

PRELIMINARY ASSESSMENT OF ATLANTIC BLUE MARLIN (*MAKAIRA NIGRICANS*) USING JABBA MODEL (1956-2022)

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SUMMARY

*We applied the JABBA model for Atlantic blue marlin (*Makaira nigricans*) with the best available data through 2022. Preliminary JABBA stock assessment results suggest reasonably robust fits to the data as judged by the presented model diagnostic results. The resulting stock status for 2022 was generally consistent and predicted with high probabilities that current fishing levels are generating overfishing ($F_{2022} > F_{MSY}$), whereas biomass is below the sustainable levels that can produce MSY ($B_{2022} < B_{MSY}$). As such, our models conclusively estimate that the stock is overfished and subject to overfishing, with a probability of 69.4% for the red quadrant of Kobe.*

RÉSUMÉ

*Nous avons appliqué le modèle JABBA pour le makaira bleu de l'Atlantique (*Makaira nigricans*) à l'aide des meilleures données disponibles jusqu'en 2022. Les résultats préliminaires de l'évaluation du stock JABBA suggèrent des ajustements raisonnablement robustes aux données, à en juger par les résultats des diagnostics des modèles présentés. L'état du stock en résultant pour 2022 était généralement cohérent et prédisait, avec de fortes probabilités, que les niveaux de pêche actuels génèrent une surpêche ($F_{2022} > F_{PME}$), tandis que la biomasse est en dessous des niveaux durables pouvant produire la PME ($B_{2022} < B_{PME}$). Par conséquent, nos modèles estiment de façon concluante que le stock est surexploité et fait l'objet de surpêche, avec une probabilité de 69,4% de se situer dans le quadrante rouge de Kobe.*

RESUMEN

*Aplicamos el modelo JABBA para la aguja azul del Atlántico (*Makaira nigricans*) con los mejores datos disponibles hasta 2022. Los resultados preliminares de la evaluación de stock de JABBA sugieren un ajuste razonablemente robusto a los datos, según los resultados de diagnóstico del modelo presentados. El estado del stock resultante para 2022 fue generalmente coherente y predijo con altas probabilidades que los niveles de pesca actuales están generando sobrepesca ($F_{2022} > F_{RMS}$), mientras que la biomasa permanece por debajo de los niveles sostenibles que pueden producir el RMS ($B_{2022} < B_{RMS}$). Así, nuestros modelos estiman de forma concluyente que el stock está sobrepescado y es objeto de sobrepesca, con una probabilidad que del 97,3 % de situarse en el cuadrante rojo del diagrama de Kobe*

KEYWORDS

Abundance, Blue marlin, Billfish, Biomass dynamic model, JABBA, CPUE fits, Stock assessment.

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1. Introduction

In 2018, the International Commission for the Conservation of Atlantic Tunas (ICCAT) conducted a full stock assessment for Atlantic blue marlin applying the Bayesian State-Space Surplus Production Model framework, JABBA (Just Another Bayesian Biomass Assessment; Winker *et al.* 2018) and a statistically integrated model Stock Synthesis (Anon., 2018). The 2018 assessment comprised catch and effort data up to 2016 and estimations of management reference points (ICCAT, 2019). The results from both models indicated that the estimated B/B_{MSY} and F/F_{MSY} were such that the current stock status is overfished and undergoing overfishing. Management benchmarks resulting from JABBA models (low and high productivity) revealed that B_{2016}/B_{MSY} was about 0.68 (0.43 – 0.93: 95% credibility interval) and F_{2016}/F_{MSY} was 1.16 (0.56 - 1.77). For the Stock Synthesis model, these management reference points were 0.69 (0.52 - 0.91: 80% confidence interval) for B_{2016}/B_{MSY} and 1.03 (0.74 - 1.50) for F_{2016}/F_{MSY} . Despite the status of the blue marlin stock being overfished, ICCAT also recognizes the high uncertainty regarding discard data and the productivity of the stock due to the lack of reliable growth parameters for this species in the Atlantic Ocean.

Here we present preliminary stock assessment results for the 2024 Atlantic blue marlin stock based on the Bayesian State-Space Surplus Production Model framework, JABBA (Just Another Bayesian Biomass Assessment; Winker *et al.* 2018), using updated catch and CPUE time series through 2022. JABBA is a fully documented, open-source software that has been applied in a number of ICCAT stock assessments since 2015.

2. Material and Methods

2.1 Fishery data

The total catch of Atlantic blue marlin from 1956-2022 was obtained from the ICCAT Secretariat and includes reported landings (**Figure 1**). Indices of relative abundance were made available in the form of standardized catch-per-unit-of-effort (CPUE) time series, which were assumed to be proportional to biomass. For this assessment eleven standardized CPUE series were made available from Japan (historical and current longline), Chinese Taipei (long line with three time series), USA (longline), Venezuela (longline, gillnet and rod & reel), Brazil (longline) and Ghana (gillnet) (**Figure 2**):

- Japanese historical longline: 1959 - 1993
- Japanese longline: 1994 - 2022
- Chinese Taipei longline: 1968 - 1989
- Chinese Taipei longline: 1990 - 1997
- Chinese Taipei longline: 1998 – 2022
- U.S. pelagic longline: 1993 - 2022
- Venezuelan longline: 1991 – 2018
- Venezuelan artisanal drift-gillnet: 1991 – 2022
- Venezuelan rod and reel recreational: 1961 – 2001
- Brazilian longline: 1978 – 2005
- Ghanaian gillnet: 2000 – 2009

2.2 JABBA stock assessment model fitting procedures

This stock assessment uses the most updated version (v2.3.0) of JABBA and can be found online at: <https://github.com/jabbamodel/JABBA>. JABBA's inbuilt options include: (1) automatic fitting of multiple CPUE time series and associated standard errors, (2) estimating or fixing the process variance, (3) optional estimation of additional observation variance for individual or grouped CPUE time series, and (4) specifying a Fox, Schaefer or Pella-Tomlinson production function by setting the inflection point B_{MSY}/K and converting this ratio into shape a parameter m .

For the unfisher equilibrium biomass K , we used default settings of the JABBA R package in the form of vaguely informative lognormal prior with a large CV of 100% and a central value that corresponds to eight times the maximum total catch and is consistent with other platforms such as Catch-MSY (Martell and Froese 2013) or SpiCt (Pederson and Berg 2017). Initial depletion was input as a “beta” prior ($\phi = B_{1956}/K$) with mean = 0.99 and CV of 1%. This distribution is considered more appropriate than a lognormal for initial depletion, given the understanding that there was very little fishing before the starting year of 1956. All catchability parameters were

formulated as uninformative uniform priors, while additional observation variances were estimated for index by assuming inverse-gamma priors to enable model internal variance weighting. Instead, the process error of $\log(B_y)$ in year y was estimated “freely” by the model using an uninformative inverse-gamma distribution with both scaling parameters set at 0.001. Observation error for CPUE estimates was fixed at 0.05. For all model runs we used a random catch error uncertainty with CV of 0.01.

Initial trials considered four alternative specifications of the Pella-Tomlinson model type based on different sets of r priors and fixed input values of B_{MSY}/K . The input r priors for these scenarios were objectively derived from age-structured model simulations (see details in Winker *et al.* 2020) based on different sources of information on von Bertalanffy growth parameters estimated from: spines readings (Hoolihan *et al.* 2019), otoliths readings (Krusic-Golub *et al.* 2024), and from the age-length relationship estimated internally by the preliminary Stock Synthesis (SS) base model (see **Appendix A, Table A1**). Additionally, the priors from the last JABBA assessment (*i.e.*, $\log(r) \sim N(\log(0.098), 0.182)$ and $B_{MSY}/K = 0.36$; see Mourato *et al.* 2018) were also compared:

- prior_Spine (growth parameters estimated by Hoolihan *et al.* 2019);
- prior_Otolith (growth parameters estimated by Krusic-Golub *et al.* 2024);
- prior_SS (growth parameters estimates from SS preliminary base model);
- prior_2018 (same as Mourato *et al.* 2018).

Based on the sensitivity analysis of these four initial runs, no major differences were found in the estimates of stock status (**Appendix A, Figure A1**). However, significant differences were observed in the shapes of the production curves. The production curve estimated from the priors derived from the otolith growth curve (estimated by Krusic-Golub *et al.* 2024) showed the greatest similarity to the production curve estimated with the priors from the last assessment of the Atlantic blue marlin (*i.e.*, Mourato *et al.* 2018). Besides, the 'prior_Otolith' seems to be more reliable for describing the growth pattern of the Atlantic blue marlin. Therefore, the 'prior_Otolith' scenario was selected for the subsequent analysis.

The subsequent trials considered three alternative specifications of r priors and fixed input values of B_{MSY}/K based on 3 different steepness ($h = 0.4$, $h = 0.5$, and $h = 0.7$) (**Appendix A, Table A2**). Based on the sensitivity analysis of the ‘steepness-specific’ r input priors (**Appendix A, Figure A2**), a consistent difference in the shape of the production function was observed across the scenarios (**Appendix A, Figure A3**). The production curve estimated with the intermediate steepness value of 0.5 closely matches the one estimated with the priors from the last assessment of the Atlantic blue marlin (Mourato *et al.* 2018). In order to maintain continuity in the assessment process, this steepness ($h = 0.5$) was chosen to estimate the priors for the preliminary reference model.

Based on this proposed preliminary reference model, four sensitivity scenarios were also evaluated based on the catch data, *i.e.*:

- catch base: Landings + reported dead discards;
- catch_S1: Landings+ dead discards+ live discards * min from the literatures of post-release mortality on LL;
- catch_S2: Landings+ dead discards+ live discards * max from the literatures of post-release mortality on LL;
- catch_S3: Landings+ dead discards+ apply 0.05 post-release mortality on RR fleet as in 2018 stock assessment.

Since no substantial change in the results was observed (**Appendix A, Figure A4**), all subsequent analyses were performed for the catch base scenario, using the priors estimates for the growth parameters provided by Krusic-Golub *et al.* (2024) and a steepness value of 0.5. This preliminary reference model translates to an associated lognormal r prior of $\log(r) \sim N(\log(0.092), 0.222)$ and a fixed input value of $B_{MSY}/K = 0.38$.

2.3 Model diagnostics

The evaluation model diagnostics adheres to the recommendations made by Carvalho *et al.* (2021) who suggested that the candidate models be objectively assessed based on the following four model plausible criteria: (1) model convergence, (2) fit to the data, (3) model consistency (retrospective pattern), and (4) prediction skill through hindcast cross-validation (Kell *et al.* 2016; 2021).

JABBA is implemented in R (R Development Core Team, <https://www.r-project.org/>) with JAGS interface (Plummer 2003) to estimate the Bayesian posterior distributions of all quantities of interest by means of a Markov Chains Monte Carlo (MCMC) simulation. In this study, three MCMC chains were used. Each model was run for 30,000 iterations, sampled with a burn-in period of 5,000 for each chain and thinning rate of five iterations. Basic diagnostics of model convergence included visualization of the MCMC chains using MCMC trace-plots as well as Heidelberger and Welch (1992), Geweke (1992), and Gelman and Rubin (1992) diagnostics as implemented in the coda package (Plummer *et al.* 2006).

To evaluate the JABBA fit to the abundance index data, the model predicted values were compared to the observed indices. Residual plots were used to examine (1) color-coded lognormal residuals of observed versus predicted CPUE indices by fleet together with (2) boxplots indicating the median and quantiles of all residuals available for any given year; the area of each box indicates the strength of the discrepancy between CPUE series (larger box means higher degree of conflicting information) and (3) a loess smoother through all residuals which highlights systematically auto-correlated residual patterns to evaluate the randomness of model residuals. In addition, it depicts the root-mean-squared-error (RMSE) as a goodness-of-fit statistic. We conducted run tests to evaluate the randomness of residuals (Carvalho *et al.* 2017). The runs test diagnostic was applied to residuals of the CPUE fit on log-scale using the function `runs.test` in the R package “tseries”, considering the 1- sided p-value of the Wald-Wolfowitz runs test (Carvalho *et al.* 2021).

To check for model consistency with respect to the stock status estimates, we also performed a retrospective analysis by removing one year of data at a time sequentially ($n = 5$), refitting the model and comparing quantities of interest (*i.e.*, biomass, fishing mortality, B/B_{MSY} , F/F_{MSY} , B/B_0 and MSY) to the model that is fitted to full time series. To compare the bias between the models, we computed Mohn’s (Mohn 1999) rho (ρ) statistic and specifically the commonly used formulation Hurtado-Ferro *et al.* (2015).

To validate a model’s prediction skill, we applied a hindcasting cross-validation (HCXval) technique (Kell *et al.* 2016), where observations are compared to their predicted future values. HCXval is a form of cross-validation where, like retrospective analysis, recent data are removed, and the model refitted with the remaining data, but HCXval involves the additional steps of projecting ahead over the missing years and then cross-validating these forecasts against observations to assess the model’s prediction skill. A robust statistic for evaluating prediction skill is the Mean Absolute Scaled Error (MASE), which scales the mean absolute error of prediction residuals to a naïve baseline prediction, where a ‘prediction’ is said to have ‘skill’ if it improves the model forecast when compared to the naïve baseline (Kell *et al.* 2021). The MASE score scales the mean absolute error of the prediction residuals to the mean absolute error of a naïve in-sample prediction and a score of higher than one can be interpreted such that the average model forecasts are no better than a random walk. Conversely, a MASE score of 0.5 indicates that the model forecasts twice as accurately as a naïve baseline prediction; thus, the model has prediction skills.

3. Results and Discussion

The results of the MCMC convergence tests (Heidelberger and Welch 1992; Geweke 1992; Gelman and Rubin 1992) and the visual examination of trace plots show that the proposed reference case model has adequate convergence and a high level of model stability.

The model fit to each standardized CPUE indices are depicted in **Figures 3**, and appeared to fit CPUE data poorly, with RMSE estimates of 51.3% (**Figure 4**). Run tests conducted on the log-residuals indicated that the CPUE residuals may not be randomly distributed for six of the 11 indices: Japan_LL_hist, Japan_LL, CTP_LL_early, CTP_LL_late, VEN_GIL and VEN_Rec (**Figure 3**). This residual pattern suggests data-conflicts caused by CPUE indices’ opposite trends. Indeed, the CPUE data-conflicting situation was also noted in the latest assessment of the blue and white marlins in the Atlantic Ocean, with high RMSE values (>50%) and poor goodness-of-fit (Mourato *et al.* 2018; Mourato *et al.* 2020).

The process error plot deviates by year, indicating a stochastic pattern with a random trend along the time series when the central tendency (median signal) fluctuates around zero (**Figure 5**). The 95% Bayesian credibility interval (CIs) always included zero, which might be considered statistical evidence for a non-significant effect of any trend.

Marginal posterior distributions along with prior densities for the preliminary reference model are shown in **Figure 6**. The prior to posterior median ratio (PPMR) for r was close to 1, indicating that the posterior is heavily influenced by the prior. This was expected, given the low CVs that were estimated in the development of the priors (**Table A2**). On the other hand, the resulting small PPVRs observed in K indicate that the input data was more informative about K , which was expected, since the high CVs were applied in the development of these priors. The marginal posteriors for initial depletion (φ) present both PPMR and PPVR close to 1, which suggests that this parameter was largely informed by the priors.

Summaries of posterior quantiles for parameters and management quantities of interest are presented in **Table 1**. The trajectory of B/B_{MSY} showed a sharp decrease until the middle of the 1970s to an overfished status, followed by a decreasing trend until 2000. Since the early 2000s, the relative biomass has remained stable at levels below B_{MSY} until 2022. The F/F_{MSY} trajectory showed an increasing trend since the beginning of the time series, crossing F_{MSY} in the middle of the 1980s, followed by a decreasing trend after the 2000s, but always higher than F_{MSY} until the last year (**Figure 7**).

Figure 8 presents a retrospective analysis, which shows minimal retrospective deviations from the full models. Furthermore, **Table 2** depicts the Mohn's rho statistic computed for a five-year retrospective evaluation period. The estimated Mohn's rho for B and B/B_{MSY} fell within the acceptable range of -0.15 and 0.20 (Hurtado-Ferro *et al.* 2015; Carvalho *et al.* 2017) and consequently indicated that the retrospective pattern was negligible.

Hindcasting cross-validation results suggest that the Venezuelan artisanal drift-gillnet, last block of Japanese longline, Chinese Taipei, and US longline indices presented MASE scores around 1 or less, which might suggest these indices have no good prediction skills (**Figure 9**). Jackknife sensitivity analysis of the CPUE indices performed on the preliminary reference model showed that none of the indices had a major influence on stock status trajectories (**Figure 10**).

Individual Kobe biplot for the JABBA preliminary reference model showed a relatively anti-clockwise pattern with the stock status moving from underexploited through a period of unsustainable fishing to the overexploited phase since middle 1980s (**Figure 11**). The resulting stock status for 2022 showed a 69.4% posterior probability of an overfished state (red), 0% for a sustainable stock (green), and 30.6% (yellow) of the posterior pairs.

In conclusion, the results of this study provide evidence that the Atlantic blue marlin biomass remained below B_{MSY} in 2022. In addition, the fishing mortality rate in 2022 likely remained close to or above sustainable levels that would be required to achieve rebuilding to biomass levels at MSY in the short- to medium-term. However, it is important to highlight that there is considerable uncertainty in the estimated fishing mortality rate levels, mainly because of the lack of reliable discard data.

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Table 1. Summary of posterior quantiles presented in the form of marginal posterior medians and associated the 95% credibility intervals of parameters for the Bayesian state-space surplus production models for Atlantic blue marlin.

<i>Estimates</i>	<i>Median</i>	<i>2.5%</i>	<i>97.5%</i>
K	83601.88	57877.55	133430.2
r	0.114901	0.079365	0.165097
σ_{proc}	0.13	0.087	0.188
F_{MSY}	0.108	0.074	0.155
B_{MSY}	31772.44	21996.05	50709.41
MSY	3422.405	2652.884	4647.909
B_{1956}/K	0.986	0.758	1.236
B_{2022}/K	0.174	0.097	0.272
B_{2022}/B_{MSY}	0.459	0.256	0.717
F_{2022}/F_{MSY}	1.12	0.729	1.76

Table 2. Summary of models Mohn's rho statistic computed for a retrospective evaluation period of five years. The larger the threshold the stronger is the retrospective bias.

<i>B</i>	<i>F</i>	<i>B/B_{MSY}</i>	<i>F/F_{MSY}</i>	<i>MSY</i>
-0.00369	0.005484	0.006092	0.003329	-0.0114

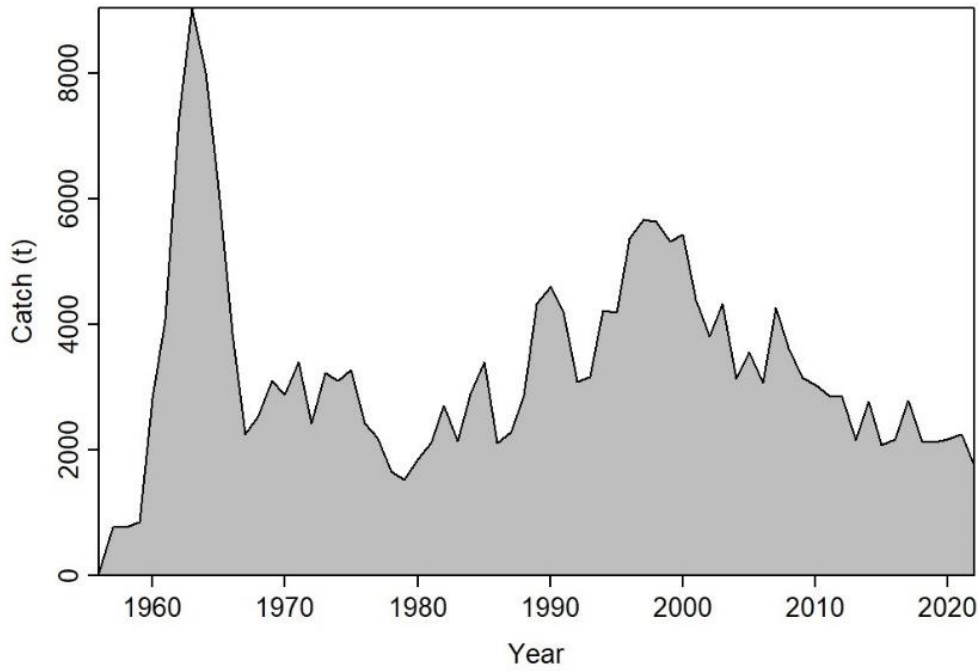


Figure 1. Available catch times series in metric tons (t) for Atlantic blue marlin for 1956 - 2022.

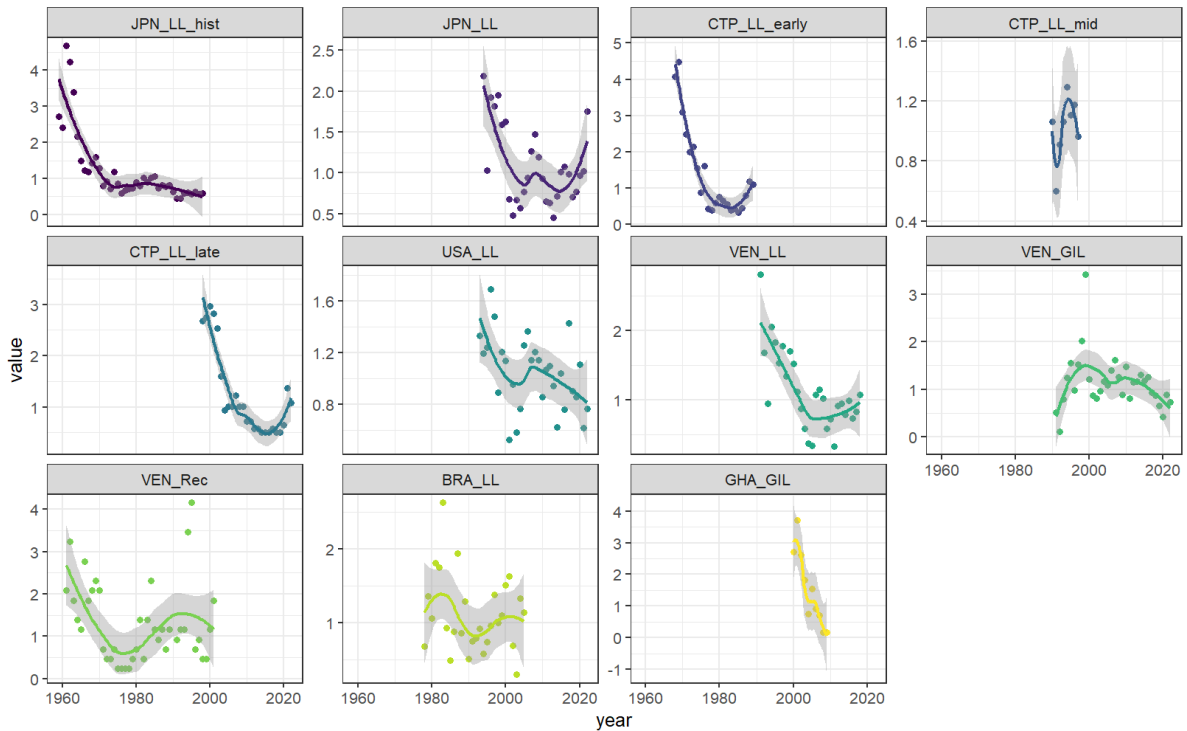


Figure 2. Available standardized CPUE series for Atlantic blue marlin assessment. Points are the observed value; Lines and grey shaded areas represent the results of smoothing regression analysis.

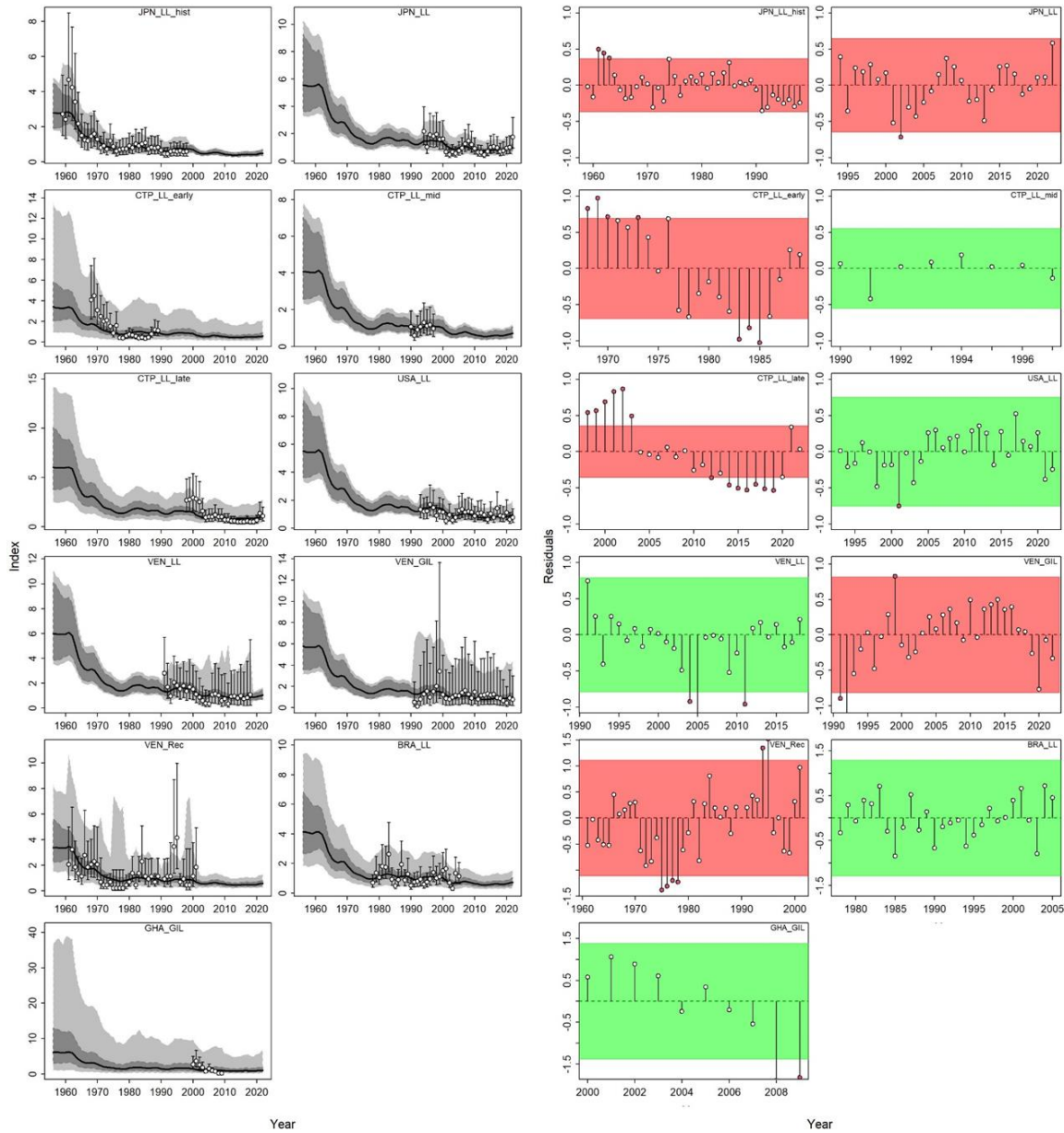


Figure 3. Left panel: Time-series of observed (circle) and predicted (solid line) CPUE of Atlantic blue marlin for the JABBA preliminary reference model. The dark-shaded grey areas show 95% credibility intervals of the expected mean CPUE, and the light-shaded grey area denote the 95% posterior predictive distribution intervals. Right panel: Runs tests to evaluate the randomness of the time series of CPUE residuals by fleet. 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).

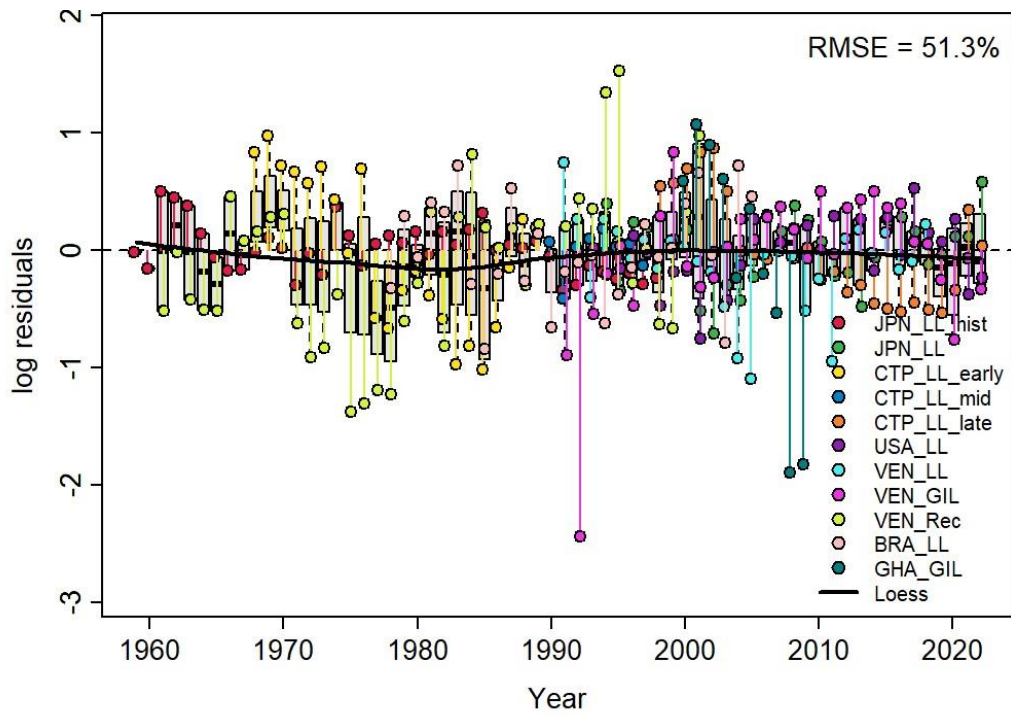


Figure 4. JABBA residual diagnostic plots for the CPUE indices used in the Atlantic blue marlin preliminary reference model. Boxplots indicate the median and quantiles of all residuals available for any given year, and solid black lines indicate loess smoother through all residuals.

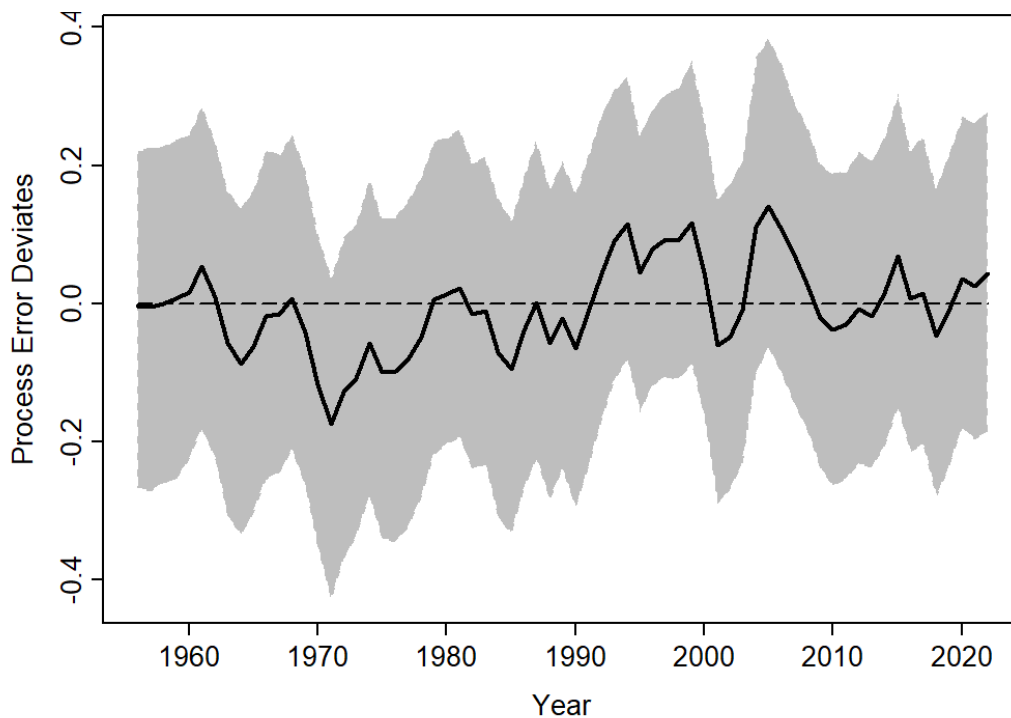


Figure 5. Process error deviates (median: solid line) for the Atlantic blue marlin preliminary reference model using the Bayesian state-space surplus production model JABBA. The shaded grey area indicates 95% credibility intervals.

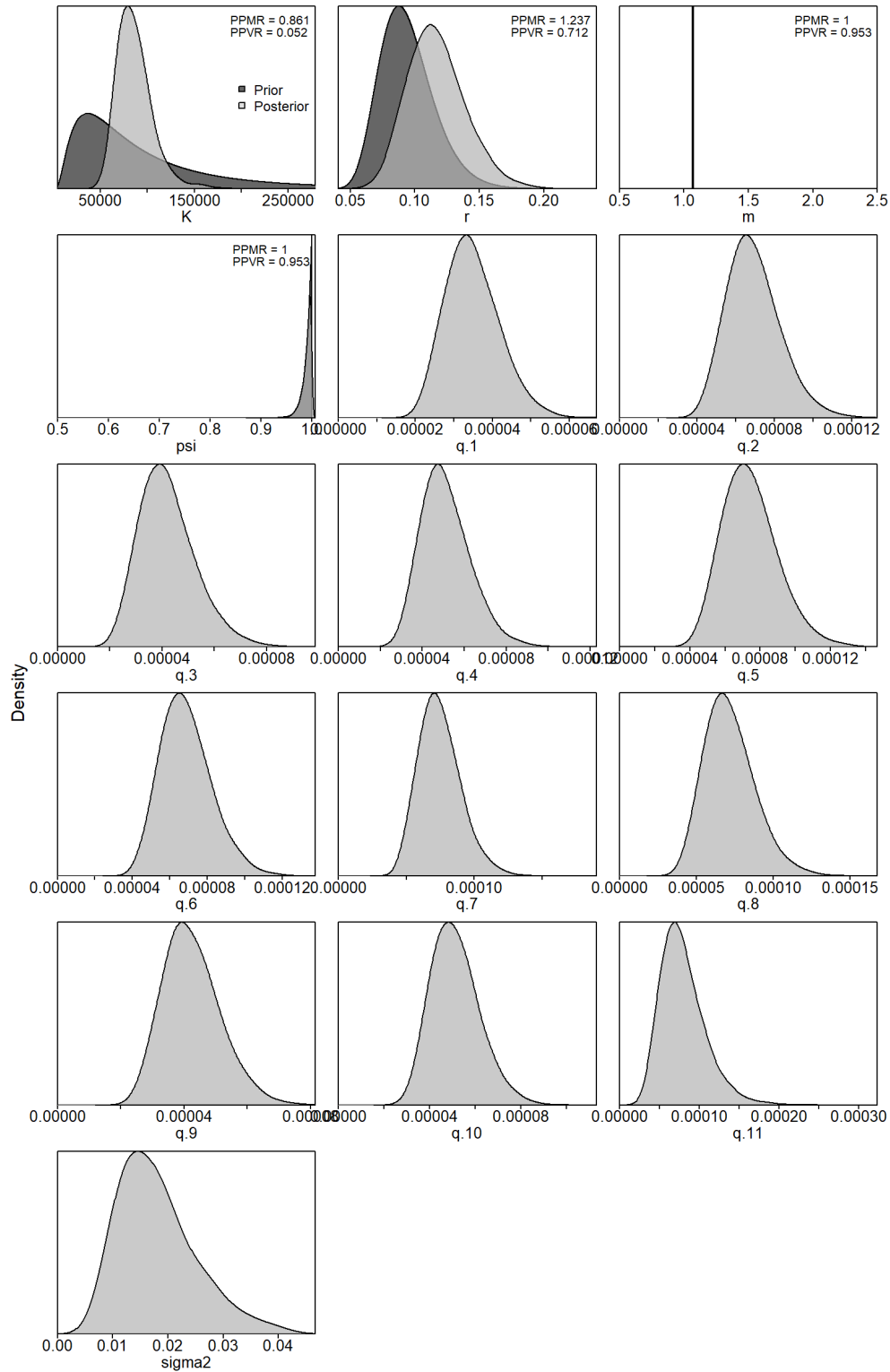


Figure 6. Prior and posterior distributions of various model and management parameters for the Bayesian state-space surplus production model (JABBA) for the Atlantic blue marlin preliminary reference model. PPMR: Posterior to Prior Ratio of Means; PPVR: Posterior to Prior Ratio of Variances.

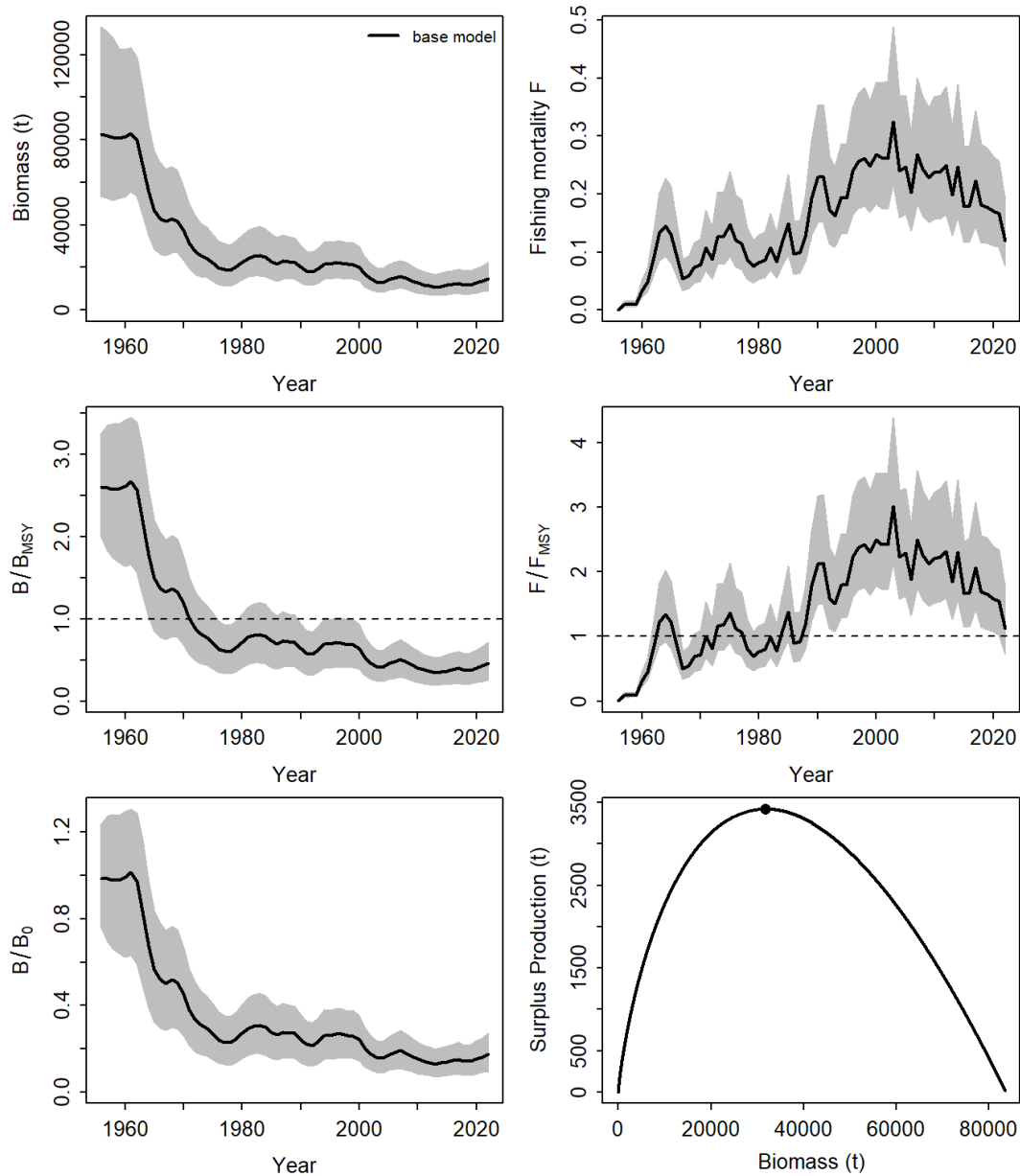


Figure 7. Biomass, fishing mortality (upper panels), biomass relative to B_{MSY} (B/B_{MSY}), fishing mortality relative to F_{MSY} (F/F_{MSY}) (middle panels), biomass relative to K (B/B_0) and surplus production curve (bottom panels) for the Atlantic blue marlin JABBA preliminary reference model.

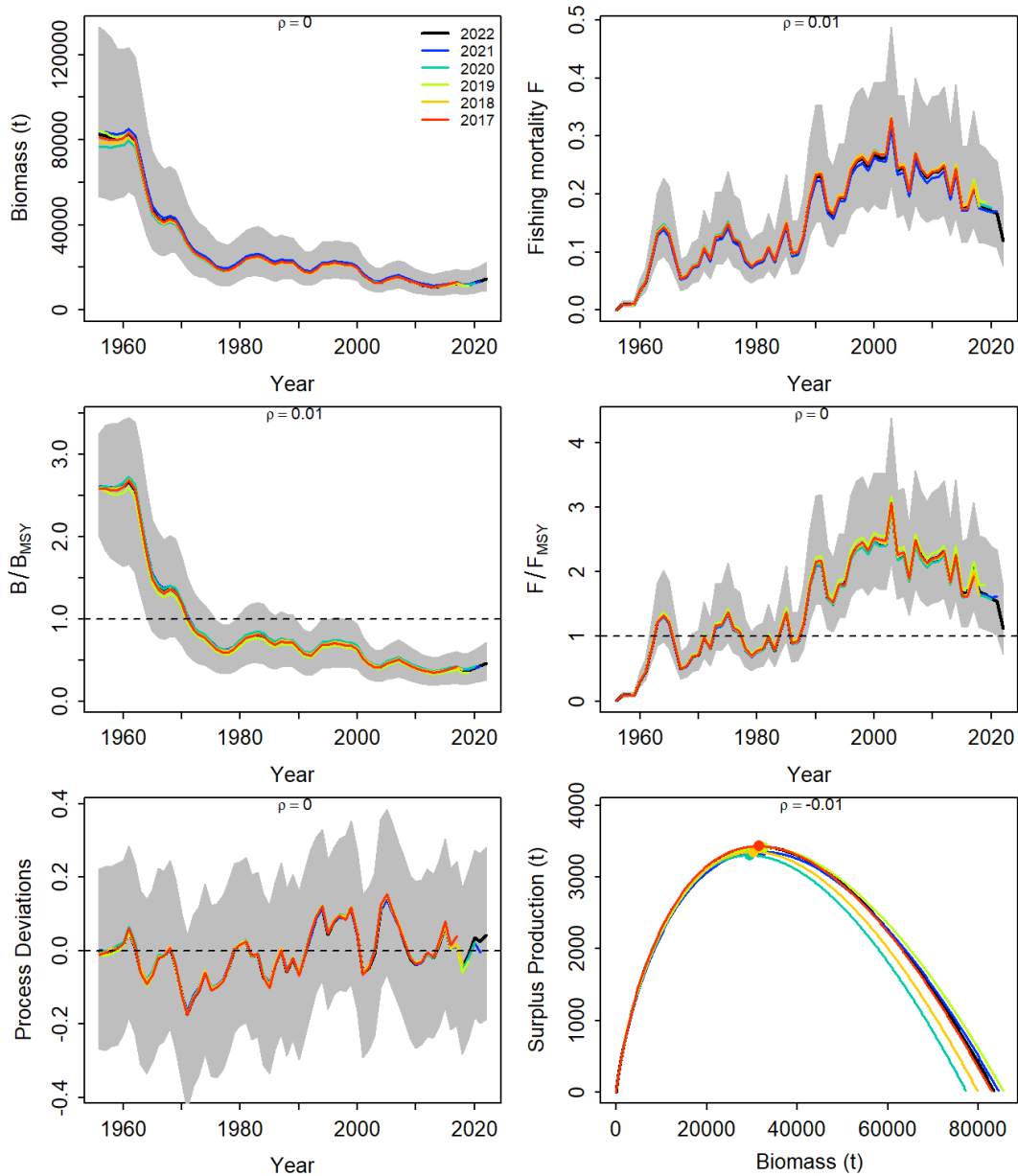


Figure 8. Retrospective analysis performed on the JABBA preliminary reference model for the Atlantic blue marlin by removing one year at a time sequentially ($n=5$) and predicting the trends in biomass and fishing mortality (upper panels), biomass relative to B_{MSY} (B/B_{MSY}) and fishing mortality relative to F_{MSY} (F/F_{MSY}) (middle panels) and biomass relative to K (B/K) and surplus production curve (bottom panels).

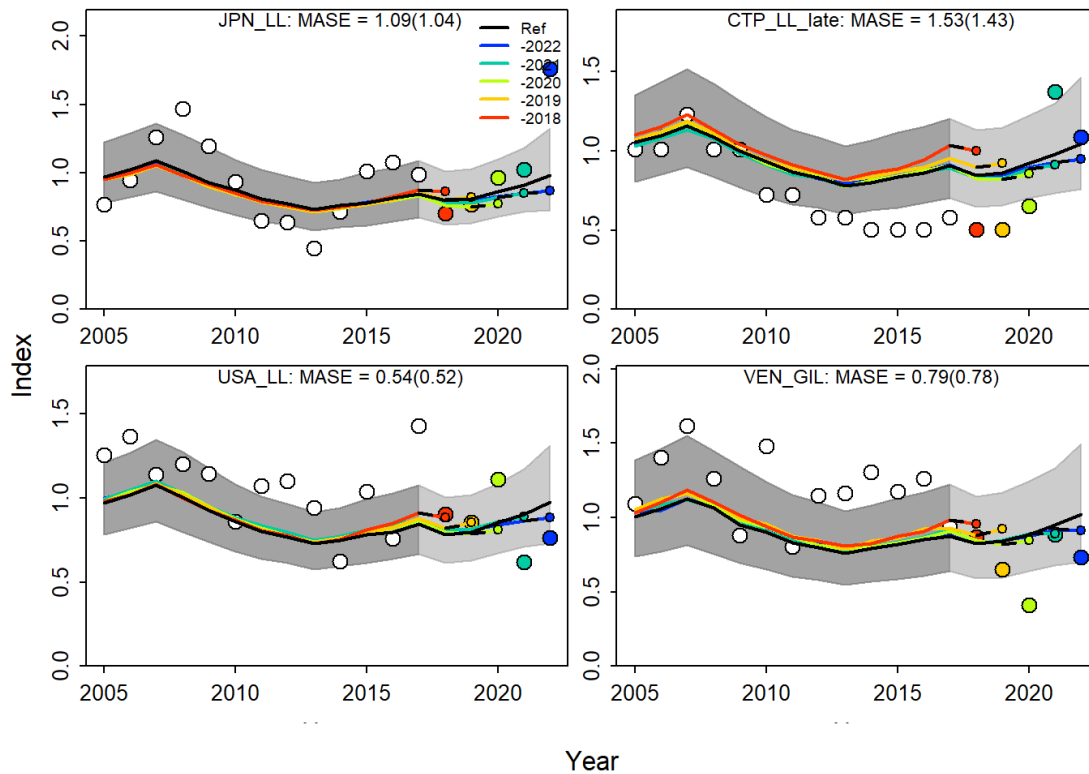


Figure 9. Hindcasting cross-validation results for the JABBA preliminary reference model for the Atlantic blue marlin, showing one-year-ahead forecasts of CPUE values (2018-2022), performed with five hindcast model runs relative to the expected CPUE. The CPUE observations, used for cross-validation, are highlighted as color-coded solid circles with associated light-grey shaded 95% confidence interval. The model reference year refers to the endpoints of each one-year-ahead forecast and the corresponding observation (i.e., year of peel + 1).

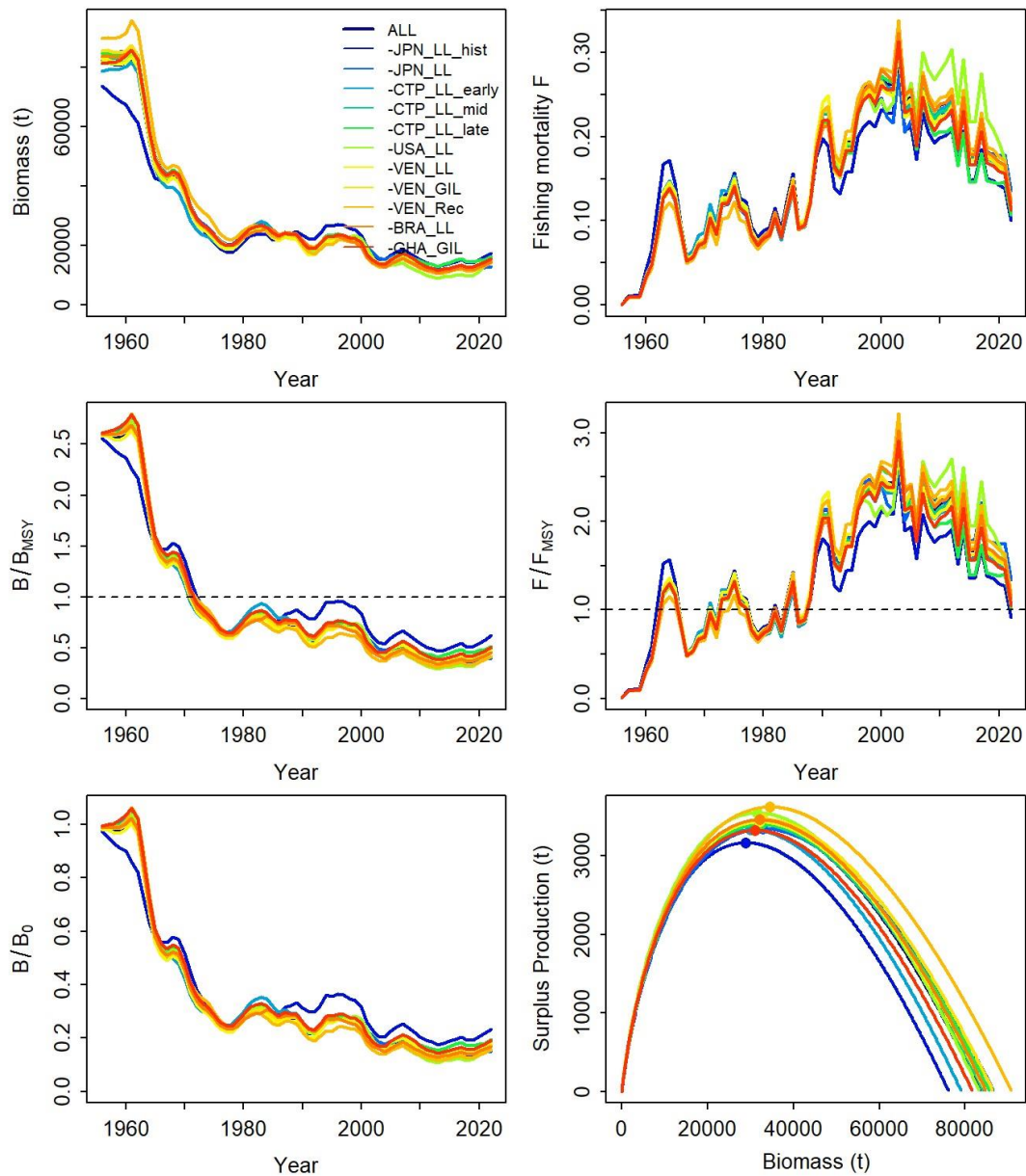


Figure 10. Jackknife index analysis performed to the JABBA preliminary reference model for the Atlantic blue marlin assessment by removing one CPUE fleet at a time and predicting the trends in biomass and fishing mortality (upper panels), biomass relative to B_{MSY} (B/B_{MSY}) and fishing mortality relative to F_{MSY} (F/F_{MSY}) (middle panels) and biomass relative to K (B/B_0) and surplus production curve (bottom panels).

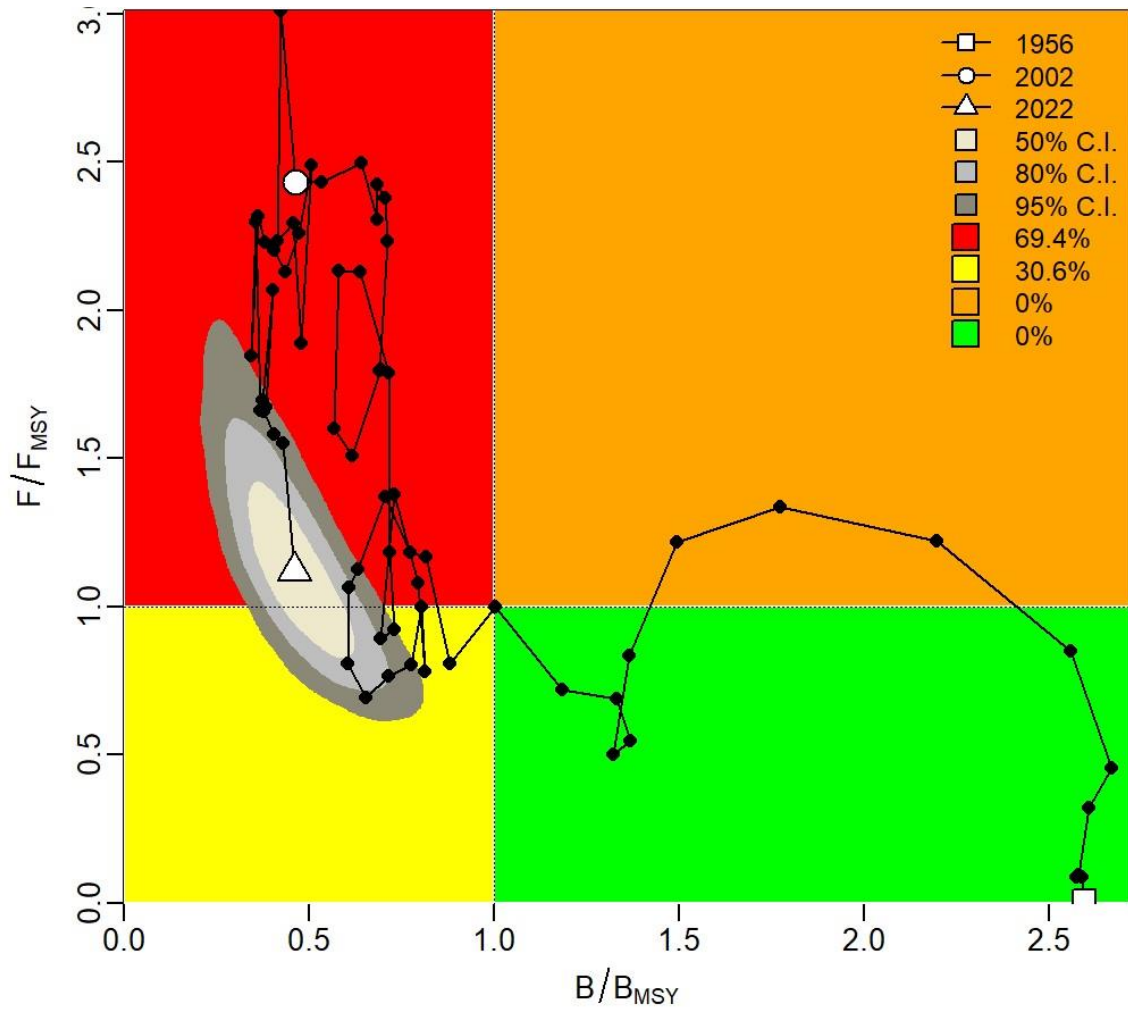


Figure 11. Kobe phase plot showing estimated trajectories (19576-2022) of B/B_{MSY} and F/F_{MSY} for the Atlantic blue marlin JABBA preliminary reference model. Different grey-shaded areas denote the 50%, 80%, and 95% credibility interval for the terminal assessment year. The probability of terminal year points falling within each quadrant is indicated in the figure legend.

Appendix A

Table A1. Life history parameters used to estimate r prior distributions and median shape parameter with corresponding B_{MSY}/K values of the Atlantic blue marlin assessment. The priors are generated using an Age-Structured Equilibrium Model (ASEM).

Sex	<i>prior_Otolith</i>		<i>prior_Spine</i>		<i>prior_SS</i>	
	Female	Male	Female	Male	Female	Male
<i>Linf (cm)</i>	279.99		302.20	209.60	327.02	209.02
<i>k</i>	0.427		0.052	0.222	0.096	0.108
<i>t₀</i>	-1.78		-15.10	-6.50	-7.81	-13.86
<i>L₅₀ (cm)</i>	206		206		206	
<i>M</i>	0.148		0.148		0.148	
<i>t_{max} (y)</i>	42		42		42	
<i>Steepness</i>	0.5		0.5		0.5	
<i>a (length-weigh)</i>	1.90e-06	2.47e-06	1.90e-06	2.47e-06	1.90e-06	2.47e-06
<i>b (length-weigh)</i>	3.2842	3.2243	3.2842	3.2243	3.2842	3.2243
<i>mean r</i>	0.092		0.078		0.075	
<i>sd of log (r)</i>	0.222		0.247		0.276	
<i>B_{MSY}/K</i>	0.38		0.43		0.41	
<i>shape m</i>	1.1		1.42		1.08	

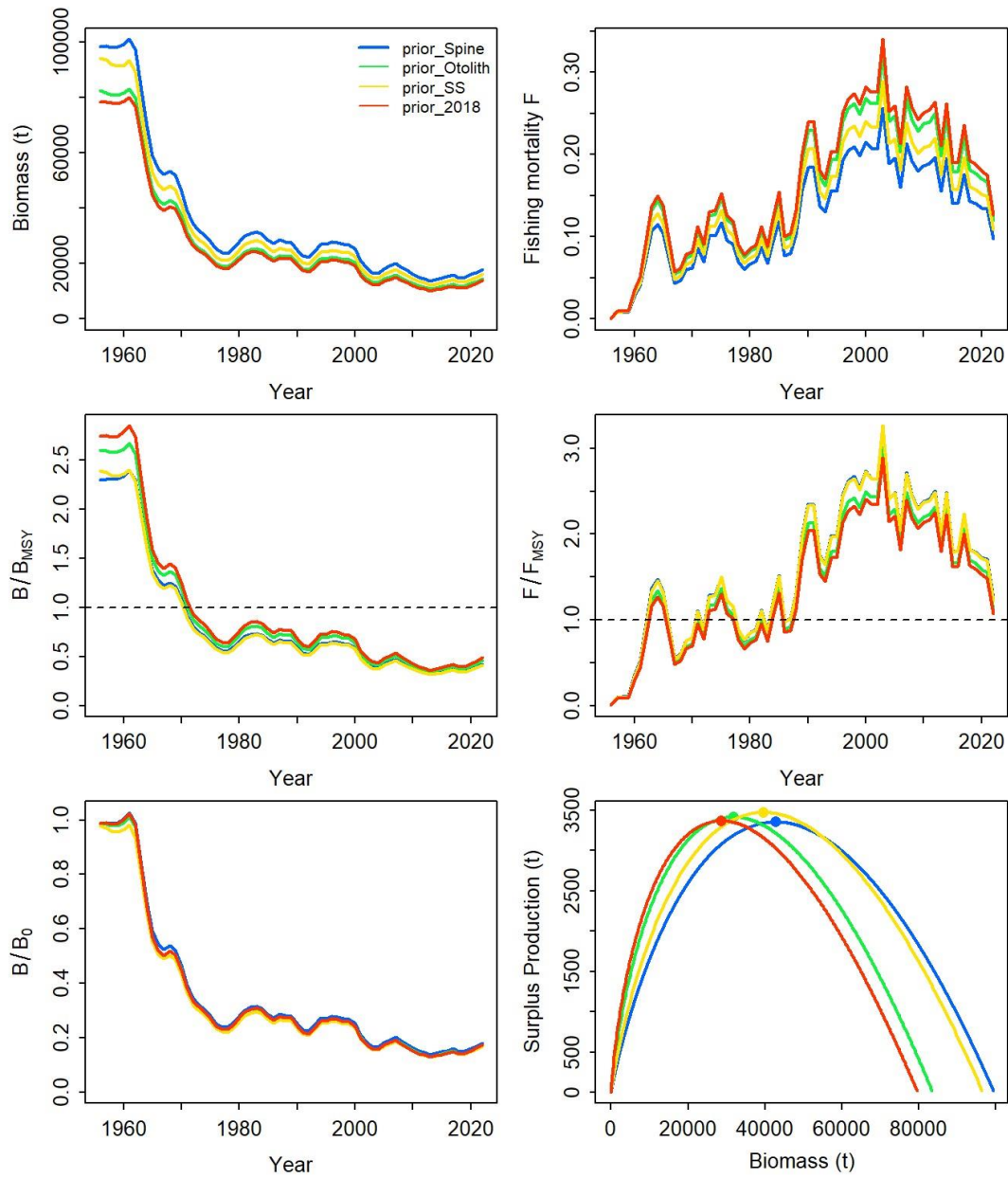


Figure A1. Comparison of biomass, fishing mortality (upper panels), biomass relative to K (B/K) and surplus production curve (middle panels), and biomass relative to B_{MSY} (B/B_{MSY}) and fishing mortality relative to F_{MSY} (F/F_{MSY}) (middle panels) and biomass relative to K (B/K) and surplus production curve (bottom panels) among four r prior JABBA for Atlantic blue marlin assessment estimated based on the growth uncertainty grid.

Table A2. Results for r prior distributions and median shape parameter with corresponding B_{MSY}/K values generated an Age-Structured Equilibrium Model (ASEM) based on the steepness uncertainty grid.

Steepness	0.4	0.5	0.7
mean r	0.076	0.092	0.112
sd of $\log(r)$	0.217	0.222	0.228
B_{MSY}/K	0.42	0.38	0.33
shape m	1.29	1.1	0.8

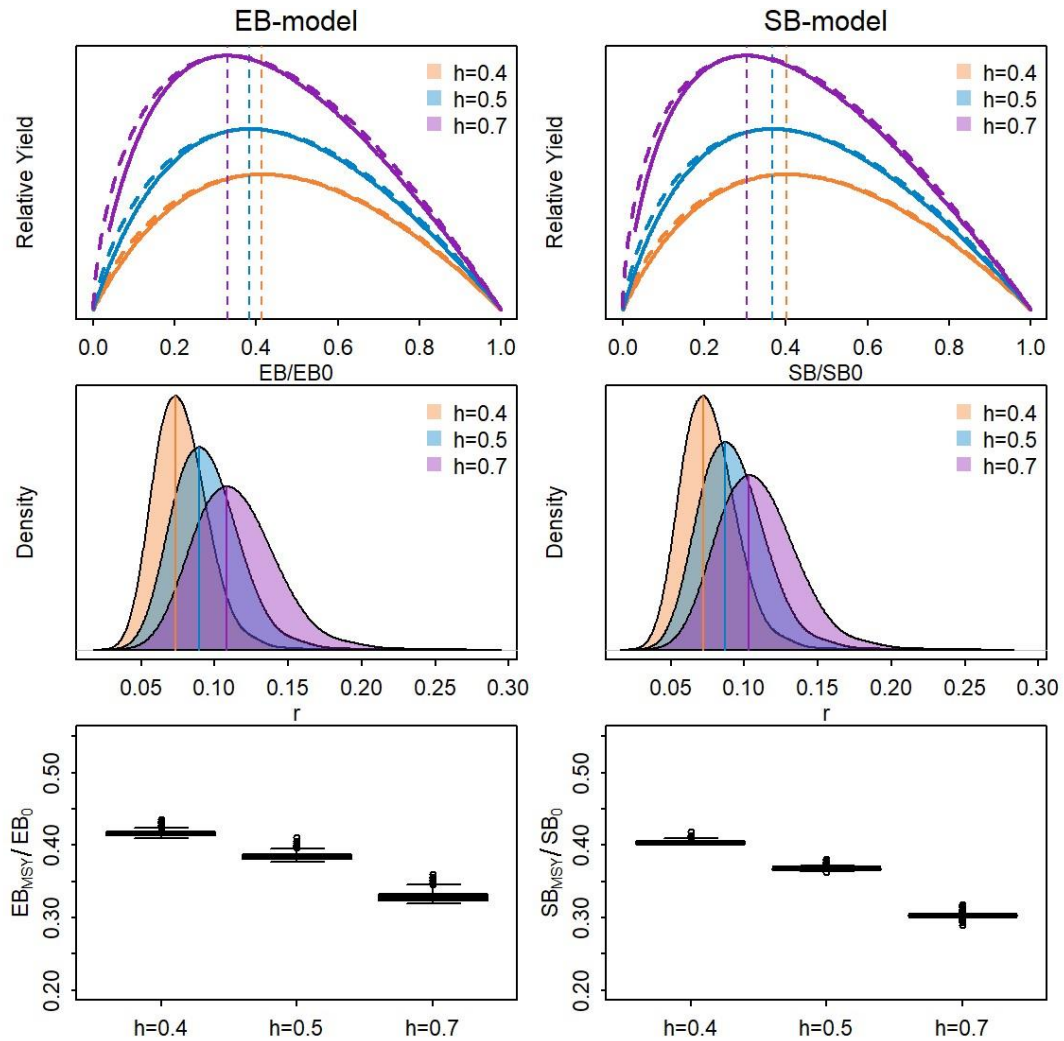


Figure A2. (Top Panel) Showing the functional form of the yield curves produced from the Age-Structured Equilibrium Model (ASEM; solid line) and the JABBA formulation of the Surplus Production function (dashed line) as a function of EB/EB_0 and SB/SB_0 for a range of fixed steepness values of the spawning recruitment relationship ($h = 0.4$, $h = 0.5$, $h = 0.7$) (top panel); (Middle Panel) density distributions of simulated r values from Monte-Carlo simulations; and (Lower Panel) boxplot generated inflection points of EB_{MSY}/EB_0 and SB_{MSY}/SB_0 for each of the fixed steepness input values.

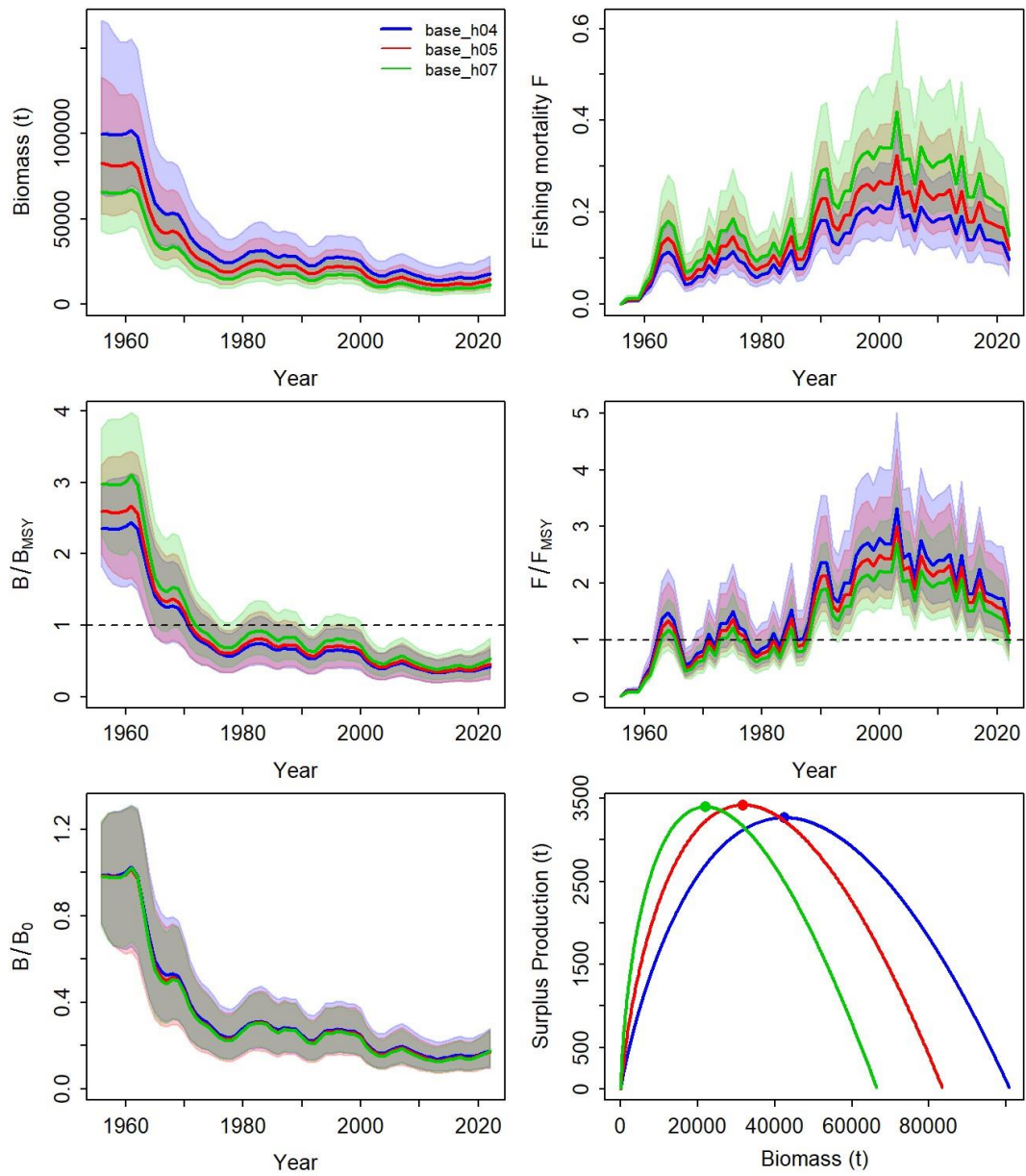


Figure A3. Comparison of biomass, fishing mortality (upper panels), biomass relative to K (B/K) and surplus production curve (middle panels), and biomass relative to B_{MSY} (B/B_{MSY}) and fishing mortality relative to F_{MSY} (F/F_{MSY}) (middle panels) and biomass relative to K (B/K) and surplus production curve (bottom panels) among three r prior JABBA for Atlantic blue marlin assessment estimated based on the steepness uncertainty grid.

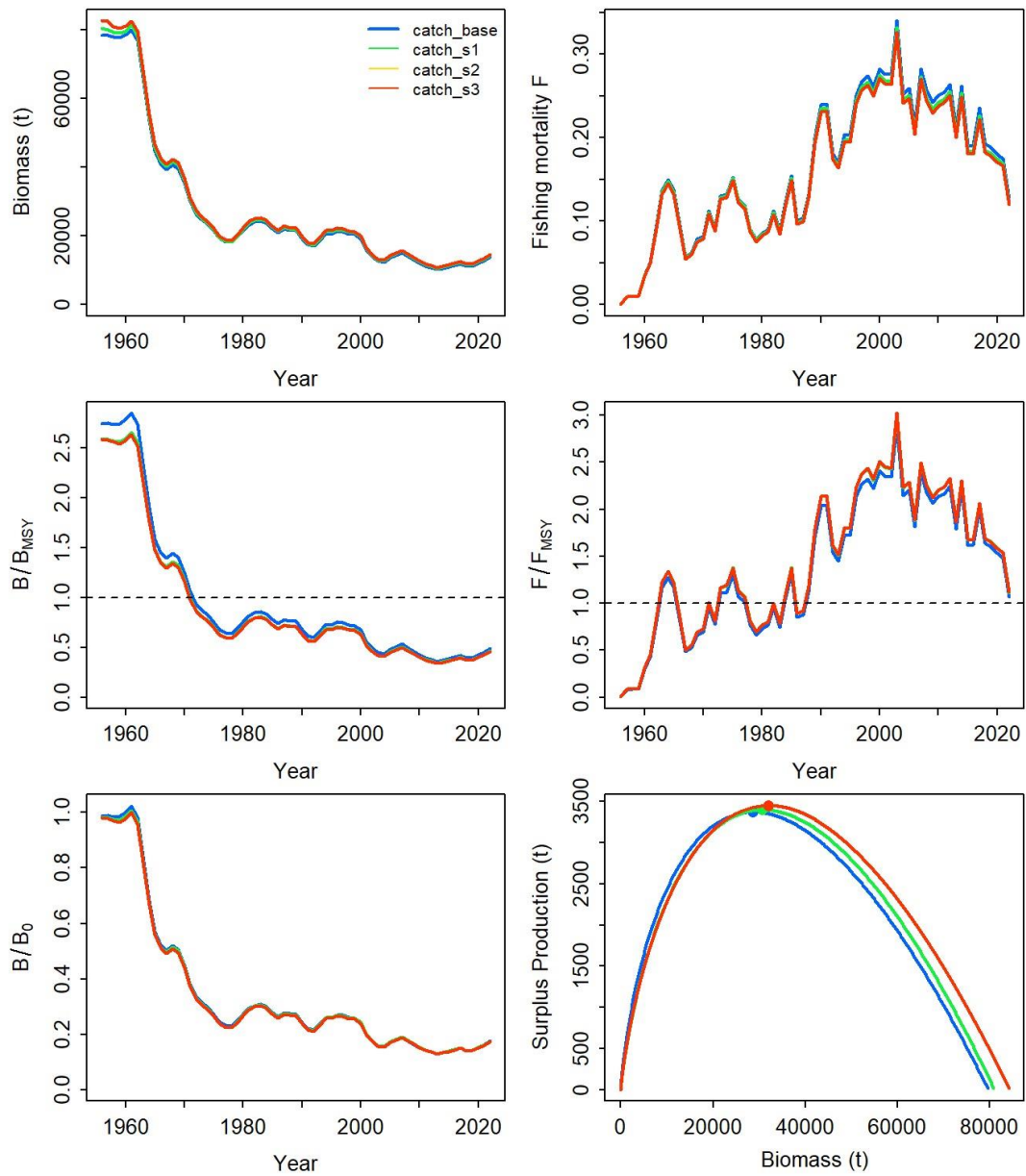


Figure A4. Comparison of biomass, fishing mortality (upper panels), biomass relative to K (B/K) and surplus production curve (middle panels), and biomass relative to B_{MSY} (B/B_{MSY}) and fishing mortality relative to F_{MSY} (F/F_{MSY}) (middle panels) and biomass relative to K (B/K) and surplus production curve (bottom panels) among four r prior JABBA for Atlantic blue marlin assessment estimated based on the catch uncertainty grid.