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REVIEW AND DIAGNOSTICS FOR THE STOCK SYNTHESIS MODEL FOR NORTH ATLANTIC ALBACORE

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SUMMARY

A new assessment model based on stock synthesis was presented during the last North Atlantic albacore stock assessment meeting. This assessment model was used to monitor the status of the stock, but in addition, it also can serve as the basis to develop a new set of operating models within the new MSE process. The diagnostics showed the robustness of the model, but however, due to the convergency issues that the model showed depending on the initial values, the group recommended evaluating some of the assumptions on the selectivity parameters to optimize the model. In this work, the sensitivity analysis listed during the assessment meeting were evaluated with standard diagnostics analysing the fits to the indices and length compositions, jitter of starting parameters, randomness tests of model residuals, retrospective, profiles of key estimated parameters, and hindcasting. Based on those results, this document proposes a revised reference case with similar outputs to the assessment model but with better diagnostic performance that can be used as a basis for the operating models for the MSE process.

RÉSUMÉ

Un nouveau modèle d'évaluation basé sur Stock Synthesis a été présenté à la dernière réunion d'évaluation du stock de germon de l'Atlantique Nord. Ce modèle d'évaluation a été utilisé pour suivre l'état du stock mais peut également servir de base au développement d'un nouvel ensemble de modèles opérationnels dans le cadre du nouveau processus de MSE. Les diagnostics ont montré la robustesse du modèle. Toutefois, en raison de problèmes de convergence présentés par le modèle en fonction des valeurs initiales, le groupe a recommandé d'évaluer certains des postulats sur les paramètres de sélectivité en vue d'optimiser le modèle. Dans le cadre de ces travaux, les analyses de sensibilité répertoriées lors de la réunion d'évaluation ont été évaluées avec des diagnostics standards en analysant les ajustements aux indices et aux compositions par taille, la fluctuation (« jitter ») des paramètres de départ, les tests du caractère aléatoire des valeurs résiduelles du modèle, les profils rétrospectifs des principaux paramètres estimés et la simulation rétrospective. D'après ces résultats, ce document propose un cas de référence révisé, avec des valeurs de sortie similaires au modèle d'évaluation mais une meilleure performance des diagnostics, à même d'être utilisé pour servir de base aux modèles opérationnels pour le processus de MSE.

RESUMEN

Durante la última reunión de evaluación del stock de atún blanco del Atlántico norte se presentó un nuevo modelo de evaluación basado en Stock Synthesis Este modelo de evaluación se utilizó para supervisar el estado del stock, pero, además, también puede servir de base para desarrollar un nuevo conjunto de modelos operativos dentro del nuevo proceso de MSE. Los diagnósticos mostraron la robustez del modelo, sin embargo, debido a los problemas de convergencia que mostraba el modelo en función de los valores iniciales, el grupo recomendó evaluar algunas de las hipótesis sobre los parámetros de selectividad para optimizar el modelo. En este documento, se evaluó el análisis de sensibilidad proporcionado en la reunión de evaluación con diagnósticos estándar para analizar los ajustes de los índices y composiciones por tallas, la fluctuación de los parámetros de partida, las pruebas de aleatoriedad de los residuos del modelo, los perfiles retrospectivos de los parámetros clave estimados y la simulación retrospectiva. Basándose en esos resultados, este documento propone un caso de referencia revisado con resultados similares a los del modelo de evaluación, pero con un mejor rendimiento del diagnóstico que puede utilizarse como base para los modelos operativos del proceso de MSE.

KEYWORDS

North Atlantic albacore, Management Strategy Evaluation, Operating Model, stock assessment, stock synthesis, diagnostics

1. Introduction

A provisional Stock Synthesis (SS) assessment model for North Atlantic albacore was presented and reviewed during the SCRS stock assessment meeting held in Madrid during June 26-30, 2023 (ICCAT 2023). The SCRS made several recommendations to revise and provide sensitivity analyses of the model in order to optimize and evaluate a proposed reference case operating model for the North Atlantic albacore MSE (N-ALB MSE). The following model revisions were requested:

1) Removal of the prior distribution on steepness, which was demonstrated to be well-estimated within SS and diverged notably from the assumed prior taken from the steepness estimated from the last assessment.
2) Inclusions of priors on fleet selectivity parameters that were modeled by double-normal distribution, specifically the top logit parameter, which showed uniform posterior distribution.
3) Remove the minimum effective sample size criteria of at least 3 fish for the age-at-length data.
4) Recalculation of effective sample sizes for the length composition and the age composition (rescaled on the natural scale versus log-transformed), and exploration of alternative data weighting scenarios, including Francis reweighting (Francis 2011) of the length composition data.
5) Sensitivity analyses that up weight individual data types (i.e. CPUEs, length composition, and conditional length-at-age.
6) Sensitivity analysis to evaluate the influence of the random walk on fleets selectivity that showed variable length composition across years.

The results of those analyses are discussed, and the summary statistics and figures from the revised reference case model are presented for further review by the SCRS.

2. Materials and Methods

The revisions to the reference case model were completed in the following order: 1) the prior on steepness was removed, 2). the minimum effective sample size criteria of at least 3 fish for the age-at-length data was measurements was removed, 3) evaluation of the effective sample size for the remaining length compositions was estimated as the number of fish measured divided by 1000 (in the reference case calculated as the natural log of the number of fish measured), 4) evaluation of the length data re-weighting with Francis method, 5) priors were added to the double normal selectivity top logit parameters assuming a normal distribution with the mean equal to the maximum likelihood estimates, and 6) sensitivity analysis were conducted that removed the random walk on fleets selectivity.

The following scenarios were evaluated during the process of model revision and optimization:

- The initial reference case model had steepness estimated assuming a normal distribution prior with a mean of 0.75, following the parameterization from the last assessment. However, there was no clear justification for that strong assumption and the updated model showed a well-defined posterior that diverged considerably from the prior. Therefore, the prior was removed, and steepness was freely estimated.
- The initial model fixed the BBisl selectivity and assumed a prior on the MWT fleet selectivity. These assumptions were changed to freely estimate selectivity assuming a double-normal distribution.
- Some of the fleet selectivity parameters (i.e. (JPLL_N & S, TAILL_N & S, USLL_N & BBisl) showed high uncertainty in the top logit parameter of the double normal distribution. Priors were added for these parameters, set as normal priors with the mean equal to the MLE and a standard deviation equal to 0.1.
- The bias correction ramp was then adjusted under the new optimized model.
- The minimum effective sample size criteria of at least 3 fish for the age-at-length data was measurements was removed to include all aging data, which was particularly important to include samples of the largest fish and better inform the estimation of growth, namely Linf.
- The following sensitivities were run on the revised reference case model:
- wRw1: DN model but without random walk in the BBisl (not season 2) fleet.
- wRw2: DN model but without random walk in the TR_GN fleet.
- wRw3: DN model but without random walk in the MWT fleet.
- WRw4: DN model but without random walk in the BBisl(ss2).

- NoTBJP: DN model without time blocks for any of the Japanese fleets.
- NoTBTAI: DN model without time blocks for any of the Chinese Taipei fleets.
- TbJP1: DN model without time blocks with only one time block for JPLL, the second and third period together.
- TbTAI1: DN model without time blocks with only one time block for TAILL, the second and third period together.
- Resamp: DN model but the length composition number of samples were considered as the sum of the number of fish measured by year and fleet but divided by 1000.
- Francis: DN model but with length composition re-weighted using Francis method running the model twice and multiplying the results of the first run and the second run (which consider the values of the first run). (**Table 1**)

The results of each model run were compared to the reference case presented during the assessment meeting, to demonstrate the effects on model time series and diagnostics (run with ss3diags R package) (Carvalho *et al.* 2021). The primary diagnostics considered included 1) model residual fits to the indices and length composition data, evaluated with a runs test, 2) retrospective pattern analysis (5-year peels) and associated Mohn's rho statistic, 3) model indices data prediction capability evaluated by hindcasting analysis and evaluated with the mean absolute standard error (MASE) estimates. Lastly, a jitter analysis was conducted on the revised reference case model to assess the stability of parameter estimates and compare model performance to the initial reference case. The initial reference case had showed relatively low proportion of runs that converged at the global MLE, and this was highlighted by the SCRS as a primary need to improve the overall model performance and stability.

3. Results and Discussion

3.1 Summary of iterative model runs and comparison to the revised reference case

Table 1 provides a brief overview of the model runs that were conducted intersessionally since the assessment workshop. **Table 2** compares the main diagnostic test statistics for each of the model scenarios. The results of the diagnostic tests suggested that the DN model (no prior steepness, no fixed selectivity, no prior in MWT, but priors in the second parameter of JPLL, TAILL, USLL and BBisl(ss2) had very similar diagnostics to the reference case (**Table 2**), but the jitter analysis was greatly improved in the DN model (**Figure 1**). Overall, 38 out of the 40 trial runs of the DN model converged to the global minimum, a significant improvement from the prior reference case where less than half of the runs converged to the best solution. Out of the 40 iterations of the reference case, only one run fell in a local minimum but resulted in minimal overall difference in the time series estimates (**Figure 1**).

Compared to the DN model, the other model scenarios had less optimal retrospective statistics, both in terms of Mohn's rho values and in the estimated initial biomass (B0) values. Only the model (wRw3) without the random walk in the MWT fleet selectivity had equally good diagnostics. However, despite 39 of 40 model converging, only 18 of them fell in the minimum negative log-likelihood. Therefore, the DN model was considered as the most robust and optimum model and is proposed as the revised reference case model.

For comparison, the results of two other models, DN and wRw3, that showed the best overall diagnostics were compared to the reference case (**Figure 2**). It was noted that the overall time series of spawning stock biomass, recruitment, and fishing mortality were very similar across the three best performing models.

3.2 Revised reference case model diagnostics

The revised Stock Synthesis reference case model showed a relatively good convergence (final gradient = 4.94979e-05), with a positive definite Hessian matrix. Included in the estimated parameters were five growth model parameters, two stock-recruitment parameters (R0 and steepness), one initial F parameter, 47 recruitment deviations, and the remaining parameters were fleet length-based selectivity parameters and random walk deviates. Parameter estimates, asymptotic standard errors, and assigned priors are provided in T**able 3**.

Plots of the observed data versus model fit and residual plots were examined to evaluate model fit to the indices (**Figures 3** and **4**) and length composition data (**Figure 5).** Overall, the model demonstrated an acceptable fit to some of the indices of abundance, but a general lack of fit was observed for the baitboat, US longlines, and Venezuela longline indices. Runs tests were applied to the residual series of each index (**Figure 6**) and length compositions (**Figure 7**) in order to quantitatively evaluate the randomness of the overall fit to the different time-series. There was evidence ($p \geq 0.05$) to reject the hypothesis of randomly distributed residuals for the baitboat, US longline N and S, and the Venezuelan longline indices (**Figure 6**), supporting the conclusion of model lack of fit to those data. Several fleet length compositions also showed poor runs test diagnostics, although the residuals were much less variable across all fleets compared to index fits (**Figure 7**).

Likelihood profiles were ran on the estimated mean unfished equilibrium recruitment (R0, log-scale), steepness (h), mean asymptotic length (Linf), and growth rate (k) across a range of plausible values (**Figure 8**). The profile of R0 by data component showed a well estimated minimum, with general agreement across data components of an estimate between approximately 11.2 and 11.6 (natural log-scale). Similar to R0, the profile on steepness indicated the parameter is estimable, although there was less agreement across data sources compared to R0. The profiles on growth parameters (Linf and k) also indicated that these parameters are well-determined, primarily informed by the conditional length-at-age data. The estimates of stock recruitment R0 and steepness were 11.47 and 0.65, respectively, and the estimates of growth Linf and k were 125 and 0.20, respectively (**Table 3**).

The retrospective analysis (**Figure 9**) indicated that spawning stock biomass and fishing mortality were consistently estimated across trials with the recent year's data removed, with Mohn's rho estimates of 0.00 and 0.05, respectively.

The hindcasting analysis (**Figure 10**) indicated that the model had the ability to predict the JPLL_S and TAILL_N CPUE with MASE values <1 and with the BB and USLL_N MASE value very close to 1.

A jitter analysis was conducted to evaluate whether the model converged to a global solution, by applying a random deviation to starting values of 10%. None of the jitter runs indicated a lower negative log-likelihood than the revised reference case model (**Figure 1**), and only 2 trials failed to converge. In this regard, the revised reference case model showed much better stability compared to the prior model reviewed by the SCRS, where a large proportion of trials failed to converge.

3.3 Model estimates

The time series of spawning stock biomass (SSB), fishing mortality (measured as biomass exploitation rate), and recruitment estimates are listed in **Table 4** and plotted in **Figures 11, 12,** and **13,** respectively**.** SSB showed a sharp decline between the mid-1950s and mid-1960s in response to increased harvest (catches exceeded 40,000 t during that period), and SSB remained at a lower and relatively stable level until 2006. The SSB showed a steady increase since 2007 to the end of the time series in 2021.

Notably strong recruitments were estimated for the years 1963, 2016, 2017, and 2018. The latter three recruitment estimates resulted in the sharp increase in biomass during the model terminal years.

Fishing mortality was estimated as exploitation rate in proportion of biomass. In general, F estimates were low at the beginning of the time series, but increased sharply during the 1950s, and remained high until 1980s when catches begin to decline notably. The estimates of F since 2008 have been consistently lower, with a terminal year exploitation rate estimate in 2020 of approximately 5% of total biomass.

The estimated benchmarks (MSY-based reference points) from the Stock Synthesis revised reference case were: SSBmsy = 99,907 t, Fmsy = 0.13 (exploitation rate), and MSY = 42,270 t. Overall, the estimates were very consistent with the prior reference case model presented at the assessment workshop, while the overall model performance was improved in terms of robustness to alternative starting parameters.

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Table 1. Description of the scenarios run as sensitivity analysis and some notes with the most sensitive conclusion of the diagnostics analysis.

SCENARIO	*DESCRIPTION*	*NOTES*
RC	Reference case from the assessment workshop	Reference case presented in the assessment meeting.
DN *(Revised reference case)*	Only priors in the selectivity top_logit parameter of double normal functions (not TR_GN).	37 jitters the same value, although the model falls in a local minimum which gives very similar results and estimates.
wRw1	DN model with no RW in BB_isl (ss 1,3,4)	Retrospective pattern is not good B0 changes
wRw2	DN model with no RW in TR_GN	Retrospective pattern is not good B0 changes
wRw3	DN model with no RW in MWT	Only 18 jitters from 40 fell in the minimum likelihood.
wRw4	DN model with no RW in BB_isl (ss 2)	Retrospective pattern is not good B0 changes
NoTBJP	DN model with no time block JPLL_N and JPLL_S	Retrospective pattern is not good B0 changes
NoTBTAI	DN model with no time block TAILL_N and TAILL_S	Retrospective pattern is not good B0 changes
TBJP1	DN model with no time block JPLL_N and JPLL_S (2nd+3rd period together)	Did not converge
TBTAI1	DN model with one time block TAILL_N and TAILL_S (2nd+3rd period together)	Differences on B0 in the retrospective
ReSamp	DN model with Nsamp of the LC data estimated as the total fish measured/1000	Retrospective pattern is not good B0 changes
Francis	DN model with LC data re-weighted with Francis method, after running twice	Retrospective pattern is not good B0 changes

Table 2. Results of diagnostics of different scenarios already described in **Table1**.

SCENARIO	*Final gradient*	*Mohns Rho-SSB*	*Mohns Rho-F*	*SSB pred Mohns Rho*	*F predict Mohns Rho*	*# of CPUE pass runs test*	*# of LC fleet pass runs test.*	*Number of hindcasting MASE<1*
RC	6.93E-05	0	-0.01	0.01	0.05	5	7	2
DN	4.95E-05	0	0	0	0.05	4	7	2
wRw1	3.18E-05	0.05	-0.02	0.06	0.05	3	4	2
wRw2	5.45E-05	0.83	-0.12	0.83	0.08	4	7	3
wRw3	4.98E-05	0	0.01	0.01	0.07	5	7	2
wRw4	1.50E-05	1.18	-0.14	0.97	-0.06	4	7	3
NoTBJP	0.000389	-0.02	0.01	0.02	0.01	4	7	2
NoTBTAI	2.11E-05	0	0	0	0.05	3	6	3
TBJP1	Did not converge					4		
TBTAI1	9.21E-05	-0.08	0.05	-0.08	0.1	4	7	2
ReSamp	6.22E-05	0.06	-0.05	0.07	0	5	4	3
Francis	7.17E-05	0.01	0.03	0.01	0.11	5	5	3

Table 3. Stock Synthesis parameter estimates for North Atlantic albacore.

	Value	Phase	Parm_StDev	Gradient	Pr_type	Prior	Pr_SD
L_at_Amin_Fem_GP_1	41.96	2	0.55	3.52E-05	No_prior	NA	NA
L_at_Amax_Fem_GP_1	124.70	2	2.41	-2.60E-05	No_prior	NA	NA
VonBert_K_Fem_GP_1	0.20	3	0.01	-3.25E-05	No_prior	NA	NA
SD_young_Fem_GP_1	3.35	3	0.16	3.63E-06	No_prior	NA	NA
SD_old_Fem_GP_1	5.43	3	0.76	2.91E-07	No_prior	NA	NA
SR_LN(R0)	11.47	1	0.13	3.42E-05	No_prior	NA	NA
SR_BH_steep	0.65	2	0.06	-4.41E-06	No_prior	NA	NA
InitF_seas_1_flt_33_TR_GN	0.06	1	0.01	7.76E-05	No_prior	NA	NA
SizeSpline_GradLo_1_BB(1)	0.47	5	0.12	3.70E-07	No_prior	NA	NA
SizeSpline_GradHi_1_BB(1)	-0.37	5	0.06	-8.03E-07	No_prior	NA	NA
SizeSpline_Val_1_1_BB(1)	-3.63	4	0.32	-1.81E-07	No_prior	NA	NA
SizeSpline_Val_2_1_BB(1)	-1.49	4	0.17	-2.47E-06	No_prior	NA	NA
SizeSpline_Val_4_1_BB(1)	-1.82	4	0.20	2.71E-06	No_prior	NA	NA
Size_DblN_peak_2_BB_isl(2)	104.28	4	5.56	1.19E-06	No_prior	NA	NA
Size_DblN_top_logit_2_BB_isl(2)	-13.55	5	193.20	4.13E-06	No_prior	NA	NA
Size_DblN_ascend_se_2_BB_isl(2)	5.35	4	0.16	6.46E-07	No_prior	NA	NA
Size_DblN_descend_se_2_BB_isl(2)	4.97	5	0.56	-2.28E-06	No_prior	NA	NA
Size_DblN_peak_3_TR_GN(3)	63.86	4	3.05	8.31E-05	No_prior	NA	NA
Size_DblN_top_logit_3_TR_GN(3)	-3.86	5	2.20	4.13E-05	No_prior	NA	NA
Size_DblN_ascend_se_3_TR_GN(3)	3.64	4	1.45	7.80E-06	No_prior	NA	NA
Size_DblN_descend_se_3_TR_GN(3)	5.21	5	0.39	8.99E-05	No_prior	NA	NA
SizeSpline_GradLo_4_MWT(4)	0.42	5	0.09	-1.47E-06	No_prior	NA	NA
SizeSpline_GradHi_4_MWT(4)	-0.23	5	0.07	-2.94E-06	No_prior	NA	NA
SizeSpline_Val_1_4_MWT(4)	-3.97	4	2.40	-3.54E-06	No_prior	NA	NA
SizeSpline_Val_3_4_MWT(4)	-3.98	4	1.97	8.61E-07	No_prior	NA	NA
Size_DblN_peak_5_JPLL_N(5)	93.18	4	2.99	-1.97E-06	No_prior	NA	NA
Size_DblN_top_logit_5_JPLL_N(5)	-13.51	5	0.10	7.20E-07	Normal	-13.507	0.1
Size_DblN_ascend_se_5_JPLL_N(5)	4.17	4	0.54	-3.92E-06	No_prior	NA	NA
Size_DblN_descend_se_5_JPLL_N(5)	5.36	5	0.53	-8.13E-06	No_prior	NA	NA
Size_DblN_peak_6_JPLL_S(6)	101.96	4	2.41	5.49E-07	No_prior	NA	NA
Size_DblN_top_logit_6_JPLL_S(6)	-13.57	5	0.10	-3.81E-07	Normal	-13.569	0.1
Size_DblN_ascend_se_6_JPLL_S(6)	4.16	4	0.44	3.35E-08	No_prior	NA	NA
Size_DblN_descend_se_6_JPLL_S(6)	5.18	5	0.51	-1.88E-06	No_prior	NA	NA
Size_DblN_peak_7_TAILL_N(7)	100.11	4	3.67	8.22E-06	No_prior	NA	NA
Size_DblN_top_logit_7_TAILL_N(7)	-14.04	5	0.10	-9.14E-07	Normal	-14.039	0.1
Size_DblN_ascend_se_7_TAILL_N(7)	5.75	4	0.25	5.52E-06	No_prior	NA	NA
Size_DblN_descend_se_7_TAILL_N(7)	5.26	5	0.54	-4.80E-06	No_prior	NA	NA
Size_DblN_peak_8_TAILL_S(8)	120.49	4	8.24	-3.12E-08	No_prior	NA	NA
Size_DblN_top_logit_8_TAILL_S(8)	-13.81	5	0.10	9.04E-07	Normal	-13.813	0.1
Size_DblN_ascend_se_8_TAILL_S(8)	6.15	4	0.30	-1.62E-06	No_prior	NA	NA
Size_DblN_descend_se_8_TAILL_S(8)	5.04	5	0.61	3.85E-06	No_prior	NA	NA
Size_DblN_peak_9_USLL_N(9)	104.12	4	1.99	2.96E-06	No_prior	NA	NA
Size_DblN_top_logit_9_USLL_N(9)	-12.39	5	0.10	-5.13E-07	Normal	-12.389	0.1
Size_DblN_ascend_se_9_USLL_N(9)	5.23	4	0.19	1.60E-06	No_prior	NA	NA
Size_DblN_descend_se_9_USLL_N(9)	4.52	5	0.58	1.30E-06	No_prior	NA	NA
Size_inflection_10_USLL_S(10)	107.43	4	2.09	4.03E-06	No_prior	NA	NA
Size_95%width_10_USLL_S(10)	12.71	5	1.41	4.17E-06	No_prior	NA	NA
Size_inflection_11_VENLL(11)	97.52	4	1.80	7.88E-07	No_prior	NA	NA
Size_95%width_11_VENLL(11)	10.50	5	1.73	4.09E-06	No_prior	NA	NA
Size_DblN_peak_15_BBisl_s2(15)	83.67	4	4.33	-6.94E-06	No_prior	NA	NA
Size_DblN_top_logit_15_BBisl_s2(15)	-14.12	5	0.10	-1.74E-06	Normal	-14.119	0.1
Size_DblN_ascend_se_15_BBisl_s2(15)	5.10	4	1.65	6.78E-06	No_prior	NA	NA
Size_DblN_descend_se_15_BBisl_s2(15)	5.70	5	0.34	7.43E-06	No_prior	NA	NA
Size_DblN_peak_5_JPLL_N(5)_BLK1repl_1970	101.43	6	5.35	-6.49E-06	No_prior	NA	NA
Size_DblN_peak_5_JPLL_N(5)_BLK1repl_1976	105.44	6	2.86	3.93E-06	No_prior	NA	NA
Size_DblN_ascend_se_5_JPLL_N(5)_BLK1repl_1970	5.65	6	0.37	-3.03E-06	No_prior	NA	NA
Size_DblN_ascend_se_5_JPLL_N(5)_BLK1repl_1976	6.20	6	0.14	6.97E-06	No_prior	NA	NA
Size_DblN_peak_6_JPLL_S(6)_BLK1repl_1970	101.86	6	7.17	3.50E-07	No_prior	NA	NA
Size_DblN_peak_6_JPLL_S(6)_BLK1repl_1976	106.14	6	2.14	4.01E-06	No_prior	NA	NA
Size_DblN_ascend_se_6_JPLL_S(6)_BLK1repl_1970	5.20	6	0.71	-5.96E-07	No_prior	NA	NA
Size_DblN_ascend_se_6_JPLL_S(6)_BLK1repl_1976	5.17	6	0.20	1.04E-06	No_prior	NA	NA
Size_DblN_peak_7_TAILL_N(7)_BLK2repl_1987	93.51	6	3.53	-9.63E-06	No_prior	NA	NA
Size_DblN_peak_7_TAILL_N(7)_BLK2repl_1999	104.53	6	1.77	5.48E-07	No_prior	NA	NA
Size_DblN_ascend_se_7_TAILL_N(7)_BLK2repl_1987	5.38	6	0.35	-1.58E-05	No_prior	NA	NA
Size_DblN_ascend_se_7_TAILL_N(7)_BLK2repl_1999	5.26	6	0.16	1.83E-06	No_prior	NA	NA
Size_DblN_peak_8_TAILL_S(8)_BLK2repl_1987	128.40	6	12.62	6.10E-08	No_prior	NA	NA
Size_DblN_peak_8_TAILL_S(8)_BLK2repl_1999	108.53	6	1.77	-2.31E-06	No_prior	NA	NA
Size_DblN_ascend_se_8_TAILL_S(8)_BLK2repl_1987	6.57	6	0.35	3.21E-07	No_prior	NA	NA
Size_DblN_ascend_se_8_TAILL_S(8)_BLK2repl_1999	5.16	6	0.17	1.28E-07	No_prior	NA	NA

Table 4. Stock Synthesis estimates of spawning stock biomass, exploitation rate (fraction of total biomass), and recruitment for North Atlantic albacore.

	Spawning Stock Biomass		*Recruitment*		*exploitation Rate (biomass)*	
Year	*Estimate*	*StdDev*	*Estimate*	*StdDev*	*Estimate*	*StdDev*
Initial	330157	48193.9	95952.2	12517.5	0.018	0.0024751
1930	330157	48193.9	94351.5	12132.6	0.023	0.003
1931	329955	48198.9	94342.7	12130.8	0.019	0.003
1932	329022	48219.5	94302.2	12122.7	0.017	0.002
1933	327100	48238.8	94218	12105.1	0.028	0.004
1934	324692	48224.1	94111.3	12081.4	0.031	0.004
1935	321914	48050.2	93986.6	12046.8	0.025	0.004
1936	318284	47810.8	93820.9	12000.5	0.021	0.003
1937	313241	47607	93585.3	11941.5	0.022	0.003
1938	308275	47367.8	93347	11881.5	0.026	0.004
1939	305480	47132	93210	11842.5	0.018	0.003
1940	304451	46949	93159	11823.2	0.020	0.003
1941	303934	46792.5	93133.4	11810.3	0.026	0.004
1942	303509	46615.7	93112.1	11797.3	0.026	0.004
1943	303687	46428.3	93121	11789.7	0.026	0.004
1944	303429	46271.7	93108.2	11779.3	0.043	0.006
1945	301827	46127	93027.8	11755.7	0.037	0.005
1946	298820	46006.7	92875	11718.6	0.033	0.005
1947	294460	45918.6	92648.8	11668.9	0.039	0.006
1948	288699	45795.4	92341.3	11603.4	0.046	0.007
1949	283667	45638.5	92064.1	11543.5	0.066	0.010
1950	279892	45533.1	91850.9	11498.8	0.059	0.009
1951	274434	45490.4	91533.9	11439.5	0.057	0.009
1952	266407	45408.5	91048.5	11352	0.054	0.009
1953	256697	45190	90428.4	11241.2	0.072	0.012
1954	247565	44879.9	89809.3	11132.4	0.058	0.010
1955	239904	44601.6	89260.8	11040	0.076	0.013
1956	234931	44396.1	88889.4	10978.4	0.081	0.014
1957	229353	44185.6	88457.7	10911.3	0.103	0.018
1958	221700	43894.9	87837.3	10820.9	0.102	0.019
1959	210497	43489.9	86865.6	10695.5	0.113	0.021
1960	198762	43019.6	64852.1	19682.1	0.098	0.018
1961	186527	42558.8	49287.1	15761.5	0.146	0.028
1962	176317	42083.7	58255.1	21368.3	0.168	0.035
1963	162152	41423.2	128649	38498.5	0.178	0.034
1964	141421	40439.8	74398.6	26618.7	0.173	0.032
1965	117406	37692.1	72184	22736.2	0.141	0.024
1966	92929.4	34023	57874.2	17620.4	0.181	0.029
1967	81581.3	31633.2	67162.4	18593.1	0.148	0.023
1968	89076.6	30406.1	62677.2	16988.8	0.156	0.023
1969	100163	29909.3	101491	19959.5	0.145	0.018
1970	93071.9	26366.6	75838.7	16955.6	0.173	0.020
1971	83975.3	23476.3	99858.5	16964.3	0.143	0.015
1972	76921.7	20933.1	69142.5	13353.5	0.132	0.013
1973	76540.6	19248	46546.3	10199	0.149	0.015
1974	83349.8	18037.9	59624.3	11121.8	0.133	0.013
1975	92705.1	17706	57146.2	11268.1	0.189	0.018
1976	98988.9	17266.9	52707.6	10838.3	0.195	0.018

1977	93962.9	16744.5	74429.2	12160.3	0.186	0.016
1978	79535.5	15303.6	73871.4	12120.4	0.190	0.015
1979	73793.1	13819.7	64787.2	11240.5	0.145	0.010
1980	69664.4	12496.3	52169.8	9568.47	0.130	0.009
1981	66185	11055.8	45739.3	8881.51	0.164	0.011
1982	66699.4	10005.3	50429.3	8954.42	0.209	0.015
1983	71253.1	9215.68	47545.7	8909.55	0.185	0.016
1984	68839.5	8533.16	67797.5	10968.9	0.178	0.018
1985	59118.6	8223.37	64142.6	10752.8	0.201	0.021
1986	51616.5	8247.55	59996.4	9638.26	0.161	0.018
1987	44046.7	8850.57	48604.9	7856.8	0.140	0.016
1988	48337.2	9920.33	50473.6	8357.66	0.135	0.016
1989	59004.2	11479.9	62993.2	10082.8	0.150	0.018
1990	70628.1	13124.6	55569.8	9668.15	0.113	0.014
1991	73083.9	13887.7	54273.7	9680.74	0.121	0.015
1992	74151.2	14011.8	63134.3	10442.8	0.145	0.018
1993	74199.8	13885.1	47715.4	9402.67	0.137	0.018
1994	73366.7	14333.4	56622.5	10151.3	0.150	0.020
1995	75787.4	15057	51135.8	10037.4	0.115	0.016
1996	73778.3	15433.8	72209.1	11827.9	0.109	0.015
1997	77950.6	16123	69030.8	11237.6	0.091	0.012
1998	80960.6	16547.6	53263.6	9149.25	0.119	0.016
1999	84661.1	16788	34851.4	7019.78	0.121	0.017
2000	84138.7	17063	40254.6	7453.11	0.102	0.015
2001	88800.9	17801.1	47982.9	8467.86	0.090	0.013
2002	95914.6	18993.5	65739.8	10314.2	0.097	0.014
2003	98170.8	19363.3	43915	8328.93	0.098	0.014
2004	91636.4	18455.2	77674.2	11947.6	0.125	0.018
2005	85874.1	17361.9	51900.3	9420.95	0.132	0.020
2006	83191.9	17165.8	56025.5	9895.74	0.080	0.013
2007	86506.8	18243.6	50729.1	9382.94	0.072	0.012
2008	89318.2	18986	69411.9	12132.1	0.051	0.009
2009	97161.2	20512.9	71318.5	12625.2	0.060	0.010
2010	107540	22331.7	64180	11860.1	0.058	0.009
2011	113192	23192.7	75673	13556.8	0.070	0.011
2012	117812	23874.1	61493.8	12591.1	0.067	0.011
2013	124609	25054.6	57663.2	12630.7	0.072	0.011
2014	133334	26912	63008.3	13878.8	0.069	0.011
2015	138773	27940.5	94125.7	18316	0.077	0.012
2016	142983	28860.4	127406	25024.5	0.065	0.010
2017	143018	29385.7	132571	31751.1	0.060	0.009
2018	139158	28930.3	103221	30162.6	0.065	0.010
2019	140163	28591.7	78268	6771.76	0.057	0.009
2020	151270	30134.3	80008.2	6886.65	0.057	0.008
2021	179729	34615.7	83727.9	7420.91	0.055	0.008
2022	214508	40610.5	-	-	-	-

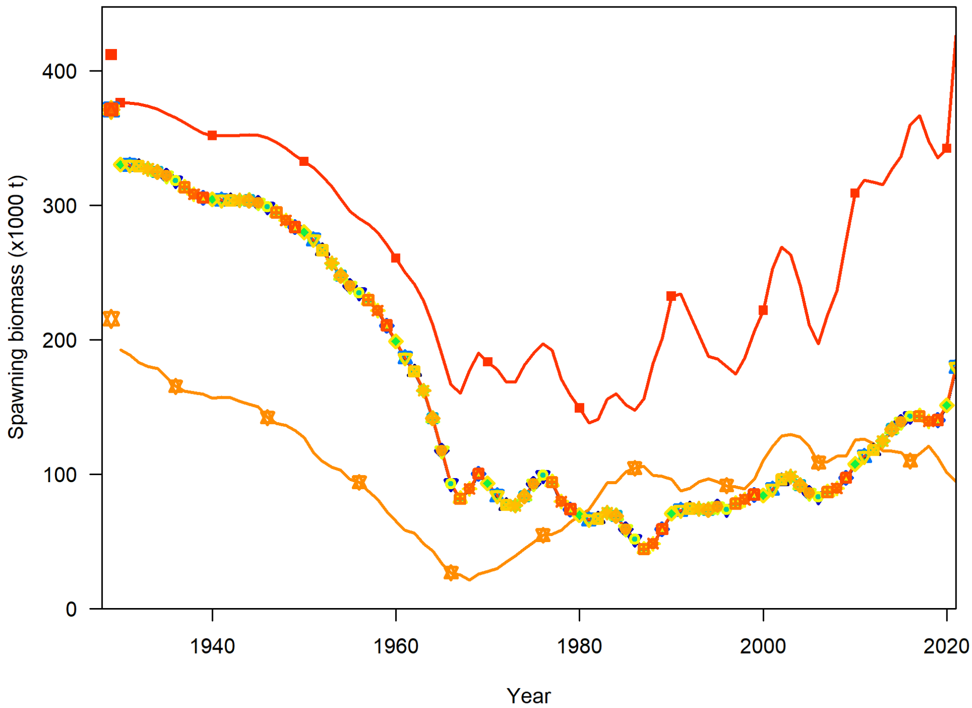

Figure 1. North Atlantic albacore Stock Synthesis revised reference case model jitter analysis results showing the spawning biomass trajectory across trials. Only two models failed to converge, shown as the divergent red and orange lines.

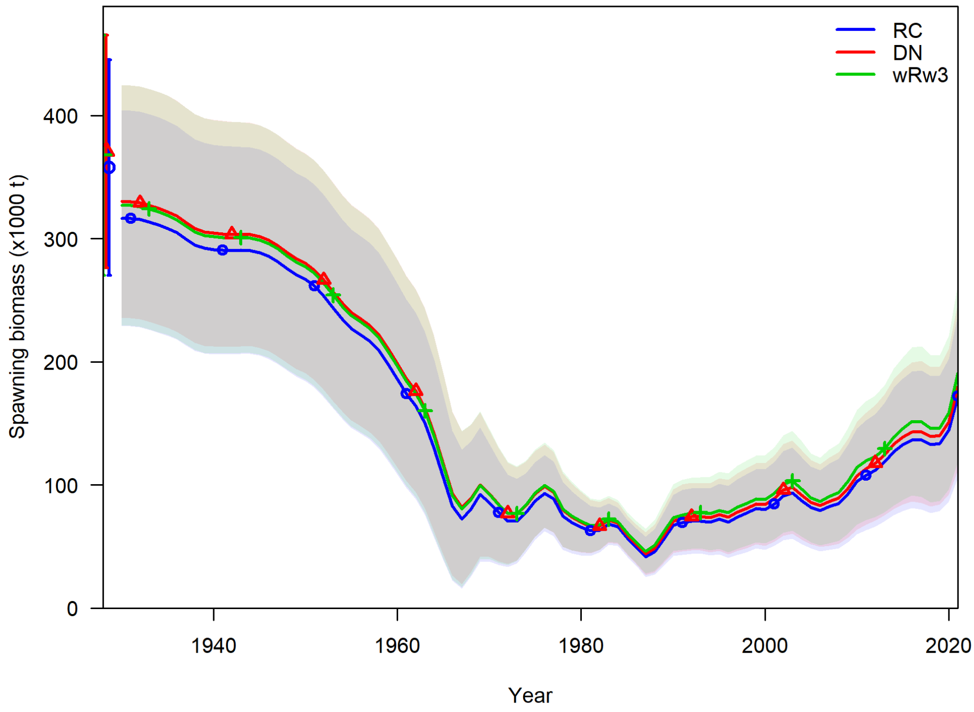

Figure 2. Stock Synthesis time series estimates of North Atlantic albacore spawning stock biomass compared across three model scenarios (meaning of RC, DN and wRw3 defined in Table 1) that showed the best overall diagnostics.

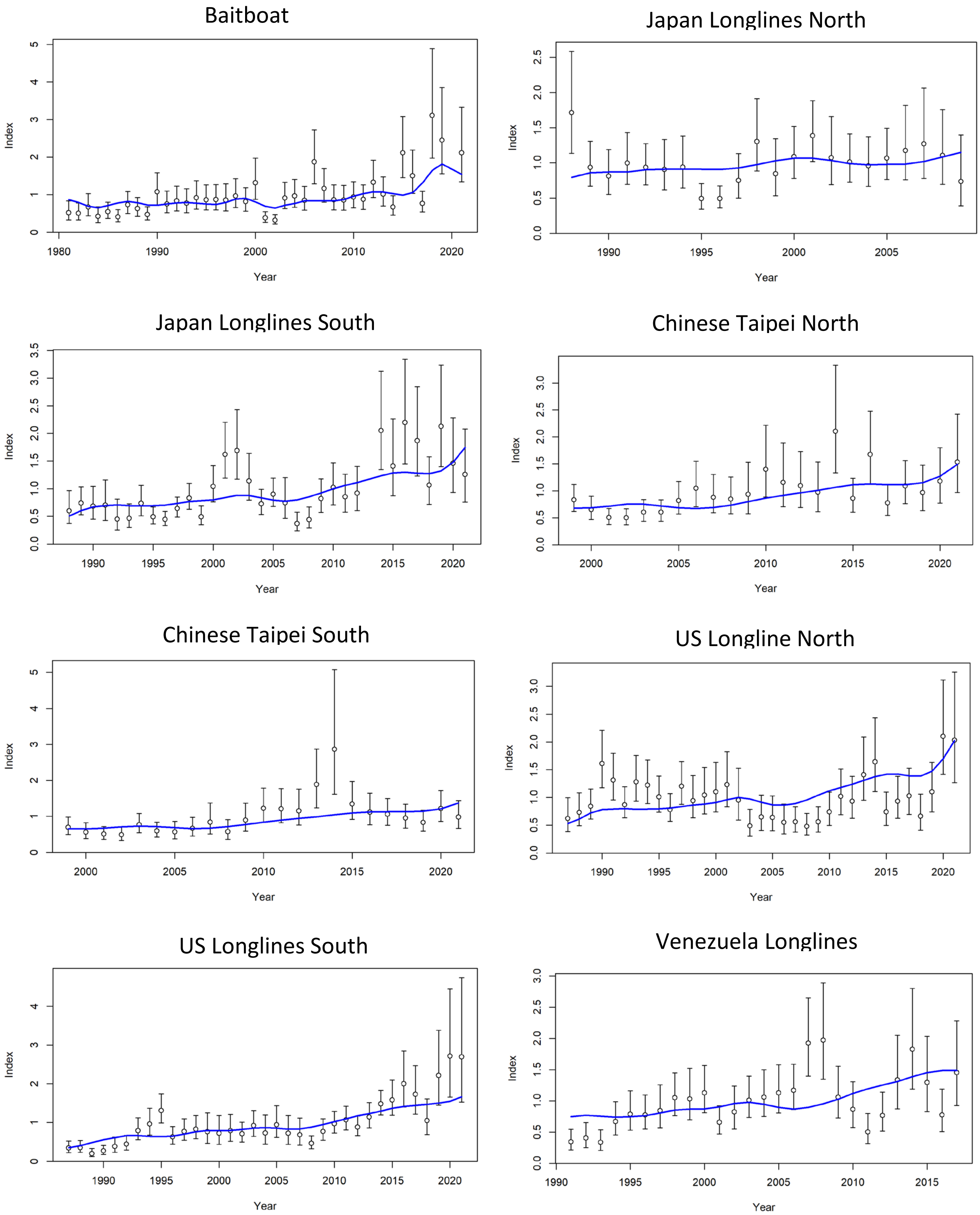

Figure 3. Stock Synthesis revised reference case model fits to the indices of relative abundance of North Atlantic albacore.

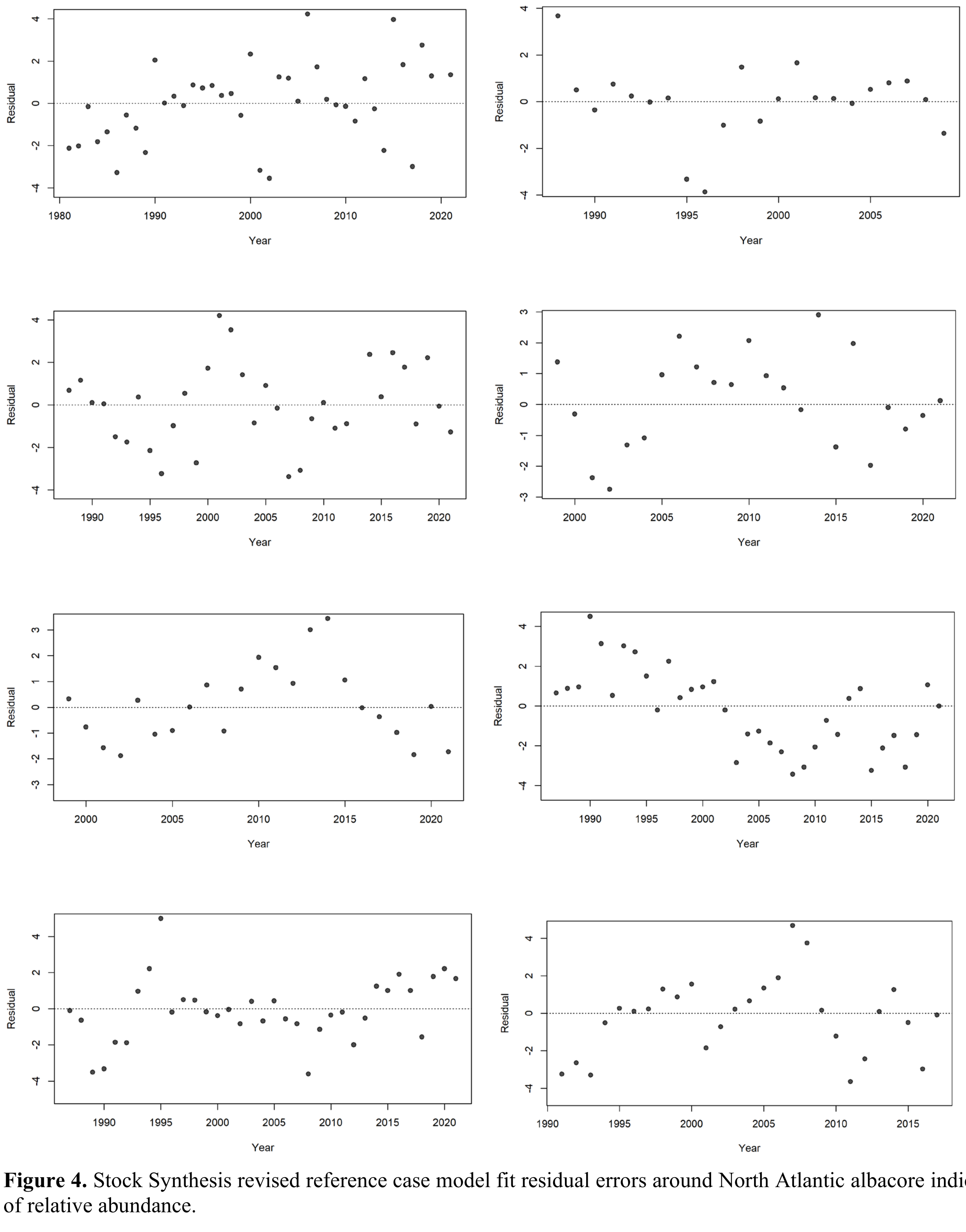

Figure 4. Stock Synthesis revised reference case model fit residual errors around North Atlantic albacore indices of relative abundance.

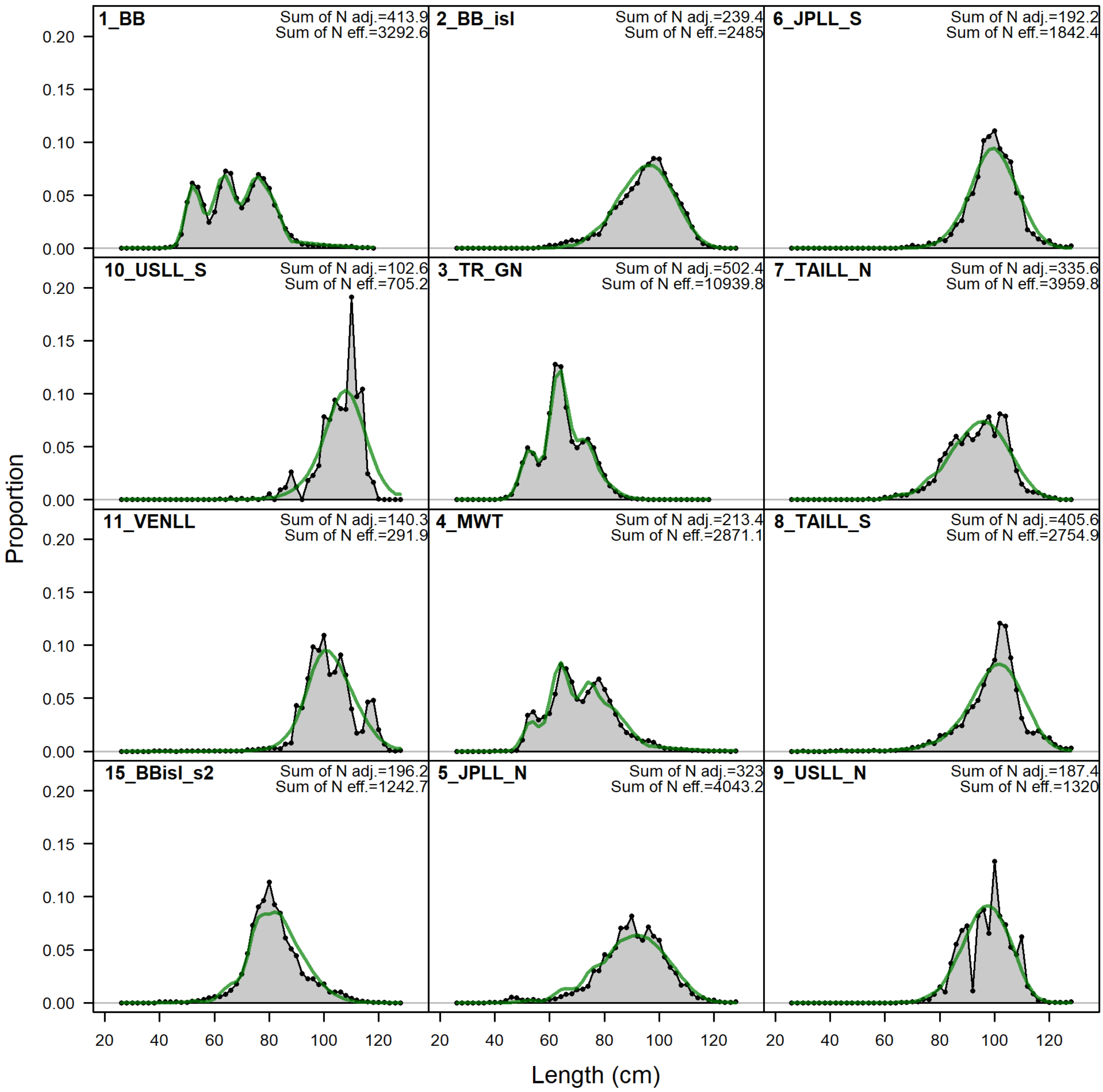

Figure 5. Stock Synthesis revised reference case fits to North Atlantic albacore length compositions by fleet. The gray distributions show the observed aggregated length composition by fleet and the green line shows the model predicted length composition.

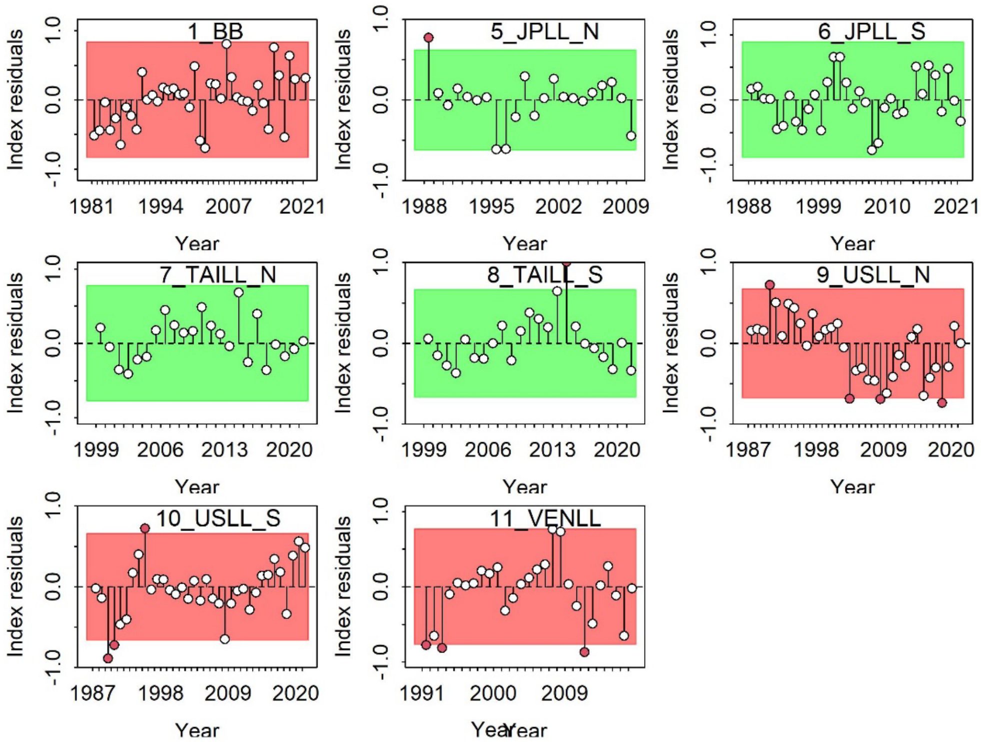

Figure 6. Revised reference case model diagnostic residual runs test on model fits to the indices of abundance.

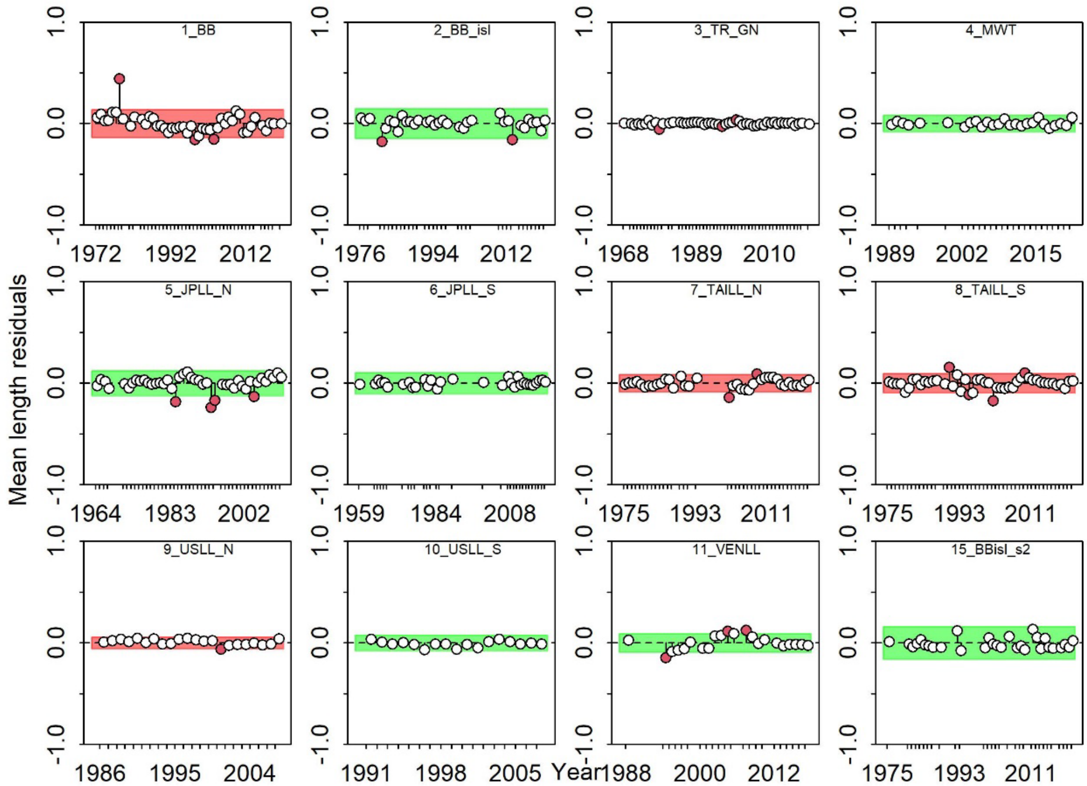

Figure 7. Revised reference case model diagnostic residual runs test on model fits to the fleet length compositions.

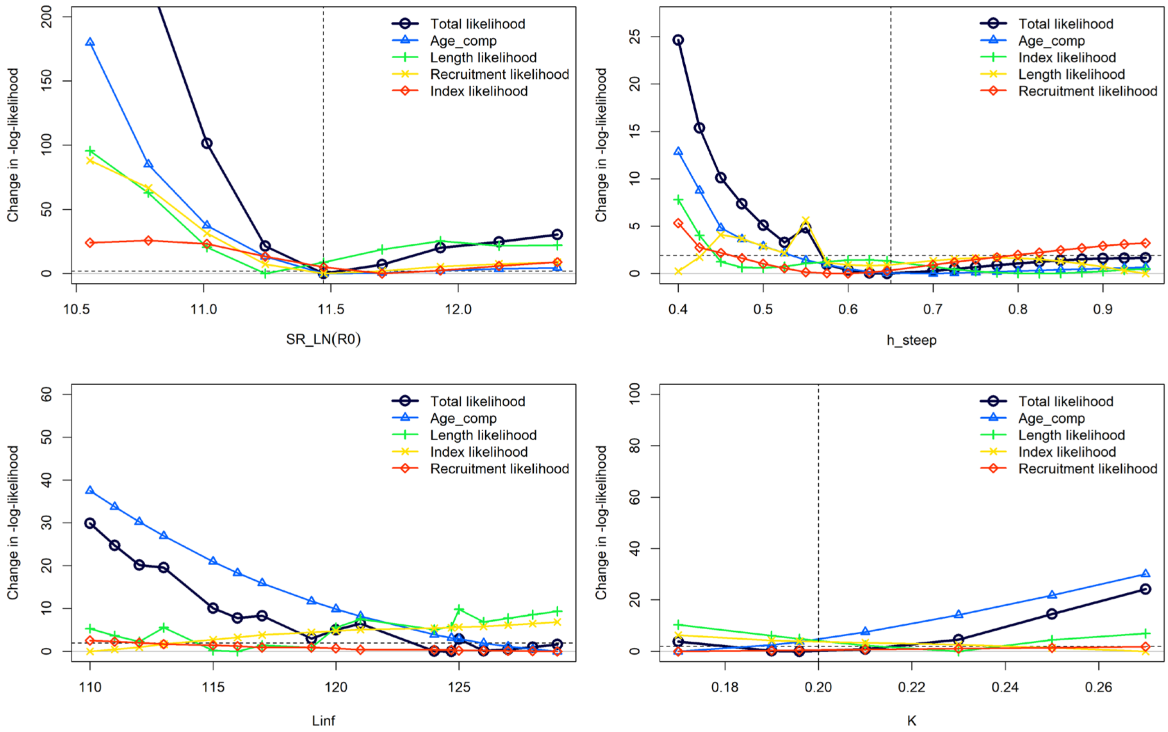

Figure 8. Likelihood profiles on unfished mean equilibrium recruitment (R0), steepness (h), mean asymptotic length (Linf), and intrinsic growth rate (k) of North Atlantic albacore.

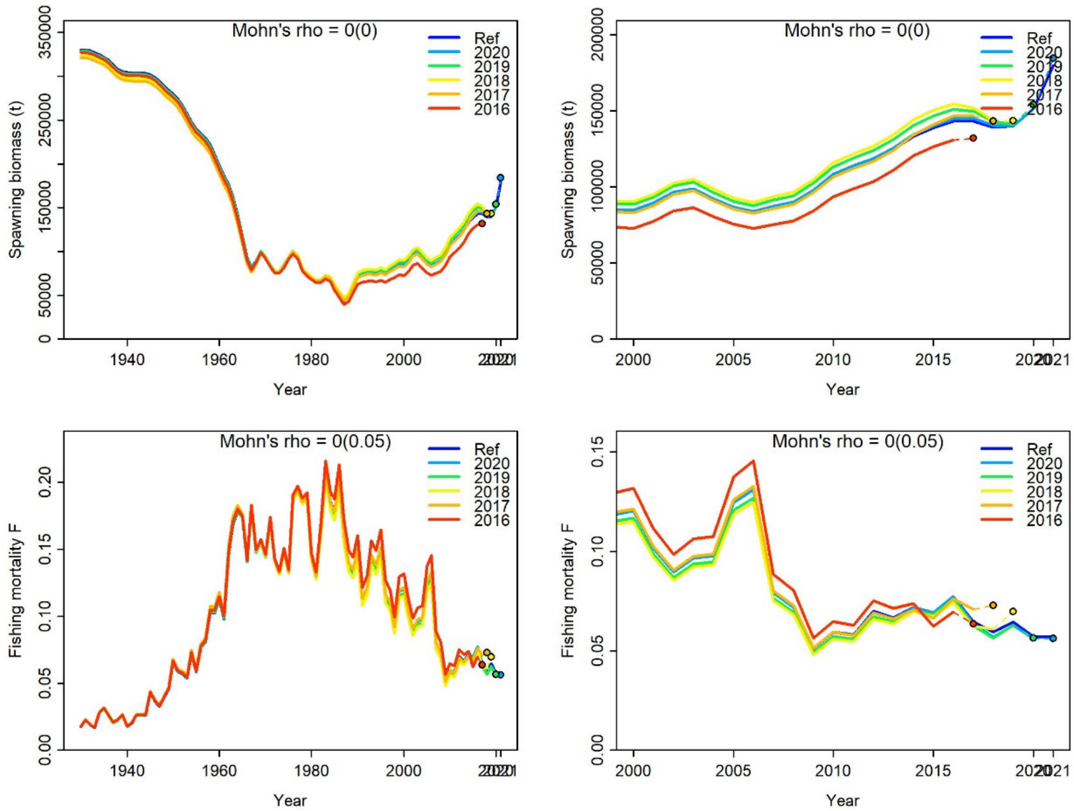

Figure 9. Retrospective analyses of the North Atlantic albacore Stock Synthesis reviewed reference case model. Upper left panel shows the SSB time series, upper right panel shows the recent SSB time series for the recent decades. The lower left panel shows the time series of exploitation rate estimates. The lower right panel shows the exploitation rate time series for the recent decades.

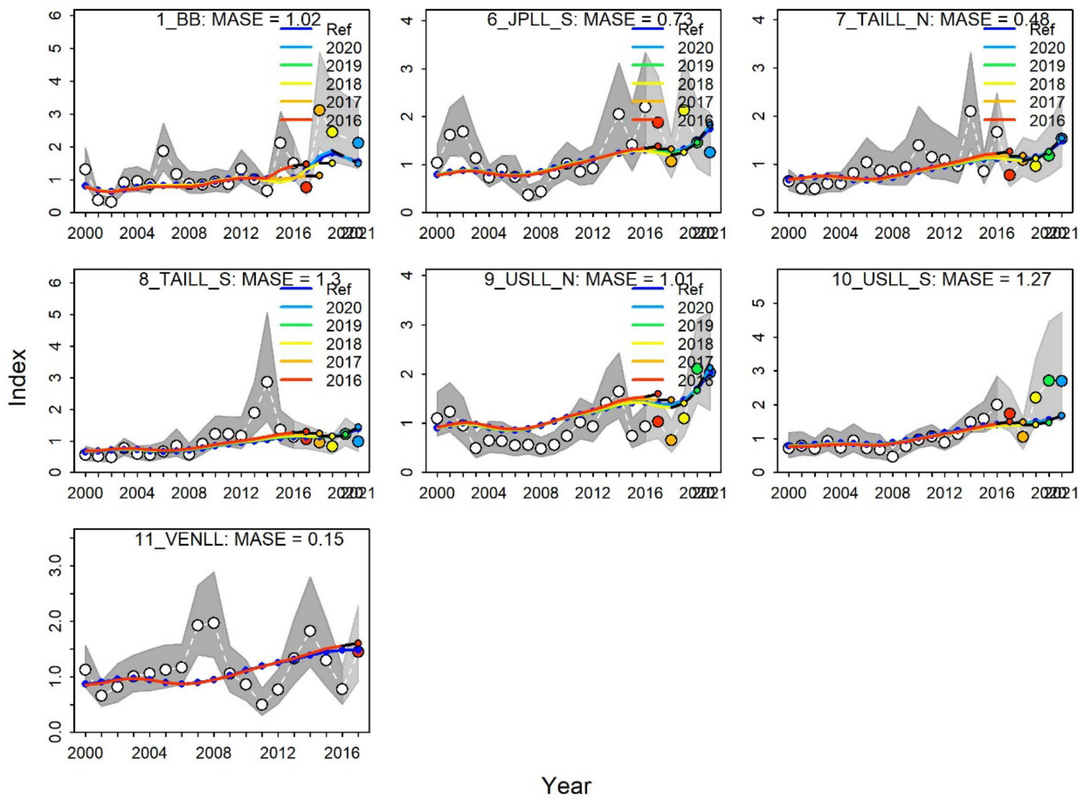

Figure 10. Hindcasting analysis of each of the indices to evaluate the predictive ability of the CPUEs by the North Atlantic albacore Stock Synthesis reviewed reference case model.

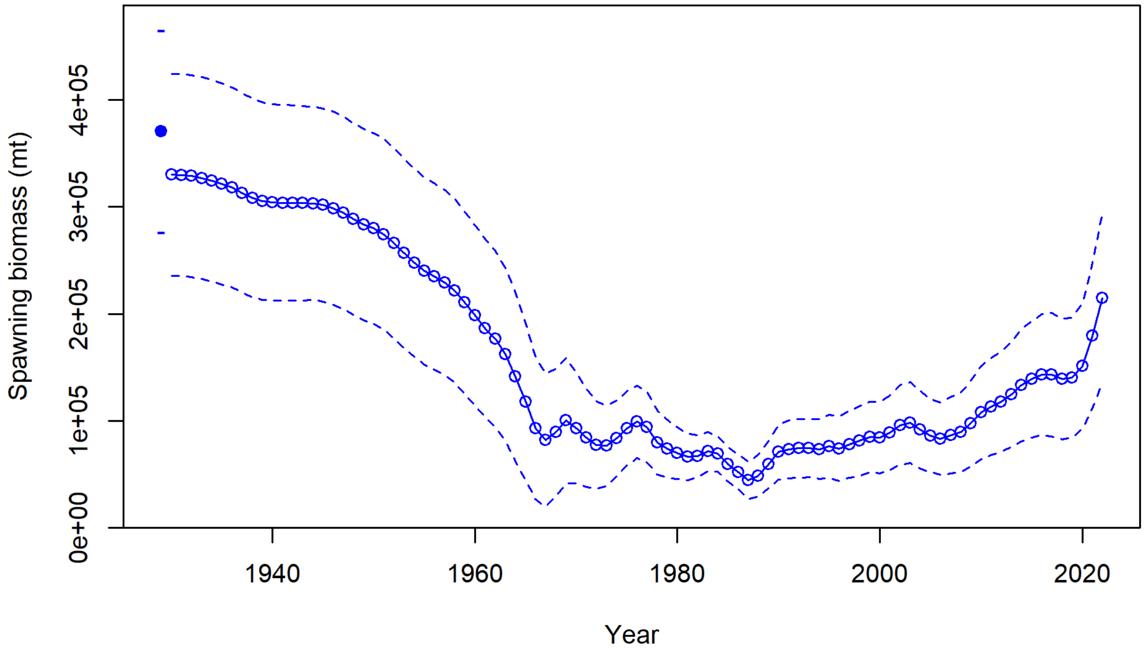

Figure 11. Stock Synthesis revised reference case estimated time series of North Atlantic albacore spawning stock biomass.

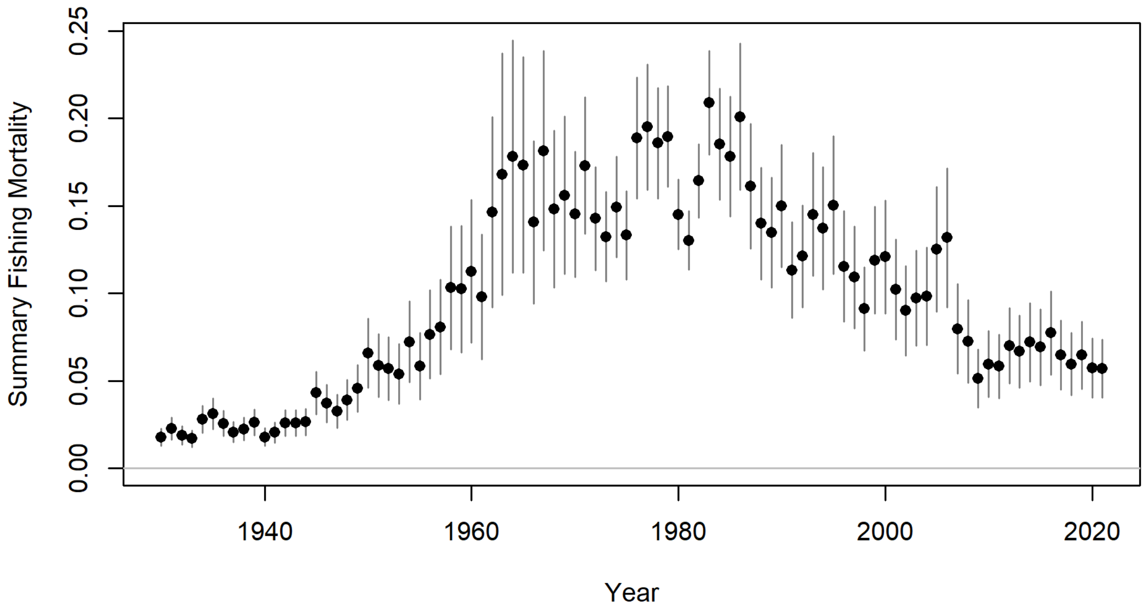

Figure 12. Stock Synthesis revised reference case estimated time series of fishing mortality on North Atlantic albacore.

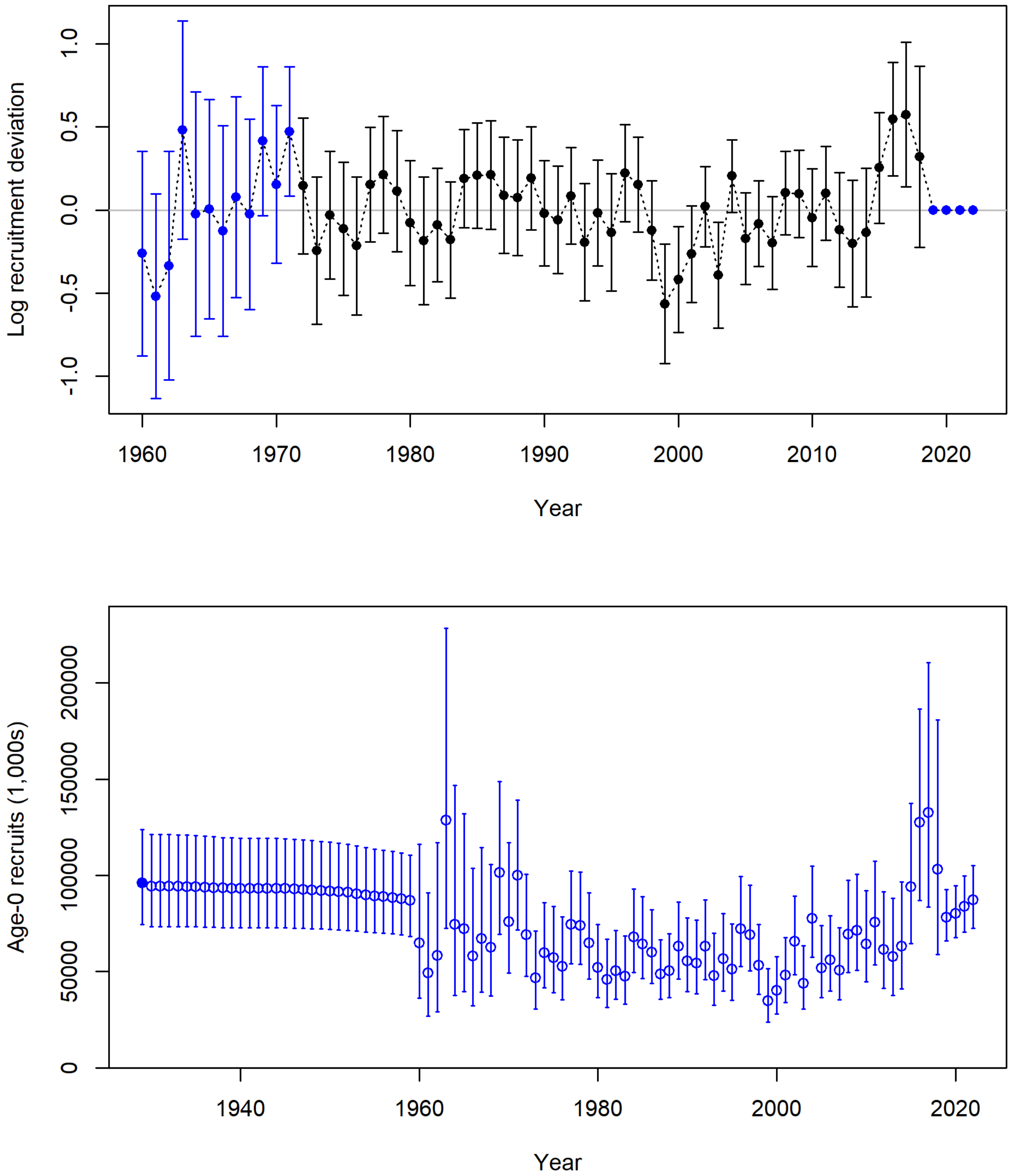

Figure 13. Stock Synthesis revised reference case estimated recruitment deviations (upper panel) and time series of North Atlantic albacore recruitment estimates (lower panel).