Report of the 2023 ICCAT Blue Shark Stock Assessment Meeting

(17-21 July, hybrid/ Madrid, Spain)

The results, conclusions and recommendations contained in this Report only reflect the view of the Sharks Species Group. Therefore, these should be considered preliminary until the SCRS adopts them at its annual Plenary meeting and the Commission reviews them at its annual meeting. Accordingly, ICCAT reserves the right to comment on, to object to and/or to endorse this report, until it is finally adopted by the Commission.

1. Opening, adoption of agenda and meeting arrangements

The meeting was held in Madrid (Spain) between 17-21 July 2023. The Shark Species Group Rapporteur and meeting Chairman, Mr. Rodrigo Forselledo, opened the meeting and welcomed the participants (the Group). Mr. Camille Manel, ICCAT Executive Secretary, welcomed the participants and wished them success in their meeting. The Chair proceeded to review the agenda which was adopted without changes (**Appendix 1**).

The List of Participants is included in **Appendix 2**. The List of Documents presented at the meeting is attached as **Appendix 3**. Document and presentation summaries are included in **Appendix 4**. The following participants served as rapporteurs:

Section	*Rapporteur*
Item 1.	N.G. Taylor
Items 2.1-2.6	N.G. Taylor, M. Braccini
Item 3.1	B. Babcock, X. Zhang
Item 3.2	H. Bowlby, G. Cardoso, D. Courtney
Item 3.3	R. Sant'Ana, C. Fernández, M. Ortiz
Item 3.4	L. Kell
Item 4.1	B. Babcock, X. Zhang
Item 4.2	G. Cardoso, D. Courtney, J. Rice, H. Bowlby
Items 4.3-4.4	R. Sant'Ana, C. Fernández, A. Kimoto, H. Bowlby
Item 4.5	A. Kimoto, J. Rice
Item 5.	M. Ortiz, A. Kimoto
Item 6.	G. Díaz, R. Coelho, R. Forselledo
Item 7.	C. Brown, R. Forselledo
Item 8.	A. Domingo
Item 9.	J.C. Báez
Item 10.	N.G. Taylor

2. Summary of available data for assessment

2.1 Stock identity

The Chair reviewed the decisions made about stock structure during the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023). He reminded the Group that tagging data supported a small degree of mixing between the northern and southern stocks and genetic analysis supported a small degree of mixing between the northern and Mediterranean stocks. However, the Group agreed that the data were not sufficient to support assessing the northern and southern stocks as a mixed stock. For the 2023 stock assessment the Group agreed to leave the current stock designations in place. The 2023 stock assessment was conducted for the northern and southern stocks only.

2.2 Catches

The Secretariat presented the updated nominal catch series. The available data were posted on the meeting's Nextcloud for the participants' review along with a dashboard that allowed users to review and visualize the available data. The Secretariat also reviewed the three CPC revised catch series that were provided after the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023). The revisions were minor, and the catch series for input into the assessment remained nearly identical to those presented at the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023). The differences between the data series used in the modeling and the updated Task 1 catch data were less than 0.5%. Therefore, the catch data used for modeling were not updated to include these revisions. Catch data used in the modelling are presented in **Figure 1**. Catch data for the northern and southern stock by fleet are summarized in **Table 1** and **Table 2**, respectively.

The Group noted that Mediterranean Sea catch series remain incomplete. To permit future stock assessments, CPCs that catch/bycatch blue shark in the Mediterranean were encouraged to submit their data including historical data.

SCRS/2023/121 summarized the revision and update of the available detailed catch and size data per fleet up to 2021. Most of the data presented in the paper were those that had been approved during the Data Preparatory Meeting. It was pointed out that approximately 99% of the catches of blue shark come from longline gear. For the stock assessment purposes, longline fleets were grouped into 10 fleets for the northern stock and 11 for the southern stock. The so-called "Other" fleet designation included all catch data (including minor purse seine and gillnet) that are not included in the other major fleet designations.

Catch series for blue shark (*Prionace glauca*) include the reconstructed catch time series used in the 2015 stock assessment. The reconstructed catch time series are considered the best estimates of catch for the northern and southern stocks. Considerable differences between reported and reconstructed catches were noted for years prior to 2000 for the northern stock and prior to 2010 for the southern stock. After the years 2000 and 2010 for the northern and southern stocks, respectively, the reconstructed time series match the reported Task 1 time series reasonably well. For the assessment, the reconstructed time series were used up to 2013 and the reported Task 1 catch time series for all years afterward (2014-2021).

The Group inquired if catches estimated in the 2015 Blue Shark Stock Assessment Session (Anon., 2016) were included in the Task 1 data. In response it was noted that they are not included. However, the plan articulated by the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023) recommendations was to send the reconstructed catch series to the CPCs by the end of July 31st for their review and approval by September 1st, 2023. CPCs requiring more time can review and approve these data series later. Upon CPC approval (or if there is no response) these reconstructed series will subsequently be submitted for approval at the Subcommittee of Statistics for the inclusion in the official Task 1 data.

The Group inquired if reconstructed catch time series included changes made between northern and southern stocks by some CPCs. In response it was noted that where CPCs had provided updated time series in the catch, then they were included. It was also noted there was some degree of overlap between the observer data (i.e., historical data) and the revised CPC data (i.e., Task 2). To avoid duplication, the Group agreed that the revised CPC data had priority.

2.3 Indices of abundance

The Chair summarized the indices that were reviewed by the Group during the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023). None of the reviewed indices was rejected for use in the stock assessment. Plots of standardized indices of abundance are presented in **Figure 2**. Available Catch Per Unit Effort (CPUE) indices for the northern and southern blue shark stock are provided in **Table 3** and **Table 4**, respectively. During the Data Preparatory Meeting, the Group also reviewed a cluster analysis that provided a way to group indices into groups that represented different hypothesis about the trajectory of the stocks.

The Group inquired about the Japanese longline (1971-1993) early series and the historical U.S. research survey series (1957-2000) that were used in the 2015 assessment. These indices did not have to be updated and were not discussed at the Data Preparatory Meeting when the other CPUE series were presented.

2.4 Biology

The Chair summarized the biological information agreed-to during the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023). This included the information used in the 2015 Blue Shark Stock Assessment Session (Anon., 2016) and relevant updated information.

2.5 Length compositions

SCRS/2023/121 also reviewed the catch length composition time series. It was noted that in the 2015 assessment, length composition data were provided by the CPCs at the meeting. In the Data Preparatory Meeting, the Group agreed to use the historical data used in the 2015 assessment plus additional data provided by CPCs, noting that some CPCs undertook a full review of the size information provided. The paper provided a summary of the blue shark size data by source. The spatial distribution of the size data was noted and the number of size samples available by sex were also presented. Size data were provided to the modelers both by sex and aggregated. In order of priority: 1) CPCs that provided revisions were used as the main source of length composition data; 2) length composition data from observer data; then 3) Task 2 size data were used.

The variability in mean size by fleet was reviewed. It was noted that there was less variability in mean size by sex when this information was available.

2.6 Other relevant data

SCRS/2023/115 provided a summary of the results of modelling life-history priors for steepness and the intrinsic rate of growth. The Group inquired about the possible effects of density dependence on the estimates of productivity given that the stock was not considered to be depleted. In response, it was noted that the paper stated that blue shark stocks have been exposed to fishing for multiple decades and their biomasses are likely far from their unexploited levels so that the parameter estimates here should only be moderately, if at all, influenced by density dependence. Accordingly, the derived productivity should not be very different from the true intrinsic, or maximum, rate of increase.

The Group discussed the appropriateness of estimated steepness for blue shark from biological perspective, because the estimates appeared to be close to those of tuna and billfish species. It was suggested that research be conducted into the methodology and resultant parameter values.

SCRS/2023/116 obtained estimates of life history parameters and steepness from Fishlife. Fishlife combines the results of both Fishbase and the Ransom Myers legacy databases. The paper concluded that the Fishlife estimates of the intrinsic rate of growth and steepness were unrealistic.

The Group noted that apparently low steepness estimates determined using Fishlife should not be surprising. Fishlife estimates are more likely to produce productivity for a generic Carcharhinidae shark as opposed to blue sharks specifically, because Fishlife is a hierarchical method based on taxonomy. Once the Fishlife estimates were updated using published estimates from the Leslie Matrix, then the updated posterior provided more realistic results.

3. Methods and other data relevant to the assessment

3.1 Production models for continuity with 2015 assessment

SCRS/2023/126 used the software and inputs from the 2015 Blue Shark Stock Assessment Session (Anon., 2016), updating only the catch and CPUE data, and found that there were some differences in results between the legacy Bayesian Surplus Production (BSP and BSP2) software, the Just another Gibbs sampler (JAGS) code used in 2015, and Just Another Bayesian Biomass Assessment (JABBA) for both the North and South stocks.

The Group discussed these differences and concluded that the differences were probably not caused by the different algorithms, but rather by the differences in priors, weighting, and how process error is treated. In particular, the older software used a less informative prior for the unfished biomass K (uniform on log(K)), which cannot be reproduced exactly in JABBA. Most other model choices could be reproduced in JABBA.

The Group also discussed the impacts of process error in the legacy BSP and JABBA. On one hand, the inclusion of process error increases model flexibility to fit the data better. On the other hand, the inclusion of too much process error may result in the estimated stock status being disconnected with the data and deteriorate model prediction skills. The Group discussed the issues of data quality such as conflicting CPUE trends due to small sample size, limited temporal-spatial coverage and conflicts among indices.

The Group acknowledged the comprehensive work conducted with the legacy BSP software for this species over the years. However, JABBA is easier to learn and provides diagnostics and model evaluation techniques needed for modern assessments that are useable for other platforms like Stock Synthesis III (SS3). Thus, the Group agreed not to use the legacy BSP software in this or future assessments. Useful techniques that were available in older software, such as a continuous time version of the production model or additional prior distributions, could be added to JABBA in the future.

To further evaluate whether differences between the 2015 and 2023 Blue Shark Stock Assessments were caused by differences in model inputs or by the new data, a set of sensitivity analyses was conducted in JABBA. For the South, the results of the sensitivity analysis showed that there was the addition of the series of relative abundance presented by Japan in the 2015 Blue Shark Stock Assessment, which was not identified for use in 2023. This early index did not have a great impact on the response of the Bayesian models of surplus production adjusted. The contribution of the inclusion of this aggregated series resulted in an initial period that was a little less stable, however, throughout the series there was no distinction of the patterns already observed (**Figure 3**).

For the North, several sensitivity runs were evaluated. There were three sets of runs: a refers to Schaefer vs. Pella and the K prior with low process error; b refers to different start years and indices with estimated process error; and c refers to the post model pre data (PMPD) runs. Some runs used a prior for B/K in the first model year that was lognormal (median=1, sd=0.2). Two older indices, the Japanese longline early index, and US-Obs-Cru (Aires-da-Silva *et al*., 2008), which were not included in the base case, were included in some sensitivities. As in the 2015 Blue Shark Stock Assessment, the US-Obs-Cru series was only used through 1991, because from 1992 forward other indices included some of the same information. Some runs used a Schaefer model, with either the base case prior or a wider lognormal prior for K. Process error was either treated as fixed at a low value (SigmaR=0.01) or estimated as in the base case. Otherwise, the CPUE weighting, and priors were the same as the base case. All the sensitivities were consistent with each other, and with the base case, in finding that the population had decreased below B_{MSY} in the 1990s before recovering to around B_{MSY} in the mid-2000s (**Figure 4**).

To further diagnose the implications of the priors and the catch data for the assessment in the North, two PMPD diagnostic runs (as was done in the 2015 Blue Shark Stock Assessment) were presented in which the model was run with the same priors and catch data, but with no index data. This can be done in JABBA by inputting a single CPUE index, with one data point with a value of 1.0, and high fixed coefficient of variation (CV) and turning off posterior predictive checks in the JABBA fitting. The PMPD diagnostic runs found a decrease followed by an increase, indicating that this trend is largely driven by the large catches in the 1980s and decreasing catches in the late 1990s and early 2000s, in combination with the priors. However, the index data are needed to estimate the scale of the decrease and increase (**Figure 4**).

The trends were very similar in biomass and fishing mortality for all the variations in the model inputs for both north and south, so the group decided to use only the JABBA base case for status estimation and projections. The consistency of the sensitivities with the base cases implies that the results are robust to these modeling decisions. In future assessments, there will be no need to either start the assessment for the north in 1957 or to include either the Japan early or the US-Obs-Cru indices.

3.2 Length-based age-structured models: Stock Synthesis (SS)

SS3 from the North

SCRS/2023/128 presented the preliminary version of the stock assessment model using Stock Synthesis (SS) for blue shark in the North Atlantic, fit to data from 1971 to 2022. There were 10 fleets and 8 CPUE indices, where the length compositions from the indices were mirrored to the catches to partition removals by length. The two-sex model used the life history parameters agreed upon at the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023), with initial CVs set at 10% for minimum age and L_{INF} in the von Bertalanffy growth model. CVs on the CPUE series were determined using the 2-stage Francis method.

Steepness of the spawner-recruit function and natural mortality were the median values from the 6 life history estimators in SCRS/2023/115.

The initial model runs had issues with convergence and did not pass diagnostic analyses. Fits to the CPUE indices were relatively poor and the model could not resolve bimodalities or abrupt discontinuities in the length composition data, which affected estimation of selectivity parameters.

The main revisions to the SS model for the North influenced the catch compositions. The U.S. length composition data were replaced with those used in 2015. During the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023), it was agreed that for fleets for which size composition data were not available, assumptions on selectivity must be made. In that sense, the Venezuelan length composition data were assumed to be representative of the Belize fleet. Similarly, the data from Chinese Taipei were assumed to be representative of 'other' catches. Selectivity for most fleets was fixed as logistic. The analysts noted that with fewer parameters, there would be reduced variance in parameter estimates.

The input CPUE CVs and length composition sample sizes for preliminary models followed the method described in SCRS/2023/128 and citations therein. The weighting method applied for the final reference case model run followed the method described above for SS3 from the South. The average standard deviation of each log(CPUE) series is the maximum of the following three quantities: 1) the average value calculated from those originally reported in the CPUE standardization documents; 2) the root mean square error (RMSE) of the residuals resulting from a LOESS fit to the log(CPUE) series; and 3) the value of 0.2.

Analysts proposed additional changes to try to improve the models fit to the data. These included allowing greater variability in recruitment, by increasing SigmaR from 0.28 to 0.38, and replacing the fixed value for natural mortality with age-specific natural mortality calculated from the deterministic life history analyses (SCRS/2023/115).

Final estimates of instantaneous natural mortality rates (yr-1) used in the North Atlantic Stock Synthesis model were obtained with 6 life-history invariant methods used in the deterministic life tables (Pers. Communication Enric Cortés July 2023), as summarized below.

Age	*Female*	*Male*	*Average of female and male*
0	0.212	0.239	0.226
1	0.200	0.222	0.211
2	0.193	0.213	0.203
3	0.188	0.208	0.198
4	0.185	0.205	0.195
5	0.182	0.202	0.192
6	0.180	0.201	0.190
7	0.179	0.199	0.189
8	0.177	0.198	0.188
9	0.176	0.197	0.187
10	0.175	0.197	0.186
11	0.175	0.196	0.185
12	0.174	0.196	0.185
13	0.173	0.196	0.185
14	0.173	0.195	0.184
15	0.173	0.195	0.184
16	0.172	0.195	0.184
17	0.172	0.195	0.183
18	0.172	0.195	0.183
19	0.171	0.195	0.183
20	0.171	0.194	0.183
21	0.171	0.194	0.183
22	0.171	0.194	0.183
23	0.171	0.194	0.182
24	0.171	0.194	0.182
25	0.170	0.194	0.182
26	0.170	0.194	0.182

Additionally, the proposal was to use the same age-specific values for both sexes prior to age 5 and then sex-specific mortality rates for older ages. All changes implemented to the SS model for the North were done sequentially.

A jitter analysis (10 iterations) was done for each sequential change in the model to help evaluate model behavior (**Figure 5**). In general, the jitters converged to the same likelihood as the model and had the same fit, except case 3 which was removed from consideration. The new base case formulation for SS in the North incorporated the updated CPUE CVs, the deterministic life history parameter values, the age-specific natural mortality series and higher SigmaR described above. This formulation passed the jitter (30 iterations), so the Group reviewed model diagnostics.

The Group discussed the likelihood profile plots of log R0 (not shown). It was noted that the length data, particularly from EU-Spain, are the most influential in the fit and thus the scale of abundance in the fitted model. The likelihood profiles indicated some conflict among the CPUE indices and the length composition, where log R0 might converge at a lower value if Spanish data were downweighed. However, the Group decided that the likelihood profiles are not necessarily a diagnostic for model acceptance or rejection, but rather a diagnostic used to explore how different information interacts in the model.

Fits to the indices time series for North Atlantic blue shark Stock Synthesis model reference case are shown in **Figure 6**. Fits to the aggregated length time series for North blue shark Stock Synthesis model reference case are shown in **Figure 7**. The residuals for the majority of CPUE indices were not randomly distributed, which is a consequence of the conflict between these indices and the information in the length compositions. However, the joint residuals (**Figure 8**) were centered on zero and there was no pervasive retrospective pattern in a 5-year peel. The analysts noted that relative to the base case in SCRS/2023/128, this model is much more stable. The final stock synthesis parameter values are provided in **Table 5**.

The Group discussed the decreasing trend in recruitment deviations plotted from 100,000 draws obtained with the Multivariate Log Normal (MVLN) distribution (**Figure 9** and Section 4 below) relative to the predicted increase in time series of spawning output (spawning stock fecundity (SSF) see Section 4) since 2010. For a productive species, it may be difficult to detect a response in recruitment following an increase or decrease in spawning output. Future work could explore the trade-off between selectivity and recruitment variability in the SS model.

It was noted that the fixed logistic selectivity for Portuguese size data was quite influential in the model fit. These data are strongly bimodal due to effort being concentrated in areas with notably different size distributions of blue shark. It was recommended to split the CPUE index and length composition into two components for future assessments.

There was discussion about the increase in SigmaR from 0.28 to 0.38. The analysts clarified that the current fixed value (0.38) is obtained iteratively based on the value estimated in the model and corresponds well to an International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC) assessment for blue shark using 0.4. While the value is smaller than what is being used in this assessment for the South (0.5), other biological assumptions are different so it is difficult to determine if they would be directly comparable.

The agreed reference case of the Stock Synthesis for the North Atlantic showed stability in the log-likelihood with different starting values (**Figure 5**). The final model gradient was lower than a target of 0.0001, and considered acceptable for model convergence, particularly since the solution was stable across different starting parameter values. A jitter analysis of the final reference case model indicated that all 100 jittered model runs converged, with no model runs resulting in a lower total negative likelihood estimate value relative to the base run (163.87 likelihood units), and few model runs resulting in larger total negative likelihood values (**Figure 5**).

Consequently, the Group noted that the jittered model was robust to the initial values of the parameters and gave no evidence that the model converged to local minimum of the objective function instead of the global minimum. The model showed generally acceptable fits to the indices (**Figure 6**) and to the length composition for all fishing fleets (**Figure 7**). The joint residuals plot was randomly distributed for the length fits (RMSE = 8.9%) as well for the indices with no apparent pattern (RMSE = 49.4%) (**Figure 8**). Estimated deviations from the stock-recruitment curve (i.e., recruitment deviates) indicated high variability in year-to-year recruitment (**Figure 9**), with decreasing trends in deviations towards the end of the time series.

Four out of six length compositions and three out of eight index residuals passed the runs test (**Figure 10**), as shown below (red highlight indicates runs test p value < 0.05).

Blue shark North Atlantic Stock Synthesis (runs test values)

	Index (S1-S8) and fleet (F1-F10)	Runs.p	Test	Sigma3.lo	Sigma3.hi	Type
1	S1_ESP-LL-N	0.012	Failed	-0.19185	0.191849	CPUE
2	S2_JP-LL-N	0	Failed	-0.53304	0.533039	CPUE
3	S3_CTP-LL-N	0.272	Passed	-0.71705	0.71705	CPUE
4	S4_US-Obs-E	0.011	Failed	-0.93773	0.937733	CPUE
5	S5_US-Obs-L	0.358	Passed	-0.61067	0.610672	CPUE
6	S6_VEN-LL	0	Failed	-1.9459	1.945901	CPUE
7	S7_POR-LL-N	0.017	Failed	-0.30599	0.305995	CPUE
8	S8_MOR-LL	0.728	Passed	-0.85162	0.851624	CPUE
9	F1_EU-ESP	0.292	Passed	-0.11964	0.119641	LEN
10	F2_JPN	0.042	Failed	-0.16278	0.162777	LEN
11	F3_CTP	0.01	Failed	-0.1666	0.166595	LEN
12	F4_USA	0.063	Passed	-0.09921	0.099213	LEN
13	F5_VEN	0.11	Passed	-0.25229	0.252295	LEN
14	F7_CPR	NA	Excluded	NA	NA	LEN
15	F10_EU-POR	0.552	Passed	-0.31647	0.316472	LEN

A retrospective analysis deleting up to five years of CPUE data starting from the final assessment year resulted in Mohn's rho values estimated for stock fecundity (-0.06) and F/F_{MSY} (0.15) fell within the acceptable range of -0.15 and 0.20 (Hurtado-Ferro *et al.*, 2014; Carvalho *et al.*, 2017) (**Figure 10**). The retrospective analysis did not show any significant departure from the previously estimated values for stock fecundity and F/F_{MSY} (**Figure 11**).

Hindcasting cross-validation with the same range of years deleted from the CPUE series and predicting the deleted CPUE values 1-year ahead resulted in four out of six indices and two out of five length compositions with mean absolute scaled error (MASE) values lower than 1, and two out of five presented MASE values near 1 (**Figure 12**), as shown below (red highlighting identifies hindcast MASE values greater than one; indicating that a 1-year ahead prediction based on a naïve random-walk was more accurate than one coming from the model for those CPUE series).

Blue shark North Atlantic Stock Synthesis (hindcast MASE values)

	Index (S1-S8) and fleet (F1-F10)	MASE	N.Eval	Type
1	S1_ESP-LL-N	2.285448	5	CPUE
2	S2_JP-LL-N	0.731159	5	CPUE
3	S3_CTP-LL-N	0.8464	5	CPUE
4	S4_US-Obs-E	NA	0	CPUE
5	S5_US-Obs-L	0.734588	5	CPUE
6	S6_VEN-LL	NA	0	CPUE
7	S7_POR-LL-N	4.896361	5	CPUE
8	S8_MOR-LL	0.840892	5	CPUE
9	F1_EU-ESP	1.364499	5	LEN
10	F2_JPN	0.89983	4	LEN
11	F3_CTP	1.089446	2	LEN
12	F4_USA	NA	0	LEN
13	F5_VEN	NA	0	LEN
14	F7_CPR	2.905658	2	LEN
15	F10_EU-POR	0.81585	4	LEN

A list of model parameters is provided in **Table 5**, including estimated values and their associated asymptotic standard errors, initial parameter values, minimum and maximum values, priors if used, and whether the parameter was fixed or estimated.

Following from what was discussed and noted in the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023), a sensitivity analysis was conducted for the North stock with SS3 considering the tagging growth model and comparing the results with the vertebral growth model used for the base case. Due to time constraints during the 2023 Blue Shark Stock Assessment Meeting, the sensitivity analysis was conducted without estimating natural mortality values in line with the tagging growth parameters. For comparing both models, a revision of the sensitivity analysis with an update of natural mortality information should be considered in future work.

SS3 from the South

Document SCRS/2023/120 presented the preliminary version of the stock assessment model using Stock Synthesis for the blue shark (*Prionace glauca*) in the South Atlantic, including the initial model setup, fleet definitions, selectivity, and parameterizations. The document proposed a two-sex reference case model from 1971 to 2021 with eight-fleet running fitted to the length composition and four indices of abundance. The life-history parameters were sex-specific based on the data preparatory recommendations. Diagnostics for the proposed model configurations demonstrated fast and stable convergence, good retrospectives, and acceptable solutions across different starting values. An eight-model uncertainty grid was proposed considering two sets of growth parameters, two resulting M–at–age vectors, and four steepness values. Furthermore, a comprehensive set of model diagnostics were presented for the reference model and estimates of spawning stock biomass (SSB) and recruitment across the entire uncertainty grid.

After the presentation, the Group raised some concerns about the fits to the length composition and questioned fixing selectivity parameters. Modelers indicated that the model didn't converge if letting SS3 freely estimate all selectivity parameters.

The Group also pointed out that running hindcasting diagnostics with a seven or eight-year peel could result in different model prediction skills.

To address the concerns raised by the Group, the modelers proposed to update the initial case by changing the growth parameters and the M at age vector by sex to one single set of growth parameters and M at age vector for both males and females combined. Growth parameters for the South Atlantic blue shark were further discussed and the Group agreed to use Joung *et al.,* (2017) model. This study was based on the larger sample sizes, more comprehensive size range, and broader geographical coverage, the parameters used were Linf = 291.8 cm FL (transformed from TL), k= 0.13 yr^{-1}, and t_0=-1.29. Furthermore, the Group agreed to use the M-at-age vector from Table 3 in SCRS/2023/115. The Group also decided to use the median steepness value of 0.8 provided in SCRS/2023/115.

After presenting the updated model version and searching for improving the fits to the indices, the Group discussed the proposed time blocks for the BR&UY, JPN, and CH-TP indices, as well as changing the M at age parameters based on median M estimated in SCRS/2023/115. The later change was proposed due to an observation of unrealistic high natural mortality at age 0 (0.9). The new M at age vector was tested on the model, and no substantial changes were observed.

Modelers proposed a time block for three of the indices of abundance based on model diagnostics. The Group highlighted the need to determine if there was information that supported using time blocks on standardized CPUE series. National scientists from Brazil and Uruguay noted that for their fleets, blue shark catches have become economically important. In the case of Japan index, it was noted that the reporting ratio for blue shark and sharks in general (SCRS/2023/049) changed substantially from 2006 to 2007.

After the presentations of diagnostics (Runs test, joint residuals plots, mean absolute scaled error (MASE) estimations, retrospective analysis, and Akaike information criterion (AIC) values) for two scenarios: with a time block for BR&UY indices and for JPN indices. The results showed that using a time block for both indices (BR&UY and JPN) improved the fits of the model to the data.

The Group agreed on a reference case scenario using the last presented model configuration and time-block for BR&UY and JPN indices (BSH_S_ATL_R012). The Group inquired if the ChineseTaipei index also indicated a potential time block, national scientists indicated no major changes in the fishery has been observed, however as mentioned during the Data Preparatory meeting the valued of the index for the 2020 year shows a high peak in the series, attributed to increased catches of small sized sharks. The Group agreed not to include a time block for this index.

The Group agreed to the reference case. The reference case of the Stock Synthesis model shows stability in the log-likelihood with different starting values (**Figure 13**). Jitter diagnostic indicated that the model converged in a global minimum. The maximum gradient component of the model was 7.23827e-05 and the model had a positive definition hessian matrix.

The reference model showed a generally acceptable fit to the indices (**Figure 14**) and to the length composition for all fishing fleets (**Figure 15**). The residual patterns of the indices and the length fits were good overall. Estimated deviations from the stock-recruitment curve (i.e., recruitment deviates) indicated high variability in year-to-year recruitment (**Figure 16**), with negative deviations in the beginning of the time series and a random pattern after 1998 until the end of the time series. The joint residuals plot showed that residuals were randomly distributed for the length fits (RMSE = 8.6%) and showed a pattern with negative residuals in the beginning, positive in the middle and negative in the end of the time series for the fits to the indices (RMSE = 24.9%) (**Figure 17**). All eight length compositions and four out of six indices "passed" into the runs test (**Figure 18**). The Mohn's rho values estimated for SSB (-0.05) and F (0.13) fell within the acceptable range of -0.15 and 0.20 (Hurtado-Ferro *et al.*, 2014; Carvalho et al., 2017) (**Figure 19**). The retrospective analysis did not show any pathological patterns. Regarding the hindcasting, two out of four indices and four out of eight length compositions have MASE values lower than 1, and three out of eight presented MASE values near 1 (**Figure 20**).

Model parameters are provided in **Table 6.** These include estimated values and their associated asymptotic standard errors, initial parameter values, minimum and maximum values, priors if used, and whether the parameter was fixed or estimated.

The Group reviewed the likelihood profile for R0. The profile indicated that there were conflicting trends in the length composition and index data. These conflicts were not considered sufficient to reject the model's use. The plot of the likelihood profile is in **Figure 21**.

The estimated time series of SSB for the reference case indicated that stock steeply decreased from the late 1980s to the early 2000s, then remained decreasing but slowly until early 2010s (**Figure 22**). It presented a discrete increase until late 2010s and a new decrease until 2021 (**Figure 22**).

3.3 JABBA North

SCRS/2023/124 presented a summary of the preliminary fits of the Bayesian surplus production model JABBA for the North Atlantic blue shark stock. As agreed in the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023), the assessment period was 1971-2021. The JABBA runs were conducted with five different configurations of a Pella-Tomlinson biomass dynamic model; the five configurations corresponded to different priors on the parameters r and m. Two different data-weighting procedures were applied to the abundance indices (standardized CPUE series) used to fit the model, one of which was based directly on the method suggested by Courtney *et al.,* 2017, whereas the other one included an additional variance component for each abundance index series, estimated within the stock assessment in JABBA. Runs were conducted including all CPUE series accepted by the Data Preparatory Meeting (scenario "All"). In addition, four other scenarios corresponding to the different groupings of CPUEs indicated by the Data Preparatory Meeting were also evaluated. In all, this resulted in 5 x 2 x 5 = 50 JABBA runs. The document presented detailed results for the scenario "All", and also provided a comparison of results among all 50 runs. The scenario "All", as well as most of the other JABBA runs conducted in the document, estimated that the harvest rate has been below target (H_{MSY}) in the most recent years and that the stock is currently around B_{MSY}.

The Group acknowledged and thanked the authors for the comprehensive work done in preparation for the assessment meeting. The Group commented with regards to the alternative weighting options, and discussed options with or without the extra parameter in the JABBA model for variance associated with each index. The modelers indicated that the additional parameter will allow the model to improve fitting to each index if it statistically improves the overall likelihood.

The Group asked about the prior for carrying capacity K. The modelers indicated that with no additional information, it was decided to use general guidelines with a prior estimated as 8* the maximum historic catch (1971-2021) (443864t) with a CV of 100%. The posterior of K estimated by the model has a smaller variance relative to the initial prior, indicating that there is information in the data that allowed the model to estimate K.

The Group also commented on the overall concept of index weighting, noting that during the data preparatory meeting, it was recommended to follow the Working Group on Stock Assessment Methods (WGSAM) to assume a fixed minimum CV for all indices, and if the estimated standardization CPUE CV was higher than 0.2 to use that value. Modelers indicated that a scenario using input CV was run, and an alternative scenario using a weighting scheme similar to the stock synthesis internal reweighting was also run, and an additional scenario allow the model to estimate an additional index variance parameter. Overall, the preliminary results indicated that major differences in model results are associated with the CPUE series, more clearly shown when comparing indices from target vs non-target fisheries.

The Group inquired about the initial B1971/K prior. The modeler clarified that this prior was chosen assuming that some fishing exploitation was already ongoing in 1971, but with no additional or auxiliary information, it was decided to use a Beta prior with mean of 0.7 and cv=0.2.

Document SCRS/2023/127 presented a summary of the preliminary fits of the Bayesian surplus production model JABBA for the South Atlantic blue shark stock. The distinct scenarios were based on a life history parameters, steepness and model weighting. The scenarios based on a more conservative values of steepness (0.5) had shown more pessimistic than others.

The Group acknowledged and thanked the contributors for the comprehensive work done in preparation for the assessment meeting.

3.4 Other methods

SCRS/2023/122 presented work conducted in response to the Recommendation in 2021 that the shark working group should *"*Consider, together with the WGSAM, alternative stock assessment methods (as per Kell, 2021b, other SCRS papers, and the fisheries literature)". The paper details a blue shark case study based on the presentation given at the 2022 ICCAT Intersessional Meeting of the Sharks Species Group (Online, 16-18 May 2022) and WGSAM in 2022, following which the authors had been asked to develop guidelines for the use of the hindcast as part of selection, rejection, weighting and extension of models in ensembles (Anon. 2022). The case study is based on the blue shark JABBA assessment (SCRS/2023/124), but the methods are also applicable to integrated stock assessments. Examples of diagnostics, weighting of ensembles, and evaluation of the skill of forecasts were also discussed, e.g., from the Center for the Advancement of Population Assessment Methodology (CAPAM), other RFMOs and ICES. Diagnostics can be used to develop a base case or best assessment (e.g., Carvalho *et al.,* 2022), or to weight ensembles (ICES, 2023).

Once a base case is developed a sensitivity analysis should be developed, where a limited set of scenarios, i.e., robustness trials, are considered that include the most important uncertainties. There are different ways of choosing the scenarios to consider, e.g., through elicitation (Leach *et al.,* 2014). These can then be used to evaluate the robustness of advice based on a base case and to identify research needs. In contrast in an uncertainty analysis the intention is to quantify the probability of derived outputs based on uncertainty in the inputs. Where there is large uncertainty about model structure and fixed parameters ensembles can be used. A problem in with an ensemble is if the choice of scenarios is non-unique or unrepresentative. The procedures adopted for selection, rejection, and weighting of scenarios will therefore affect the robustness of advice, and when developing ensembles, the weighting scheme should be pre-specified. Given the time available in the meeting, it was not possible to develop such an ensemble.

The standard set of diagnostics is available in both JABBA and SS3 platforms. These were applied and reviewed for models under consideration in this assessment. A next step could be to use the blue shark assessments to further develop tools for model validation, the skill of assessments to classify stock status and perform stock forecasts. These could be implemented in a common framework and made available for the next shark assessment.

4. Stock status results

For all the models, the CVs on the CPUE indices were reweighted, after discussion in the Group. The weighting method applied for the final runs, for both North and South stocks, used as the average standard deviation of each log(CPUE) series the maximum of the following three quantities: 1) the average value calculated from those originally reported in the CPUE standardization documents; 2) the RMSE of the residuals resulting from a LOESS fit to the log(CPUE) series; and 3) the value of 0.2.

4.1 Production models

The sensitivity runs conducted for continuity with the 2015 Blue Shark Stock Assessment were all similar to the base case in both the North and South Atlantic. Therefore, no further analyses were conducted, and these models were not incorporated into the joint Kobe plot to assess status or used in the population projections.

4.2 Stock Synthesis (SS)

North Atlantic blue shark Stock Synthesis model estimates

The time series of spawning stock output, recruitment, and fishing mortality (measured as instantaneous fishing mortality rates for all fleets combined) are plotted in **Figures 23, 24**, and **25**, respectively. Spawning stock size in the stock-recruitment relationship was modelled as spawning stock fecundity (SSF) and calculated as the sum of female numbers at age (reported in 1,000s) multiplied by annual female pup production at age (male and female pups, assuming a 1:1 ratio of male to female pups) at the beginning of each calendar year. The estimated time series of SSF for the reference case indicated that the stock maintained a relatively stable spawning stock size and then gradually decreased from the mid-1980s to approximately 2005, followed by an increase throughout the remainder of the time series (**Figure 23**).

Periods of lower recruitments were estimated for the years 2002 and 2019 (**Figure 24**), however slightly lower recruitments in the 1990s combined with increasing landings resulted in the decreasing biomass trend between 1990 and 2000. Recruitment in years prior to 1990 exactly follows the stock recruitment relationship.

The estimated total annual fishing mortality for all fleets combined (F) was calculated with SS3 option 4 = true. F for range of ages (0-28) is relative to the fishing mortality obtained by SS3 at equilibrium MSY in the same units. In general, F steadily increased until 1995 (**Figure 25**), followed by a decrease until 2007, after which the estimated fishing mortality increased and then decreased in the terminal years.

An age-structured production model (ASPM) diagnostic was presented to the Group which showed that the model had internal consistency between the catches and the CPUE series used in the analysis.

The multivariate lognormal (MVLN) approach was used to develop the Kobe phase plot for the North Atlantic blue shark Stock Synthesis model. The apparent lack of a clear negative correlation between relative F and relative biomass (B) was discussed as a potential issue that needed to be explored. It was not clear if this was a result of differences between Markov Chain Monte Carlo simulation (MCMC) and sampling the MVLN, an issue in extracting the MVLN, or a problem with the fit of the model.

In response, a sub-group began investigation of the MVLN approach for the North Atlantic blue shark Stock Synthesis model. The sub-group noted that the true density of the MVLN distribution may be obscured when plotting overlapping points. It may be clearer from a greater number of replicates or a contour plot of the point density. It was also noted that the difference between MVLN and MCMC may not necessarily be a methodological issue. However, the lack of a negative correlation between F and B in the estimated Hessian matrix appears uncommon for an assessment model. An SCRS document summarizing any consensus understanding or recommendations obtained from the sub-group's review of this specific application may be presented during the upcoming SCRS Shark Species meeting from 20-21 September 2023, if available.

South Atlantic blue shark Stock Synthesis model estimates

The time series of spawning stock output, recruitment estimates, and fishing mortality (measured as instantaneous fishing mortality rates for all fleets combined) are plotted in **Figures 22, 26,** and **27**, respectively. The estimated time series of spawning output for the reference case indicated that the stock rapidly decreased from the late 1980s to the early 2000s, then continued decreasing at a slower rate until the early 2010s (**Figure 22**). It presented a discrete increase until the late 2010s and a new decrease until the end of the time series in 2021 (**Figure 22**).

Notably strong recruitments were estimated for the years 2008, 2012, and 2013. The 2012 and 2013 recruitments (**Figure 26**) have resulted in biomass increase during the 2010s (**Figure 28**). Lower recruitments in the late 2010s combined with increasing landings resulted in the decreasing biomass trend in the model terminal years.

Fishing mortality was estimated as the sum of the full Fs by fleet (apical Fs) divided by F_{MSY} calculated in the same units. In general, F steadily increased from the 1990s until early 2010s, reaching the series maximum in 2011 (F=1.33) (**Figure 27**). After a slight decrease, F increased again in the model terminal years, reaching a value of 1.16 in 2021 (**Figure 27**).

4.3 JABBA stock status results

North stock

The Group reviewed the updated JABBA fits to the North stock. The reweighting method for the CPUE CVs resulted in average values of 0.2 for the Spanish, Portuguese, Japanese and Moroccan indices, 0.29 and 0.28 for the two U.S. series, and 0.64 and 0.97 for the Chinese Taipei and Venezuela series, respectively. The interannual variability in the standard deviation of the log(CPUE) series was kept as in the original CPUE standardization documents, resulting in the annual values shown in **Figure 28**, which were used as input for the North stock JABBA assessment. In addition, an extra term, added to the variance, was estimated as part of the stock assessment within JABBA for each CPUE series.

The Group agreed that the JABBA reference case for the North Atlantic stock be based on the life history parameter provided in Cortés and Taylor (SCRS/2023/115). Log-normal prior distributions approximating the range of values identified as most likely from that document were derived for r (prior median=0.39 and CV=0.31) and m (prior median=1.5 and CV=0.31). A log-normal prior distribution was also used for K, as required in JABBA, with "default" median value = 8*max(observed catch from 1971-2021)=443864 t and a large CV=1, to make it relatively non-informative. A beta distribution with mean=0.7 and CV=0.2 was used for the population stability index (PSI), where PSI corresponds to B(1971)/K. Process error stochastic deviations were allowed around the surplus production dynamic model in all years, with a very small fixed CV value (0.01) for the period 1971-1991 and an estimated CV value for the years 1992 and onwards, when the CPUE series used to fit the model began. The CV on the catch series was fixed to 0.01.

A set of diagnostics following Carvalho *et al*. (2021) was provided: model convergence, fit to the data, model consistency (retrospective pattern), and prediction skill through hindcast cross-validation (Kell *et al*., 2016; 2021a).

The results of the MCMC convergence tests and visual examination of MCMC trace plots showed that this model has adequate convergence properties. Marginal prior and posterior distributions are provided in **Figure 29** For r and m, the prior and posterior distributions are very similar, whereas for K the posterior is much narrower than the prior, indicating that there is information in the input data about K. The estimated process error deviates show some continued periods of years with positive or negative estimated values (**Figure 30**), with no obvious trend departing from zero when considering the entire time series.

The fit to the eight CPUE indices is provided in **Figure 31**, together with the residuals and the results of the runs test for the residuals, which was only passed by three of the eight CPUE indices. Goodness-of-fit statistics indicated a high RMSE estimate of 52.8% (**Figure 32**). The residuals suggest data-conflicts caused by different trends in the CPUE indices, particularly in the last years, starting around 2015 (**Figure 31**).

A retrospective analysis deleting up to five years of CPUE data starting from the final assessment year showed minimal deviations from the full model (**Figure 33**). The estimated Mohn's rho values fell within the acceptable range of -0.15 and 0.20 (Hurtado-Ferro *et al*., 2015; Carvalho *et al*., 2017) and were low for both B/B_{MSY} and F/F_{MSY}, indicating that the retrospective pattern is negligible. Hindcasting cross-validation with the same range of years deleted from the CPUE series and predicting the deleted CPUE values 1-year ahead resulted in MASE statistic values above 1 for most CPUE series, indicating that a 1-year ahead prediction based on a naive random-walk was more accurate than one coming from the model for those CPUE series (**Figure 34**). However, when posterior predictive intervals were computed for the CPUE observations also taking into account their associated observation error (CV), after removing the last 5 years of the CPUE series, the corresponding posterior predictive intervals encompassed the observed CPUE values, including those of the last 5 years that had been excluded when fitting the model (**Figure 35**). The jackknife analyses of CPUE indices, fitting the model excluding one CPUE series at a time, indicated that the Portuguese and Japanese CPUE series are the most influential on the model results (**Figure 36**).

The Group agreed that although the diagnostics were not particularly good, the results obtained from the different JABBA formulations discussed at the meeting were consistent and should be informative to include in the management advice. The results suggest that the final reference case model is stable and provides a reasonably robust fit to the data.

The final annual stock trends are shown in **Figure 37**. Biomass shows a declining trend from the 1990s to the early 2000s, then slowly increases to 2016, and declines slightly thereafter (top left panel). Fishing mortality was initially low in the 1970s but increased throughout the 1980s and remained at similar values until 2015 and declined afterwards (top right panel).

Summaries of the posterior quantiles for parameters and management quantities of interest are presented in **Table 7**. The MSY estimate is 33,822 t (31,085 t – 36,465 t) and the median marginal posterior value for B_{MSY} is 120,012 t (83,682 t – 176,399 t). The F_{MSY} median estimate is 0.28 (0.18-0.42).

The final model estimated median values of B_{2021}/B_{MSY} = 0.96 (95%CI: 0.71-1.35) and F_{2021}/F_{MSY} =0.68 (95%CI: 0.47-0.91), are presented in **Table 7**.

Sensitivity analyses were also done to explore the impact of incorporating the U.S. early survey and early Japanese indices and starting the model in 1957, consistent with the 2015 Blue Shark Stock Assessment. The analyses showed that the conclusions were not sensitive to the starting year or to the inclusion of the two additional CPUE indices. The Group agreed to use as the reference case the model starting in 1971 and the CPUE indices agreed at the 2023 Blue Shark Data Preparatory Meeting (Anon., 2023).

South stock

The Group agreed that the JABBA reference case for the South Atlantic stock should be based on the life history parameters presented by Cortés and Taylor (SCRS/2023/115) and use all CPUEs, with time-blocks on two of them (see section 3.3). A set of diagnostics following Carvalho *et al*. (2021) was provided: model convergence, fit to the data, model consistency (retrospective pattern), and prediction skill through hindcast cross-validation (Kell *et al*., 2016; 2021a). In addition, jackknife analyses were also provided.

The results of the MCMC convergence tests and the visual examination of trace plots show that this model has adequate convergence and a high level of model stability. Marginal posterior distributions along with prior densities were provided in **Figure 38**. The posterior to prior median ratio (PPMR) for r was close to 1, indicating, as expected, that the posterior is heavily influenced by the prior. The small posterior-prior-variance-ratio (PPVRs) for K indicated that the input data was more informative about K. Estimated process error deviates show an increasing trend in the most recent years (**Figure 39**), which might indicate that the stock's productivity has been above average during this recent period. Although this trend is noticeable, the estimated credibility intervals for this quantity always contained zero throughout the entire time series. The estimated CV values in the model are shown in **Table 8**.

Time series of observed (circle, input data) and predicted (solid line) CPUE of the South Atlantic blue shark JABBA reference case are shown in **Figure 40**. Five of the six CPUE indices passed the runs test (**Figure 40**, right panel) with reasonable goodness-of-fit and high RMSE estimate of 23.2% (**Figure 41**). The residual patterns suggest data conflicts caused by opposite trends in the CPUE indices, particularly in the last seven years (2015-2021). More specifically, the EU-Spain longline index shows an increasing trend while the Japan longline index shows a decreasing pattern in recent years (**Figure 41**). Additionally, the high variation (e.g., higher residuals of the whole time series) observed in the Chinese Taipei index for the last years of the time series also contributed to this pattern.

A retrospective analysis for eight years shows some deviations from the full model for F, B, and F/F_{MSY} estimates (**Figure 42**) with the Mohn's rho values of 0.29, -0.22, and 0.23, respectively. The estimated Mohn's *rho* for these quantities fell outside of the acceptable range of -0.15 and 0.20 (Hurtado-Ferro *et al*., 2015; Carvalho *et al*., 2017). In general, the retrospective patterns are influenced by the conflict among the indices of abundance, mainly by the strong influence of the Chinese Taipei 2020 index value, that is almost two times higher than all values used in this assessment. The author of the index reminded the Group that the fleet operated in 2020 in different fishing areas than usual and with a lower observer coverage due to the COVID pandemic, and the fleet captured a significant amount of small size blue sharks resulting in a high CPUE in number (Anon., 2023).

For B/B_{MSY}, process error, and MSY, the values of Mohn's rho (-0.1, -0.01, and -0.08, respectively) indicated that the retrospective pattern was negligible for these quantities. Hindcasting cross-validation results indicated that Brazil-Uruguay longline index and the Chinese Taipei index have good prediction skills (**Figure 43**). The jackknife analyses of CPUE indices indicated that all indices are influential to the surplus production function shape, and trajectories of B/B_{MSY} and F/F_{MSY} especially in the period between the mid-1990s and the late 2000s (**Figure 44**).

The results suggest that the final model was stable and provides a reasonable fit to the data. Summaries of the posterior quantiles for parameters and management quantities of interest are presented in **Table 8**. The MSY estimate was 29,299 t (23,128 t – 47,758 t) and the median marginal posterior for B_{MSY} was 135,211 t (91,781 t - 225,806 t). The F_{MSY} median estimate was 0.22 (0.15-0.32).

Overall, the median of the estimated B/B_{MSY} remained above 1.0 for all assessed years (**Figure 45**). The B/B_{MSY} trajectory showed a relatively stable trend for two decades since 1971 and declined from about 2.0 to 1.2 in the following decade from the late 1980s to the mid-1990s. The estimated biomass remained at around 1.2 until the mid-2000s before they slightly increased and stabilized at around 1.5 in the 2010s. In recent years, following the recent high catches, the estimates showed a decreasing trend but remained above the B_{MSY} level.

The median of the estimated F/F_{MSY} was under 1.0 in all assessed years (**Figure 46**). It showed a slow increase until the late 1980s, followed by a large increase (0.2 to 0.7) from the late 1980s to the mid-1990s, driven primarily by the increase in the catches. After the peak in the mid-1990s, F/F_{MSY} slightly fluctuated between about 0.6 and 0.8 until the beginning of 2010s. Fishing mortality suddenly decreased from 0.8 to around 0.5 and 0.6 in the early 2010s but then quickly increased back to the historical highest level.

The final model estimated median values of B_{2021}/B_{MSY} = 1.41 (95%CrI: 0.93 - 1.87) and F_{2021}/F_{MSY} = 0.82 (95%CrI: 0.39-1.47), respectively.

4.4 Other methods

Other than those listed below, final results of no other assessment methods were presented during the meeting.

4.5 Synthesis of assessment results

The Group had a lengthy discussion on various topics related to how to develop scientific advice for both stocks, like how to address uncertainties associated with the stock assessment, how to weigh scenarios, etc. The Group agreed to focus on developing an internally consistent, best-possible stock assessment model and consequently decided not to implement a model-grid approach. The Group felt that a grid approach may help quantify some of the model uncertainties, however, all tasks related to running a structural uncertainty grid could not be accomplished during the meeting. Acknowledging the importance of model weighting methods and approaches, the Group considered that this is a common feature of all stock assessments, noting that in general the SCRS defaults to an equal weighting of accepted models but deferred further discussions to the WGSAM for future guidelines.

North stock

The Group reviewed both JABBA and Stock Synthesis results and discussed how to produce scientific advice and management recommendations for the North Atlantic blue shark stock. The Group compared outputs between the models (**Figure 46** and **Table 9**). The trajectories and estimates of F/F_{MSY} were similar between the models, and the credibility interval of the JABBA reference case fully covered the confidence interval of the Stock Synthesis reference case in the entire period. The trajectories of B/B_{MSY} were similar, but the estimates by Stock Synthesis were above the ones from JABBA until the 2000s. Thereafter, the trends and estimates of B/B_{MSY} became more similar with a complete overlap of the uncertainty associated with these estimates.

The Group noted that conflicts in the indices of abundance affected model performances in both platforms and that there is still room for improvement in the Stock Synthesis model. The Group agreed that for the North blue shark stock assessment, the scientific advice will be based on the combined results from the JABBA and Stock Synthesis reference cases with equal weighting. It was agreed also that the stock projections would be done for each platform assuming constant catch scenarios from 2024 onward and combined thereafter to produce the Kobe II strategy matrices.

It was noted that the SCRS agreed to report biomass or spawning stock biomass at the end of the year and the corresponding fishing mortality that was applied during the entire year. Therefore, in the assessment results, SSB/SSB_{MSY} from Stock Synthesis gives biomass estimates at the end of the year. However, it was noted that JABBA produces the estimates of the B-ratio at the beginning of the year from the code checking. The Group recommended that modelers (via WGSAM) confirm the output timeframe associated with biomass and the corresponding fishing mortality in both JABBA and Stock Synthesis to assure proper comparison and combination of results, as this will affect most of the ICCAT assessments for all species.

The joint time series of relative B and relative F and the Kobe phase plot were built with 100,000 iterations based on the Monte-Carlo multivariate lognormal (MVLN) approach for the Stock Synthesis reference case and 100,000 MCMC samples from the JABBA reference case. The joint results (**Figure 47**) showed that the trajectory of B/B_{MSY} was stable at the historically highest level (around 2.0) until the mid-1980s followed by a continuous decrease to the historically lowest level (around 0.7) in the early 2000s responding to the increase of catches and fishing mortality. The biomass then gradually increased to B_{MSY} level in the mid-2010s and remained at about B_{MSY} levels at the end of the 2021 assessment year. The trajectory of F/F_{MSY} was similar to the catch history. It showed a rapid increase in the 1980s to the level above F_{MSY} and fluctuated between 1.0 and 1.5 until 2018. The estimates since 2019 were below F_{MSY} responding to a decrease in the catch in recent years. The joint MSY was 32,689 t (geometric mean of both models, with a 95% confidence interval range of 30,403-36,465 t).

The combined results indicate that the stock is at MSY level (B_{2021}/B_{MSY} = 1.00, with 95% confidence interval: 0.75-1.31) and is not experiencing overfishing (F_{2021}/F_{MSY} = 0.70 with a 95% confidence interval: 0.50-0.93). The Kobe phase plot indicates that there is a 49.6% probability that the stock currently falls within the yellow quadrant of the Kobe plot, a 49.7% probability that the stock falls within the green, and less than a 1% chance that it is in the red or orange quadrants (**Figure 48**).

South stock

The Group reviewed both JABBA and Stock Synthesis reference case results and compared the outputs between the models for the South Atlantic blue shark stock (**Figure 49** and **Table 10**). The median trajectories of B/B_{MSY} showed that the stock has not been below B_{MSY} level during the entire period considered in the present assessment for both models. Both models showed a decreasing trend of B/B_{MSY} in the 1990s from the virgin biomass, and the estimates after the 2000s ranged between 1.0 and 1.5. Although the trajectories were different, the confidence bounds overlapped for most of the years. It was noted that the magnitude of the estimates before the 2000s largely differed between models (about 2.0 for JABBA and 3.5 for Stock Synthesis in the 1970s).

The trajectories of F/F_{MSY} were similar between models, but the magnitude of the estimates was higher in Stock Synthesis since the mid-2000s. Generally, the estimates of F/F_{MSY} were below 1.0 except for some years with large catches that resulted in differences in predicted stock status in the most recent years between models. The JABBA estimate for 2021 was below F_{MSY}, whereas the Stock Synthesis estimate was above F_{MSY}. However, the confidence bounds from both models overlapped completely, with much higher uncertainty indicated by the JABBA results.

The Group considered that both models showed reasonable model fits and diagnostics, therefore the Group agreed to combine the JABBA and SS3 models when assessing stock status and producing projections. The joint time series and the Kobe plot were built with 15,000 iterations based on Monte-Carlo multivariate lognormal (MVLN) approach for the Stock Synthesis reference case and 15,000 MCMC samples from the JABBA reference case. The combined results (**Figure 50**) showed that the trajectory of B/B_{MSY} was stable at the historically highest level (below 3.0) until the late 1980s followed by a continuous decrease to the historically lowest level (around 1.3) in the mid-2000s. Since then, the estimates were relatively stable between 1.3 and 1.5. The trajectory of F/F_{MSY} was like the catch history, showing a gradual continuous increase from the late 1980s to the historically highest level in 2011 (1.14). The estimates were below F_{MSY} in the mid-2010s but increased again to the F_{MSY} level in most recent years. The estimated joint MSY was 27,711 t (geometric mean of both models, with 95% confidence interval range of 23,128 – 47,758 t).

The combined results indicate that the stock is not overfished (B_{2021}/B_{MSY} = 1.29, with 95% confidence interval: 0.89-1.81) but is undergoing overfishing (F_{2021}/F_{MSY} = 1.03 with 95% confidence interval: 0.45 – 1.55). A joint Kobe phase plot (**Figure 51**) shows that there is a 46.5% probability that the stock is currently in the orange quadrant of the Kobe plot, a 44.7% probability that the stock falls within the green, and 8.02% probability of being in the red quadrant, with less than 1% chance that it is in the yellow quadrant.

The Group discussed the different distribution shapes of the iterations in the Kobe plots for JABBA and Stock Synthesis in both the North and South blue shark stocks (**Figure 51**). It was noted that the surplus production models (JABBA) estimate fewer model parameters and tend to show a much higher correlation between F and B compared to age-structure models (Stock Synthesis) which estimate a greater number of parameters. The Group questioned if there is no correlation in the stock synthesis results or if the MVLN approach does not take into consideration the correlation of parameters. The Group agreed that this will be better investigated by running stochastic MCMC projections in stock synthesis and comparing them with equivalent projections from the MVLN approach, and that this work will be done intersessionally.

5. Projections

The Group agreed to conduct stochastic stock status projections based on both the selected JABBA and Stock Synthesis reference cases for both North and South Atlantic blue shark stocks, giving equal weighting to each model platform. Due to time constraints, the Group agreed to conduct the stochastic projections after the meeting due to time constraints.

As the official reported blue shark Task 1 nominal catches for 2022 were not available, the Group suggested reviewing the official catch reports at the Sharks Species Group meeting in September 2023 to evaluate if the catch assumptions for 2022 for both stock projections need further refinement. The Secretariat will coordinate with the Chair in early September 2023 to conduct this revision.

North Atlantic blue shark

Projection setting:

- Set 23,418 t (average mean catch of 2019-2021 in Task 1 nominal catches) as the best estimate of the 2022 and 2023 expected catch. This includes the U.S. preliminary estimates of N-BSH catches for 2022 of 37 t provided by national scientists during the meeting.
- 11 constant future catch scenarios for the periods between 2024 and 2033 as follows: 0, 20,000 to 40,000 t with a 2,500 t interval; and 32,689 the estimated combined MSY level.
- 100,000 iterations in both models.
- For Stock Synthesis, use a 3-year average (2019-2021) for future catch distribution by fleet and their corresponding selectivity.

- For Stock Synthesis, apply the multivariate lognormal (MVLN) approach for the stochastic projections.
- For Stock Synthesis, future recruitment values (beyond the year 2019) were taken directly from the stock-recruitment relationship.
- For JABBA, sample the posteriors for all parameters including the leading parameters (r and K), the observation error parameters, and the process error.

Projection results:

The annual trends of the relative B/B_{MSY} and F/F_{MSY} stochastic projections of the current combined stock status for North Atlantic blue shark stock are presented in **Figure 52**. **Table 11** shows the percentage of model projection runs for which the biomass level fell below 20% of $B_{MSY.}$ Results indicated that future constant catches at or above 35,000 t would bring the stock to low biomass levels considered to be high risk and not sustainable in the long term. The Kobe II Strategy Matrices (**Table 12**) were estimated and show the probability that overfishing is not occurring ($F<=F_{MSY}$), that the stock is not overfished ($B>=B_{MSY}$), and the joint probability of being in the green quadrant of the Kobe plot (i.e., $F<= F_{MSY}$ and $B>= B_{MSY}$). Equilibrium MSY was estimated to be 32,689 t.

The stochastic projections (**Figure 52**) indicated that future (2024 and thereafter) constant catch levels of 32,689 t (MSY) will maintain the North Atlantic blue shark stock above the reference B_{MSY} and below the F_{MSY} point with a 50% or higher probability (i.e., in the green quadrant of the Kobe plot (**Table 12c**)) by the end of the projection period (10 years; 2033). There is, however, a transition period in the projections (2025 – 2029) where, while fishing at the MSY level, the stock will have a lower probability of being in the green quadrant (46%). This transition period reflects the age structure and recent predicted average recruitment trends, particularly from the Stock Synthesis model results.

If current catches (average of 2019-2021) of about 23,500 t are maintained, the stock is expected to remain in the green quadrant of the Kobe phase plot through the whole projection period with a probability of 50% or higher. The same holds for catch levels not exceeding 27,500 t per year (**Table 12c**).

South Atlantic blue shark

Projection settings:

- Set 34,983 t (average mean catch of 2019-2021 in Task 1) as the best estimate of the 2022 and 2023 expected catch.
- 10 future constant catch scenarios: 0; 15,000 – 32,500 t with 2,500 t interval; and the estimated joint MSY level of 27,711 t (geometric mean of combined JABBA and stock synthesis estimates).
- 15,000 iterations in both models.
- For Stock Synthesis, use a 3-year average (2019-2021) for future catch distribution by fleet and corresponding selectivity.
- For Stock Synthesis, apply the multivariate lognormal (MVLN) approach for the stochastic projections.
- For Stock Synthesis, future recruitment values (beyond the year 2019) were taken directly from the stock-recruitment relation estimated within the model, excluding the last 3 years (2019-2021) of recruitment deviations.
- For JABBA, sample the posteriors for all parameters including the leading parameters (r and K), the observation error parameters, and the process error.

Projection results:

The annual trends of the relative B/B_{MSY} and F/F_{MSY} stochastic projections of the current combined stock status for South Atlantic blue shark stock are presented in **Figure 53. Table 13** shows the percentage of model projection runs for which the biomass level fell below 20% of $B_{MSY.}$ Results indicated that future constant catches at or above 30,000 t would bring the stock to low biomass levels and were considered high risk and not sustainable in the long term. The Kobe 2 Strategy Matrices (**Table 14**) were estimated and show the probability that overfishing is not occurring ($F<=F_{MSY}$), stock is not overfished ($B>=B_{MSY}$), and the joint probability of being in the green quadrant of the Kobe plot (i.e., $F<= F_{MSY}$ and $B>= B_{MSY}$). Equilibrium MSY was estimated to be 27,711 t.

The stochastic projections (**Figure 53**) indicated that a future (2024 and thereafter) constant catch level of 27,711 t (MSY) will maintain the South Atlantic blue shark stock above the reference B_{MSY} and below the F_{MSY} point with a 50% or higher probability (i.e., in the green quadrant of the Kobe plot (**Table 14c**)) by the end of the projection period (10 years; 2033).

If current catches (average of 2019-2021) of about 35,000 t are maintained, the stock is expected to rapidly decline in biomass. Removals at this level are not sustainable in the long term, with a risk of falling below 20% of the estimated B_{MSY} reference level in a few years. Only catches at MSY (27,711 t) or less will keep the stock in the green quadrant of the Kobe plot.

6. Recommendations

6.1 Research and statistics

Recommendations without financial implications

Considering the need to reduce uncertainty in the stock assessments of pelagic shark species impacted by ICCAT fisheries and bearing in mind *Recommendation by ICCAT to replace Recommendation 16-13 on improvement of compliance review of conservation and management measures regarding sharks caught in association with ICCAT fisheries* (Rec. 18-06) and other previous recommendations which made the submission of shark Task 1 and 2 data mandatory, the Group once again strongly urges CPCs to provide the corresponding statistics, including estimates of discards (dead and alive) from all ICCAT fisheries, including recreational and artisanal fisheries, and to the extent possible non-ICCAT fisheries capturing these species. The Group considers that a basic premise for correctly evaluating the status of any stock is to have a solid basis to estimate total removals.

As a result of changes in the data reporting requirements over time, significant gaps in the historical shark data remain in the ICCAT-DB. Therefore, the Group once again reiterates previous recommendations that national scientists review the SCRS reports cards to identify shark data gaps and submit the missing data to the Secretariat to comply with ICCAT data reporting requirements. The Group recommends that national scientists from CPCs that in the past have reported shark data as part of a species complex explore the possibility of re-submitting those data at the species level.

The Group recommends that CPCs that catch blue sharks in the Mediterranean Sea provide the required Task 1 nominal catches (including estimates of dead and live discards) and Task 2 size and catch-effort data including historical time series. In addition, the Group also recommends that CPCs endeavor to increase their efforts to collect blue shark biological samples in the Mediterranean Sea.

The Group recommends promoting the activities of the SCRS Ad Hoc Working Group on Coordination of Tagging Information and that national scientists further emphasize conventional shark tagging activities.

The Group recommends that the SCRS Working Group on Stock Assessment Methods (WGSAM) review and recommend the appropriate reporting of biomass and fishing mortality time reference. More specifically, if the biomass to be considered should be the estimate at the end or the beginning of the year for which the corresponding fishing mortality is provided. This should be confirmed for the commonly used stock assessment models (e.g., JABBA, Stock Synthesis).

The Group also recommends that new efforts be made on the possibility of having CITES permits issued directly to ICCAT for biological sampling and research purposes.

Recognizing the difficulties to collect, introduce from the sea, and share biological samples for CITES listed species, the Group recommends that the SCRS and the Commission encourage CPCs to explore mechanisms to facilitate permitting within CPCs for introductions from the sea and to ship samples between CPCs.

The Group recommends that, if possible, a representative from ICCAT attend the 77th Meeting of the CITES Standing Committee which will be held from 6-10 November 2023 to identify some of the difficulties with permitting that ICCAT is experiencing.

The Group recommends exploring the possibility of using the blue shark assessments to further develop tools for model validation, for evaluating the capability of assessments to estimate stock status, and for performing stock forecasts. These could be implemented in a common framework and made available for future stock assessments.

Recommendations with financial implications

The Group recommends that the Secretariat acquire and make available to the SCRS Species Groups high-performance computer Cloud resources to conduct tasks such as standard diagnostics, MCMC runs, stochastic projections, and uncertainty grids.

6.2 Management

Management recommendations will be developed at the Sharks Species Group meeting.

7. Responses to the Commission

During the meeting, the list of responses to the Commission was reviewed. Most of these responses correspond to the conservation of shortfin mako i.e., *Recommendation by ICCAT on the conservation of the North Atlantic stock of shortfin mako caught in association with ICCAT fisheries* (Rec. 21-09) (north stock) and *Recommendation by ICCAT on the conservation of the South Atlantic stock of shortfin mako caught in association with ICCAT fisheries* (Rec. 22-11) (south stock). It was noted that most of the responses could not be developed before the 31 July 2023, deadline for the data submission of Task 1 and 2 corresponding to year 2022. The Group agreed to work intersessionally to prepare the responses using the same methodology applied during the 2022 Sharks Species Group meeting. It was also noted that given the similarity of these two Recommendations, some of the responses would apply to both.

8. Shark Research and Data Collection Programme (SRDCP)

The activities and conclusions of the ICCAT Workshop on the Shark Research and Data Collection Programme (SRDCP) that was held from 13 to 15 July 2023, were presented to the Group. The main conclusion of the workshop will be included in an SCRS document that will be prepared before the September 2023 Species Group Meeting (SCRS/2023/138). The tasks developed within this project involved: age and growth, genetics movements and habitat utilization, post-release mortality, reproduction studies, improvement of available information for population assessments, and other activities. The difficulties faced by the programme, and possible ways to overcome those, were discussed. Future steps for the second phase of the programme were also discussed, including the new elasmobranch species that were recently included as part of the ICCAT Convention, advances in available information on pelagic sharks not included in the SRDCP, activities to be continued, and new activities to be included.

In order to establish the outline of the next phase of the SRDCP, and continuing what was previously done in 2013, the Group agreed to develop a data gap analysis to guide research and data collection in the coming years prior to the SCRS plenary meeting in 2023. This will include all the highly migratory elasmobranch species that are now under the ICCAT Convention.

Considering that 92% of shark species in the ICCAT Convention are currently listed under CITES, other discussions focused on the need for greater flexibility and more efficient mechanisms for the collection and sharing of samples from CITES-listed species. This aspect was considered crucial by the workshop participants, as many of the tasks under the SRCDP require the collection and sharing of biological samples, and therefore the success of many of the SRDCP tasks depends on the ability to collect the samples from those pelagic shark species currently listed in Appendix II of CITES. Consequently, the advice that the Sharks Species Group and the SCRS can provide to the Commission depends on continuing those studies.

During the workshop, it was also felt necessary to promote the activities of the ICCAT Ad Hoc Working Group on Coordination of Tagging Information. The Group recommended that scientists further emphasize conventional shark tagging activities.

After the presentation on the SRDCP workshop, most of the discussions centered on the consequences of CITES listing of shark species and the corresponding difficulties with importing samples from international waters, and then sharing samples among scientists in different countries. It was again noted that many of those difficulties can be resolved by CITES national authorities, but the reality is that in practice this has not happened. The workshop's discussion cited examples of actual cases where it is simply not possible to conduct sampling.

It was also noted that in the past, the Sharks Species Group, with the support of the Secretariat, the SCRS, and the Chair of Panel 4, contacted CITES to discuss the possibility of having special sampling permits issued directly to ICCAT, as well as other tRFMOs that are developing biological research on those species. This would be mostly for solving the complex issue of the "introductions from the sea", i.e., introducing samples from international waters to national countries. It was noted that the CITES Standing Committee will meet in November 2023, and that they will discuss several aspects related to permits, including scientific sampling and introductions from the sea. Ideally, some CPCs that are also Parties to CITES could send a proposal requesting that the CITES Standing Committee open a discussion on those points; such documentation needs to be sent to CITES by September.

9. Other matters

SCRS/2023/123 provides an exploratory analysis of the catches of blue shark by the Spanish longline fleet operating in the waters of the western Mediterranean. The authors use logbook data to provide basic information about blue shark catches, fishing effort, and the different gear types used by the fleet, which vary in the fishing depth, number of hooks used, seasonality and fishing areas depending on the target species. Observer data show that catches and nominal CPUE of blue shark (estimated as number of individuals caught per thousand hooks) change across gear types with the highest values occurring in the surface longline gears and the smallest in bottom and semi-pelagic longlines targeting swordfish. In addition, there are spatial differences in the observed nominal CPUEs which showed that the Southeast coast of Spain is a potential area of high blue shark nominal CPUE values. Moreover, the largest blue shark individuals were caught in the semi-pelagic and bottom longline fleets targeting swordfish. Further analyses can be conducted on the spatio-temporal trends in CPUEs as well as the estimation of annual indices of abundance and/or total catches.

The Group discussed the differences between each type of longline gear. They have different target species (i.e., albacore, bluefin tuna, little tunny or swordfish), fishing depth, areas and seasons, as well as different configurations (number and size of hooks, nylon thickness or whether or not the nylon is braided), among others. All these factors can potentially influence the catchability of blue shark.

The Group also noted that while nominal CPUEs were different among the different longline gear types, these differences did not seem to be substantial. However, no formal statistical analyses were conducted to test if the differences were significant.

The Group noted that results for the surface longline targeting bluefin tuna should be interpreted with caution as very few trips and sets were monitored by the observers in this fleet.

The Group asked if blue shark is considered a commercial or a bycatch species. The blue shark in the Spanish longline Mediterranean fishery is a bycatch species, and although it is sold in the local market, fishers do not retain and land them in large numbers due to the problem of preserving the meat onboard until the vessels return to port. Blue shark meat requires a special refrigeration process and equipment that vessels operating in the Mediterranean, which are generally smaller than the Spanish vessels operating in the Atlantic, do not have. For this reason, blue sharks are usually discarded, except for those caught in the last few hauls before returning to home-base port.

The Group asked about catches of blue shark in other gears like purse seine in the Spanish Mediterranean. Currently there is no information available about catches in other gears, but this is something that can be explored in the future. The Group agreed that it would be very useful to update catch information from other fisheries and all CPCs in the Mediterranean Sea.

The Spanish scientists have conducted biological sampling of blue shark in previous projects, but sampling activities are not currently being conducted. Nevertheless, biological sampling can be conducted again if necessary. The Group agreed that it would be very useful to update life history information in the Mediterranean Sea.

The Group encourages CPCs to submit their blue shark data from the Mediterranean. The Group recommends the submission of all biological and fishery statistical data concerning blue sharks from the Mediterranean Sea, including different fishing fleets, and gears.

Due to the current data limitations that preclude conducting stock assessments for the blue shark Mediterranean stock, the Group discussed the potential use of alternative methodologies such as Ecological Risk Assessment (ERA), Productivity and Susceptibility Analysis (PSA) or Sustainability Assessment for Fishing Effect (SAFE).

Given the time constraints, it was agreed that sections 4 and 5 of this report would be adopted by correspondence according to the following schedule: 1) Initial draft to be send to meeting participants via email on 9 August 2023; 2) then participants will have a period until 16 August 2023 to review and send comments to the Chair.

The Group also agreed to prepare in advance draft documents for the Sharks Species Group meeting in September, including the updates for the Blue Shark Executive Summary, Responses to the Commission, and the Shark Workplan.

10. Adoption of the report and closure

The Group could not finish sections 4 and 5 at the meeting. These were to be adopted by correspondence after the meeting. The Chair thanked all participants for their hard work during the meeting. The meeting was adjourned.

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Table 1. Summary of total catches of blue shark for the northern stock by fleet.

Yr	EU-Portugal	EU-Spain	Japan	Chinese Tai Pei	United States	Venezuela	Canada	People's Republic of China	Belize	Other
1970	0	13817	2501	760	0	0	0	0	0	0
1971	0	14085.2	1257.87	737.79	0	0	0	0	0	0
1972	0	13361	1674.82	932.29	0	0	0	0	0	0
1973	0	15954.1	653.64	901.07	0	0	0	0	0	0
1974	0	12041.5	3421.98	740.45	0	0	1.52	0	0	0
1975	0	15596.1	4380.45	658.98	0	0	15.92	0	0	0
1976	0	11721	1130.01	800.47	0	0	11.37	0	0	0
1977	0	13773.1	3295.02	742.17	0	0	85.67	0	0	0
1978	0	15030.1	3368.29	734.21	0	0	1754.4	0	0	4
1979	0	10747.1	924	701.74	0	0	2251.76	0	0	12
1980	0	15858.4	4902.49	648.92	0	0	1360.15	0	0	12
1981	0	16703.3	6342.45	404	204.27	0	410.93	0	0	10
1982	0	18955.1	5331.14	880	155.62	0	410.93	0	0	8.8
1983	0	29552.3	3460.67	919	605.27	0	727.84	0	0	8
1984	29.14	26285	2455.01	970	106.97	0	352.55	0	0	14
1985	62.43	30930.1	3650.34	868	340.98	0	416.99	0	0	39
1986	1864.71	40424.3	2928.4	1175	1112.34	10.61	320	0	0	50
1987	4095.71	46343.1	2975.08	440	1400.47	14.78	147	0	0	67
1988	2547.33	39958.1	2388.19	248	776.09	8.19	968	0	0	91
1989	1215.39	23708.5	4532.7	165	750.52	8.62	978	0	0	81
1990	1387	23875	3599.22	1174	828.68	9.16	680	0	0	132.6
1991	2257	27080	3579.6	2675	1080.14	7.14	774	0	0	188
1992	1583	26434.8	4509.07	2025	399.2	23.94	1277	0	0	277
1993	5726	26605.4	5942.43	1428	1816.37	22.83	1702	22	0	322
1994	4669	25086.2	2526.12	2684	601.09	18.3	1260	46	0	351.34
1995	4722	28919.7	2813.01	1569	641.04	15.62	1494	68	0	282.82
1996	4843	22971.8	4179.26	2004	986.75	5.51	528	65.6	0	282
1997	2630	24497.4	4191.43	1479	391.12	27.34	831	23.2	0	214.5
1998	2440.4	22504.3	3460.87	893	446.96	7.31	612	73.2	0	166.3
1999	2226.59	21811.3	3149.59	1177	316.77	47.4	547	128	0	481.88
2000	2081	24111.9	2838.4	1157	428.52	43.34	624	136	0	446.8
2001	2109.9	17361.7	2723.72	906	145.24	47.11	1162	300	0	289.37
2002	2264.6	15665.9	1890.03	1108	67.87	29.04	836	168	0	712.72
2003	5642.8	15974.5	3097.72	1449	0	39.55	346	240	0	70.96
2004	2024.65	17313.9	3194.83	1378	71.57	9.95	965	192	0	115.65
2005	4027.02	15006.1	3530.98	857	67.9	27.73	1134	232	0	126.72
2006	4337.88	15463.6	2824.18	364	46.98	11.63	977	256	0	358.03
2007	5283.26	17038.5	2270.99	292	54.32	19.25	843	367	0	1108.46
2008	6166.77	20787.8	3186.59	109.57	137.32	8.14	0	109	0	873.77
2009	6251.56	24465.5	2942.14	72.94	107.11	72.77	0	88	113.82	2020.99
2010	8261.08	26094.3	2755.04	98.51	176.11	75.04	0	52.84	460.53	198.29
2011	6509.13	27988.2	2147.89	148.3	271.31	117.8	0	108.83	1039.17	676.35
2012	3767.78	28665.8	2256.35	115.12	162.27	98.39	0	97.62	902.52	538.96
2013	3694.38	28562	1353.72	135.02	263.77	51.61	0	326.72	1216.15	1144.52

2014	3059.53	29041.1	3286.88	83.14	165.79	115.68	0.64	177.72	391.86	1810.85
2015	3859.15	30078.3	4011.13	238.07	114.15	130.42	5.54	1.24	4.28	1748.49
2016	7819.01	29018.7	4217.09	286.56	74.05	117.47	16.03	27.28	5.74	2503.53
2017	5664.25	27316.5	4443.85	75.63	66.68	107.68	32.01	2.44	201.09	2094.35
2018	5194.57	21684.7	4111.12	153.1	30.14	112.44	70.91	5.69	316.6	2299.44
2019	4507.33	16314.2	3855.22	38.49	36.27	55.96	3.91	17.93	368.9	2014.08
2020	3836.28	12324.9	2289.79	73.6	32.17	59.01	193.31	65.44	300.68	1972.23
2021	4299.98	13124.6	1985.26	53.37	34.45	10.97	173.18	2.21	349.43	1814.7

Table 2. Summary of total catches of blue shark for the southern stock by fleet.

Year	**EU-Spain**	**Brazil**	**Chinese Taipei**	**Japan**	**Uruguay**	**Namibia**	**Portugal**	**Others**
1971	0	87.04	3,512.92	1,132.36	0	0	0	0
1972	0	68.39	4,439.01	759.7	0	0	0	0
1973	0	90.99	4,290.35	2,478.94	0	0	0	0
1974	0	262.81	3,525.59	666.01	0	0	0	0
1975	0	290.5	3,137.68	643.09	0	0	0	0
1976	0	206.29	3,811.35	488.87	0	0	0	0
1977	0	217.03	3,533.80	5,764.68	0	0	0	0
1978	0	207.42	3,495.90	6,800.44	0	0	0	0
1979	0	293.89	3,341.26	7,627.67	0	0	0	0
1980	0	892.41	3,089.75	8,655.38	0	0	0	0
1981	0	369.62	3,048.00	4,441.91	64.45	0	0	0
1982	0	575.35	3,187.00	9,579.35	233.9	0	0	0
1983	0	441.4	2,235.00	2,813.28	460.01	0	0	0
1984	0	263.94	1,438.00	7,601.39	655.49	0	0	0
1985	0	317.63	1,666.00	6,155.67	361.54	0	0	0
1986	0	425.01	3,733.00	7,716.97	128.04	0	0	0
1987	0	535.22	4,260.00	4,706.75	84.62	0	0	0
1988	5,194.88	656.73	3,992.00	7,016.24	68.09	0	0	0
1989	9,135.08	660.12	5,338.00	6,806.85	56.84	0	0	0
1990	7,291.51	958.53	8,798.00	8,058.33	78.57	0	0	0
1991	6,811.40	741.51	7,066.00	6,559.97	40.45	0	0	0
1992	6,682.50	1,474.54	10,217.00	4,748.23	106.86	0	0	0
1993	8,247.00	1,137.69	5,792.00	7,833.96	84.08	0	0	33
1994	9,385.78	887.89	8,636.00	7,658.81	83.76	0	0	69
1995	13,350.80	1,113.39	7,784.00	5,555.57	56.65	0	847	102
1996	11,378.30	1,069.31	11,628.00	4,851.81	258.63	0	867	105.06
1997	5,272.42	2,317.21	9,558.00	4,396.52	180.29	0	1,335.90	45.48
1998	5,573.94	2,172.53	8,771.00	3,720.34	247.84	0	876	140.03
1999	7,173.37	2,668.18	8,390.00	3,133.50	118.1	0	1,110.00	408.07
2000	6,950.70	1,682.50	9,064.00	2,950.82	80.52	0	2,134.40	226.19
2001	7,742.58	2,173.40	6,061.00	1,666.67	66.32	0	2,562.40	536.14
2002	5,368.08	1,970.50	8,445.00	1,446.59	84.7	0	2,323.50	2,527.93
2003	6,626.11	2,165.76	7,228.00	5,469.22	480.01	0	1,840.80	2,909.57
2004	7,366.30	1,667.36	6,005.00	2,680.30	462.45	0	1,863.17	2,358.09
2005	6,410.13	2,523.27	5,045.00	1,660.23	375.8	0	3,184.26	7,394.39

2006	8,724.38	2,591.33	2,433.00	3,281.84	231.72	0	2,751.23	4,432.54
2007	8,941.76	2,645.28	2,177.00	3,653.30	337.48	0	4,493.50	4,323.24
2008	9,615.25	2,012.58	1,842.56	5,521.34	358.88	0	4,866.39	2,624.43
2009	13,098.70	1,273.50	1,356.25	3,768.00	941.81	0	5,358.23	625.08
2010	13,953.40	1,500.50	1,625.49	5,335.59	207.93	0	6,338.02	3,012.83
2011	16,978.10	1,979.53	2,141.55	4,242.17	724.56	0	7,642.33	3,976.72
2012	14,348.00	1,607.26	2,146.88	4,447.36	432.75	0	2,424.06	2,328.20
2013	10,473.50	1,008.13	2,286.73	3,509.40	129.87	0	1,646.17	1,745.33
2014	11,446.70	2,551.41	2,239.94	3,232.00	0	2,470.60	1,622.30	2,689.85
2015	10,133.30	2,420.47	1,853.53	2,277.42	0	2,136.60	2,420.14	1,257.04
2016	10,107.30	1,334.30	1,991.79	2,127.30	0	2,774.90	5,609.21	1,471.88
2017	11,487.60	2,176.72	2,053.32	3,111.65	0	1,356.61	6,662.68	1,706.31
2018	13,515.40	3,010.73	1,372.27	3,495.36	0	3,290.43	8,015.30	1,814.49
2019	18,496.70	3,784.27	861.45	2,513.27	0	2,473.98	6,753.01	2,525.29
2020	14,717.00	3,434.90	1,337.92	2,116.49	0	4,120.02	7,349.51	797.58
2021	16,777.90	4,629.16	1,051.77	1,639.42	0	3,237.30	5,523.80	901.87

Table 3. Available Catch Per Unit Effort indices for the northern blue shark stock.

	Venezuela LL	Spain BB	Portugal LL	US pelagic LL	Japan LL	Chinese-Taipei LL	Morocco LL
	VEN-LL	SPN-LL	POR-LL	US-LL	JPN-LL	CTP-LL	MOR-LL
SCRS Doc No.	SCRS/2015/022	SCRS/2023/040	SCRS/2023/045	SCRS/2023/046	SCRS/2023/050	SCRS/2023/059	SCRS/2023/058
Age range							
Catch Units	Number						
Effort Units	1000 hooks						
Std. Methods	Delta log-normal						

Year	VenLL.CPUE	VenLL.CV	SPLL.CPUE	SPLL.CV	POR.CPUE	POR.CV	US.CPUE	US.CV	JPN.CPUE	JPN.CV	CTP.CPUE	CTP.CV	MOR.CPUE	MOR.CV
1990														
1991														
1992							6.109	0.27						
1993							9.362	0.248						
1994	0.05	1.08					8.27	0.247	1.03	0.12				
1995	0.07	0.87					8.215	0.252	1.17	0.11				
1996	0.02	1.90					6.03	0.446	1.01	0.11				
1997	0.15	0.69	186.37	0.0226	160.89	0.08	12.443	0.284	1.06	0.12				
1998	0.22	0.67	180.36	0.0227	163.87	0.07	14.726	0.293	0.93	0.11				
1999	0.12	0.84	212.08	0.0248	141.54	0.07	6.711	0.278	0.64	0.12				
2000	0.15	0.74	285.83	0.0240	189.44	0.08	9.441	0.267	0.71	0.14				
2001	0.13	0.77	259.30	0.0236	215.57	0.08	4.877	0.324	0.74	0.11				
2002	0.07	1.03	222.91	0.0240	191.07	0.08	5.813	0.318	0.53	0.11				
2003	0.04	1.26	258.79	0.0273	229.91	0.08	3.897	0.293	0.77	0.10				
2004	0.03	1.53	233.39	0.0278	262.03	0.08	8.941	0.285	0.53	0.09				
2005	0.01	3.88	223.52	0.0293	217.76	0.08	3.584	0.293	0.69	0.07				
2006	0.01	2.24	221.88	0.0324	213.06	0.08	3.914	0.292	0.87	0.08				
2007	0.06	1.35	250.51	0.0335	235.13	0.08	6.665	0.312	1.02	0.09	0.55	0.07		
2008	0.09	1.16	289.60	0.0336	223.60	0.08	6.844	0.294	1.49	0.08	0.46	0.07		
2009	0.05	1.56	274.86	0.0320	233.14	0.08	6.383	0.294	1.24	0.11	0.52	0.07		
2010	0.04	1.54	269.23	0.0313	274.04	0.08	7.451	0.286	1.44	0.16	0.89	0.04	94	0.11
2011	0.04	1.51	279.63	0.0315	244.96	0.07	13.683	0.271	1.15	0.18	0.77	0.06	233	0.08
2012	0.11	1.00	275.01	0.0309	310.08	0.08	7.184	0.279	1.63	0.20	0.68	0.06	248	0.04
2013	0.04	1.84	288.31	0.0319	309.59	0.08	6.864	0.278	1.26	0.23	0.95	0.06	165	0.04
2014			272.34	0.0300	288.26	0.07	6.487	0.275	1.36	0.22	0.88	0.08	261	0.08
2015			281.97	0.0283	383.11	0.08	6.467	0.298	1.37	0.18	0.07	0.18	304	0.06
2016			257.40	0.0279	373.44	0.08	8.442	0.274	1.17	0.20	1.66	0.03	385	0.05
2017			244.98	0.0289	344.19	0.08	6.909	0.276	1.13	0.21	0.93	0.06	333	0.03
2018			241.42	0.0315	330.21	0.08	4.027	0.342	0.74	0.21	0.81	0.06	267	0.09
2019			239.11	0.0312	340.89	0.08	3.664	0.306	0.91	0.21	0.71	0.06	383	0.05
2020			260.78	0.0202	373.14	0.07	3.505	0.307	0.64	0.21	0.67	0.06	262	0.06
2021			263.46	0.0282	345.71	0.08	3.616	0.317	0.77	0.21	0.24	0.09	340	0.05
2022							4.25	0.33					270	0.07

Table 4. Available Catch Per Unit Effort indices for the southern blue shark stock.

	Spain BB		Japan LL		Chinese-Taipei LL		Brazil-Uruguay LL	
	SPN-LL		JPN-LL		CTP-LL		BRA_URY-LL	
SCRS Doc No.	SCRS/2023/041		SCRS/2023/049		SCRS/2023/059		SCRS/2023/057	
Age range								
Catch Units								
Effort Units								
Std. Methods								
Year	SP.CPUE	SP.CV	JPN.CPUE	JPN.CV	CTP.CPUE	CTP.CV	BRZ.CPUE	BRZ.CV
1990								
1991								
1992							1.13	0.147
1993							0.75	0.147
1994			1.11	0.14			0.48	0.101
1995			0.46	0.16			0.94	0.093
1996			0.72	0.19			0.55	0.072
1997	310.498	0.0254	0.75	0.17			0.57	0.051
1998	324.441	0.0282	0.63	0.16			0.8	0.041
1999	339.351	0.0283	0.71	0.16			0.61	0.044
2000	438.835	0.0301	0.48	0.19			0.67	0.042
2001	403.786	0.0254	0.46	0.21			0.7	0.041
2002	379.787	0.0263	0.53	0.23			0.63	0.035
2003	346.252	0.0286	0.7	0.18			0.66	0.041
2004	358.338	0.0313	0.6	0.18			0.58	0.035
2005	408.236	0.0361	0.59	0.19			0.67	0.036
2006	402.998	0.0352	0.94	0.17			0.48	0.038
2007	401.32	0.0372	0.91	0.16	0.85	0.06	0.68	0.039
2008	391.849	0.0319	1.34	0.13	1.13	0.06	0.86	0.039
2009	440.309	0.0306	1.21	0.11	0.88	0.06	0.91	0.033
2010	429.144	0.032	1.66	0.11	1.36	0.05	0.82	0.049
2011	412.368	0.0311	1.7	0.12	0.87	0.06	1.14	0.042
2012	443.843	0.0348	1.32	0.12	1.38	0.06	1.58	0.036
2013	445.452	0.0364	1.42	0.14	1.43	0.06	1.14	0.051
2014	471.983	0.0372	1.52	0.16	1.67	0.06	0.93	0.042
2015	481.62	0.0382	1.17	0.14	1.10	0.07	1.19	0.044
2016	562.566	0.042	1.22	0.16	1.70	0.05	0.88	0.049
2017	533.862	0.0403	1.22	0.16	0.93	0.06	1.02	0.102
2018	477.055	0.0363	1.23	0.14	1.16	0.05	1.24	0.042
2019	506.571	0.0309	1.23	0.17	0.72	0.06	1.28	0.055
2020	424.626	0.0206	1.08	0.17	2.35	0.05	0.72	0.072
2021	483.047	0.028	1.08	0.2	0.60	0.06	1.49	0.044
2022					0.96	0.04	1	0.046

Table 5. List of model parameters for north stock blue shark reference case of the stock synthesis model. Uninformative priors were used in this model, parameters with a negative phase were fixed at their initial value, and parameters estimated near their bounds (indicated below with an *) were not highly influential on overall model results.

Label	Value	Phase	Min	Max	Parm_StDev	Pr_type
SR_LN(R0)	8.02	1	2.3	13.82	0.02	SRR
SR_regime_BLK1add_1970	-0.11	1	-5	5	0.07	SRR
InitF_seas_1_flt_1F1_EU-ESP	0.05	1	0	0.2	0.01	InitF
InitF_seas_1_flt_2F2_JPN	0.01	1	0	0.2	0.00	InitF
InitF_seas_1_flt_3F3_CTP*	0.00	1	0	0.2	0.00	InitF
Size_DblN_peak_F1_EU-ESP(1)	93.09	2	35	370	3.31	Sel
Size_DblN_top_logit_F1_EU-ESP(1)	-2.60	3	-6	4	1.26	Sel
Size_DblN_ascend_se_F1_EU-ESP(1)	4.48	3	-1	9	0.48	Sel
Size_DblN_descend_se_F1_EU-ESP(1)	4.99	3	-1	9	24.12	Sel
Size_DblN_start_logit_F1_EU-ESP(1)	-15.00	-2	-15	9	_	Sel
Size_DblN_end_logit_F1_EU-ESP(1)	6.99	2	-15	9	5.74	Sel
SzSel_Fem_Peak_F1_EU-ESP(1)	10.87	4	-100	100	4.92	Sel
SzSel_Fem_Ascend_F1_EU-ESP(1)	1.00	4	-15	15	0.60	Sel
SzSel_Fem_Descend_F1_EU-ESP(1)	4.63	4	-15	15	24.14	Sel
SzSel_Fem_Final_F1_EU-ESP(1)*	-14.45	4	-15	15	14.17	Sel
SzSel_Fem_Scale_F1_EU-ESP(1)	0.82	5	0	1	0.08	Sel
Size_DblN_peak_F2_JPN(2)	171.51	2	35	370	11.30	Sel
Size_DblN_top_logit_F2_JPN(2)	4.00	-3	-6	4	_	Sel
Size_DblN_ascend_se_F2_JPN(2)	7.52	3	-1	9	0.36	Sel
Size_DblN_descend_se_F2_JPN(2)	-1.00	-3	-1	9	_	Sel
Size_DblN_start_logit_F2_JPN(2)	-15.00	-2	-15	9	_	Sel
Size_DblN_end_logit_F2_JPN(2)	9.00	-2	-15	9	_	Sel
SzSel_Male_Peak_F2_JPN(2)	52.16	4	-100	100	23.52	Sel
SzSel_Male_Ascend_F2_JPN(2)	1.02	4	-15	15	0.51	Sel
SzSel_Male_Descend_F2_JPN(2)	0.00	-4	-15	15	_	Sel
SzSel_Male_Final_F2_JPN(2)	0.00	-4	-15	15	_	Sel
SzSel_Male_Scale_F2_JPN(2)	0.85	5	0	1	0.22	Sel
Size_DblN_peak_F3_CTP(3)	183.46	2	35	370	6.69	Sel
Size_DblN_top_logit_F3_CTP(3)	4.00	-3	-6	4	_	Sel
Size_DblN_ascend_se_F3_CTP(3)	5.06	3	-1	9	0.87	Sel
Size_DblN_descend_se_F3_CTP(3)	-1.00	-3	-1	9	_	Sel
Size_DblN_start_logit_F3_CTP(3)	-15.00	-2	-15	9	_	Sel
Size_DblN_end_logit_F3_CTP(3)	9.00	-2	-15	9	_	Sel
SzSel_Male_Peak_F3_CTP(3)	19.58	4	-100	100	14.08	Sel
SzSel_Male_Ascend_F3_CTP(3)	1.40	4	-15	15	1.12	Sel
SzSel_Male_Descend_F3_CTP(3)	0.00	-4	-15	15	_	Sel
SzSel_Male_Final_F3_CTP(3)	0.00	-4	-15	15	_	Sel
SzSel_Male_Scale_F3_CTP(3)*	0.96	5	0	1	0.26	Sel

Table 5. Continued.

Label	Value	Phase	Min	Max	Parm_StDev	Pr_type
Size_DblN_peak_F4_USA(4)	121.95	2	35	370	7.06	Sel
Size_DblN_top_logit_F4_USA(4)	-5.38	3	-6	4	2.20	Sel
Size_DblN_ascend_se_F4_USA(4)	6.98	3	-1	9	0.36	Sel
Size_DblN_descend_se_F4_USA(4)	7.39	3	-1	9	0.84	Sel
Size_DblN_start_logit_F4_USA(4)	-15.00	-2	-15	9	_	Sel
Size_DblN_end_logit_F4_USA(4)	-1.96	2	-15	9	0.98	Sel
Size_DblN_peak_F5_VEN(5)	214.52	2	35	370	28.61	Sel
Size_DblN_top_logit_F5_VEN(5)	4.00	-3	-6	4	_	Sel
Size_DblN_ascend_se_F5_VEN(5)	7.93	3	-1	9	0.74	Sel
Size_DblN_descend_se_F5_VEN(5)	-1.00	-3	-1	9	_	Sel
Size_DblN_start_logit_F5_VEN(5)	-15.00	-2	-15	9	_	Sel
Size_DblN_end_logit_F5_VEN(5)	9.00	-2	-15	9	_	Sel
SzSel_Male_Peak_F5_VEN(5)	46.02	4	-100	100	86.91	Sel
SzSel_Male_Ascend_F5_VEN(5)	0.82	4	-15	15	1.36	Sel
SzSel_Male_Descend_F5_VEN(5)	0.00	-4	-15	15	_	Sel
SzSel_Male_Final_F5_VEN(5)	0.00	-4	-15	15	_	Sel
SzSel_Male_Scale_F5_VEN(5)*	0.94	5	0	1	0.90	Sel
SizeSel_P1_F6_CAN(6)	1.00	-99	0	10	_	Sel
SizeSel_P2_F6_CAN(6)	36.00	-99	10	100	_	Sel
Size_DblN_peak_F7_CPR(7)	133.66	2	35	370	28.86	Sel
Size_DblN_top_logit_F7_CPR(7)	-0.73	3	-6	4	0.71	Sel
Size_DblN_ascend_se_F7_CPR(7)	6.43	3	-1	9	1.75	Sel
Size_DblN_descend_se_F7_CPR(7)	5.33	3	-1	9	3.83	Sel
Size_DblN_start_logit_F7_CPR(7)	-15.00	-2	-15	9	_	Sel
Size_DblN_end_logit_F7_CPR(7)	-4.69	2	-15	9	15.85	Sel
SzSel_Male_Peak_F7_CPR(7)	-11.00	4	-100	100	40.81	Sel
SzSel_Male_Ascend_F7_CPR(7)	-0.23	4	-15	15	2.82	Sel
SzSel_Male_Descend_F7_CPR(7)	2.25	4	-15	15	3.73	Sel
SzSel_Male_Final_F7_CPR(7)	-3.15	4	-15	15	151.91	Sel
SzSel_Male_Scale_F7_CPR(7)	0.86	5	0	1	0.40	Sel
SizeSel_P1_F8_BEL(8)	1.00	-99	0	10	_	Sel
SizeSel_P2_F8_BEL(8)	36.00	-99	10	100	_	Sel
SizeSel_P1_F9_OTH(9)	1.00	-99	0	10	_	Sel
SizeSel_P2_F9_OTH(9)	36.00	-99	10	100	_	Sel

Table 5. Continued.

Label	Value	Phase	Min	Max	Parm_StDev	Pr_type
Size_DblN_peak_F10_EU-POR(10)	222.39	2	35	370	27.84	Sel
Size_DblN_top_logit_F10_EU-POR(10)	4.00	-3	-6	4	_	Sel
Size_DblN_ascend_se_F10_EU-POR(10)	8.60	3	-1	9	0.47	Sel
Size_DblN_descend_se_F10_EU-POR(10)	-1.00	-3	-1	9	_	Sel
Size_DblN_start_logit_F10_EU-POR(10)	-15.00	-2	-15	9	_	Sel
Size_DblN_end_logit_F10_EU-POR(10)	9.00	-2	-15	9	_	Sel
SzSel_Fem_Peak_F10_EU-POR(10)	2.83	4	-100	100	34.35	Sel
SzSel_Fem_Ascend_F10_EU-POR(10)	0.10	4	-15	15	0.61	Sel
SzSel_Fem_Descend_F10_EU-POR(10)	0.00	-4	-15	15	_	Sel
SzSel_Fem_Final_F10_EU-POR(10)	0.00	-4	-15	15	_	Sel
SzSel_Fem_Scale_F10_EU-POR(10)	0.71	5	0	1	0.27	Sel

Table 6. List of model parameters for south stock blue shark reference case of the stock synthesis model. Estimated values (value) and their associated asymptotic errors (lower low STdEr and upper Up STdEr) initial parameter values (Init), minimum (Min), and maximum (Max) values, priors (Prior) if used, and whether the parameter was fixed or estimated (negative Phase integers indicate the parameter was fixed, whereas positive values indicate it was estimated).

Label	Phase	Value	Init	Min	Max	Prior type	Prior	low STdEr	Up STdEr
L_at_Amin_Fem_GP_1	-3	47	47	-50	100	No_prior	NA	NA	NA
L_at_Amax_Fem_GP_1	-2	291.8	291.8	1	500	No_prior	NA	NA	NA
VonBert_K_Fem_GP_1	-3	0.13	0.13	0.001	2	No_prior	NA	NA	NA
CV_young_Fem_GP_1	-4	0.1	0.1	0.001	5	No_prior	NA	NA	NA
CV_old_Fem_GP_1	-4	0.1	0.1	0.001	5	No_prior	NA	NA	NA
Wtlen_1_Fem_GP_1	-99	1.10E-06	1.10E-06	0	3	No_prior	NA	NA	NA
Wtlen_2_Fem_GP_1	-99	3.35	3.35	2	4	No_prior	NA	NA	NA
Mat50%_Fem_GP_1	-99	183.8	183.8	1.00E-04	1000	No_prior	NA	NA	NA
Mat_slope_Fem_GP_1	-99	-0.1326	-0.1326	-2	4	No_prior	NA	NA	NA
Eggs_intercept_Fem_GP_1	-3	-23.655	-23.655	-50	10	Normal	-23.66	-23.655	-23.655
Eggs_slope_len_Fem_GP_1	-3	0.27966	0.27966	-3	3	Normal	0.2797	0.27966	0.27966
L_at_Amin_Mal_GP_1	-3	47	47	-50	100	No_prior	NA	NA	NA
L_at_Amax_Mal_GP_1	-2	291.8	291.8	1	500	No_prior	NA	NA	NA
VonBert_K_Mal_GP_1	-3	0.13	0.13	0.001	2	No_prior	NA	NA	NA
CV_young_Mal_GP_1	-4	0.1	0.1	0.001	5	No_prior	NA	NA	NA
CV_old_Mal_GP_1	-4	0.1	0.1	0.001	5	No_prior	NA	NA	NA
Wtlen_1_Mal_GP_1	-99	2.20E-06	2.20E-06	0	3	No_prior	NA	NA	NA
Wtlen_2_Mal_GP_1	-99	3.189	3.189	2	4	No_prior	NA	NA	NA
CohortGrowDev	-1	1	1	0.1	10	No_prior	NA	NA	NA
FracFemale_GP_1	-99	0.5	0.5	0.01	0.99	No_prior	NA	NA	NA
SR_LN(R0)	1	8.10363	8.10363	1.00E-04	20	No_prior	NA	NA	NA
SR_BH_steep	-1	0.8	0.8	0.2	1	Log_Norm	0.8	0.8	0.8
SR_sigmaR	-6	0.5	0.5	0	2	No_prior	NA	NA	NA
SR_regime	-99	0	0	-5	5	No_prior	NA	NA	NA
SR_autocorr	-99	0	0	0	2	No_prior	NA	NA	NA
SR_regime_BLK1add_1970	1	-0.0295	-0.0295	-5	5	Normal	0	-0.228315	0.169366

Early_RecrDev_1990	0	-0.6713	0	-5	5	dev	NA	NA	NA
Early_RecrDev_1991	0	-0.6075	0	-5	5	dev	NA	NA	NA
Early_RecrDev_1992	0	-0.5142	0	-5	5	dev	NA	NA	NA
Early_RecrDev_1993	0	-0.3912	0	-5	5	dev	NA	NA	NA
Early_RecrDev_1994	0	-0.1678	0	-5	5	dev	NA	NA	NA
Main_RecrDev_1995	2	-0.4508	0	-5	5	dev	NA	NA	NA
Main_RecrDev_1996	2	-0.4796	0	-5	5	dev	NA	NA	NA
Main_RecrDev_1997	2	-0.3385	0	-5	5	dev	NA	NA	NA
Main_RecrDev_1998	2	0.12434	0	-5	5	dev	NA	NA	NA
Main_RecrDev_1999	2	-0.0758	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2000	2	-0.2725	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2001	2	-0.28	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2002	2	0.01182	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2003	2	0.05354	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2004	2	-0.0353	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2005	2	0.12025	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2006	2	0.25084	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2007	2	0.02791	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2008	2	0.49598	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2009	2	0.09897	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2010	2	0.07032	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2011	2	-0.0738	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2012	2	0.45716	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2013	2	0.40108	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2014	2	-0.1758	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2015	2	0.04182	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2016	2	-0.0369	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2017	2	0.12542	0	-5	5	dev	NA	NA	NA
Main_RecrDev_2018	2	-0.0604	0	-5	5	dev	NA	NA	NA
Late_RecrDev_2019	1	0.2736	0	-5	5	dev	NA	NA	NA
Late_RecrDev_2020	1	-0.0489	0	-5	5	dev	NA	NA	NA
Late_RecrDev_2021	1	0	0	-5	5	dev	NA	NA	NA
ForeRecr_2022	1	0	0	-5	5	dev	NA	NA	NA
InitF_seas_1_flt_2FS2_BRA	1	0.00089	0.00089	0	0.2	Normal	0.03	0.00065226	0.0011304
InitF_seas_1_flt_3FS3_CHI_TAI	1	0.01007	0.01007	0	0.2	Normal	0.03	0.00721589	0.0129197
InitF_seas_1_flt_4FS4_JPN	1	0.00859	0.00859	0	0.2	Normal	0.03	0.00630999	0.0108704
LnQ_base_FS1_EU_SPN(1)	-1	-11.415	-11.415	-15	15	No_prior	NA	NA	NA
LnQ_base_FS3_CHI_TAI(3)	-1	-7.7128	-7.7128	-15	15	No_prior	NA	NA	NA
LnQ_base_BRA_index_TB1(9)	-1	-8.1441	-8.1441	-15	15	No_prior	NA	NA	NA
LnQ_base_BRA_index_TB2(10)	-1	-7.6669	-7.6669	-15	15	No_prior	NA	NA	NA
LnQ_base_JPN_index_TB1(11)	-1	-8.7328	-8.7328	-15	15	No_prior	NA	NA	NA
LnQ_base_JPN_index_TB2(12)	-1	-8.1203	-8.1203	-15	15	No_prior	NA	NA	NA
Size_DblN_peak_FS1_EU_SPN(1)	2	201.843	201.843	15	365	No_prior	NA	NA	NA
Size_DblN_top_logit_FS1_EU_SPN(1)	1	-3.0801	-3.0801	-15	15	No_prior	NA	NA	NA
Size_DblN_ascend_se_FS1_EU_SPN(1)	2	6.96066	6.96066	-4	12	No_prior	NA	NA	NA

Size_DblN_descend_se_FS1_EU_SPN(1)	1	6.64031	6.64031	-15	15	No_prior	NA	NA	NA
Size_DblN_start_logit_FS1_EU_SPN(1)	-2	-15	-15	-999	15	No_prior	NA	NA	NA
Size_DblN_end_logit_FS1_EU_SPN(1)	1	-4.9849	-4.9849	-5	20	No_prior	NA	NA	NA
Size_DblN_peak_FS2_BRA(2)	2	178.829	178.829	15	365	No_prior	NA	NA	NA
Size_DblN_top_logit_FS2_BRA(2)	-1	15	15	-15	15	No_prior	NA	NA	NA
Size_DblN_ascend_se_FS2_BRA(2)	2	7.34907	7.34907	-4	12	No_prior	NA	NA	NA
Size_DblN_descend_se_FS2_BRA(2)	-1	-15	-15	-15	6	No_prior	NA	NA	NA
Size_DblN_start_logit_FS2_BRA(2)	-2	-15	-15	-999	15	No_prior	NA	NA	NA
Size_DblN_end_logit_FS2_BRA(2)	-1	15	15	-5	20	No_prior	NA	NA	NA
SzSel_Fem_Peak_FS2_BRA(2)	-3	19.8789	19.8789	-20	20	No_prior	NA	NA	NA
SzSel_Fem_Ascend_FS2_BRA(2)	-2	0.45162	0.45162	-4	12	No_prior	NA	NA	NA
SzSel_Fem_Descend_FS2_BRA(2)	-4	0	0	-15	15	No_prior	NA	NA	NA
SzSel_Fem_Final_FS2_BRA(2)	-3	-493.05	-493.05	-999	15	No_prior	NA	NA	NA
SzSel_Fem_Scale_FS2_BRA(2)	-5	0.51823	0.51823	-15	15	No_prior	NA	NA	NA
Size_DblN_peak_FS3_CHI_TAI(3)	2	208.732	208.732	15	365	No_prior	NA	NA	NA
Size_DblN_top_logit_FS3_CHI_TAI(3)	-1	15	15	-15	15	No_prior	NA	NA	NA
Size_DblN_ascend_se_FS3_CHI_TAI(3)	2	7.44219	7.44219	-4	12	No_prior	NA	NA	NA
Size_DblN_descend_se_FS3_CHI_TAI(3)	-1	-15	-15	-15	6	No_prior	NA	NA	NA
Size_DblN_start_logit_FS3_CHI_TAI(3)	-2	-15	-15	-999	15	No_prior	NA	NA	NA
Size_DblN_end_logit_FS3_CHI_TAI(3)	-1	15	15	-5	20	No_prior	NA	NA	NA
Size_inflection_FS4_JPN(4)	2	137.56	137.56	50	190	No_prior	NA	NA	NA
Size_95%width_FS4_JPN(4)	-3	55.8	55.8	0.01	100	No_prior	NA	NA	NA
SzSel_Fem_Infl_FS4_JPN(4)	-2	-5	-5	-50	50	No_prior	NA	NA	NA
SzSel_Fem_Slope_FS4_JPN(4)	-3	-5	-5	-50	50	No_prior	NA	NA	NA
SzSel_Fem_Scale_FS4_JPN(4)	-4	1	1	-1	5	No_prior	NA	NA	NA
Size_inflection_FS5_URY(5)	2	120.094	120.094	50	180	No_prior	NA	NA	NA
Size_95%width_FS5_URY(5)	3	37.6717	37.6717	0.01	100	No_prior	NA	NA	NA
Size_inflection_FS6_NAMB(6)	2	81.3523	81.3524	50	180	No_prior	NA	NA	NA
Size_95%width_FS6_NAMB(6)	3	51.7939	51.7939	0.01	100	No_prior	NA	NA	NA
Size_DblN_peak_FS11_EU_POR(7)	2	201.717	201.717	15	365	No_prior	NA	NA	NA
Size_DblN_top_logit_FS11_EU_POR(7)	1	-8.0471	-8.0471	-15	15	No_prior	NA	NA	NA
Size_DblN_ascend_se_FS11_EU_POR(7)	2	6.34127	6.34127	-4	12	No_prior	NA	NA	NA
Size_DblN_descend_se_FS11_EU_POR(7)	1	7.60007	7.60007	-15	15	No_prior	NA	NA	NA
Size_DblN_start_logit_FS11_EU_POR(7)	-2	-15	-15	-999	15	No_prior	NA	NA	NA
Size_DblN_end_logit_FS11_EU_POR(7)	1	-3.906	-3.906	-5	20	No_prior	NA	NA	NA
Size_inflection_FS10_ELSE(8)	2	144.037	144.037	50	180	No_prior	NA	NA	NA
Size_95%width_FS10_ELSE(8)	3	66.0421	66.0421	0.01	100	No_prior	NA	NA	NA

Table 7. Summary of posterior quantiles presented in the form of marginal posterior medians and associated 95% probability intervals (2.5% LCI and 97.5% UCI) of parameters for the North Atlantic blue shark JABBA reference case. The parameters "SQRT(tau2)" are the square root of the JABBA-estimated additional variance term for the process error of each abundance index.

	50%	2.5%	97.5%
K	277107	202555	386920
r	0.40	0.25	0.64
m	1.45	0.92	2.27
B_{MSY}/K	0.44	0.35	0.52
B_{MSY}	120012	83682	176399
F_{MSY}	0.28	0.18	0.42
MSY	33822	31085	36465
psi	0.72	0.45	0.93
cvProcErr	0.07	0.04	0.11
SQRT(tau2)VEN	0.14	0.03	0.67
SQRT(tau2)SPN	0.06	0.02	0.15
SQRT(tau2)POR	0.07	0.02	0.20
SQRT(tau2)USA1	0.24	0.05	0.46
SQRT(tau2)USA2	0.12	0.03	0.48
SQRT(tau2)JPN	0.15	0.05	0.27
SQRT(tau2)CTP	0.13	0.03	0.48
SQRT(tau2)MOR	0.27	0.11	0.55
qVEN	9.2E-07	4.7E-07	1.8E-06
qSPN	2.5E-03	1.5E-03	4.3E-03
qPOR	2.6E-03	1.5E-03	4.3E-03
qUSA1	7.4E-05	4.3E-05	1.2E-04
qUSA2	4.5E-05	2.5E-05	8.0E-05
qJPN	9.7E-06	5.8E-06	1.6E-05
qCTP	7.5E-06	4.1E-06	1.3E-05
qMOR	2.4E-03	1.4E-03	4.2E-03

Table 8. Summary of posterior quantiles presented in the form of marginal posterior medians and associated with the 95% credibility intervals (95% LCI and 95% UCI) of parameters for the JABBA reference case for the South Atlantic blue shark stock.

	Median	**LCI**	**UCI**
K	302,747	205,505	505,597
r	0.335	0.231	0.487
psi	0.906	0.799	0.970
sigma.proc	0.069	0.031	0.124
m	1.517	1.517	1.517
F_{MSY}	0.221	0.152	0.321
B_{MSY}	135,211	91,781	225,806
MSY	29,299	23,128	47,758
B_{MSY}/K	0.447	0.447	0.447
B_{1971}/K	0.901	0.743	1.067
B_{2021}/K	0.628	0.417	0.837
B_{2021}/B_{MSY}	1.406	0.933	1.874
F_{2021}/F_{MSY}	0.824	0.390	1.468
q.1	0.000	0.000	0.000
q.2	0.000	0.000	0.000
q.3	0.000	0.000	0.000
q.4	0.000	0.000	0.000
q.5	0.000	0.000	0.000
q.6	0.000	0.000	0.000
psi	0.906	0.799	0.970
sigma2	0.005	0.001	0.015
tau2.1	0.002	0.000	0.015
tau2.2	0.018	0.001	0.119
tau2.3	0.004	0.000	0.032
tau2.4	0.026	0.001	0.189
tau2.5	0.005	0.001	0.036
tau2.6	0.025	0.002	0.112

Table 9. Annual estimates of relative biomass (B/B_{MSY}) and fishing mortality (F/F_{MSY}) from the JABBA and Stock Synthesis models for the North Atlantic blue shark stock. Joint results show the combined estimates from both platforms.

Contents	B/Bmsy or SSB/SSBmsy									F/Fmsy								
Method	JABBA			Stock Synthesis			joint results			JABBA			Stock Synthesis			joint results		
Year	median	95%LCI	95%UCI	median	95%LCI	95%UCI	median	95%LCI	95%UCI	median	95%LCI	95%UCI	median	95%LCI	95%UCI	median	95%LCI	95%UCI
1971	1.63	1.04	2.31							0.29	0.21	0.47						
1972	1.70	1.17	2.27	2.26	1.82	2.80	2.00	1.26	2.71	0.28	0.21	0.42	0.30	0.25	0.36	0.29	0.22	0.39
1973	1.75	1.28	2.24	2.27	1.83	2.80	2.01	1.37	2.71	0.29	0.23	0.42	0.34	0.28	0.41	0.32	0.24	0.41
1974	1.78	1.37	2.21	2.27	1.83	2.80	2.01	1.45	2.71	0.27	0.22	0.36	0.29	0.24	0.34	0.28	0.22	0.35
1975	1.81	1.46	2.21	2.25	1.83	2.78	2.01	1.53	2.69	0.34	0.27	0.43	0.37	0.31	0.43	0.35	0.28	0.43
1976	1.80	1.50	2.17	2.28	1.87	2.78	2.02	1.55	2.70	0.22	0.18	0.28	0.25	0.22	0.30	0.24	0.19	0.29
1977	1.85	1.57	2.21	2.31	1.93	2.76	2.07	1.61	2.68	0.29	0.24	0.35	0.32	0.27	0.36	0.30	0.24	0.36
1978	1.85	1.59	2.20	2.33	1.98	2.72	2.08	1.63	2.66	0.33	0.28	0.40	0.39	0.35	0.45	0.37	0.29	0.44
1979	1.82	1.58	2.16	2.36	2.05	2.72	2.10	1.62	2.66	0.24	0.20	0.28	0.30	0.26	0.34	0.27	0.20	0.34
1980	1.86	1.62	2.20	2.36	2.07	2.68	2.13	1.65	2.63	0.36	0.30	0.43	0.41	0.37	0.46	0.39	0.31	0.45
1981	1.82	1.59	2.15	2.34	2.08	2.63	2.11	1.62	2.58	0.39	0.33	0.46	0.42	0.38	0.47	0.41	0.34	0.46
1982	1.78	1.56	2.09	2.31	2.07	2.58	2.08	1.59	2.53	0.43	0.36	0.50	0.46	0.41	0.51	0.45	0.37	0.51
1983	1.73	1.52	2.04	2.26	2.04	2.50	2.04	1.55	2.46	0.60	0.50	0.71	0.69	0.62	0.76	0.65	0.52	0.75
1984	1.62	1.44	1.90	2.21	2.01	2.44	1.97	1.46	2.40	0.55	0.46	0.64	0.60	0.54	0.66	0.58	0.48	0.65
1985	1.58	1.41	1.84	2.14	1.95	2.35	1.92	1.43	2.32	0.68	0.57	0.79	0.74	0.67	0.81	0.72	0.59	0.81
1986	1.50	1.34	1.74	2.03	1.85	2.22	1.81	1.36	2.19	0.95	0.80	1.09	1.03	0.94	1.14	1.00	0.83	1.13
1987	1.33	1.19	1.55	1.88	1.71	2.06	1.65	1.21	2.03	1.23	1.04	1.41	1.29	1.17	1.42	1.27	1.07	1.42
1988	1.13	0.99	1.34	1.74	1.58	1.92	1.50	1.00	1.89	1.24	1.02	1.43	1.21	1.09	1.35	1.22	1.05	1.40
1989	1.01	0.85	1.22	1.65	1.50	1.82	1.42	0.87	1.79	0.92	0.74	1.10	0.83	0.75	0.93	0.86	0.75	1.07
1990	1.03	0.87	1.24	1.57	1.42	1.73	1.36	0.90	1.70	0.91	0.73	1.10	0.92	0.81	1.06	0.92	0.76	1.08
1991	1.05	0.89	1.25	1.47	1.32	1.63	1.30	0.91	1.60	1.06	0.85	1.29	1.07	0.92	1.24	1.07	0.88	1.27
1992	1.00	0.84	1.24	1.38	1.24	1.54	1.24	0.86	1.52	1.08	0.85	1.31	1.01	0.87	1.18	1.04	0.86	1.27
1993	0.97	0.82	1.24	1.28	1.14	1.44	1.17	0.84	1.41	1.33	1.02	1.60	1.34	1.16	1.55	1.33	1.07	1.57
1994	0.88	0.72	1.16	1.20	1.07	1.35	1.09	0.75	1.33	1.25	0.93	1.52	1.16	1.02	1.33	1.20	0.98	1.47
1995	0.84	0.69	1.13	1.10	0.96	1.25	1.00	0.71	1.23	1.43	1.04	1.73	1.49	1.28	1.74	1.46	1.12	1.74
1996	0.76	0.61	1.04	0.99	0.85	1.15	0.90	0.63	1.13	1.40	1.00	1.72	1.29	1.12	1.49	1.33	1.07	1.67
1997	0.71	0.56	0.98	0.92	0.78	1.09	0.84	0.58	1.07	1.43	1.02	1.78	1.34	1.15	1.56	1.37	1.09	1.72
1998	0.67	0.52	0.94	0.89	0.75	1.06	0.80	0.54	1.04	1.35	0.95	1.70	1.27	1.08	1.49	1.30	1.01	1.64
1999	0.66	0.51	0.92	0.85	0.71	1.02	0.77	0.53	1.00	1.36	0.94	1.71	1.23	1.04	1.45	1.27	1.00	1.66
2000	0.67	0.52	0.96	0.80	0.66	0.97	0.75	0.54	0.97	1.41	0.96	1.79	1.42	1.20	1.68	1.42	1.05	1.75
2001	0.64	0.48	0.93	0.76	0.62	0.93	0.71	0.50	0.93	1.16	0.78	1.51	1.13	0.96	1.34	1.14	0.85	1.46
2002	0.64	0.48	0.92	0.74	0.60	0.91	0.70	0.50	0.91	1.06	0.71	1.38	1.04	0.88	1.24	1.05	0.77	1.34
2003	0.67	0.51	0.97	0.72	0.58	0.88	0.70	0.53	0.92	1.19	0.80	1.54	1.02	0.85	1.21	1.07	0.84	1.48
2004	0.67	0.50	0.97	0.72	0.58	0.88	0.70	0.52	0.92	1.12	0.76	1.47	1.07	0.89	1.29	1.09	0.82	1.41
2005	0.69	0.51	0.98	0.73	0.59	0.89	0.71	0.53	0.93	1.09	0.74	1.42	0.90	0.75	1.07	0.96	0.75	1.36
2006	0.73	0.56	1.04	0.74	0.61	0.90	0.74	0.57	0.98	1.00	0.69	1.29	0.88	0.75	1.04	0.92	0.72	1.24
2007	0.82	0.63	1.14	0.74	0.61	0.91	0.77	0.62	1.07	0.99	0.70	1.27	0.98	0.84	1.15	0.99	0.75	1.23
2008	0.89	0.70	1.23	0.75	0.62	0.92	0.81	0.64	1.15	1.05	0.74	1.32	1.09	0.92	1.29	1.07	0.80	1.30
2009	0.92	0.72	1.25	0.78	0.64	0.95	0.84	0.66	1.18	1.17	0.84	1.47	1.07	0.91	1.26	1.11	0.88	1.42
2010	0.93	0.73	1.26	0.82	0.67	0.99	0.86	0.69	1.19	1.23	0.88	1.54	1.16	0.99	1.37	1.19	0.93	1.49
2011	0.93	0.73	1.27	0.87	0.71	1.05	0.89	0.72	1.20	1.25	0.89	1.57	1.21	1.02	1.43	1.23	0.95	1.52
2012	0.93	0.73	1.28	0.89	0.73	1.09	0.91	0.73	1.21	1.17	0.83	1.48	1.16	0.98	1.38	1.16	0.89	1.43
2013	0.94	0.73	1.30	0.89	0.72	1.09	0.91	0.73	1.22	1.16	0.82	1.47	1.09	0.92	1.28	1.11	0.88	1.42
2014	0.97	0.76	1.34	0.92	0.75	1.12	0.94	0.76	1.27	1.17	0.82	1.46	1.20	1.03	1.41	1.19	0.89	1.44
2015	1.01	0.80	1.41	0.98	0.80	1.19	0.99	0.80	1.32	1.18	0.83	1.48	1.25	1.07	1.46	1.22	0.89	1.47
2016	1.02	0.80	1.44	1.00	0.82	1.22	1.01	0.81	1.35	1.29	0.89	1.61	1.38	1.18	1.63	1.35	0.96	1.62
2017	0.94	0.72	1.35	1.02	0.83	1.25	0.99	0.75	1.29	1.27	0.86	1.61	1.33	1.11	1.58	1.30	0.93	1.59
2018	0.87	0.65	1.26	1.04	0.85	1.28	0.98	0.68	1.27	1.16	0.78	1.52	1.12	0.93	1.35	1.14	0.84	1.46
2019	0.86	0.63	1.24	1.06	0.87	1.30	0.98	0.66	1.28	0.95	0.63	1.26	1.00	0.82	1.23	0.98	0.69	1.24
2020	0.88	0.65	1.26	1.05	0.86	1.29	0.98	0.68	1.28	0.72	0.49	0.96	0.77	0.62	0.95	0.75	0.52	0.95
2021	0.96	0.71	1.35	1.03	0.84	1.27	1.00	0.75	1.30	0.68	0.47	0.91	0.73	0.56	0.95	0.70	0.50	0.93

Table 10. Annual estimates of relative biomass (B/B$_{MSY}$) and fishing mortality (F/F$_{MSY}$) from the JABBA and Stock Synthesis models for the South Atlantic blue shark stock. Joint results show the combined estimates from both platforms.

Contents	B/Bmsy or SSB/SSBmsy									F/Fmsy								
Method	JABBA			Stock Synthesis			joint results			JABBA			Stock Synthesis			joint results		
Year	median	95%LCI	95%UCI	median	95%LCI	95%UCI	median	95%LCI	95%UCI	median	95%LCI	95%UCI	median	95%LCI	95%UCI	median	95%LCI	95%UCI
1971	2.02	1.66	2.39							0.08	0.05	0.11						
1972	2.05	1.67	2.48	3.51	2.79	4.42	2.65	1.73	4.26	0.09	0.05	0.12	0.05	0.04	0.06	0.06	0.04	0.12
1973	2.07	1.67	2.52	3.51	2.79	4.42	2.68	1.74	4.26	0.11	0.07	0.16	0.06	0.04	0.08	0.08	0.05	0.15
1974	2.07	1.65	2.53	3.54	2.81	4.45	2.69	1.73	4.29	0.07	0.04	0.11	0.04	0.03	0.05	0.05	0.03	0.10
1975	2.09	1.66	2.55	3.56	2.85	4.45	2.72	1.74	4.29	0.07	0.04	0.10	0.04	0.03	0.05	0.05	0.03	0.09
1976	2.10	1.66	2.57	3.59	2.91	4.42	2.77	1.75	4.27	0.07	0.04	0.11	0.04	0.03	0.05	0.05	0.03	0.10
1977	2.11	1.68	2.57	3.57	2.94	4.33	2.80	1.76	4.20	0.15	0.09	0.22	0.08	0.06	0.10	0.10	0.06	0.21
1978	2.08	1.65	2.53	3.54	2.98	4.22	2.79	1.74	4.10	0.17	0.10	0.25	0.09	0.07	0.11	0.11	0.07	0.23
1979	2.05	1.62	2.50	3.51	3.00	4.11	2.83	1.70	4.00	0.19	0.11	0.27	0.09	0.07	0.12	0.12	0.08	0.26
1980	2.02	1.58	2.48	3.47	3.01	4.01	2.81	1.66	3.91	0.21	0.12	0.31	0.11	0.09	0.13	0.13	0.09	0.29
1981	1.99	1.54	2.44	3.47	3.04	3.96	2.83	1.63	3.87	0.13	0.08	0.20	0.07	0.05	0.09	0.08	0.06	0.19
1982	2.00	1.56	2.46	3.42	3.02	3.89	2.82	1.64	3.80	0.23	0.13	0.35	0.12	0.09	0.14	0.14	0.10	0.32
1983	1.97	1.52	2.43	3.44	3.06	3.88	2.85	1.60	3.80	0.10	0.06	0.15	0.05	0.04	0.06	0.06	0.04	0.14
1984	2.00	1.54	2.46	3.43	3.05	3.86	2.84	1.62	3.78	0.17	0.10	0.26	0.08	0.07	0.10	0.10	0.07	0.24
1985	1.99	1.54	2.45	3.42	3.05	3.84	2.86	1.62	3.77	0.14	0.08	0.22	0.07	0.06	0.09	0.09	0.06	0.20
1986	2.00	1.55	2.44	3.39	3.03	3.80	2.85	1.62	3.74	0.20	0.12	0.31	0.10	0.09	0.13	0.12	0.09	0.29
1987	1.97	1.51	2.41	3.39	3.16	3.63	3.00	1.60	3.59	0.16	0.09	0.25	0.09	0.07	0.10	0.10	0.07	0.23
1988	1.97	1.51	2.41	3.31	3.10	3.53	2.97	1.59	3.49	0.29	0.17	0.45	0.20	0.18	0.23	0.22	0.17	0.42
1989	1.91	1.44	2.35	3.19	2.99	3.40	2.87	1.52	3.36	0.39	0.22	0.61	0.29	0.26	0.34	0.31	0.24	0.57
1990	1.82	1.34	2.26	3.05	2.86	3.25	2.74	1.44	3.22	0.47	0.26	0.75	0.32	0.28	0.37	0.35	0.27	0.69
1991	1.73	1.25	2.17	2.95	2.77	3.15	2.65	1.33	3.12	0.42	0.22	0.68	0.29	0.25	0.33	0.31	0.24	0.63
1992	1.69	1.19	2.12	2.86	2.68	3.05	2.58	1.27	3.02	0.47	0.25	0.78	0.32	0.27	0.37	0.35	0.27	0.72
1993	1.62	1.12	2.05	2.77	2.59	2.96	2.44	1.20	2.93	0.49	0.25	0.83	0.34	0.29	0.40	0.37	0.28	0.77
1994	1.55	1.06	1.99	2.60	2.42	2.80	2.31	1.14	2.76	0.59	0.29	1.02	0.42	0.35	0.49	0.45	0.33	0.94
1995	1.44	0.94	1.89	2.35	2.15	2.57	2.07	1.02	2.53	0.69	0.33	1.24	0.55	0.46	0.64	0.57	0.38	1.12
1996	1.36	0.87	1.83	2.06	1.84	2.31	1.83	0.96	2.27	0.76	0.36	1.38	0.61	0.51	0.74	0.64	0.41	1.26
1997	1.28	0.82	1.76	1.87	1.62	2.14	1.67	0.89	2.10	0.62	0.28	1.14	0.48	0.40	0.59	0.51	0.33	1.04
1998	1.31	0.84	1.79	1.74	1.49	2.02	1.58	0.92	1.98	0.57	0.26	1.03	0.49	0.40	0.61	0.51	0.30	0.94
1999	1.31	0.84	1.80	1.62	1.36	1.92	1.51	0.92	1.88	0.60	0.28	1.10	0.59	0.47	0.73	0.59	0.32	1.00
2000	1.32	0.85	1.80	1.50	1.24	1.81	1.44	0.93	1.81	0.60	0.28	1.09	0.64	0.50	0.80	0.63	0.32	1.00
2001	1.32	0.85	1.80	1.41	1.15	1.73	1.38	0.93	1.77	0.54	0.25	0.99	0.65	0.51	0.82	0.62	0.29	0.91
2002	1.32	0.86	1.79	1.37	1.11	1.69	1.35	0.93	1.75	0.58	0.27	1.05	0.63	0.49	0.82	0.62	0.31	0.96
2003	1.32	0.86	1.80	1.34	1.08	1.66	1.33	0.93	1.75	0.69	0.32	1.26	0.74	0.57	0.95	0.72	0.37	1.15
2004	1.29	0.83	1.78	1.33	1.07	1.66	1.32	0.90	1.73	0.59	0.27	1.09	0.66	0.52	0.85	0.64	0.32	0.99
2005	1.34	0.87	1.81	1.27	1.01	1.60	1.30	0.94	1.74	0.68	0.32	1.23	0.78	0.60	1.01	0.75	0.37	1.14
2006	1.33	0.86	1.80	1.23	0.98	1.56	1.27	0.92	1.73	0.63	0.30	1.14	0.77	0.60	1.00	0.73	0.34	1.06
2007	1.39	0.91	1.84	1.20	0.95	1.52	1.28	0.94	1.77	0.66	0.31	1.17	0.87	0.68	1.12	0.80	0.36	1.14
2008	1.40	0.93	1.85	1.18	0.93	1.50	1.27	0.93	1.78	0.66	0.32	1.16	0.89	0.70	1.15	0.82	0.36	1.15
2009	1.43	0.96	1.87	1.17	0.92	1.50	1.28	0.93	1.80	0.63	0.31	1.11	0.95	0.74	1.21	0.84	0.35	1.19
2010	1.52	1.05	1.96	1.15	0.90	1.48	1.30	0.92	1.90	0.72	0.36	1.23	1.10	0.85	1.42	0.96	0.41	1.38
2011	1.55	1.08	2.01	1.09	0.83	1.44	1.28	0.86	1.93	0.83	0.41	1.41	1.34	1.02	1.75	1.14	0.47	1.68
2012	1.52	1.04	2.01	1.15	0.88	1.50	1.30	0.91	1.92	0.63	0.30	1.07	0.93	0.71	1.24	0.82	0.35	1.20
2013	1.51	1.02	1.99	1.27	0.99	1.64	1.37	1.00	1.92	0.47	0.23	0.81	0.64	0.49	0.85	0.58	0.26	0.84
2014	1.54	1.05	2.00	1.34	1.04	1.73	1.43	1.04	1.93	0.58	0.29	1.01	0.73	0.55	0.96	0.68	0.33	0.98
2015	1.51	1.02	1.96	1.39	1.08	1.79	1.44	1.06	1.91	0.51	0.25	0.88	0.63	0.48	0.82	0.59	0.29	0.85
2016	1.53	1.04	1.98	1.43	1.11	1.84	1.47	1.08	1.93	0.57	0.28	0.98	0.71	0.54	0.92	0.66	0.32	0.95
2017	1.53	1.04	1.98	1.48	1.16	1.90	1.51	1.10	1.95	0.64	0.32	1.10	0.79	0.61	1.03	0.74	0.36	1.06
2018	1.53	1.05	1.98	1.46	1.14	1.88	1.50	1.10	1.94	0.77	0.38	1.32	0.94	0.73	1.22	0.89	0.44	1.26
2019	1.49	1.02	1.94	1.37	1.05	1.78	1.42	1.04	1.89	0.86	0.42	1.48	1.11	0.85	1.45	1.02	0.49	1.46
2020	1.43	0.97	1.89	1.27	0.96	1.69	1.34	0.96	1.82	0.81	0.39	1.41	1.07	0.81	1.43	0.98	0.45	1.42
2021	1.41	0.93	1.87	1.19	0.88	1.62	1.29	0.89	1.81	0.82	0.39	1.47	1.16	0.85	1.59	1.03	0.45	1.55

Table 11. Percent of the model runs that resulted in B levels ≤20% of B_{MSY} during the projection period for a given catch level for the North Atlantic blue shark stock.

Catch (t)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
20000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22500	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
27500	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32500	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32689	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35000	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
37500	0%	0%	0%	0%	0%	0%	0%	1%	3%	6%
40000	0%	0%	0%	0%	0%	1%	2%	6%	13%	22%

Table 12. N-BSH. Kobe 2 Strategic Matrices for the North Atlantic blue shark stock combined models. Top: the probability that overfishing is not occurring ($F \le F_{MSY}$); middle: the probability that the stock is not overfished ($B \ge B_{MSY}$); and bottom: the joint probability of being in the green quadrant of the Kobe plot (i.e. $F \le F_{MSY}$ and $B \ge B_{MSY}$).

(a) Probability $F \le F_{MSY}$.

Catch (t)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
0	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
20000	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
22500	99%	99%	99%	100%	100%	100%	100%	100%	100%	100%
25000	95%	96%	96%	97%	98%	98%	99%	99%	99%	100%
27500	87%	87%	88%	89%	90%	92%	93%	94%	95%	95%
30000	75%	74%	74%	75%	76%	77%	78%	79%	80%	81%
32500	62%	60%	59%	59%	59%	59%	59%	59%	59%	59%
32689	61%	59%	58%	57%	58%	58%	58%	58%	58%	57%
35000	50%	47%	44%	43%	41%	39%	38%	37%	36%	35%
37500	40%	35%	31%	27%	24%	21%	19%	17%	15%	14%
40000	31%	24%	19%	14%	11%	8%	7%	5%	4%	4%

(b) Probability $B \ge B_{MSY}$.

Catch (t)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
0	71%	83%	95%	100%	100%	100%	100%	100%	100%	100%
20000	59%	58%	62%	73%	84%	91%	95%	97%	98%	99%
22500	58%	56%	59%	68%	78%	85%	90%	93%	95%	97%
25000	56%	53%	55%	63%	71%	77%	82%	86%	88%	91%
27500	55%	51%	52%	58%	64%	69%	73%	76%	78%	81%
30000	54%	49%	50%	53%	58%	61%	63%	65%	67%	68%
32500	53%	48%	47%	49%	51%	53%	53%	54%	54%	54%
32689	53%	47%	46%	48%	50%	52%	53%	53%	53%	53%
35000	53%	46%	44%	43%	44%	43%	42%	41%	40%	38%
37500	52%	44%	40%	38%	35%	33%	30%	27%	24%	22%
40000	51%	42%	36%	32%	27%	22%	18%	15%	13%	10%

(c) Probability $F \le F_{MSY}$ and $B \ge B_{MSY}$.

Catch (t)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
0	71%	83%	95%	100%	100%	100%	100%	100%	100%	100%
20000	59%	58%	62%	73%	84%	91%	95%	97%	98%	99%
22500	58%	56%	59%	68%	78%	85%	90%	93%	95%	97%
25000	56%	53%	55%	63%	71%	77%	82%	86%	88%	91%
27500	55%	51%	52%	58%	64%	69%	73%	76%	78%	80%
30000	53%	49%	50%	53%	57%	60%	63%	65%	66%	67%
32500	51%	47%	46%	47%	49%	51%	51%	52%	52%	53%
32689	50%	46%	46%	47%	49%	50%	51%	51%	51%	51%
35000	46%	42%	40%	39%	38%	37%	36%	35%	34%	33%
37500	38%	33%	29%	26%	23%	21%	19%	17%	15%	14%
40000	30%	23%	18%	14%	11%	8%	7%	5%	4%	3%

Table 13. S-BSH. Percent of the model runs that resulted in B levels <= 20% of B_{MSY} during the projection period for a given catch level for the South Atlantic blue shark stock.

Catch (t)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
17500	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
20000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22500	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25000	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%
27500	0%	0%	0%	0%	1%	1%	1%	1%	2%	3%
27711	0%	0%	0%	0%	1%	1%	1%	2%	2%	3%
30000	0%	0%	0%	1%	1%	1%	2%	3%	5%	6%
32500	0%	0%	0%	1%	2%	3%	5%	8%	11%	16%

Table 14. S-BSH. Kobe 2 Strategic Matrices for the South Atlantic blue shark stock combined models. Top: the probability that overfishing is not occurring ($F<=F_{MSY}$); middle: the probability that the stock is not overfished ($B>=B_{MSY}$); and bottom: the joint probability of being in the green quadrant of the Kobe plot (i.e. $F<= F_{MSY}$ and $B>= B_{MSY}$).

(a) Probability $F\leq F_{MSY}$.

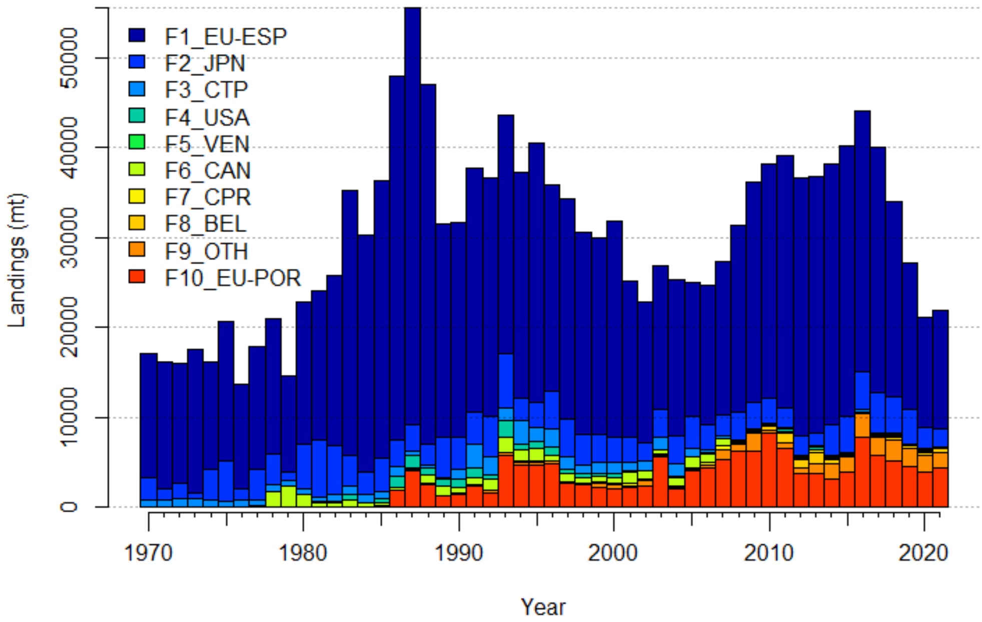
Catch (t)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
0	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
15000	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
17500	98%	99%	99%	99%	99%	99%	100%	100%	100%	100%
20000	95%	96%	97%	97%	97%	97%	98%	98%	98%	98%
22500	89%	90%	91%	91%	91%	91%	91%	92%	92%	92%
25000	80%	81%	80%	80%	79%	79%	78%	78%	78%	77%
27500	70%	69%	68%	66%	65%	64%	62%	61%	60%	59%
27711	69%	68%	67%	65%	63%	62%	61%	60%	59%	58%
30000	58%	57%	54%	52%	50%	48%	47%	45%	44%	43%
32500	47%	45%	42%	40%	37%	36%	34%	33%	32%	32%

(b) F Probability $B\geq B_{MSY}$.

Catch (t)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
0	93%	99%	100%	100%	100%	100%	100%	100%	100%	100%
15000	83%	89%	93%	95%	97%	98%	99%	99%	99%	99%
17500	81%	86%	90%	92%	94%	95%	96%	97%	97%	98%
20000	79%	83%	86%	88%	89%	90%	91%	92%	93%	94%
22500	77%	79%	81%	82%	82%	83%	84%	84%	85%	86%
25000	75%	75%	75%	75%	75%	74%	74%	74%	74%	73%
27500	72%	71%	69%	68%	66%	64%	63%	61%	60%	60%
27711	72%	70%	69%	67%	65%	63%	62%	61%	60%	58%
30000	70%	67%	63%	60%	57%	54%	52%	50%	48%	47%
32500	68%	62%	57%	52%	48%	45%	42%	40%	39%	38%

(c) Probability $F\leq F_{MSY}$ and $B\geq B_{MSY}$.

Catch (t)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
0	93%	99%	100%	100%	100%	100%	100%	100%	100%	100%
15000	83%	89%	93%	95%	97%	98%	99%	99%	99%	99%
17500	81%	86%	90%	92%	94%	95%	96%	97%	97%	98%
20000	79%	83%	86%	88%	89%	90%	91%	92%	93%	94%
22500	77%	79%	81%	82%	82%	83%	84%	84%	85%	86%
25000	74%	75%	75%	75%	74%	74%	73%	73%	73%	72%
27500	68%	68%	67%	65%	63%	61%	59%	59%	54%	53%
27711	67%	67%	66%	63%	61%	60%	58%	56%	55%	54%
30000	58%	57%	54%	51%	49%	47%	44%	43%	41%	40%
32500	47%	45%	42%	39%	37%	34%	32%	31%	29%	28%



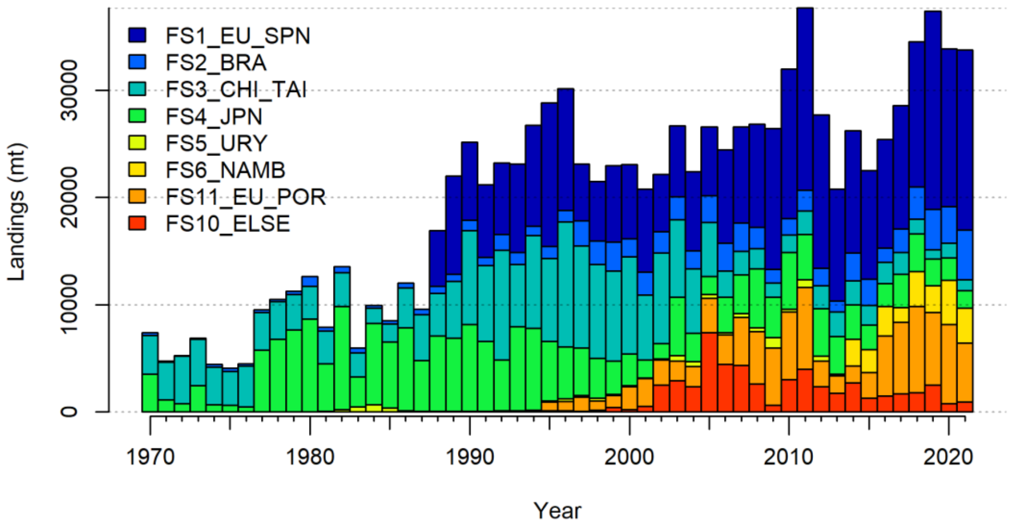


Figure 1. Total landed catch of blue shark for northern (upper) and southern (lower) blue shark stocks.

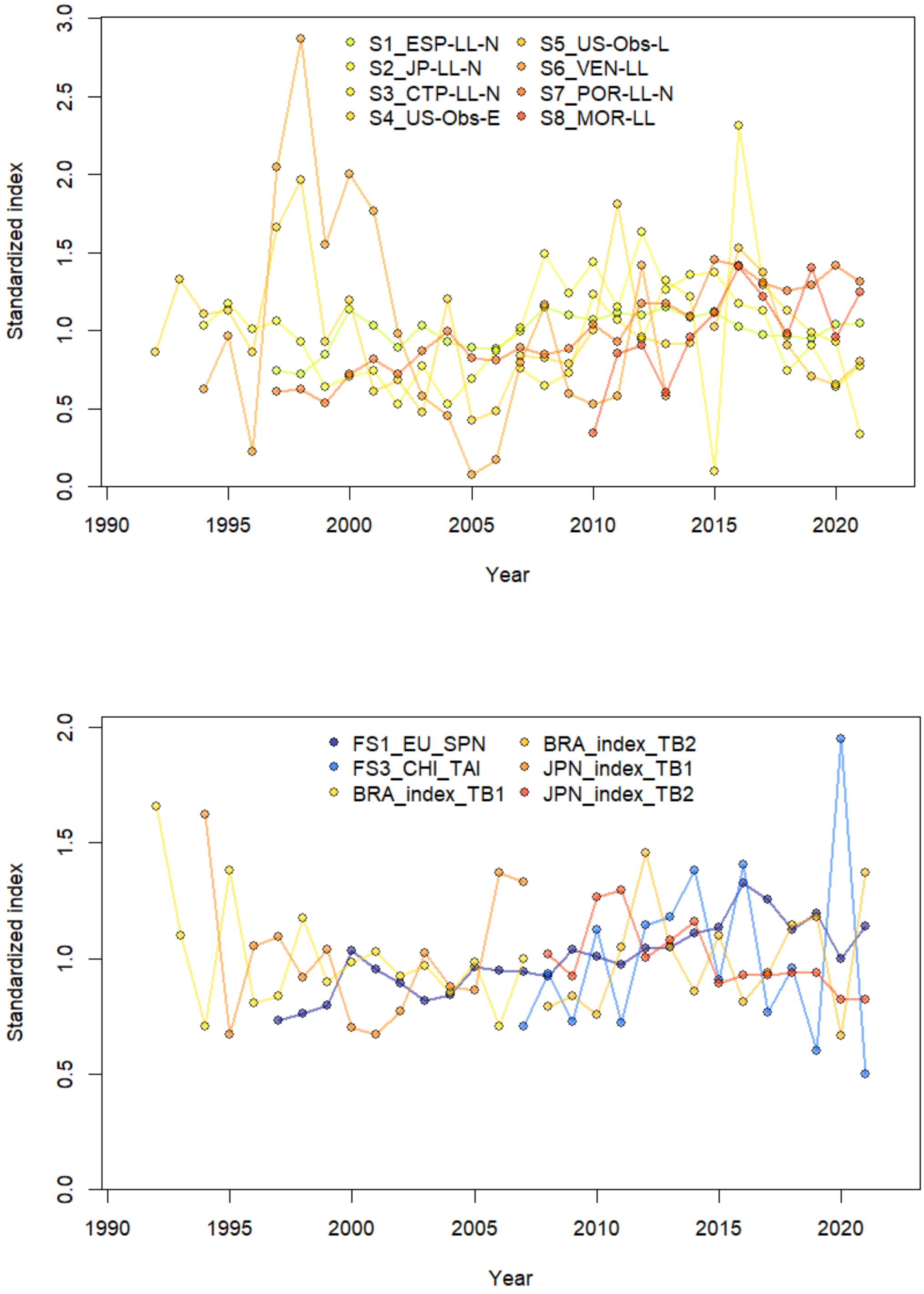


Figure 2. Standardized indices of abundance of blue shark for the northern stock (upper) and the southern stock (lower).

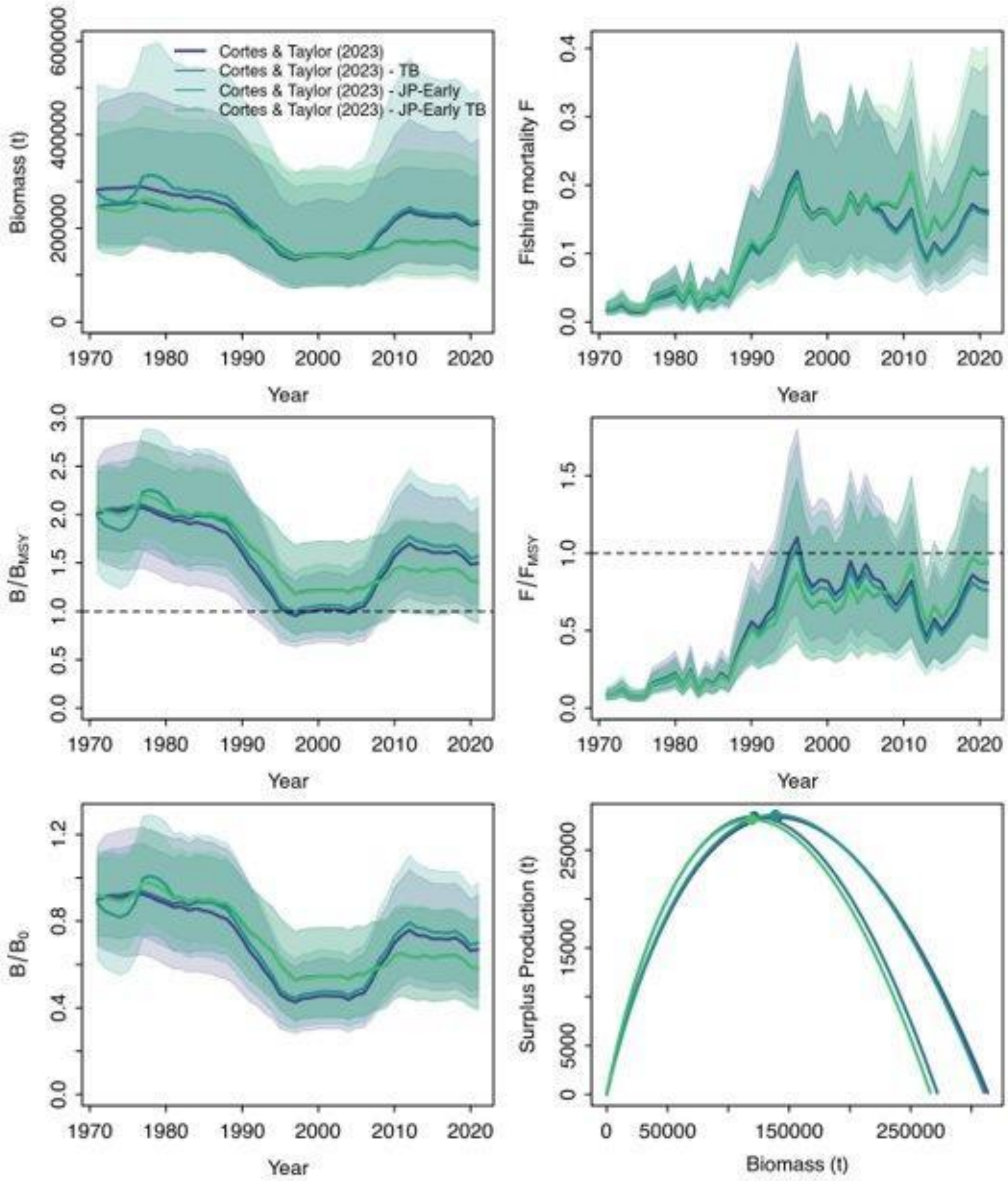
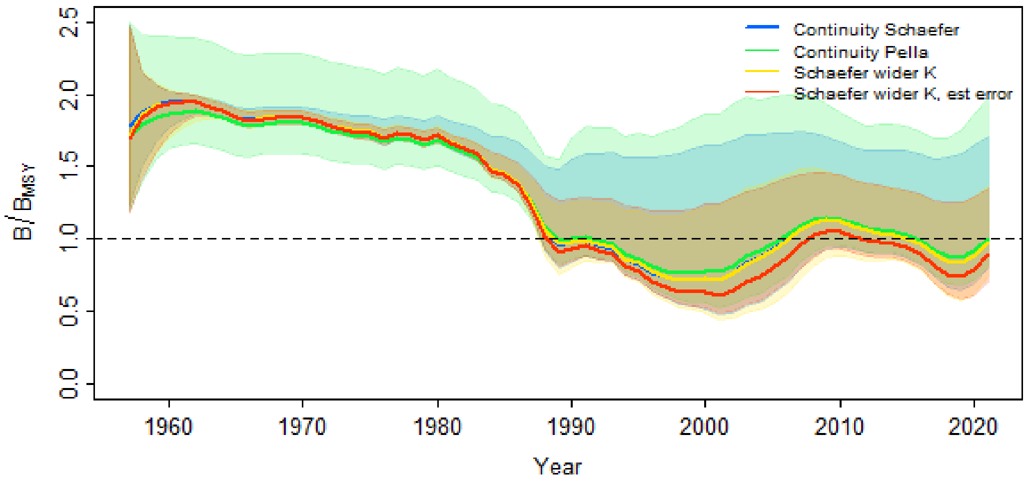
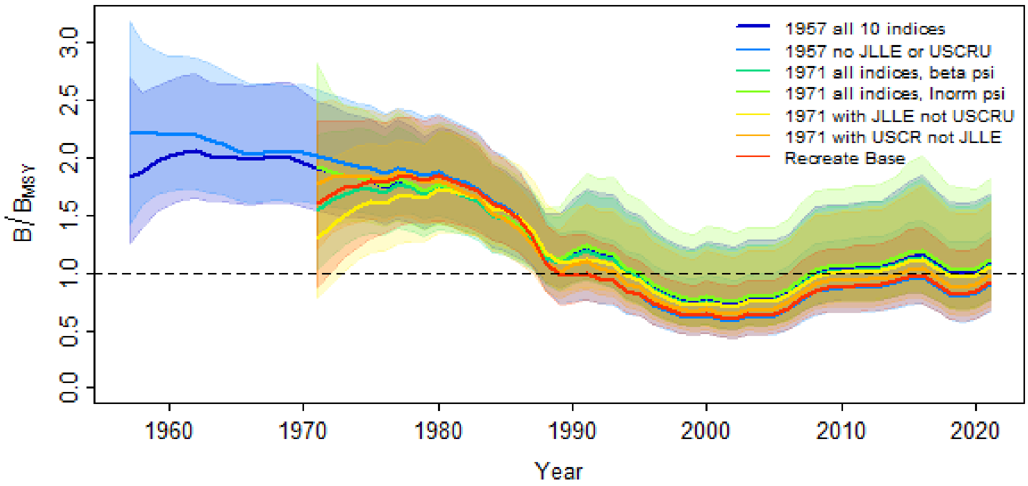


Figure 3. Sensitivity analyses for South Atlantic blue shark stock (JABBA).

(a) Schaefer vs Pella and K prior with all 10 indices, low process error.



(b) Pella varying start year, Bo/K prior or indices, otherwise same as base.



(c) Post model pre data (pmpd) diagnostic with no indices, low process error.

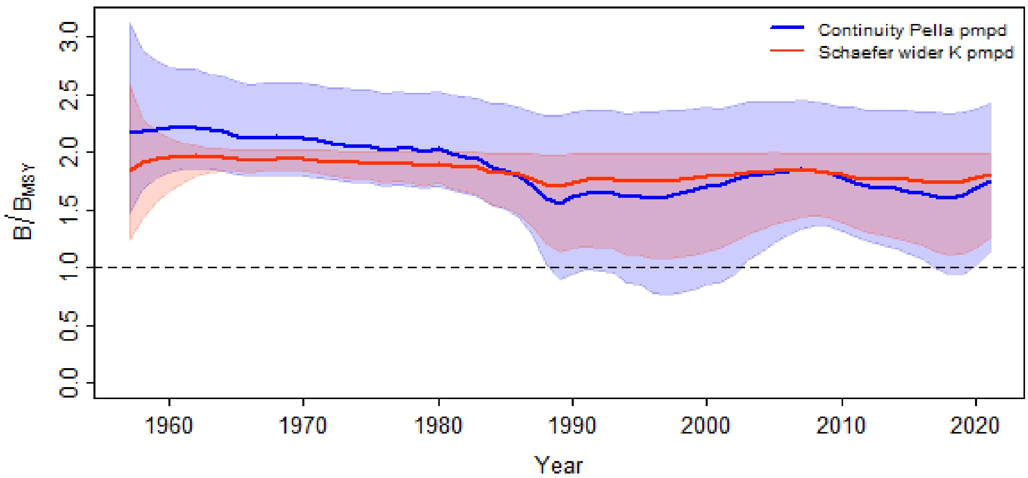
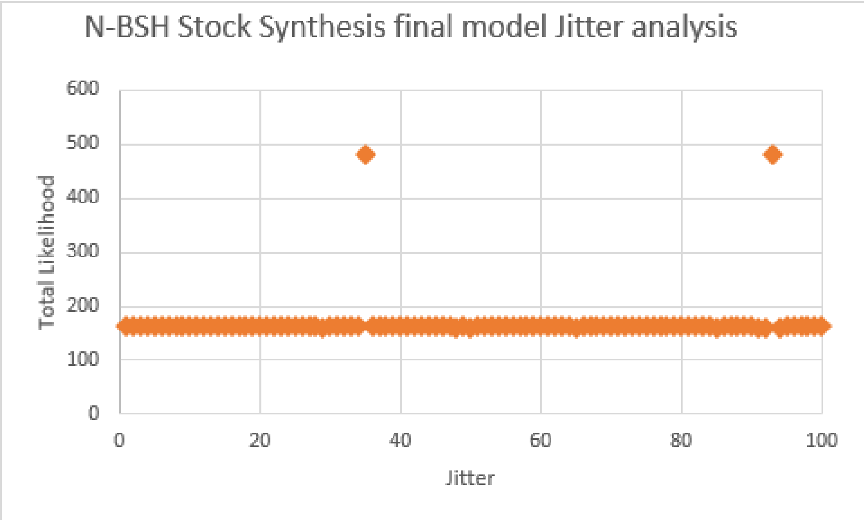


Figure 4. Sensitivity analyses for North Atlantic blue shark stock (JABBA).



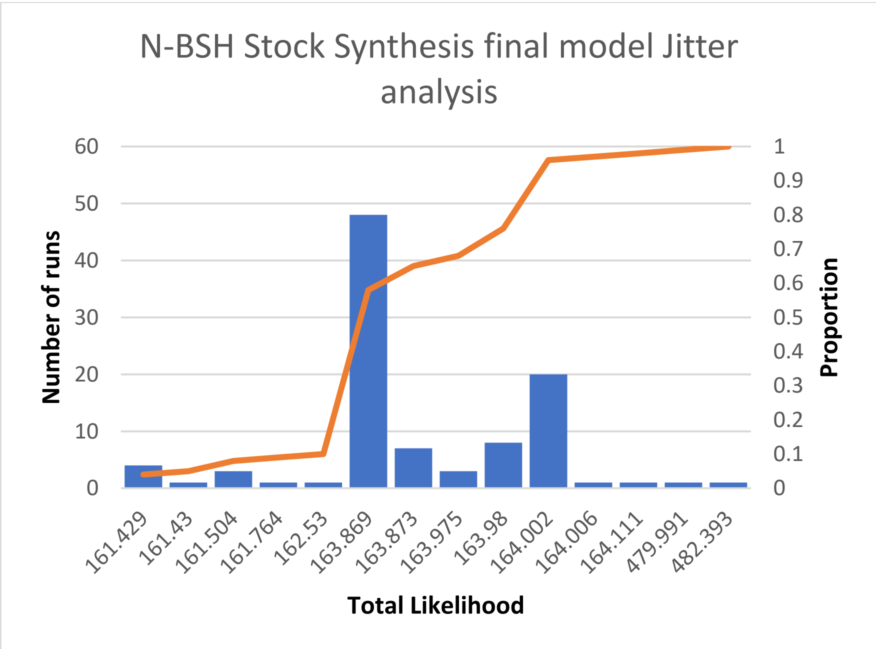


Figure 5. Jitter results (100) for the northern blue shark Stock Synthesis model reference case.

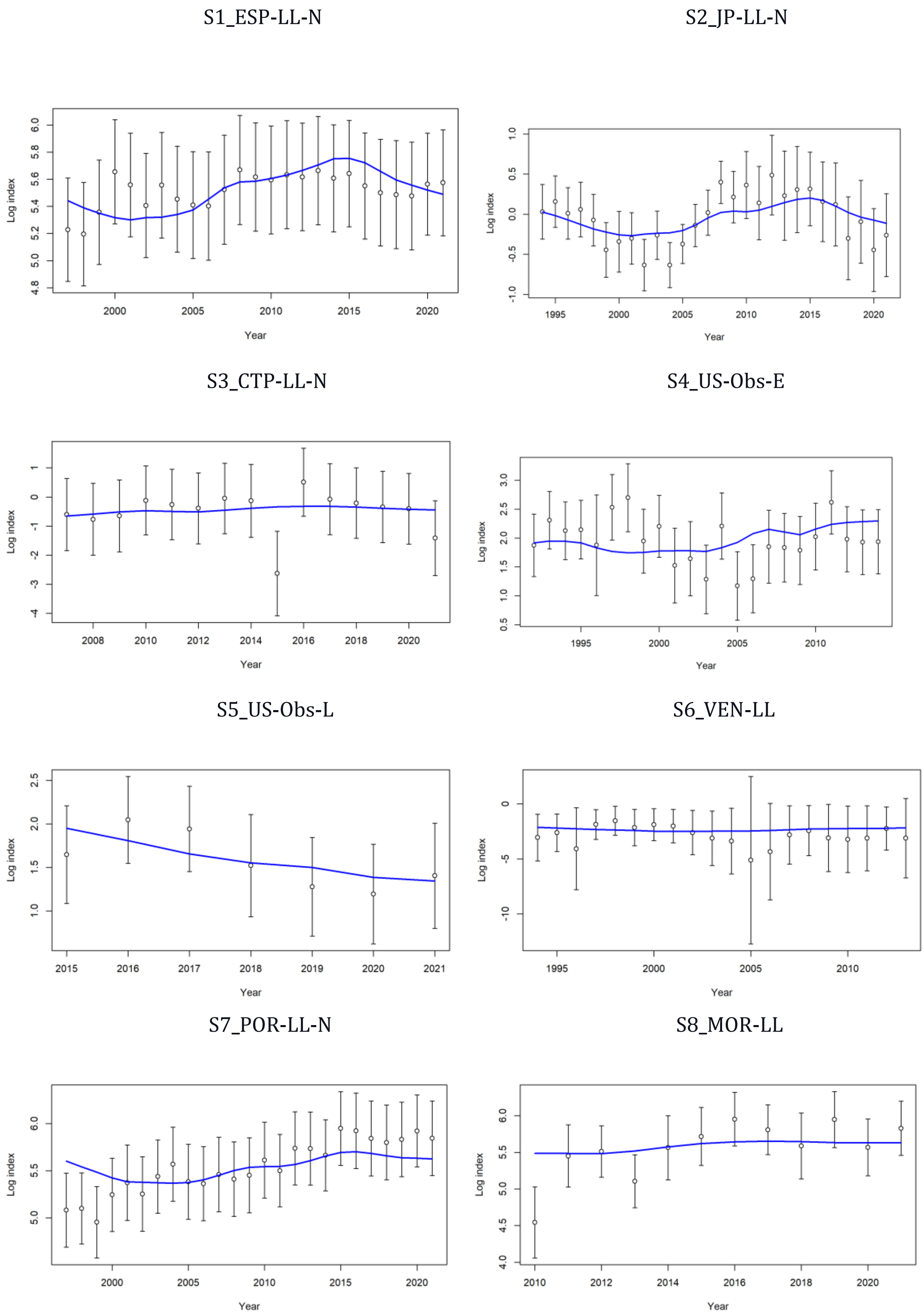


Figure 6. Fit to the indices time series for North blue shark Stock Synthesis model reference case.

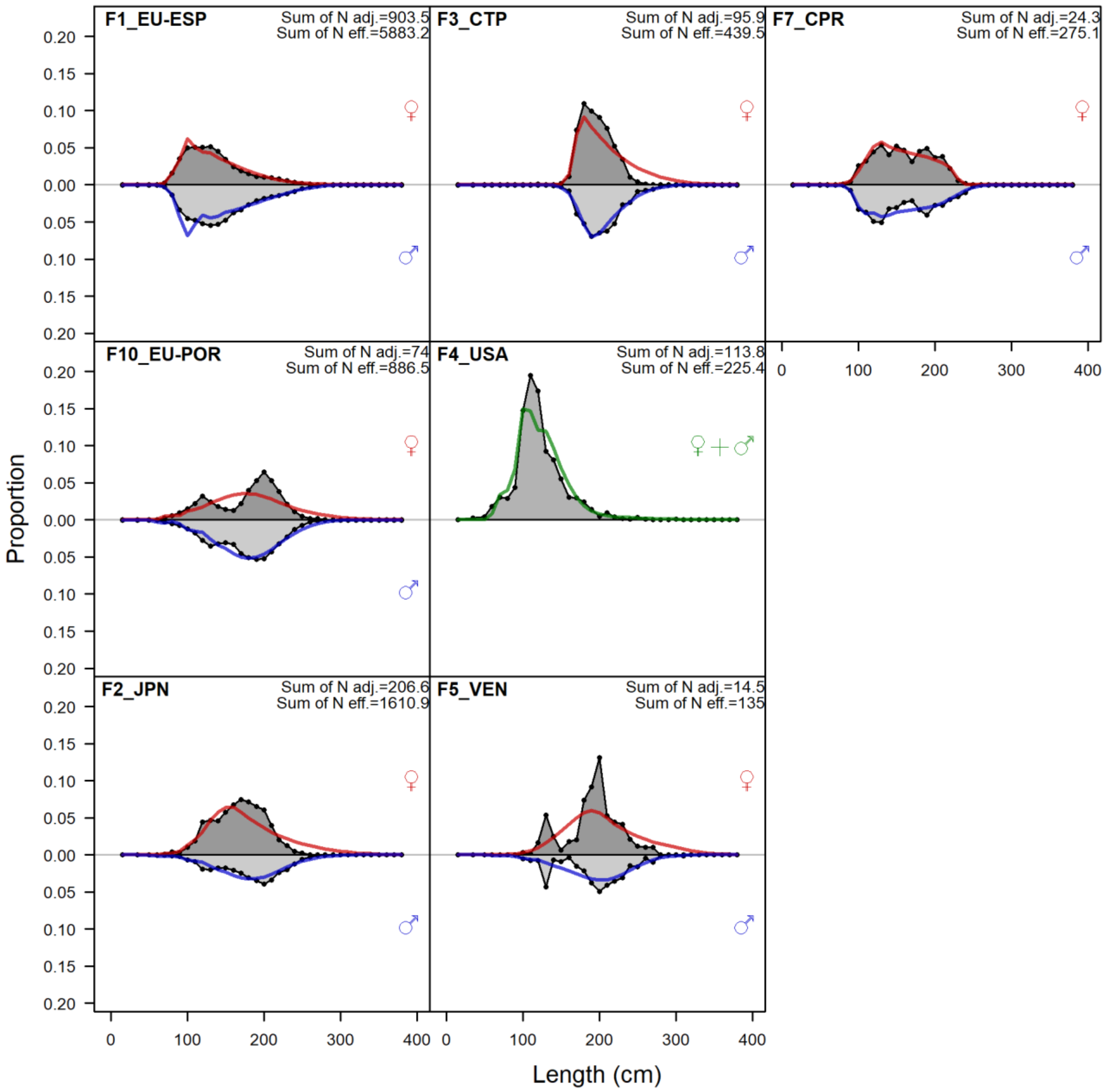


Figure 7. Fit to the aggregated length time series for north blue shark Stock Synthesis model reference case.

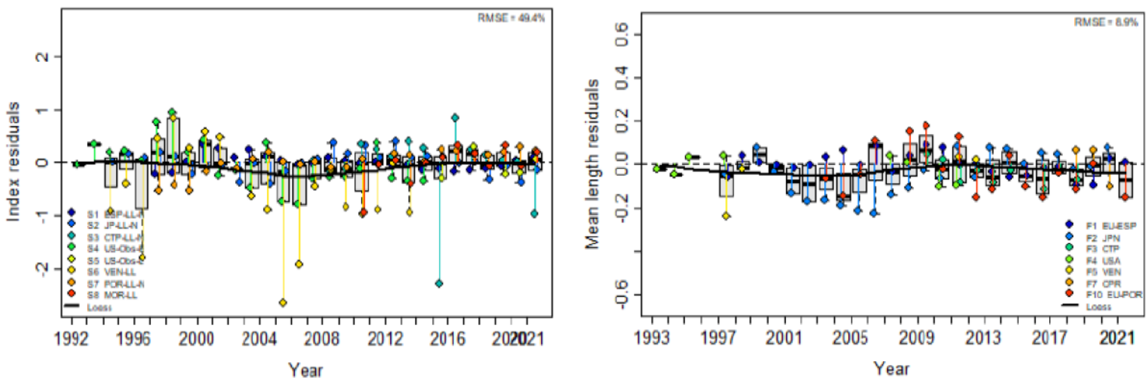


Figure 8. Joint residuals plot for the index (left panel) and length composition (right panel) fits for the North blue shark Stock Synthesis model reference case.

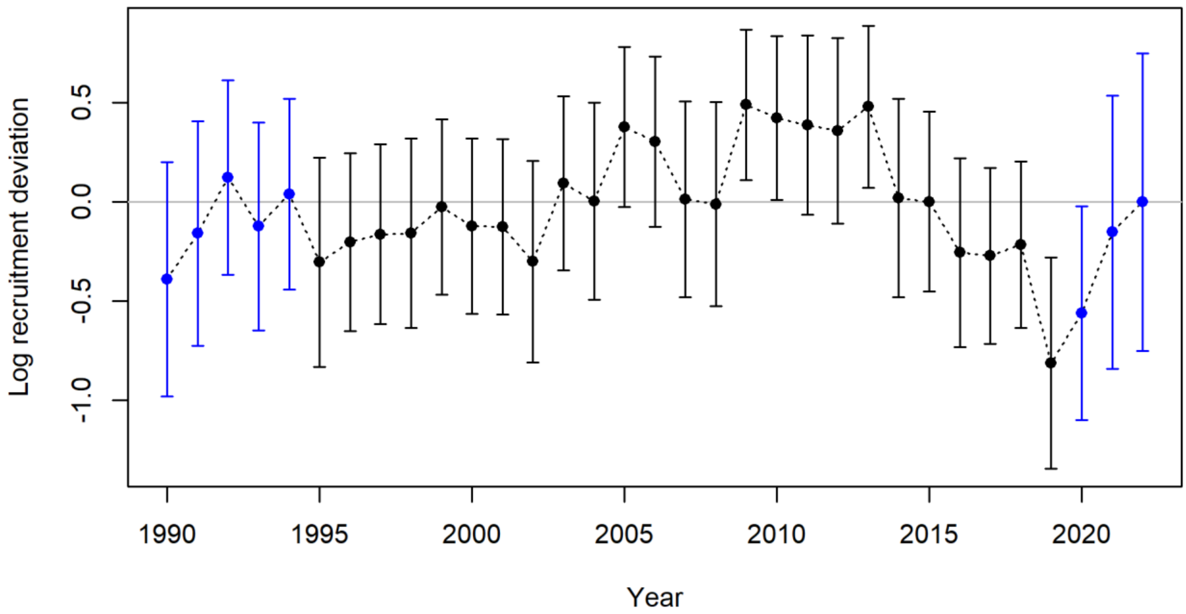


Figure 9. Recruitment deviations for the north blue shark Stock Synthesis model reference case.

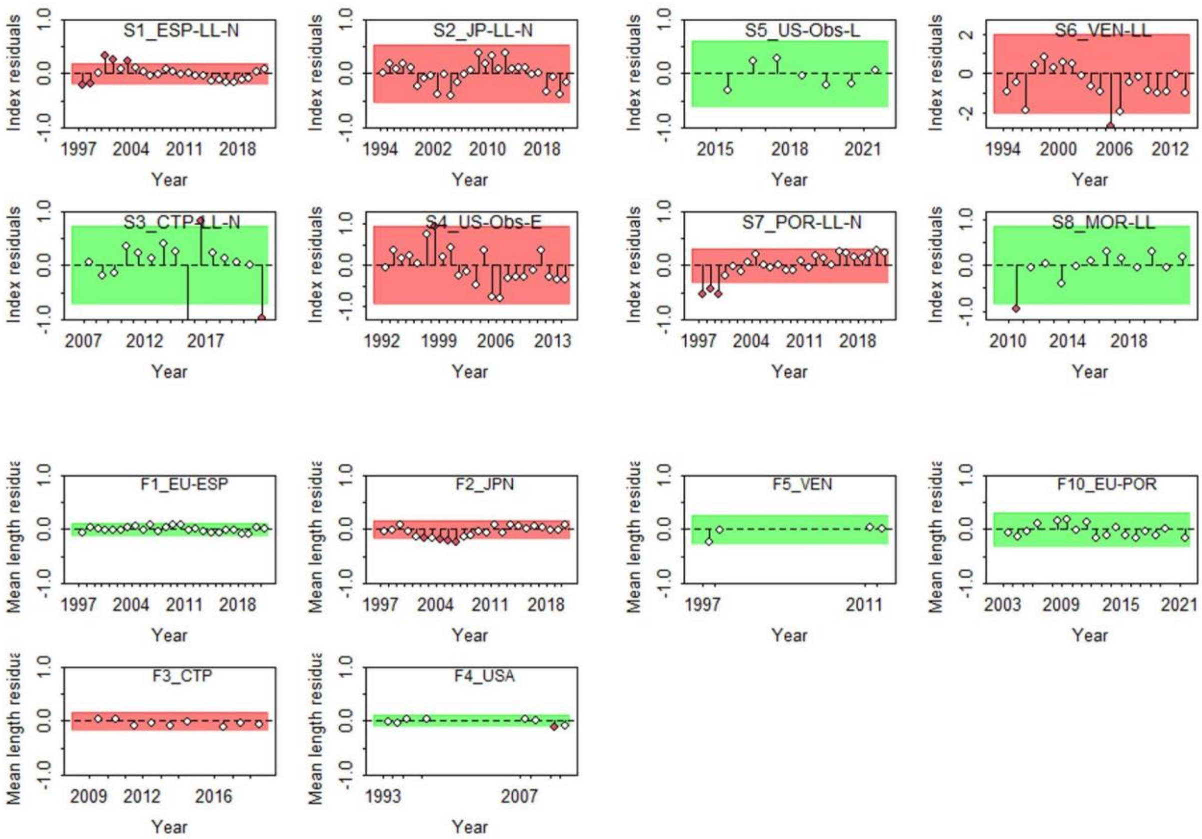


Figure 10. The runs test for the index (upper panels) and length composition (lower panels) fits for the north blue shark Stock Synthesis model reference case. Indices with serial autocorrelation in the residuals are identified in red.

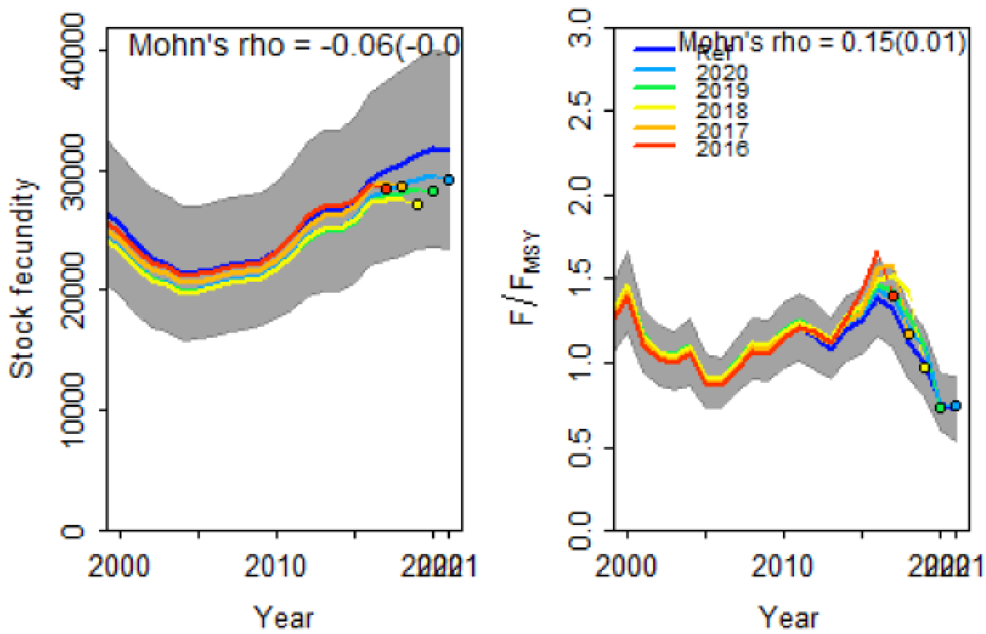
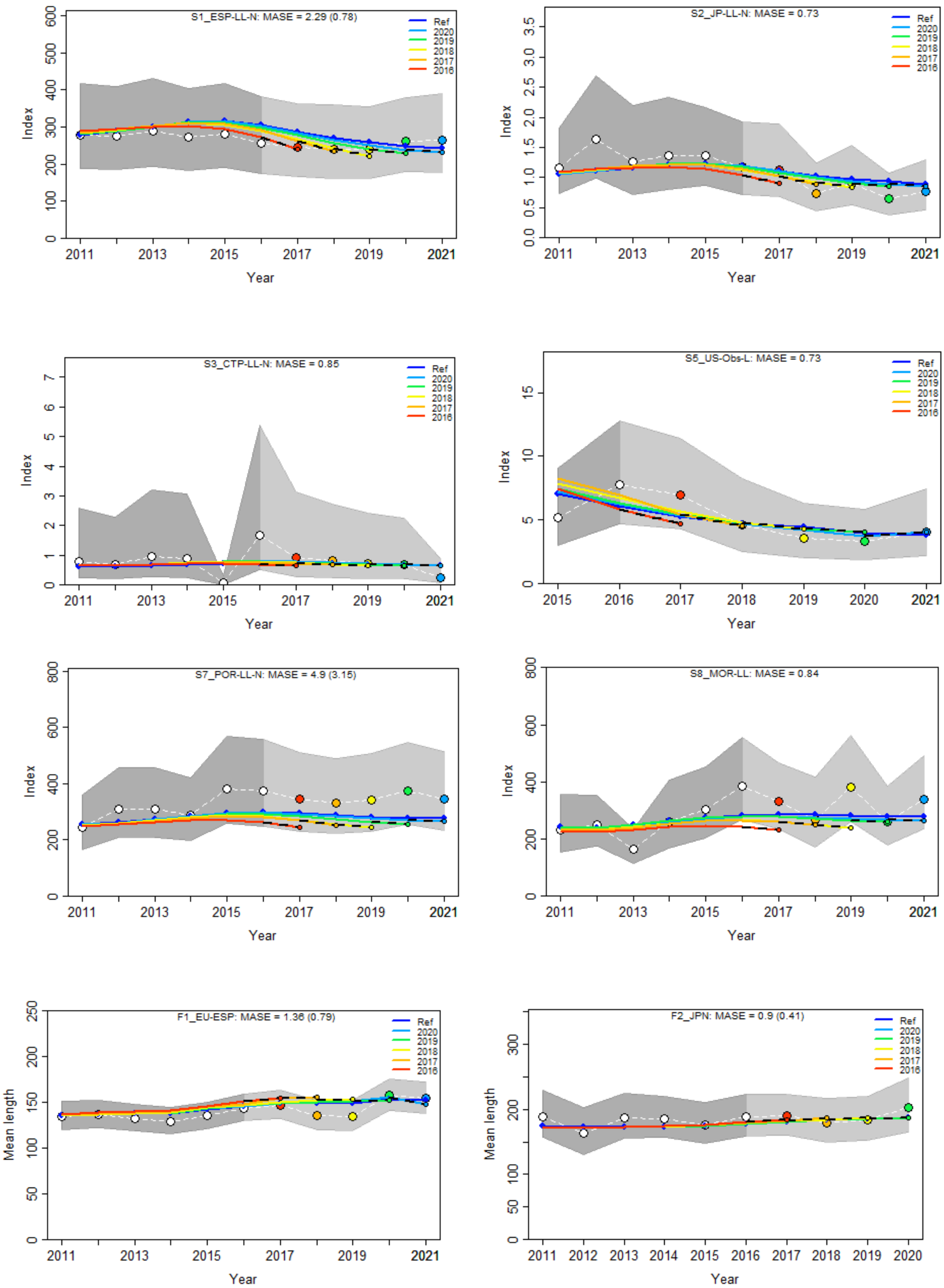


Figure 11. The retrospective analysis for the northern stock fecundity (left panel) and F/F_{MSY} (right panel) for the North blue shark Stock Synthesis model reference case.


S1_ESP-LL-N: MASE = 2.29 (0.78)
S2_JP-LL-N: MASE = 0.73
S3_CTP-LL-N: MASE = 0.85
S5_US-Obs-L: MASE = 0.73
S7_POR-LL-N: MASE = 4.9 (3.15)
S8_MOR-LL: MASE = 0.84
F1_EU-ESP: MASE = 1.36 (0.79)
F2_JPN: MASE = 0.9 (0.41)
Ref
2020
2019
2018
2017
2016
Index
Mean length
Year

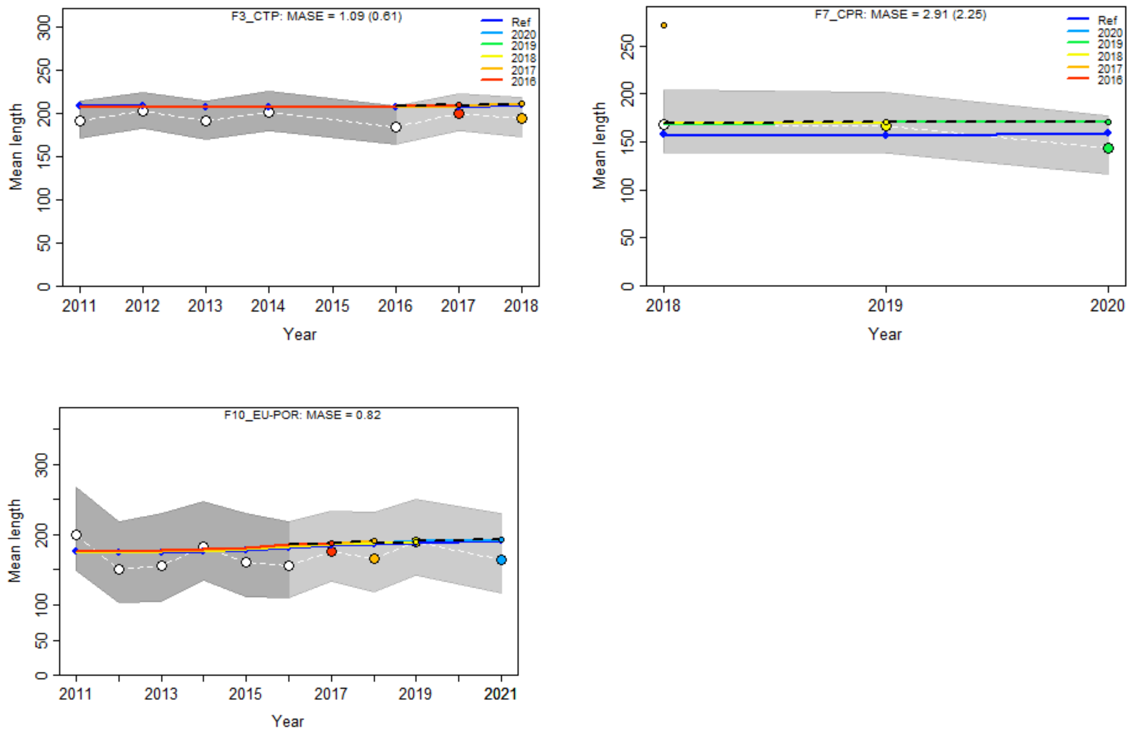


Figure 12. Hindcasting plots for the index (upper panels) and length fits (lower panels) for the North blue shark Stock Synthesis model reference case; numbers in parenthesis represent an adjustment to the MASE value, which was not evaluated within the current assessment.

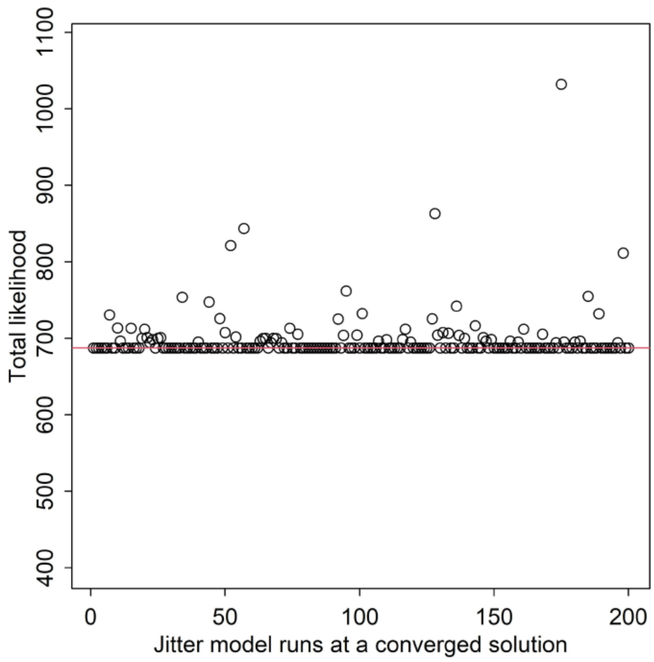


Figure 13. Jitter results for the southern stock synthesis case.

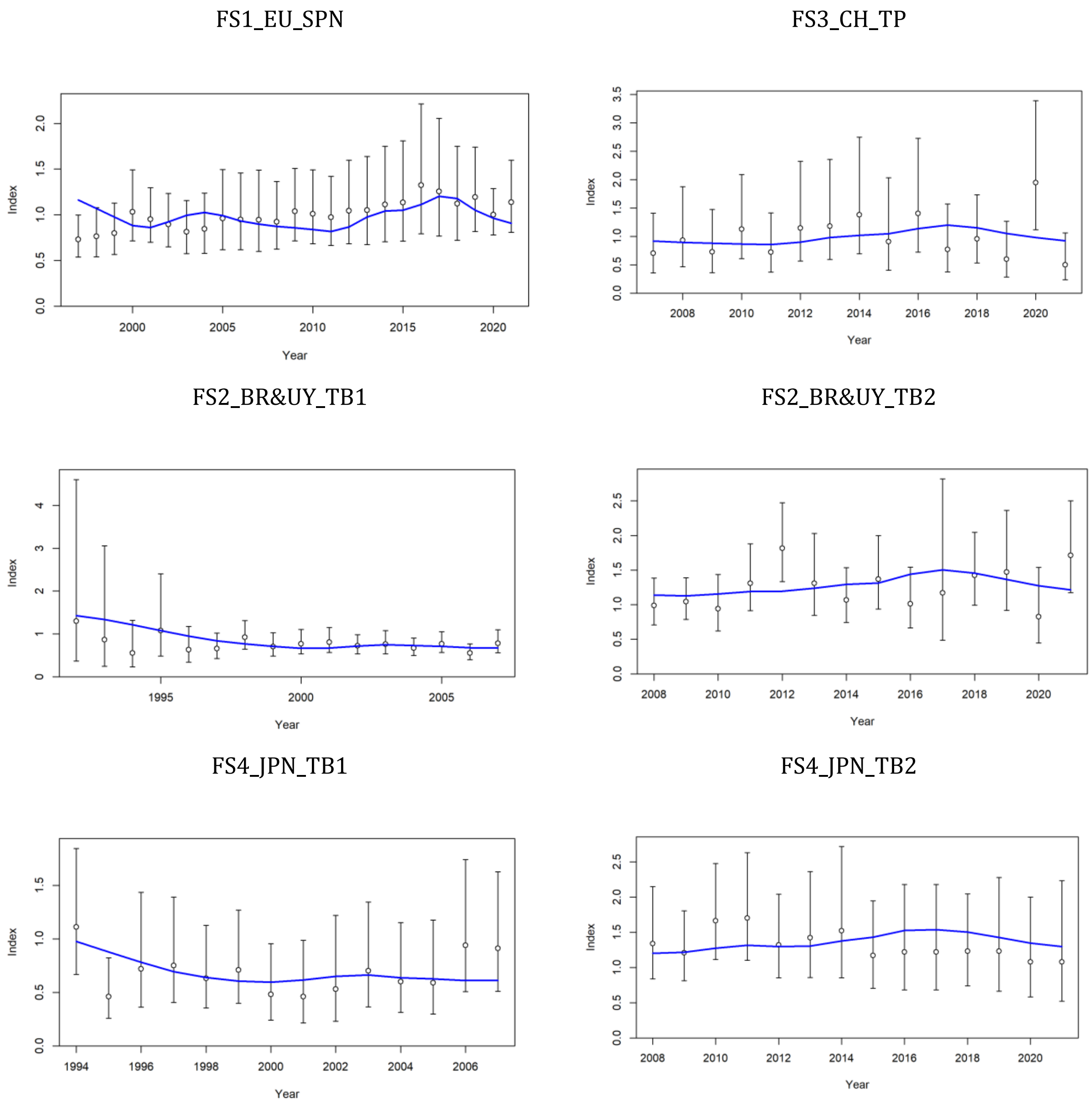


Figure 14. Fit to the indices time series for south BSH Stock synthesis model reference case.

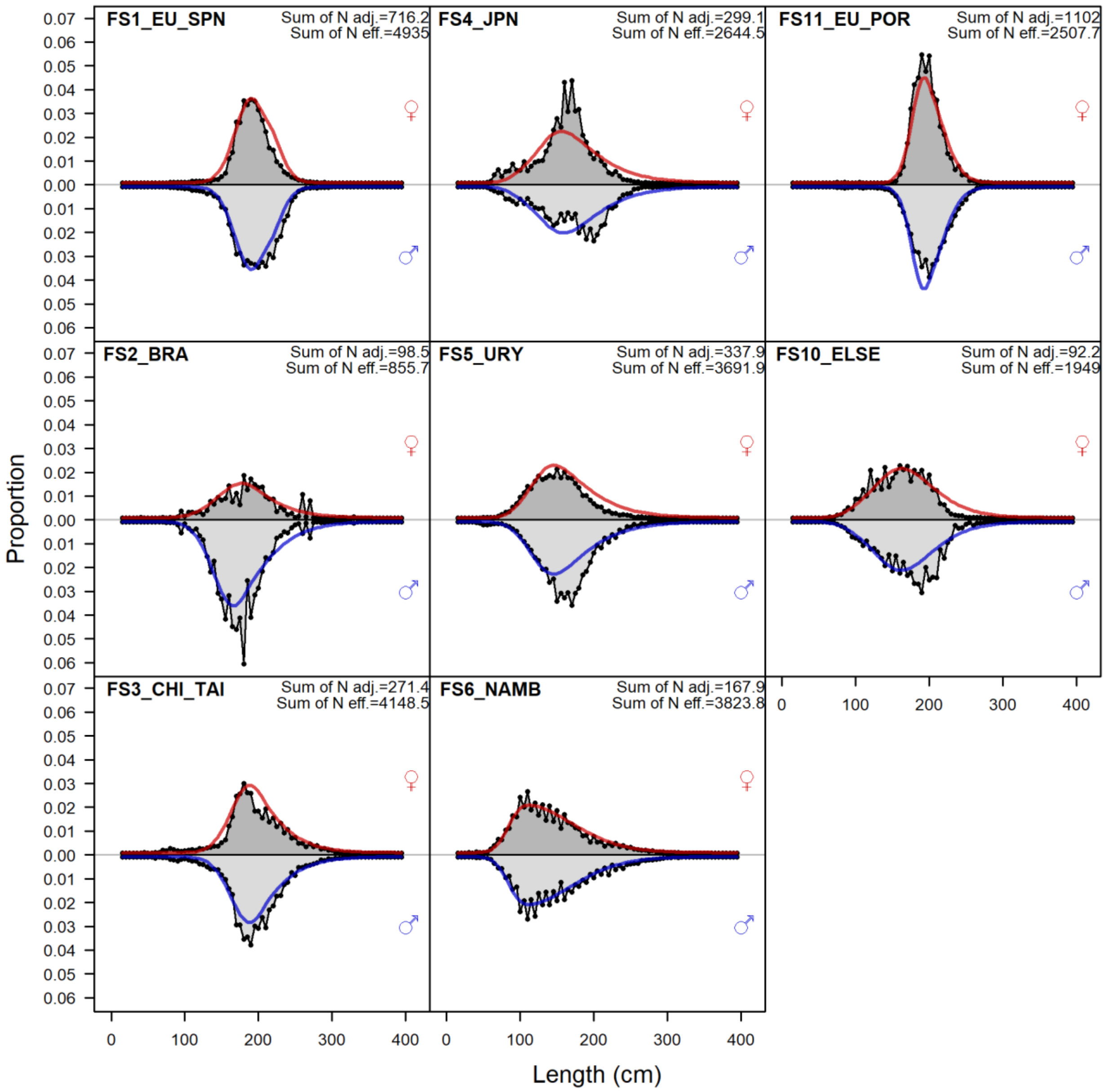


Figure 15. Fit to the aggregated length time series for south BSH Stock synthesis model reference case.

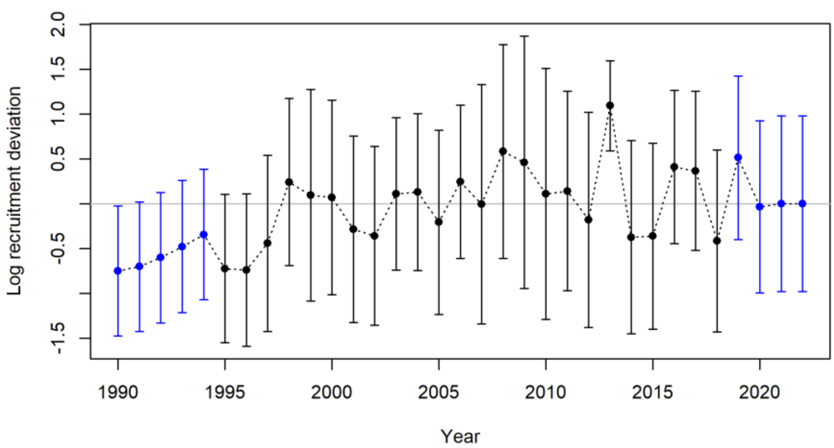


Figure 16. Recruitment deviations for the south BSH Stock synthesis model reference case.

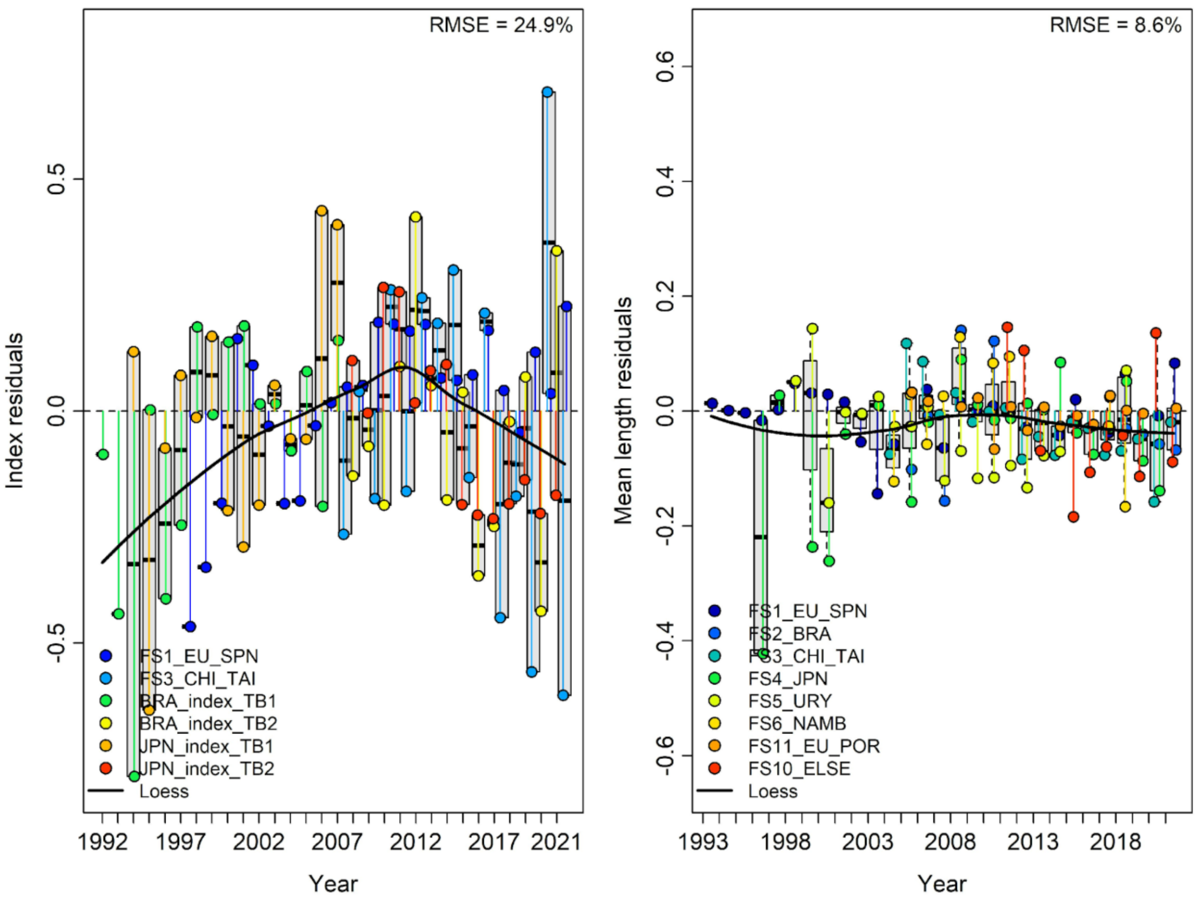


Figure 17. The joint residuals plot for the index (left panel) and length composition (right panel) fits for the south BSH Stock synthesis model reference case.

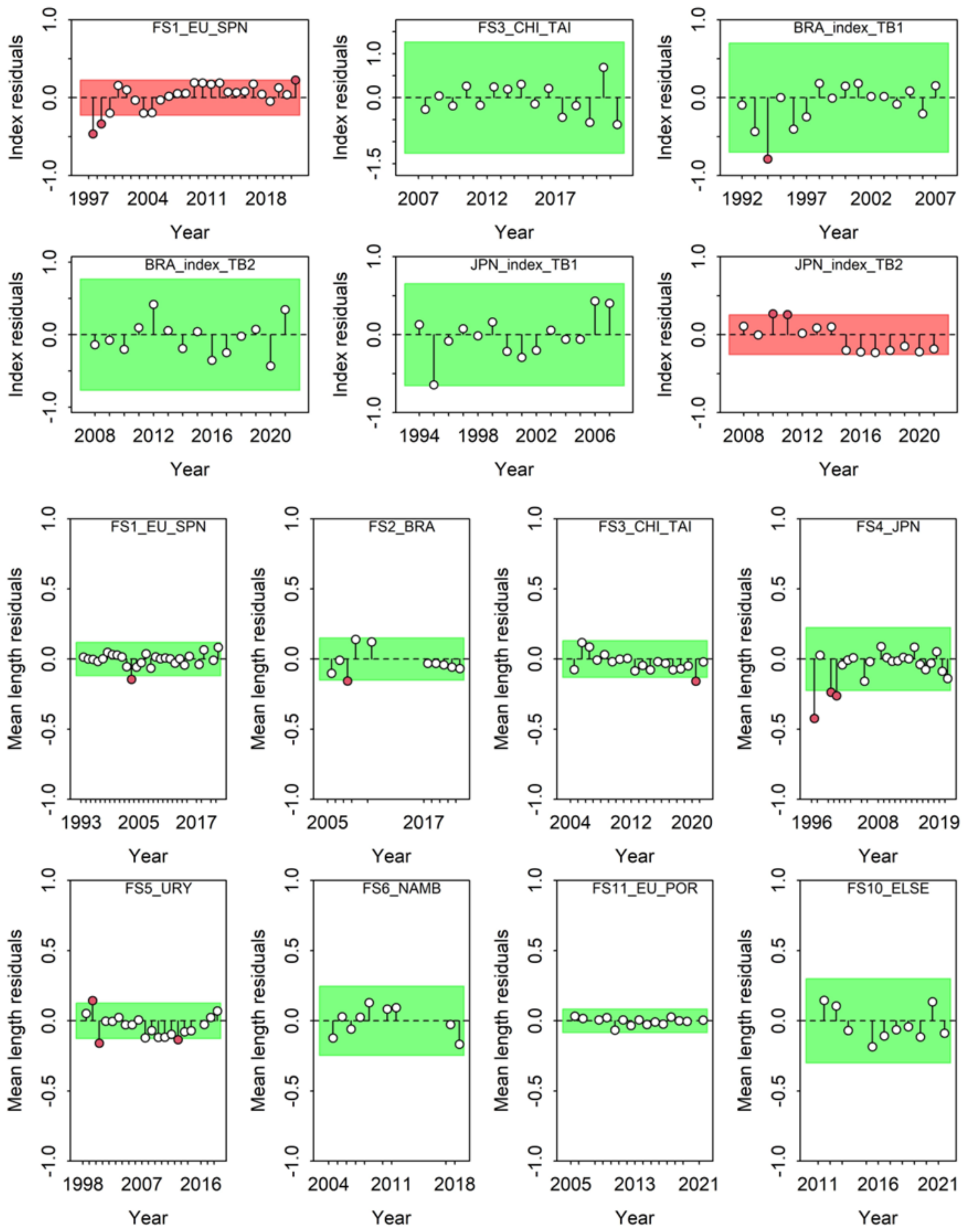


Figure 18. The runs test for the index (upper panel) and length composition (lower panel) fits for the south BSH Stock synthesis model reference case.

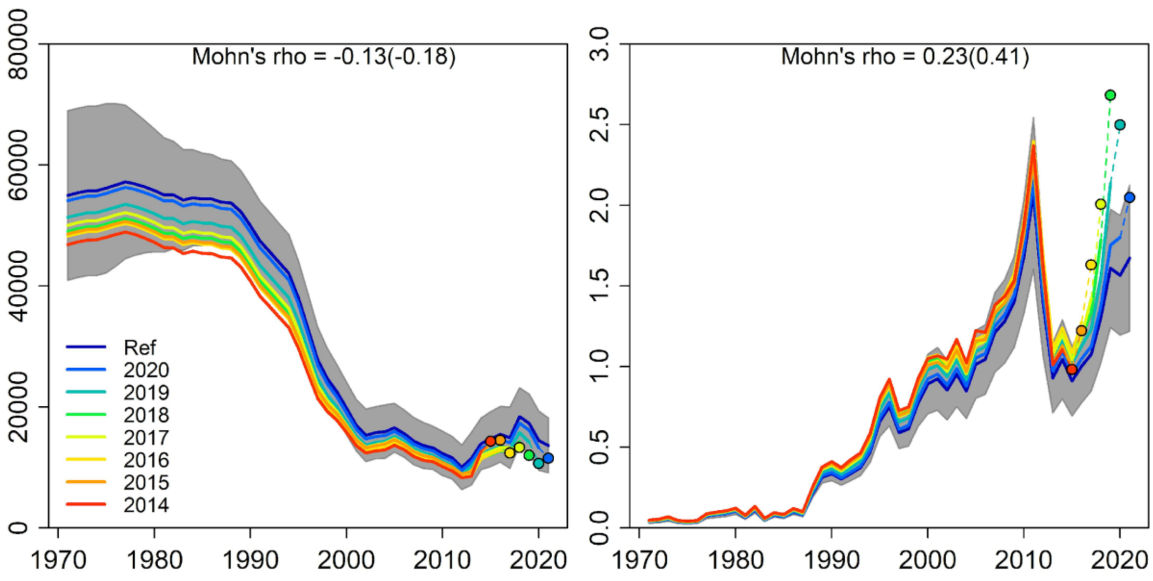


Figure 19. The retrospective analysis for the spawning output (left panel) and F (right panel) for the south BSH Stock synthesis model reference case.

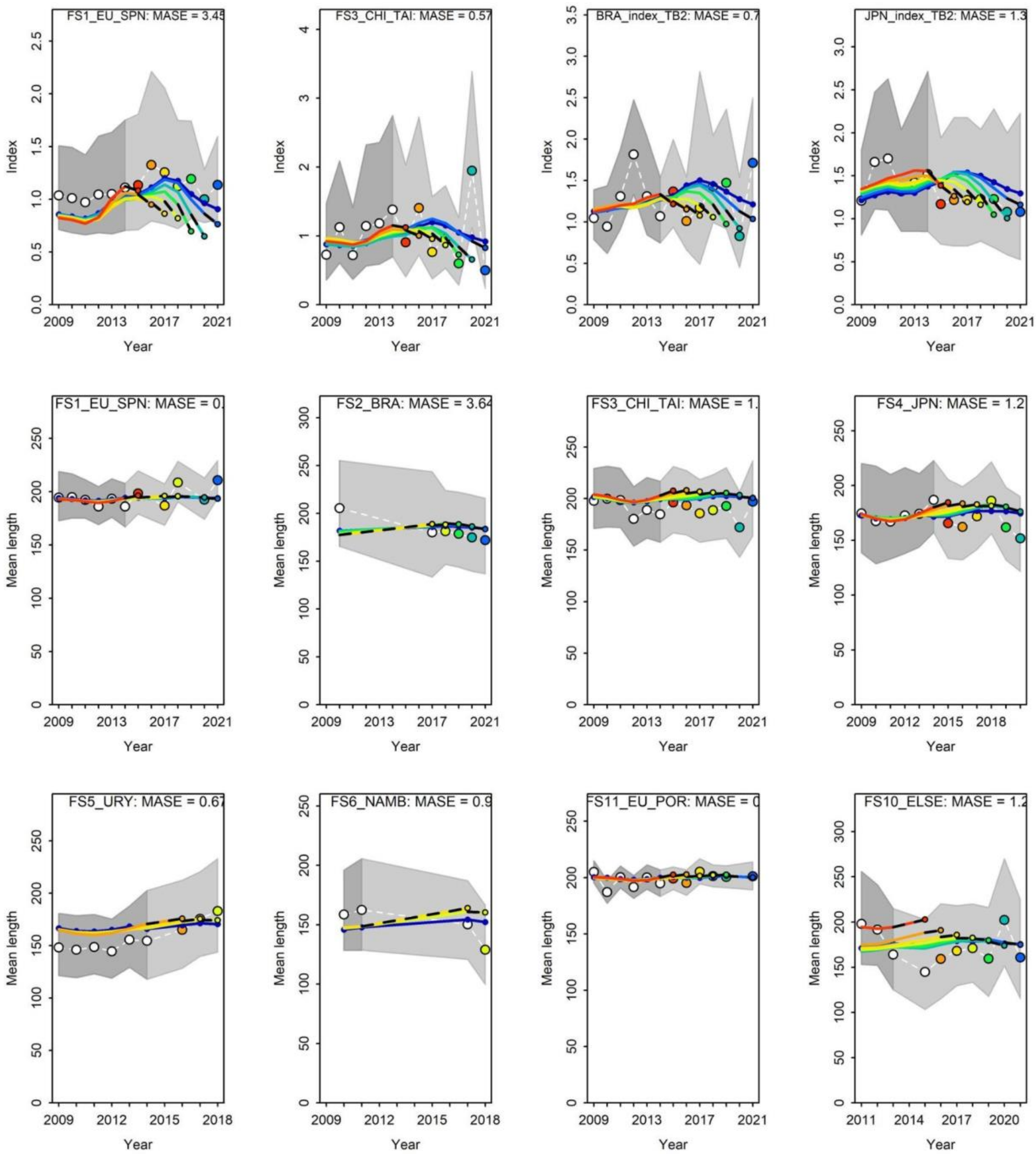


Figure 20. Hindcasting plots for the index (upper panel) and length fit (lower panel) for the south BSH Stock synthesis model reference case.

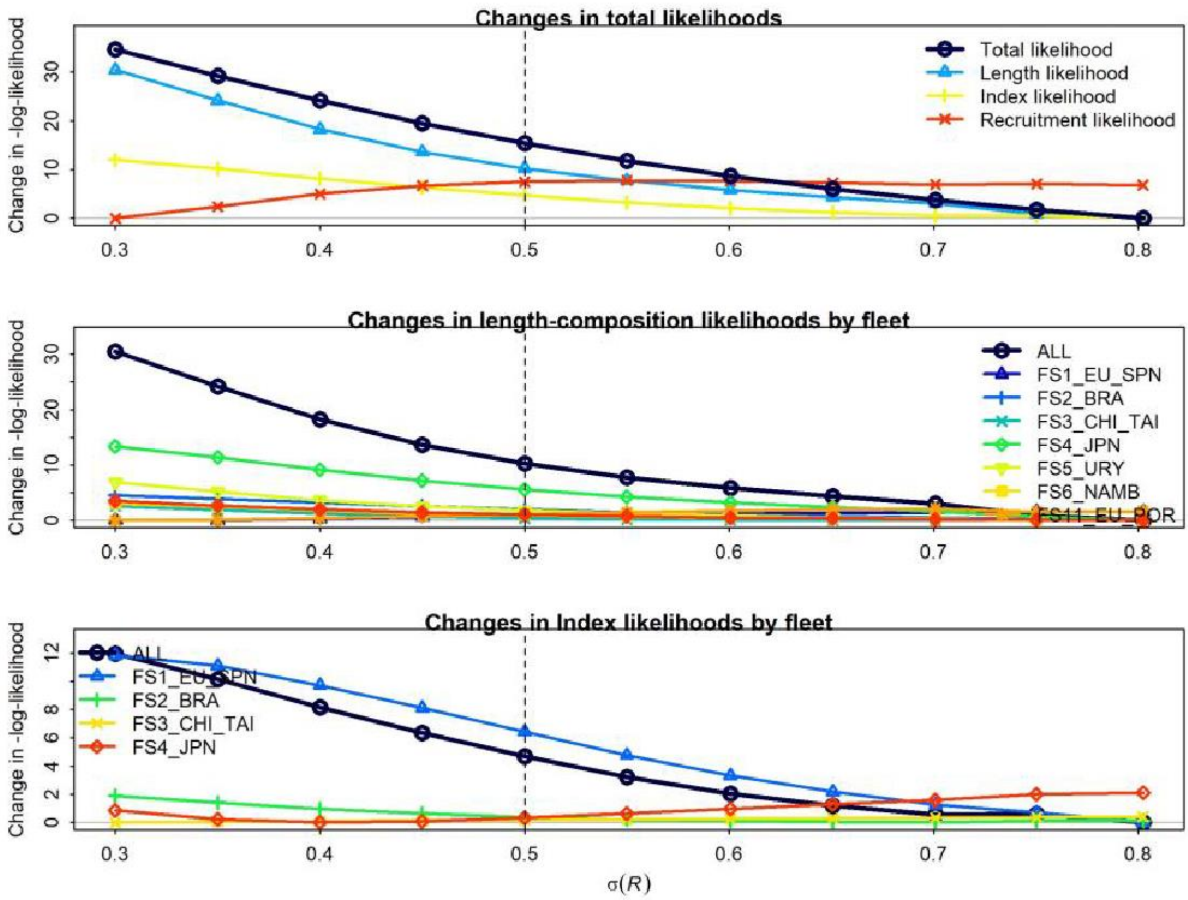


Figure 21. Likelihood profile for the southern stock SS3 model.

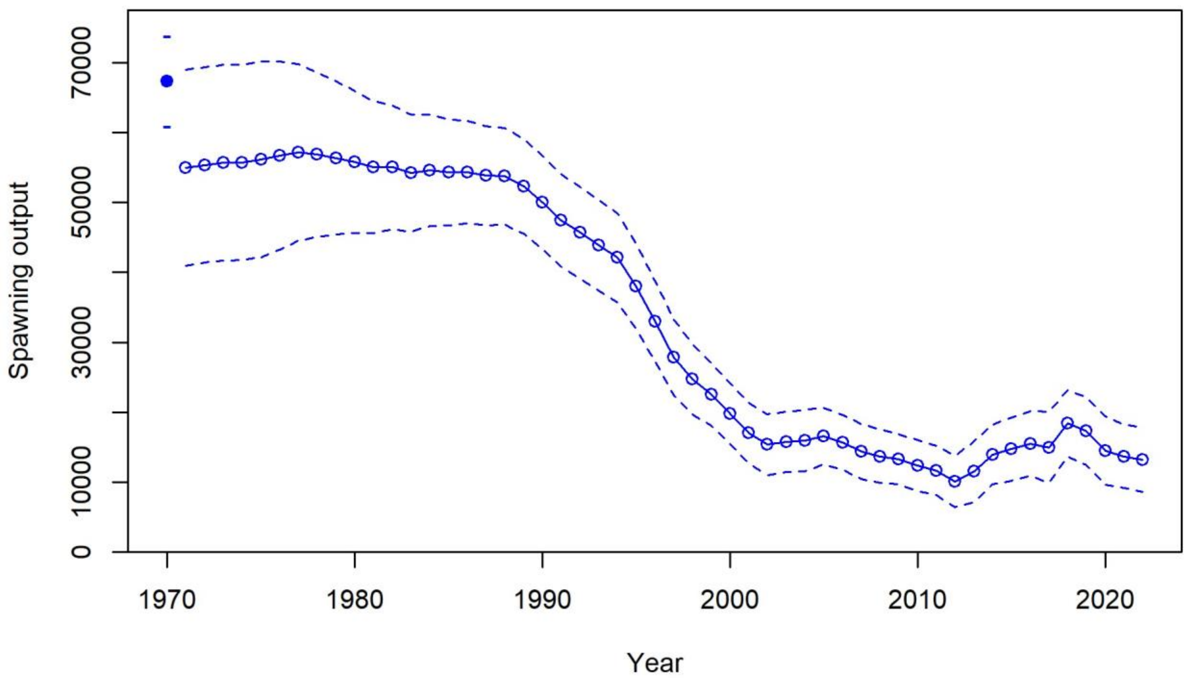


Figure 22. Spawning output estimates for the south BSH Stock synthesis model reference case.

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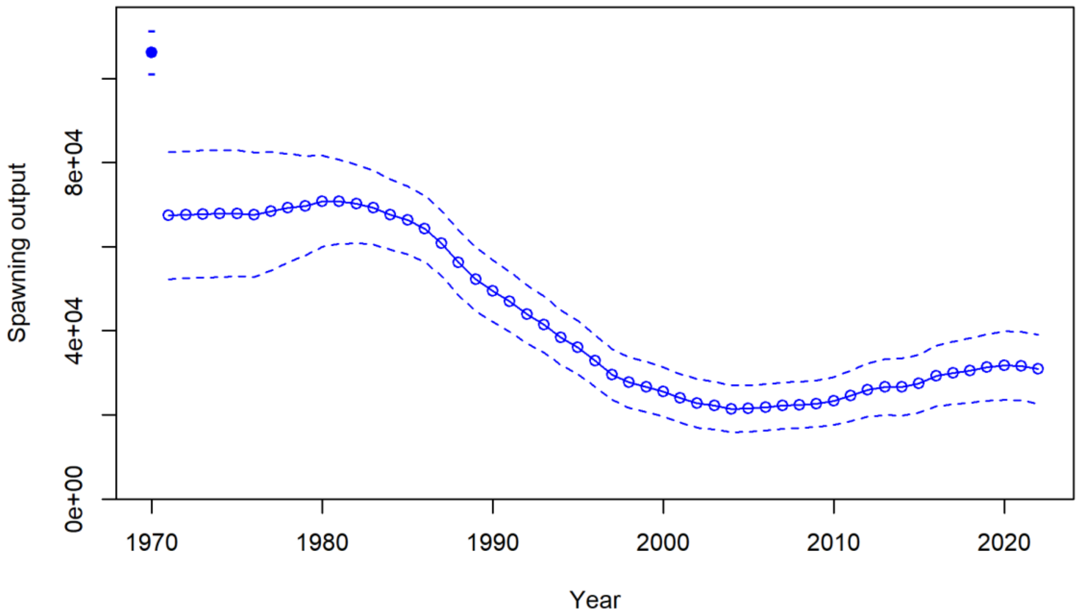


Figure 23. Stock Synthesis estimated time series of North Atlantic blue shark spawning stock output.

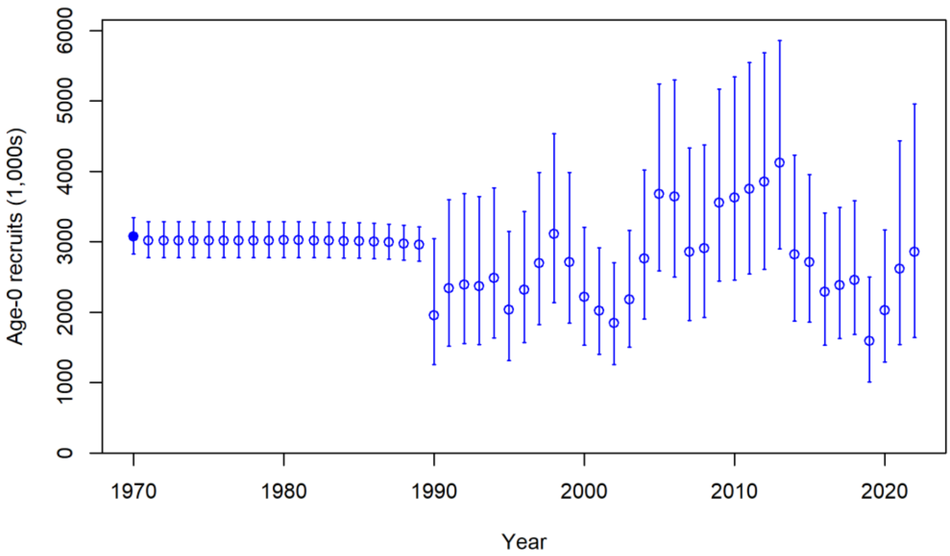


Figure 24. 2023 reference case Stock Synthesis North Atlantic blue shark model estimated recruitment showing the estimated annual age-0 recruitment (circles) with 95% asymptotic confidence intervals; recruitment in years prior to 1990 and after 2021 follows the stock recruitment relationship exactly.

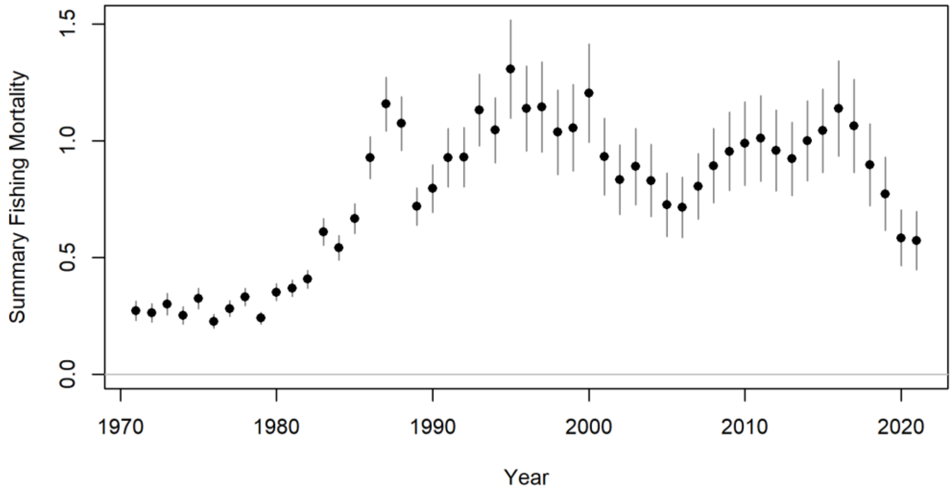


Figure 25. 2023 reference case Stock Synthesis North Atlantic blue shark model estimated instantaneous fishing mortality rates for all fleets combined (continuous F).

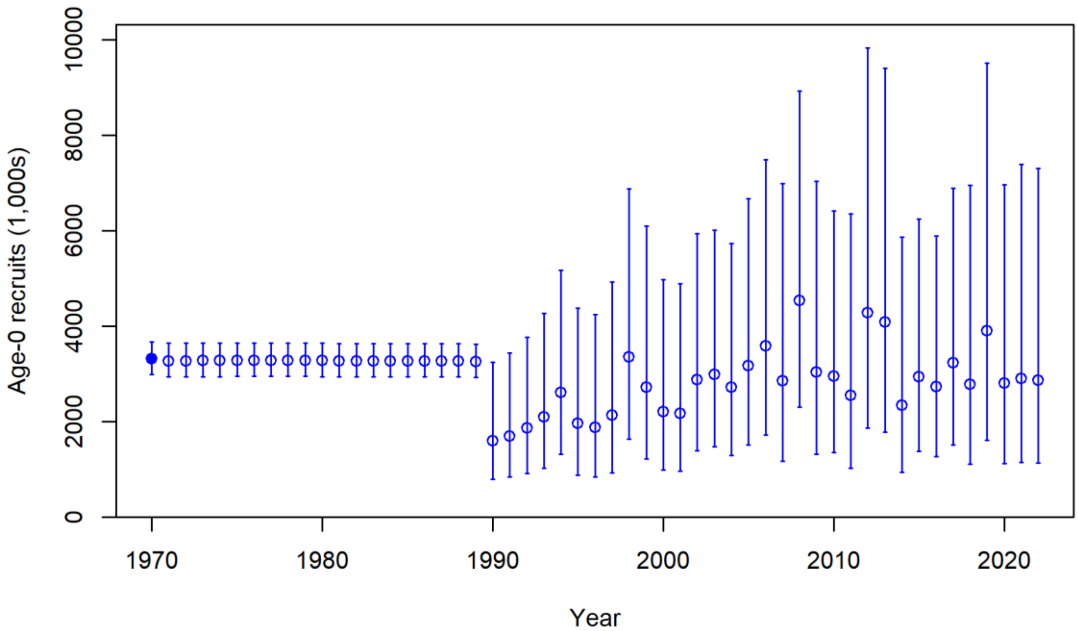


Figure 26. Stock Synthesis estimated time series of South Atlantic blue shark recruitments. Vertical bars indicate 95% CI.

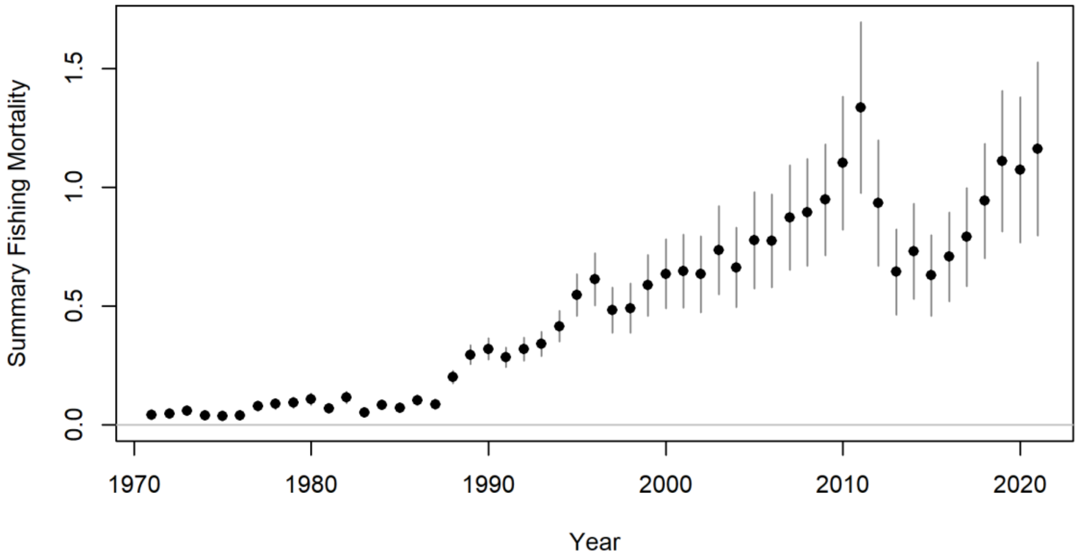


Figure 27. Stock Synthesis estimated time series of fishing mortality on South Atlantic blue shark. Vertical bars indicate 95% CI.

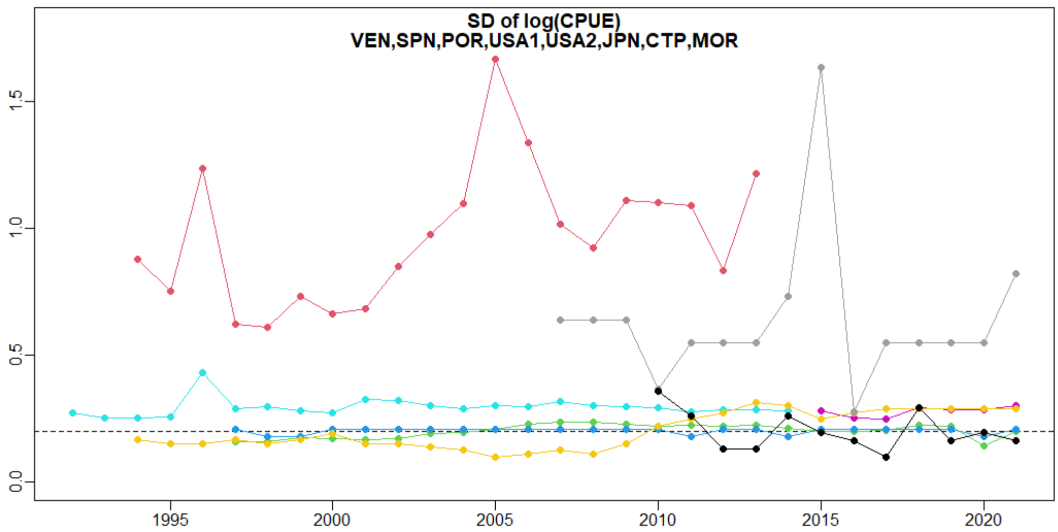


Figure 28. Annual values used as input standard deviation of log(CPUE) in the JABBA reference case for the North Atlantic blue shark stock. The colors correspond to Venezuela (red), Spain (green), Portugal (darker blue), USA1 (sky blue), USA2 (pink), Japan (yellow), Chinese Taipei (grey), Morocco (black).

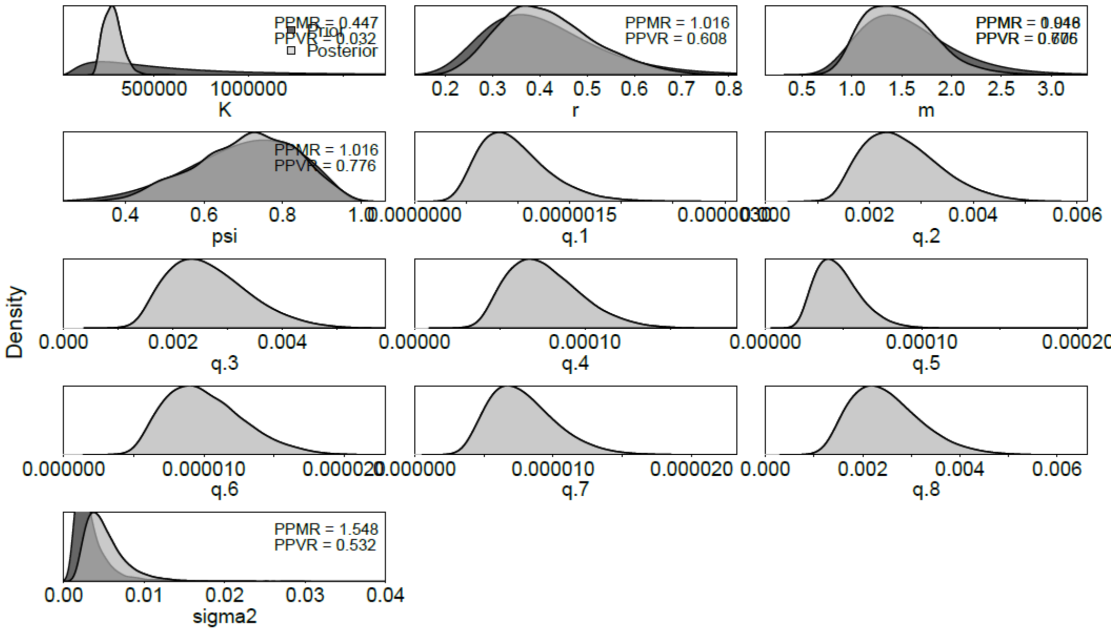


Figure 29. Prior and posterior distributions of the JABBA reference case for the North Atlantic blue shark stock. PPRM: Posterior to Prior Ratio of Means; PPRV: Posterior to Prior Ratio of Variances.

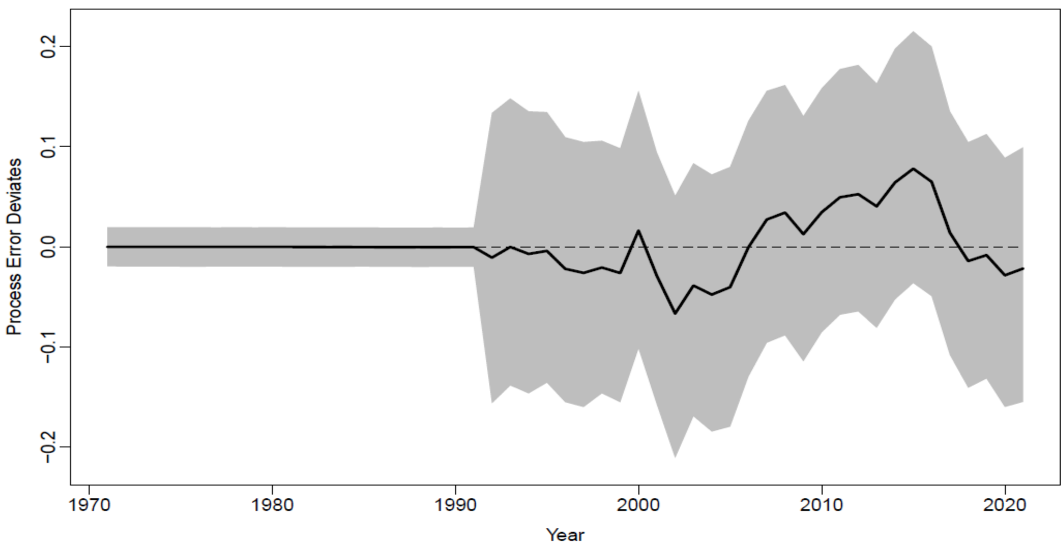


Figure 30. Process error deviates for the North Atlantic blue shark JABBA reference case. The solid line is the posterior median, and the shaded grey area indicates 95% posterior probability intervals.

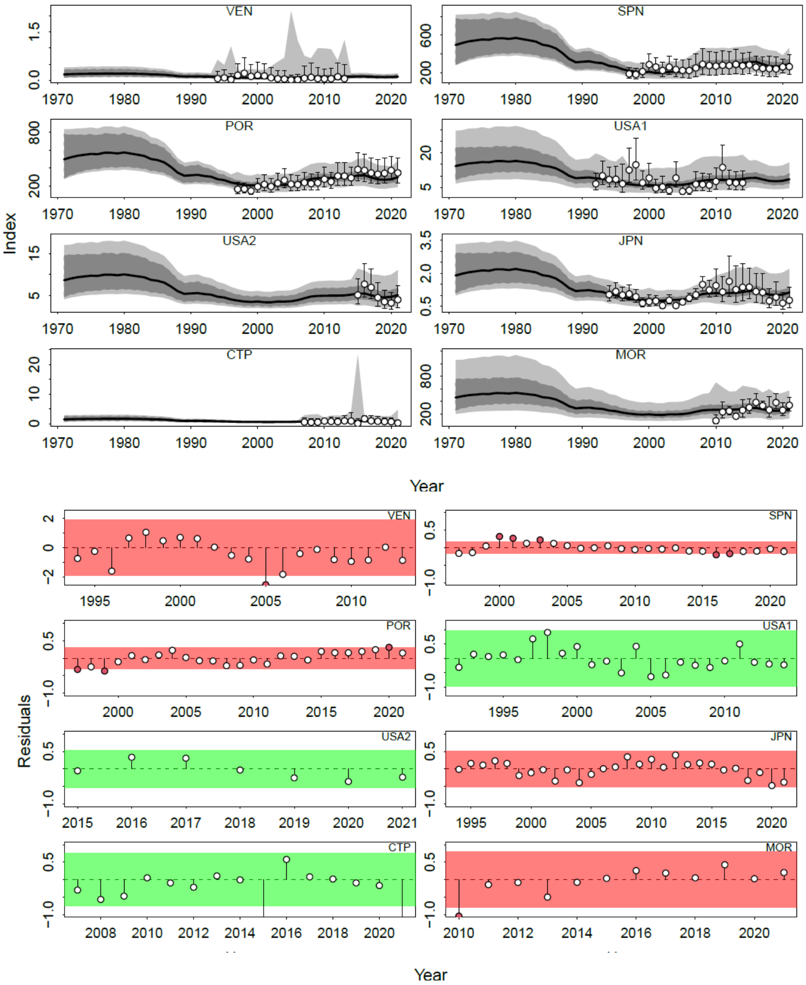


Figure 31. Top panels: Time series of observed (circle) and predicted (solid black line) CPUE of the North Atlantic blue shark JABBA reference case. The dark grey shaded areas show 95% posterior probability intervals of the expected mean CPUE, and the light grey shaded areas denote the 95% posterior predictive distribution intervals. Bottom panels: Runs tests to evaluate the randomness of the time series of CPUE residuals by fleet for the North Atlantic blue shark JABBA reference case. Green panels indicate no evidence of lack of randomness of time-series residuals (p>0.05) while red panels indicate possible autocorrelation. The inner shaded area shows three standard errors from the overall mean and red circles identify a specific year with residuals greater than this threshold value (3x sigma rule).

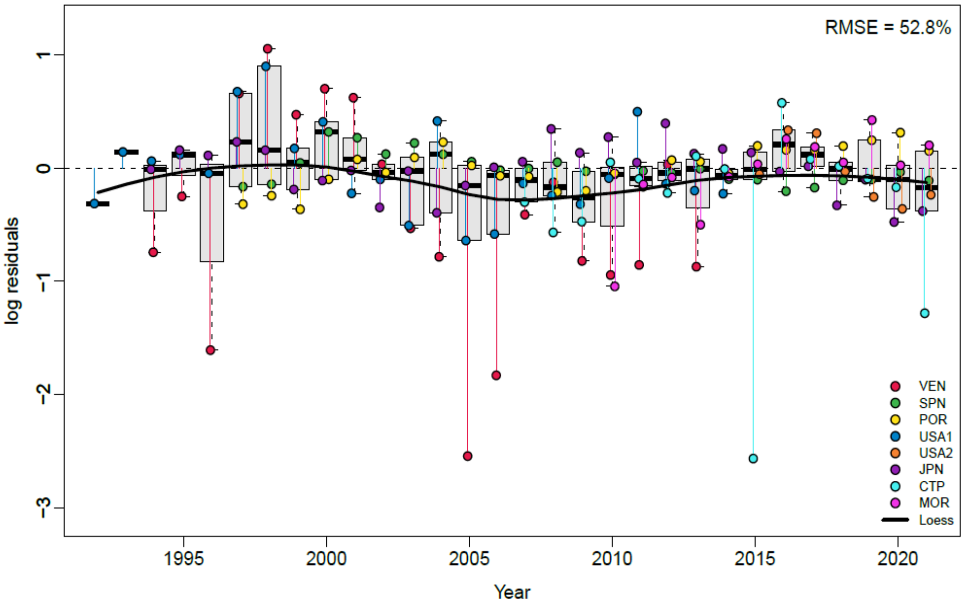


Figure 32. Residual diagnostic plots of log(CPUE) indices for the North Atlantic blue shark JABBA reference case. Boxplots indicate the median and quantiles of all residuals available for any given year, and solid black lines indicate a LOESS smoother through all residuals.

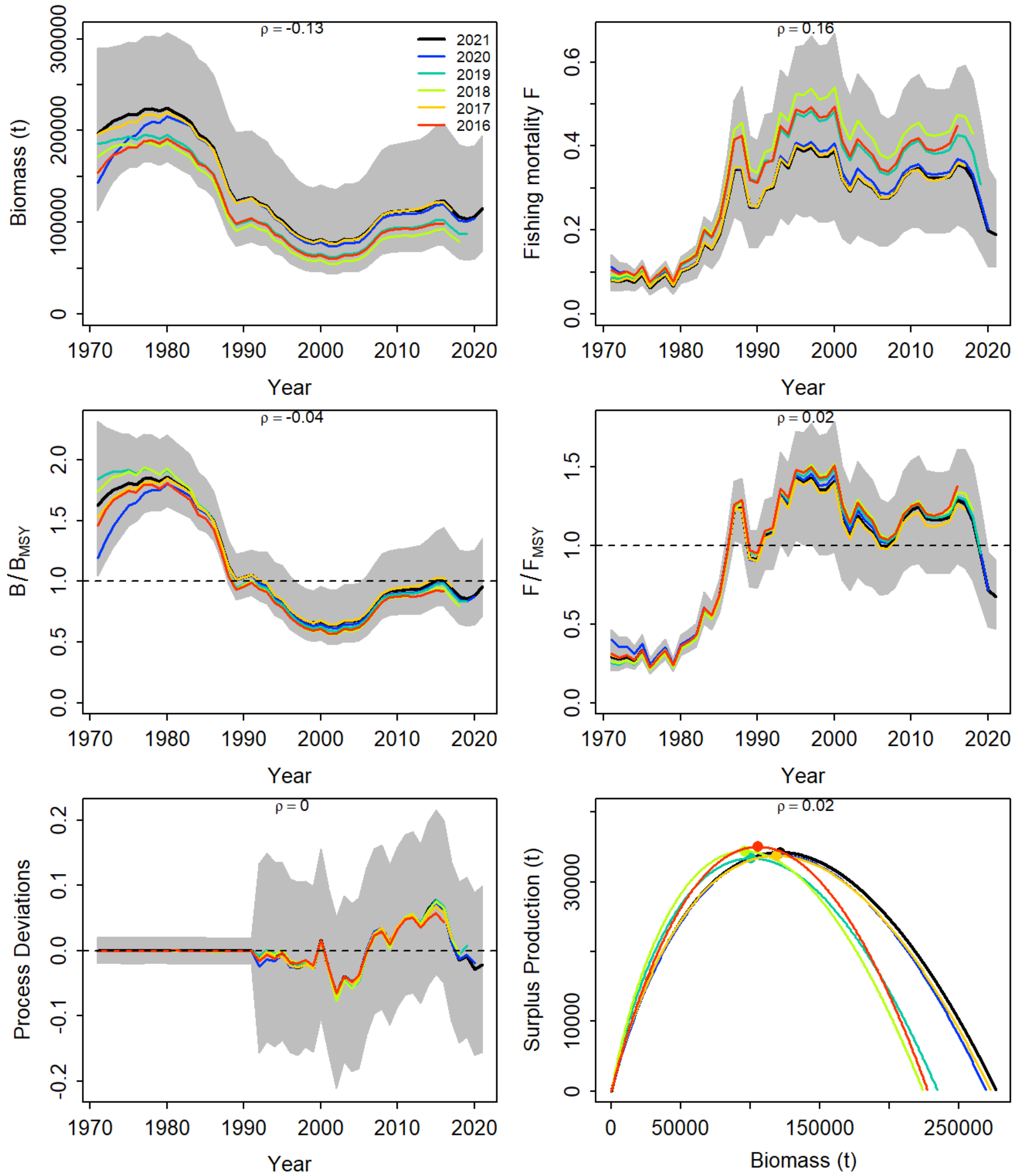


Figure 33. Retrospective analysis of the North Atlantic blue shark JABBA reference case, by removing one year at a time sequentially (up to 5 years) and estimating the trends in biomass and fishing mortality (upper panels), biomass relative to B_{MSY} (B/B_{MSY}) and fishing mortality relative to F_{MSY} (F/F_{MSY}) (middle panels) and biomass relative to K (B/K) and surplus production curve (bottom panels).

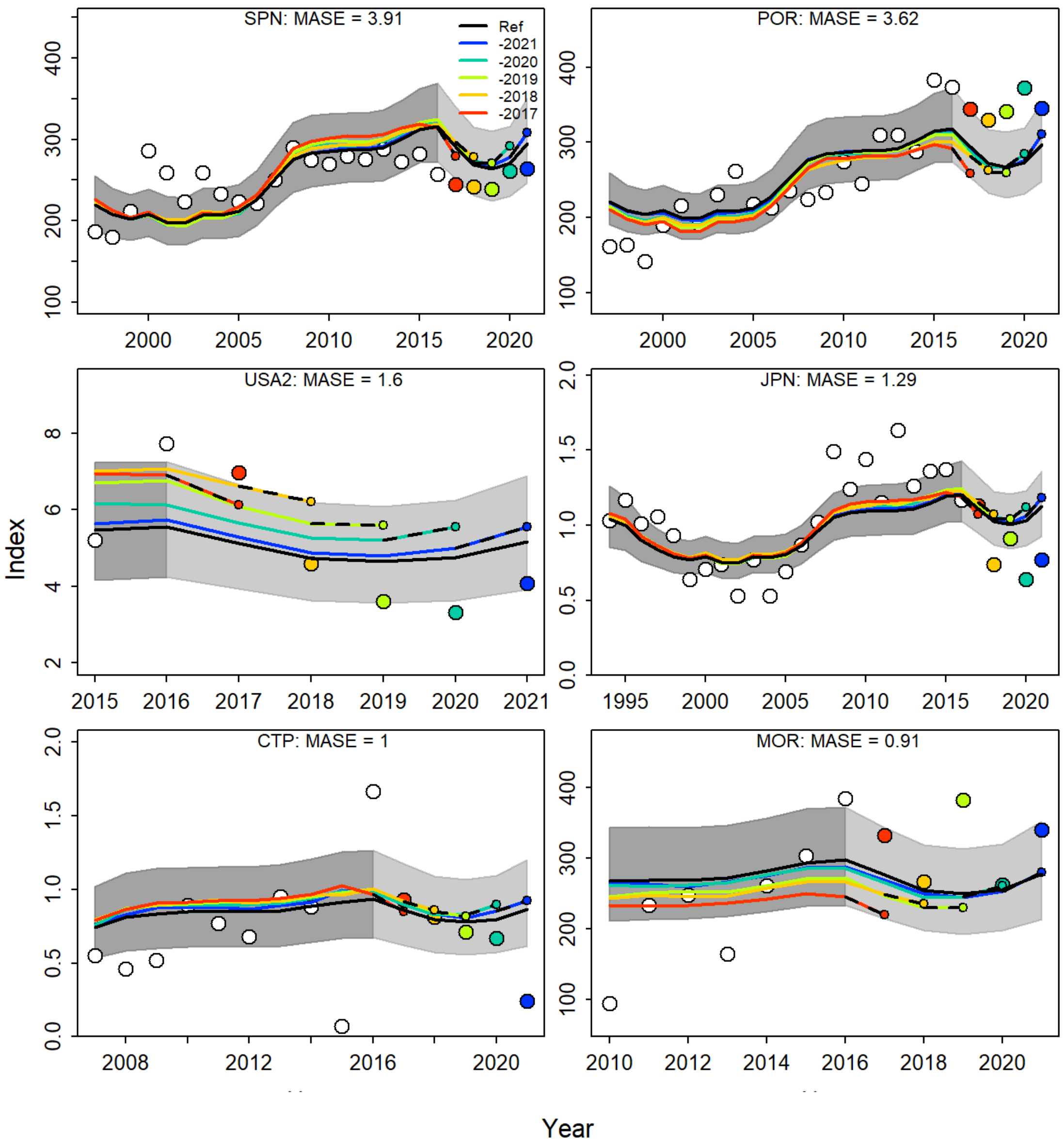


Figure 34. Hindcasting cross-validation results for the North Atlantic blue shark JABBA reference case, showing one-year-ahead forecasts of CPUE values (2017-2021), performed with five hindcast model runs relative to the expected CPUE. The CPUE observations, used for cross-validation, are highlighted as color-coded solid circles with associated light-grey shaded 95% confidence interval. The model reference year refers to the end points of each one-year-ahead forecast and the corresponding observation (i.e. year of peel + 1).

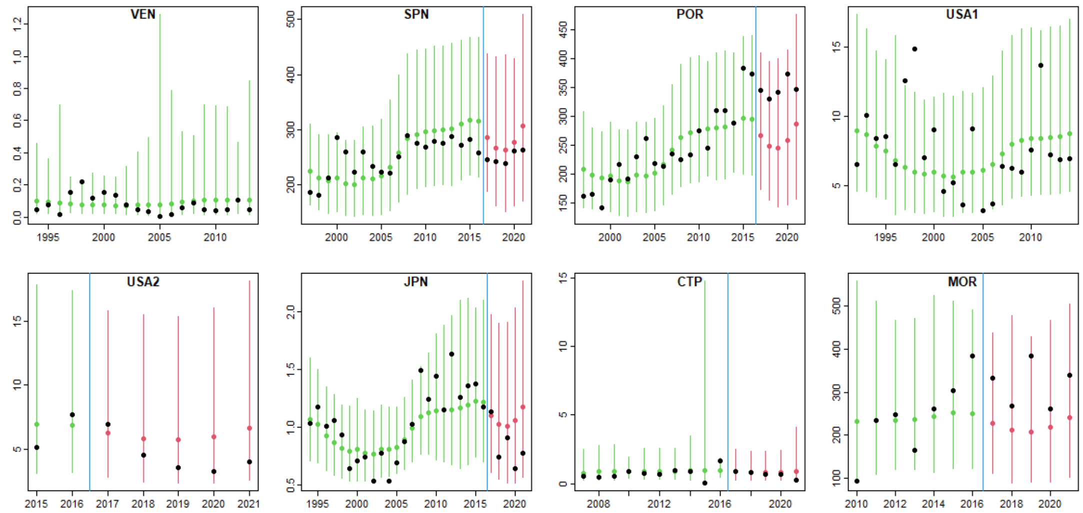


Figure 35. Posterior predictive intervals for CPUE values, taking into account the observation error of the CPUEs, for the North Atlantic blue shark JABBA reference case, from a model run deleting the last 5 years of CPUE data (2017-2021). Black dots are the observed CPUE values, and the posterior predictive intervals (90% probability) are colored green and red for the years in which the CPUE values were included or excluded from the model run.

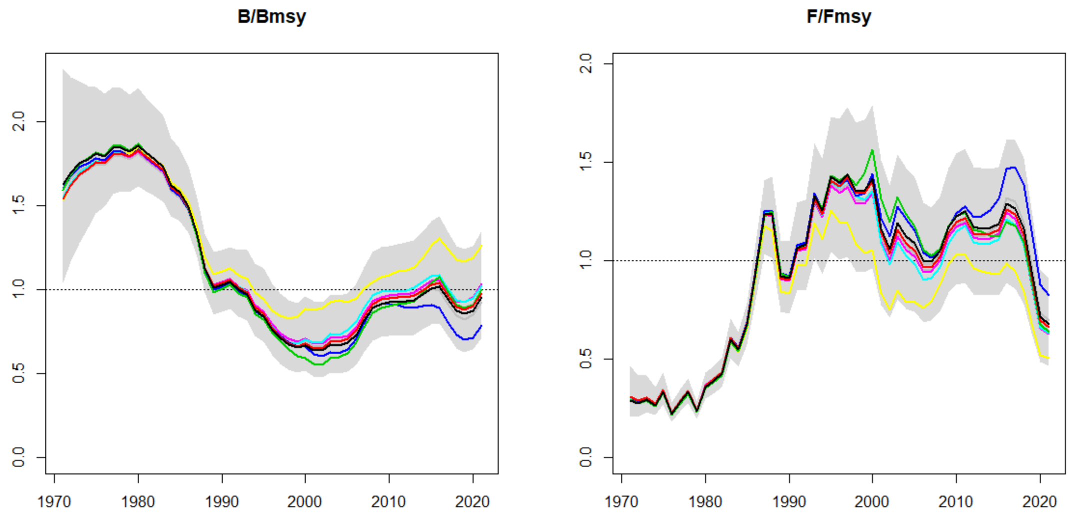


Figure 36. Jackknife analysis of the North Atlantic blue shark JABBA reference case. The black lines and grey shaded intervals correspond to the reference case, and the colored lines to the same model fitted after removing one CPUE series at a time. The blue line is the fit when removing the Portuguese CPUE series and the yellow line the fit when removing the Japanese CPUE series.

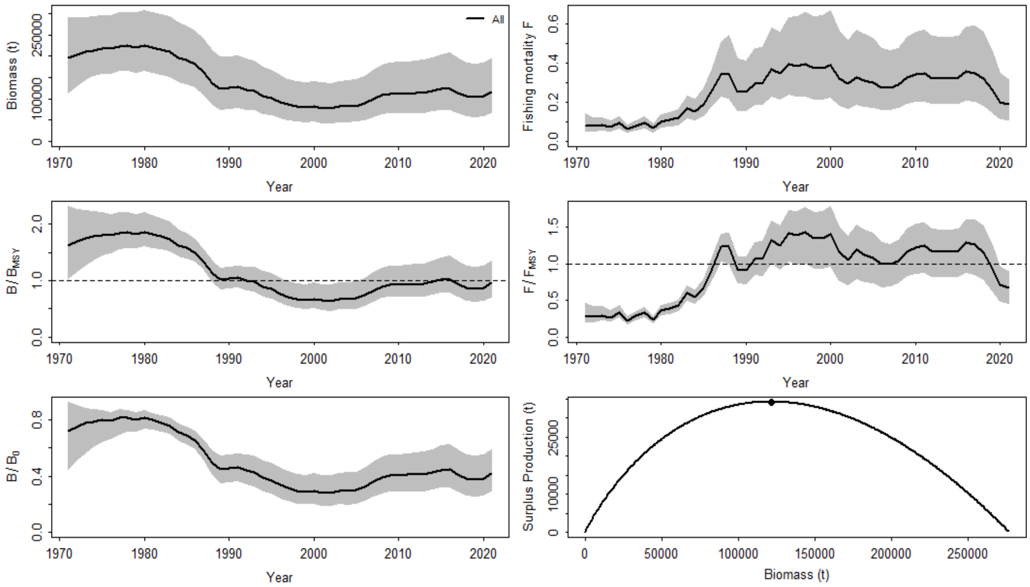


Figure 37. Annual stock trends as estimated by the North Atlantic blue shark JABBA reference case. The solid line represents the median value, and the shaded area indicates the 95% posterior probability interval.

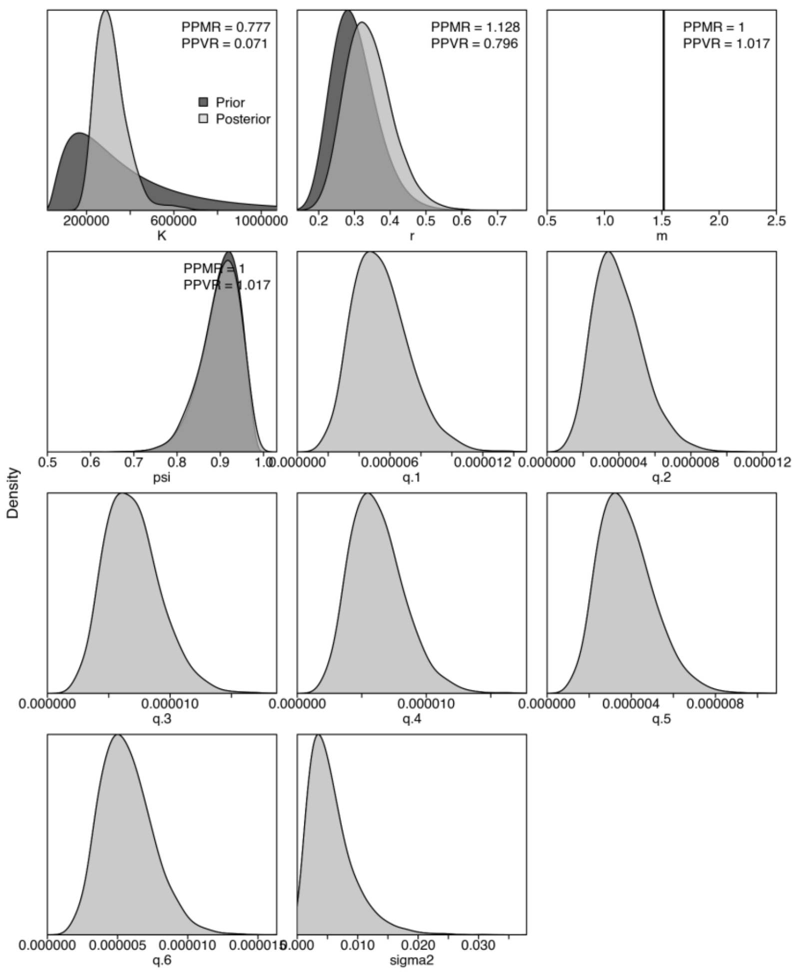


Figure 38. Prior and posterior distributions of the JABBA reference case for the South Atlantic blue shark stock. PPRM: Posterior to Prior Ratio of Means; PPRV: Posterior to Prior Ratio of Variances.

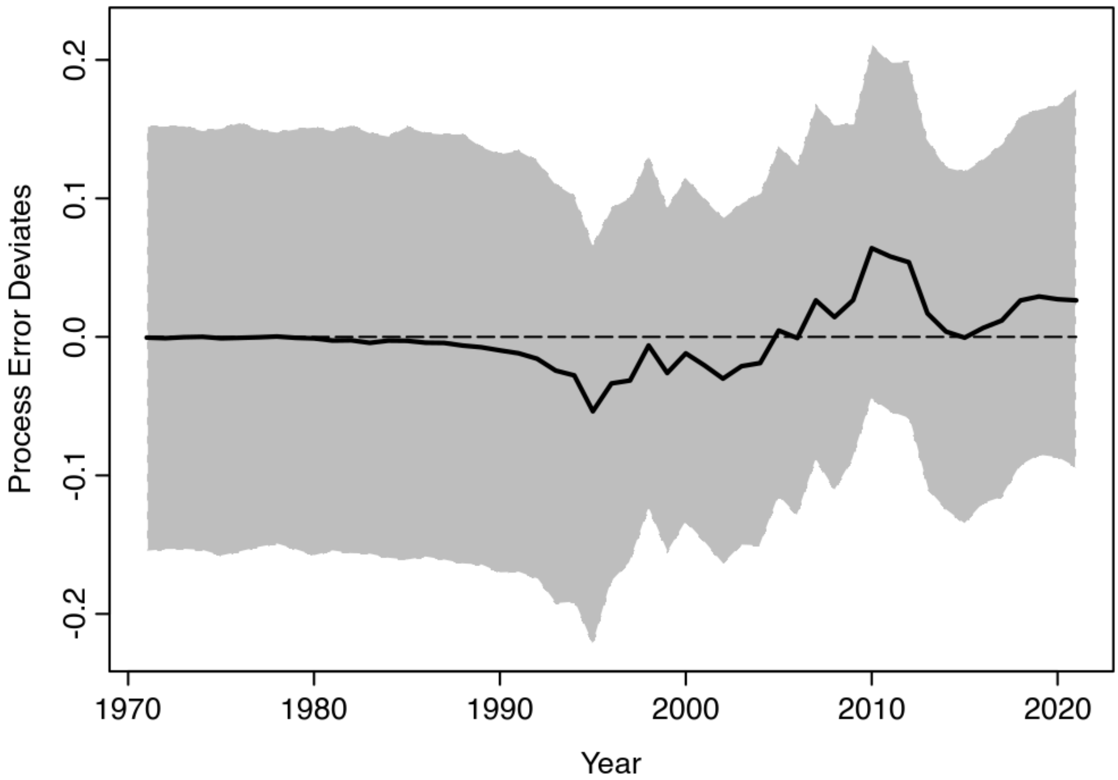


Figure 39. Process error deviates (median: solid line) for the South Atlantic blue shark JABBA Reference Case. The shaded grey area indicates 95% credibility intervals.

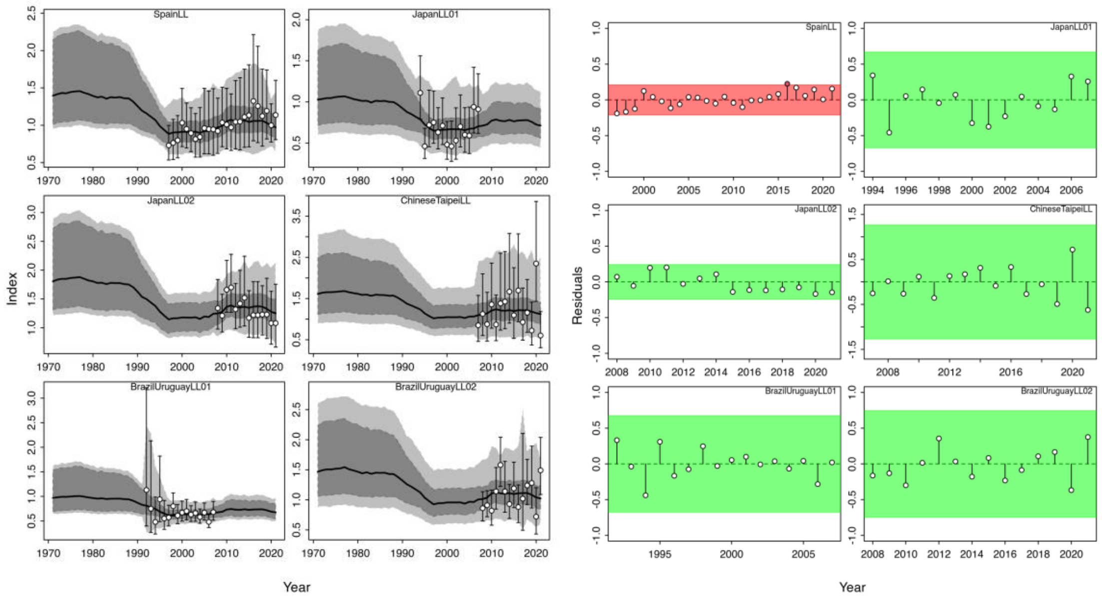


Figure 40. Left panels: Time series of observed (circle, input data) and predicted (solid line) CPUE of the South Atlantic blue shark JABBA reference case. The dark grey shaded areas show 95% credibility intervals of the expected mean CPUE, and the light grey shaded areas denote the 95% posterior predictive distribution intervals. Right panels: Runs tests to evaluate the randomness of the time series of CPUE residuals by fleet for the South Atlantic blue shark JABBA Reference Case. Green panels indicate no evidence of lack of randomness of time-series residuals (p>0.05) while red panels indicate possible autocorrelation. The inner shaded area shows three standard errors from the overall mean and red circles identify a specific year with residuals greater than this threshold value (3x sigma rule).

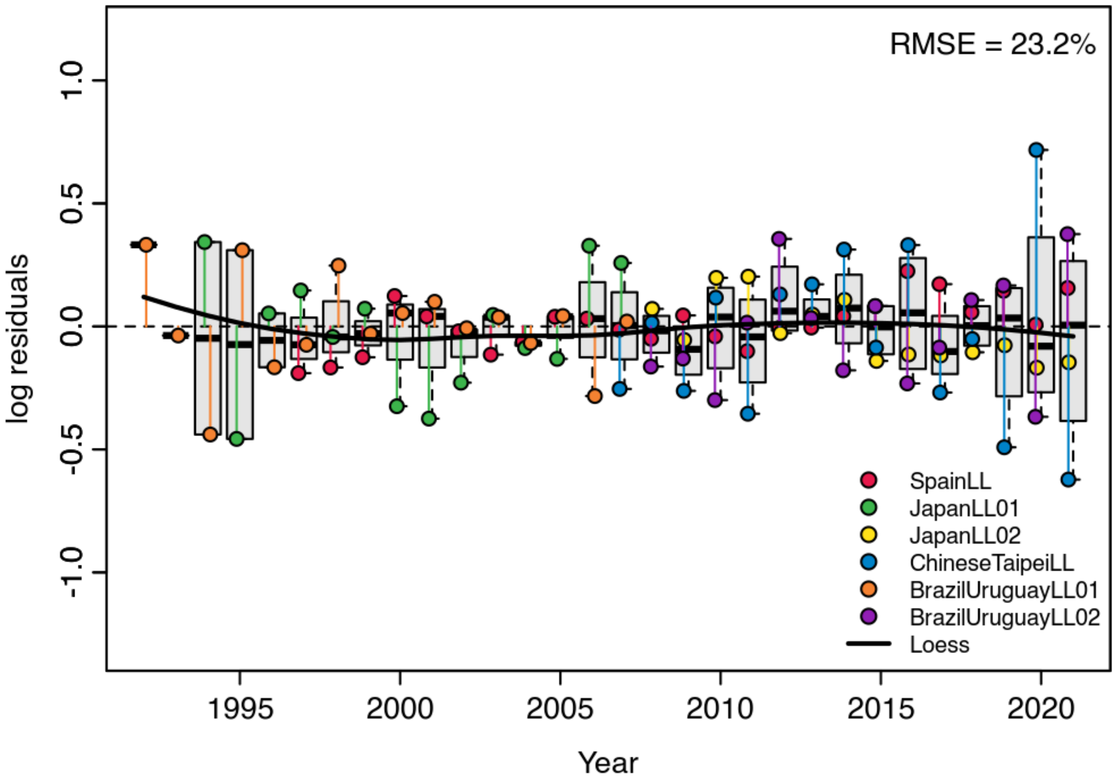


Figure 41. Residual diagnostic plots of CPUE indices for the South Atlantic blue shark JABBA reference case. Boxplots indicate the median and quantiles of all residuals available for any given year, and solid black lines indicate a LOESS smoother through all residuals.

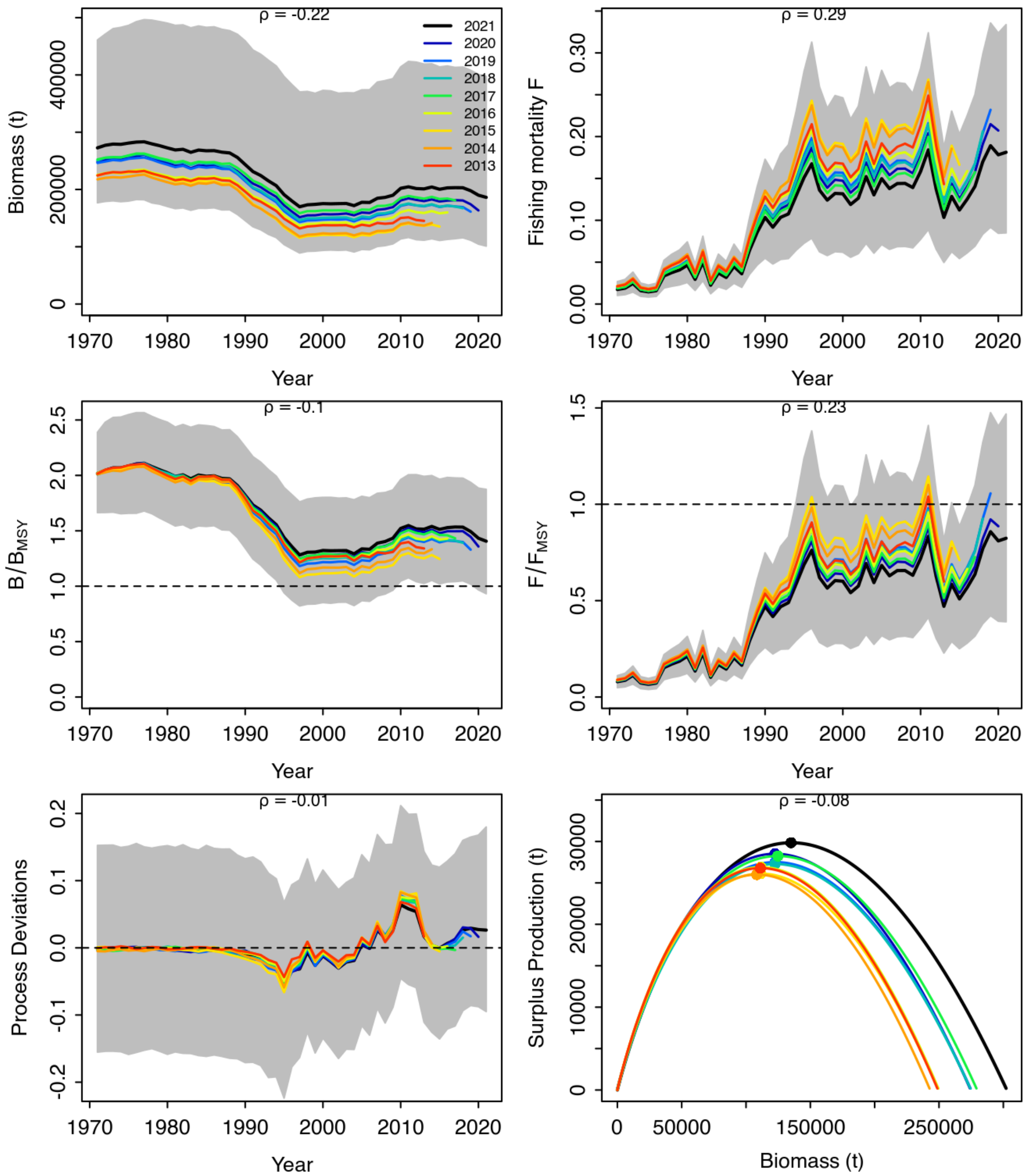


Figure 42. Retrospective analysis of the South Atlantic blue shark JABBA reference case, by removing one year at a time sequentially (n=5) and predicting the trends in biomass and fishing mortality (upper panels), biomass relative to B_{MSY} (B/B_{MSY}) and fishing mortality relative to F_{MSY} (F/F_{MSY}) (middle panels) and biomass relative to K (B/K) and surplus production curve (bottom panels).

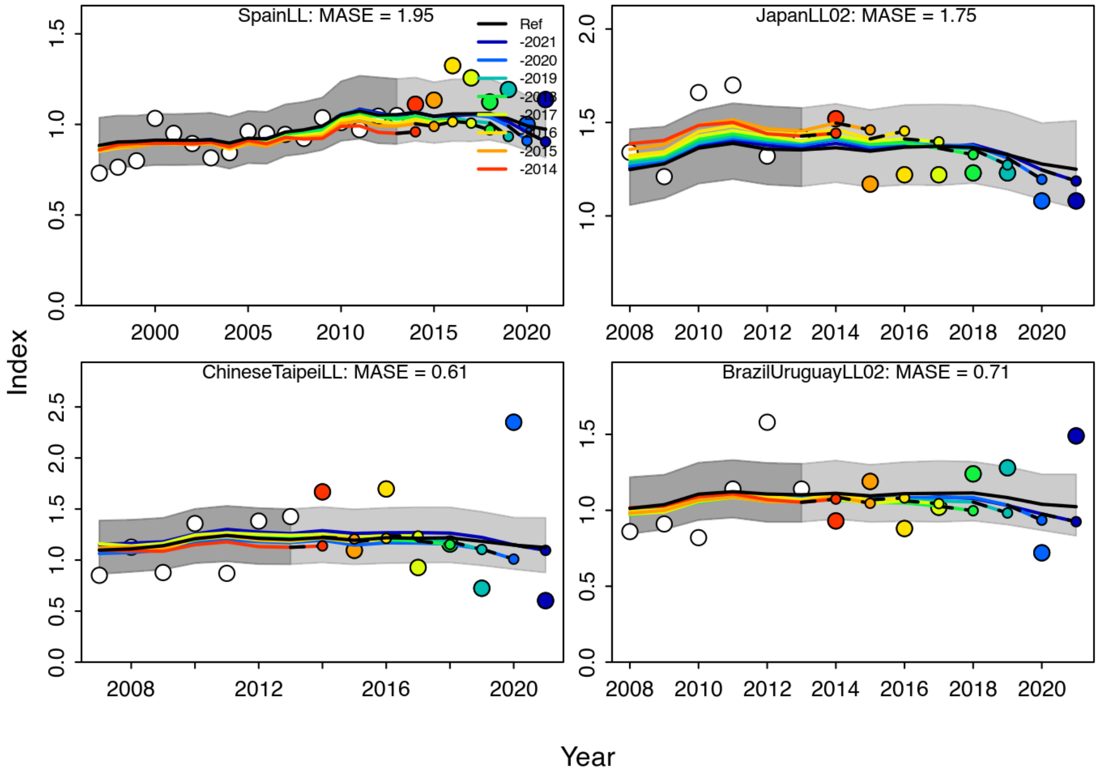


Figure 43. Hindcasting cross-validation results for the South Atlantic blue shark JABBA reference case, showing one-year-ahead forecasts of CPUE values (2017-2021), performed with five hindcast model runs relative to the expected CPUE. The CPUE observations, used for cross-validation, are highlighted as color-coded solid circles with associated light-grey shaded 95% confidence interval. The model reference year refers to the end points of each one-year-ahead forecast and the corresponding observation (i.e. year of peel + 1).

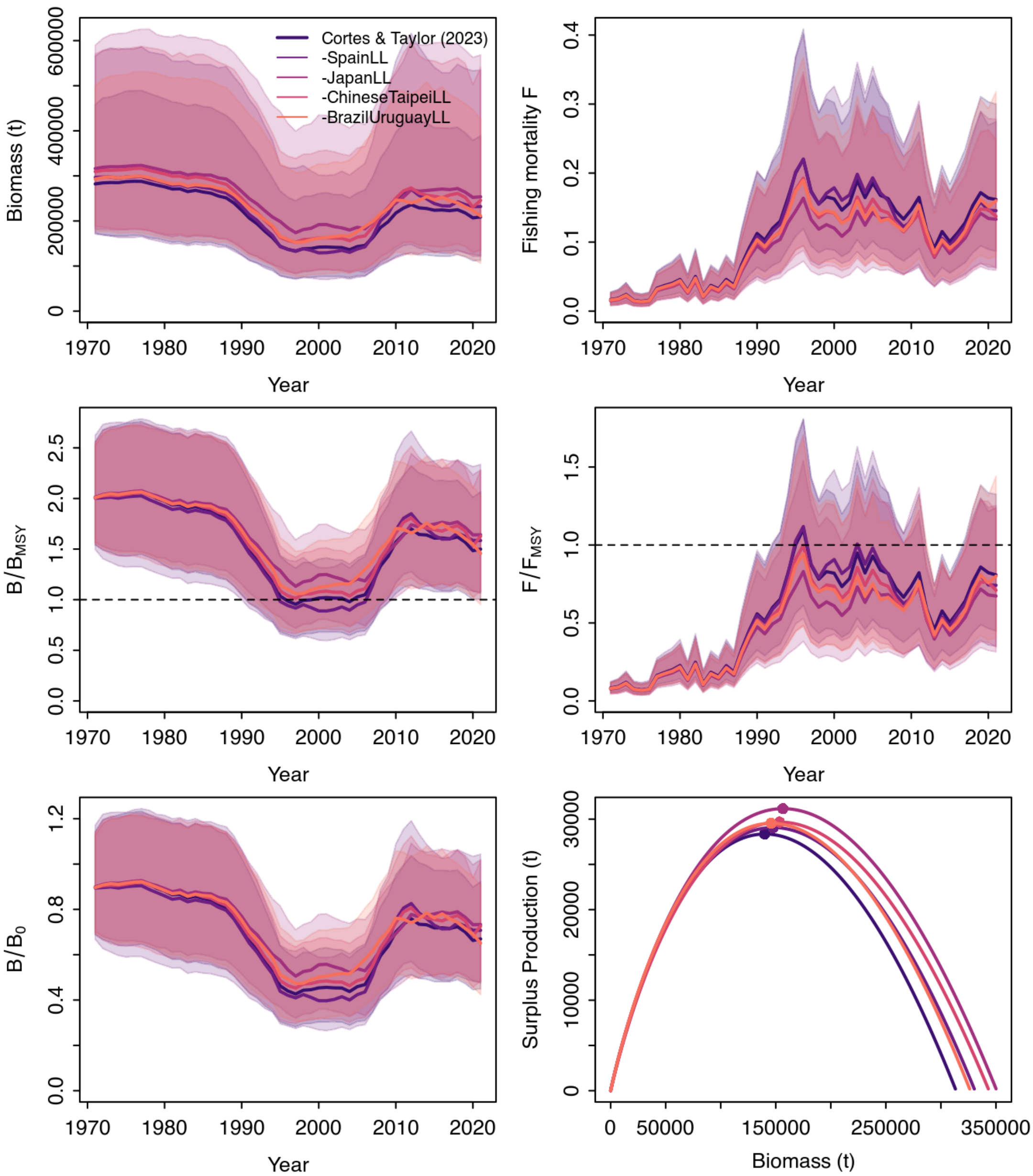
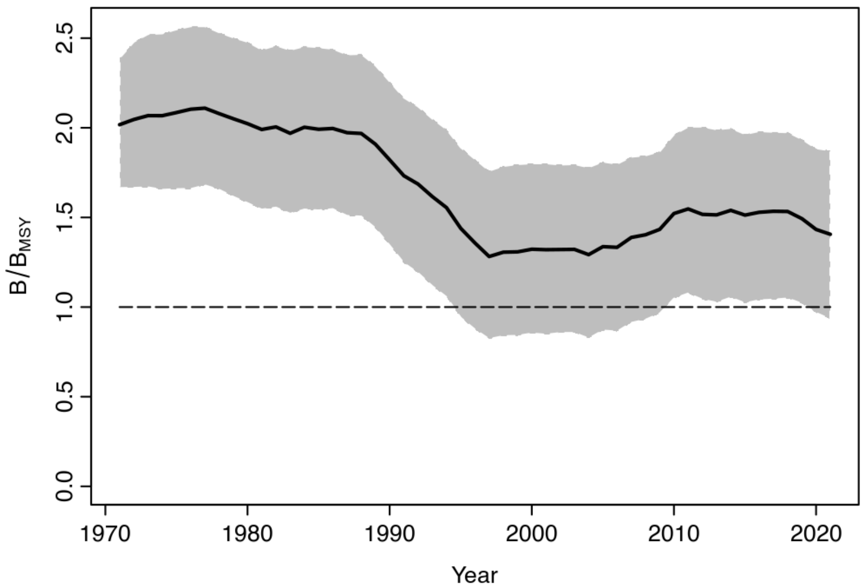


Figure 44. Jackknife index analysis of the South Atlantic blue shark JABBA reference case, by removing one CPUE fleet at a time and predicting the trends in biomass and fishing mortality (upper panels), biomass relative to B_{MSY} (B/B_{MSY}) and fishing mortality relative to F_{MSY} (F/F_{MSY}) (middle panels) and biomass relative to K (B/K) and surplus production curve (bottom panels).



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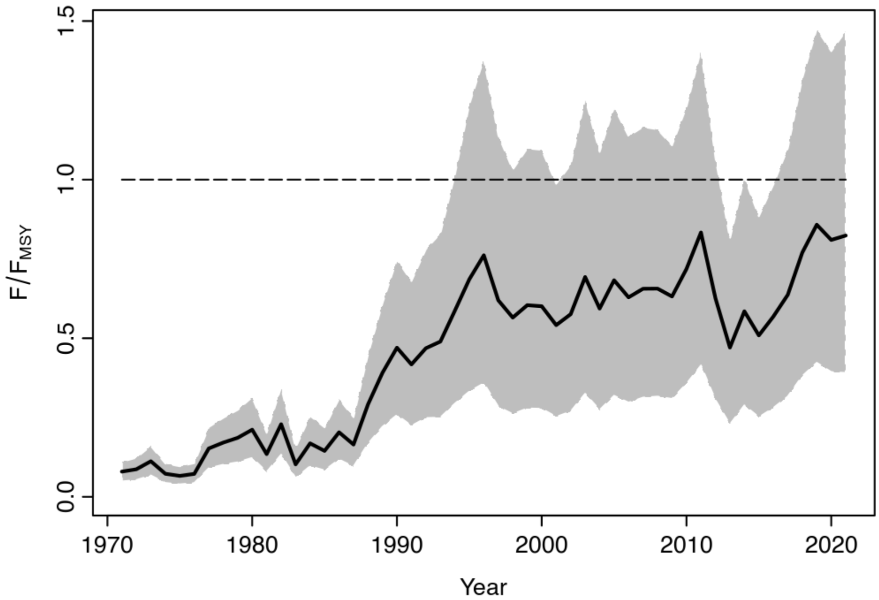

Figure 45. Annual trends of B/B_{MSY} (top) and F/F_{MSY} (bottom) as estimated by the South Atlantic blue shark JABBA Reference Case. The solid line represents the median value, and the shaded area indicates the 95% credibility interval.

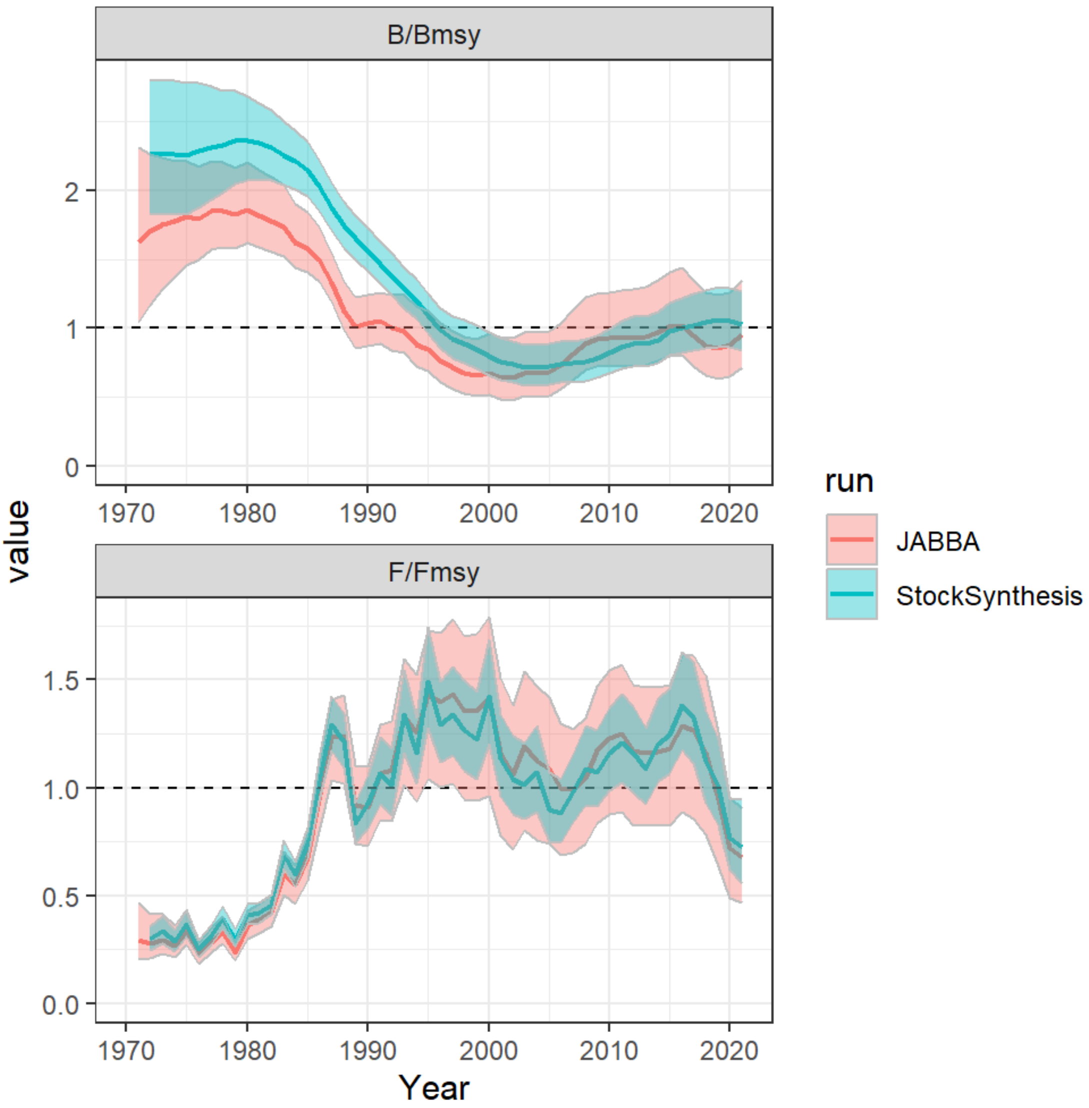

Figure 46. Estimated annual trends from JABBA (orange lines) and Stock Synthesis (green lines) for B/B_{MSY} (JABBA) or SSB/SSB_{MSY} (Stock Synthesis) (upper panel), and F/F_{MSY} (lower panel) with 95% CI (JABBA: 100,000 iterations, Stock Synthesis: 100,000 iterations using MVLN).

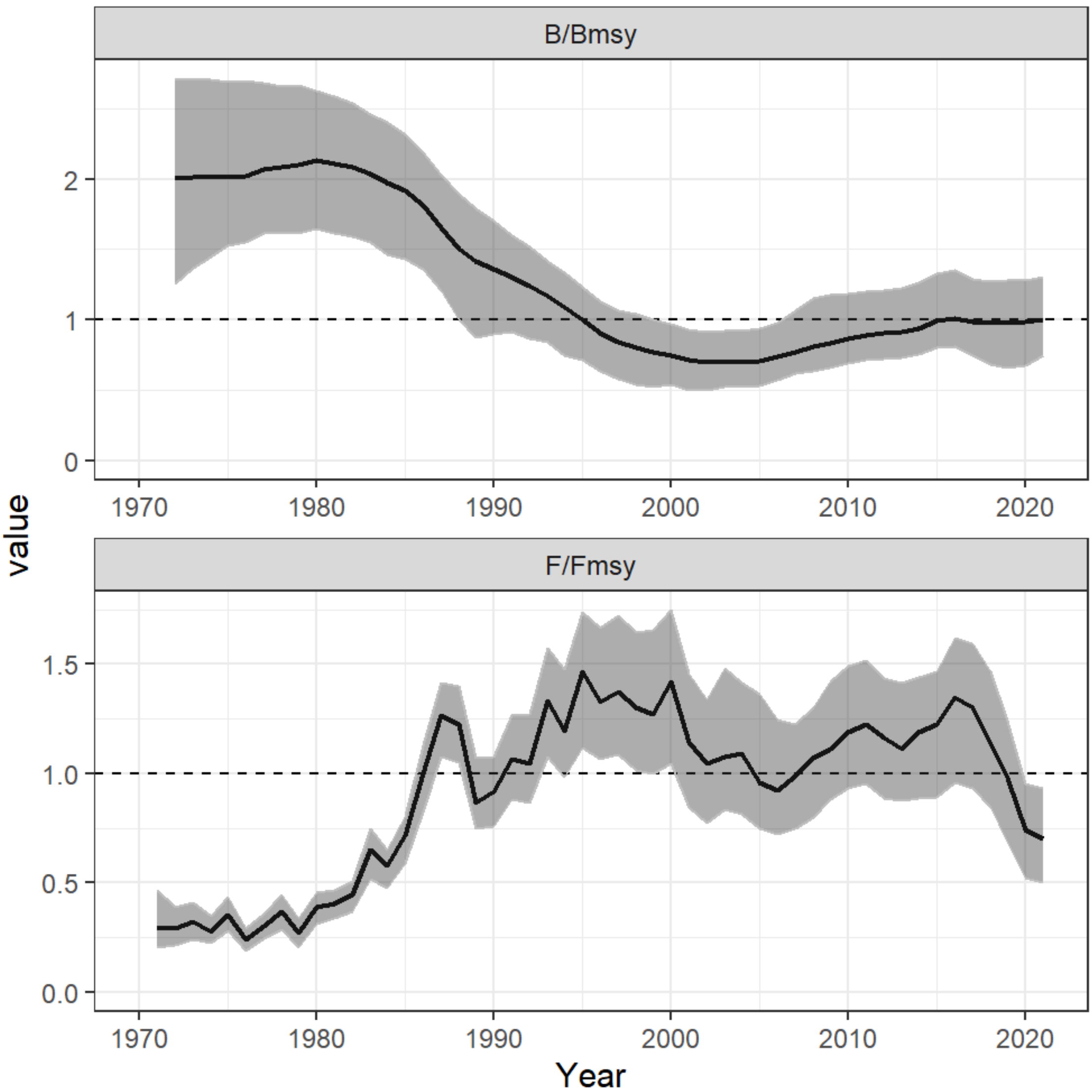

Figure 47. Joint time series of relative B and relative F and the Kobe phase plot were built with 100,000 iterations based on the Monte-Carlo multivariate lognormal (MVLN) approach for the Stock Synthesis reference case and 100,000 MCMC samples from the JABBA reference case.

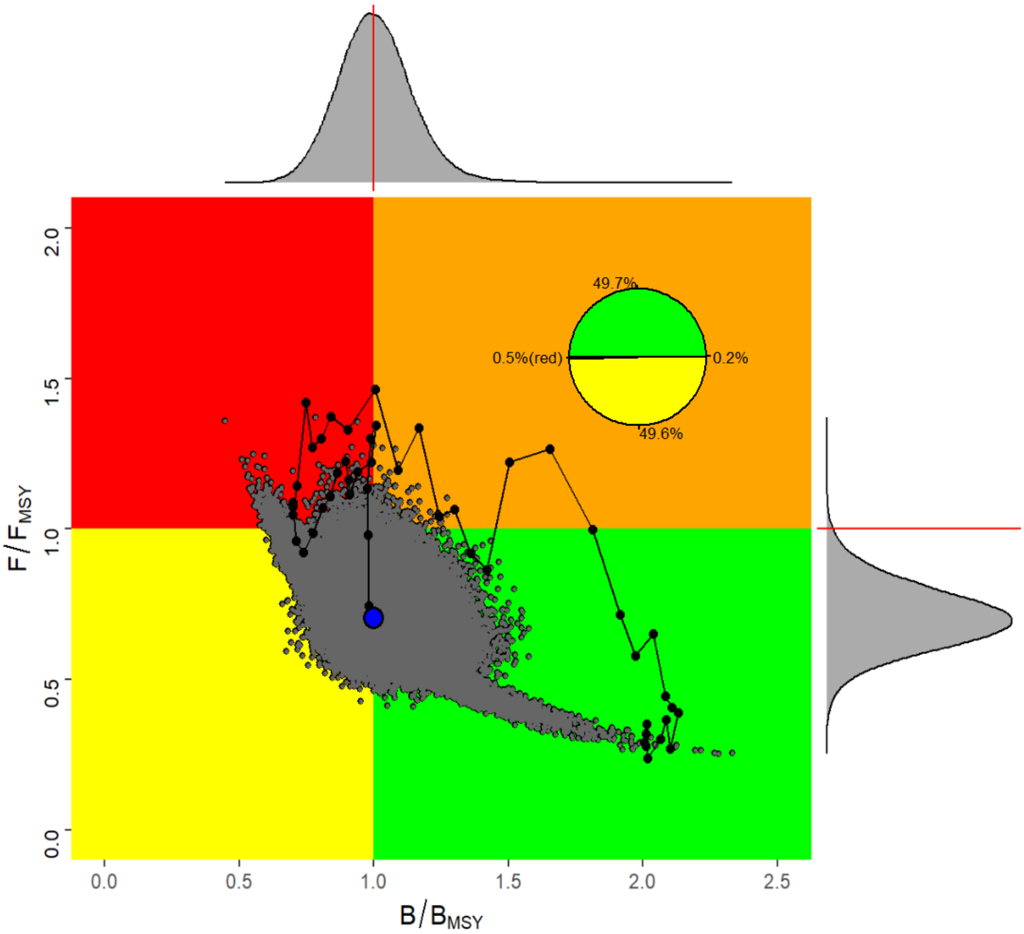

Figure 48. Joint Kobe phase plot from JABBA and Stock Synthesis for the North Atlantic blue shark stock. Solid black dots and solid line indicate the stock status trajectory, with the blue dot indicating the terminal year (2021), grey dots are the interactions from each model for the terminal year with the marginal distributions plotted in the lateral axis.

Figure 49. Estimated annual trends from JABBA (orange lines) and Stock Synthesis (green lines) for B/B_{MSY} (JABBA) or SSB/SSB_{MSY} (Stock Synthesis) (upper panel), and F/F_{MSY} (lower panel) with 95% CI (JABBA: 15,000 iterations, Stock Synthesis: 15,000 iterations using MVLN).

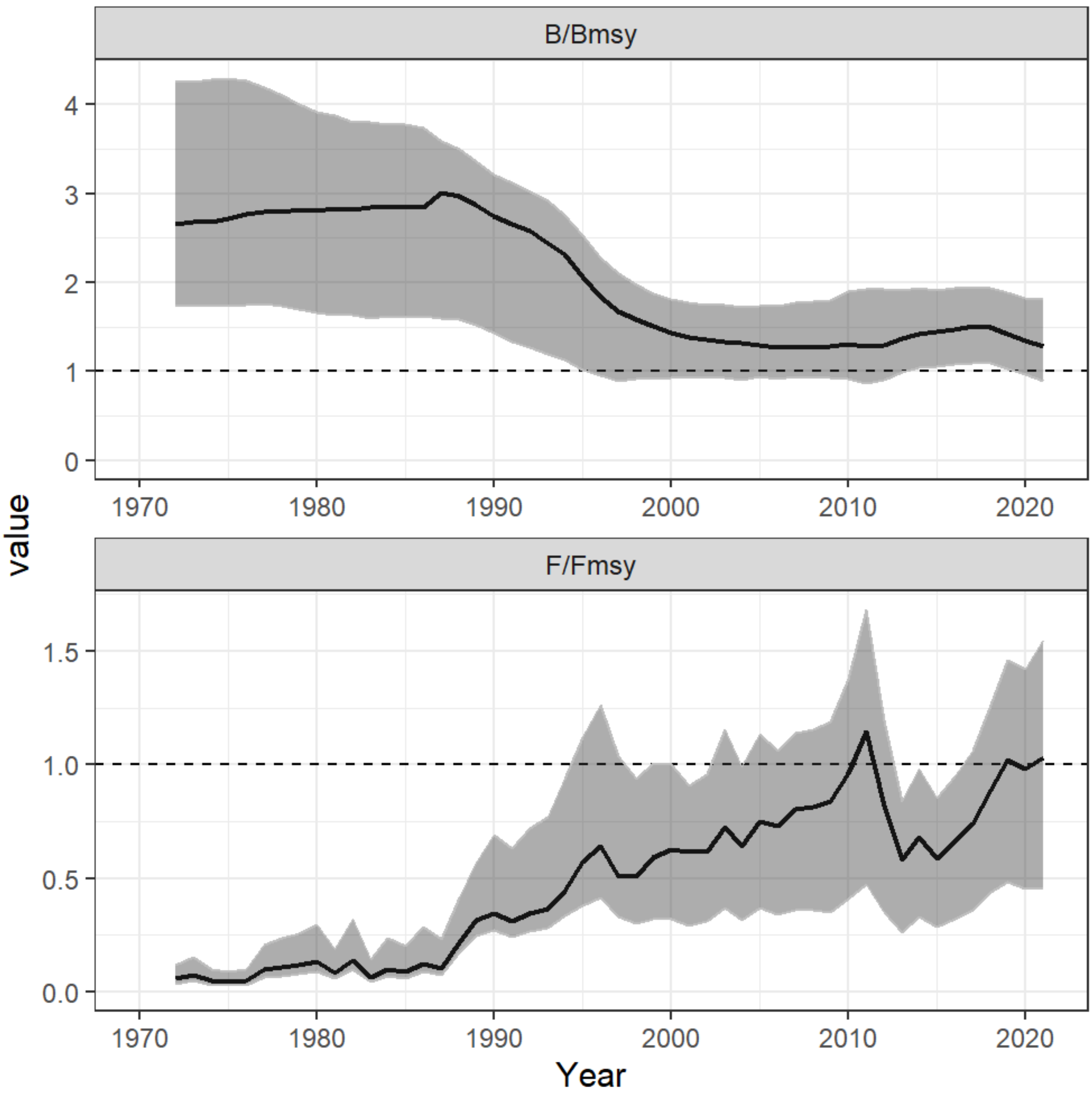

Figure 50. The combined results between JABBA and Stock Synthesis for B/B_{MSY} (JABBA) or SSB/SSB_{MSY} (Stock Synthesis) (upper panel), and F/F_{MSY} (lower panel) with 95% confidence interval using 30,000 iterations from JABBA (15,000 iterations) and Stock Synthesis (15,000 iterations using MVLN).

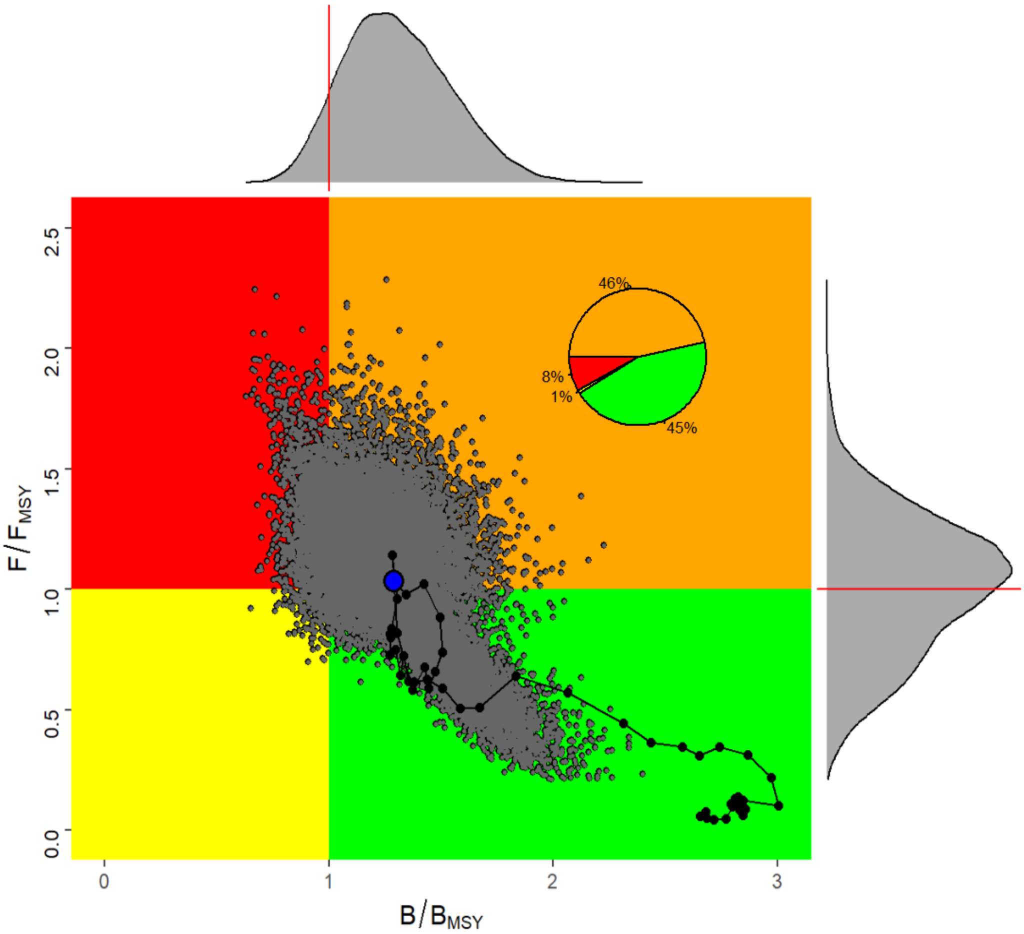

Figure 51. Joint Kobe phase plot from JABBA and Stock Synthesis for the South Atlantic blue shark stock. Solid black dots and solid line indicate the stock status trajectory, with the blue dot indicating the terminal year (2021), grey dots are the interactions from each model for the terminal year with the marginal distributions plotted in the lateral axis.

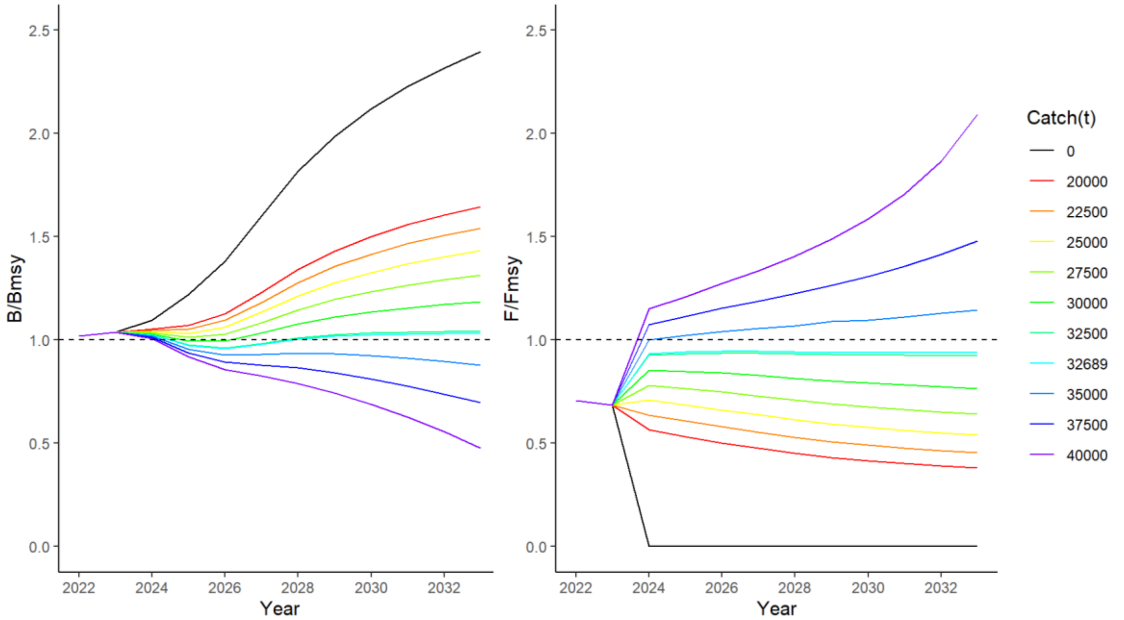

Figure 52. Projections for B/B_{MSY} and F/F_{MSY} based on both Stock Synthesis and JABBA reference cases for North Atlantic blue shark stock for various levels of future constant catch ranging from 20,000 – 40,000 t, including a zero-catch scenario starting in 2024. The initial catch for the years 2022-2023 was set to 23,418 t, which is the average catch of the recent 3 years (2019-2021). The projections are run until 2033 (10 years).

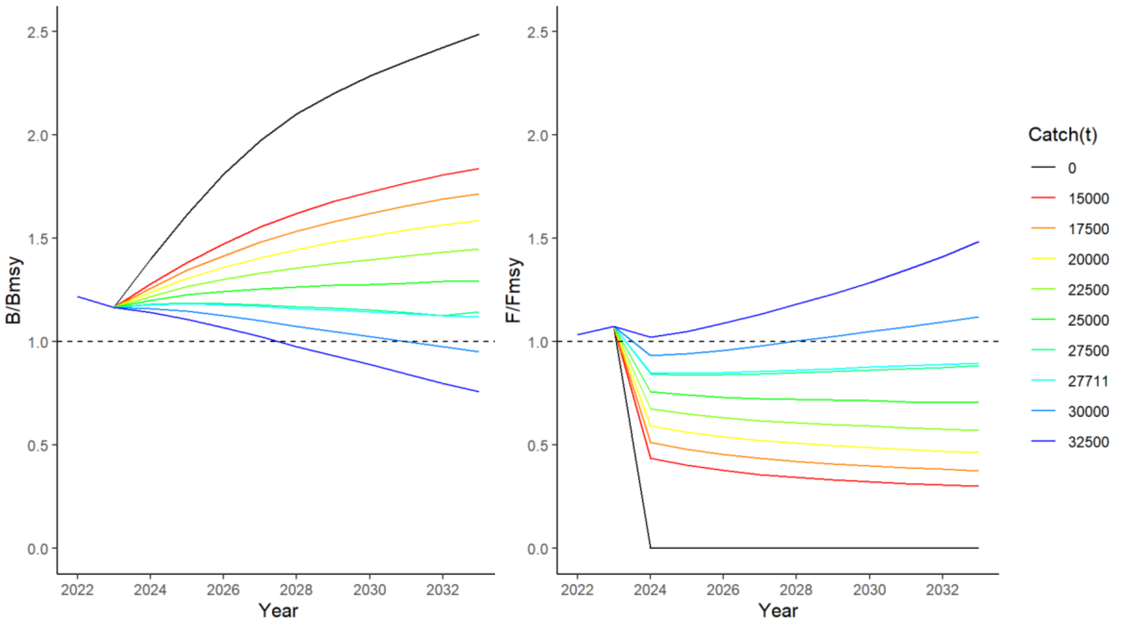

Figure 53. Projections for B/B_{MSY} and F/F_{MSY} based on both Stock Synthesis and JABBA reference cases for South Atlantic blue shark stock for various levels of future constant catch ranging from 15,000 – 32,500 t, including a zero-catch scenario starting in 2024. The initial catch for the years 2022-2023 was set to 34,983 t, which is the average catch of the recent 3 years (2019-2021). The projections are run until 2033 (10 years).

Appendix 1

Agenda

1. Opening, adoption of agenda and meeting arrangements
2. Summary of available data for assessment
   - 2.1 Stock identity
   - 2.2 Catches
   - 2.3 Indices of abundance
   - 2.4 Biology
   - 2.5 Length compositions
   - 2.6 Other relevant data
3. Methods and other data relevant to the assessment
   - 3.1 Production models
   - 3.2 Length-based age-structured models: Stock Synthesis
   - 3.3 Just Another Bayesian Biomass Assessment (JABBA)
   - 3.4 Other methods
4. Stock status results
   - 4.1 Production models
   - 4.2 Stock Synthesis
   - 4.3 JABBA
   - 4.4 Other methods
   - 4.5 Synthesis of assessment results
5. Projections
6. Recommendations
   - 6.1 Research and statistics
   - 6.2 Management
7. Responses to the Commission
8. Shark Research and Data Collection Programme (SRDCP)
9. Other matters
10. Adoption of the report and closure

Appendix 2

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Appendix 3

List of papers and presentations

Doc Ref	*Title*	*Authors*
SCRS/2023/115	Estimates of Vital Rates and Population Dynamics Parameters of Interest for Blue Sharks in the North and South Atlantic Ocean	Cortés E., Taylor N.G.
SCRS/2023/116	Multivariate Model Estimates of Life History Parameters and Productivity for North and South Atlantic Blue Shark Stocks	Taylor N.G., Cortés E.
SCRS/2023/120	South Atlantic Blue Shark Stock Assessment 1971-2021 Using Stock Synthesis	Gustavo-Cardoso L., Kikuchi E., Rice J., Courtney D., Sant'Ana R., Leite Mourato B., Fernandez C.
SCRS/2023/121	Update of Input Data (Catch and Size) for the Atlantic Blue Shark (*Prionace Glauca*) Stock Assessment Models 2023	Ortiz M., Kimoto A., Palma C., Mayor C.
SCRS/2023/122	Model Validation for Selection and Weighting of Scenarios	Kell L.T., Winker H.
SCRS/2023/123	Exploratory analysis of blue shark catches, *Prionace glauca* in the Spanish Mediterranean waters	Rueda L., Baez J.C., Garcia-Barcelona S., Moreno J., Macias D.
SCRS/2023/124	JABBA Runs for the North Atlantic Blue Shark	Fernandez C.
SCRS/2023/126	Bayesian Surplus Production Models for Blue Sharks using the Legacy BSP Software	Babcock E.A.
SCRS/2023/127	South Atlantic Blue Shark Stock: Just Another Bayesian Biomass Assessment	Sant'Ana R., Mourato B., Cardoso L.G., Kimoto A., Ortiz M.
SCRS/2023/128	Preliminary Stock Synthesis (SS3) Model Runs Conducted for North Atlantic Blue Shark (1971-2021)	Courtney D., Fernandez C., Rice J., Cardoso L.G., Kikuchi E.
SCRS/P/2023/098	Age Structured Production Model Diagnostic SS3 Reference Case	Rice J.

Appendix 4

SCRS documents and presentation abstracts as provided by the authors

SCRS/2023/115 - Estimates of vital rates and population dynamics parameters of the North and South Atlantic stocks of blue shark (*Prionace glauca*) for potential use as inputs into production and integrated stock assessment models were computed based on the latest biological information available gathered at the 2023 Blue Shark Data Preparatory Meeting. Population dynamics parameters included maximum population growth rate (rmax), generation time ( ), steepness of the Beverton-Holt stock-recruitment relationship (h), spawning potential ratio at maximum excess recruitment (SPRMER), position of the inflection point of population growth curves (R) and the corresponding shape parameter (m), and natural mortality (M). Six methods were used to compute deterministic estimates of rmax: four age-aggregated methods and two analogous age-structured methods. Additionally, a Leslie matrix approach was used to incorporate uncertainty in growth parameters, the maturity ogive, fecundity, natural mortality, and lifespan by assigning statistical distributions to those biological traits. For the North Atlantic stock, productivity (rmax) estimated with the Euler-Lotka/Leslie matrix deterministic method using a length-based mortality estimator was 0.283 yr-1and increased to 0.386 yr-1when using the mean of six life-history invariant mortality estimators; productivity estimated with the stochastic Leslie matrix was very similar to that estimated with the deterministic method using the mean of the six M estimators (rmax=0.385; 95% CI: 0.224-0.596). This high productivity was also expressed in the values of steepness (h=0.86, 95% CI: 0.57-0.96). For the South Atlantic stock, productivity (rmax) estimated with the Euler-Lotka/Leslie matrix deterministic method using the length-based M estimator was substantially lower than for the North Atlantic ((rmax=0.142 yr-1), but increased to 0.291 yr-1when using the mean of six M estimators; productivity estimated with the stochastic Leslie matrix was very similar to that estimated with the deterministic method using the mean of the six M estimators (rmax=0.299; 95% CI: 0.165-0.389) with a corresponding steepness of h=0.80 (95% CI: 0.46-0.93). The high values of productivity estimated here are in line with previously reported values for these and other populations of this species. The estimates of rmax and of the position of the inflection point of the production curve (R) and the associated shape parameter (m) can be used to generate priors for production models; the estimates of generation time can help identify the time horizon for projections; and the estimates of steepness and M can also be used as fixed parameter values or priors in Stock Synthesis.

SCRS/2023/116 - We obtain estimates of life history parameters and steepness from the Fishlife database that contains the metanalytical information from Fishbase and from the Myers Legacy data. The first stage in the estimation process was to conduct the analysis using the existing records in the FishLife database. The second stage was to update the analysis with most recent life history parameters being applied in the 2023 ICCAT Blue Shark Assessment. Finally, we compare the results of the parameters derived using Fishlife with those used Leslie Matrix approaches. The set of life-history parameters and steepness can form the basis for priors in assessments and Operating Models for Management Strategy Evaluation.

SCRS/2023/120 - This document describes the provisional version of the stock assessment model using Stock Synthesis (SS) for the blue shark (*Prionace glauca*) in the South Atlantic, including the initial model setup, fleet definitions, selectivity, and parameterizations. The eight-fleet model runs from 1971 to 2021 and was fit to length composition data by sex for eight fleets and four indices of abundance. Life-history parameters were sex-specific, and the values were used based on the ICCAT Shark Working Group recommendations. Diagnostics for the proposed reference model demonstrated fast and stable convergence, good retrospectives, and a robust solution across different starting values. An eight-model uncertainty grid was proposed considering two sets of growth parameters, two resulting M–at–age vectors, and four steepness values. Furthermore, a comprehensive set of model diagnostics are presented for the reference model as well as estimates of SSB and recruitment across the entire uncertainty grid. The estimated SSB time series and depletion (B/B0) indicate a decreasing stock from the late 1980s to the early 2000s, remaining relatively low during the 2000s to the early 2010s, then recovering until 2017 when presented a slight decrease until the end of the time series. Fishing mortality increased significantly from the late 1980s, reaching its all-time high in the early 2010s, decreasing fast until mid-2010s. Since then, it presented a steady increase reaching near-all-time high values in recent years.

SCRS/2023/121 - The Sharks Species Group (SHKSG) is scheduled to evaluate the North and South Atlantic blue shark stocks in 2023. During the Data Preparatory Meeting, the SHKSG requested the Secretariat to provide input data of catch and size until 2021 for Stock Synthesis and Surplus Production models based on the preliminary fleet structure used in 2016. This document summarizes the revision and update of the available detailed catch and size data per fleet up to 2021.

SCRS/2023/122 - The blue shark assessment, as do many stock assessments, has to consider alternative data sets, uncertain life history information, and auxiliary data sets such as length and tagging data. The shark working group has also been asked to provide, "... options for a harvest control rule (HCR) with associated limit, target and threshold reference points for the management of blue shark in the ICCAT Convention area". Furthermore, the Working Group on Stock Assessment Methods recommended that working groups should identify model uncertainties, biases and misspecifications, to be considered when specifying uncertainty grids to be considered. This worked example has therefore been conducted in response to the Recommendation that the Shark Working Group together with the Working Group on Stock Assessment Methods, should help develop guidelines for the selection, rejection, weighting and extension of stock assessment models when providing robust management advice.

SCRS/2023/123 - This study analyses information of blue shark catches from the longline fleet operating in the Spanish Mediterranean waters. Data from observers and logbooks have been used to provide an exploratory analysis of the main factors associated with such catches. Catch per Unit of Effort (CPUE) has been calculated as number of individuals caught per thousand hooks. Differences in catches and CPUEs have been observed for the different types of longline used, as well as spatio-temporal patterns. In addition, basic biological information on the BSH caught is provided. Further analysis can provide more accurate information on important aspects such as inter- and intra-annual variation in catches and identification of potential areas of higher concentration of catches of BSH.

SCRS/2023/124 - This document presents JABBA runs for Blue Shark in the North Atlantic. As agreed in the ICCAT Data Preparatory Meeting (April 2023), the assessment period is 1971-2021. JABBA runs were conducted with 5 different configurations of a Pella-Tomlinson biomass dynamic model; the 5 configurations correspond to different priors on the parameters r and m. Two different data weighting procedures were applied to the abundance indices (standardized CPUE series) used to fit the model, one of which includes statistical weighting using JABBA-estimated components of the weights. Runs were conducted including all CPUE series accepted by the Data Preparatory Meeting (scenario "All"). In addition, four other scenarios corresponding to the different clusters of CPUEs indicated by the Data Preparatory Meeting were also evaluated. In all, this resulted in 5 x 2 x 5 = 50 JABBA runs. This document presents detailed results for the scenario "All", and also provides a comparison of results among all 50 runs. The scenario "All", as well as most of the other JABBA runs conducted in this document, esmate that the harvest rate has been below HMSY for several years now and that the stock is currently around or above B_{MSY}.

SCRS/2023/126 - The 2015 blue sharks stock assessment included Bayesian surplus production models conducted with an old software called BSP that used the Sampling-Importance-Resampling algorithm rather than MCMC for numerical integration, along with some JAGS code that was similar to the JABBA R package that is currently used. The legacy BSP software and the old JAGS code were used with the new catch and CPUE data, but the same settings as were used for the 2015 assessment to verify that that the choice of software does not influence the assessment results. The BSP software has some features that are not available in JABBA and have been used for blue sharks, such as the ability to estimate catches in the early years of the fishery from effort, and then use catches for the rest of the years. Conversely, BSP does not have JABBA's ability to model catches as uncertain, and JABBA provides many useful diagnostics. Because the differences in software are minor and JABBA is more convenient to and reproducible, JABBA should be the preferred Bayesian state-space production models for future assessments.

SCRS/2023/127 - Bayesian State-Space Surplus Production Models were fitted to South Atlantic blue shark tuna catch and CPUE data using the 'JABBA' R package. The third six distinct scenarios were based on a life history parameters, steepness and model weighting. All scenarios were based in a Pella-Tomlinson production function from an Age-Structured Equilibrium Model (ASEM). All scenarios showed similar trend for the trajectories of B/BMSY and F/FMSY over time. In general, B/BMSY had shown a decrease pattern at the first half of the time series followed by a slight increase after 1998. The F/FMSY shown a general pattern with a sharp increase trend during 1990's, followed by stable trend. Kobe stock status plots had shown median quantities estimated for the last data year in the green quadrant. However, the scenarios based on a more conservative values of steepness (0.5) had shown more pessimistic than others.

SCRS/2023/128 - Stock Synthesis model runs were conducted for the North Atlantic blue shark based on the available catch, CPUE, length composition, and life history data compiled by the Shark Working Group. A sex-specific model was implemented in order to allow for observed differences in growth between sexes. Beverton-Holt stock-recruitment was assumed. The steepness of the stock recruitment relationship and natural mortality at age were fixed at independently estimated values. A two-stage data weighting approach was implemented. Model sensitivity was evaluated to CPUE groupings, to the steepness of the stock recruitment relationship, and to natural mortality at age compiled by the Shark Working Group. A wide range of model results were obtained from these preliminary structural uncertainty analyses that could be useful to inform a structural uncertainty grid for the 2023 blue shark stock assessment. A preliminary reference case model was identified that may be useful as a starting point for continued model development during the 2023 blue shark stock assessment.

SCRS/P/2023/098 provided a summary of diagnostics used for the stock synthesis base case.