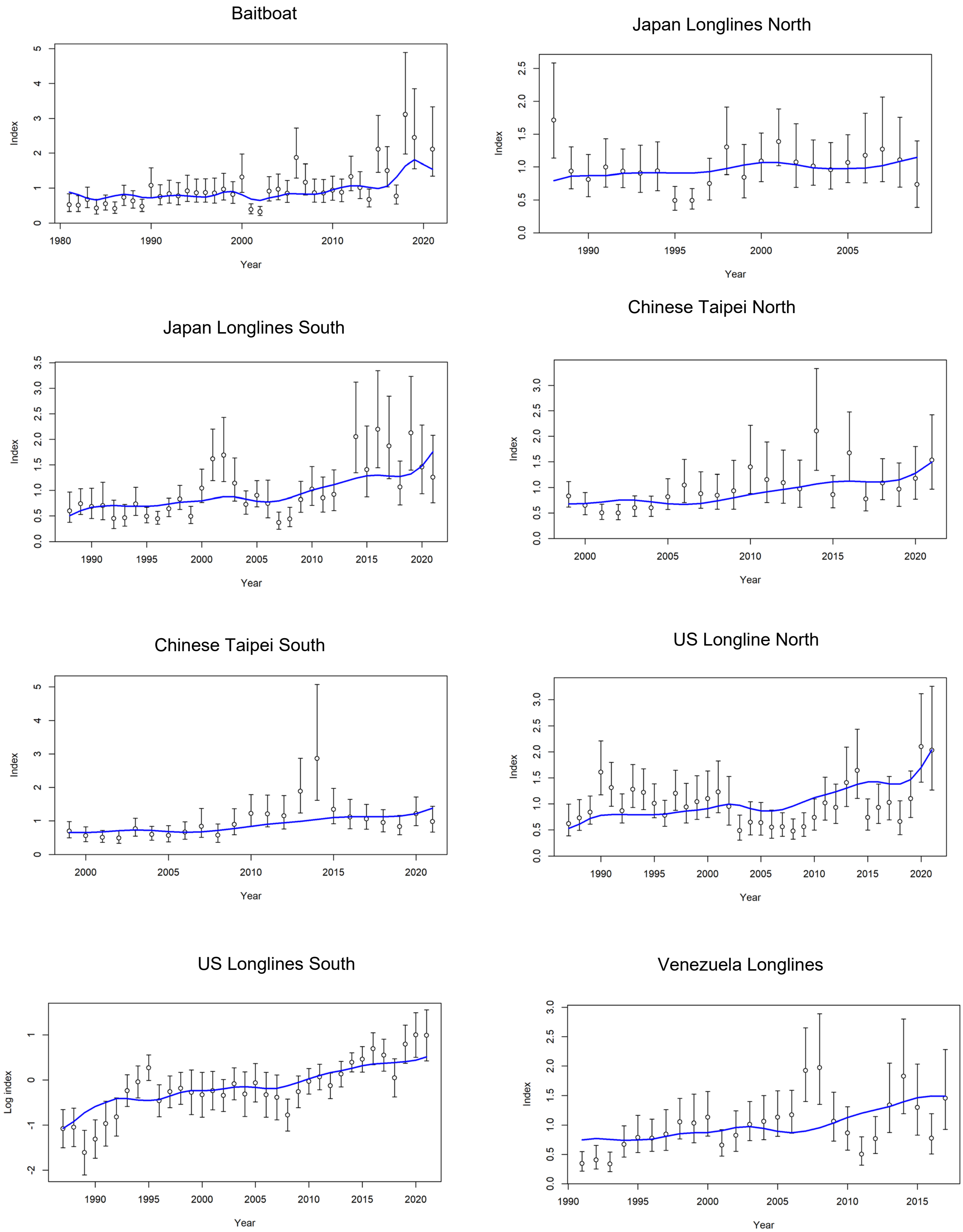

Figure 8. Stock Synthesis model fits North Atlantic albacore indices of relative abundance.

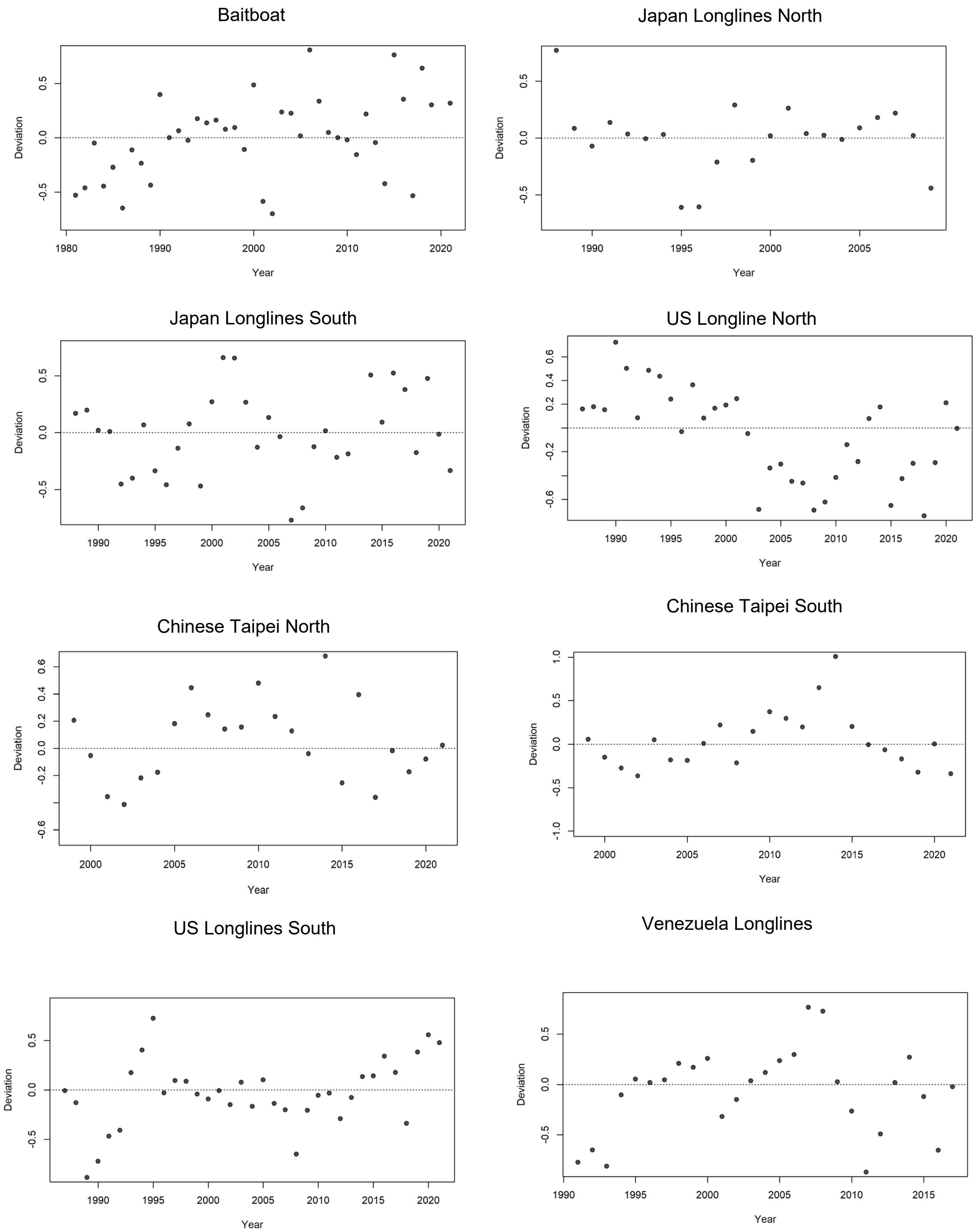

Figure 9. Stock Synthesis model fit residual errors around North Atlantic albacore indices of relative abundance.

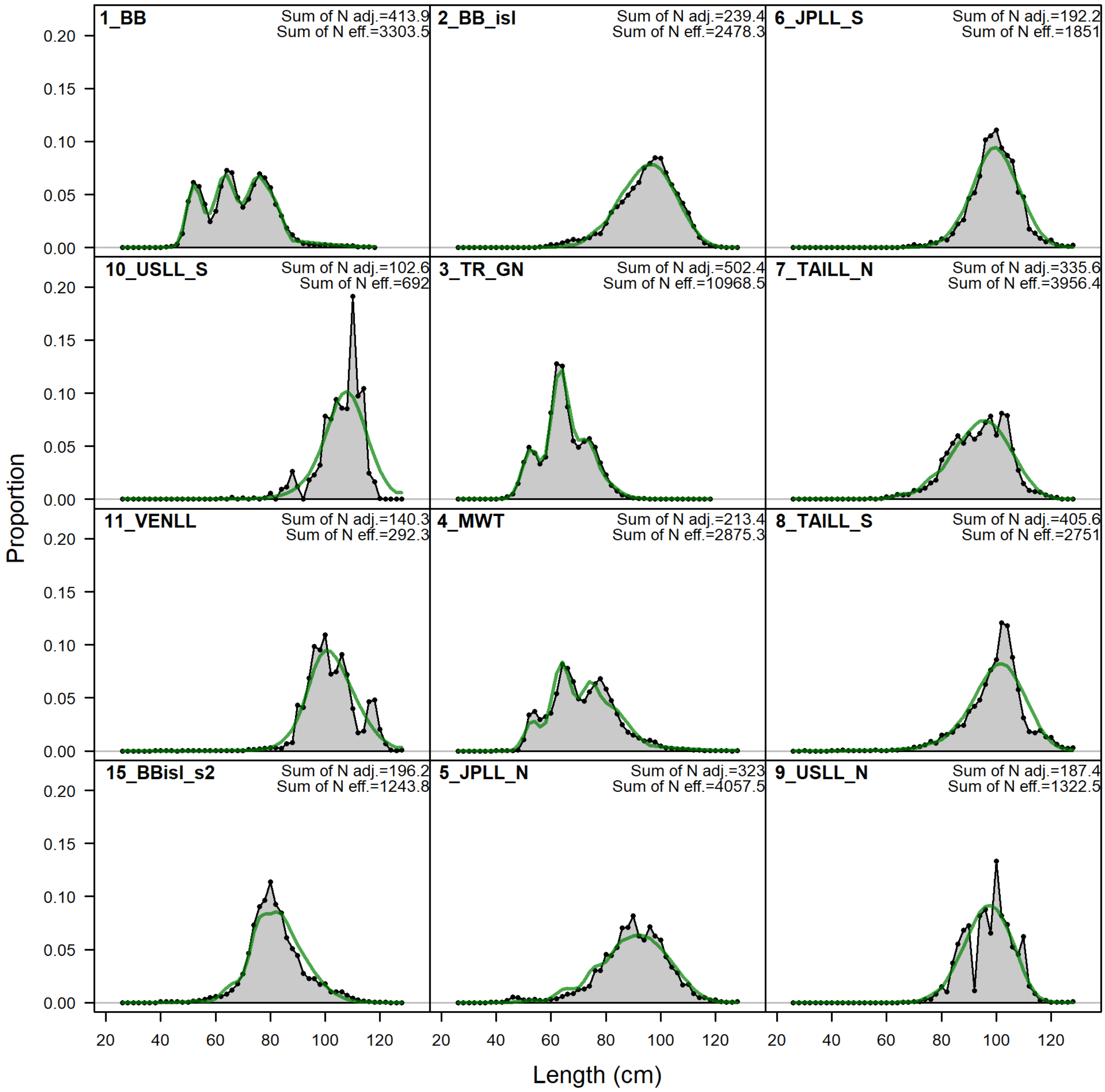

Figure 10. Stock Synthesis fits to the North Atlantic albacore length compositions by fleet. The gray distributions show the observed aggregated length composition by fleet and the green line shows the model-predicted length composition.

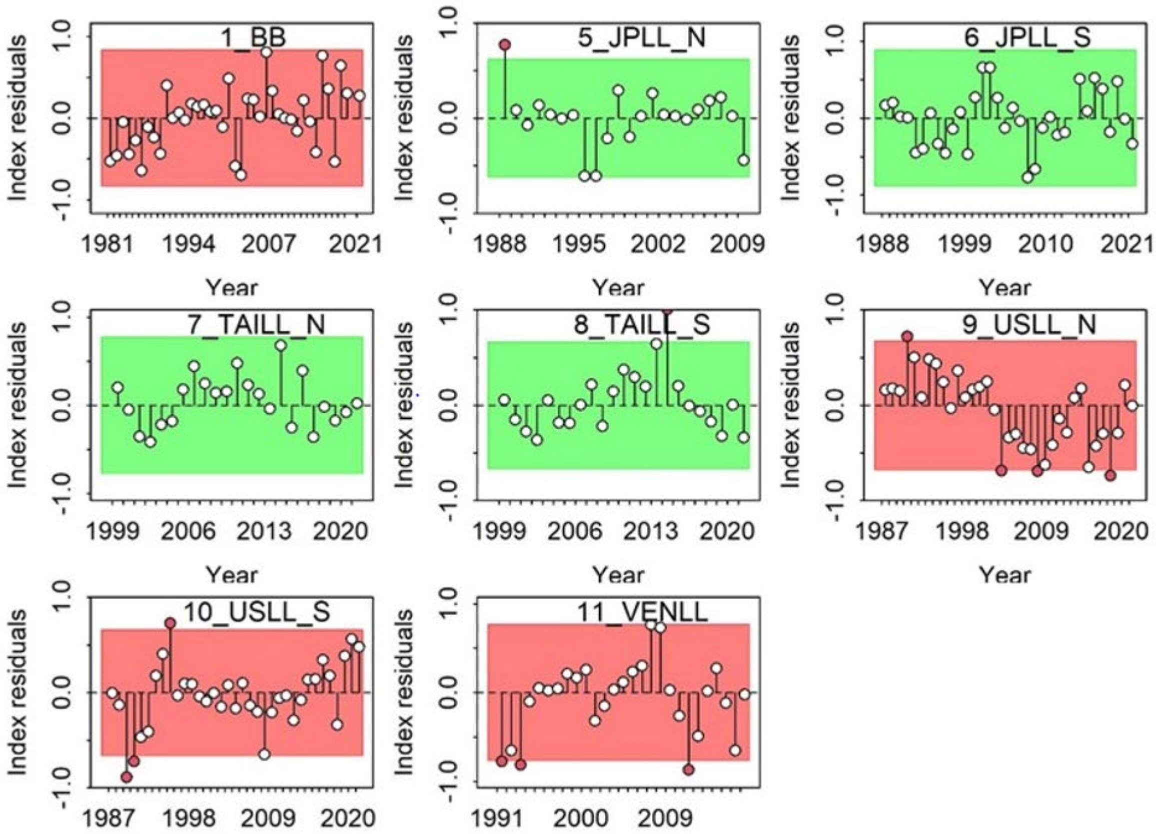

Figure 11. Diagnostic residual runs test on model fits to the indices of abundance.

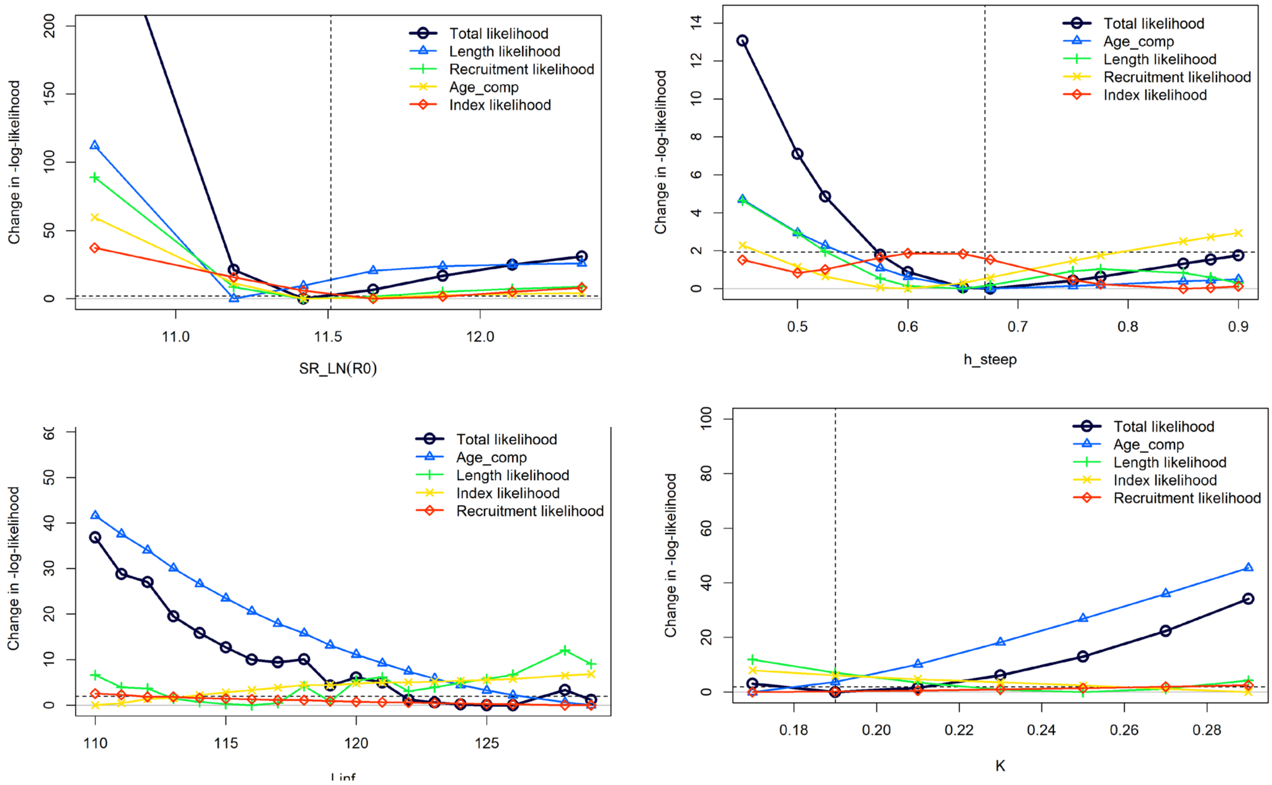

Figure 12. Likelihood profiles on unfished mean equilibrium recruitment (R0), steepness (*h*), mean asymptotic length (L_{inf}), and intrinsic growth rate (*k*) of North Atlantic albacore.

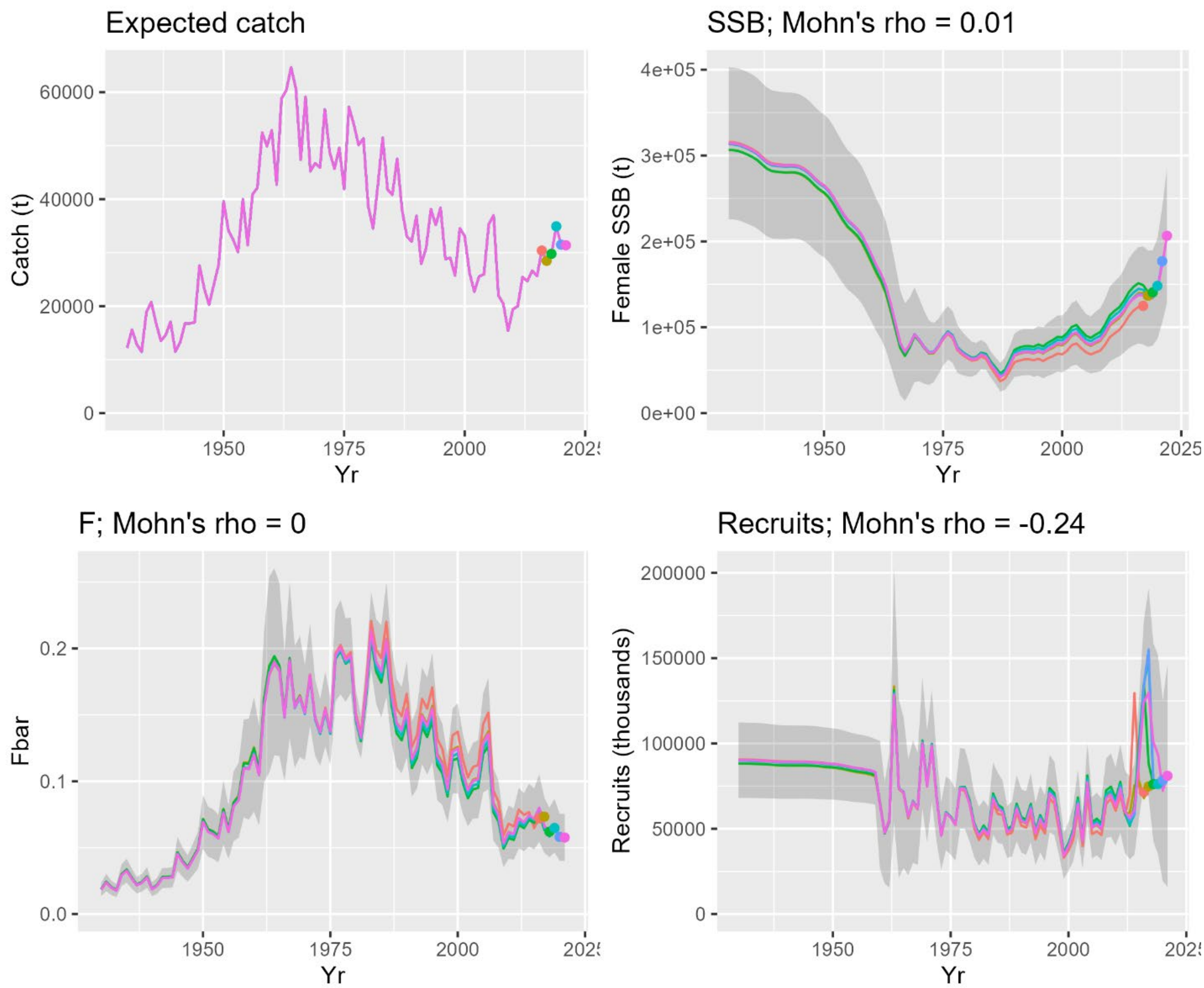

Figure 13. Retrospective analyses of the North Atlantic albacore Stock Synthesis reference case model.

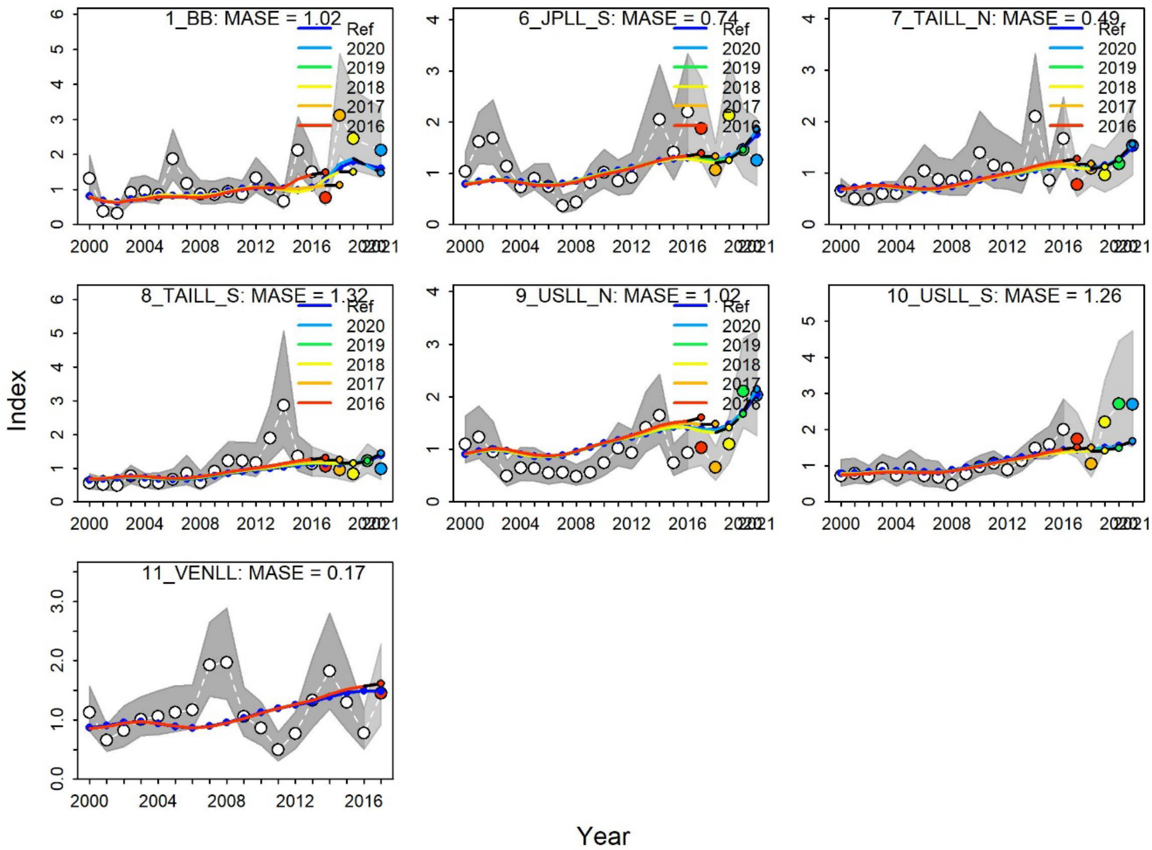

Figure 14. Hindcasting cross-validation results to evaluate the indices prediction skill of the model. 5-year hindcasting runs were used to estimate the MASE value. MASE <=1 indicates that the model has predictive skills. The observations used for cross-validation are highlighted as color-coded solid circles with associated 95 % confidence intervals (light-gray shading). The model reference year refers to the endpoints of each one-year-ahead forecast and the corresponding observation (i.e., year of peel + 1).

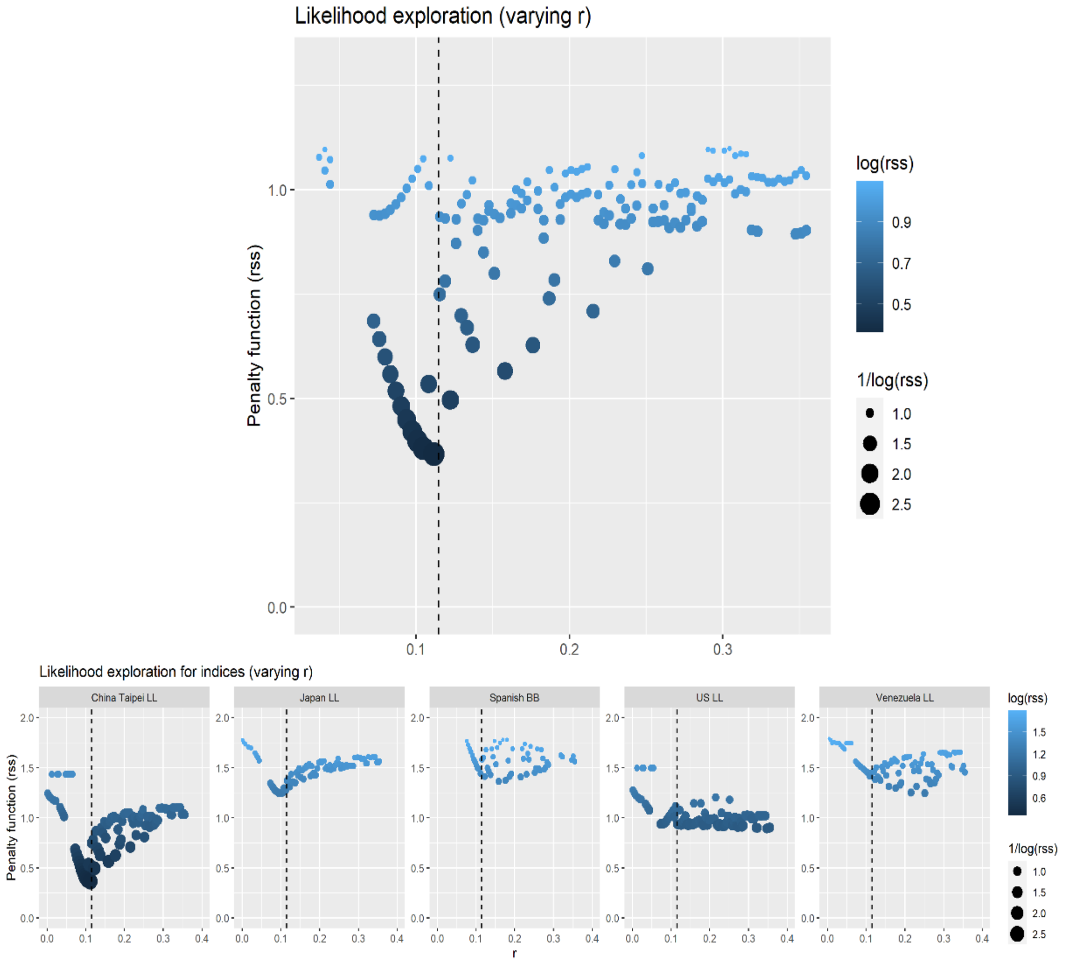

Figure 15. Bivariate residual plots for likelihood exploration with model *mpb.* Penalty function for different values of *r* and indices.

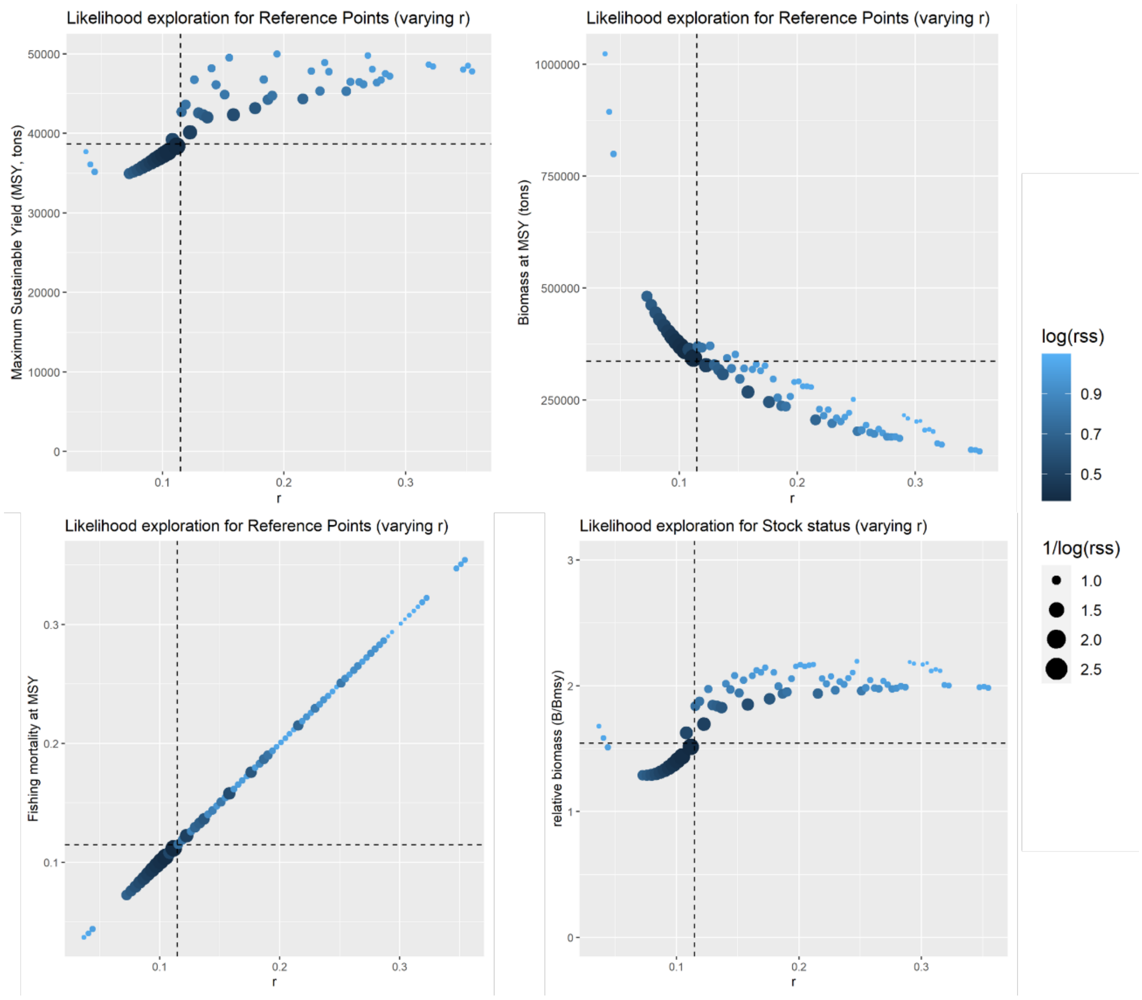

Figure 16. Bivariate residual plots for likelihood exploration with model *mpb.* Penalty function for different values of r and indices. Correlation between reference points and model estimates.

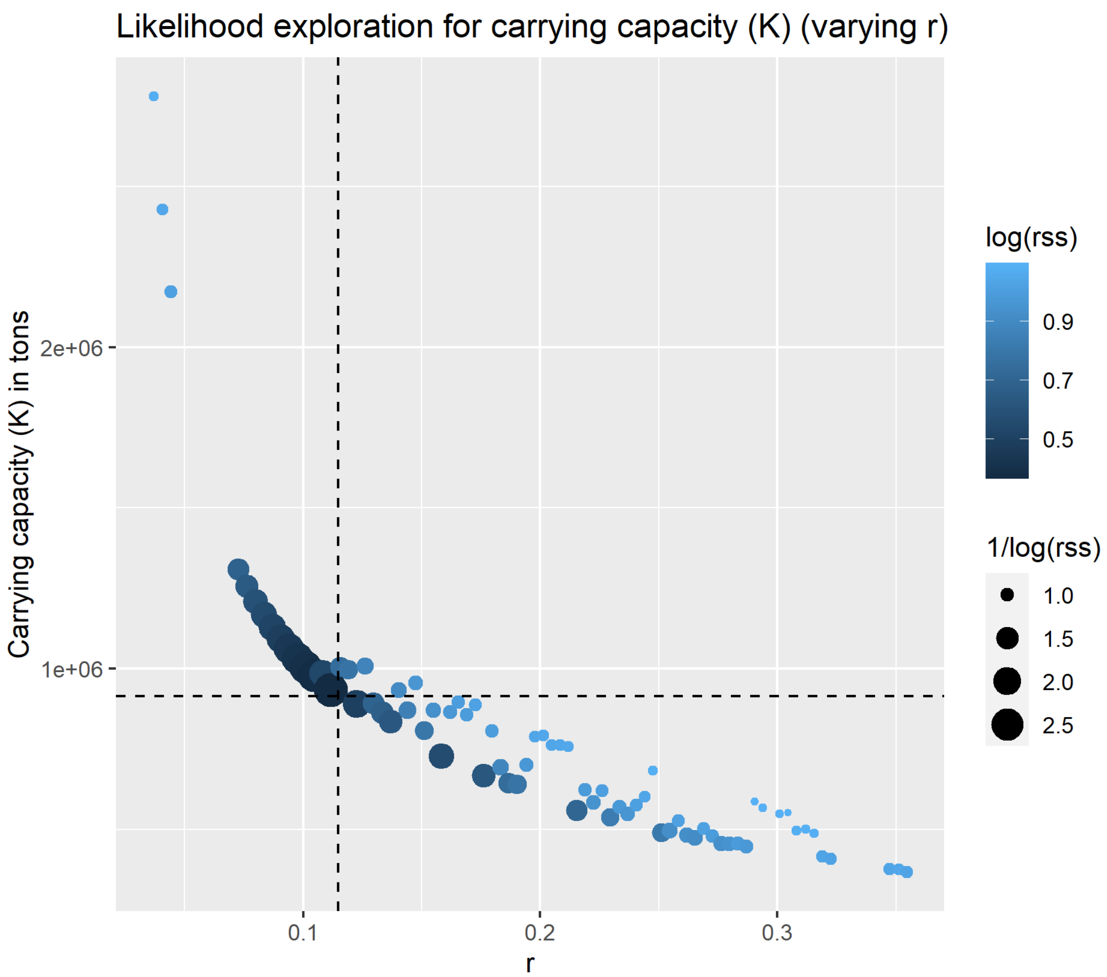

Figure 17. Bivariate residual plots for likelihood exploration with model *mpb.* Penalty function for different values of r and indices. Correlation between r and K.

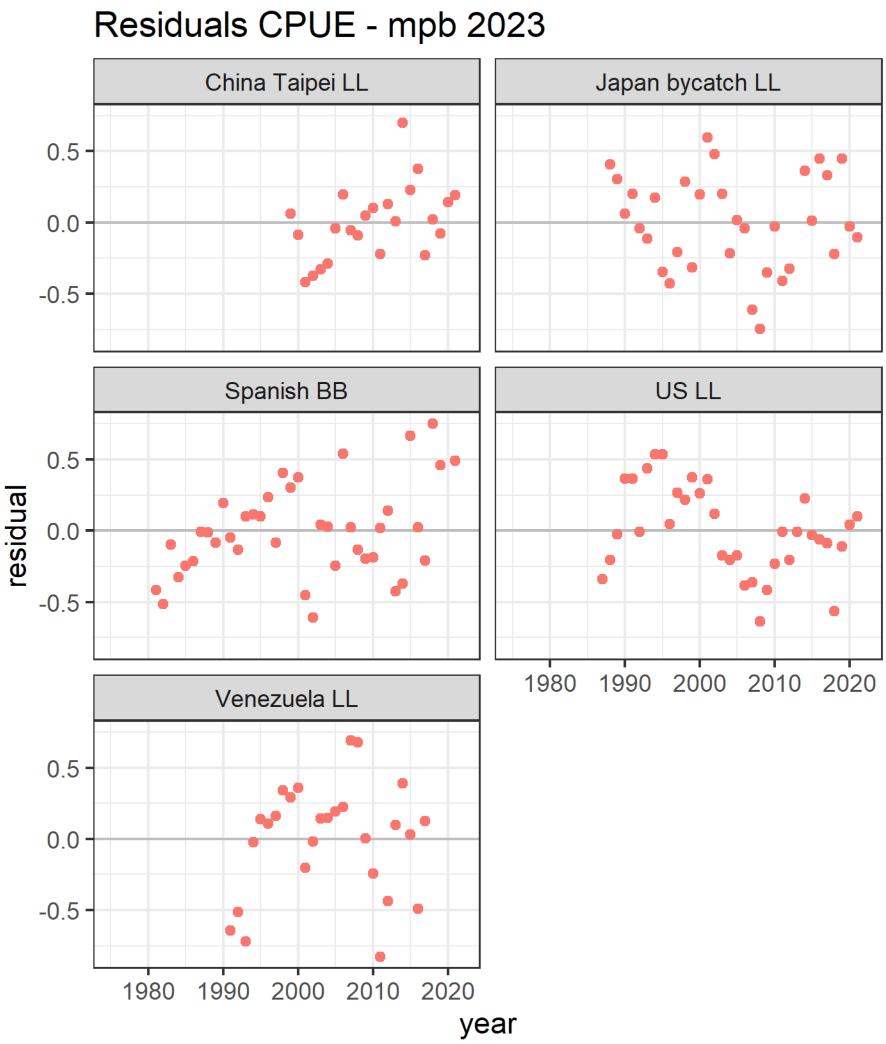

Figure 18. Time series of residuals of fit for each of the five indices available for this stock assessment.

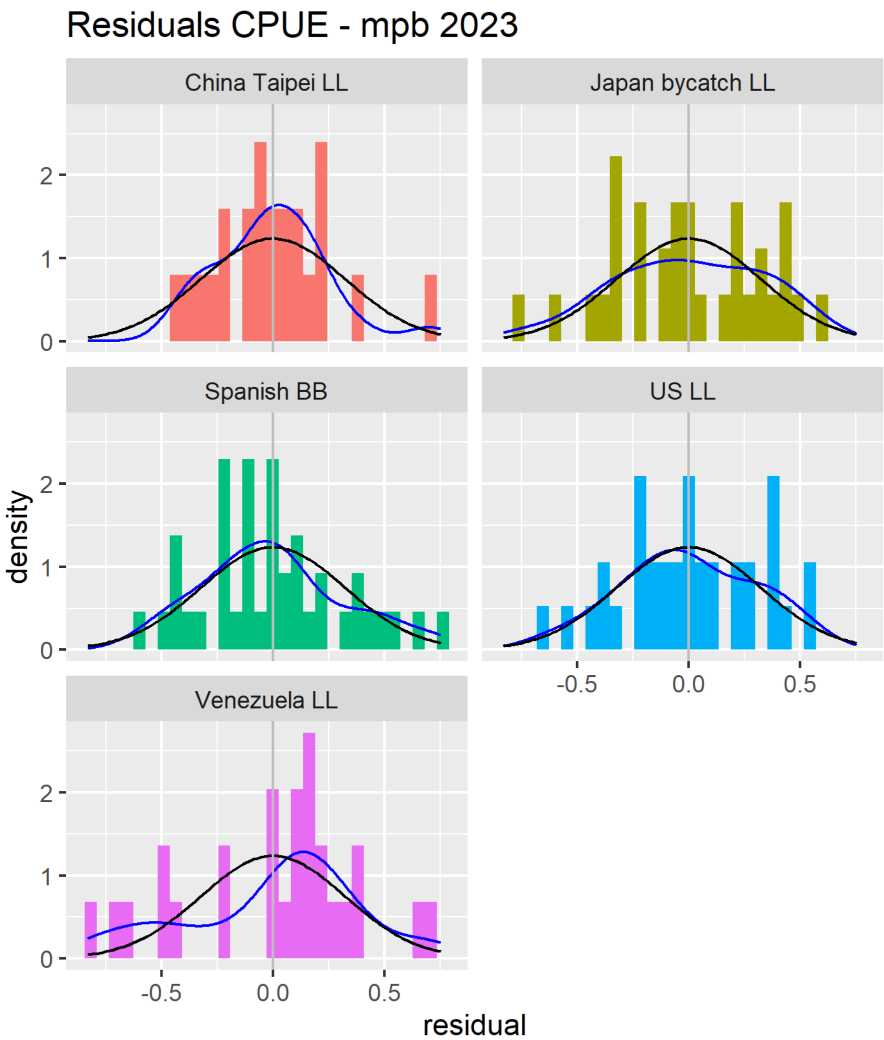

Figure 19. Histogram and density of residuals of fit for each of the five indices used in the biomass dynamics model. Blue line is the empirical density distribution of the residuals. Black line is the distribution with mean 0 and sd of the residuals.

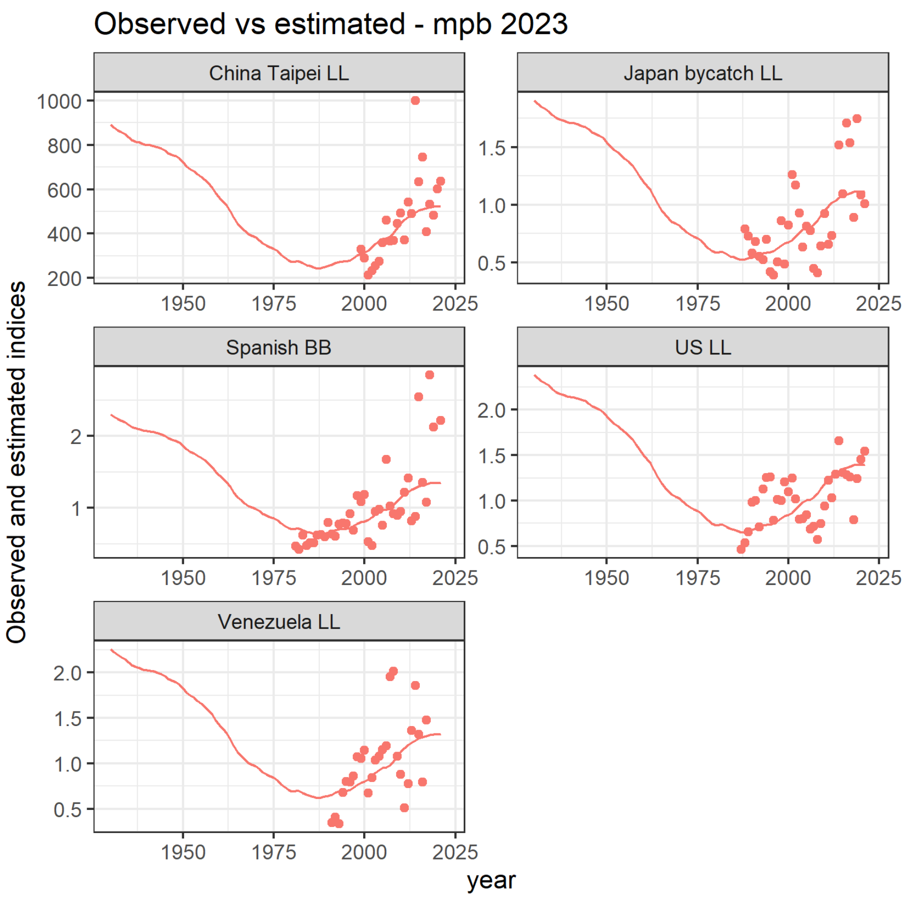

Figure 20. Time series of observed and estimated indices in the biomass dynamics model.

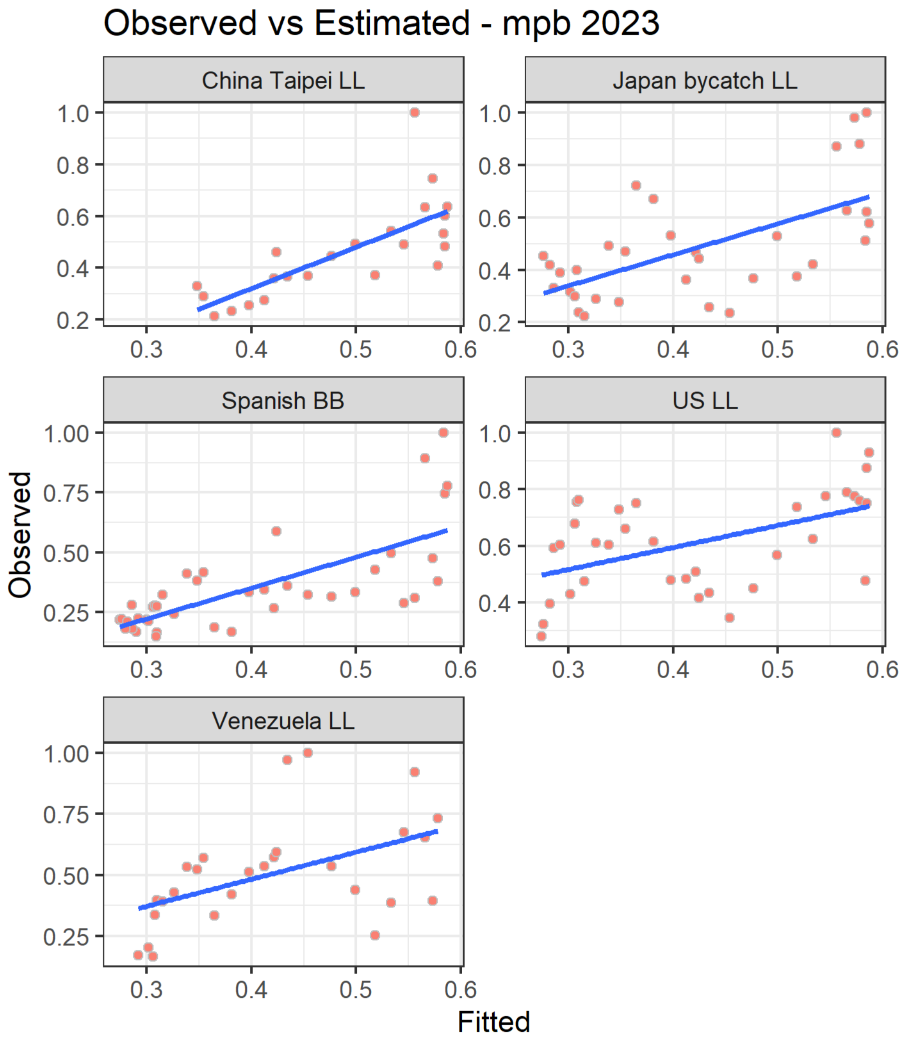

Figure 21. Biomass dynamics model: observed and estimated abundance indices and linear regression.

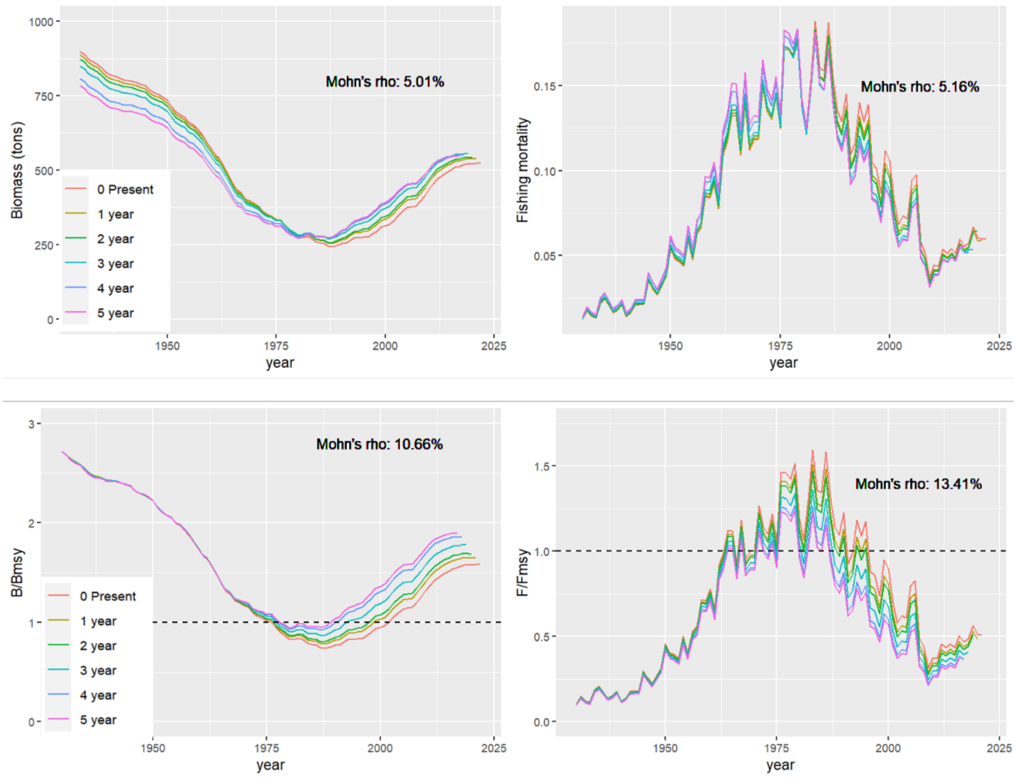

Figure 22. Retrospective analysis of the biomass production model, with Mohn's rho indicated for each indicator.

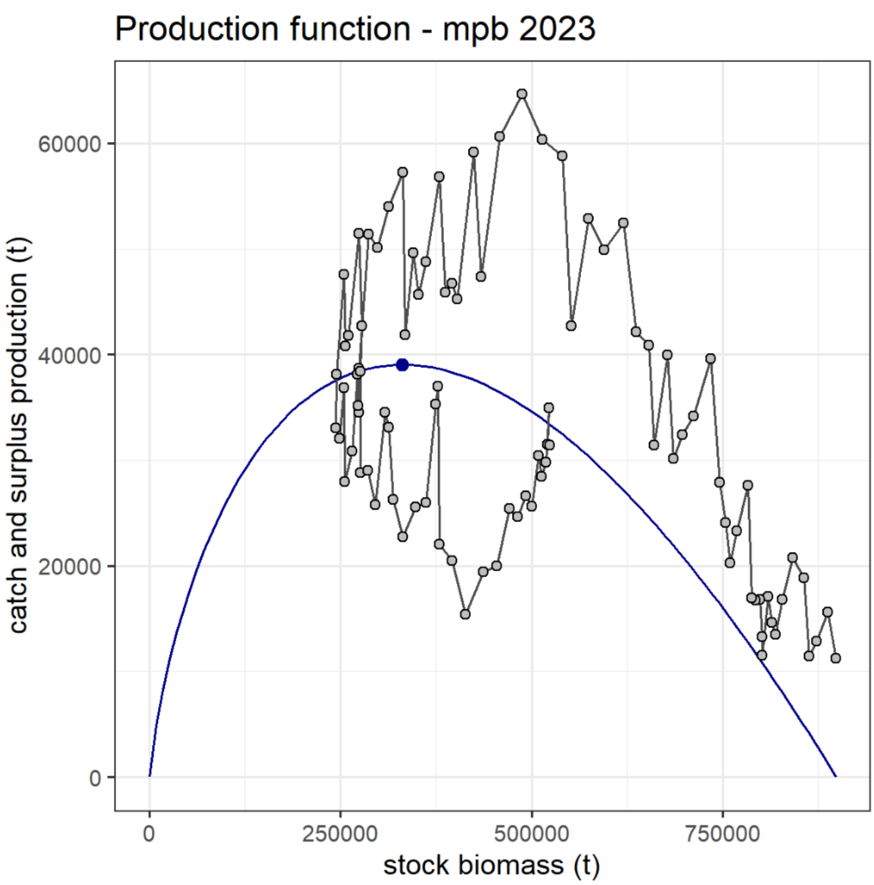

Figure 23. Estimated production function of the stock and catch and surplus production.

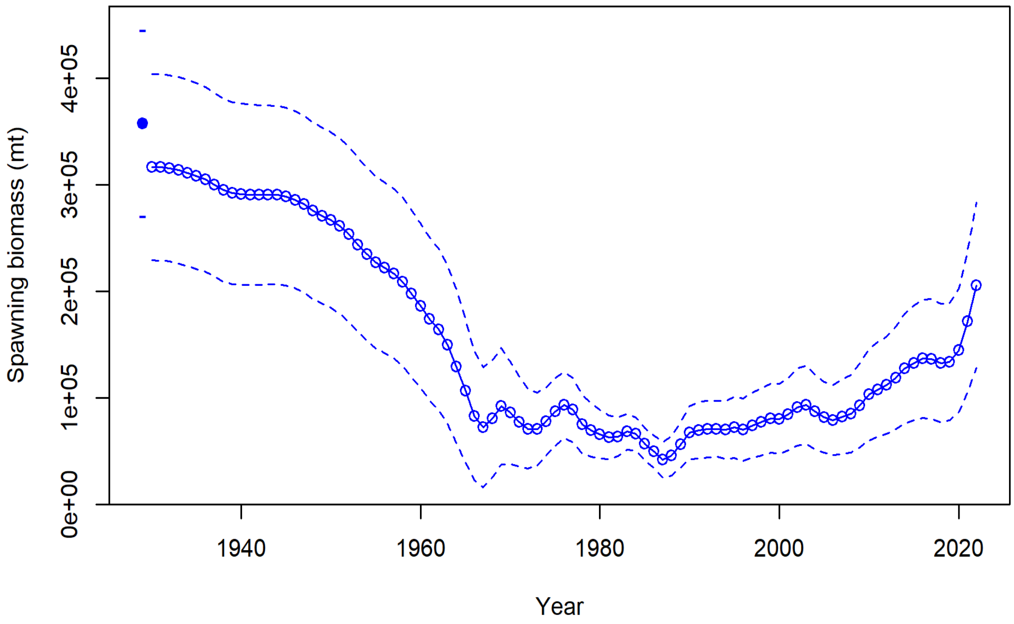

Figure 24. Stock Synthesis estimated time series of North Atlantic albacore spawning stock biomass and 95% confidence bounds.

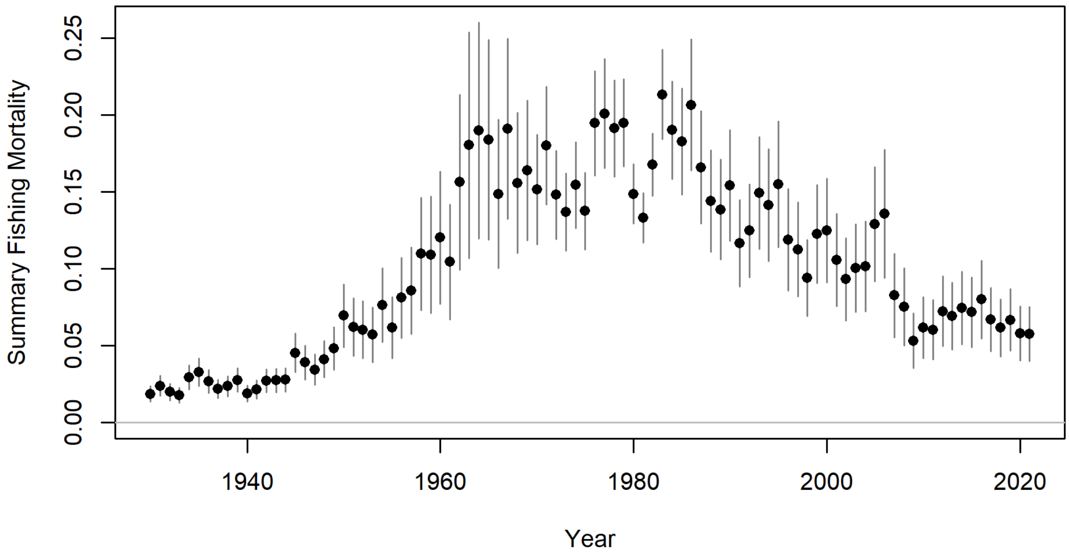

Figure 25. Stock Synthesis estimated time series of fishing mortality and 95% confidence intervals from the North Atlantic albacore.

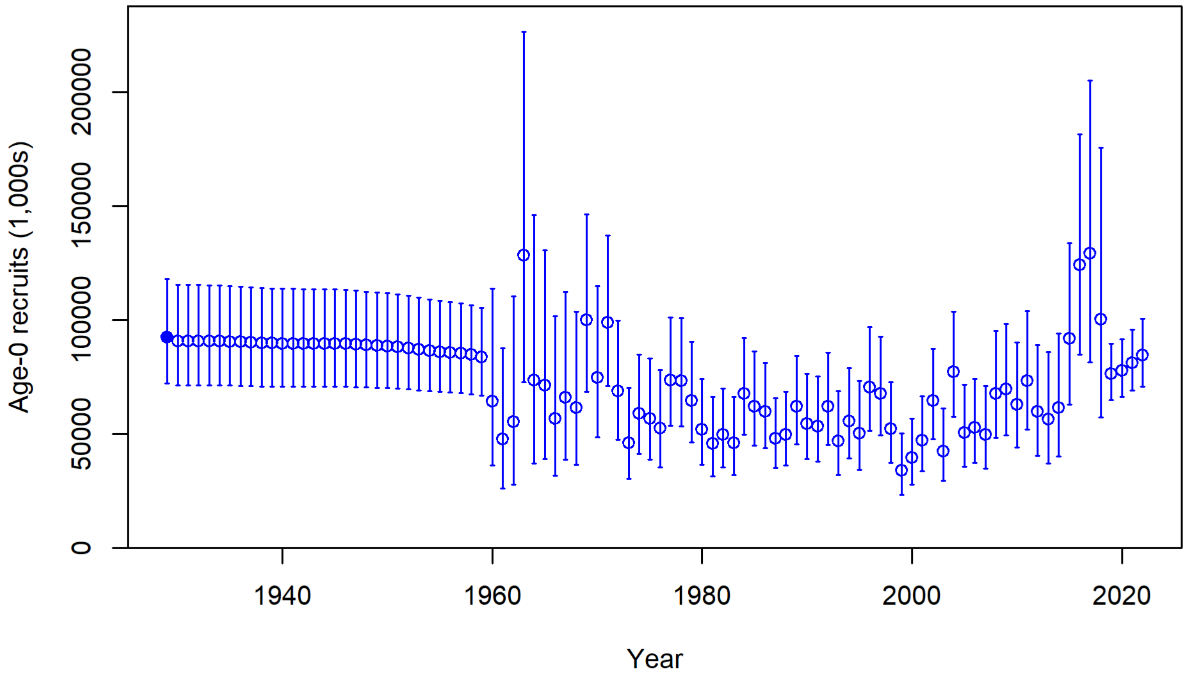

Figure 26. Stock Synthesis estimated time series of North Atlantic albacore recruitments including the 95% confidence bounds.

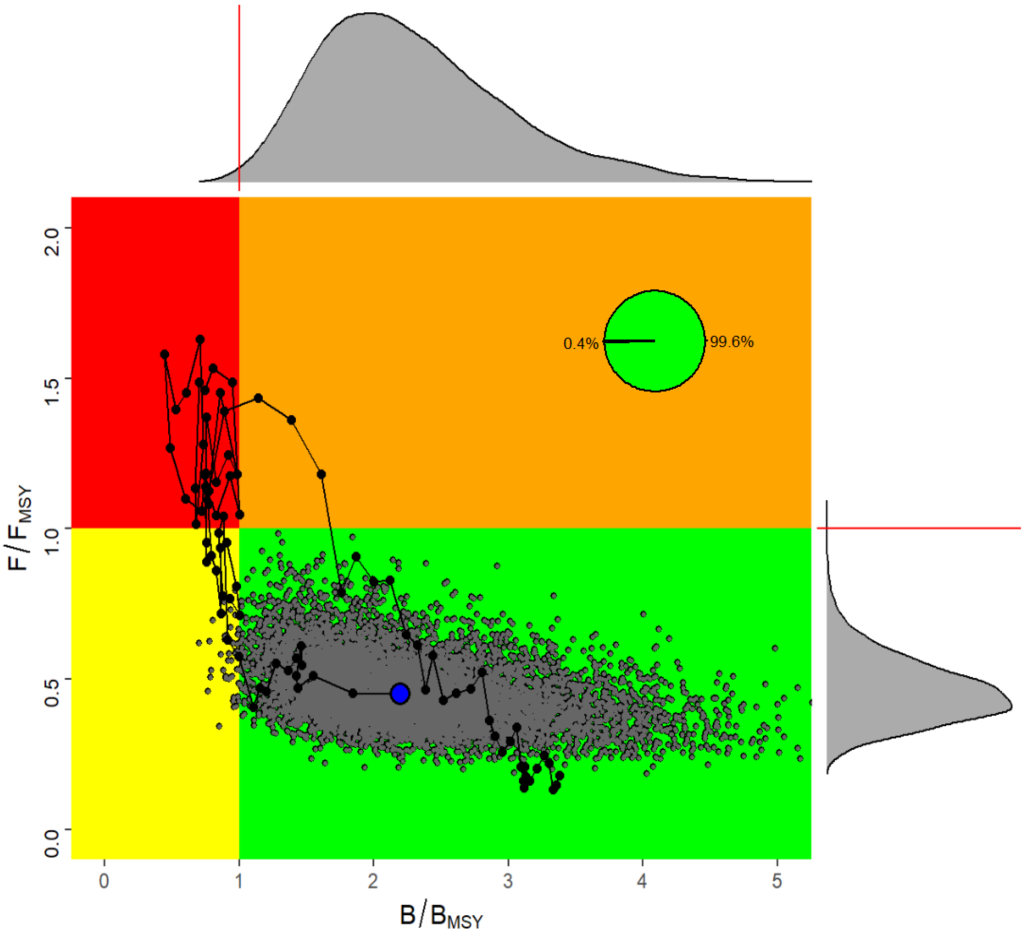

Figure 27. The trajectory and stock status estimated with the MVLN method (Winker *et al.*, 2020) with 10,000 iterations. The blue point indicates the estimated median of the stock status in 2021. 99.6% of the iterations fall in the green quadrant and 0.4% in the yellow. The density plots are estimated in grey for F/F_{MSY} and B/B_{MSY}, including the marginal distributions for each parameter.

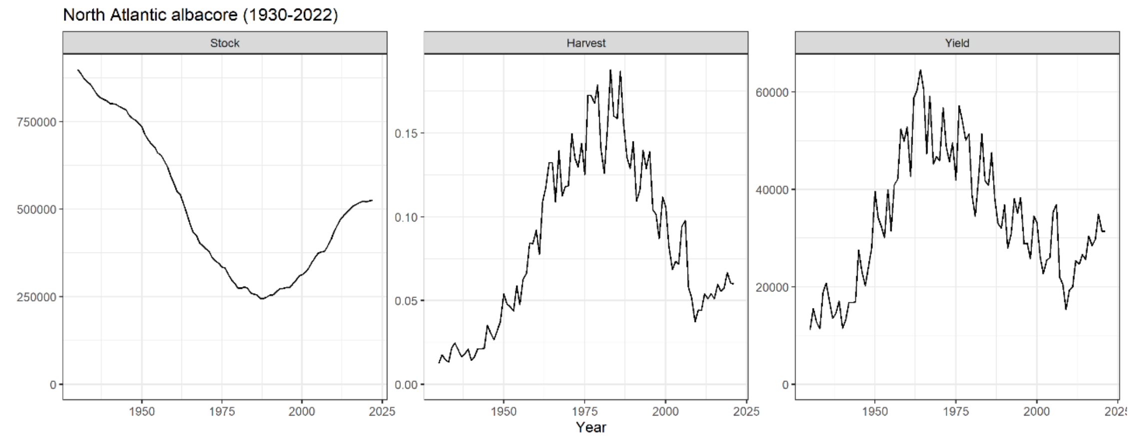

Figure 28. Results of deterministic fit to catch and CPUE with *mpb*.

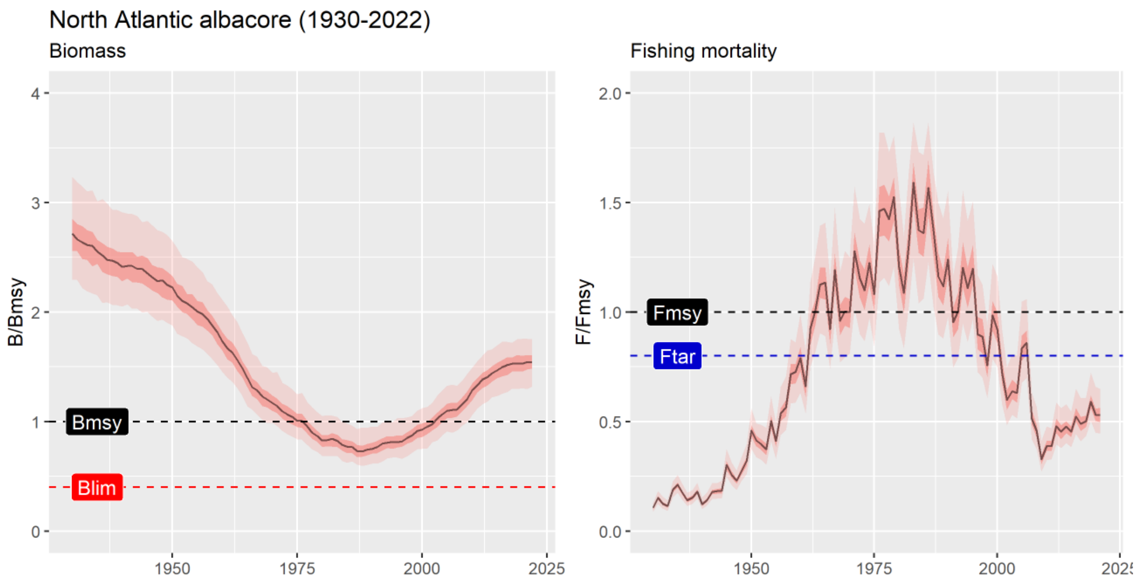

Figure 29. Relative biomass (B/B_{MSY}) and fishing mortality (F/F_{MSY}) estimated from the bootstrap fit to catch and CPUE with *mpb*. Ftar is the target fishing mortality ($0.8*F_{MSY}$).

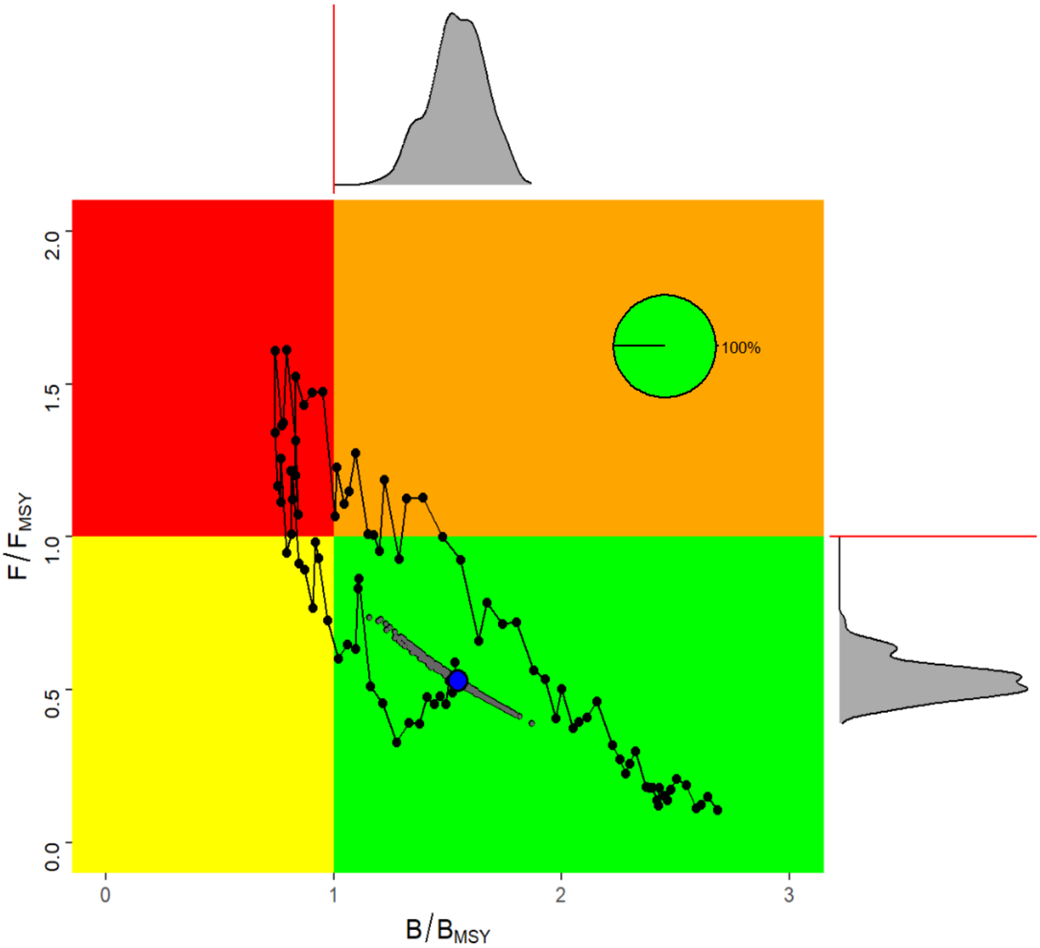

Figure 30. Estimated trajectory of relative biomass and fishing mortality and terminal years bootstrapped estimates.

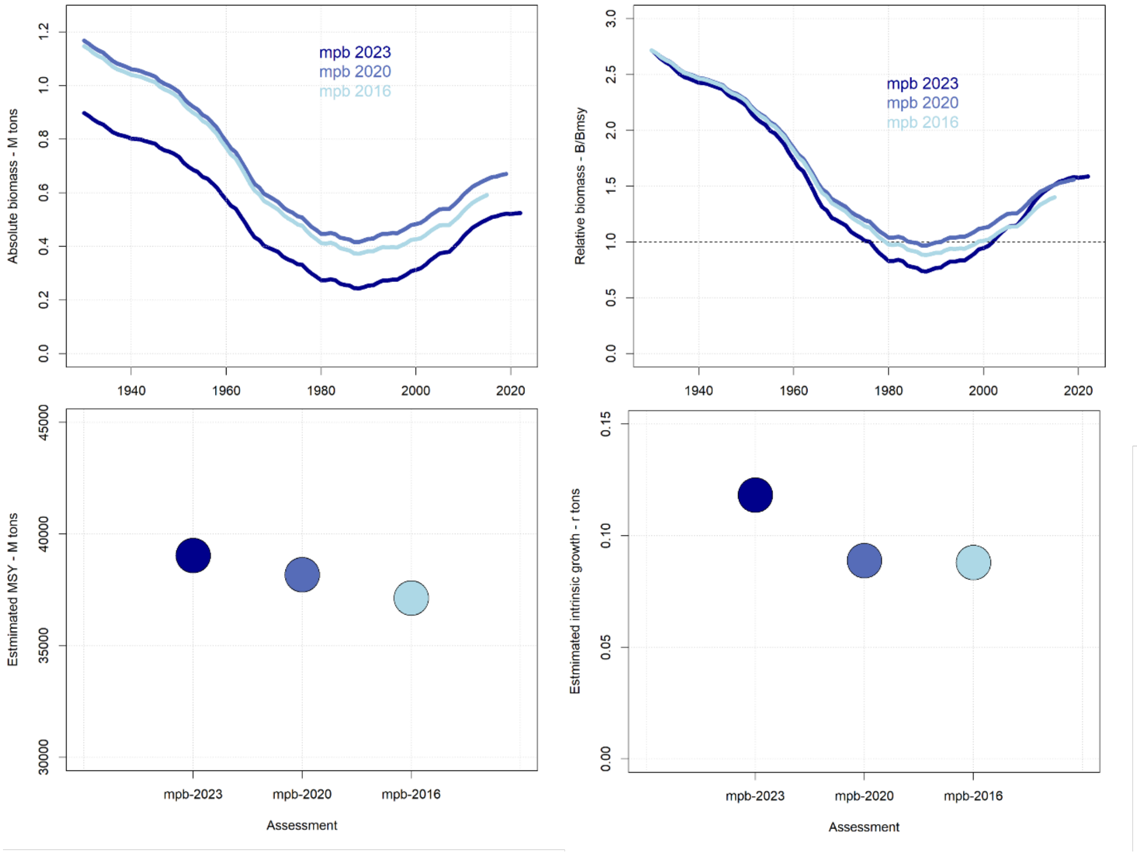

Figure 31. Comparison between the current and recent stock assessments using *mpb* (2016, 2020 and 2023).

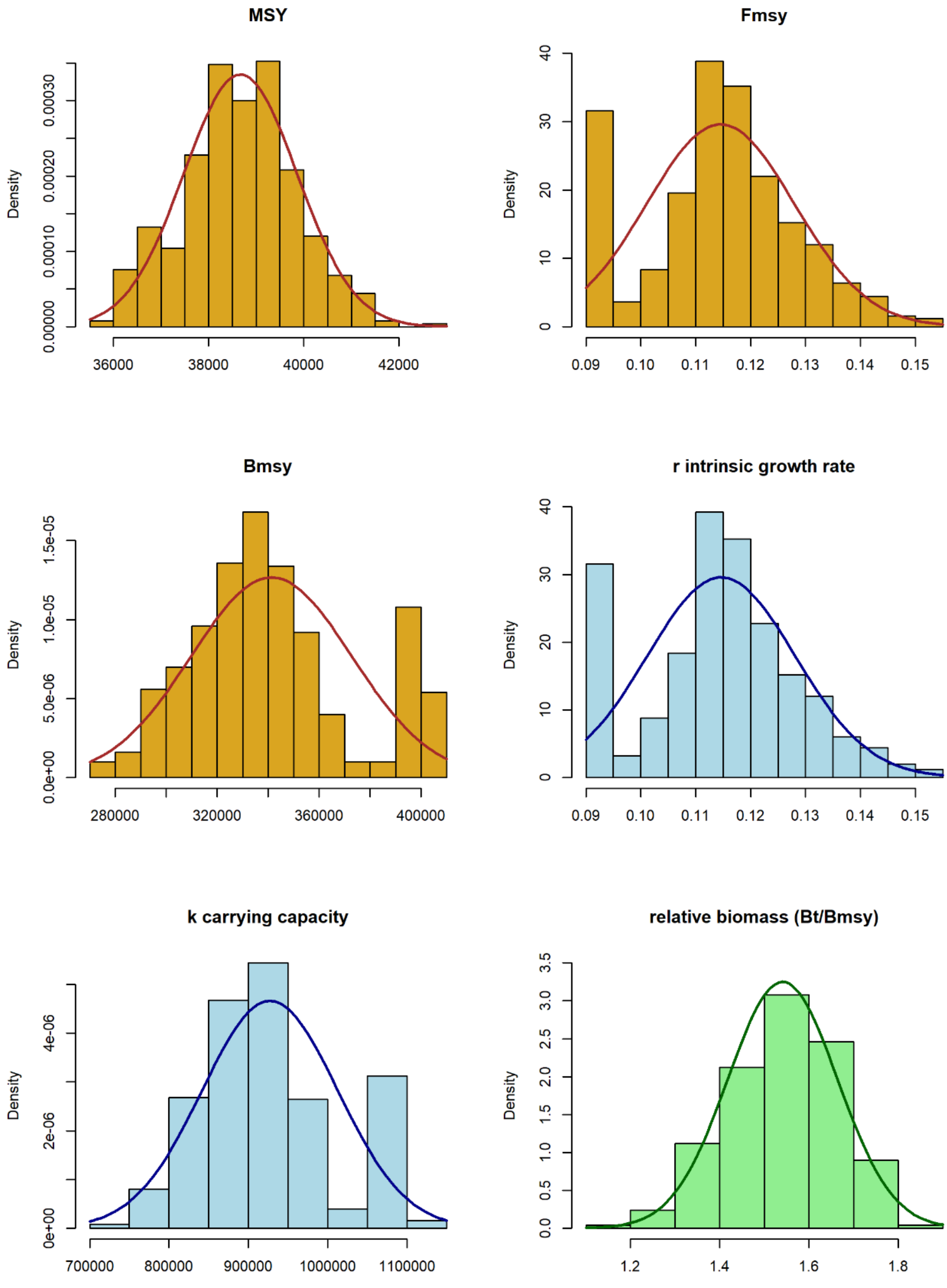

Figure 32. Probabilistic estimates of model parameters and reference points.

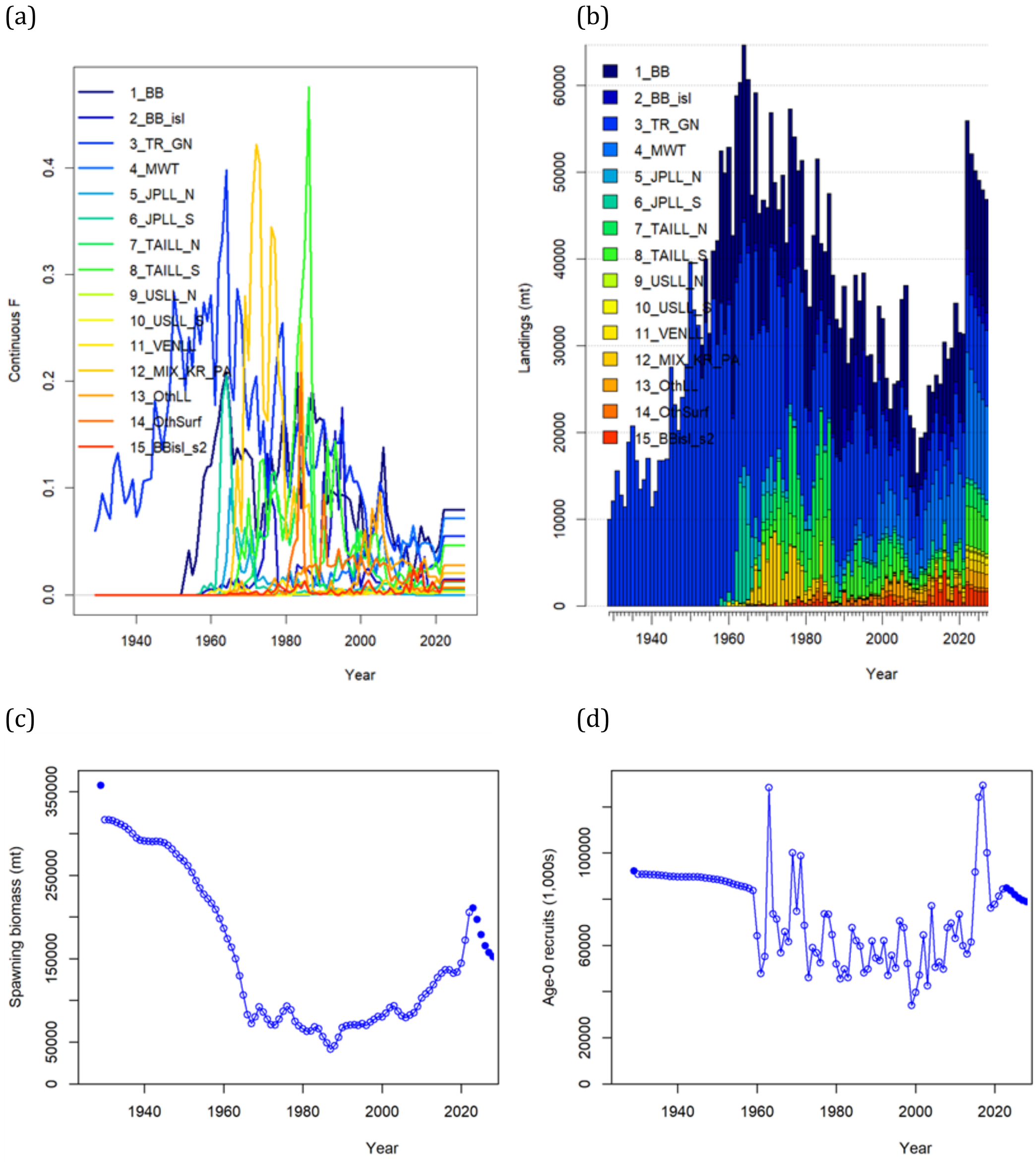

Figure 33. Stock Synthesis deterministic projections from 2022 to 2026 at constant 0.8*F_{MSY}. (a) fishing mortality by fleet, (b) catch by fleet, (c) spawning biomass, and (d) recruitment at age 0.

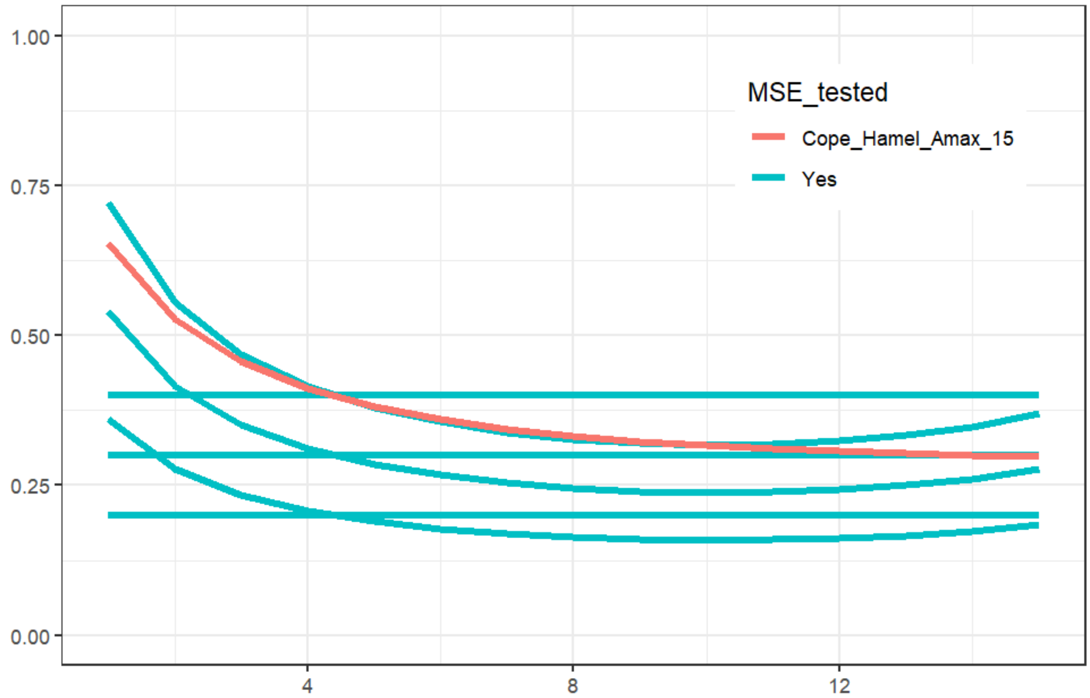

Figure 34. Natural mortality vector adopted during the Data Preparatory meeting (red line) and the values of natural mortality used in the MSE framework (blue lines).

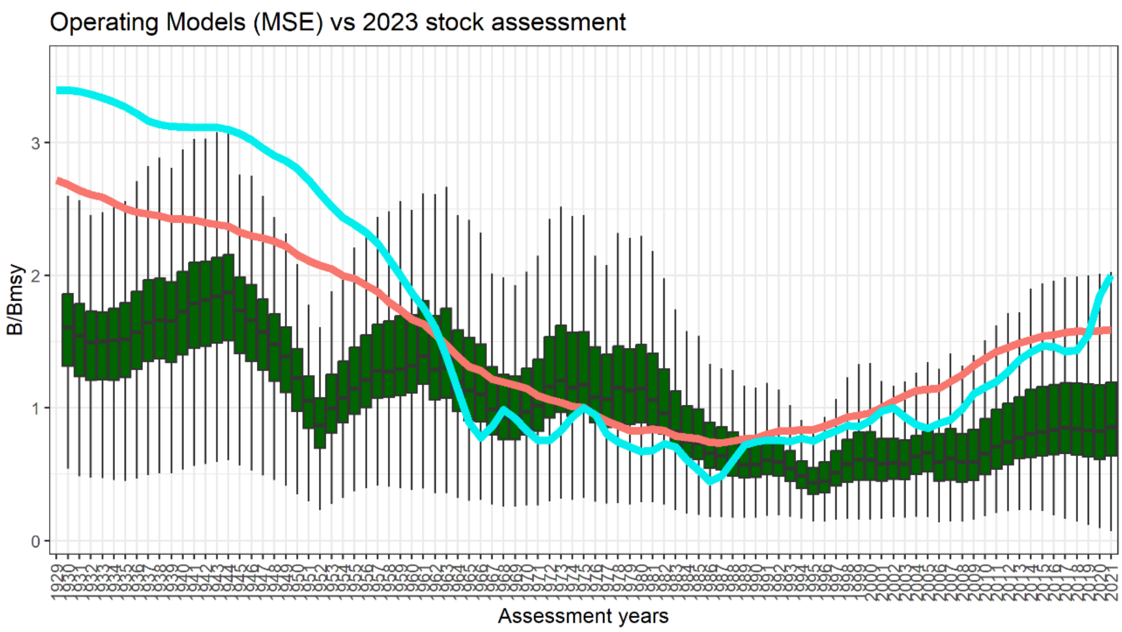

Figure 35. Relative biomass (B/B_{MSY}) estimated in the Oms of the MSE (green boxplot, boxes represent 50% CI and whiskers 95% CI) and estimates from the 2023 Stock Assessment (red is *mpb* and light blue is SS3).

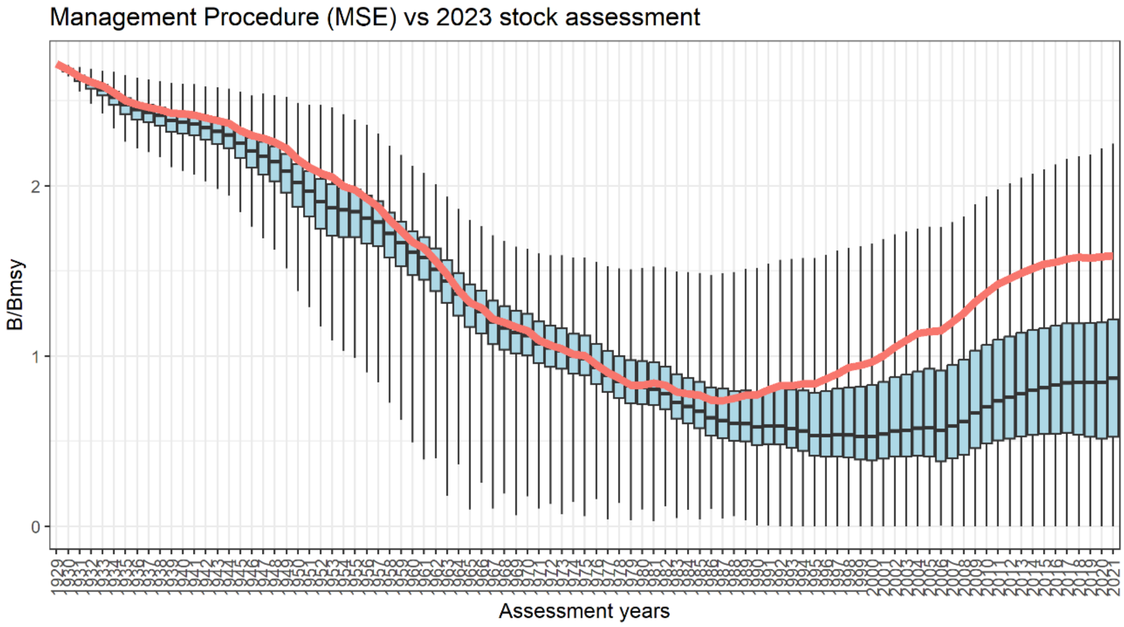

Figure 36. Relative biomass (B/B_{MSY}) estimated in the MPs of the MSE (blue boxplot, boxes represent 50% CI and whiskers 95% CI) and estimates from the 2023 *mpb* stock assessment (red).

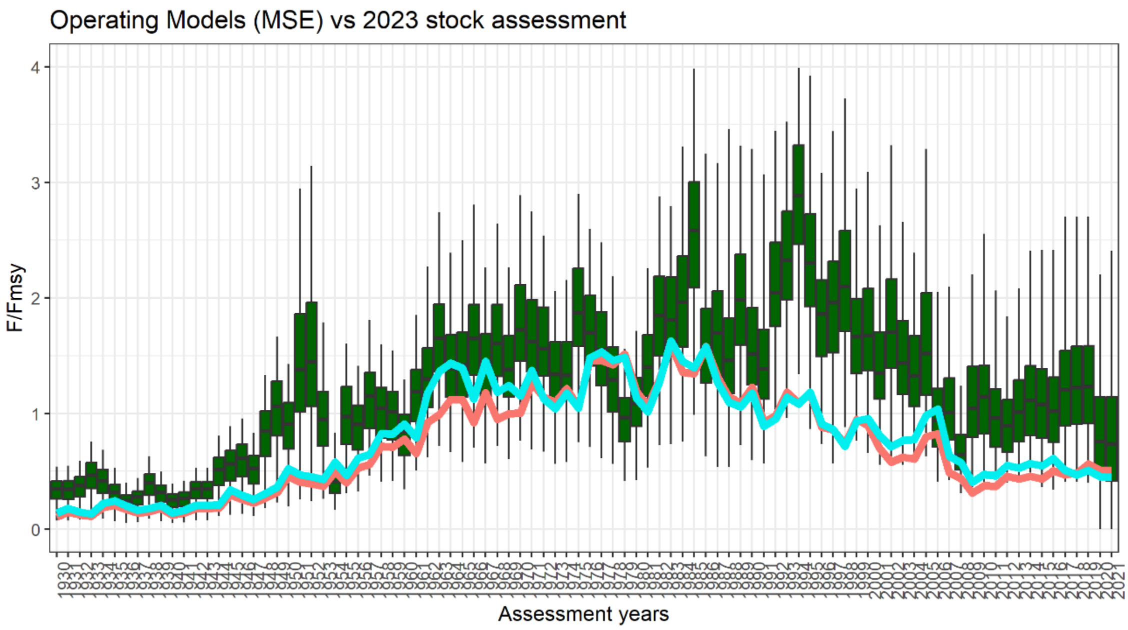

Figure 37. Relative fishing mortality (F/F_{MSY}) estimated in the Oms of the MSE (blue boxplot, boxes represent 50% CI and whiskers 95% CI) and estimates from the 2023 stock assessment (red is *mpb* and light blue is SS3).

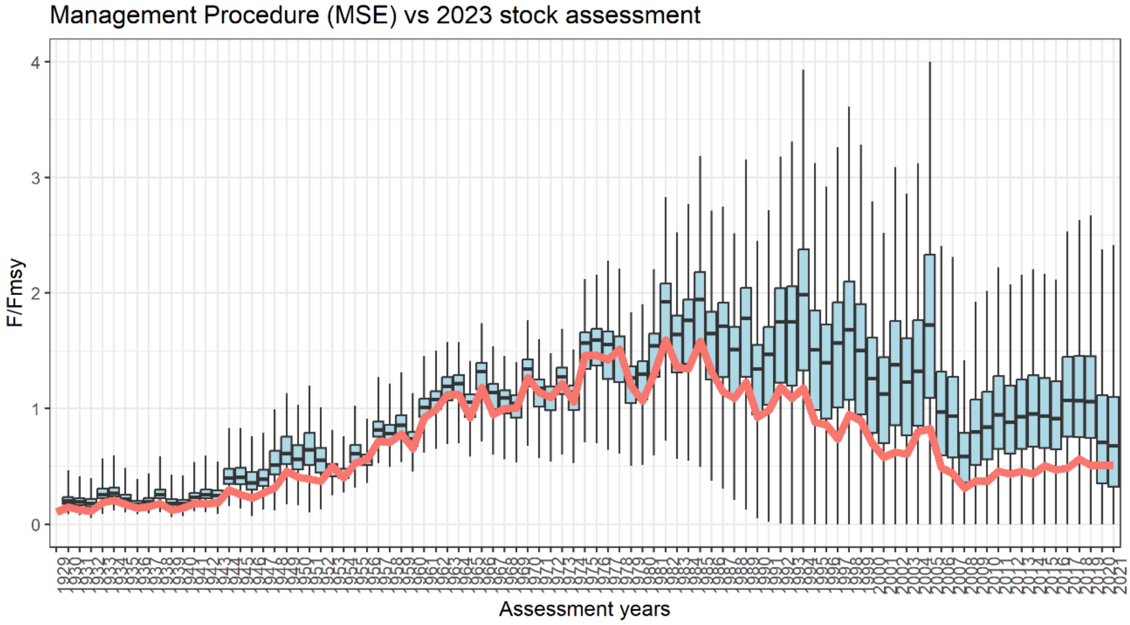

Figure 38. Relative fishing mortality (F/Fmsy) estimated in the MPs of the MSE (green boxplot, boxes represent 50% CI and whiskers 95% CI) and estimates from the 2023 *mpb* stock assessment (red).

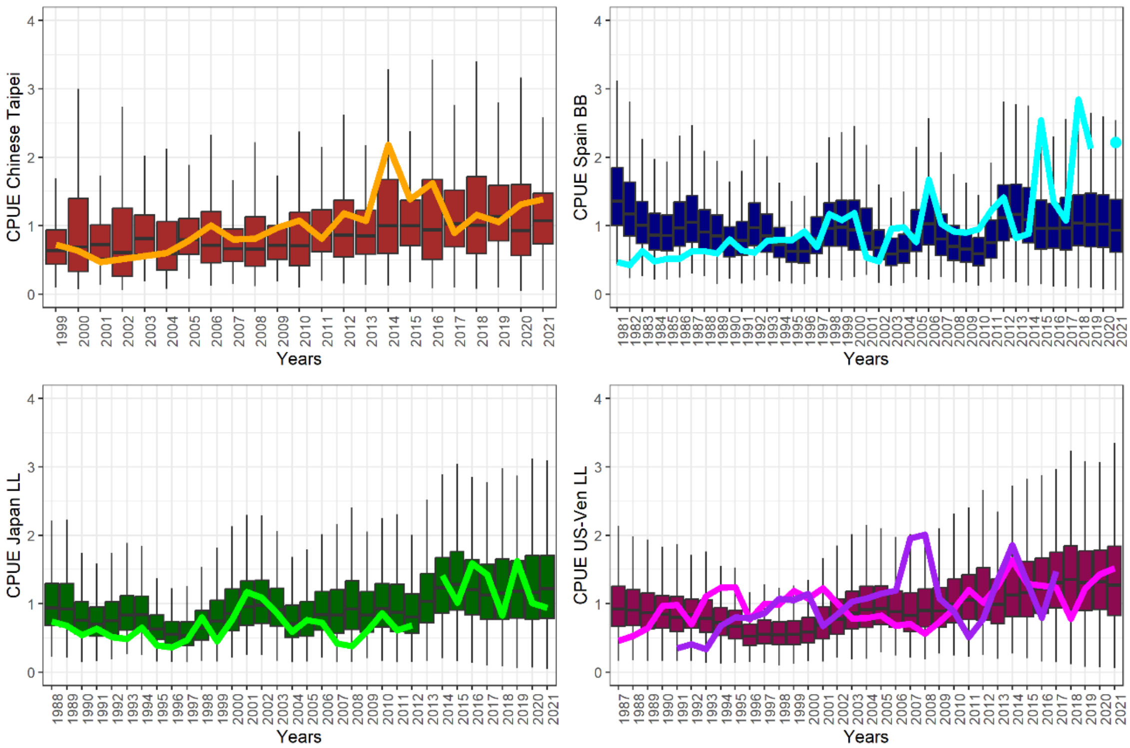

Figure 39. CPUE trajectories simulated in the MSE and standardized CPUEs available for the 2023 stock assessment.

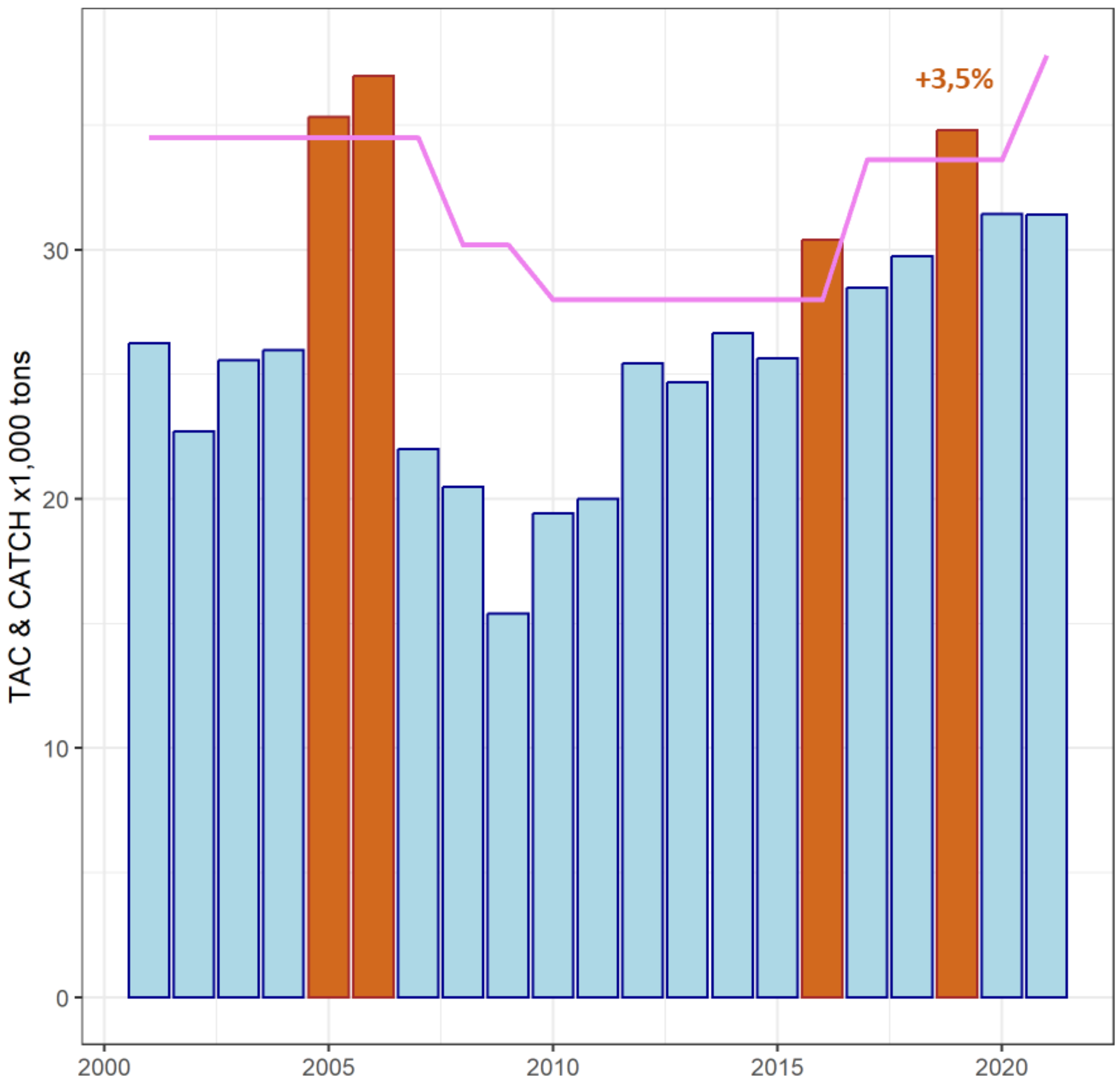

Figure 40. N-ALB reported catch (Task 1NC, bars) and TAC (solid line). Orange bars indicate years when the catch exceeded the TAC. Note that TAC established with the N-ALB harvest control rule or the MP started in 2018.

Appendix 1

Agenda

1. Opening, adoption of agenda and meeting arrangements
2. Summary of input data for stock assessment and MP iteration.
   - 2.1. Biology
   - 2.2. Catches
   - 2.3. Size
   - 2.4. Indices of abundance
   - 2.5. Fleet structure
3. Methods and Model Settings
   - 3.1. Stock Synthesis
   - 3.2. Surplus Production models
4. Model diagnostics
   - 4.1. Stock Synthesis
   - 4.2. Surplus Production models
5. Model results
   - 5.1. Stock Synthesis
   - 5.2. Surplus Production models
   - 5.3. Synthesis of assessment results
6. Stock projections
7. Iteration of the management procedure
8. Evaluation of Exceptional Circumstances
9. Discussion on the new MSE: steps and timeline
10. Responses to the Commission
    - 10.1. Rec. 21-04: effects of underreporting
11. Recommendations
    - 11.1. Research and statistics
    - 11.2. Management
12. Albacore Research Program: update on ongoing activities and future planning
    - 12.1. Reproductive biology north-ALB and south-ALB
    - 12.2. Electronic tagging
13. Other matters
14. Adoption of the report and closure

Appendix 2

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Appendix 3

List of Papers and Presentations

DocRef	Title	Authors
SCRS/2023/100	Application of Management Procedure (Recommendation 21-04) for North Atlantic albacore	Merino G., Urtizberea, A., Arrizabalaga, H., Moron G., and Santiago, J.
SCRS/2023/101	Robustness tests for North Atlantic albacore MSE, including new options for underreporting and natural mortality	Merino G., Urtizberea A., Arrizabalaga H., Artetxe-Arrate I., Luque P.L., Moron G., and Santiago J.
SCRS/2023/107	Preliminary stock synthesis assessment model for Northern Atlantic Albacore	Urtizberea A., Merino G., Kimoto A., Ortiz M., Lauretta M., Schirripa M., Calay S., Brown C., Ortiz de Zarate V., and Arrizabalaga H.
SCRS/2023/117	*Thunnus alalunga* (Bonaterre 1788) reproductive biology study in South Atlantic.	Travassos P., Araujo M.L.G, Rego M., Evencio J., Cardoso L.G., Parker D., Domingo A., Su N.J., and Santana F.
SCRS/2023/118	Spatial distribution of albacore tuna by size caught in the Chinese Taipei longline fishery in the north Atlantic Ocean	Su N-J., Huang W.H.
SCRS/P/2023/075	Updated Indicators of Exceptional Circumstances	Merino G., Arrizabalaga, H, Urtizberea A., Moron G., and Santiago J.
SCRS/P/2023/079	North Atlantic Albacore Stock Assessment, 25-29 June 2023 Status of Albacore Fishery at the Egyptian Mediterranean Coast.	Saber M.

Appendix 4

SCRS Documents Abstracts as provided by the authors

SCRS/2023/100. This document presents a preliminary stock assessment for North Atlantic albacore tuna (*Thunnus alalunga*) using the biomass production model *mpb* (Kell, 2016). The assessment integrates nominal catch data with abundance indices of five fisheries. The assessment model covers the period 1930-2021 and represents an update and revision of the previous assessments of 2016 and 2020. The assessment assumes that North Atlantic albacore constitutes a single stock distributed across the North Atlantic area. Standardized CPUE series from the main longline fleets (China Taipei, Japan, US and Venezuela) and the bait boat (Spain) are included in the model. For this assessment, we include an overview of the data, a diagnostic analysis of the model fit including analyses of residuals, likelihood exploration, retrospective analyses and an evaluation of consistency with previous models. Also, we provide model results in a probabilistic way and calculate the recommended catch limits for the 2024-2026 management period following ICCAT's Recommendation 21-04. Our results indicate that North Atlantic albacore is not overfished and that overfishing is not occurring and the TAC set by the current management procedure for the period 2024-2026 would be 47,251 tons**.**

SCRS/2023/101. This document presents a series of analyses developed to evaluate the robustness of the Harvest Control Rule (HCR) adopted in Recommendation 21-04 to new natural mortality assumptions and underreporting levels not evaluated in the reference grid of Operating Models (OM) of the Management Strategy Evaluation framework developed for North Atlantic albacore. We do this to help identify and quantify the implications of potential Exceptional Circumstances that would result in suspending or modifying the application of the HCR. We reconditioned OMs with the newly adopted natural mortality at age vectors and re-evaluated the HCR under different levels of overcatch and underreporting during the projection period. Overall, our results suggest that the new natural mortality vectors would not result in not achieving the management objectives for the stock but that systematic increases of overcatch/underreporting of 10% or more would pose an immediate threat to the effectiveness of the HCR. The results shown throughout this document will be discussed in the next albacore stock assessment meeting (Madrid, 26-29th June 2023).

SCRS/2023/107. The North Atlantic albacore Management Strategy Evaluation (MSE) provided scientific support for the adoption of an interim harvest control rule by ICCAT in 2017. Within the new MSE process started for this stock one of the first tasks is to develop a new assessment model that can serve as a benchmark to monitor the status of the stock and as the basis to develop a new set of Operating Models. In this document, we show a preliminary configuration of Stock Synthesis based on the model developed using Multifan-CL in 2013 with some modifications based on the discussions and recommendations by the north Atlantic Albacore working group. The assessment model is annual, covers the period 1930-2021 and integrates nominal catch data, length composition data, abundance indices of eight fisheries and age composition data estimated from reading spines. In this document an overview of the data is shown as well as standard diagnostics to analyse the fits to index and length compositions, jitter of starting parameters, randomness tests of model residuals, retrospective, profiles of key estimated parameters, and hindcasting.

SCRS/2023/117. Information on reproduction biology for South Atlantic *Thunnus alalunga* is limited. The reproductive parameters used in the stock assessment refer to North Atlantic stock data. One hundred and sixty-seven individuals were analyzed to study the reproductive biology of fish caught by the longline fleet from Brazil and China Taipei. The range of FL was 81 - 125 cm. The histological criteria used to assess the maturity status indicate that reproductive activity occurred in 30.5.% of the mature individuals analyzed 13.3% of adults were in regressing phase. The range of the number of rings in the spine sections analyzed was 6 to 9 rings. The estimated L50 from pooled preterit data from individuals captured along the Brazilian coast was 102.3 cm FL for males and 96.3 cm for females. Batch fecundity ranged from 0.14 to 1.7 million oocytes. The results of this study reflect the period sampled, which was the spawning period of *T. alalunga* in the Southwest Atlantic Ocean.

SCRS/2023/118. Albacore tuna (*Thunnus alalunga*) are widely distributed in the Atlantic Ocean. This species is the main targeting for the Chinese Taipei longline fishery in the North Atlantic Ocean, with the fishing ground between 15°N to 40°N. The Chinese Taipei longline vessels were selected to collect size samples from 2018 to 2022 for analysis. The size of albacore tuna caught in this fishery ranged from 80 to 120 cm fork length (FL), with median values around 100 cm in FL. However, albacore tuna smaller than 100 cm FL were distributed in the Atlantic Ocean north than 30°N, whereas individuals larger than 100 cm FL were caught mainly in the North Atlantic Ocean south than 30°N. Results could provide better understanding regarding to the size structure and spatial distribution of albacore tuna in the North Atlantic Ocean.

SCRS/P/2023/075. Not provided by the authors.

SCRS/P/2023/079. Not provided by the authors.