5.1 Stock Synthesis 3

A one-area, combined sex, yearly structured model was implemented for the Southern Atlantic Albacore stock using Stock Synthesis version 3.30.23.1 (SS3; Methot et al., 2025). The available time series of catch (section 2.1), abundance indices (section 2.2), and length composition (section 2.3) data considered in the SS3 model runs were assigned to specific "fleets" and "surveys," with the survey structure used to incorporate the abundance index associated with each fleet. A summary of the data sources and their respective assignments is provided in **Table 2.1**. The model was configured to cover the period from 1956 to 2018, using the same datasets applied in the most recent stock assessments (Winker et al., 2020; Matsumoto, 2020) for conditioning.

Table 2.1. *(Suggestion to improve the table)* Time series of catch, relative abundance index, and length composition data considered for use in preliminary SS3 scenarios.

Name	Definition	Catch	Abundance index	Length composition
Fleet_01	Chinese Taipei (LL), Korea (LL)	1964 – 2018		1975 – 2018
Fleet_02	China (LL), E. C. Spain (LL), E. C. Portugal (LL), Japan (LL), Philippines (LL), St Vincent and Grenadier (LL), USA (LL), Vanuatu (LL), Honduras (LL), Nei (LL), Côte D'Ivoire (LL), EU.United Kingdom (LL), Seychelles (LL), UK.Sta Helena (LL), Angola (LL), Senegal (LL), Trinidad and Tobago (LL)	1956 – 2018		1956 – 2018
Fleet_03	Brazil (LL, SU), Panama (LL), South Africa (LL, UN), Argentina (LL, TW, UN), Belize (LL), Cambodia (LL), Cuba (LL, UN), Namibia (LL)	1959 – 2018		1969 – 2018
Fleet_04	Brazil (BB, GN, HL, PS, TW, UN), E. C. Spain (PS), E. C. France (BB, PS), E. C. Portugal (BB, PS), Japan (BB, PS), Namibia (BB), Korea (BB) ,Maroc (PS), Panama (PS), South Africa (BB, HL, PS, RR, SP), USA (PS), USSR (SU, UN), UK St Helena (BB, RR), Chinese Taipei (GN), Nei (BB, PS), Argentina (PS), Belize (PS), Cape Verde (PS), Curaçao (PS), Guatemala (PS), Côte D'Ivoire (PS), Ghana (BB, PS), Guinea Ecuatorial (UN, HL), Guinée Rep. (PS), St. Vincent and Grenadines (PS), Guinea Ecuatorial (HL)	1964 – 2018		1980 – 2018
Fleet_05	Uruguay (LL)	1981 – 2013		1983 – 2013
CTP-LL	Chinese Taipei longline index		1968 – 2018	Mirror Fleet_01
JPN-LL3	Japan longline index		1976 – 2011	Mirror Fleet_02
URY-LL	Uruguay longline index		1983 – 2011	Mirror Fleet_05

5.1.1 SS3 Model structure

5.1.1.1 Stock recruitment and Fecundity

A Beverton–Holt stock–recruitment relationship was assumed in SS3, with ln(R0) estimated internally with a normal prior with wide bounds, steepness (*h*) and recruitment variability (σR) fixed at the values shown in **Table 3.1**. An examination of preliminary SS3 outputs using the r4ss package (Taylor et al., 2021) indicated limited recruitment information in the data prior to approximately 1966, when length composition data were available for only one fleet and no abundance indices were present. For this reason, the estimation of main recruitment deviations was set to start in 1967, with early recruitment deviations beginning six years before the main estimation period. In addition, to account for the reduced influence of length composition data on recruitment estimates near the terminal year, the estimation period was truncated in 2015.

Fecundity was modeled as female stock spawning biomass (SSB) (i.e., weight-at-age multiplied by the maturity ogive), and proportional to length ($eggs=a*L^b$).

5.1.1.2 Length composition and Selectivity

Available length composition in 5 cm FL were obtained from ICCAT and assigned to fishing "fleets" 1 to 5. Years with small sample size (total number of fish measured < 100) were excluded from the preliminary models. To reduce the influence of annual extreme sample sizes on the fit to length composition data, a transformation was applied to the original annual sample sizes (ONsamps). Instead of using raw values, which can disproportionately weight certain years, sample sizes were rescaled using a power function, defined as Nsamps = ONsamps$^{0.25}$. For this assessment, a total of 36 population length bins were implemented (ranging from 20 to 195 cm FL in 5 cm intervals).

A double normal selectivity function was implemented in SS3 for all fleets (**Table 2.1**) and fit to the available length composition data (5 cm FL bin width; **Figure 5.1**). The double normal selectivity function includes six parameters: p1 - Peak value, p2 - Top logistic, p3 - Ascending width, p4 - Descending width, p5 - Selectivity at initial size bin, and p6 - Selectivity at final size bin. Initial values for all parameters were obtained by fitting the selectivity curve by eye to the available length composition data separately for each fleet externally to the stock assessment model with the assistance of the R Shiny-based Stock Assessment Continuum Tool (Cope, 2025). This approach resulted in dome shaped selectivity for all fleets (**Figure 5.2)**.

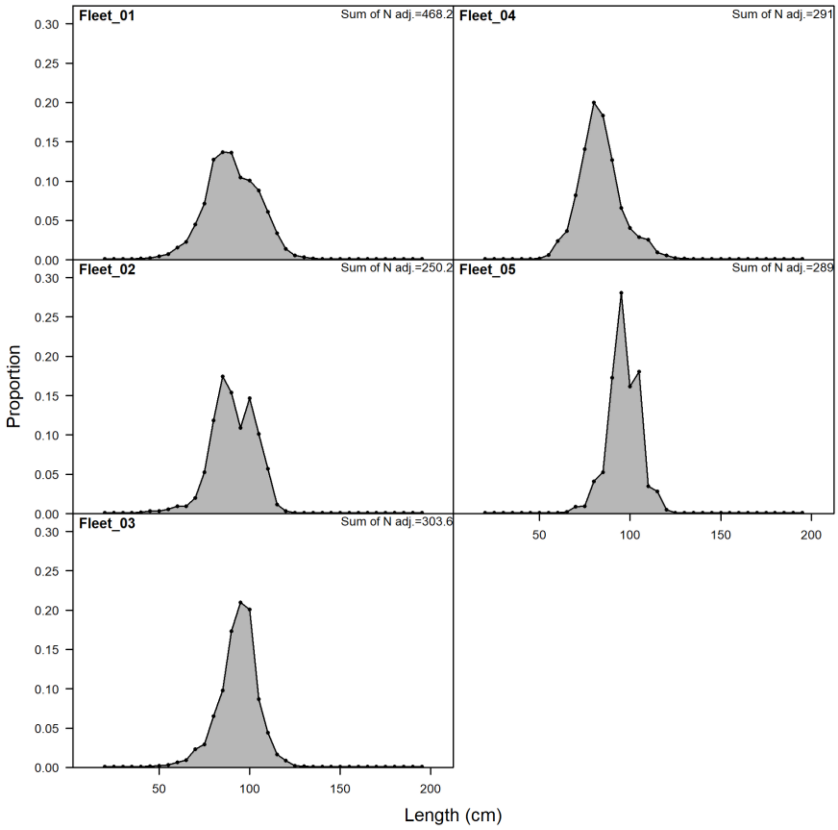

Figure 5.1. Available length composition data for Southern Atlantic Albacore. The "Sum of N adj." refers to the sum of input effective sample sizes calculated using the Francis method (Stage 2) as implemented in the R package *r4ss*, as described in the main text.

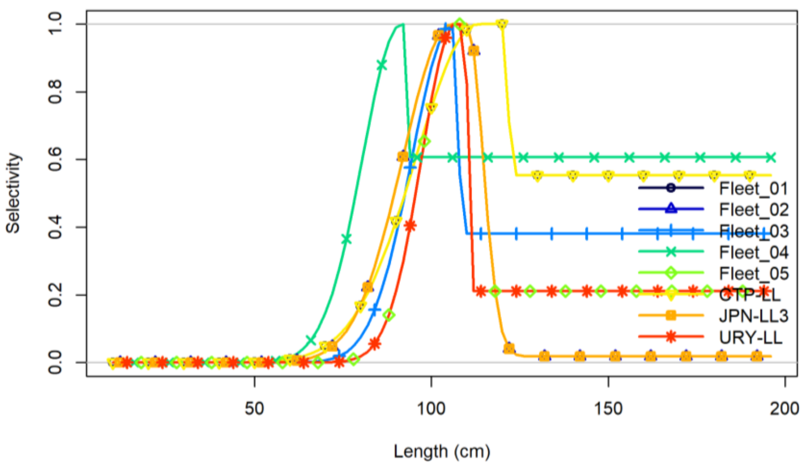

Figure 5.2. Dome-shaped selectivity patterns estimated for all fleets using the double normal selectivity function (Stock Synthesis selectivity pattern 24). Initial values for the six parameters were fitted visually to fleet-specific length composition data.

5.1.1.3 Data weighting

A two-stage (Francis, 2011) data weighting approach was implemented, flowing the same approach described in Courtney *et al.* (2017a). In stage one, a minimum average standard error (SE; on the natural log scale) was implemented in SS3 for each abundance index series. The minimum SE was based on fitting a simple smoother to each CPUE (on the natural log scale) external to the stock assessment and then calculating the residual variance of each CPUE relative to the smooth curve. In stage two, the effective sample size (Effn) of each length composition data set was obtained from the residuals of the SS3 model fit to each length composition data set using the Francis (2011) method.

In stage 1, a LOESS smoother was fit to each CPUE data on the log scale. The square root of the residual variance was calculated for each CPUE series based on the fit of the simple smoother to the CPUE series on the log scale. The average annual CV input (SE.in) for each CPUE series in the SS3 was assumed to be equal to the average SE on the log scale. The SE was then adjusted based on the expectation that the stock assessment model would fit each CPUE time series at best as well as a LOESS smoother (Francis, 2011; Lee *et al*., 2014a, 2014b; e.g., Courtney *et al.*, 2017a, 2017b). On one hand, if SE.in for a CPUE series was less than RMSEsmoother for that CPUE series, then the input SE for the CPUE series was adjusted (SE.adj) in SS3 before running the model so that the new average SE was equal to RMSEsmoother (SE.in + SE.adj = RMSEsmoother). On the other hand, if SE.in for a CPUE series was greater than or equal to the RMSEsmoother for that CPUE series, then the SE of the CPUE series was not adjusted in the SS3 model. Additionally, a minimum SE of 0.2 was also assumed. For any observation whose SE remained below this threshold after data weighting, the SE was fixed at 0.2.

5.1.2. Models diagnostics

Model diagnostics were assessed using the Carvalho *et al*., (2021) flow chart. The first diagnostic was whether the Hessian (i.e., the matrix of second derivatives of the likelihood concerning the parameters) inverts. The second measure observed the joint residuals plot and ensured that they were randomly distributed. The third measure was the retrospective analyses conducted on the reference-case model with five-year retrospective peels. The fourth measure analyzed the model prediction skill by completing model-based hindcasting. The ASPM RecDev diagnostic was used to evaluate whether indices of abundance alone contain sufficient information to estimate recruitment deviations, in the absence of composition data (Minte-Vera et al., 2017). In this approach, the model is fit only to CPUE indices while estimating annual recruitment deviations, with all length composition data removed from the likelihood. All selectivity and structural parameters were fixed to values estimated in the fully integrated model. Differences between the ASPM RecDev and full model results indicate the extent to which recruitment variability depends on composition data.

6 Historical Fishery Dynamics

6.1. SS3 results

Model results are presented below for the nine scenarios Uncertainty Grid, identified as described above, along with the stochastic approach.

6.1.1 Convergence, fits and diagnostics

The Hessian matrix inverted and was presumably positive definite for all scenarios. The final gradient was reasonably small (< 1.00E-05). Some parameters, depending upon the model run, were estimated above the maximum correlation threshold *(cormax = 0.95)* or below the minimum correlation threshold (*cormin* = 0.01).

The final model gradient values for each assessment scenario are summarized below:

- ALB-S_h0.7_M0.30 = 3.32433e-05
- ALB-S_h0.7_M0.35 = 3.74568e-05
- ALB-S_h0.7_M0.40 = 6.58937e-06
- ALB-S_h0.8_M0.30 = 5.71705e-06
- ALB-S_h0.8_M0.35 = 3.24047e-05
- ALB-S_h0.8_M0.40 = 9.89194e-05
- ALB-S_h0.9_M0.30 = 4.52265e-05
- ALB-S_h0.9_M0.35 = 9.95421e-05
- ALB-S_h0.9_M0.40 = 9.16146e-05

6.1.1.1 Indices of abundance

Predicted and observed standardized indices of relative abundance for the median scenario of the grid (i.e., ALB-

S_h0.8_M0.35) are shown in **Figure 6.1**. Model fits are displayed on both nominal and logarithmic scales. Because the fits were similar across scenarios, only the results from median scenario of the grid are presented. Residuals for each CPUE series are provided in **Figures 6.2**. Residuals for the URY_LL fleet index were strongly negative in the final years of the time series (2001–2011), contributing to elevated RMSE values in the joint residual plots and resulting in a non-random residual pattern (**Figure 6.3**).

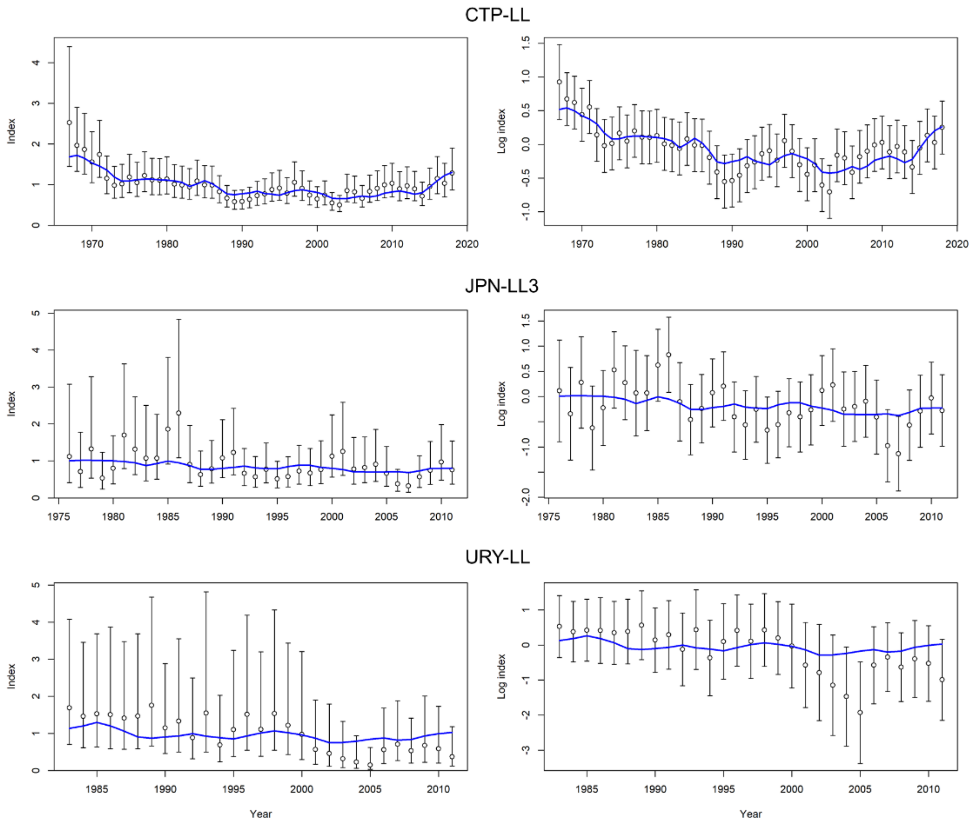

Figure 6.1. Predicted (lines) and observed (points) standardized indices of relative abundance under median scenario ALB-S_h0.8_M0.35**,** plotted on both nominal (left) and logarithmic (right) scales. Only the median scenario is shown, given the similarity of fits across all model configurations.

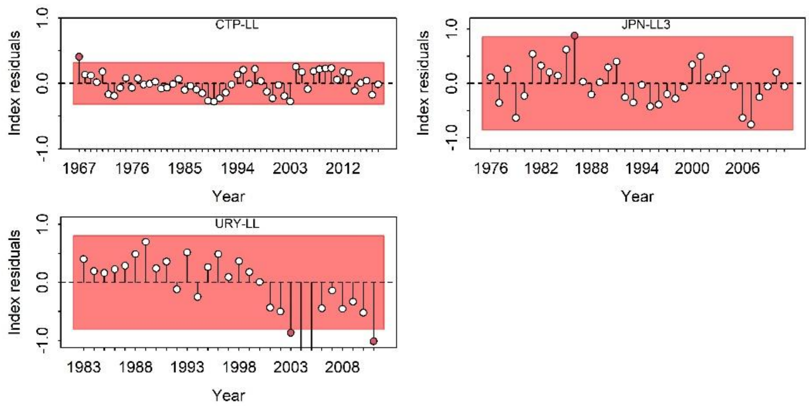

Figure 6.2. Southern Atlantic Albacore, scenario ALB-S_h0.8_M0.35, Runs test on the residuals of the CPUE indices.

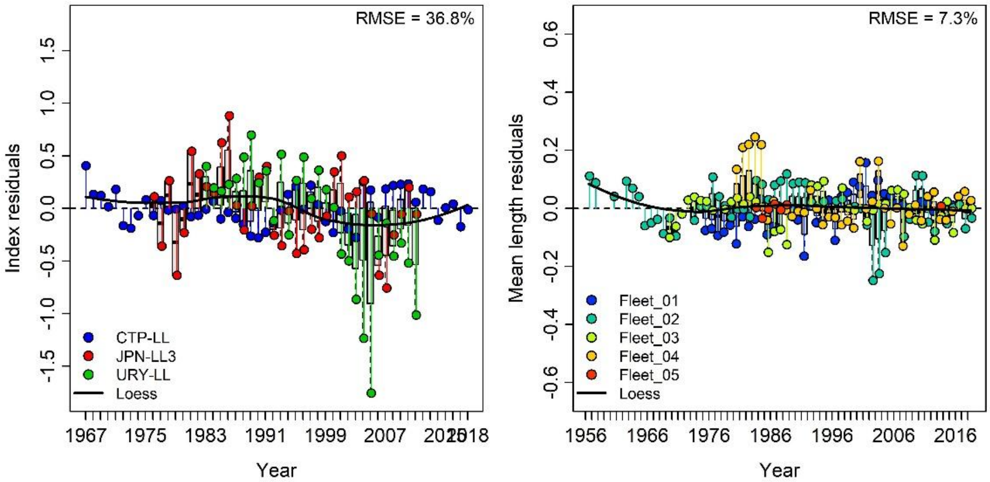

Figure 6.3. Joint residual plots for CPUE (right panel) and length composition (left panel) under scenario ALB-S_h0.8_M0.35.

6.1.1.2. Length compositions

Model-predicted and observed aggregated length compositions are shown in **Figure 6.4**. Because the fits were similar across scenarios, only the results from median scenario of the grid (*i.e.* ALB-S_h0.8_M0.35) are presented. The fits to aggregated length compositions were reasonably accurate for all fleets, suggesting that the estimated selectivity curves removed individuals from the modeled population at lengths comparable to those observed in the data. The joint residual plots showed low RMSE values and exhibited a random pattern of residuals **(Figure 6.3)**. However, at the individual level, the runs test indicated that only two length composition series displayed normally distributed residuals (**Figure 6.5**).

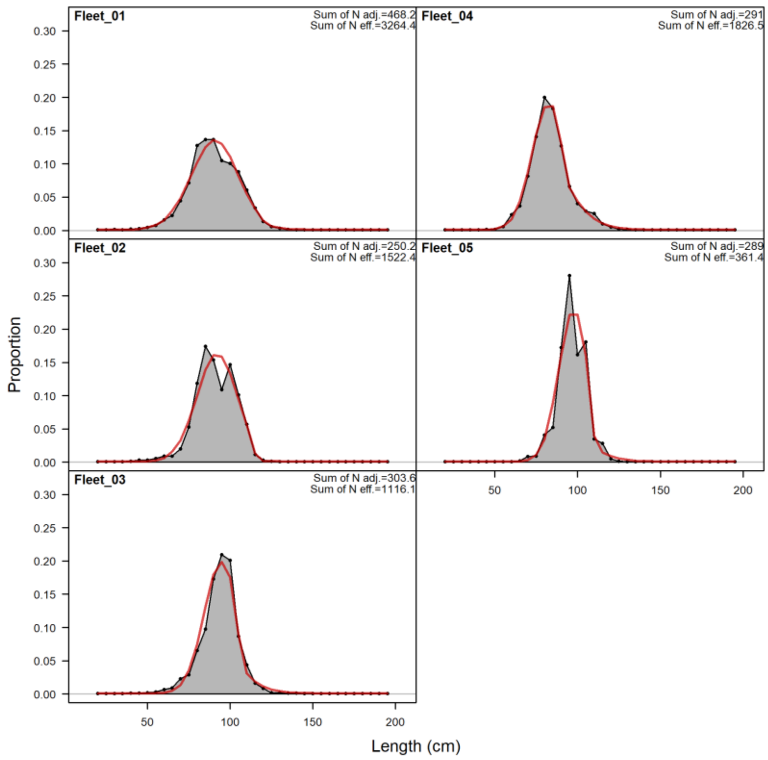

Figure 6.4. Observed (black line) and predicted (red line) length composition data for the Southern Atlantic Albacore for scenario ALB-S_h0.8_M0.35.

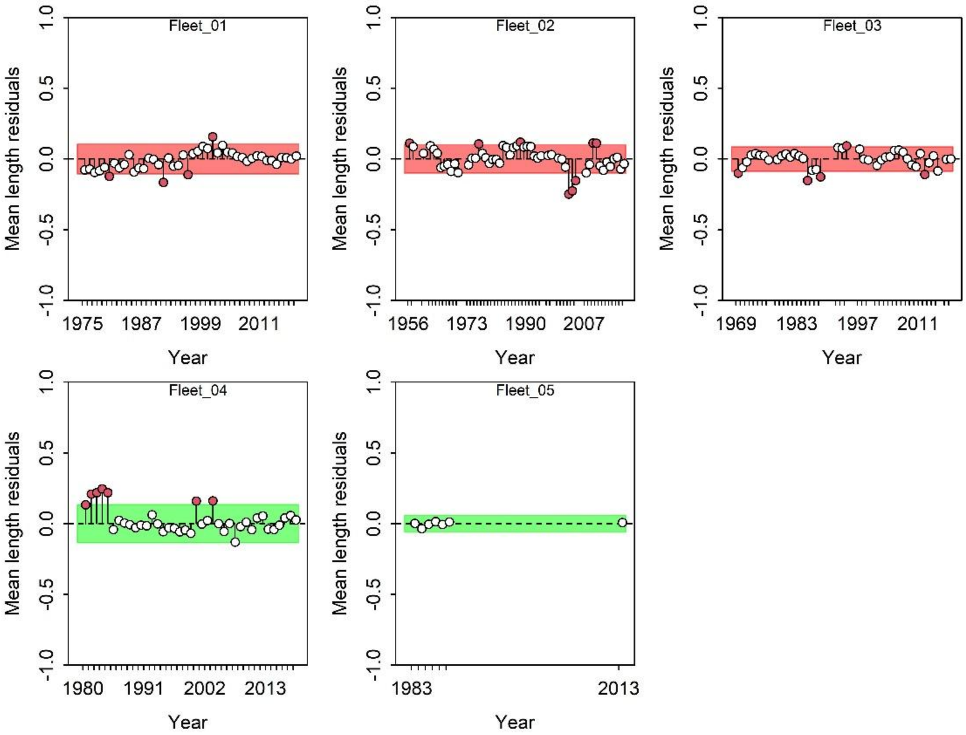

Figure 6.5. Southern Atlantic Albacore, scenario ALB-S_h0.8_M0.35, Runs test on the residuals of the length compositions**.**

6.1.1.3. Hind cast

When evaluating the model's predictive skill, most predicted length composition observations fell within the hindcast evaluation period (2013–2018; **Figure 6.6.**). Mean Absolute Scaled Error (MASE) scores were below 1 in almost all cases, indicating good predictive performance. In the single case where the MASE value exceeded this threshold, the increase was minimal, suggesting only a slight reduction in prediction accuracy. The only CPUE series with data extending to the end of the time series also showed good predictive skill, with a MASE score below the threshold.

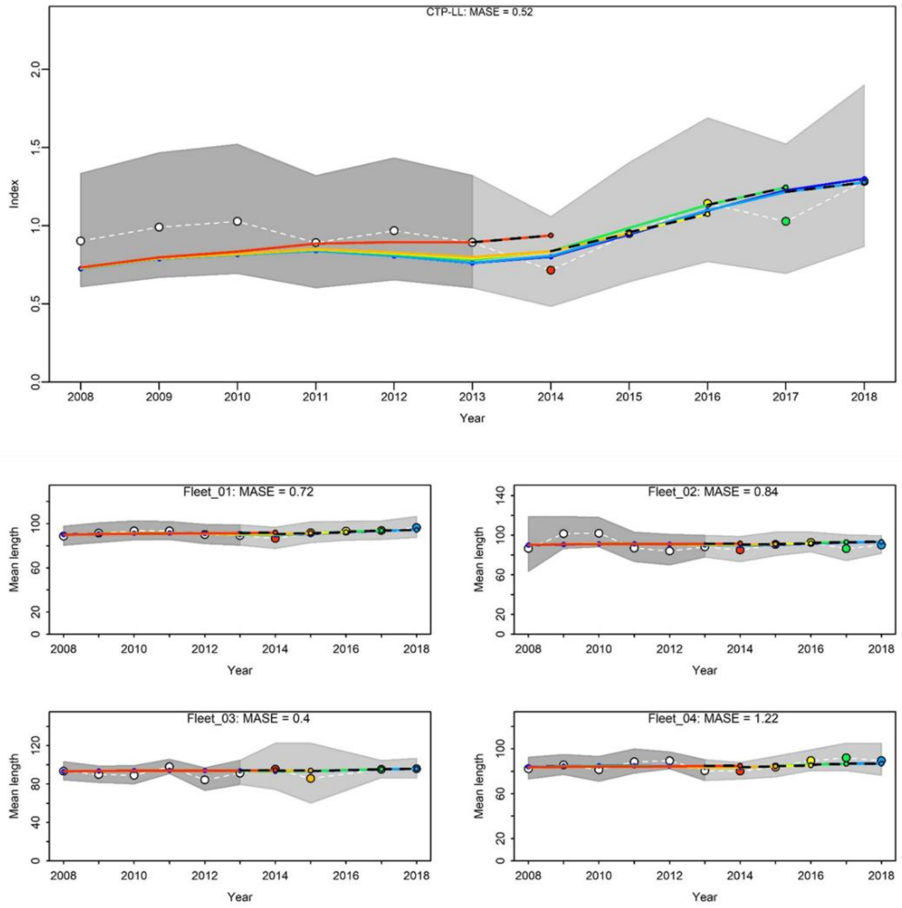

Figure 6.6. Hind cast test results for CPUE index and length compositions under scenario ALB-S_h0.8_M0.35. Mean Absolute Scaled Error (MASE) values are shown for each length composition and index configuration during the evaluation period (2013–2018).

6.1.1.4. Retrospectives

The results of a five-year retrospective analysis applied to scenarios ALB-S_h0.8_M0.35 are shown in **Figure 6.7** and indicate a negligible retrospective pattern across models. The estimated Mohn's rho values for both spawning stock biomass (SSB) and the F/F_{MSY} ratio fell within the acceptable range of −0.15 to 0.20 (Hurtado-Ferro *et al*., 2015; Carvalho *et al*., 2021), confirming the absence of an undesirable retrospective bias.

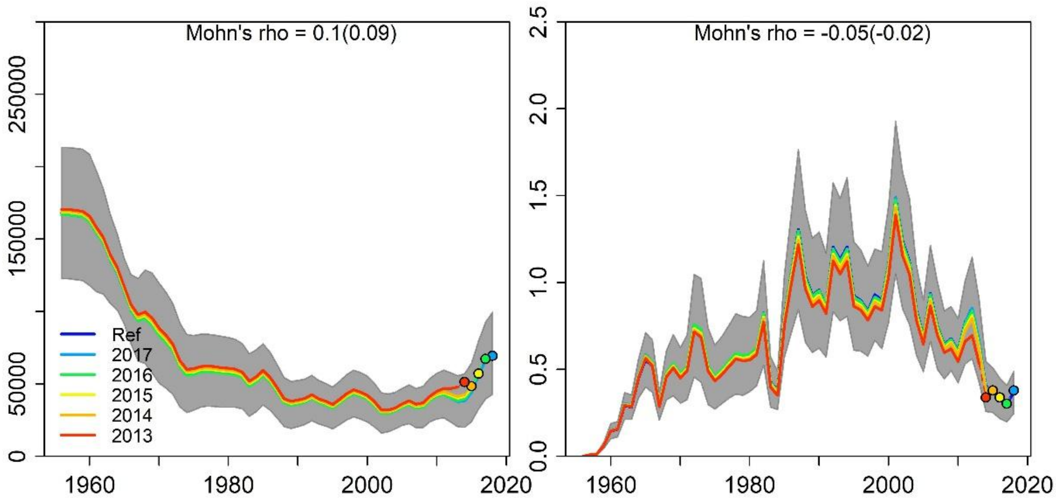

Figure 6.7. Retrospective analysis results for all scenarios based on a five-year peel (2013–2018). Mohn's ρ values for spawning stock biomass (left panel) and fishing mortality ratio (right panel).

3.1.1.5 ASPM with Rec Dec

The comparison between the fully integrated model (ALB-S_h0.8_M0.35***)*** and their corresponding ASPM RecDev diagnostics indicated that the trajectories of spawning output, SSF_{ratio}, F_{ratio}, and recruitment were generally consistent across models throughout most of the time series (**Figure 6.8.**). The overlap in confidence intervals suggests that abundance indices alone, when combined with estimated recruitment deviations, were capable of capturing the overall population dynamics.

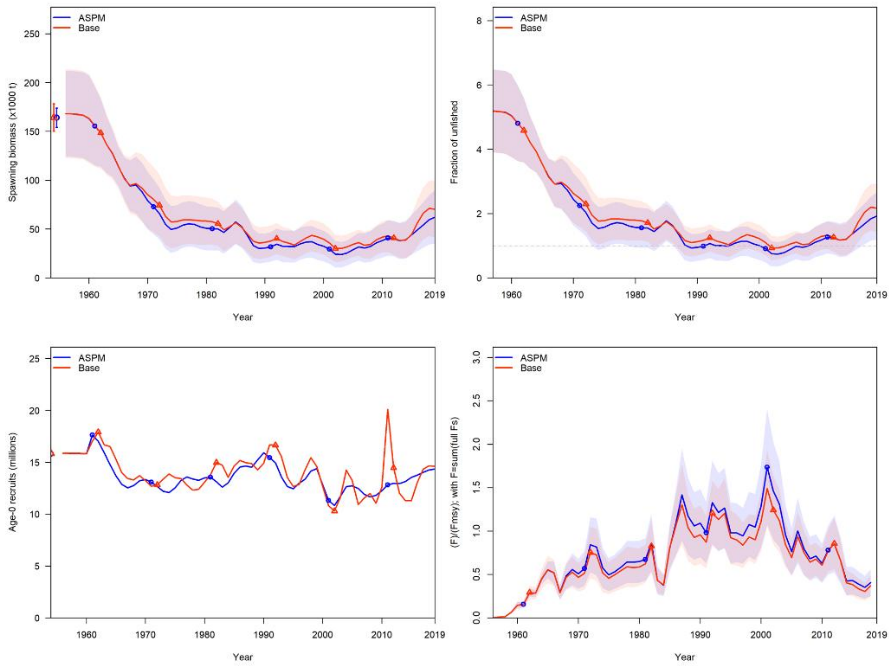

Figure 6.8. Comparison between the fully integrated base model (ALB-S_h0.8_M0.35; red) and the ASPM RecDev diagnostic model (blue) for the Southern Atlantic Albacore. The panels show (top-left) spawning stock fecundity (SSB), (top-right) fraction of unfished SSB, (bottom-left) recruitment and (bottom-right) fishing mortality relative to F_{MSY}. Shaded areas represent approximate confidence intervals.

6.1.2. SS3 Scenarios outputs

6.1.2.1 SS3 Uncertainty grid approach

A total of nine model scenarios were analyzed to evaluate the sensitivity of the South Atlantic albacore stock assessment to alternative natural mortality (*M*) and steepness (*h*) values. Resulting estimates of reference points and stock status indicators (**Table 6.1**) showed a consistent pattern of spawning biomass above MSY levels and fishing mortality below F_{MSY} across all scenarios. SSB_{2018} estimates ranged from 58,792 t to 108,170 t. The SSB_{2018}/SSB_{MSY} ratio was always above 1.0 (1.77–3.58), indicating that spawning biomass remained well above MSY benchmarks under all parameter combinations. Conversely, F_{2018}/F_{MSY} values were consistently below the overfishing threshold (0.23–0.45), suggesting no evidence of overfishing in any scenario. MSY estimates ranged from 25,074 to 28,865 t. Comparative trajectories of stock status for these scenarios are shown in **Figure 6.9**.

Table 6.1. Summary of model outputs for the nine Stock Synthesis scenarios evaluated for the Southern Atlantic albacore stock.

Scenario	SSB_{2018}	SSB_{2018}/SSB_{MSY}	F_{2018}/F_{MSY}	MSY
ALB-S_h0.7_M0.30	108,170	1.77	0.45	25,074.2
ALB-S_h0.7_M0.35	86,617	1.84	0.44	25,246.3
ALB-S_h0.7_M0.40	73,826	1.97	0.41	25,590.2
ALB-S_h0.8_M0.30	86,090	2.04	0.40	25,472.7
ALB-S_h0.8_M0.35	71,218	2.20	0.37	25,849.1
ALB-S_h0.8_M0.40	63,235	2.45	0.33	26,532.8
ALB-S_h0.8_M0.30	69,148	2.64	0.32	26,207.5
ALB-S_h0.9_M0.35	61,665	3.09	0.27	27,206.8
ALB-S_h0.9_M0.40	58,792	3.58	0.23	28,864.6

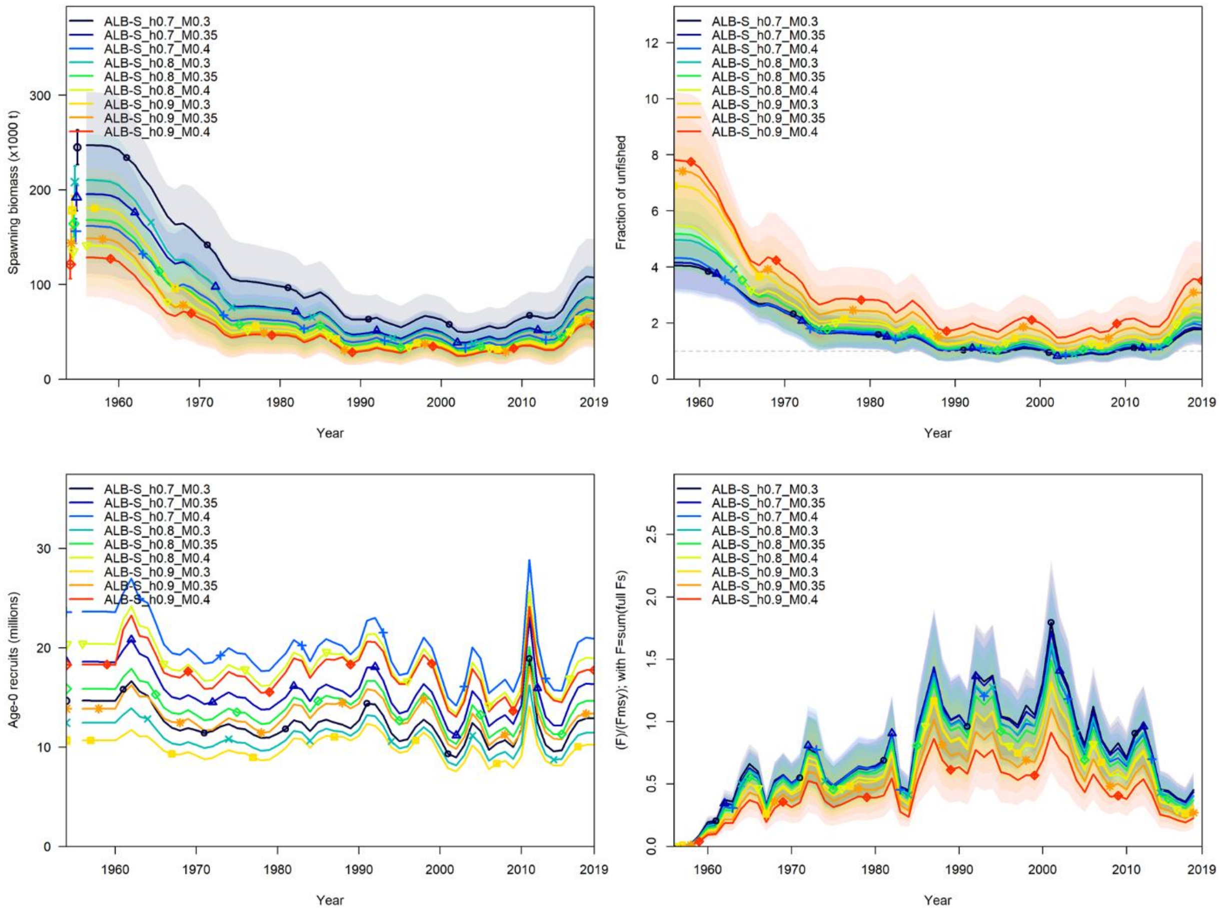

Figure 6.9. Comparison among the nine Stock Synthesis scenarios evaluated for the Southern Atlantic albacore stock. The panels show (top-left) spawning stock fecundity (SSB), (top-right) fraction of unfished SSB, (bottom-left) recruitment and (bottom-right) fishing mortality relative to F_{MSY}. Shaded areas represent approximate confidence intervals.

6.1.2.2 SS3 Stochastic approach

A total of 200 stochastic samples of life-history parameters were evaluated to examine the variability in reference points and stock status indicators. The median spawning biomass in 2018 (SSB_{2018}) was 70,941 t, with a 95% interval from 57,792 t to 105,227 t (**Table 6.2**). The SSB_{2018}/SSB_{MSY} ratio had a median of 2.18 (95% interval: 1.72–3.45), remaining above 1.0 in all simulations, indicating spawning biomass consistently above MSY benchmarks. The fishing mortality ratio (F_{2018}/F_{MSY}) had a median of 0.37 (95% interval: 0.23–0.46), always below the overfishing threshold. MSY estimates had a median of 25,840 t (95% interval: 25,009–29,684 t).

Time-series trajectories (**Figure 6.10**) indicate a historical decline in biomass and recruitment since the late 1950s, followed by stabilization in recent years. In all stochastic runs, SSB/SSB_{MSY} remained above 1.0 in the terminal period, while F/F_{MSY} stayed below 1.0 since the mid-2000s, supporting the conclusion that the stock is not overfished and is not undergoing overfishing, even when accounting for uncertainty in life-history parameters.

Table 6.2. Summary of median values and corresponding 95% intervals from the 200 stochastic Stock Synthesis runs for the Southern Atlantic albacore stock.

	SSB_{2018}	SSB_{2018}/SS_{BMSY}	F_{2018}/F_{MSY}	MSY
Lower inteval	57,792	1.72	0.23	25,008.71
Median	70,942	2.18	0.37	25,839.91
Upper inteval	10,5227	3.45	0.46	29,684.4

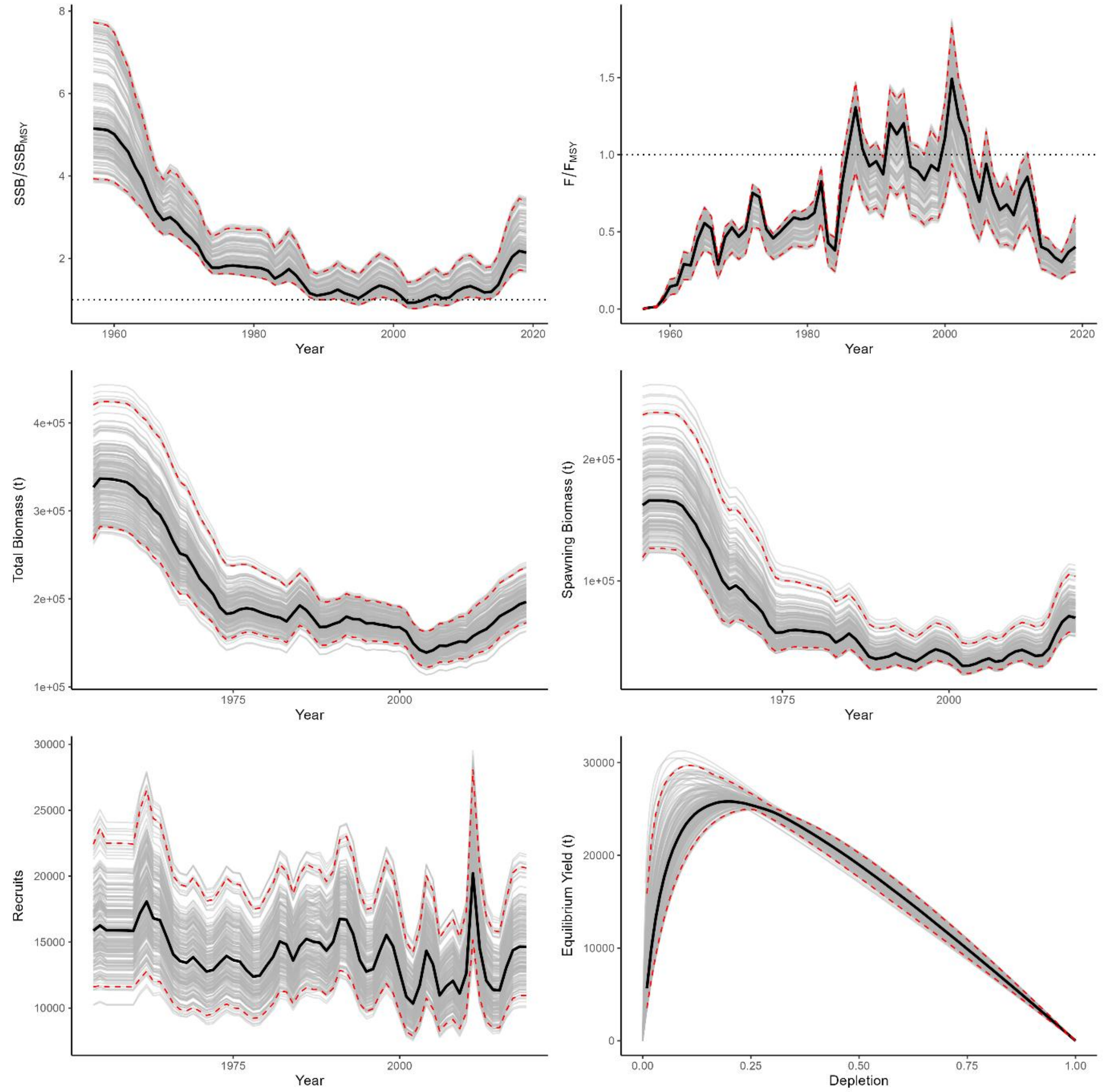

Figure 6.10. Time-series and equilibrium curves from 200 stochastic model runs for the South Atlantic albacore stock. The solid black line represents the median across simulations, and the red dashed lines indicate the 95% interval of the simulated outputs.

A comparison between the deterministic uncertainty grid and the stochastic life-history parameter approach shows that both methods lead to the same overall conclusion regarding the current status of the South Atlantic albacore stock: SSB_{2018} remains above MSY levels and F_{2018} is below the overfishing threshold in all configurations. The results were highly consistent between approaches, with very similar ranges for key indicators, SSB_{2018}/SSB_{MSY} spanned 1.72–3.45 in the stochastic runs and 1.77–3.58 in the grid, while F_{2018}/F_{MSY} ranged from 0.23–0.46 and 0.23–0.45, respectively. Median values were also nearly identical (*e.g*., SSB_{2018}/SSB_{MSY} = 2.18 vs. 2.20; F_{2018}/F_{MSY} = 0.37 vs. 0.36).

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