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DEVELOPING OF BAYESIAN STATE-SPACE SURPLUS PRODUCTION MODEL *JABBA* FOR ASSESSING ATLANTIC WHITE MARLIN (*Kajikia albida*) STOCK

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SUMMARY

Bayesian State-Space Surplus Production Models were fitted to Atlantic blue marlin (Kajikia albida*) catch and CPUE data using the open-source stock assessment tool JABBA. The three scenarios (S1- sensitivity run 1, S2- sensitivity run 2 and S3 – base case model) were based on sensitivity analysis of the initial runs, which corresponded to a 'steepness-specific' of h = 0.6 with an associated lognormal r prior of log(r) ~ N(log(0.181),0.180) and a fixed input value of* $B_{MSY}/K = 0.39$*. The results for the three alternative scenarios estimated MSY between 1,535 to 1,646 tons. Stock status trajectories showed a typical anti-clockwise pattern, moving from initially underexploited through a period of unsustainable fishing, leading to a > 95% probability of stock biomass in 2017 being below levels that can produce MSY. The 2017 fishing mortality rate estimates were below to the sustainable exploitation levels (base case* $F_{2017}/F_{MSY} = 0.606$*) that would be required to achieve rebuilding to biomass levels at MSY in the short- to medium term. Based on multi-model inference from all three scenarios, there is a 99.5% probability that the stock remains overfished and a 98.5% probability that overfishing is still occurring. Our results, therefore, provides consistent evidence for classifying the Atlantic white marlin stock status in general as "rebuilding".*

RÉSUMÉ

*Les modèles de production excédentaire état-espace de type bayésien ont été ajustés aux données de capture et de CPUE du makaire bleu de l'Atlantique (*Kajikia albida*) à l'aide de l'outil d'évaluation des stocks open source JABBA. Les trois scénarios (S1- scénario de sensibilité 1, S2- scénario de sensibilité 2 et S3 - cas de base du modèle) étaient basés sur l'analyse de sensibilité des scénarios initiaux, qui correspondaient à une steepness spécifique de h = 0,6 avec un prior lognormal r associé de log(r) ~ N(log(0,181),0,180) et une valeur d'entrée fixe de* $B_{PME}/K = 0{,}39$*. Les résultats pour les trois scénarios alternatifs ont estimé la PME entre 1.535 et 1.646 t. Les trajectoires de l'état des stocks ont montré une tendance typique dans le sens inverse des aiguilles d'une montre, passant d'une sous-exploitation initiale à une période de pêche non durable, conduisant à une probabilité > 95 % que la biomasse des stocks en 2017 soit inférieure aux niveaux qui peuvent produire la PME. Les estimations du taux de mortalité par pêche pour 2017 étaient inférieures aux niveaux d'exploitation durable (cas de base* $F_{2017}/F_{PME} = 0{,}606$*) qui seraient nécessaires pour permettre le rétablissement à des niveaux de biomasse à la PME à court et moyen terme. D'après l'inférence multi-modèles des trois scénarios, il y a une probabilité de 99,5 % que le stock demeure surexploité et une probabilité de 98,5 % que la surpêche se poursuive. Nos résultats fournissent donc des preuves cohérentes pour classer le stock de makaire blanc de l'Atlantique en général dans la catégorie « en voie de rétablissement ».*

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RESUMEN

Los modelos de producción excedente estado-espacio bayesianos se ajustaron a los datos de CPUE y de captura de aguja blanca del Atlántico (Kajikia albida)utilizando una herramienta de evaluación de stock de fuente abierta JABBA. Los tres escenarios (S1 -ensayo de sensibilidad 1; S2-ensayo de sensibilidad 2 y S3 -caso base del modelo) se basaron en análisis de sensibilidad de los ensayos iniciales que correspondieron a una «inclinación específica» de h=0,6 con una distribución a priori lognormal de r asociada de log(r) ~ N(log(0,181),0,180) y un valor de entrada fijo de BRMS/K = 0,39. Los resultados de los tres escenarios alternativos estimaron un RMS que osciló entre 1.535 y 1.646 t. Las trayectorias del estado del stock mostraban un típico patrón contrario a las agujas del reloj, moviéndose desde subexplotado hasta un periodo de pesca insostenible, que conducía a una probabilidad > 95% de que la biomasa del stock en 2017 se sitúe por debajo de los niveles que permiten el RMS. Las tasas de mortalidad por pesca estimadas de 2017 se situaban en un nivel inferior a los niveles de explotación sostenible (caso base F2017/FRMS = 0,606) que se requerirían para conseguir la recuperación de los niveles de biomasa hasta niveles en RMS a corto medio plazo, Basándose en la inferencia del multi modelo a partir de los tres escenarios, hay una probabilidad del 99,5% de que el stock permanezca sobrepescado y una probabilidad del 98,5% de que se esté produciendo todavía sobrepesca. Por tanto nuestros resultados proporciona una evidencia coherente para poder clasificar el estado del stock de aguja blanca en general como «recuperándose».

KEYWORDS

Billfish, stock status, CPUE fits, biomass dynamic model, Pella-Tomlinson surplus production function

1. Introduction

The latest stock assessment for the Atlantic white marlin (*Kajikia albida*) was carried out by the International Commission for the Conservation of Atlantic Tunas (ICCAT) in 2012. Two modeling approaches were used to estimate the stock status: (i) a non-equilibrium surplus production model ASPIC (Prager, 2002) and (ii) the integrated Stock Synthesis model (Methot and Wetzel, 2013). Results from both models indicated that the stock was overfished but most likely was not undergoing overfishing at the time (ICCAT, 2012). Management benchmarks resulting from two alternative ASPIC model scenarios estimated that B_{2010}/B_{MSY} was 0.50 (0.42-0.60, 10th and 90th percentiles) and F_{2010}/F_{MSY} was 0.99 (0.75-1.27, 10th and 90th percentiles). For the Stock Synthesis model these management reference points were 0.32 for SSB_{2010}/SSB_{MSY} with 95% confidence intervals of 0.23 to 0.41, and 0.75 for F_{2009}/F_{MSY} with 95% confidence intervals of 0.51 to 0.93 and thus notably more pessimistic. Despite the status of the white marlin stock being characterized as overfished, ICCAT recognized the high uncertainty in the stock assessment results, mainly due to uncertainty in input data (e.g. total catch) and lack of life history information (*e.g.* age and growth parameters), which makes the estimation of productivity of the stock more uncertain.

To assist with the 2019 Atlantic white marlin stock assessment, we developed a JABBA model (Winker et al., 2018a), using updated catch and CPUE time series through 2017. JABBA is a Bayesian State Space Surplus Production Model that has been formally included in the ICCAT stock catalogue (https://github.com/ICCAT/software/wiki/2.8-JABBA). In this document we present the preliminary results of the JABBA model runs, which include estimates of key model parameters, trends in population abundance and fishing mortality, as well as model diagnostics.

2. Material and Methods

2.1. Fishery data

The ICCAT secretariat estimates catch for many fleets and nations based on the best information available. For this stock assessment, total catch from 1956-2017 were obtained from the analysis carried out during the data preparatory meeting in March 2019 (ICCAT, 2019) and includes reported landings and dead discards (**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. The standardized CPUE series covering the majority of the fishing fleets operating in the Atlantic Ocean, including longline (LL), recreational (Rec) and artisanal drift gillnet (Gil) fisheries. For the 2019 stock assessment, 14 standardized CPUE series were made available, they are from: Japan (LL), United States (LL & Rec), Venezuela (LL & Gil) Taiwan (LL), Brazil (LL & Rec) and Spain (LL) (**Figure 2**).

2.2. JABBA stock assessment model fitting procedures

This stock assessment uses the most updated version (v1.5 Beta) of JABBA and can be found online at: www.github.com/henning-winker/JABBAbeta. 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 unfished equilibrium biomass K, we assumed a vaguely informative lognormal prior with a mean of 25,000 mt and a large CV of 200%. Initial depletion lognormal prior ($\varphi = B_{1959}/K$; for details see Winker et al., 2018a) was inputted with mean = 1 and CV of 25% (*c.f.* Mourato et al., 2018). All catchability parameters were formulated as uninformative uniform priors, while the observation variance was implemented by assuming inverse-gamma priors. 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 setting at 0.001 (for details see Winker et al., 2018a).

Initial trials considered three alternative specifications of the Pella-Tomlinson model type based on different three sets of r priors and fixed input values of B_{MSY}/K. The input r priors were objectively derived from age-structured model simulations (see details in Winker et al. 2019 and Winker et al., 2018b), which allowed approximating the parameterizations considered for the Stock Synthesis model based on range of stock recruitment steepness values for the stock-recruitment relationship (h = 0.5, h = 0.6 and h = 0.7), while admitting reasonable uncertainty about the natural mortality M (CV of 30% and the central value mean value of 0.2). Based on sensitivity analysis of the initial runs, including the three 'steepness-specific' r input priors (results not shown here), the following three specific scenarios were considered, which corresponded to steepness reference case of h = 0.6 with an associated lognormal r prior of $\log(r) \sim N(\log(0.181),0.180)$ and a fixed input value of $B_{MSY}/K = 0.39$:

- ✓ **S1**: sensitivity run 1; included 13 CPUEs (excluding only Spanish longline index);
- ✓ **S2**: sensitivity run 2; included all 14 CPUEs, and;
- ✓ **S3**: base case; same setting as S1 but removed data for 1959-1961 in early Japanese longline index

To evaluate CPUE fits, the model predicted CPUE indices were compared to the observed CPUE. JABBA-residual plots were also examined, and the randomness of model residuals was evaluated by means of the Root-Mean-Squared-Error (RMSE). Also, to verify systematic bias in the estimation of B or F, we also performed a retrospective analysis for each scenario, by removing one year of data at a time sequentially (n=8) and predicting the stock status in the form of B/B_{MSY} and F/F_{MSY} trajectories one year ahead.

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, two MCMC chains were used. The models were run for 30,000 iterations, sampled with a burn-in period of 5,000 for each chain. Basic diagnostics of model convergence included visualization of the MCMC chains throughout trace-plots.

3. Results

For all scenarios the visual inspection of trace plots (results not shown here) of the key model parameters showed good mixing of the two chains (*i.e.*, moving around the parameter space). This is also an indicative of convergence of the MCMC chains and that the posterior distribution of the model parameters was adequately sampled with the MCMC simulations. JABBA-residual plots showed that the exclusion of Spanish longline index improved model fit by reducing RMSE from 58% to around 53% (S1). Also, the exclusion of the first three years of early Japanese longline index showed a slight decrease in RMSE (**Figure 3**), and it estimated the initial biomass ratio (1956) to a more reasonable estimate (0.86) compared to initial runs. The longline fleets from Spain, Taiwan and Brazil seems to be the most influential and exhibited the highest discrepancies between CPUE series and model predictions. The predicted CPUE indices fits were compared to the observed CPUE for each scenario (**Figure 4, 5** and **6**). The model fits for white marlin CPUEs indicated that there was a lack of fit from longline fisheries of Chinese Taipei and Brazil, in the third time block period (2001-2017) of Japanese fleet, and US recreational fishery. Plots of process error deviates by year indicated that models presented a similar stochastic pattern with a pronounced negative trend after middle 90's (**Figure 7**).

Posterior densities along with prior densities are shown in **Figures 8-10** and summaries of posterior quantiles for parameters and management quantities of interest are presented in **Table 1**. The median of marginal posterior for *r* varied between 0.163 and 0.17 among scenarios. When comparing posterior and prior distributions for *r*, all scenarios produced similar results, indicating a good agreement and overlapping between the density distributions. The median of marginal posterior for *K* varied between 26,230 metric tons (sensitivity run S1) and 29,249 metric tons (base case scenario S3) **(Table 1**). It was also noted that posterior distributions for *K* was narrower in comparison to their priors, which indicates that the input data was very informative about *K* for all fitted models (**Figures 8-10)**. The marginal posteriors for initial depletion (φ) were similar for all scenarios, with median estimates varying from 0.734 to 0.862 (**Table 1**). Estimates of *MSY* showed little variation across model runs, ranging from 1,535 to 1,646 metric tons among all three scenarios **(Table 1**). The marginal posterior median for B_{MSY} varied between 10,232 metric tons (sensitivity run S1) and 11,409 metric tons (base case scenario S3) (**Figures 8-10**). As expected, the F_{MSY} median estimates were very similar (close to 0.15) among scenarios **(Table 1**).

In general, all scenarios presented similar trends for the medians of B/B_{MSY} and F/F_{MSY} over time (**Figure 11**). The trajectory of $\mathrm{B/B_{MSY}}$ showed a sharp decrease in the mid-1970s to an overfished status followed by a continuing decreasing trend until 2000. Since the early 2000s the relative biomass showed a slight recovery but remained at levels below $\mathrm{B_{MSY}}$ to the end of the time series (base case $B_{2017}/B_{MSY} = 0.463$). The F/F_{MSY} trajectory showed an overall increasing trend from the beginning of the time series until mid-1990s, followed by a decreasing trend after 2000s with no overfishing (base case $F_{2017}/F_{MSY} = 0.606$) in recent years (**Figure 11**). The slow rebuilding in the biomass estimated in recent years is explained by the fact that fishing mortality remained above F_{MSY} until 2011 and partially because of the persistent decline in the process error since 1995. A retrospective analysis for eight years was also presented, which showed no evidence of strong retrospective patterns and was very consistent among scenarios in terms of similar stock status (F/F_{MSY}; B/B_{MSY}) and *MSY* (**Figures 12-14**).

Kobe biplots for all scenarios revealed similar trends among the fitted models, showing a relatively anti-clockwise pattern with the stock status moving from underexploited through a period of unsustainable fishing to the overexploited phase since middle 1970s (**Figure 15** and **16**). The resulting stock status posteriors for 2017 were generally consistent and predicted with high probabilities that current fishing levels are sufficiently low to facilitate rebuilding ($F < F_{MSY}$), whereas biomass remains below sustainable levels that can produce *MSY* ($B < B_{MSY}$). While there was constancy in characterizing the stock as rebuilding (yellow area), there were slightly differences between base case model (S3) and the other scenarios, with the former predicting a slight increased probability of around 3% (**Figure 15**) for a unsustainable fishing (red) compared to just 0.5-1.2% for S1 and S2 (**Figure 16**). Finally, a Kobe phase plot is presented to provide multi-model inference based on combined of all three scenarios (**Figure 17**), which predicts with 98.5% probability that the stock is not currently subject of overfishing but also a 99.5% probability that stock remains below biomass level that can produce *MSY*. This, therefore, provides consistent evidence for classifying the stock status in general as “rebuilding”.

4. Discussion

Our results of the three presented JABBA scenarios for Atlantic white marlin are consistent with the 2012 Stock Synthesis model (ICCAT, 2012). The results suggest that the stock’s biomass remains well below the sustainable biomass target ($B < B_{MSY}$), while fishing mortality was estimated to be sufficiently low to facilitate rebuilding to biomass levels at *MSY*. The similar posterior densities of *r* across the scenarios, seems to indicate that the observed data might hold information about the stock’s productivity. However, it is important to note that there is considerable lack of basic life history information for the Atlantic white marlin (e.g. growth parameters) which makes it even more important to admit uncertainty about the stock’s productivity (see details in Winker et al. 2019). Initial runs (not shown here) explored the impact of fixing the shape parameter of the surplus production function for a range of $B_{MSY}/K = 0.36 – 0.42$ values, which are equivalent to a choice of steepness values of $h = 0.5 – 0.7$ in age-structured models with Beverton and Holt spawning stock recruitment function (Winker et al. 2019). After discussions during the assessment meeting, steepness was assumed equal to 0.6 to be consistent with estimates from SS, which corresponds *r* prior as ($log(r) \sim N(log(0.181), 0.180)$) and a fixed input value of $B_{MSY}/K = 0.39$, $m = 1.12$). By comparison, the previous Stock Synthesis model assessment estimated a steepness of the stock-recruit relationship at $h = 0.65$ (ICCAT, 2012).

Results of residuals analysis evidenced that the overall CPUE fits were still associated with substantial noise (RMSE > 50%). Although there was no evidence for an undesirably retrospective pattern, the consistent negative trend of process error deviates after the year middle 90's points towards increasing conflicts between the trends CPUE and catch time series. This could be possibly caused by underreported catches, unaccounted discard mortality and CPUE trends not reflecting the trends in abundance adequately in recent years. The underlying factors causing the systematic trend in process error deviations from 2000 through 2017 should be carefully evaluated, which could include sensitivity runs for alternative (by-)catch scenarios as conducted during the 2012 assessment (ICCAT 2012). Despite some emerging data conflicts all three JABBA scenarios presented here were consistent in terms of similar stock status (F/F_{MSY}; B/B_{MSY}) and *MSY* estimates (around 1,500-1,600 t among retrospective models). Overall, we recommend that the models presented here can be considered suitable with regards its predictive capabilities and determination of stock status for Atlantic white marlin.

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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 white marlin.

	S3 (base case)			**S1 (sensitivity run 1)**			**S2 (sensitivity run 2)**		
Estimates	*Median*	*2.50%*	*97.50%*	*Median*	*2.50%*	*97.50%*	*Median*	*2.50%*	*97.50%*
K	29,249	21,026	43,041	26,230	18,853	37,395	26,604	19,261	38,197
r	0.163	0.122	0.215	0.17	0.125	0.225	0.168	0.126	0.223
σ_{proc}	0.158	0.105	0.205	0.17	0.11	0.207	0.17	0.114	0.207
F_{MSY}	0.144	0.108	0.191	0.151	0.111	0.2	0.149	0.112	0.198
B_{MSY}	11,409	8,202	16,789	10,232	7,354	14,587	10,378	7,513	14,900
MSY	1,646	1,290	2,222	1,535	1,208	1,977	1,549	1,211	2,046
B_{1956}/K	0.862	0.667	1.023	0.759	0.558	1.016	0.734	0.492	1.007
B_{2017}/K	0.181	0.1	0.304	0.206	0.126	0.349	0.203	0.116	0.331
B_{2017}/B_{MSY}	0.463	0.257	0.778	0.529	0.322	0.895	0.52	0.297	0.849
F_{2017}/F_{MSY}	0.606	0.386	0.932	0.566	0.351	0.866	0.575	0.364	0.897

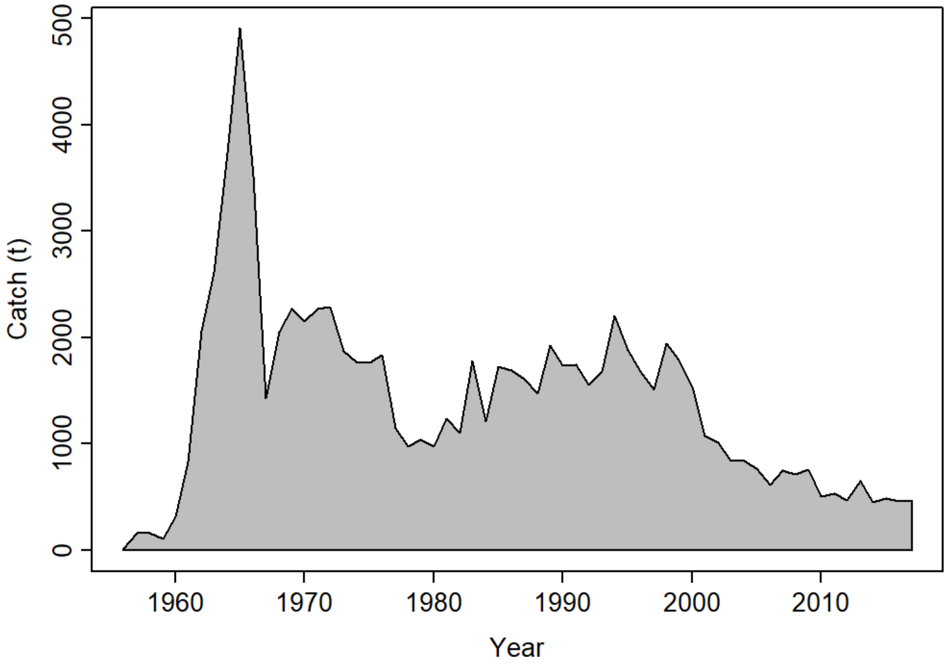

Figure 1. Time-series of catch in metric tons (t) for the white marlin in the Atlantic Ocean.

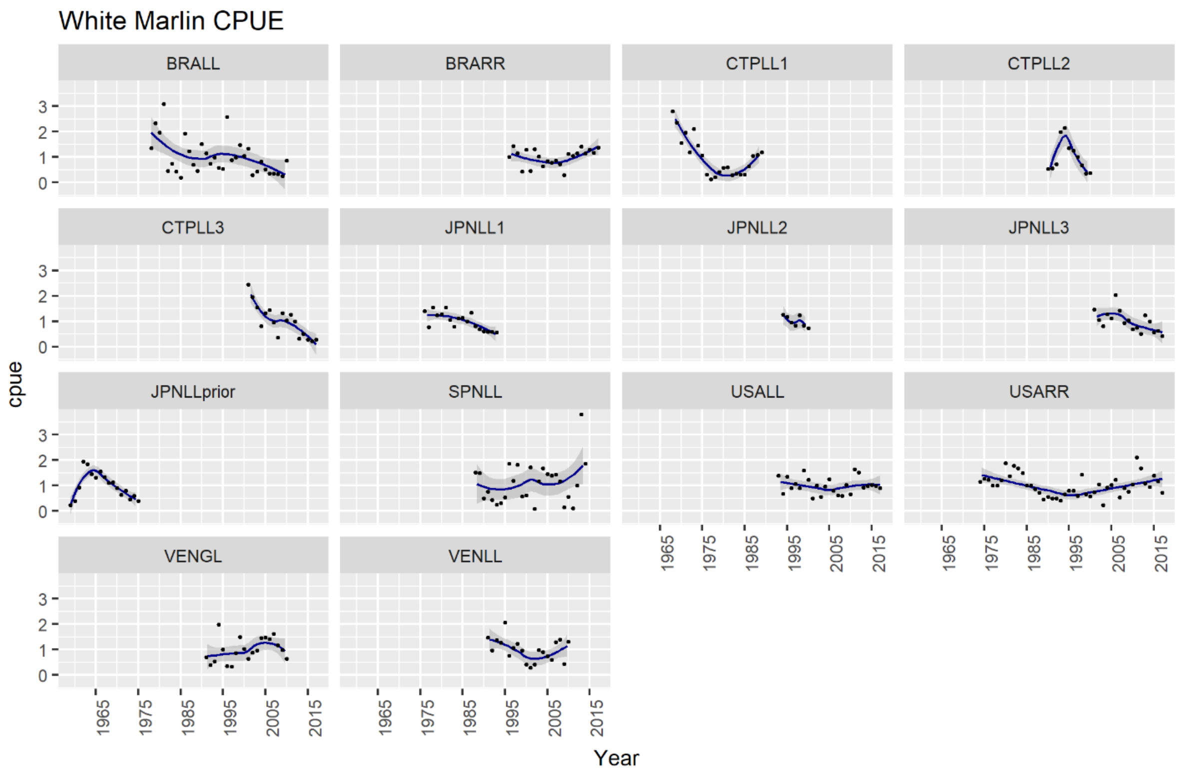

Figure 2. Time-series of 14 standardized scaled CPUE series (black dots) for white marlin in the Atlantic Ocean used in the state-space surplus production model JABBA. The solid blue line and associated grey shaded area represent the CPUE fits and associated 95% confidence interval, respectively, from a loess smooth regression.

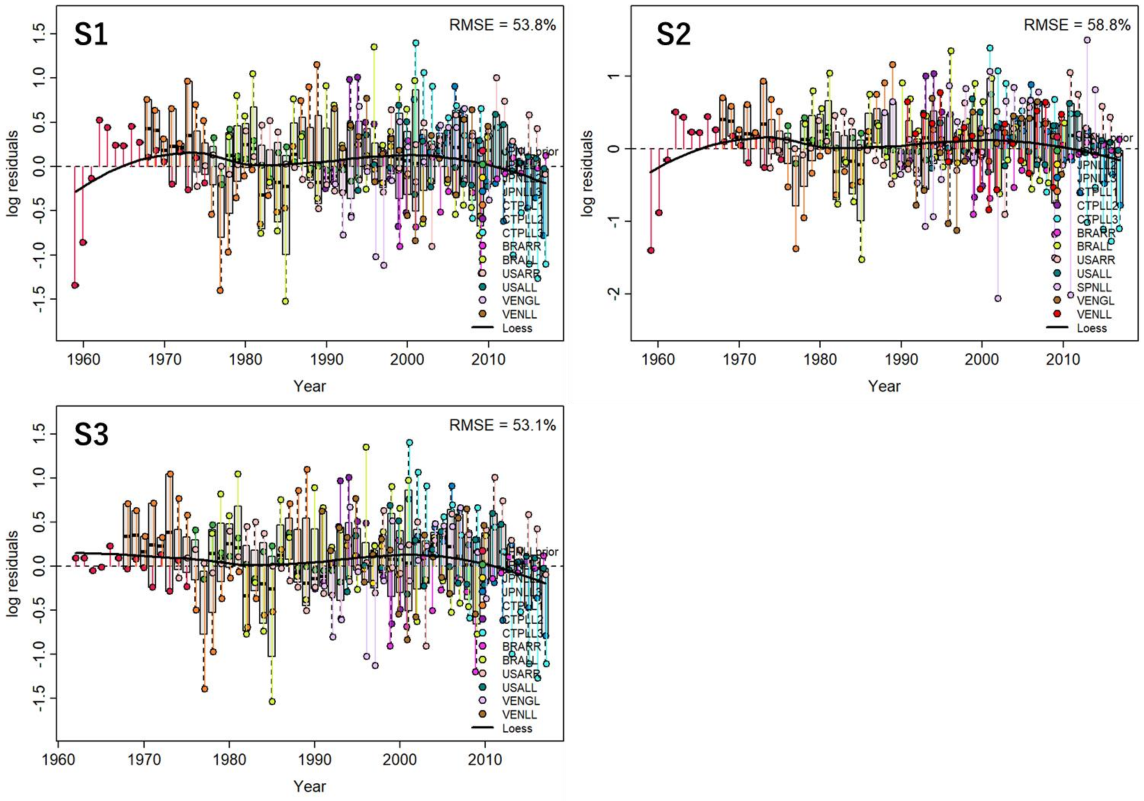

Figure 3. JABBA residual diagnostic plots for alternative sets of CPUE indices examined for each scenario for the Atlantic white marlin. Boxplots indicate the median and quantiles of all residuals available for any given year, and solid black lines indicate a loess smoother through all residuals.

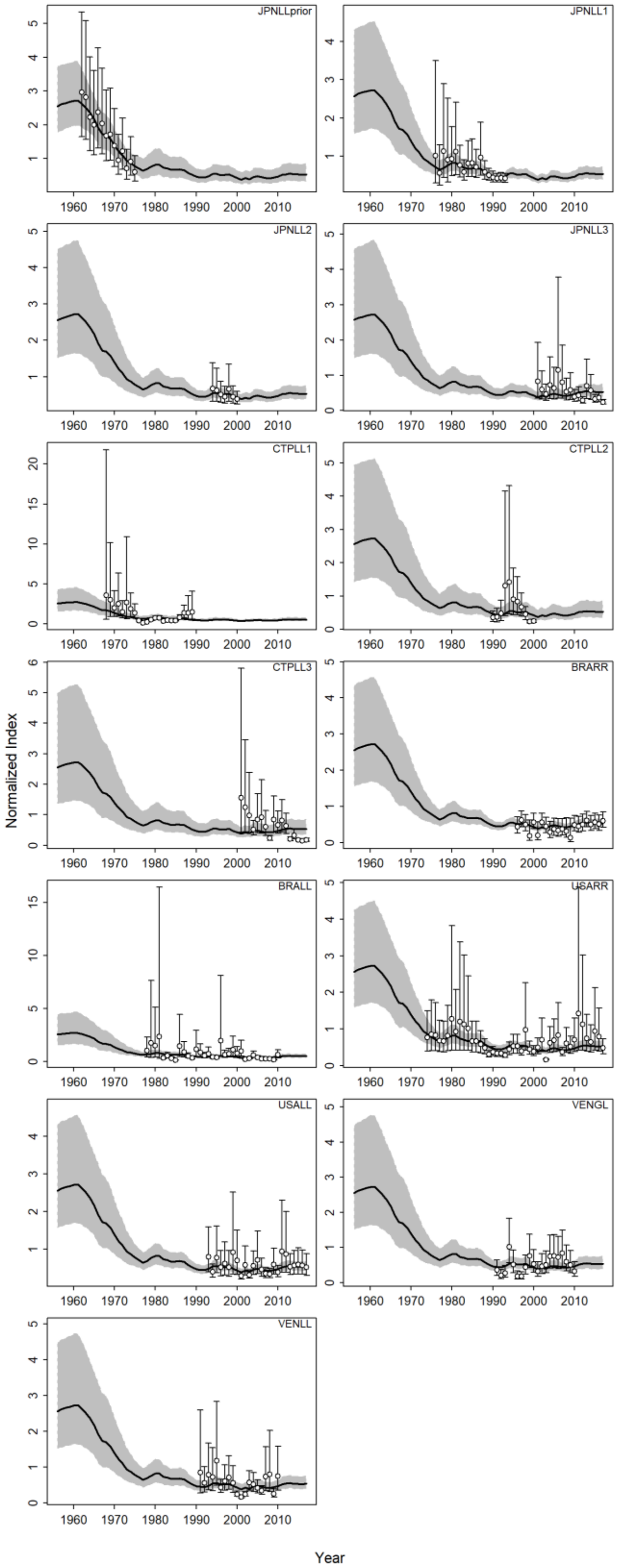

Figure 4. Time-series of observed (circle and SE error bars) and predicted (solid line) CPUE of white marlin in the Atlantic Ocean for the JABBA base case model (S3). Shaded grey area indicates 95% credibility intervals.

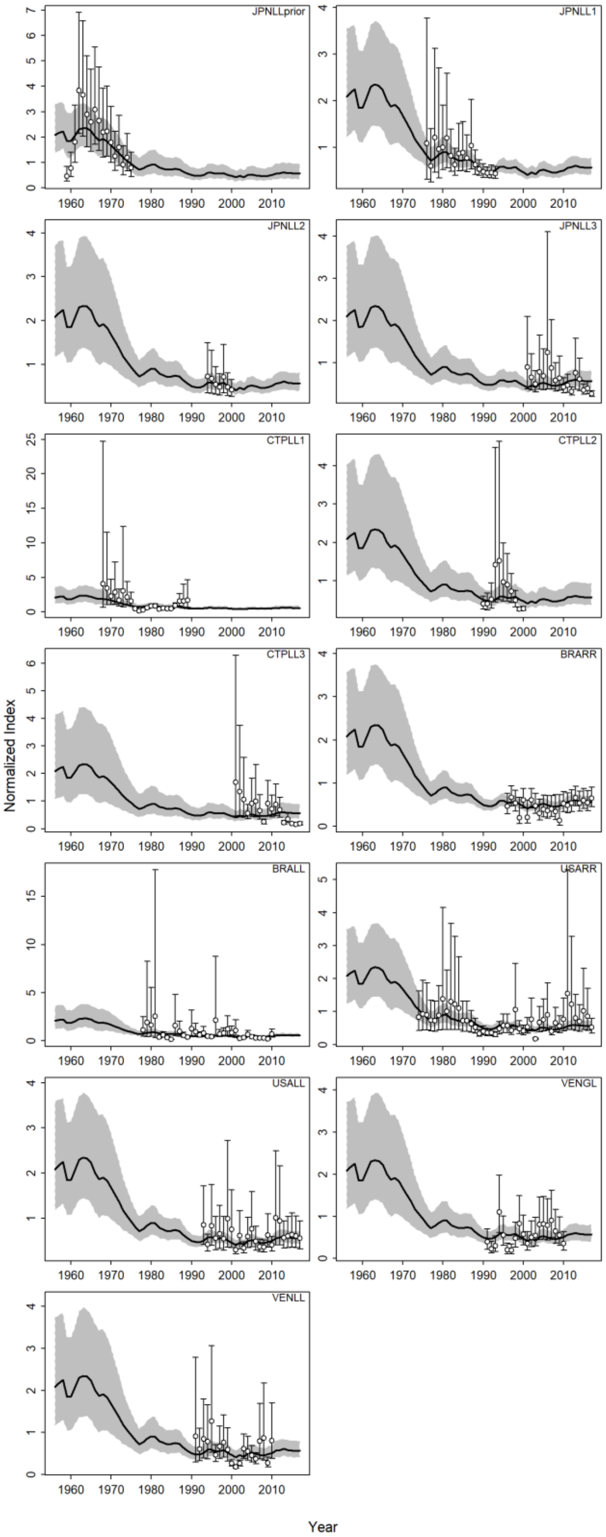

Figure 5. Time-series of observed (circle and SE error bars) and predicted (solid line) CPUE of white marlin in the Atlantic Ocean for the JABBA sensitivity run 1 (S1). Shaded grey area indicates 95% credibility intervals.

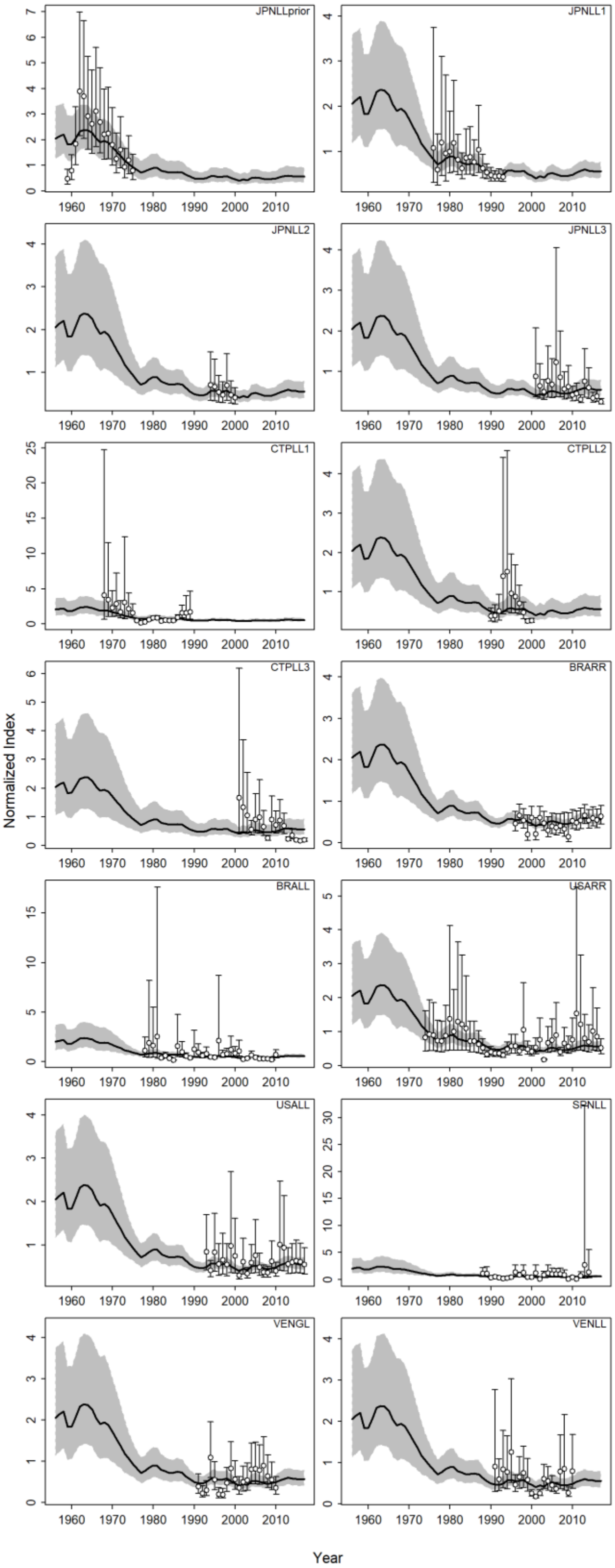

Figure 6. Time-series of observed (circle and SE error bars) and predicted (solid line) CPUE of white marlin in the Atlantic Ocean for the JABBA sensitivity run 2 (S2). Shaded grey area indicates 95% credibility intervals.

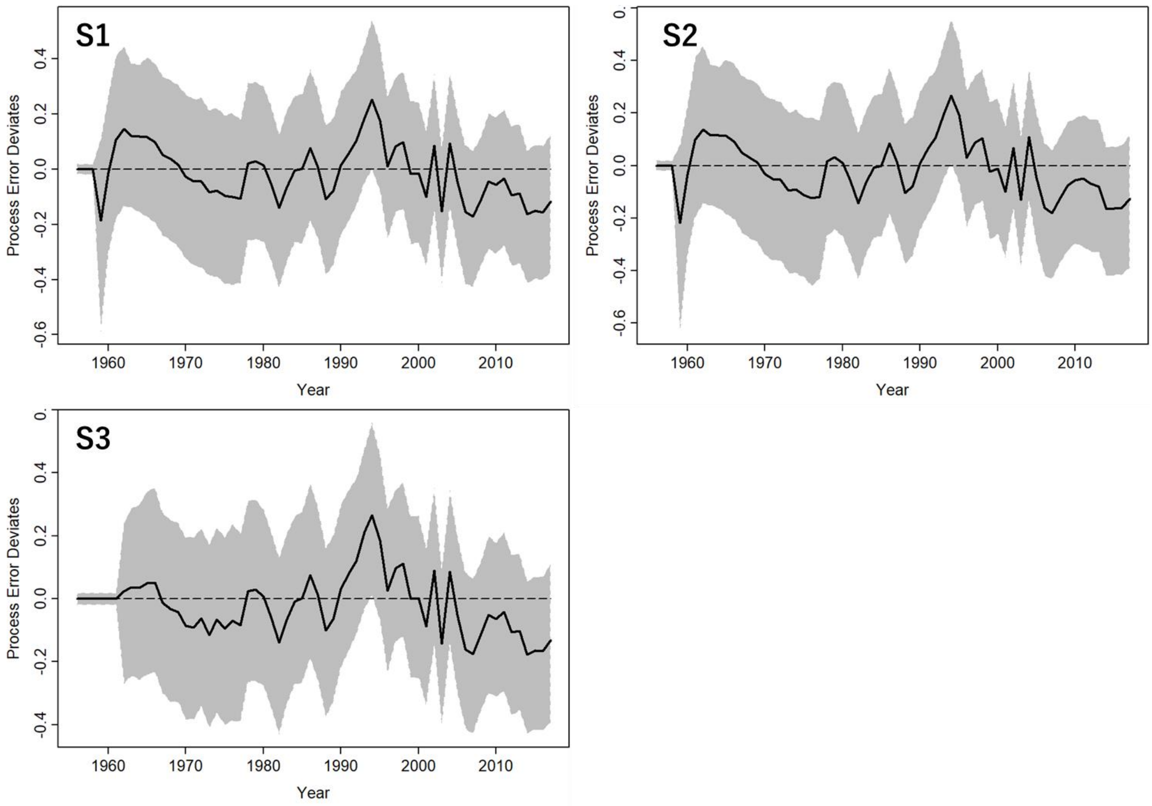

Figure 7. Process error deviates (median: solid line) of white marlin in the Atlantic Ocean for each JABBA model (S1- sensitivity run 1, included 13 CPUEs with the exclusion of only Spanish longline index; S2 - sensitivity run 2, included all 14 CPUEs, and; S3 - base case; same setting as S1 but removed data for 1959-1961 from the early Japanese longline index). Shaded grey area indicates 95% credibility intervals.

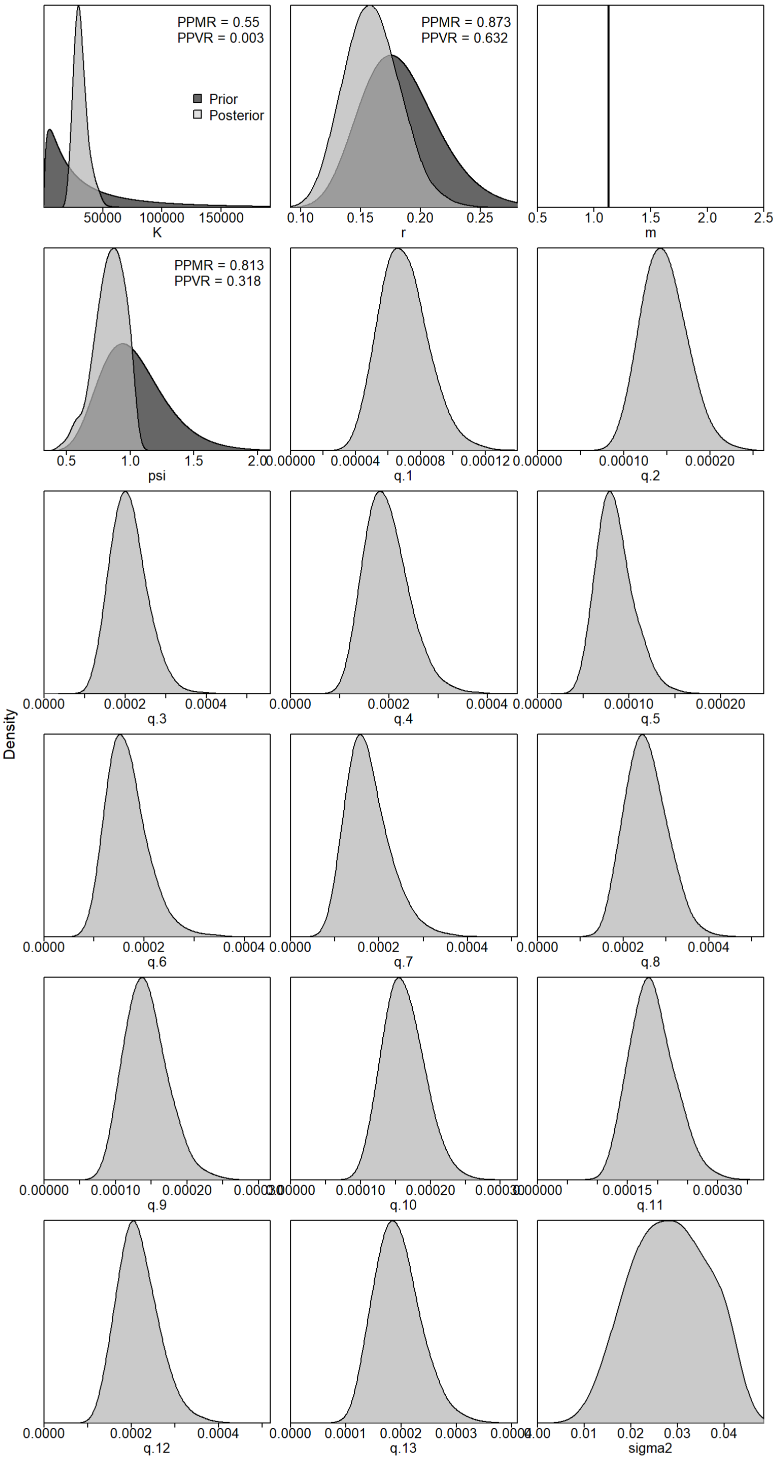

Figure 8. Prior and posterior distributions of various model and management parameters for the JABBA base case model (S3) for white marlin in the Atlantic Ocean.

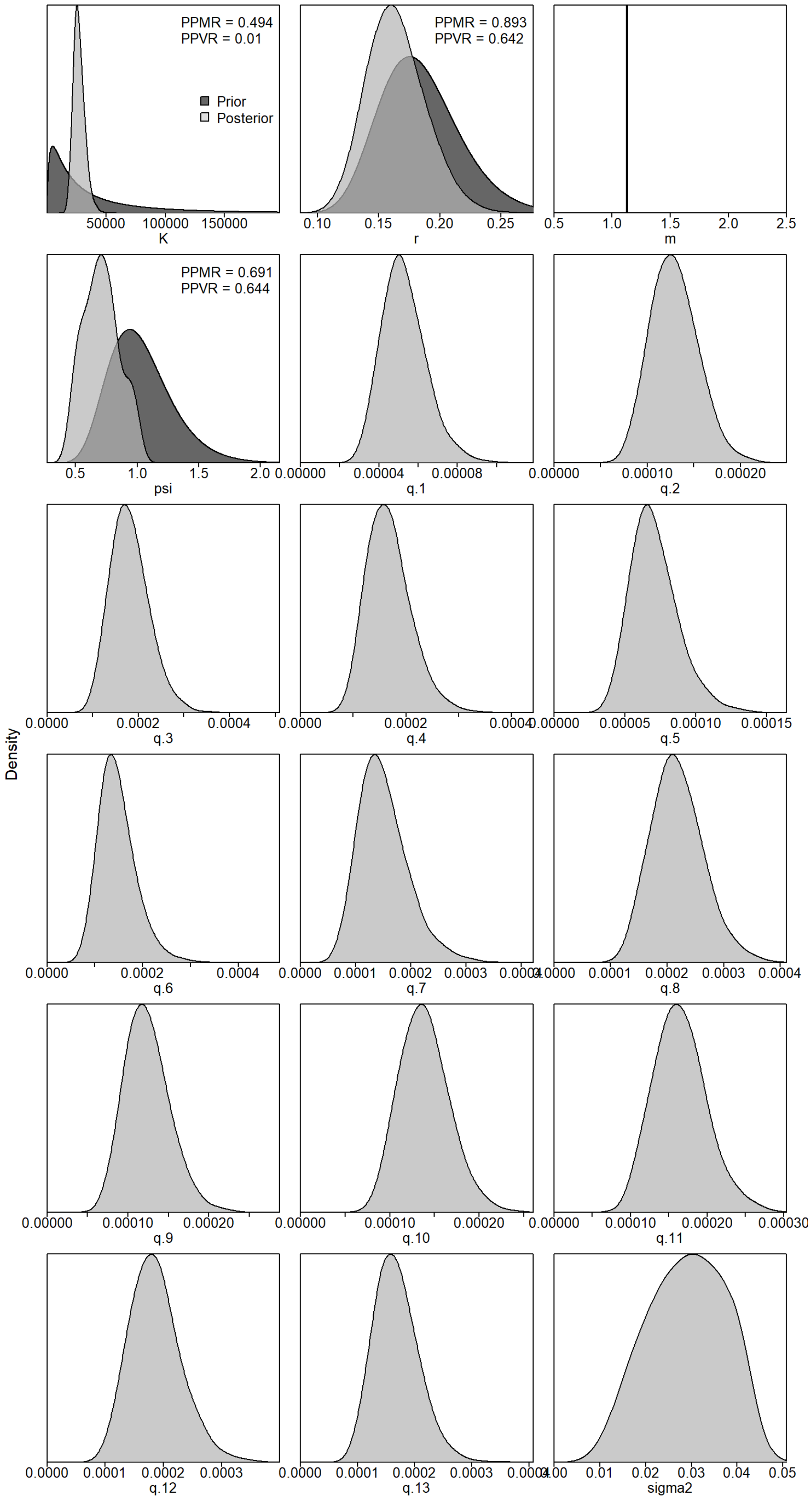

Figure 9. Prior and posterior distributions of various model and management parameters for the JABBA sensitivity run1 (S1) for white marlin in the Atlantic Ocean.

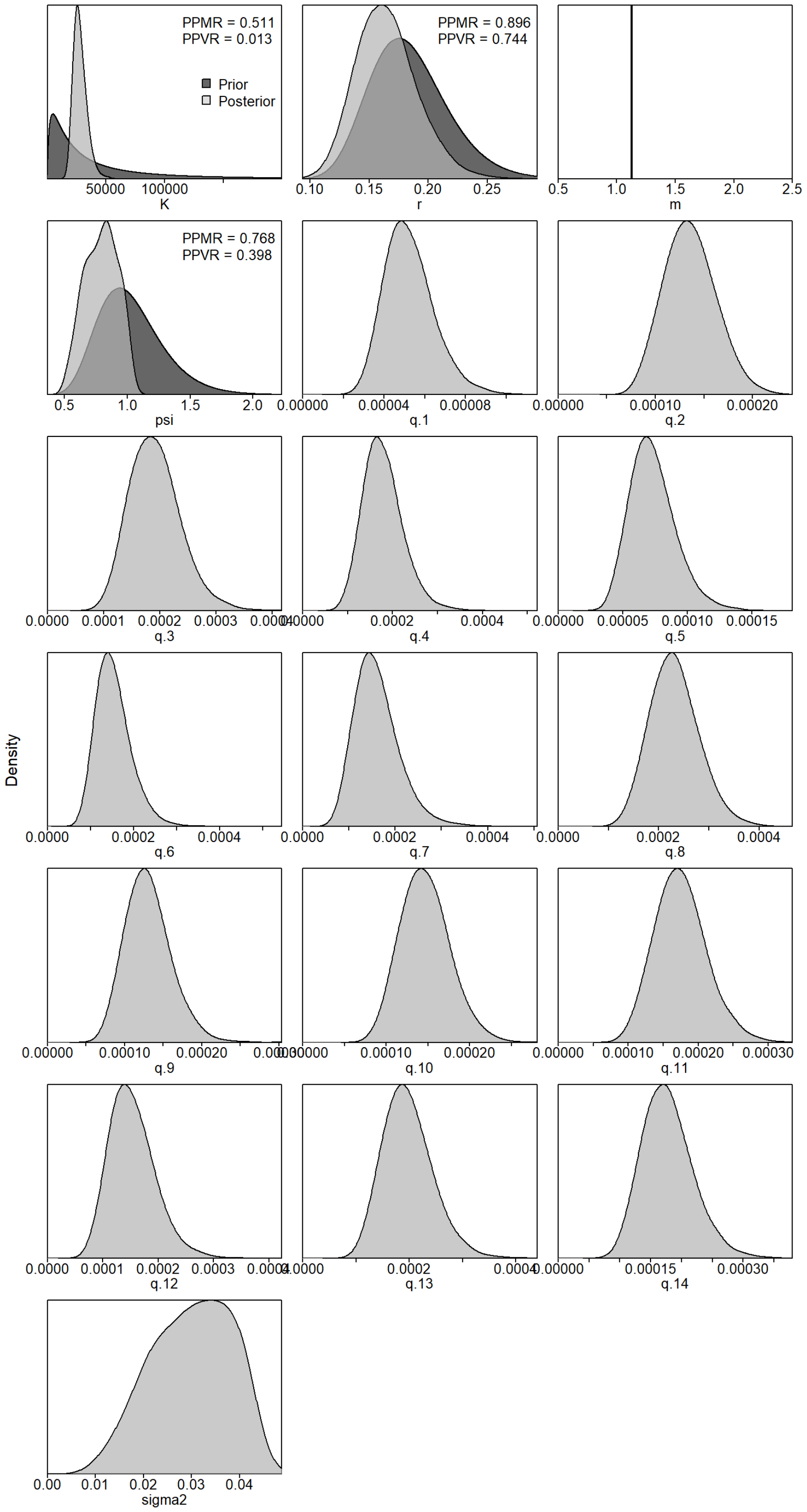

Figure 10. Prior and posterior distributions of various model and management parameters for the JABBA sensitivity run2 (S2) for white marlin in the Atlantic Ocean.

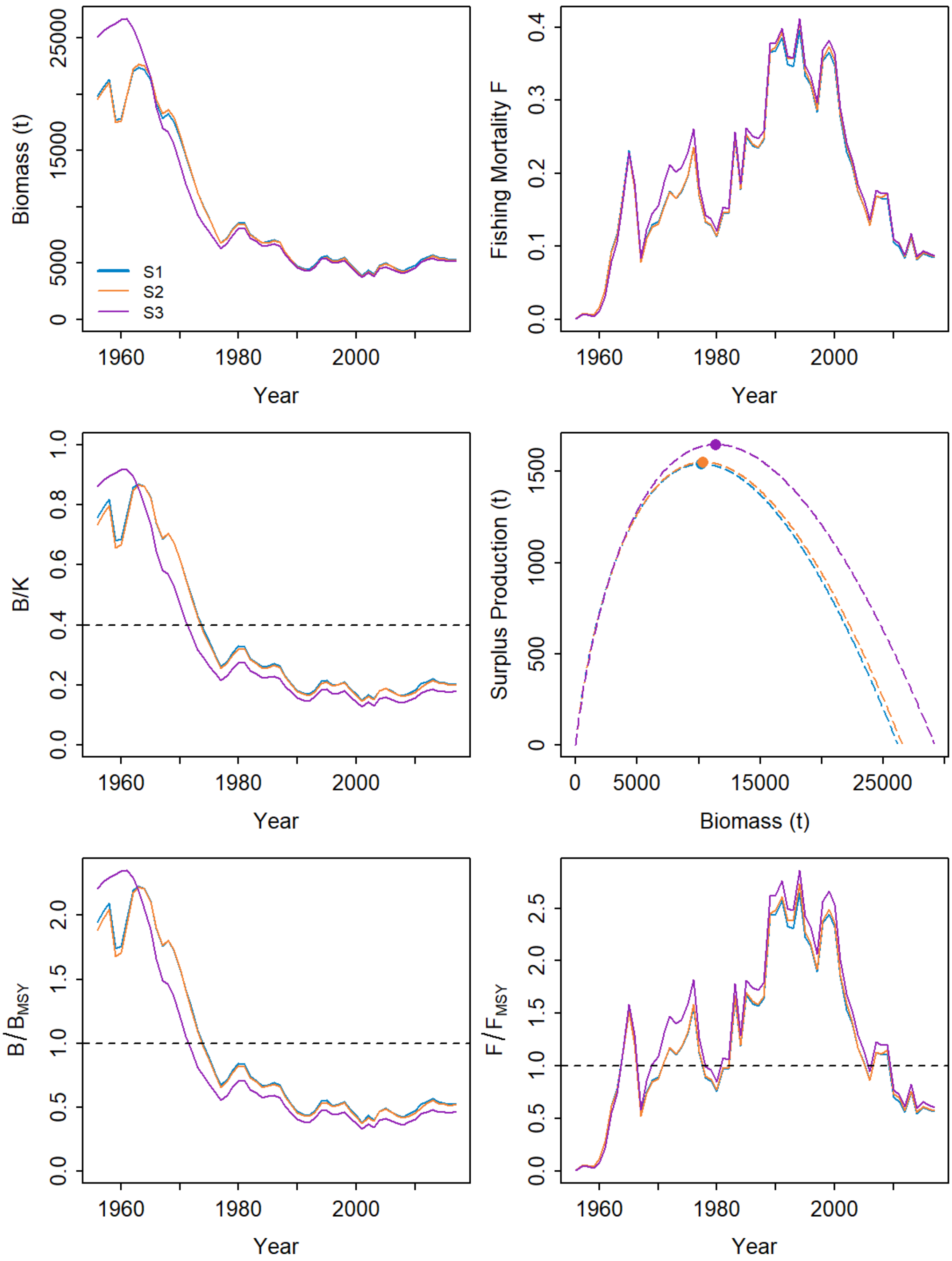

Figure 11. Comparison of biomass, fishing mortality (upper panels), biomass relative to *K* (*B/K*) and surplus production curve (middle panels), and biomass relative to B_{MSY} (B/B_{MSY}) and fishing mortality relative to F_{MSY} (F/F_{MSY}) (bottom panels) among JABBA scenarios (S1- sensitivity run 1, included 13 CPUEs with the exclusion of only Spanish longline index; S2 - sensitivity run 2, included all 14 CPUEs, and; S3 - base case; same setting as S1 but removed data for 1959-1961 in early Japanese longline index) for Atlantic white marlin.

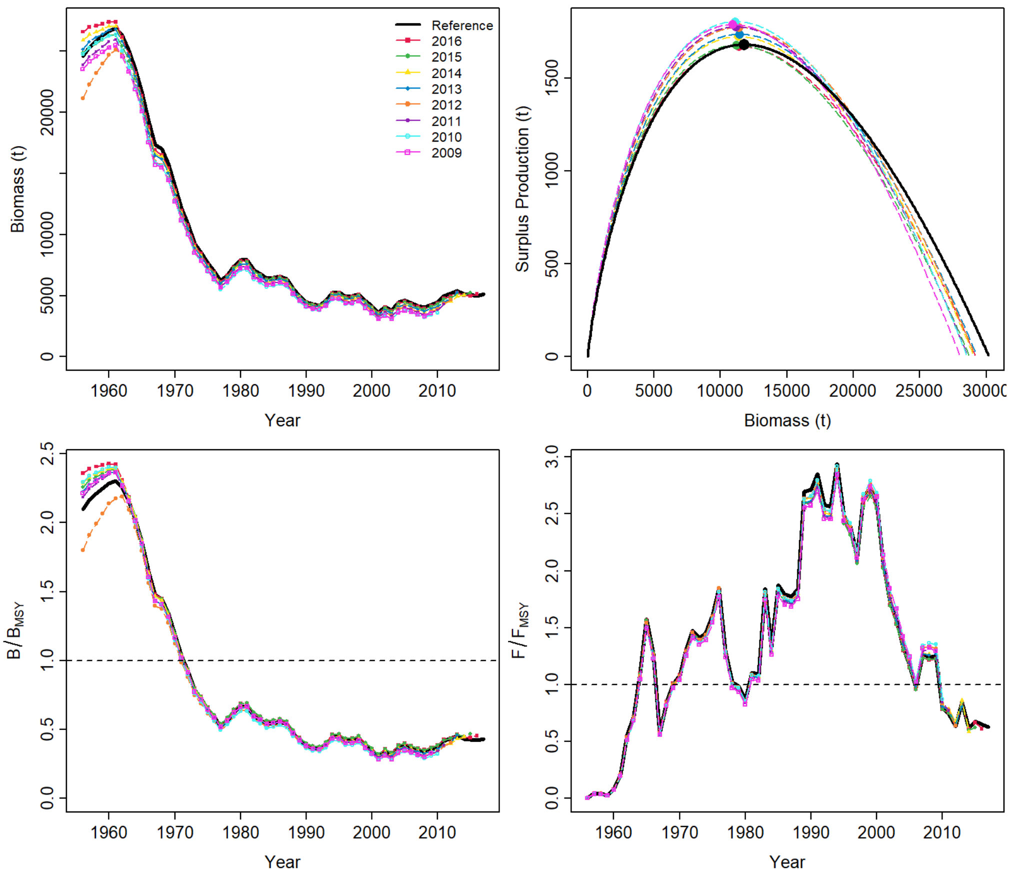

Figure 12. Retrospective analysis for stock biomass (t), surplus production function (maximum = *MSY*), B/B_{MSY} and F/F_{MSY} for the JABBA base case final model (S3) for Atlantic white marlin. The label “Reference” indicates the base case model fits to the entire time series 1956-2017. The numeric year label indicates the retrospective results from the retrospective ‘peel’, sequentially excluding CPUE data back to 2009.

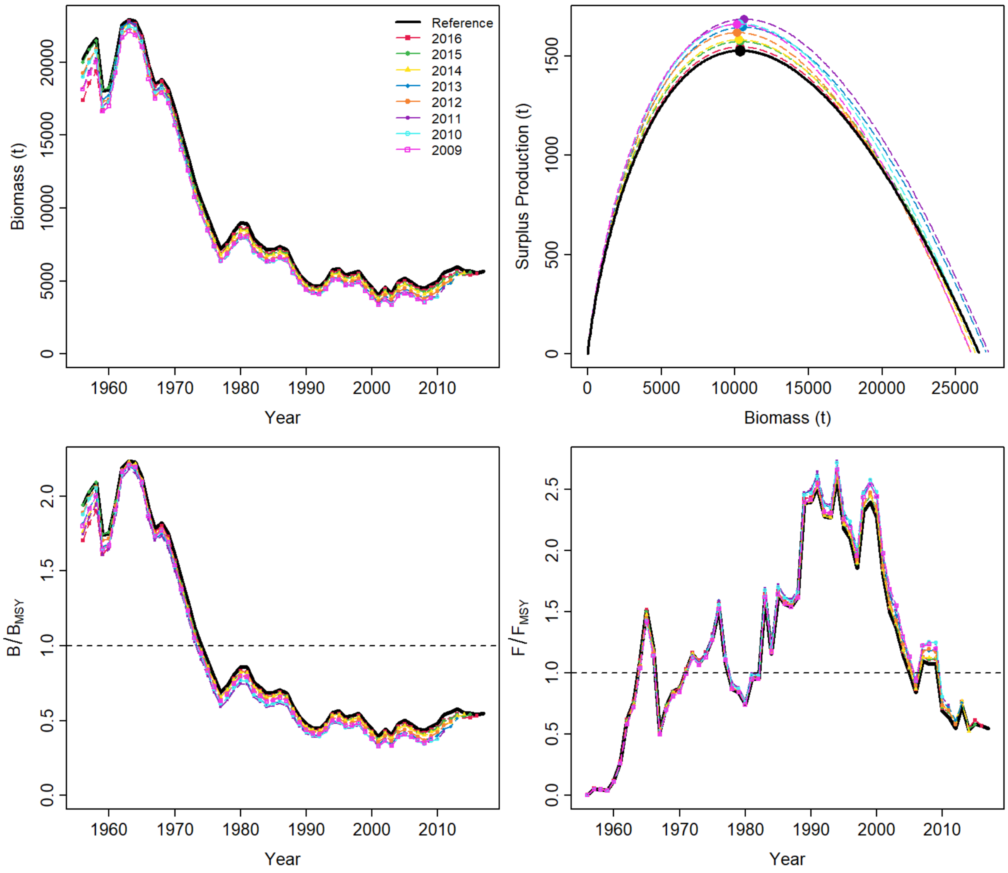

Figure 13. Retrospective analysis for stock biomass (t), surplus production function (maximum = *MSY*), B/B_{MSY} and F/F_{MSY} for the JABBA sensitivity run1 (S1) with Spanish longline index for Atlantic white marlin. The label "Reference" indicates the base case model fits to the entire time series 1956-2017. The numeric year label indicates the retrospective results from the retrospective 'peel', sequentially excluding CPUE data back to 2009.

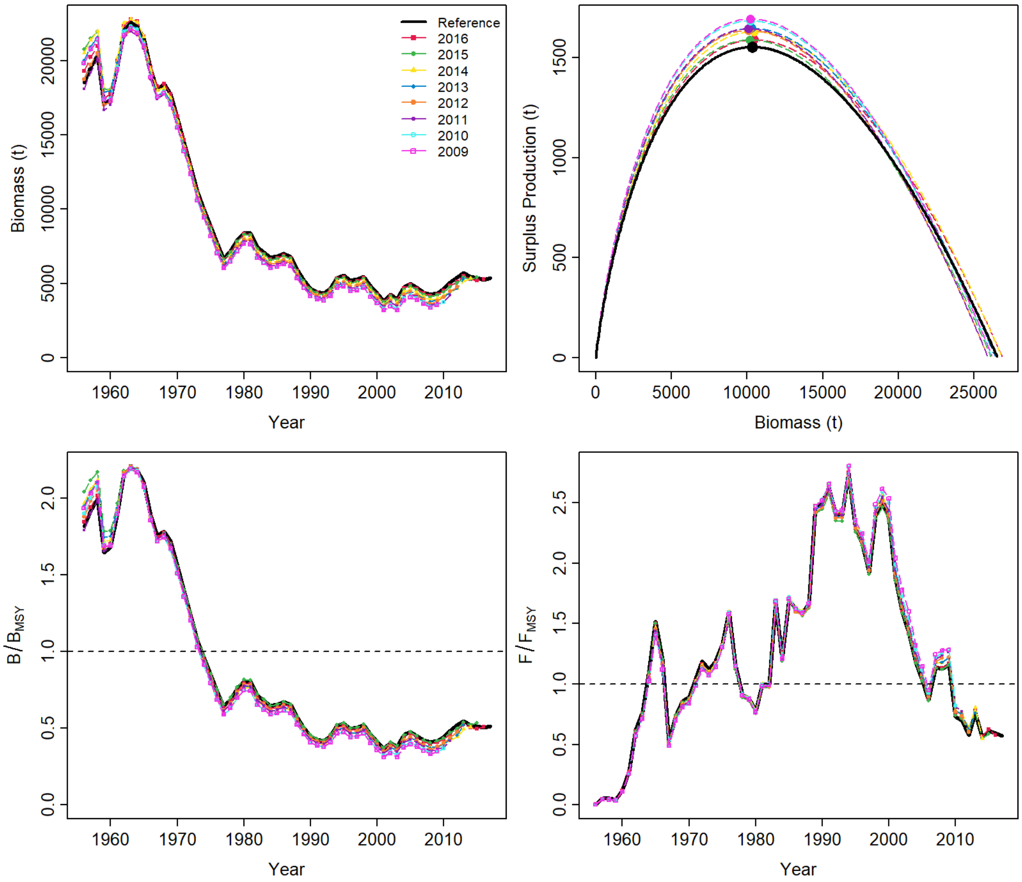

Figure 14. Retrospective analysis for stock biomass (t), surplus production function (maximum = *MSY*), B/B_{MSY} and F/F_{MSY} for the JABBA sensitivity run2 (S2) remove 1956-1961 from early Japanese longline index for Atlantic white marlin. The label "Reference" indicates the base case model fits to the entire time series 1959-2017. The numeric year label indicates the retrospective results from the retrospective 'peel', sequentially excluding CPUE data back to 2009.

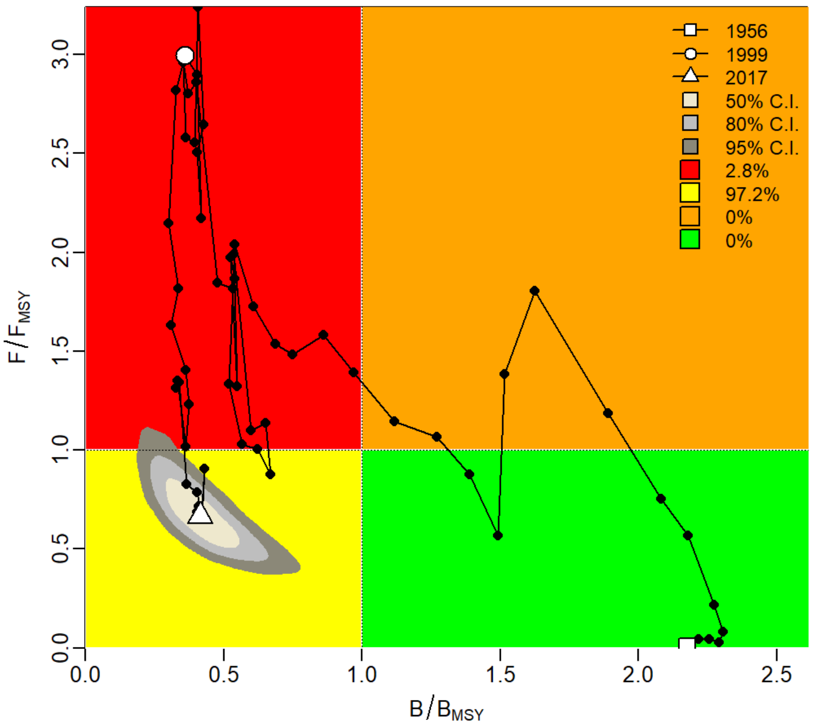

Figure 15. Kobe phase plot showing estimated trajectories (1959-2017) of *B/B_{MSY}* and *F/F_{MSY}* for the JABBA base case model (S3) for the Atlantic white marlin. Different grey shaded areas denote the 50%, 80%, and 95% credibility interval for the terminal assessment year. The probability of terminal year points falling within each quadrant is indicated in the figure legend.

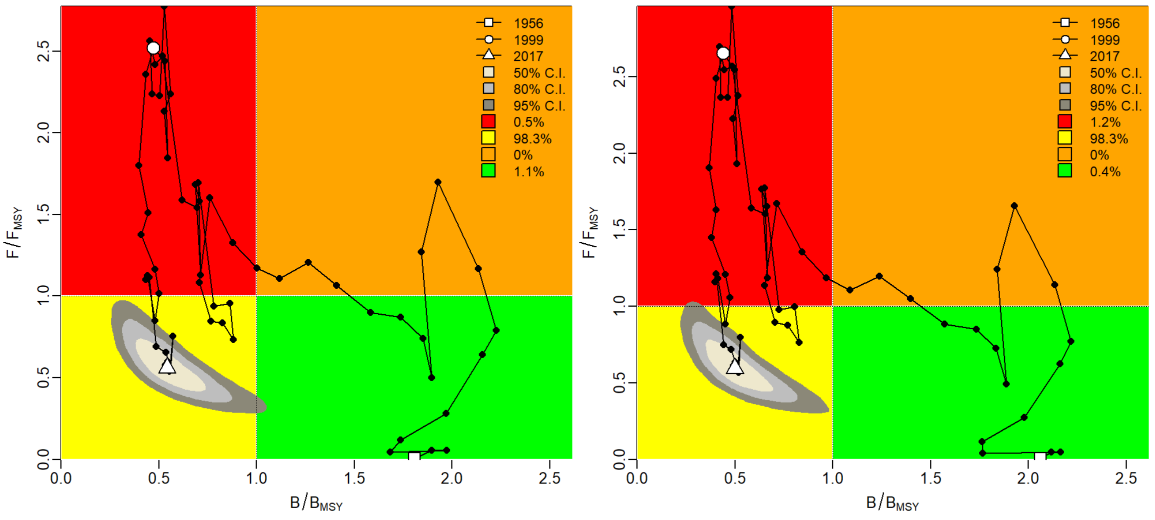

Figure 16. Kobe phase plots showing estimated trajectories (1959-2017) of *B/B_{MSY}* and *F/F_{MSY}* for the JABBA sensitivity runs 1 (S1, left) and 2 (S2, right). Different grey shaded areas denote the 50%, 80%, and 95% credibility interval for the terminal assessment year. The probability of terminal year points falling within each quadrant is indicated in the figure legend

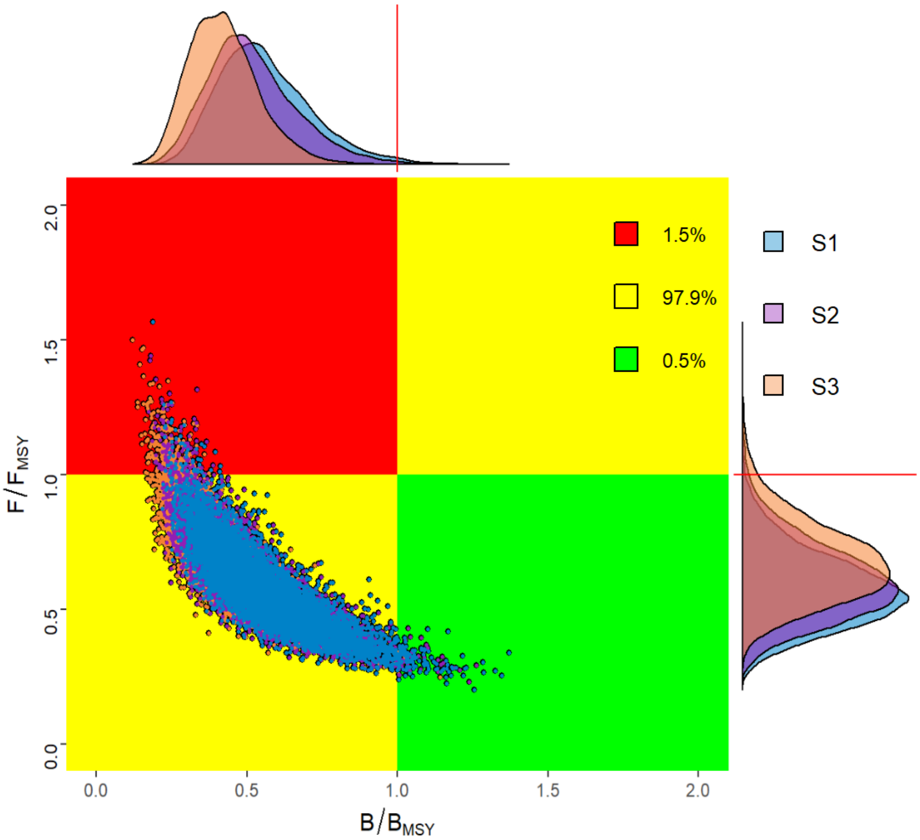

Figure 17. Kobe phase plot showing the combined posteriors of *B*/*B$_{MSY}$* and *F*/*F$_{MSY}$* (1959-2016) from all four scenarios runs using the ‘Kobe’ library in FLR (Kell et al., 2007). The probability of terminal year points falling within each quadrant is indicated in the figure legend.