REPORT OF THE 2017 ICCAT SHORTFIN MAKO ASSESSMENT MEETING

(Madrid, Spain 12-16 June 2017)

1. Opening, adoption of Agenda and meeting arrangements

The meeting was held at the ICCAT Secretariat in Madrid, June 12 to 16, 2017. Dr Enric Cortés (USA), the Species Group ("the Group") rapporteur and meeting Chairman, opened the meeting and welcomed participants. Dr Miguel Neves dos Santos (ICCAT Assistant Executive Secretary) addressed the Group on behalf of the ICCAT Executive Secretary, welcomed the participants and wished them the best for this important assessment. The Chairman proceeded to review the Agenda which was adopted with minor changes (**Appendix 1**).

The List of Participants is included in **Appendix 2**. The List of Documents presented at the meeting is attached as **Appendix 3**. The abstracts of all SCRS documents presented at the meeting are included in **Appendix 4**. The following served as rapporteurs:

Sections	*Rapporteur*
Items 1, 7 and 8	P. de Bruyn
Item 2	J. Fernández Costa, E. Cortés, R. Coelho, D. Macias, M. Byrne, P. De Bruyn
Item 3	D. Courtney, B. Babcock, H. Winker, H. O'Farrell, D. Die, D. Parker
Item 4	D. Courtney, B. Babcock, H. Winker, H. O'Farrell, D. Parker, E. Cortés, M. Kai, P. de Bruyn
Item 5	B. Babcock, H. O'Farrell.
Item 6	E. Cortés, G. Diaz, A. Domingo

2. Summary of available data submitted by the assessment data deadline (30 April 2017)

2.1 Stock identity

No new information was presented on stock structure.

2.2 Catches

The Secretariat stated that very little Task I or II information had been received since the data preparatory meeting in March. The major change was the receipt of Task I catches from South Africa for the southern stock. This submission filled an important gap in the catch series for the southern stock.

Document SCRS/2017/110 provided updates on the alternative hypothesis for the reconstruction of time series of catches for north and south Atlantic stocks of shortfin mako shark. It was noted that the reconstruction of shark catch time series is important for stock assessments, as the nominal catch data on sharks is usually limited. The estimation method is based on ratios of shark catches to catches of the main target species obtained from observer programs, literature reviews, and/or personal communications.

The Group noted that these estimated catches were significantly higher than the official Task I catches (**Figure 1**), particularly for the historic time series. It was acknowledged that the Task I data, particularly in the early part of the time series, are highly uncertain due to the lack of reporting of shark captures during that period. The estimation presented here provides a potentially more realistic representation of the captures for the early years of exploitation. It was thus recommended that these estimations be used in an alternative model run for each of the models.

It was also questioned whether trade data had ever been used to estimate total catches for shortfin makos. It was noted that fin trade data had been used in the past for blue sharks (Anon, 2016), but that these estimates were only valid until 2012 (due to the trade data collected) and also were dependent on the ICCAT Effdis data used in their estimation, which is currently under revision.

2.3 Indices of abundance

Document SCRS/2017/108 provided standardized CPUEs for the shortfin mako shark from the Spanish surface longline fleet targeting swordfish in the North and South Atlantic Ocean over the period 1990-2015. Standardization was based on GLM analysis of trip data. A base case and two sensitivity analyses (GLM and MIXED procedure) were carried out. Area was identified to be the most relevant factor explaining the CPUE variability in all models. The base case explained between 40-46% of CPUE variability. All tested scenarios showed very similar and stable trends in general CPUE over time in the North and South Atlantic stocks during the 26 years analyzed.

The Group discussed the use in the model of the variable "type of trip" (ratio) defined as the percentage of swordfish in relation with the total of swordfish plus blue shark catches. The Group suggested the use of clusters in the analysis instead of the ratio to avoid redundancy in the model. Researchers of EU-Portugal, whose fleet is similar to the EU-Spain fleet, carried out an analysis of clusters in their fleet and, they obtained the same results using clusters as when using ratios. Furthermore, the clusters showed the same redundancy in the model. Taking into account the previous considerations, and the history of the EU-Spain fishery, the authors consider that the ratio is a good indicator for the criteria of the skipper targeting swordfish and/or blue shark during a fishing trip.

A question was raised about the number of zero catches and the authors indicated that there was a low proportion of trips with zero catches (mean values of 2.8% and 4.3% for the North and South Atlantic stocks, respectively). In addition, the zero catch trips showed a stable trend over time. The Group welcomed this update to the EU-Spain North and South LL CPUE series and recommended that they be considered for the assessment models.

SCRS/P/2017/017 presented a new standardized CPUE data time series for shortfin mako shark caught by the South African large pelagic shark longline fleet for the Group to review. The majority of these catches occur in an area that straddles the ICCAT/IOTC 20 degree boundary, which is a known juvenile aggregation area. Given the uncertainty regarding regional assignment of this boundary stock, the Group suggested that the standardized CPUE indices should not be included in the assessment of the South Atlantic shortfin mako shark.

2.4 Biology

Document SCRS/2017/111 presented the results of the age and growth Project for the North Atlantic within the ICCAT-SRDCP - Shark Research and Data Collection Programme. Ageing from vertebrae and growth models were presented for the North Atlantic. A 2-parameter von Bertalanffy growth model provided the most biological reasonable estimates, especially for females. The difference in growth parameters between males and females was noted, with males having almost double the growth rate of females.

Additionally, preliminary plots of the integrated growth analysis using both tag-recapture data and age readings was shown (work done in cooperation between ICCAT and IATTC scientists). For this analysis the ICCAT conventional tag data are being used. It was noted that for this model it is not possible to have sex-specific parameters, because of the current structure of the ICCAT tagging dataset (sex data currently not available). The Group acknowledged the work done so far and encouraged the continuity of this integrated growth analysis.

Document SCRS/2017/126 presented estimates of maximum population growth rate and steepness for shortfin makos in the North and South Atlantic Ocean. A dual life table/Leslie matrix approach was carried out to obtain estimates of productivity (r_{max}), net reproductive rate (R_0), generation time (μ_1), and steepness derived analytically. Natural mortality at age was obtained from the minimum of five estimates obtained through different life history invariant methods to approximate maximum population growth rate.

It was noted that productivity estimates from the North Atlantic are different from those in the South, with the South having higher estimated r_{max}. Regarding mortality, the estimated mortality rates of males and females are very different in the younger ages. It was discussed that mortality should be the same for males and females up to the age at maturity for males, because length at age up to approximately age 8 is similar for males and females and feeding grounds are probably similar. It was further discussed that because the objective is to approximate ideal conditions and a maximum density-dependent response to obtain r_{max}, use of a Lorenzen or similar size-specific life history invariant method to predict mortality results in extremely low or even negative values of r_{max}. Therefore, it was thought that making mortality rates of males equal to those of females as described in the paper was the best approach to produce credible estimates of r_{max}.

SSB_{MSY}/SB_0 and steepness were obtained analytically from the life table/Leslie matrix approach. The inflection point was translated into the shape parameter for the generalised Pella Tomlinson surplus production function by (SCRS/2017/P/020 and SCRS/2017/135):

$$\frac{SB_{MSY}}{SB_0} = m^{\left(-\frac{1}{m-1}\right)}$$

2.5 Length compositions

The results provided at the data preparatory meeting (Coelho *et al.*, in press) were used for the stock assessments. EU-Spain provided additional length composition data (2009-2015) that was also used.

It was noted in presentation SCRS/2017/P/017 that the majority of length-frequency data from South Africa came from the Indian Ocean, and not the Atlantic.

The full description of the use of the size data is in Section 4 of the report.

2.6 Other relevant data

The presentation SCRS/P/2017/022 provided updated results of a study presented at the data preparatory meeting that quantified fishing mortality of satellite-tagged shortfin makos in the western North Atlantic. The update included 11 additional individuals and an additional year of tracking data. The updated results were similar to those reported previously, with ca. 28% of tagged sharks harvested and F = 0.32 (0.19 – 0.53). It was noted that results may not be representative of the entire stock because the study was limited to immature sharks only tracked within the western North Atlantic. It was suggested to compare fishing mortality rates from stock synthesis over the ages of the sharks that were tagged. The presentation also included movement and behavior data for satellite-tagged sharks which highlighted low spatial overlap of sharks tagged off the northeast coast of the U.S., and off the Yucatán Peninsula in Mexico. Behavioral analysis of these sharks indicated two distinct core areas of intensive use corresponding to the mid-Atlantic Bight and the western edge of the Yucatán Channel.

Document SCRS/2017/129 reported on anomalously high landings of mako sharks relative to blue sharks reported by 21 E.U. longline fishing vessels in 2008. The authors suggested that the high mako landings may have been a result of misreporting where swordfish were reported as makos.

The Group raised a number of concerns with this hypothesis. Firstly, it was noted that swordfish quotas were not reached in 2008, and it was therefore unlikely that fishers would disguise swordfish landings as makos. Secondly, available ICCAT landing data did not indicate a noticeable spike in mako landings during this time period. It was therefore suggested by the Group that these perceived anomalies are likely artefacts of data reporting and fleet behavior. Reasons for this include that landings were reported in weight (kg) which may not be a reasonable proxy for numbers of individuals landed (i.e. several large makos would weigh more than many small blue sharks). The Group advised caution when interpreting landing data as long-range boats may employ strategies that do not allow the direct relation of landings to trips.

Document SCRS/2017/130 reported spatially explicit mako shark landings of two longline vessels during a 16 year period (1997-2012). The presentation described CPUE changed over time for the two vessels, as well as where the vessels fished in relation to shark densities described by satellite tagging data.

The possibility of using habitat selection results derived from satellite tracking data in the North Atlantic to predict distributions of sharks in the data-poor South Atlantic was discussed, to which the Group noted that ICCAT is currently engaged in several satellite tagging studies. The Group suggested that interpreting any change in CPUE should be considered in relation to changes in gear and fishing methodology.

3. Methods and other data relevant to the assessment

3.1 Production models

Bayesian Surplus Production Model (BSP)

Babcock and Cortés (in press) (which updated the same document presented at the data preparatory meeting) presented a comparison of Bayesian Surplus Production (BSP) model software applications. The paper applied both the BSP1 software (without process error) and the BSP2 software (with process error), and two independent MCMC software packages, JAGS and Stan, to the data from the 2012 mako shark assessment for the North Atlantic to determine whether the results are consistent. The authors also used the SIR and MCMC algorithms from the LearnBayes R library to fit the same function with both algorithms. Although all the modeling approaches give fairly consistent posteriors for r, the posteriors of K were somewhat different. This may be because there is a long period of catches with no CPUE data, or because the catch and CPUE data are not consistent with each other. The lack of information in the data may cause the model to be sensitive to minor differences in how the model is configured.

The 2012 shortfin mako assessment used the BSP VisualBASIC software that does not include process error (BSP1, Babcock and Cortés (in press)). As a continuity run, the same software was used with similar settings, applied to the updated data for both the North and South Atlantic (**Appendix 5**). Because the models did not adequately capture the trends in the CPUE indices, the version of the VisualBASIC software that includes process error (BSP2) was also applied. Finally, a model was coded with similar priors and assumptions to the BSP models in JAGS; this model will be referred to as JAGS2-BSP.

For the BSP1, BSP2, and BSP2-JAGS runs, catches were either the catches from the data preparatory meeting (C1), starting in 1950 in the north and 1971 in the south, or the alternative estimated catch series (C2) based on ratios (SCRS/2017/110), starting in 1971. The prior for the starting biomass ratio B0/K was lognormal with a mean of 1 and log-sd of 0.2 for the southern runs, and for the northern runs starting in 1950. For the northern runs starting in 1971, the mean was 0.85, with the same log-sd. The CPUE series in the north were US-Log, JPLL-N, POR-LL-N, ESP-LL-N, and CH-TA-LLN. In the south the CPUE series were UR-LL-Log, JPLL-S, BR-LL, UR-LL-Obs, ESP-LL-S, and CH-TA-LLS. The observation error standard deviation was estimated as a single parameter for the BSP1 runs (equal weighting). It was estimated separately for each series in the BSP2 and BSP2-JAGS runs. In all cases, the prior for K was uniform on log(K) between 0.001 and 5 million. The prior for r was calculated by converting updated ranges for r (SCRS/2017/126) into informative lognormal distributions following the approach outlined in (SCRS/2017/135), which resulted in a mean of 0.0254 and log-sd of 0.434 in the North Atlantic and a mean of 0.052 and log-sd of 0.275 in the South Atlantic. For the North Atlantic, we used either the Schaefer model, or the generalized production model as implemented in BSP1 with a shape parameter of 5 ($B_{MSY}/K=0.67$) (McAllister *et al.*, 2000). For the South Atlantic, only the Schaefer model was used.

To evaluate the relative impact of the priors, catches and CPUE data on the model outputs, a post-model pre-data run was conducted with BSP2-JAGS (model with priors and catch data but without CPUEs), and also fitted the model to each index separately.

Projections were implemented within the BSP2-JAGS model with fixed TACS from 0 to 4,000 t in increments of 500 t, with a time horizon of 50 years (approximately 2 generations; SCRS/2017/126). The projections set the catch in 2016 and 2017 equal to the catch in 2015, and catches from 2018 forward were equal to the TAC. The biomass relative to K was projected forward using random draws from the process error equation within the JAGS MCMC algorithm.

Just Another Bayesian Biomass Assessment (JABBA) model

In addition to BSP1, BSP2, and BSP2-JAGS runs, the recently developed Bayesian State-Space Surplus Production Model R to JAGS interface framework, JABBA, was applied to the North Atlantic (NA) and South Atlantic (SA) shortfin mako shark catch and CPUE data series (SCRS/2017/135). JABBA represents a further development of the modeling framework applied in the 2016 ICCAT South Atlantic blue shark assessment (Carvalho and Winker, 2015), the 2017 North Pacific blue shark assessment (Kai *et al.*, 2017) and the 2017 Mediterranean Albacore assessment. The 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 a shape parameter m.

For the JABBA runs, the same lognormal r and intitial biomass depletion ($\varphi= B_1/K$) priors as for the other BSP model versions were used. All catchability parameters were formulated as uninformative uniform priors, while the process variance and observation variance were implemented by assuming inverse-gamma priors (SCRS/2017/135). To incorporate available standard errors of the year-effect estimated from the standardization models, an additional variance approach for the observation error variance was adopted.

Monitoring the trace and applying Gelman and Rubin (1992) and Heidelberger and Welch (1983) diagnostics suggested that convergence of the MCMC samples to the posterior distribution was achieved after only 100,000 iterations, sampled with a thinning rate of 10 with a burn-in period of 20,000 for each of the two chains.

As additional model performance diagnostics, a jackknife procedure and prediction-validation was applied, including a visual inspection of the retrospective patterns for the C1 catch series runs for the North and South Atlantic. For the jackknife, the Group focused on the relative influence of individual CPUE series by dropping one CPUE at a time and predicting CPUE and the stock status (B / B_{MSY} and H / H_{MSY}) trajectories where H = C/B as defined in SCRS/2017/135. It is used interchangeably in this case with F for surplus production models. For the prediction-validation, the last ten years of CPUE observations were iteratively excluded, the model was refitted and projected forward until the final year 2015. During each backward-iteration, all CPUE observations were removed simultaneously for the respective year. The retrospectives were visualized by only showing projections for the next year instead of projecting all the way forward to the final year 2015.

3.2 Other methods

Catch-only Monte-Carlo method CMSY

Typical production models use time series of catch and fitting of abundance indices to estimate productivity. Instead, the CMSY method uses catch and productivity to estimate biomass, exploitation rate, MSY, and related fisheries reference points as well as the resilience of the species from catch data. In doing so, CMSY provides an alternative assessment tool for situations where CPUE indices are not available or potentially unreliable. Assuming underlying population dynamics of the Schaefer Model, probable ranges of parameters r and K are filtered with a Monte-Carlo algorithm to detect 'viable' r-K pairs. As such, CMSY builds on the concepts of the Catch-MSY method of Martell and Froese (2013), but the main achievement of CMSY compared with the Catch-MSY method lies in overcoming the problems created by a triangular, rather than ellipsoid, distribution of the viable r-k pairs as a result of the Monte-Carlo filtering procedure. Other improvements include adding estimation of biomass and exploitation rates as standard CMSY output and the implementation of a Bayesian state-space Schaefer surplus production model (CMSY.BSM) as a routine tool within the CMSY software (Froese *et al.*, 2016).

For the purpose of this assessment, an "ICCAT-friendly" version (CMSY_ICCATv2.R) was developed for the original CMSY R code by Froese *et al.* (2016) to facilitate comparison of CMSY results with outputs of conventionally used Bayesian surplus production models. Among the newly implemented features are: (1) a plot comparing normalized trends of CMSY biomass projection to observed and predicted CPUE from the CMSY.BSM, (2) plots comparing CMSY distributions for K, r, $Bcur/B_{MSY}$ and $Fcur/F_{MSY}$ to the corresponding posteriors from the CMSY.BSM, as well as priors for K an r and (3) a Kobe-type biplot that allows comparing the CMSY and CMSY.BSM trajectories of the ratios F/F_{MSY} (y-axis) over B/B_{MSY} (x-axis).

For the purpose of comparability, the same r ranges as for the BSP models were used. The CMSY framework allows setting depletion priors (B/K) for the start, middle and end of the time series, which are mainly required for CMSY. The same informative B / K uniform prior range for the first year as Bstart / K = 0.85-0.99 was assumed and vaguely to moderately informative prior ranges for the intermediate Bint / K = 0.3 - 0.9 and final year 2015 Bend / K = 0.1 - 0.8. The only difference between the North and South Atlantic was the setting of the intermediate year to 1990 and 1995, respectively. For the C2 catch time series the authors only adjusted Bstart / K = 0.6-0.99 to allow more flexibility.

3.3 Length-based age-structured models: Stock Synthesis

A length-based age-structured statistical model was implemented with Stock Synthesis (Methot and Wetzel, 2013) version 3.24U (SS3; e.g. Methot, 2015) for the North Atlantic shortfin mako stock. A sex-specific model was implemented to allow for observed sex-specific differences in length and maturity at age. A two-stage data weighting approach was implemented (Francis 2011) to iteratively tune (re-weight) variance adjustment factors for the different fleet-specific data sets (relative abundance indices and length frequency distributions of the catch) used in the model. This approach was previously investigated for North Atlantic blue shark (Courtney *et al.*, 2017). Available time series for 1950-2015 of catch, relative abundance, relative abundance coefficients of variation, and length composition data considered for use in the SS3 model runs were assigned to twelve modelled fleets of catch and six modelled surveys of relative abundance. The catch series used corresponds to C1. During the meeting C2 was used as a sensitivity. Length composition data by sex in 10 cm bins were available for four modelled fleets (Japan LL, Chinse Taipei LL, USA LL, and Venezuela LL) and a length composition for combined sexes was used for one modelled fleet (EU España + Portugal LL). Catch for the remaining five fleets and relative abundance for all surveys were assigned to one of the available length compositions indentified above. Life history inputs were obtained from data first assembled at the 2014 Intersessional meeting of the Shark Species Group (Anon., 2015), and revised during the 2016 Intersessional Meeting of the Shark Species Group (Anon., 2017) and the 2017 Shortfin Mako Shark Data Preparatory Meeting (Anon. (in press)). The model considered age groups zero to 30+. Mean length at each age was assumed to follow a normal distribution and the CV of the mean length at age was assumed to be a linear function of length. Maturity was assumed to change with age. The resulting pup production varied between age groups and was also a function of the length of the mating and gestation cycles. Model convergence was based on whether or not the Hessian inverted, although other convergence diagnostics were also evaluated. Uncertainty in estimated and derived parameters was obtained from asymptotic standard errors calculated from the maximum likelihood estimates of parameter variances at the converged solution. More details of the implementation of SS3 for North Atlantic shortfin mako can be found in SCRS/2017/125.

Natural mortality and stock-recruitment relationship

The Group discussed the plausibility of males having approximately two times higher natural mortality (M) schedules than females at lower ages. The M schedules were assumed, in part, because the estimate of growth completion rate, k, of males was almost double that of females. However, the different M schedules at lower ages are implausible because the length at lower ages of males and females are very similar, especially until both sexes reach maturity. Therefore the Group assumed that males and females have the same M schedules until the age at maturity. The length-at-age of males and females differs after reaching maturity. However, the M schedules of males and females are likely to be only slightly different after reaching maturity because of the large size reached by mature shortfin makos. Furthermore, the original M schedules of females derived from life history invariant methods are almost constant at age and the biological parameters of females are more crucial than those of males in population modeling. Therefore the Group assumed that both males and females have approximately the same M (0.08) for all ages.

The Group discussed the applicability and parameterization of the Low Fecundity Spawner Recruitment (LFSR) developed by Taylor *et al.* (2013) to the stock-recruitment (SR) relationships of shortfin mako in the North Atlantic. The LFSR is a survival based SR function and the equation can produce a variety of SR relationships and pre-recruit survival against pups or spawning biomass. The shape of SR-relationships is governed by two parameters, Sfrac and Beta. The former represents the reduction in mortality as a fraction of –log (unfished recruitment over unfished spawning biomass) and the latter controls the shape of the density-dependent relationship between spawning depletion and pre-recruit survival. The LFSR can produce the same SR relationships as those with the Beverton-Holt (BH) model and the two parameters of the LFSR from the value of steepness (Taylor *et al.* 2013) can be compared. Document SCRS/2017/132 concluded that the LFSR is more suitable for shortfin mako sharks than the BH model because the LFSR can produce a pre-recruit survival against pups or spawning biomass with an increase in survival occurring fastest closer to the unfished equilibrium (convex decreasing survival). In contrast, the pre-recruit survival of the BH model increases fastest at low spawning output (concave decreasing survival). After discussions, the Group decided, although not unanimously, that the concave decreasing survival is less likely for shortfin mako (with survival decreasing fastest at low stock size) and it may be more reasonable for shortfin mako to expect that offspring survival would decrease fastest due to competition when the population approaches unfished biomass level (Beta > 1). The Group then selected parameters of the LFSR (Sfrac=0.171, Beta=3) from two convex decreasing survival curves (Beta=2 and 3) proposed by Document SCRS/2017/132. Based on the comparisons of the likelihood computed by the SS model, the fitting of the model (Beta=3) to the data was slightly better.

4. Stock status results

4.1 Production models

North Atlantic

BSP

For the North Atlantic, all the continuity analysis models in BSP1 converged adequately with percent maximum weight less than 0.5% and similar values of the log(weights) and log(likelihood*priors). All BSP1 results had high K values and were fairly optimistic about current status (**Appendix 5**). However, this model did not fit the abundance trends and was therefore not considered reliable to provide management advice.

When process error was added to the models for the North Atlantic using the BSP2 model, the mode of the posterior distribution was able to track the changes in CPUE indices throughout the time series (**Appendix 5**). These models were not able to converge on the complete posterior distribution, as the percent maximum weight was greater than 0.5% even after 36 million SIR draws. Therefore this model was not considered reliable to provide management advice either.

The North Atlantic BSP2-JAGS model runs all converged adequately, with Gelman-Rubin diagnostics near 1 and effective number of parameters greater than 100 (**Table 1**). The four models were consistent in finding that the mean of current biomass is below B_{MSY} and mean H is above H_{MSY} (**Table 1, Figure 2**). These models all closely tracked the trend in the CPUE series. Although the CVs are wide, current stock status is mostly predicted to be overfished with overfishing occurring (**Figure 3**).

In the diagnostic runs (**Table 2, Figure 4**), the post-model pre-data run caused the population to crash implying that the priors were somewhat pessimistic given the amount of catch that has been removed. When the indices were fitted separately, they were fairly consistent in finding a biomass decline in the 1990s, followed by an increase, but they varied in their estimate of current stock status.

Additional sensitivity analyses done with BSP2-JAGS are presented in **Appendix 5**.

JABBA

Stock depletion (B/K) and status estimates (B / B_{MSY} and H / H_{MSY}) are provided together with the model parameter estimates in **Table 3**. All scenarios consistently predict biomass depletion at close to 50% below B_{MSY} for the final assessment year, 2015, with the range of associated 95% credibility intervals falling entirely below B_{MSY}. The results are therefore similar to the BSP2-JAGS results for the North Atlantic. The estimated H / H_{MSY} trajectories would imply that sustainable harvest rates were already exceeded prior to the 1990s and in 2015 are approximately three to four times higher than sustainable levels.

The jackknife procedure demonstrated that the Schaefer C1 catch run for the North Atlantic (SCRS/2017/135) was fairly insensitive to dropping any one CPUE series at a time as this resulted in hardly discernable effects on the predicted CPUE and stock status trajectories of B / B_{MSY} and H / H_{MSY} (**Figure 5**). The retrospective pattern for the North Atlantic model appeared robust and indicates that the JABBA would have been able to accurately determine the current stock status based on CPUE from 2010 (**Figure 6**).

The prediction validation for the North Atlantic C1 catch scenario suggests that the prediction capacity of JABBA is sufficiently robust to adequately forecast the stock status over time periods of up to eight years, with high accuracy possible over a period of three years (**Figure 7**).

South Atlantic

BSP

The BSP1 continuity runs in the South Atlantic estimated a trajectory where the biomass increased with increasing CPUE (**Appendix 5**). These results are similar to what was found in the 2012 Shortfin Mako Stock Assessment and Ecological Risk Assessment Meeting (Anon., 2013). The BSP2 runs were unable to converge. As the BSP1 model did not fit the abundance trends and the BSP2 model did not converge, neither of these models were considered reliable to provide management advice.

The BSP2-JAGS runs estimated a slightly decreasing biomass trend in the 1970s, before increasing to track the increasing trend in the indices (**Table 4, Figure 8**). The informative prior on B_0/K is probably preventing the model from estimating a lower value of B_0/K. However, the credible intervals are very wide, implying that the trend is very uncertain. At the mean, the population is above B_{MSY}, but the two models disagree on whether the mean harvest rate relative to H_{MSY} is above 1 (**Table 4**).

JABBA

South Atlantic CPUE data were highly variable, and the model was unable to accurately fit the Japanese and Brazilian indices for the South Atlantic shortfin mako stock resulting in considerable noise for the C1 catch series fit (**Figure 9**). In general, the estimated H /H_{MSY} trajectories for South Atlantic JABBA runs show a steadily increasing but fluctuating trend, which started to become unsustainable in the 1990s, peaked around 2005, and then showed a slight decline, but remained unsustainable, in the final year 2015 (**Figure 10**).

The B/B_{MSY} and H/H_{MSY} trajectories for the JABBA model are illustrated by means of Kobe plots for the South Atlantic C1 scenario (**Figure 10**). Contrary to population theory, the trajectory of the South Atlantic stock reveals a clockwise pattern (**Figure 11**) moving from an underexploited state to a recovery as a result of decreasing biomass under sustainable fishing, which is followed by a short period of overfishing before a biomass rebuilding phase during the recent period of unsustainable harvest rate above H_{MSY}. The resulting stock status posterior for 2015 is therefore implausible, with 8% support for an overfished state (red), 3.7% for a sustainable stock (green) and 88.3% (yellow) of the posterior pairs falling within the area of unsustainable harvesting (H / H_{MSY} > 1 and B / B_{MSY} > 1), despite an extended recent period of biomass increase. This pattern points towards a severe contradiction between the state process in the form of catch and resilience (r) information and the observation process in the form of CPUE data.

The jackknife validation procedure applied to the C1 run for the South Atlantic indicated that removing the Uruguay LL Obs data had the strongest effect on the estimate of B / B_{MSY} with the results being more pessimistic. H / H_{MSY} was fairly insensitive to dropping any of the available CPUE time series (**Figure 12**). The diagnostics revealed a strong retrospective pattern that affected B / B_{MSY}, but again to a lesser extent, H / H_{MSY} (**Figure 13**). Such patterns are undesirable, and the South Atlantic diagnostics highlight the poor performance with regards to the robustness of estimates and forward projections of B / B_{MSY} and H / H_{MSY} estimates in the JABBA model.

4.2 Other methods

South Atlantic

CMSY

The Group first explored the performance of CMSY for the North Atlantic as a proof of concept to be applied to the South Atlantic. Comparisons between CMSY and the CMSY.BSM fitted to U.S. logbook LL CPUE and North Atlantic catch data (1950-2015) showed general agreement for the 2015 estimates of H/H_{MSY} and B/B_{MSY} (**Figure 14**). The estimated trajectories also showed similar trends, albeit with some intermittent divergences in the B/B_{MSY} trajectory. The similarity between CMSY, CMSY.BSM and JABBA for the C1 catch series further corroborates that the North Atlantic CPUE indices can be consistently described by these three modelling frameworks.

Although the CMSY and CMSY.BSM estimates of r and K are more similar for the South Atlantic (**Figure 10**) than for the North Atlantic, the 2015 estimates of H / H_{MSY} and B / B_{MSY} were in poor agreement. The CMSY results suggest that the South Atlantic stock status is as pessimistic as that of the North Atlantic. The strong discrepancy between the fitted models and CMSY, which is independent of CPUE, further highlights that the CPUE-driven stock status estimates for the South Atlantic should be treated with caution. There was agreement between the process error model stock estimates for North Atlantic and the catch-only method CMSY, but strong discrepancies between CMSY and fitted models for South Atlantic. It is therefore likely that the poor fit in the South Atlantic can be attributed to the apparent contradiction between the observation process (i.e. CPUE) and process equation, which is informed by the catch and resilience (*r*).

The CMSY model B/B_{MSY} and H /H_{MSY} trajectories are illustrated by means of Kobe plots for the South Atlantic. C1 and C2 scenarios are illustrated in **Figures 15 and 16**, as well as **Table 5**. The results for CMSY scenario 1 is more pessimistic than that of scenario 2, with scenario 1 indicating that the South Atlantic shortfin mako stock is in an overfished state whereas scenario 2 indicates it is a little above MSY. Both scenarios indicate the stock is currently experiencing overfishing, with scenario 1 indicating strong overfishing and scenario 2 indicating that H is just above H_{MSY}.

4.3 Stock Synthesis

North Atlantic

Three Stock Synthesis model runs were evaluated. Comparisons of stock status indicator trajectories between the three model runs are provided in **Figure 17**. Stock Synthesis model run 1 represented the original model presented to the Group as described in (SCRS/2017/125). The Kobe plot for this model is presented in **Figure 18**. The Stock Synthesis model was updated (Stock Synthesis model run 2) to set natural mortality for males equal to that for females (**Figure 19**). The Group recommended evaluating four Stock Synthesis model runs using the LFSR relationship. Three Stock Synthesis model runs using the LFSR relationship were developed by fixing the Beta parameter at values of 1, 2, and 3, and then solving analytically for the LFSR sfrac parameter values (0.212, 0.176, and 0.171, respectively) which correspond to the original steepness value (0.345) of the BH stock-recruitment relationship used in Stock Synthesis. An additional model run was developed by solving for the LFSR Beta (0.642) and sfrac (0.263) parameter values simultaneously with an optimization routine which correspond to the original steepness value (0.345) of the BH stock-recruitment relationship used in Stock Synthesis. Based on a Group recommendation, the Stock Synthesis model was updated (Stock Synthesis model run 3) to replace the BH stock recruitment relationship with the LFSR relationship using Beta = 3 and sfrac = 0.171 (**Figure 20**). Model results are presented below for model run 3, which the Group considered to be the base run for Stock Synthesis (**Tables 6-8**).

Five model sensitivities were also evaluated as summarized below. Model sensitivity 1 evaluated model sensitivity to uncertainty in *catch* data. Model run 1 was modified by replacing the catch data series (C1:1950-2015) in the model with an alternative catch data series (C2: 1971-2015). Initial fishing mortality was estimated in 1971 by assuming that catch prior to 1971 was equal to the average total alternative catch for the years 1971-1980, and estimating one additional parameter in the model for the initial fishing mortality necessary to remove the historic catch annually. It was noted that the same Stock Synthesis model (model run 1) was not able to estimate initial fishing mortality with the original catch series (C1) when truncated from 1971-2015. It was noted that the ability to estimate initial fishing mortality with the alternative catch data (C2) indicates that the higher alternative catch data early in the time series may be consistent with the other data in the model. In other words, the model sensitivity analysis provided support for higher historic catch. However, the Group discussed that the alternative catch data may not be appropriate at this time for use in the model because of insufficient time to evaluate the SS3 fits to this alternate catch series.

Model sensitivity 2 evaluated model sensitivity to uncertainty in *length-based selectivity*. Model run 2 was modified by replacing the double normal length-based selectivity curves estimated in the model with logistic selectivity consistent with the previous assessment conducted for North Atlantic shortfin mako (Anon., 2013). The previous assessment used empirically derived logistic selectivity at age for roughly the same fleets using available length composition data.

It was noted that results from the sensitivity run 2 showed a different pattern in the modelled population's response to fishing pressure than the results obtained from model runs 1, 2, and 3. In particular, under the sensitivity analysis, the annual spawning stock size appeared to fluctuate slightly over time in response to changes in stock size which resulted from observed changes in fishing pressure and estimated recruitment. In contrast, under model runs 1, 2, and 3 (**Figure 17**) the annual spawning stock size appeared to decrease monotonically over time as if under equilibrium and did not fluctuate in response to observed changes in fishing pressure and estimated recruitment. It was noted that because of the combination of low natural mortality and dome-shaped selectivity in model run 2, there was a large proportion of the modelled population numbers at higher ages (both mature male and mature female) present, in particular the age 30+ age bin. That is consistent with the observation that the body weight of the mature sharks is much higher than that of most of the sharks available to the fishery. Mature sharks are not harvested due to the assumptions of the selectivity curves and the length data. Consequently, the mature biomass at older ages and the 30+ age sharks declined gradually over time only in response to natural mortality and most of the mature fish including the spawner biomass remained, contributing to the recruitment.

It was noted that the model runs 1, 2, and 3 with dome-shaped selectivity appeared to result in hyper stability of spawning stock size (e.g. **Figures 18-20**), i.e. under fishing mortality with dome-shaped selectivity on immature animals, few recruits reach reproductive age and growth overfishing is occurring. The spawning stock then only appears to be stable because the mature sharks are not selected. The Group noted that this is problematic for the management implementation because under this scenario the spawning stock size would not be expected to respond to a reduction in fishing mortality on immature sized animals until after those immature animals mature and contribute to the reproduction, which could be many years.

In contrast, model sensitivity 2, which assumed asymptotic selectivity, did not appear to have a hyper stable spawning stock size, which is more consistent with the expectation of a stock that responds directly to fishing pressure. However, it was noted that the asymptotic selectivity scenario fits to both relative abundance and length composition were very poor. Consequently a lot of work would be needed to identify plausible causes of the poor fit to each data set and to recommend ways of addressing them either in the model, by adding more structure to the model or externally to the model, for example by reformulating the data as was proposed for the bluefin shark assessment (Anon., 2016). It was noted that in an effort to fit the available data expediently for the current assessment, dome-shaped selectivity was allowed based on estimation of the selectivity parameters, which allowed the shape of the selectivity curve at lengths greater than the peak in selectivity to be estimated based on fits to the length composition data.

Model sensitivity 3 continued the evaluation of model sensitivity to uncertainty in *length-based selectivity*. Model sensitivity 3 modified the selectivity for fleet 4 (U.S. LL) to allow the shape of the selectivity curve at lengths greater than the peak in selectivity to be estimated based on fits to the length composition data. The length frequency of sharks caught by the U.S. LL is centered at a smaller size than the other fleets, and this scenario resulted in dome-shaped selectivity for fleet 4 (and all fleets which mirrored the selectivity of fleet 4) and imposed asymptotic selectivity for all other fleets. However, the results of this scenario were similar to the poor fits to relative abundance and length composition as obtained in model sensitivity 2, and was therefore not pursued further.

Model sensitivity 4 evaluated model sensitivity to the *CV in the distribution of length at age*. Model run 2 was modified to estimate the CV for L_{Amin} (female and male). A concern raised by the Group was that the current CVs were based only on uncertainty in the length at age data and did not account for other sources of uncertainty especially for the youngest ages. The Group suggested that the CV for L_{Amin} (female and male) should probably be larger in order to account for this uncertainty in the model. However, the estimated values for the CV of L_{Amin} (0.034 for young females and 0.095 for young males) were smaller than those obtained from the data (0.093 for females and 0.097 for males). This did not seem plausible and was not pursued further.

Model sensitivity 5 evaluated model sensitivity to *stage 2 estimation of effective sample size (effN) for length composition data*. Model run 2 was modified by replacing the eff*N* for length composition obtained with the Francis method with the eff*N* for length composition obtained with the McAllister and Ianelli method. Both methods are defined in the cited references provided in SCRS/2017/125 and were presented and discussed in detail at the 2016 Intersessional Meeting of the Shark Species Group (Anon., 2017), and based on the material presented at that meeting both methods appear reasonable. However, because the two approaches use different methods to arrive at the eff*N*, the resulting values for eff*N* differ. In this case, the eff*N* values obtained from the McAllister and Ianelli method (using the harmonic mean) were higher than those obtained using the Francis method (gave more weight to the length data in the model likelihood). An evaluation of the model likelihood indicated that this also resulted in a relatively worse fit to the abundance indices. This result suggests that there is conflict in the data when used in the assessment (i.e. increasing the weight given to one data set in the model likelihood resulted in worse fit to another data set). The Group suggested that when there is data conflict in an assessment model, then it is important not to let the fit to length composition reduce the fit to the indices. Consequently the Group recommended using the relatively lower eff*N* provided by the Francis method.

General comments on the Stock Synthesis model

Although several misspecifications and uncertainties might be included in the current model setting, the current base model of SS3 converged reasonably well and produced reasonable results for the available fishery and biological data. In consideration of the biological and fisheries characteristics (i.e. age- and sex-specific growth, sex-specific mature size, fecundity proportional to body length, low-fecundity stock recruitment relationship, lower natural mortality through all the age classes, and all fleets are only selecting immature sharks and the availability and vulnerability is different by sexes) of shortfin makos, the results of the sex- and age-specific structured model (SS) may in the future be more suitable to provide the management advice than production type models (BSPM) once the model has been fully explored.

It is worth noting that high values of F (>0.20) were obtained with SS3 starting in 1993. These values are consistent with those estimated from satellite tagging data for shortfin makos of similar lengths and ages. Specifically, the F value derived from tagging (SCRS/P/2017/022) for the period 2013-2016 was 0.33 (0.19-0.56 95% CI) and the F values estimated in SS3 for 2013-2015 ranged from 0.21 to 0.25.

4.4 Synthesis of assessment results

Considerable progress was made since the last assessment on the integration of new data sources (in particular size data and sex-specific information) and modelling approaches (in particular model structure). Uncertainty in data inputs and model configuration were explored through sensitivity analysis. The production models in the South had difficulty fitting the increasing trends in the CPUE series combined with increasing catches. The results obtained from these models for this region were implausible as there is conflict between the data and the model assumptions. Management advice was thus based on the CMSY model in the South. The results are summarized below.

North Atlantic

For the North Atlantic stock, scenarios with the BSP2-JAGS estimated that the stock was both overfished (B_{2015}/B_{MSY}=0.63 to 0.85) and that overfishing was occurring (H_{2015}/H_{MSY}=1.93 to 3.58). The probability of the stock being overfished and experiencing overfishing was 82.1 – 97.8% (Kobe red zone: **Figure 21**). The JABBA model indicated that the stock was both overfished (B_{2015}/B_{MSY}=0.57 to 0.76) and that overfishing was occurring (H_{2015}/H_{MSY}=3.75 to 4.37), resulting in a 92.6 – 99.9% probability of being in an overfished state and still experiencing overfishing (**Figure 21**). Estimates obtained with the final SS3 run predicted that the stock was probably overfished (SSF_{2015}/SSF_{MSY}=0.95, where SSF is spawning stock fecundity) and that overfishing was occurring (F_{2015}/F_{MSY}=4.38, CV=0.11) with a probability of 56.1% of being overfished and experiencing overfishing (**Figure 21**). The Kobe phase plots for the individual model runs in the North Atlantic are provided in **Figure 22**, while the combined Kobe phase plot is provided in **Figure 23**. The combined probability from all the models of being in an overfished state while still experiencing overfishing was 90% (**Figure 24**). CMSY was only used as a proof of concept in the North (and the results were similar to the production models) and so the results are not presented here.

The models agree that the northern stock was overfished and was undergoing overfishing. The results obtained in this evaluation are not comparable with those obtained in the last assessment in 2012 because the input data and model structures have changed significantly. The catch time series are different (they now start in 1950 vs. 1971 in the 2012 assessment) and were derived using different assumptions; the CPUE series have been decreasing since 2010 (the last year in the 2012 assessment models)); some of the biological inputs have changed and are now sex specific; and additional length composition data became available. Additionally, in 2012 only the BSP1 production model and a catch-free age-structured production model were used. This updated assessment represents a significant improvement in our understanding of current stock status for North Atlantic shortfin mako.

South Atlantic

For the South Atlantic stock, scenarios with the BSP2-JAGS estimated that the stock was not overfished (B_{2015}/B_{MSY}=1.69 to 1.75) but that overfishing may be occurring (F_{2015}/F_{MSY}=0.86 to 1.07). For the BSP2-JAGS model, estimates from the 2 runs indicated a 0.3-1.4% probability of the stock being overfished and overfishing occurring (red quadrant in Kobe plot), a 29-47.4% probability of the stock not being overfished but overfishing occurring, or alternatively, the stock being overfished but overfishing not occurring (yellow quadrants in Kobe plot), and a 52.3-69.6% probability of the stock not being overfished and overfishing not occurring (green quadrant in Kobe plot) (**Figure 25**). In the JABBA model Kobe plot the South Atlantic stock trajectory reveals a clockwise pattern moving from an underexploited state to a recovery as a result of decreasing biomass under sustainable fishing, which is followed by a short period of overfishing, which is implausible. The model results were therefore not considered for management advice. Model estimates obtained for the CMSY model indicate that the stock could be overfished (B_{2015}/B_{MSY}= 0.65 to 1.12) and that overfishing is likely occurring (F_{2015}/F_{MSY}=1.02 to 3.67). Considering catch scenarios C1 and C2, model estimates from the CMSY model indicated a 23-89% probability of the stock being overfished and overfishing occurring (red quadrant in Kobe plot), a 11-48% probability of the stock not being overfished but overfishing occurring, or alternatively, the stock being overfished but overfishing not occurring (yellow quadrants in Kobe plot), and only a 0-29% probability of the stock not being overfished and overfishing not occurring (green quadrant in Kobe plot) (**Figure 25**). The combined model results indicate a probability of 19% that the stock is both overfished and experiencing overfishing (**Figure 26**). The Group considers the stock status results for the South Atlantic to be highly uncertain. Despite this uncertainty, it is not possible to discount that in recent years the stock may have been at, or already below, B_{MSY} and that fishing mortality is already exceeding F_{MSY}. The Kobe phase plots for the individual model runs in the South Atlantic are provided in **Figure 27**, while the combined Kobe phase plot is provided in **Figure 28**.

5. Projections

Projections were only carried out for BSP2-JAGS models in the North Atlantic. No projections were conducted for the South Atlantic due to the uncertainty of stock status explained above.

The BSP2-JAGS model projections indicated that current catch levels (C1 = 3,600 t, and C2 = 4,750 t, mean of the last 5 years) in the North Atlantic will cause continued population decline. According to the more optimistic C1 and C2 catch series Schaefer model projections, catches would need to be 1000 t or lower to prevent further population declines (**Figure 29 a and b**). For the corresponding generalized production models, catches would also have to be reduced to below 1000 t to prevent further population declines (**Figure 29 c and d**). Overall, this implies reductions in catches in the order of 72-79%. Kobe II matrices showing the probabilities of $F<F_{MSY}$, $B>B_{MSY}$, and $B>B_{MSY}$ + $F<F_{MSY}$ (green quadrant of the Kobe plot) under different constant catch levels are shown in **Table 9**.

Although in terms of SSF the current stock size for SS3 appears more optimistic than the aggregated biomass dynamic models, the future outlook is probably more pessimistic. This is because the juveniles are being removed beginning at age at first capture and so are not reaching maturity. It can be anticipated that spawning stock size will decline for many years after fishing pressure has been reduced until the recruits reach maturity.

6. Recommendations

6.1 Research and statistics

- The Group noted the importance of having the sex information on the conventional tagging database. Such data are usually reported for sharks, but currently are not available in the ICCAT database. Therefore, the Group recommends that the Secretariat revises the conventional tagging database to include this field and make it available in the cases where such information was reported.
- The Group recommends to focus research efforts on identifying pupping grounds to increase our knowledge of shortfin mako reproductive behaviour which could lead to improved scientific advice.
- The Group recommends further research on the implications of priors and error structure in Bayesian surplus production models.
- The Group reiterates the recommendations from the Data Preparatory Meeting http://iccat.int/Documents/Meetings/Docs/2017_SMA_DATA_PREP_ENG.pdf
- The Group emphasizes that identification of a robust TAC in the future will require developing projections in SS3 in addition to those undertaken using production models.

6.2 Management

- For the North Atlantic stock, projections were based on the production modelling approach only (BSP2-JAGS), which indicated that catches would need to be reduced to 1,000 t or lower to prevent further population declines. However, taking into consideration the timeline for stock rebuilding based on this approach, it should be noted that for a TAC of 1,000 t the probability of being in the Kobe plot green zone ($F<F_{MSY}$ and $B>B_{MSY}$) (**Table 9**) is estimated to be only 25% by 2040.
- The Group indicated that releasing animals brought to the vessel alive could be a potentially effective measure to reduce fishing mortality as studies indicate post-release survival is likely to be about 70%. Following best practices to correctly handle and release live specimens could therefore further increase post-release survival. However, at this time the Group does not have enough information to assess if the adoption of live releases alone will be enough to reduce landings to 1,000 t or less and stop further stock decline.

- For the South Atlantic stock, given the uncertainty in stock status and considering the large fluctuations in catch, the Group recommends that until this uncertainty is reduced, catch levels should not exceed the average catch in the last five years (2,854 t with scenario C1 or 2,933 t with scenario C2), or about 2,900 t.
- Given the limited time available for discussing management recommendations, the Group decided to continue discussing them at the Shark Species Group meeting in September.

7. Other matters

There were no other matters.

8. Adoption of the report and closure

The report was partially adopted by the Group and the meeting was adjourned. Sections 4.1, 4.4, and 6.2 of the report were later adopted by correspondence.

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Table 1. North Atlantic BSP2-JAGS model runs. Rhat is the Gelman-Rubin diagnostic, n.eff is the effective number of parameters (Values are means and CVs are in parentheses).

Parameter	**1N C1**	**2N C2**	**3N C1 generalized**	**4N C2 generalized**
Rhat	1.02	1.01	1.01	1.01
n.eff	160	230	320	160
K(1000)	154.29(0.29)	246.95(0.32)	125.11(0.37)	214.03(0.35)
r	0.04(0.54)	0.03(0.47)	0.04(0.58)	0.03(0.48)
Bo/BMSY	1.82(0.13)	1.68(0.16)	1.36(0.13)	1.28(0.15)
B2015/BMSY	0.85(0.2)	0.75(0.21)	0.78(0.23)	0.63(0.24)
H2015/HMSY	2.97(0.47)	3.58(0.45)	1.93(0.48)	2.41(0.44)

Table 2. North Atlantic BSP2-JAGS diagnostic runs **(**Values are means and CVs are in parentheses).

Parameter	**5N pmpd**	**6N index 1**	**7N index 2**	**8N index 3**	**9N index 4**	**10N index 5**
Rhat	3.17	1.03	1.01	1.01	1.02	1.01
n.eff	3	74	1200	460	810	330
K(1000)	221.65(2.91)	231.3(0.58)	694.27(1.06)	394.83(1.32)	873.6(0.93)	363.71(1.43)
r	0.03(0.46)	0.03(0.5)	0.03(0.46)	0.03(0.46)	0.03(0.45)	0.03(0.47)
Bo/Bmsy	1.82(0.13)	1.85(0.12)	1.79(0.14)	1.8(0.13)	1.78(0.14)	1.82(0.13)
Bcur/Bmsy	0.29(2.21)	0.95(0.26)	1.58(0.27)	1.13(0.43)	1.92(0.27)	0.98(0.61)
Hcur/Hmsy	14977(0.9)	2.75(0.53)	0.99(0.91)	2.9(1.06)	0.58(0.87)	6.83(2.05)

Table 3. Stock depletion and status estimates, together with model parameters, for the JABBA model applied to the North Atlantic shortfin mako for catch scenarios C1 and C2.

(A) Base-case catch time series (C1)						
	NA.Schaefer.C1			NA.Pella.C1		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	137365.3	79046.5	247732.8	123223.9	70840.1	260386.8
r	0.032	0.013	0.098	0.074	0.029	0.204
σ	0.09	0.063	0.134	0.089	0.063	0.134
H_{MSY}	0.016	0.006	0.049	0.015	0.006	0.041
B_{MSY}	68682.6	39523.2	123866.4	82558.3	47461.9	174455.6
MSY	1146.8	445.8	2523.1	1287.3	526.3	2863.5
B_{1950}/K	0.746	0.554	0.994	0.781	0.575	0.989
B_{2015}/K	0.381	0.257	0.545	0.414	0.276	0.586
B_{2015}/B_{MSY}	0.763	0.514	1.090	0.618	0.412	0.874
H_{2015}/H_{MSY}	3.749	1.465	10.582	4.128	1.606	11.414
(B) Alternative catch time series (C2)						
	NA.Schaefer.C2			NA.Pella.C2		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	187530.6	113905.0	351652.0	172713.1	100950.1	348444.0
r	0.030	0.012	0.073	0.076	0.030	0.203
σ	0.10	0.063	0.145	0.095	0.063	0.141
H_{MSY}	0.015	0.006	0.036	0.015	0.006	0.04
B_{MSY}	93765.3	56952.5	175826.0	115715.4	67635.2	233452.7
MSY	1440.3	559.0	3337.5	1831.6	727.9	4193.5
B_{1950}/K	0.834	0.605	1.024	0.844	0.573	1.04
B_{2015}/K	0.344	0.215	0.518	0.384	0.236	0.569
B_{2015}/B_{MSY}	0.689	0.430	1.036	0.573	0.352	0.849
H_{2015}/H_{MSY}	4.379	1.608	12.374	4.167	1.571	11.414

Table 4. South Atlantic BSP2-JAGS model runs (Values are means and CVs are in parentheses).

Parameter	**11S C1**	**12S C2**	**13S pmpd**
Rhat	1.01	1.01	1
n.eff	160	200	1000
K(1000)	121.94(0.39)	139.76(0.38)	137.7(0.36)
r	0.06(0.27)	0.06(0.27)	0.06(0.27)
Bo/Bmsy	1.48(0.18)	1.48(0.18)	1.47(0.18)
Bcur/Bmsy	1.75(0.19)	1.69(0.19)	1.69(0.19)
Hcur/Hmsy	1.07(0.46)	0.86(0.44)	0.86(0.43)

Table 5. Stock depletion and status estimates, together with model parameters, for the C_{MSY} model applied to the South Atlantic shortfin mako for catch scenarios C1 and C2.

	CMSY.SA.C1			CMSY.SA.C2		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	66067.715	42003.174	103919.360	129096.863	64563.960	258131.624
r	0.069	0.053	0.089	0.069	0.053	0.089
H_{MSY}	0.034	0.026	0.045	0.034	0.026	0.045
B_{MSY}	33033.857	21001.587	51959.680	64548.431	32281.980	129065.812
MSY	1.132	0.778	1.649	2.213	0.950	5.157
B_{2015}/K	0.324	0.109	0.527	0.562	0.141	0.784
$B_{2015}/B_{\mathrm{MSY}}$	0.647	0.218	1.053	1.125	0.282	1.569
$H_{2015}/H_{\mathrm{MSY}}$	3.666	2.252	10.867	1.024	0.734	4.088

Table 6. Stock Synthesis model run 3 estimates of ending year (2015) stock status relative to maximum sustainable yield (MSY), including spawning stock fecundity (SSF_{2015}), fishing mortality (F_{2015}, calculated as the sum of continuous F obtained for each fleet), and recruits (R_{2015}), along with equilibrium SSF (SSF_0) and R (R_0), maximum sustainable yield (MSY), SSF at MSY (SSF_{MSY}), F at MSY (F_{MSY}) and the ratios SSF_{2015}/SSF_{MSY} and F_{2015}/F_{MSY}. Asymptotic standard errors (SE) calculated from the maximum likelihood estimates of parameter variances at the converged solution and CV based on the SE (where available) are also provided for the parameter estimates.

Ending year (2015) stock status relative to MSY reference points	Estimate	SE	CV
SSF_{2015} (1,000s)	558	50	9%
F_{2015}	0.247	---	---
R_{2015} (1,000s)	140	12	8%
SSF_0	1,126	52	5%
R_0	220	10	5%
MSY (t)	1,004	33.29	3%
SSF_{MSY}	586	27	5%
F_{MSY}	0.056	0.002	4%
SSF_{2015}/SSF_{MSY}	0.952	---	---
F_{2015}/F_{MSY}	4.379	0.49	11%

Table 7. Stock Synthesis model run 3 annual estimates of total biomass (B), spawning stock fecundity (SSF), recruits (R), total fishing mortality (F, calculated as the sum of continuous F obtained for each fleet).

Year	B (t)	SSF ((1,000s)	R (1,000s)	F
Virg		1,126	220	
Init		1,126	220	
1950	277,435	1,126	220	0.004
1951	277,310	1,126	220	0.002
1952	277,212	1,126	220	0.002
1953	277,107	1,126	220	0.003
1954	276,976	1,126	220	0.001
1955	276,915	1,126	220	0.002
1956	276,831	1,126	220	0.001
1957	276,769	1,126	220	0.002
1958	276,656	1,125	220	0.002
1959	276,557	1,125	220	0.003
1960	276,434	1,125	220	0.002
1961	276,343	1,125	220	0.004
1962	276,166	1,125	220	0.006
1963	275,925	1,125	220	0.003
1964	275,790	1,124	220	0.005
1965	275,580	1,124	220	0.004
1966	275,401	1,123	220	0.008
1967	275,090	1,123	220	0.007
1968	274,794	1,122	220	0.009
1969	274,415	1,122	220	0.009
1970	274,025	1,121	220	0.008
1971	273,658	1,120	220	0.012
1972	273,136	1,120	220	0.011
1973	272,622	1,119	220	0.011
1974	272,116	1,118	220	0.015
1975	271,408	1,117	220	0.018
1976	270,577	1,116	220	0.009
1977	270,118	1,115	220	0.014
1978	269,469	1,114	220	0.013
1979	268,894	1,112	220	0.013
1980	268,392	1,111	220	0.019
1981	267,625	1,109	220	0.030
1982	266,213	1,107	220	0.034
1983	264,546	1,104	220	0.038
1984	262,899	1,102	219	0.040
1985	260,775	1,099	182	0.087
1986	255,945	1,095	169	0.120
1987	250,774	1,091	167	0.124
1988	245,659	1,086	170	0.112
1989	240,574	1,081	186	0.083

Table 7. Continued.

Year	B (t)	SSF (1,000s)	R (1,000s)	F
1990	236,134	1,077	179	0.102
1991	231,458	1,071	176	0.106
1992	226,733	1,065	167	0.151
1993	220,930	1,058	166	0.201
1994	213,765	1,050	160	0.200
1995	206,865	1,040	144	0.276
1996	197,888	1,028	143	0.352
1997	188,682	1,014	177	0.273
1998	181,327	1,000	229	0.289
1999	174,051	983	223	0.235
2000	168,455	966	266	0.199
2001	163,695	946	264	0.206
2002	159,188	925	191	0.234
2003	154,592	902	283	0.260
2004	150,071	877	311	0.239
2005	146,061	850	312	0.220
2006	142,810	822	233	0.203
2007	139,983	792	177	0.224
2008	136,671	762	190	0.197
2009	133,790	731	210	0.241
2010	129,881	700	162	0.268
2011	125,502	669	145	0.224
2012	121,963	639	141	0.285
2013	117,478	610	151	0.251
2014	113,706	583	145	0.212
2015	110,638	558	140	0.247

Table 8. Stock Synthesis model run 3 annual estimates of total fishing mortality (F, calculated as the sum of continuous F obtained for each fleet) relative to fishing mortality at MSY (F/F_{MSY}) and spawning stock fecundity (SSF 1,000s) relative to spawning stock fecundity at MSY (SSF/SSF_{MSY}).

Year	F/F_{MSY}	SSF/SSF_{MSY}
1950	0.064	1.921
1951	0.043	1.921
1952	0.043	1.921
1953	0.053	1.921
1954	0.013	1.921
1955	0.027	1.921
1956	0.017	1.921
1957	0.044	1.921
1958	0.037	1.921
1959	0.049	1.921
1960	0.032	1.921
1961	0.078	1.920
1962	0.107	1.920
1963	0.047	1.919
1964	0.087	1.919
1965	0.069	1.918
1966	0.138	1.917
1967	0.124	1.916
1968	0.164	1.915
1969	0.163	1.914
1970	0.148	1.913
1971	0.205	1.912
1972	0.197	1.911
1973	0.202	1.910
1974	0.259	1.908
1975	0.315	1.907
1976	0.167	1.905
1977	0.249	1.903
1978	0.231	1.901
1979	0.222	1.898
1980	0.330	1.896
1981	0.532	1.893
1982	0.598	1.889
1983	0.666	1.885
1984	0.702	1.880
1985	1.549	1.875
1986	2.128	1.868
1987	2.199	1.861
1988	1.979	1.854
1989	1.466	1.846

Table 8. Continued.

Year	F/F_{MSY}	SSF/SSF_{MSY}
1990	1.813	1.838
1991	1.869	1.828
1992	2.670	1.818
1993	3.556	1.806
1994	3.542	1.791
1995	4.887	1.775
1996	6.227	1.755
1997	4.828	1.731
1998	5.126	1.707
1999	4.170	1.679
2000	3.525	1.648
2001	3.653	1.615
2002	4.143	1.579
2003	4.599	1.540
2004	4.228	1.497
2005	3.892	1.451
2006	3.589	1.403
2007	3.964	1.353
2008	3.493	1.301
2009	4.268	1.248
2010	4.748	1.195
2011	3.971	1.142
2012	5.054	1.091
2013	4.444	1.042
2014	3.763	0.995
2015	4.379	0.952

Table 9. Kobe II risk matrix giving the probability that the fishing mortality will be below the fishing mortality rate at MSY (top), the probability that the biomass will exceed the level that will produce MSY (middle), and the two combined (bottom) based on BSP2-JAGS results for North Atlantic shortfin mako.

Probability that $F<F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	75	75	74	75	75	74	75	75	74	76	75	75	75	75	76	76	76	74	75	74	75	75	75
1000	0	0	30	31	32	32	32	31	32	33	34	35	35	35	36	35	35	36	38	37	38	38	38	38	38
1500	0	0	11	11	10	11	11	13	13	13	14	14	14	14	14	14	15	14	15	15	16	16	16	16	16
2000	0	0	2	2	3	4	4	4	4	4	4	5	5	4	4	5	5	5	5	6	5	6	6	6	6
2500	0	0	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Probability that $B>B_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
0	7	7	6	8	10	13	16	19	21	24	27	29	31	33	36	38	41	42	43	45	46	47	50	52	54
500	5.8	5	4	6	9	10	12	14	15	16	19	20	21	23	24	25	27	28	29	31	30	32	33	35	35
1000	6	5	6	7	9	9	10	13	13	14	16	17	18	20	21	21	22	24	23	25	25	25	25	26	27
1500	6	6	6	7	8	8	10	10	11	11	12	12	12	13	13	14	15	15	16	16	17	17	16	16	16
2000	6	5	5	6	7	7	7	8	8	8	9	9	9	8	8	9	9	9	8	9	9	9	9	9	9
2500	6	6	6	6	7	7	7	6	6	6	7	6	6	7	7	6	7	6	6	6	6	6	6	6	6
3000	6	6	5	7	6	5	5	6	5	5	5	5	5	4	4	4	4	3	3	3	3	3	3	3	3
3500	6	5	6	6	6	5	5	5	5	5	5	3	3	3	3	2	2	2	2	2	2	2	2	2	2
4000	6	5	6	5	4	4	3	3	2	2	2	2	2	1	1	1	1	1	1	1	1	0	0	0	0

Probability of being in the green zone ($F<F_{MSY}$ and $B>B_{MSY}$)

TAC (t)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
0	0	0	6	8	11	13	16	19	21	24	27	29	31	33	36	38	41	42	43	45	46	47	50	52	54
500	0	0	4	6	9	10	12	14	15	16	19	20	21	23	24	25	27	27	29	31	30	32	33	35	35
1000	0	0	5	6	8	8	9	10	11	12	15	15	15	17	19	19	20	22	21	23	23	23	23	24	25
1500	0	0	3	3	4	5	5	6	7	7	7	8	8	9	9	10	10	10	11	11	12	12	12	12	12
2000	0	0	0	1	2	2	2	3	3	2	3	3	3	3	3	4	4	4	4	5	4	5	5	5	5
2500	0	0	0	0	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

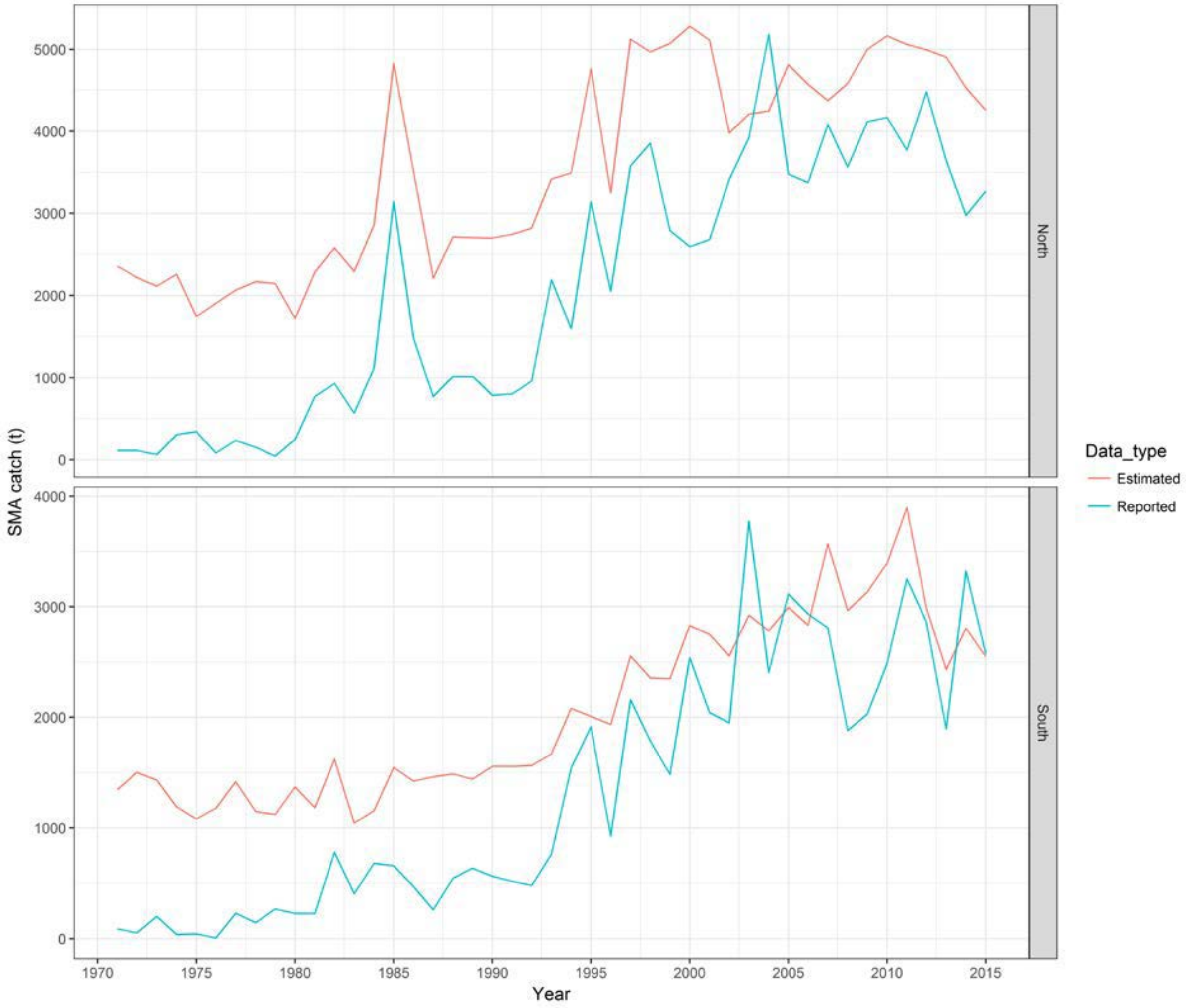


Figure 1. Time series of reported (Task I) and estimated shortfin mako shark (SMA) catches, between 1971 and 2015, for the North and South Atlantic stocks.

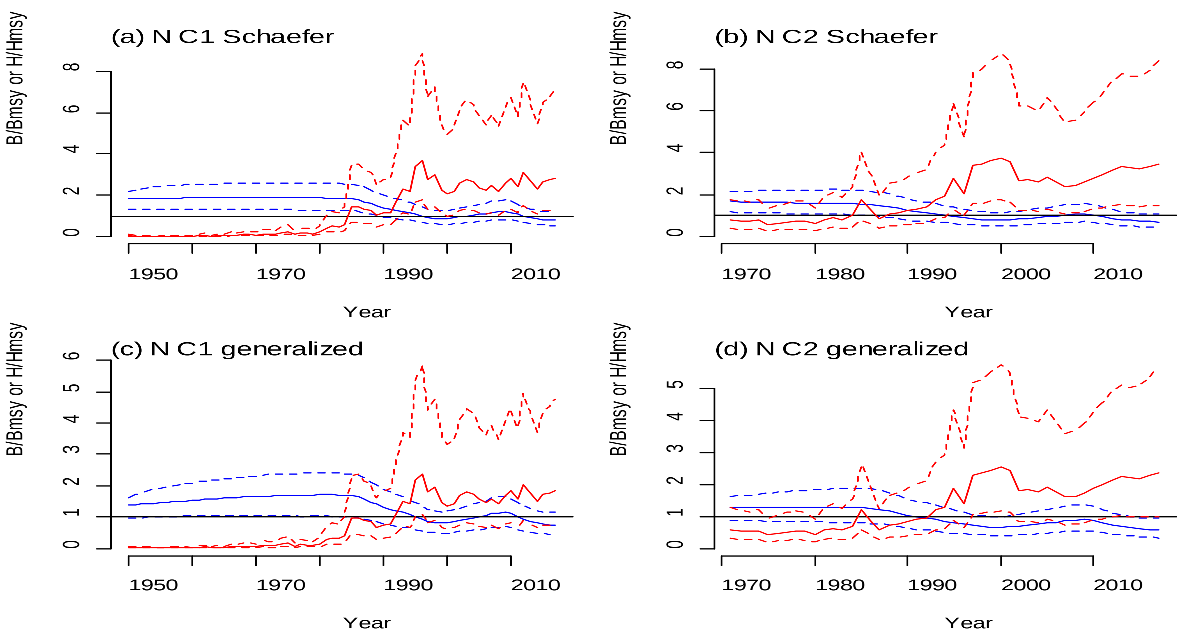


Figure 2. North Atlantic BSP2-JAGS biomass (blue) and harvest rate (red) histories for (a) C1 Schaefer, (b) C2 Schaefer, (c) C1 generalized production model, and (d) C2 generalized production model.

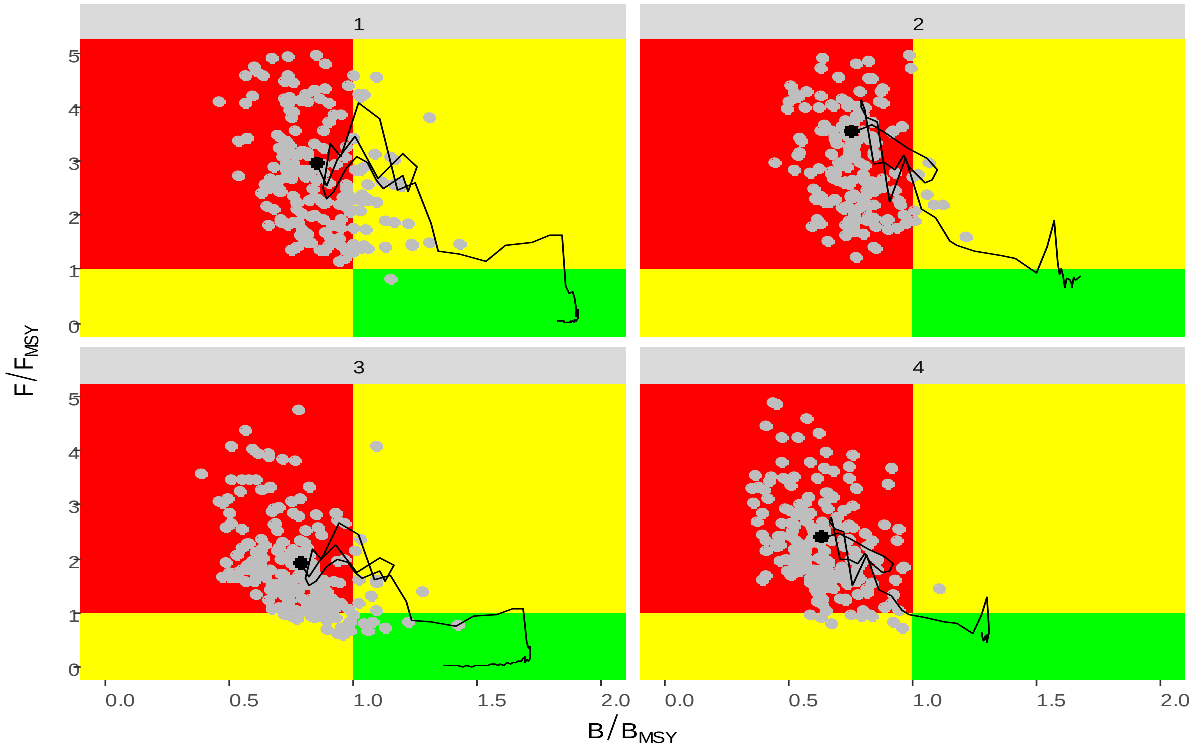


Figure 3. Kobe plots for BSP2-JAGS in the North Atlantic, for (a) C1 Schaefer, (b) C2 Schaefer, (c) C1 generalized production model, and (d) C2 generalized production model. Each point represents an MCMC draw. The solid black dot denotes current (2015) stock status.

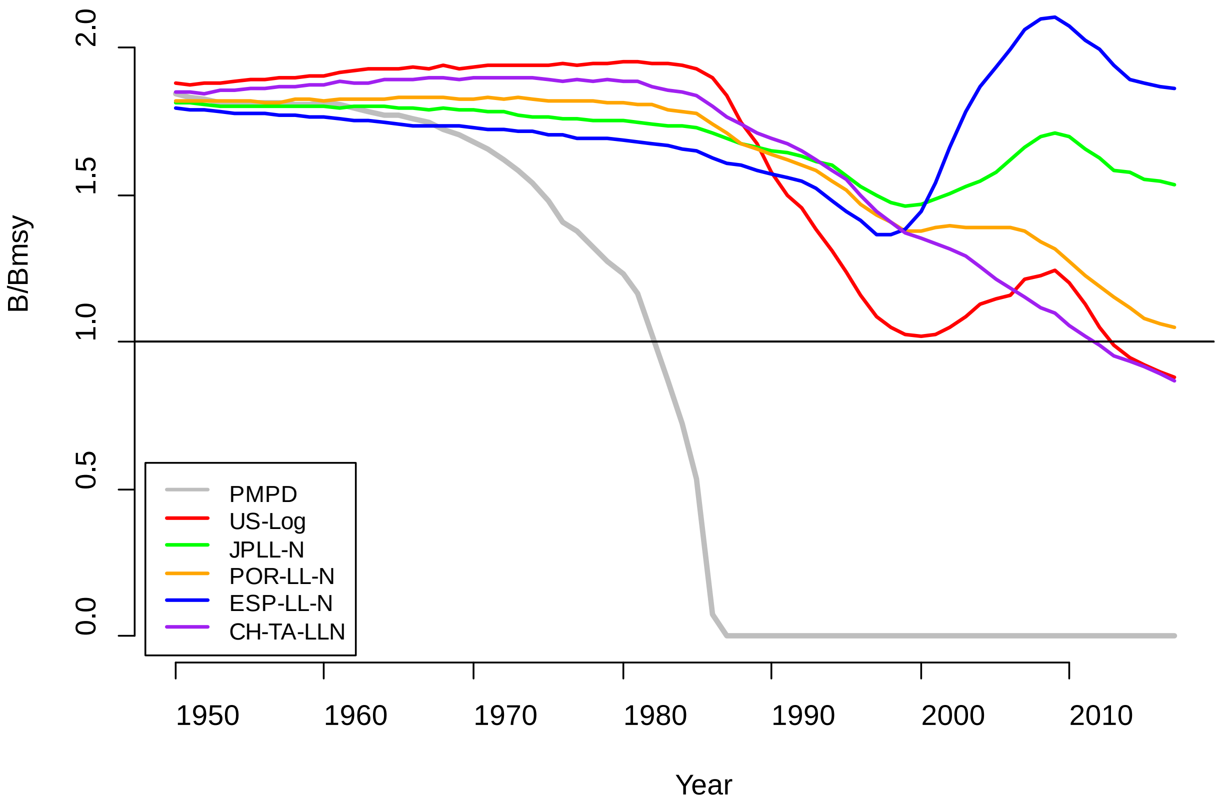


Figure 4. North Atlantic BSP2-JAGS diagnostic model runs, including post-model pre-data (PMPD), and each index of abundance fitted separately.

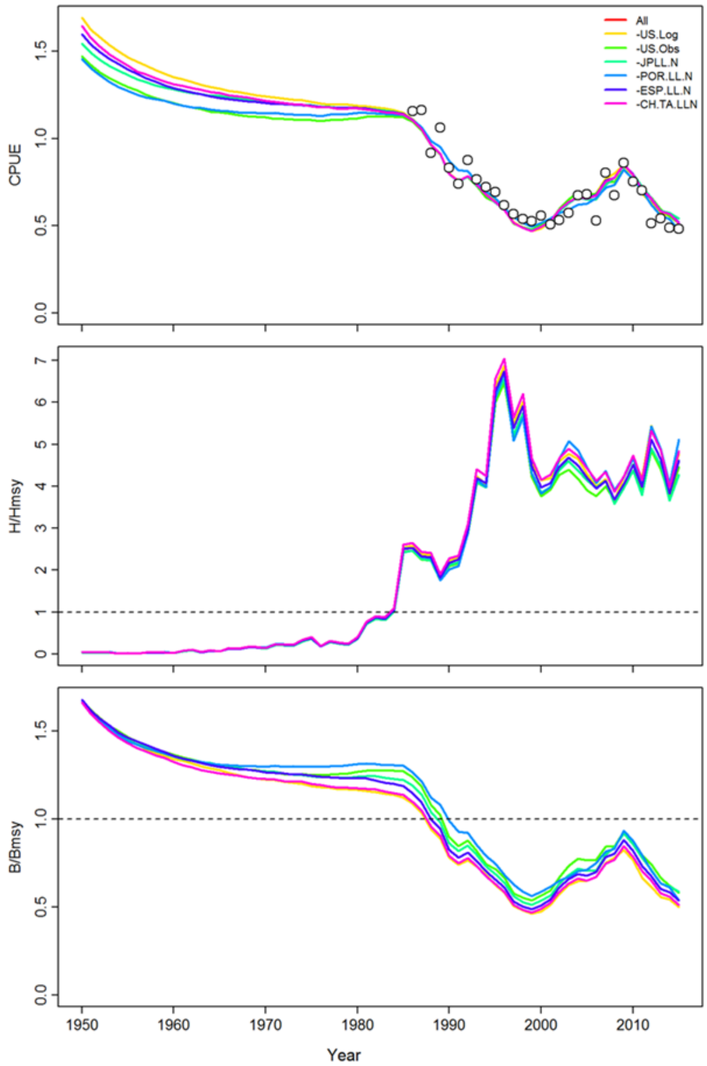


Figure 5. Jackknife diagnostics with respect to the CPUE series, F/F_{MSY} and B/B_{MSY} over time for the North Atlantic C1 scenario, with open circles illustrating the US LL CPUE.

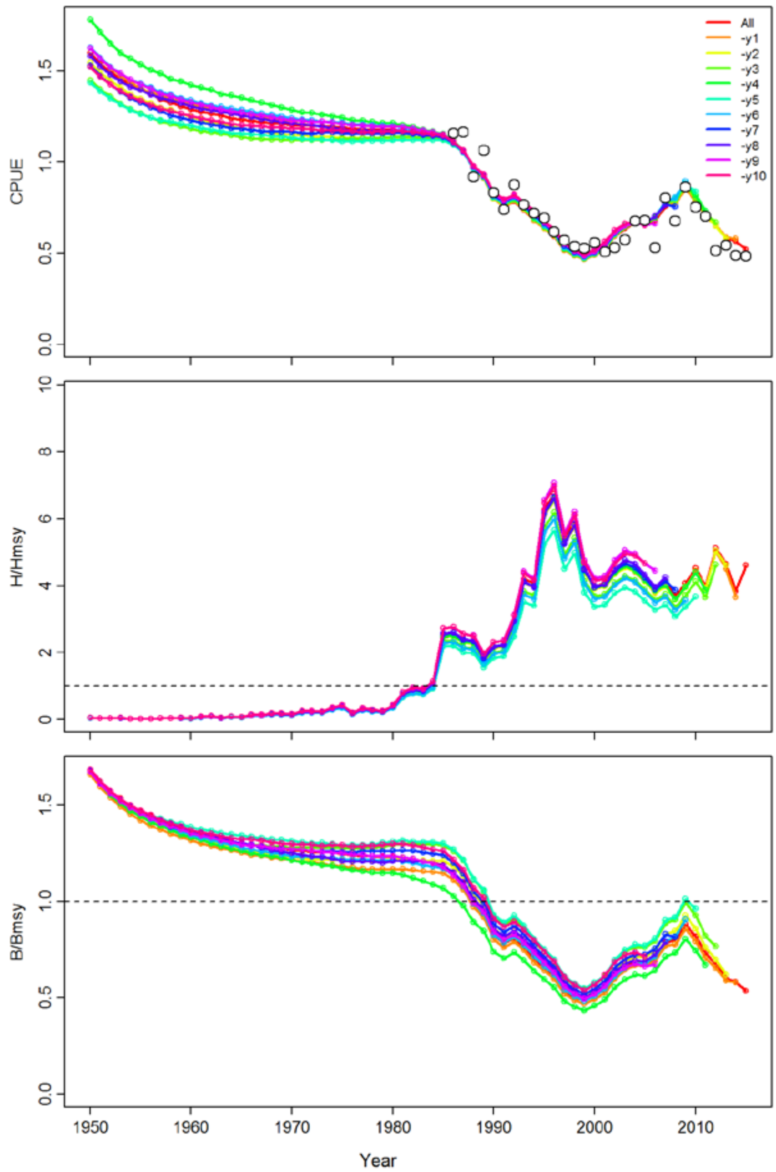


Figure 6. Retrospective diagnostics with respect to the CPUE series, F/F_{MSY} and B/B_{MSY} over time for the North Atlantic C1 scenario, with open circles illustrating the US LL CPUE.

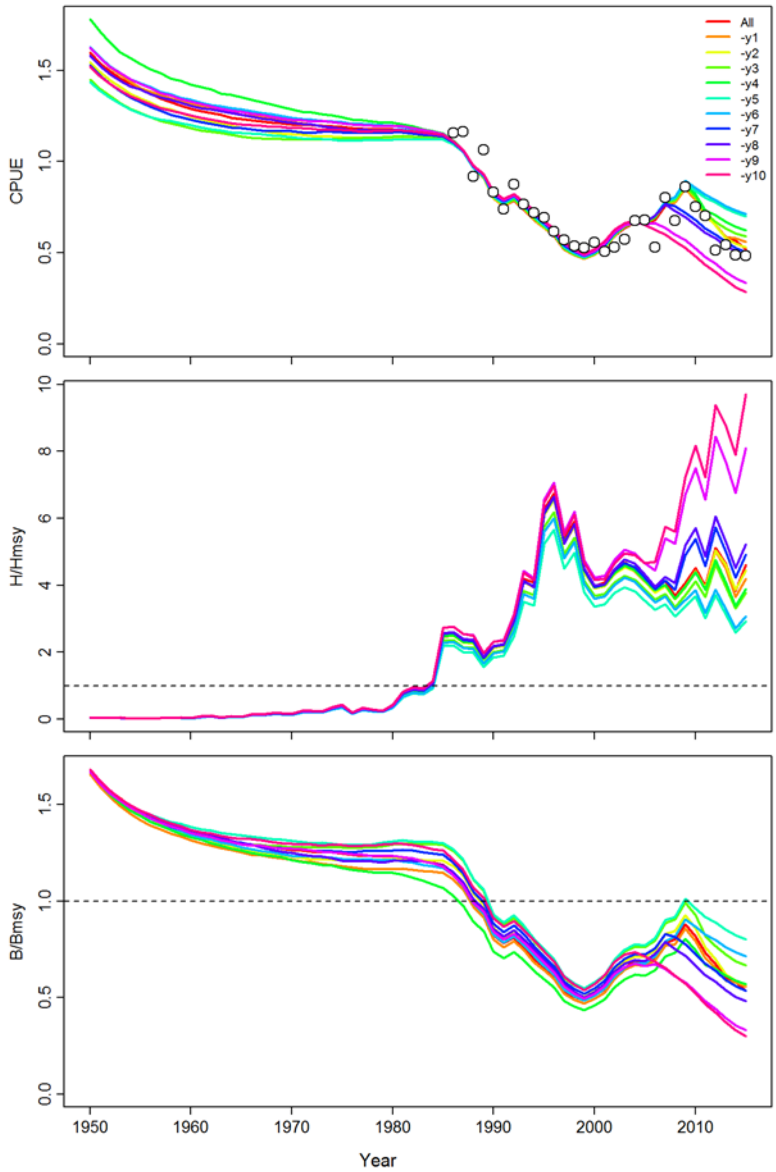


Figure 7. Cross-validation prediction diagnostics with respect to the CPUE series, F/F_{MSY} and B/B_{MSY} over time for the North Atlantic C1 scenario, with open circles illustrating the US LL CPUE.

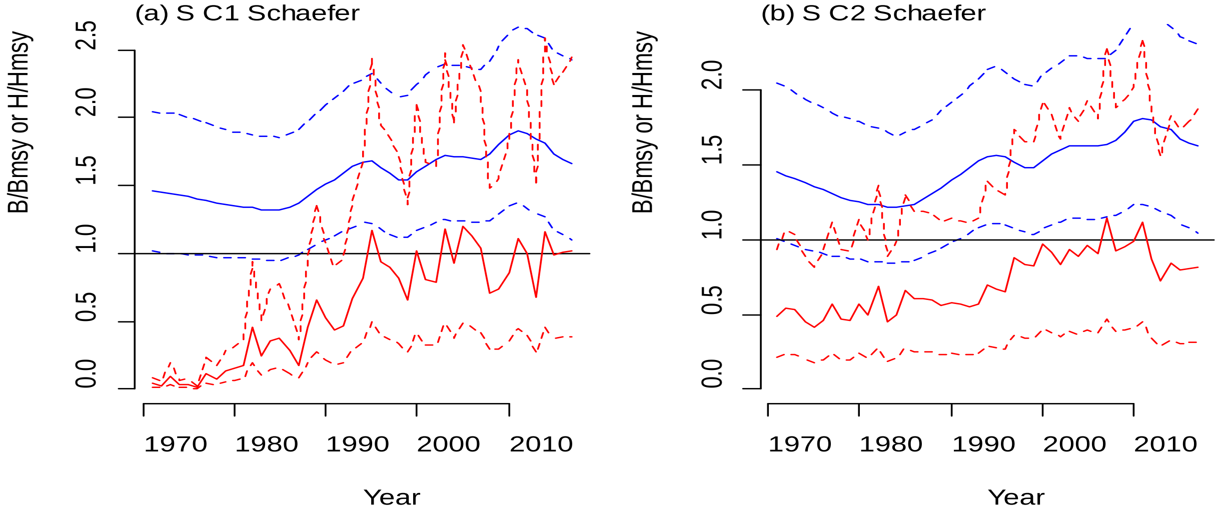


Figure 8. South Atlantic BSP2-JAGS biomass (blue) and harvest rate (red) histories for (a) C1 catch Schaefer, and (b) C2 catch Schaefer.

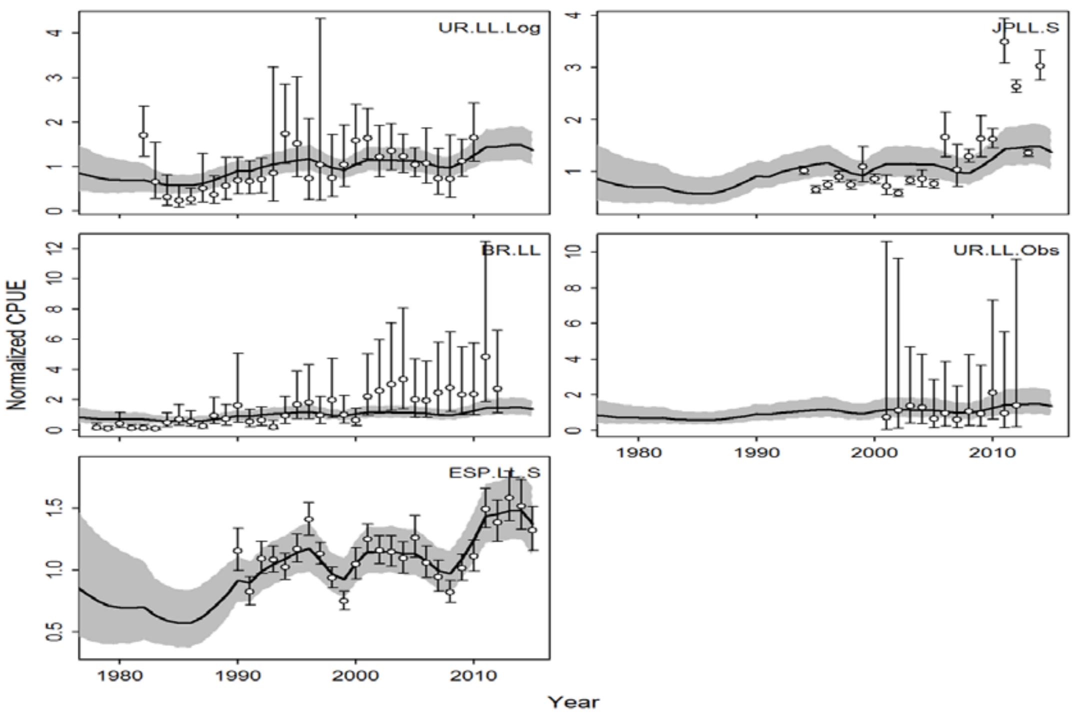


Figure 9. Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) for the shortfin mako shark in the South Atlantic C1 scenario using JABBA. Shaded grey area indicates 95% C.I.

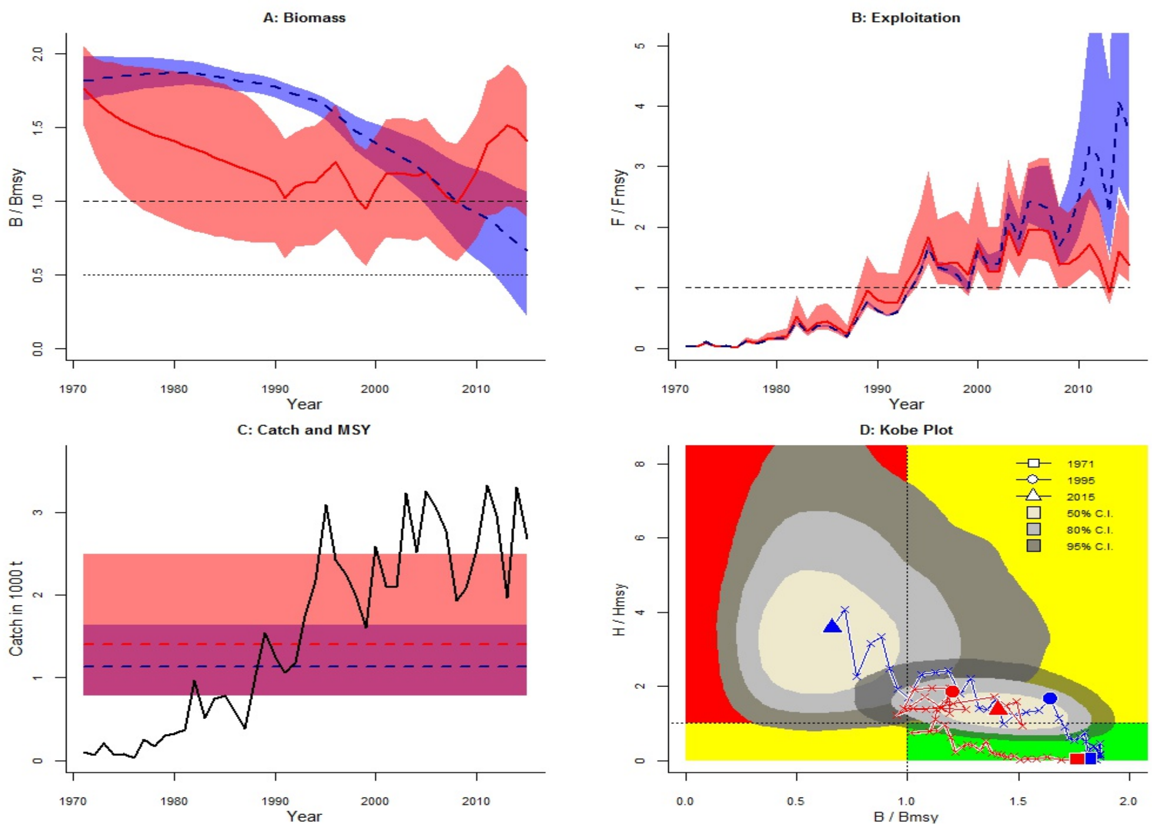


Figure 10. Comparison of CMSY (blue) and CMSY_BSM (red) for South Atlantic SMA scenario C1 showing the trajectories of (A) predicted B / B_{MSY}, (B) predicted F / F_{MSY}, (C) catches superimposing the MSY region (95% CIs), and (D) Kobe plot with uncertainty for the final year illustrated by kernel densities. Note that F is used here interchangeably with harvest rate H = C/B.

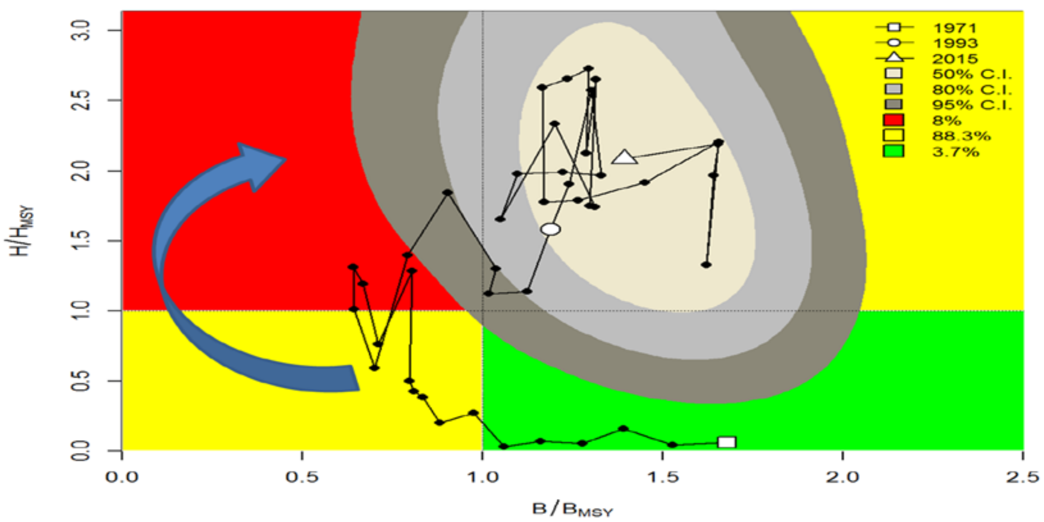


Figure 11. Kobe diagram showing the estimated trajectories (1971-2015) of B/B_{MSY} and H/H_{MSY} for the C1 scenario for the South Atlantic shortfin mako shark stock assessment with the JABBA model. The South Atlantic stock reveals a clockwise pattern moving from an underexploited state to a recovery as result of decreasing biomass under sustainable fishing, which is followed by a short period of overfishing, which is somewhat biologically implausible and ambiguous. This erroneous trend can be attributed to the apparent contradiction between the observation process (i.e. CPUE) and process equation, as both CPUE and biomass trends increase.

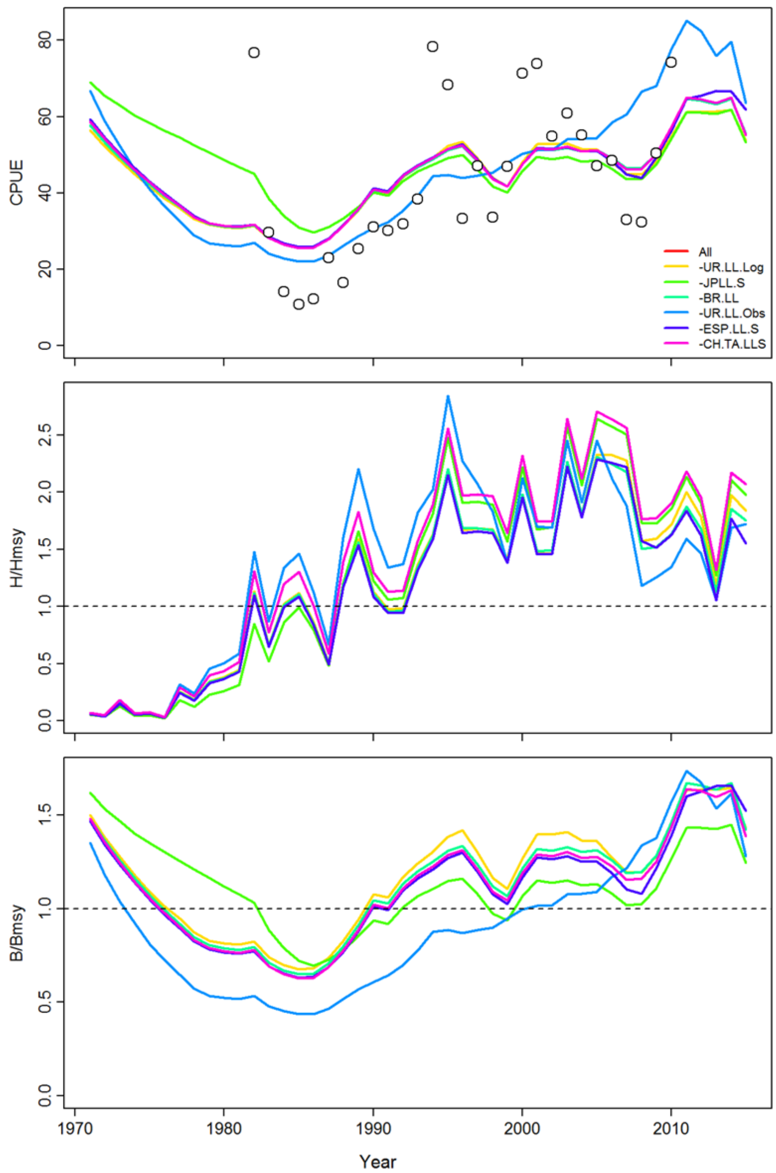


Figure 12. Jackknife diagnostics of the JABBA model with respect to the CPUE series, F/F_{MSY} and B/B_{MSY} over time for the South Atlantic C1 scenario, with open circles illustrating the Brazilian LL CPUE.

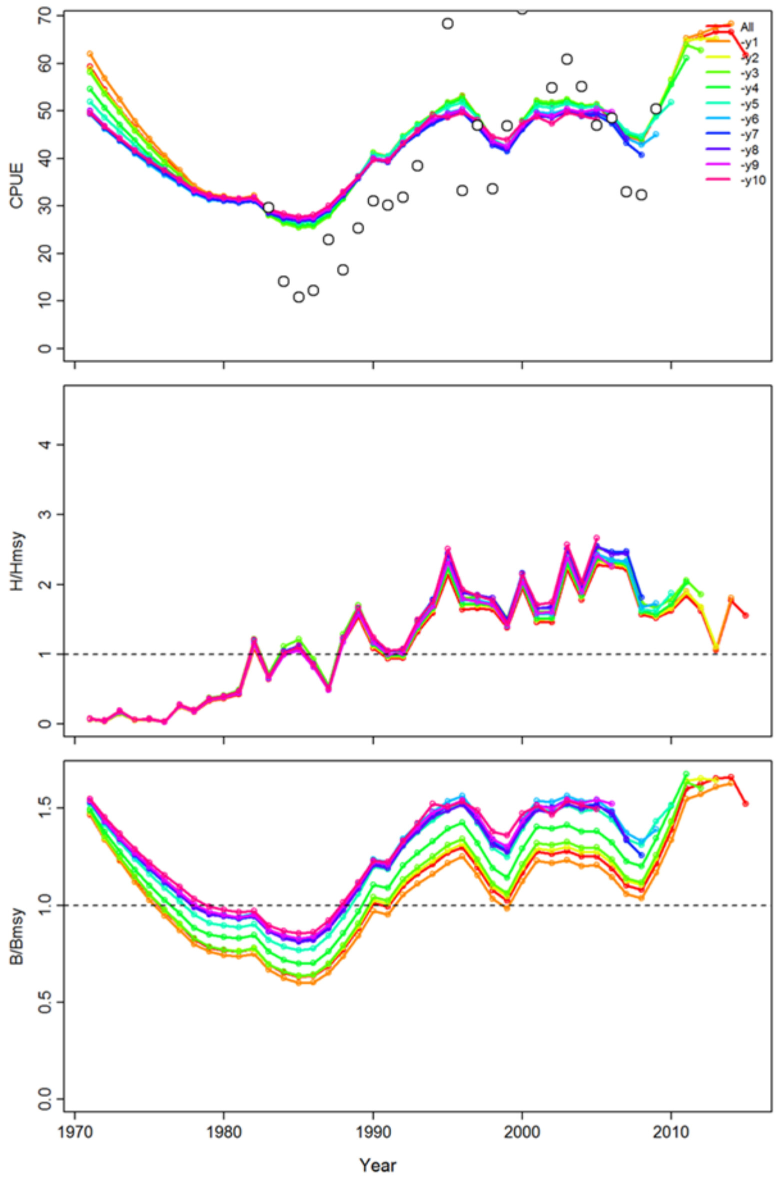


Figure 13. Retrospective diagnostics of the JABBA model with respect to the CPUE series, F/F_{MSY} and B/B_{MSY} over time for the South Atlantic C1 scenario, with open circles illustrating the Brazilian LL CPUE.

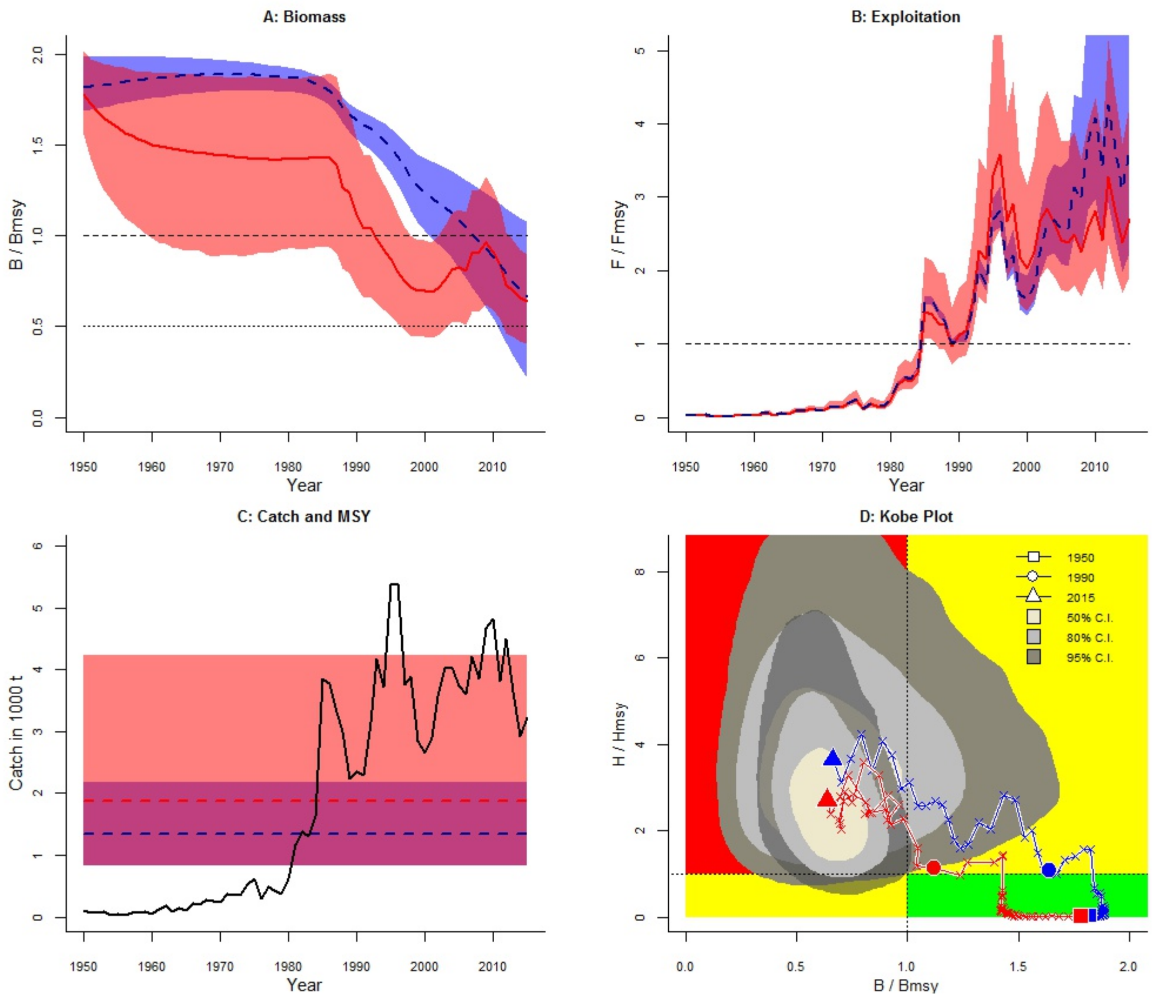


Figure 14. Comparison of CMSY (blue) and CMSY_BSM (red) for North Atlantic SMA scenario C1 showing the trajectories of (A) predicted B / B_{MSY}, (B) predicted F / F_{MSY}, (C) catches superimposing the MSY region (95% CIs), and (D) Kobe plot with uncertainty for the final year illustrated by kernel densities. Note that F is used here interchangeably with harvest rate H = C/B.

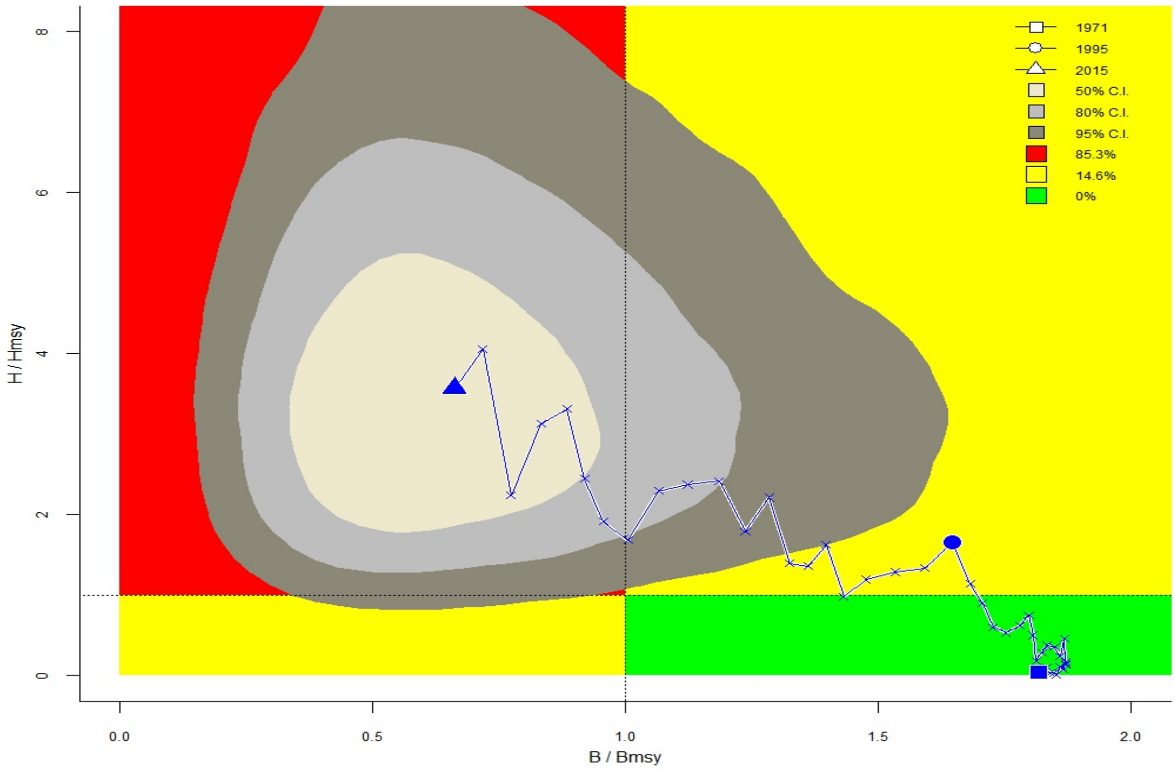


Figure 15. Kobe plot for C_{MSY} assessment results for South Atlantic SMA scenario C1 with uncertainty for the final year illustrated by kernel densities.

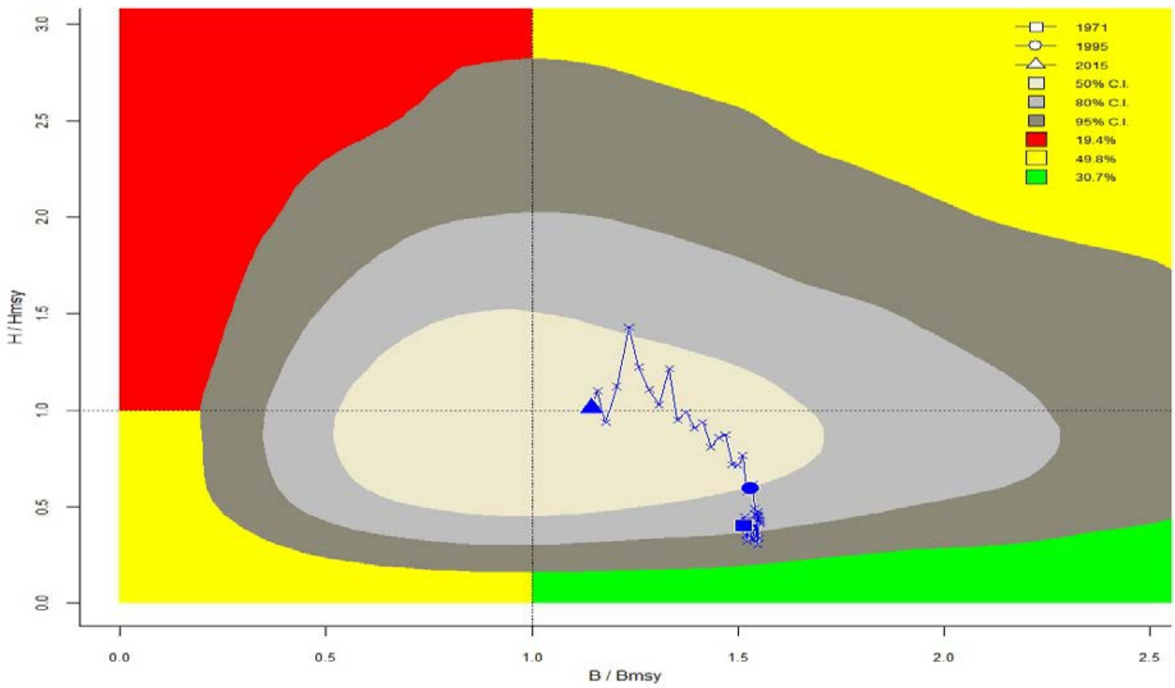


Figure 16. Kobe plot for CMSY assessment results for South Atlantic SMA scenario C2 with uncertainty for the final year illustrated by kernel densities.

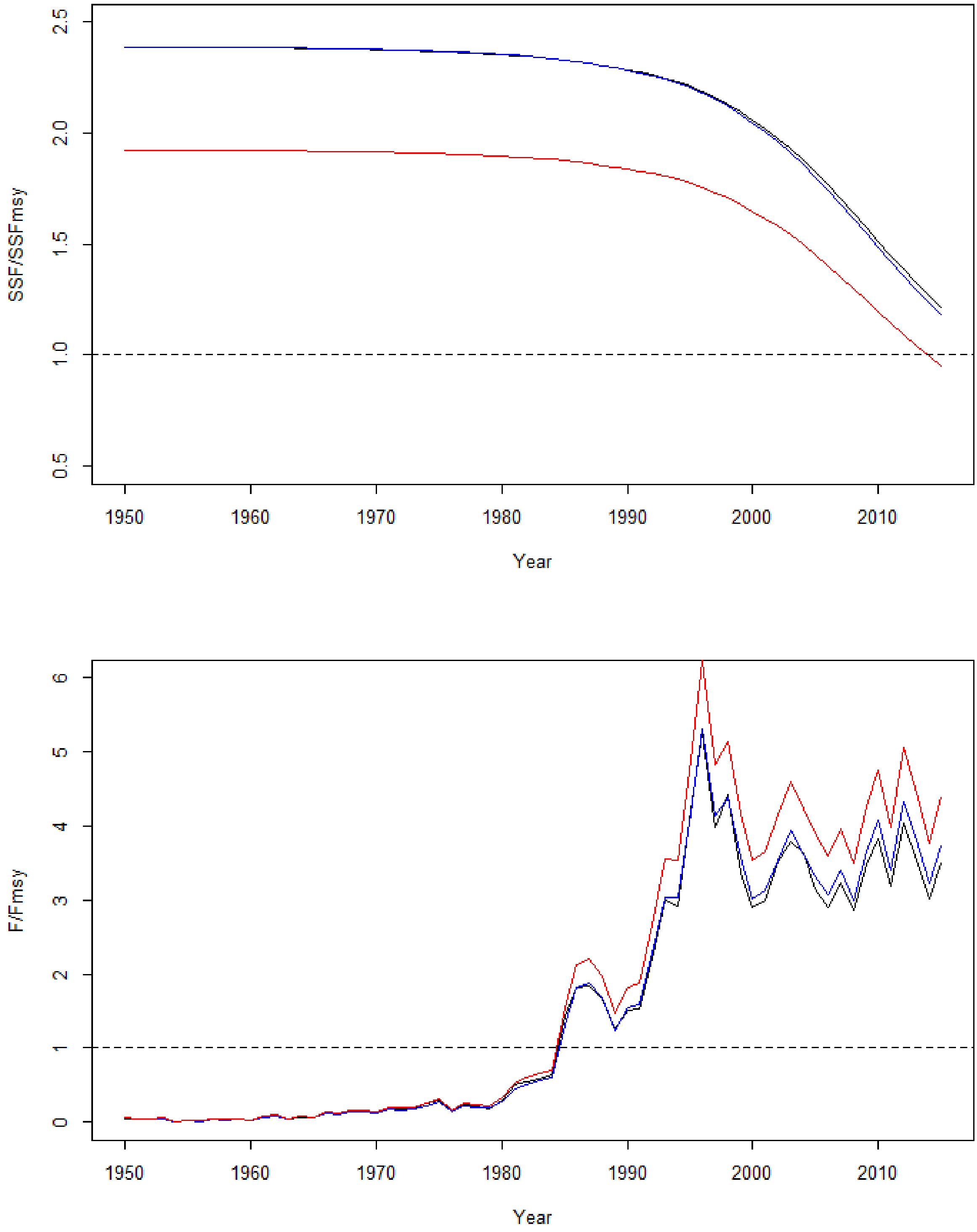


Figure 17. SSF/SSF_{MSY} and F/F_{MSY} for Stock Synthesis model run 1 (black), model run 2 (blue), and model run 3 (red) relative to the values at MSY (stippled line).

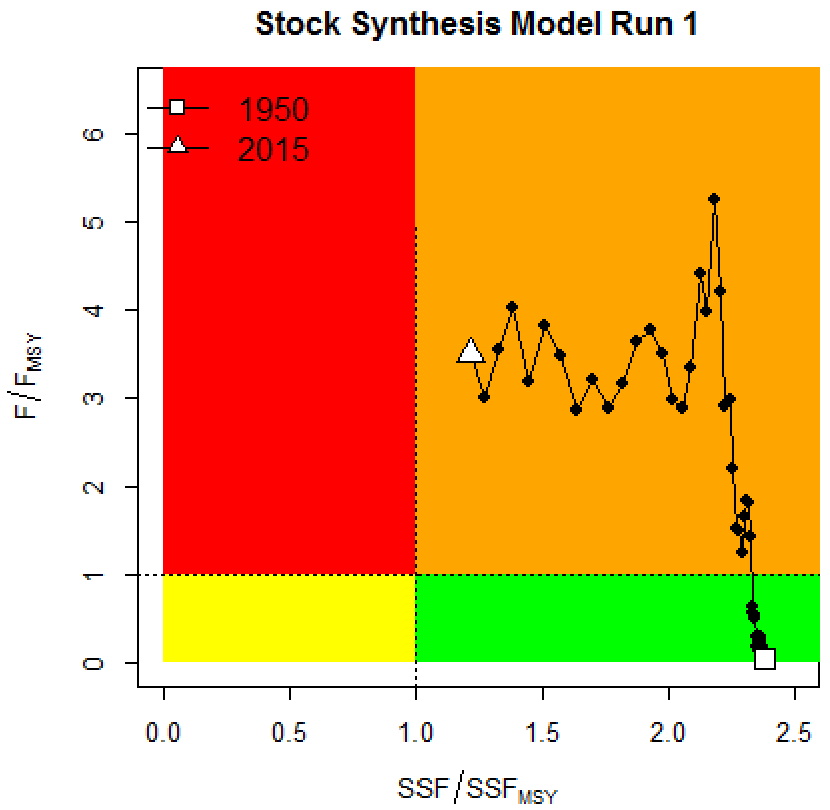


Figure 18. Kobe plot (SSF/SSF_{MSY} and F/F_{MSY}) for Stock Synthesis model run 1 relative to the values at MSY (stippled lines).

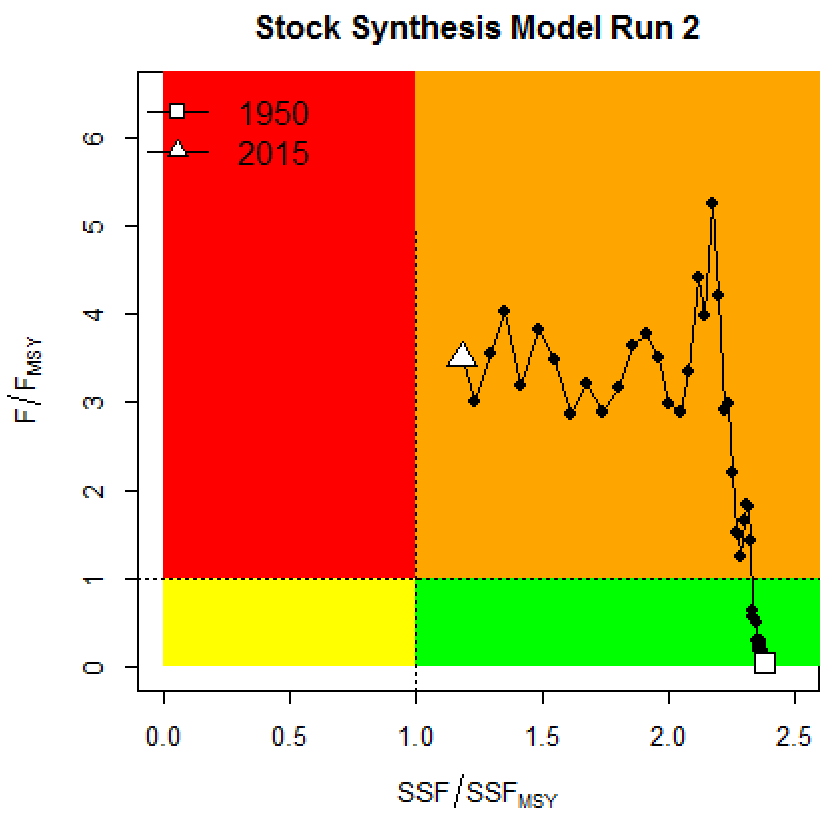


Figure 19. Kobe plot (SSF/SSF_{MSY} and F/F_{MSY}) for Stock Synthesis model run 2 relative to the values at MSY (stippled lines).

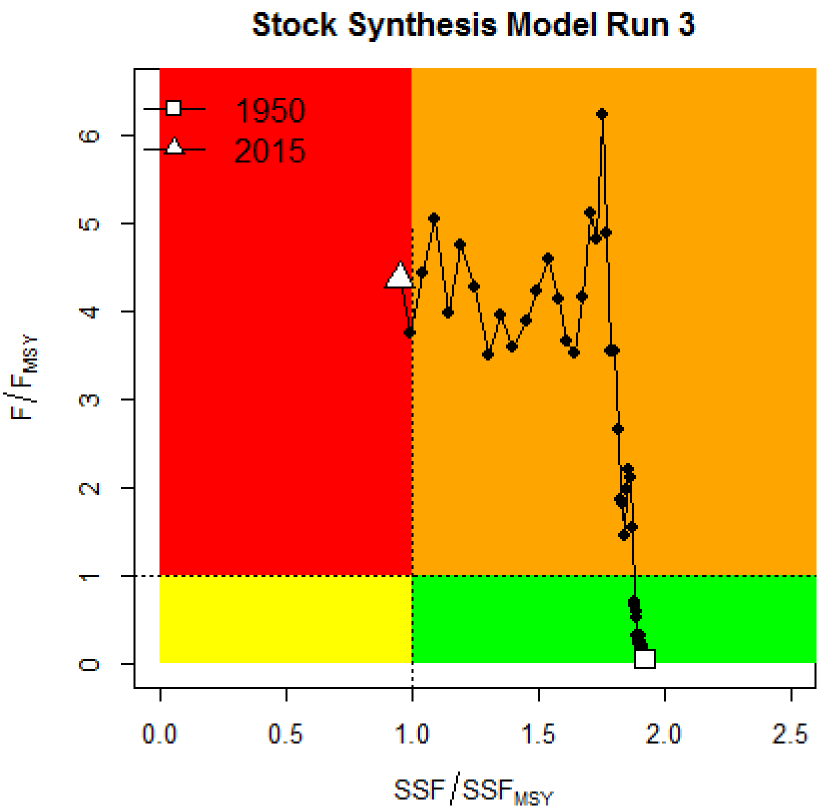
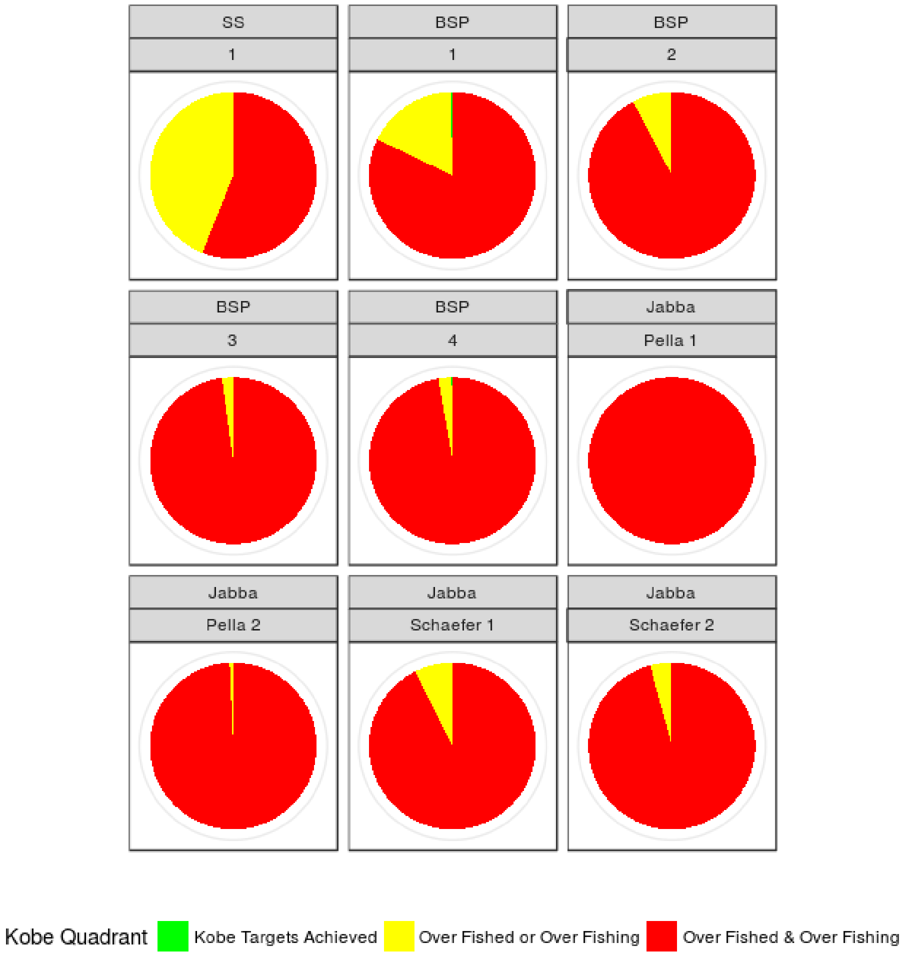


Figure 20. Kobe plot (SSF/SSF_{MSY} and F/F_{MSY}) for Stock Synthesis model run 3 relative to the values at MSY (stippled lines).



	Method	Run	red	yellow	green
1	SS	1	56.07287	43.92713	0.0
2	BSP	1	82.10000	17.50000	0.4
3	BSP	2	92.30000	7.70000	0.0
4	BSP	3	97.80000	2.20000	0.0
5	BSP	4	97.30000	2.50000	0.2
6	Jabba	Pella 1	99.90000	0.10000	0.0
7	Jabba	Pella 2	99.30000	0.60000	0.1
8	Jabba	Schaefer 1	92.60000	7.40000	0.0
9	Jabba	Schaefer 2	95.80000	4.20000	0.0

Figure 21. Kobe Pie Chart for the individual runs in the North Atlantic. From left to right, models are: SS=Stock Synthesis; BSP1=BSP2JAGS, Catch 1, Schaefer; BSP2= BSP2JAGS, Catch 1, Schaefer; BSP3= BSP2JAGS, Catch2, Generalized; BSP4=BSP2JAGS, Catch 2, Generalized; JABBA Pella, with Catch 1; JABBA Pella with Catch 2; JABBA Schaefer with Catch 1; JABBA Schaefer with Catch 2.

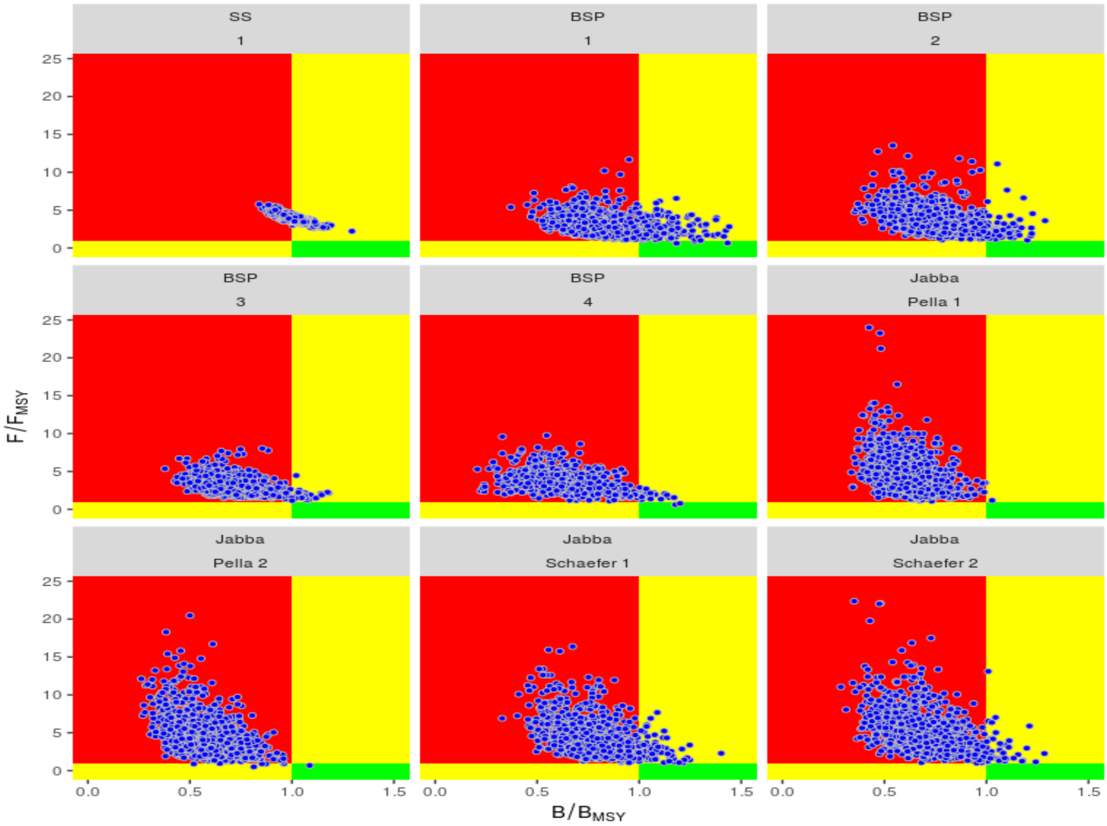


Figure 22. Kobe phase plots for the individual model runs in the North Atlantic. See Figure 21 caption for a description of the models.

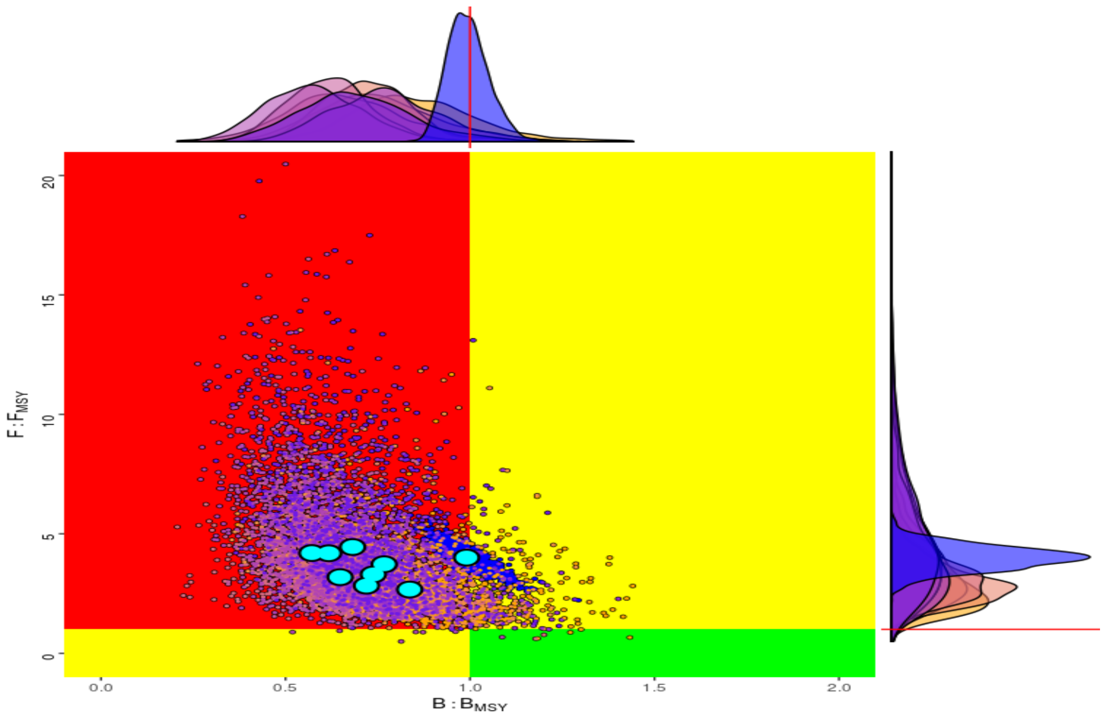


Figure 23. Kobe phase plot for North Atlantic shortfin mako showing current status (2015) based on all assessment models used. Large points show the medians for each assessment scenario; small points show the individual simulations. Marginal distributions are also shown.

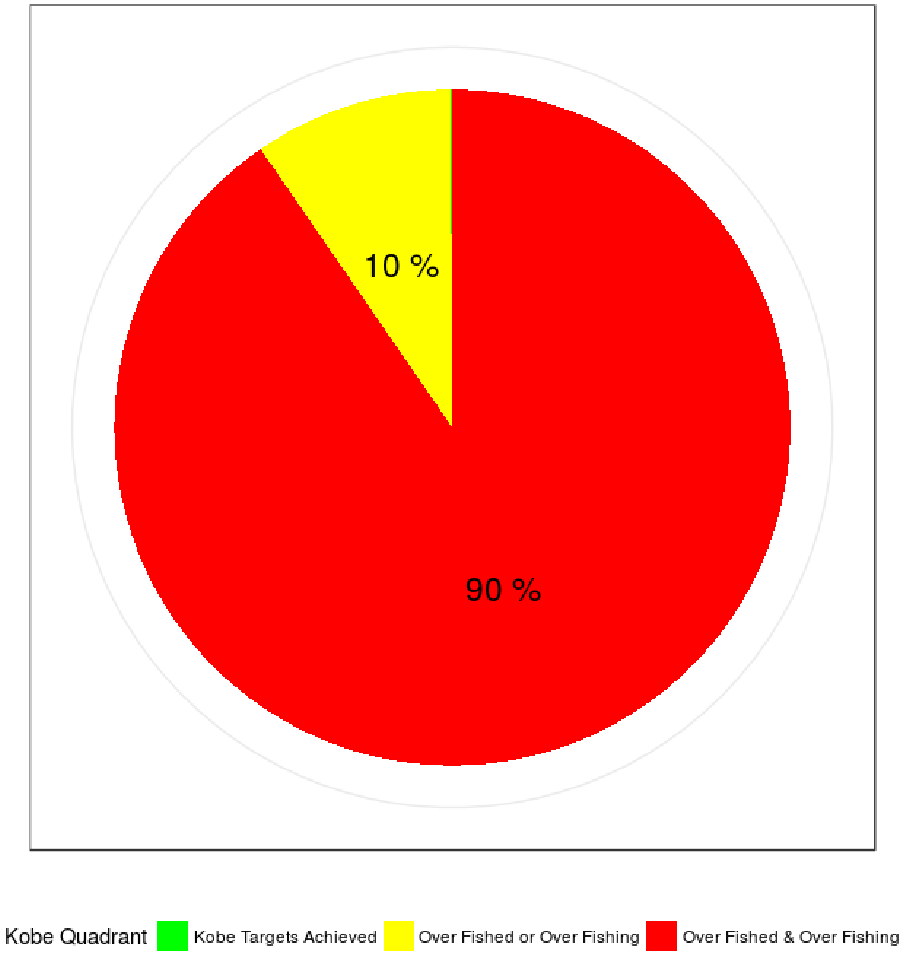
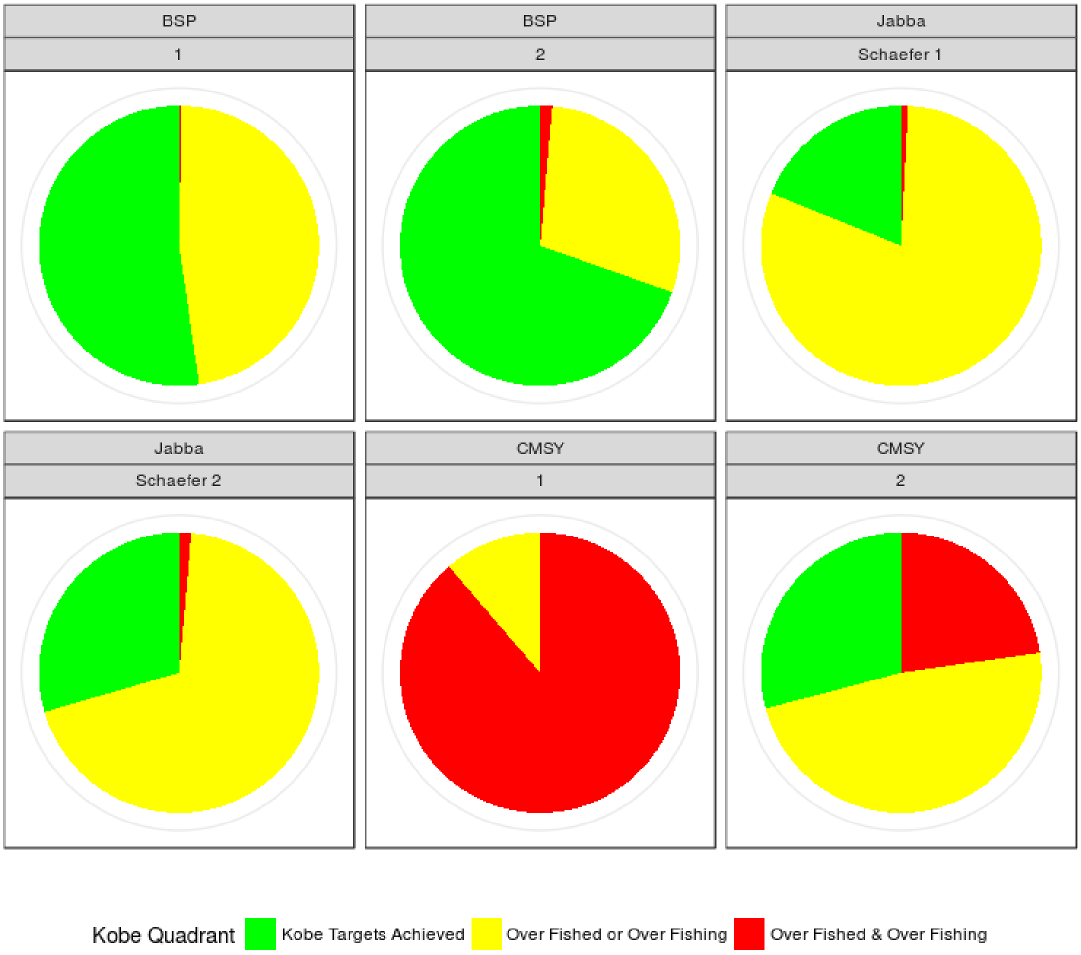


Figure 24. Kobe Pie Chart for the combined runs in the North Atlantic.



	Method	Run	red	yellow	green
1	BSP	1	0.3	47.4	52.3
2	BSP	2	1.4	29.0	69.6
3	Jabba Schaefer	1	0.8	80.3	18.9
4	Jabba Schaefer	2	1.4	69.1	29.5
5	CMSY	1	88.7	11.2	0.1
6	CMSY	2	22.7	48.2	29.1

Figure 25. Kobe Pie Chart for the individual runs in the South Atlantic. From left to right, models are: BSP1=BSP2JAGS, Catch 1, Schaefer; BSP2= BSP2JAGS, Catch 2, Schaefer; JABBA Schaefer with Catch 1; JABBA Schaefer with Catch 2; CMSY with Catch 1; CMSY with Catch 2.

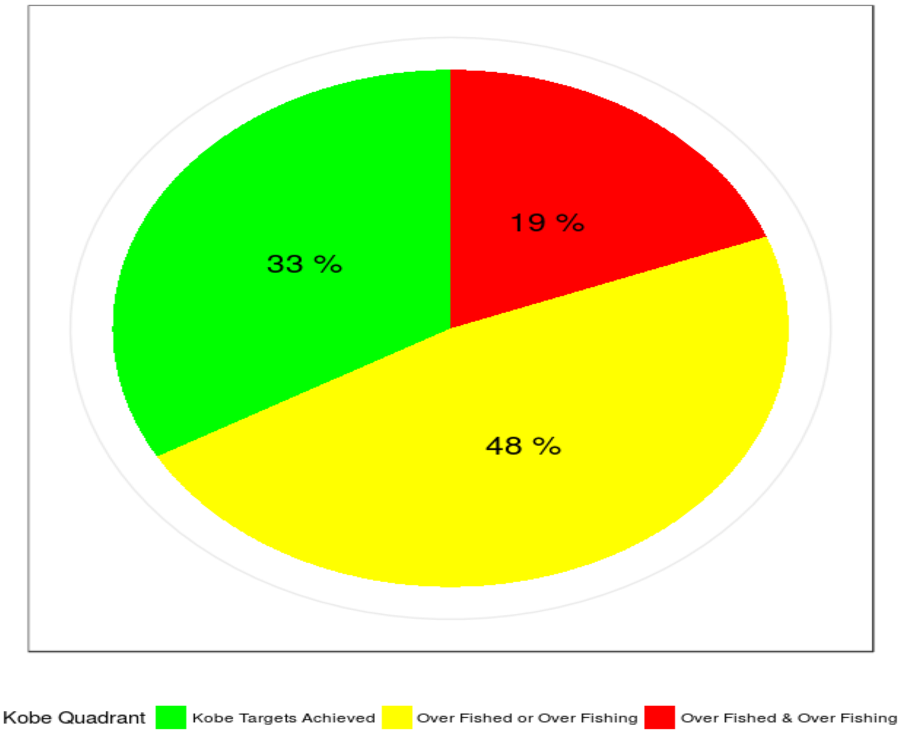


Figure 26. Kobe Pie Chart for the combined runs in the South Atlantic.

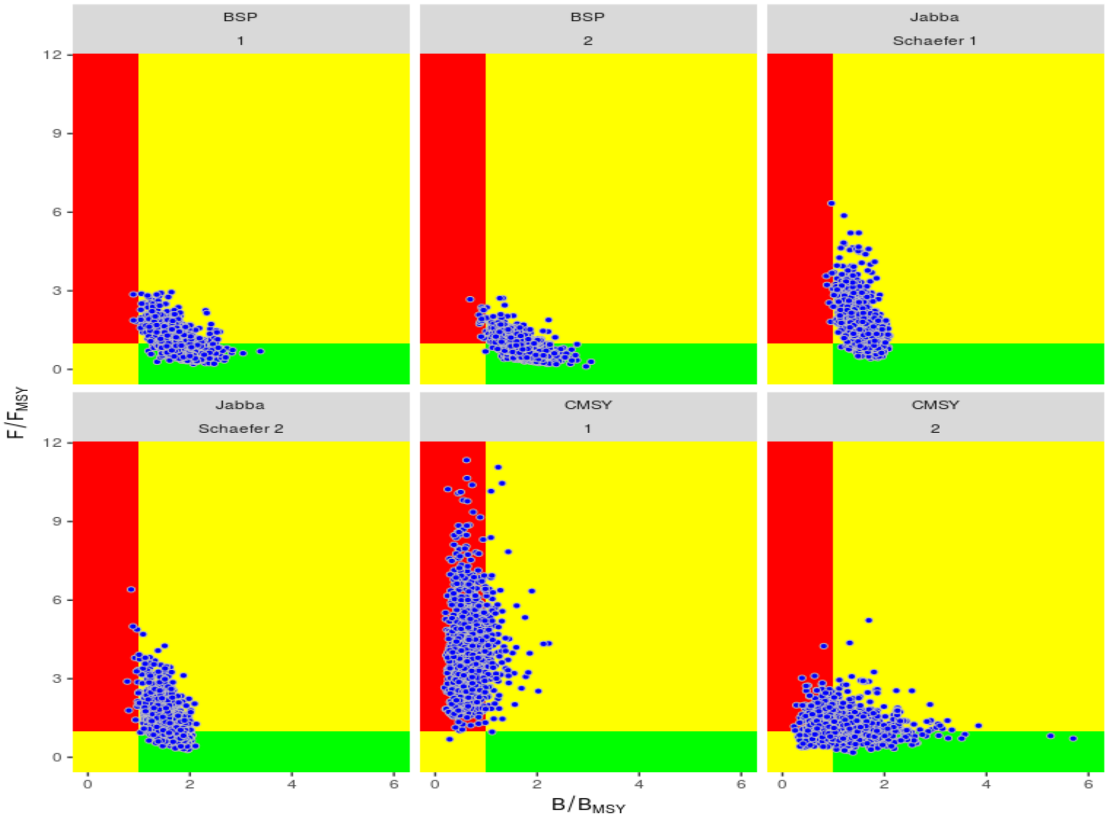


Figure 27. Kobe phase plots for the individual model runs in the South Atlantic. See Figure 25 caption for a description of the models.

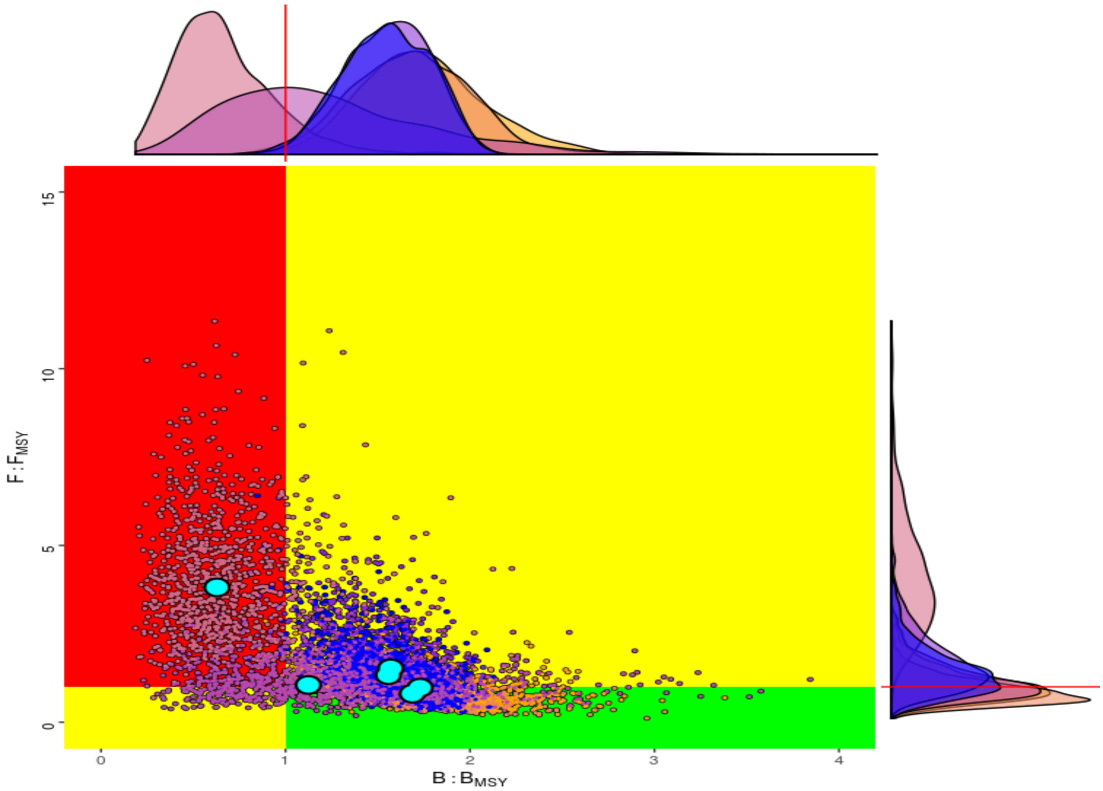


Figure 28. Kobe phase plot for South Atlantic, large points show the medians for each assessment scenario, small points show the individual simulations, marginal distributions are also shown.

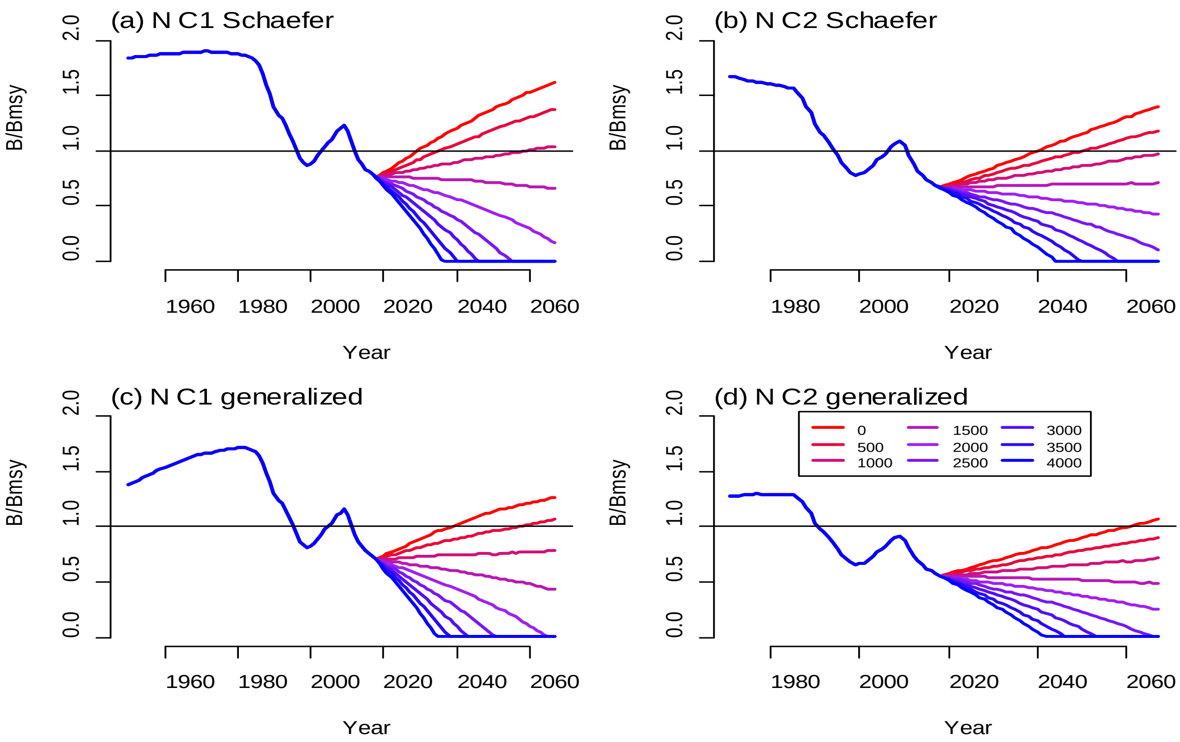


Figure 29. Median TAC projections (0 – 4000 t) from BSP2-JAGS North Atlantic for JAGS fits for (a) C1 Schaefer, (b) C2 Schaefer, (c) C1 generalized production model, and (d) C2 generalized production model.

Appendix 1

Agenda

1. Opening, adoption of Agenda and meeting arrangements
2. Summary of available data submitted by the assessment data deadline (30 April, 2017)
   - 2.1 Stock identity
   - 2.2 Catches
   - 2.3 Indices of abundance
   - 2.4 Biology
   - 2.5 Length compositions
   - 2.6 Other relevant data
3. Methods and other data relevant to the assessment
   - 3.1 Production models
   - 3.2 Other methods
   - 3.3 Length-based age-structured models: Stock Synthesis
4. Stock status results
   - 4.1 Production models
   - 4.2 Other methods
   - 4.3 Stock Synthesis
   - 4.4 Synthesis of assessment results
5. Projections
6. Recommendations
   - 6.1 Research and statistics
   - 6.2 Management
7. Other matters
8. Adoption of the report and closure

Appendix 2

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Appendix 3

List of Papers and Presentations

Reference	Title	Authors
SCRS/2017/108	Updated standardized catch rates of shortfin mako (*Isurus oxyrinchus*) caught by the Spanish surface longline fishery targeting swordfish in the Atlantic ocean during the period 1990-2015	Fernández-Costa J., García-Cortés B., Ramos-Cartelle A. and Mejuto J.
SCRS/2017/110	An alternative hypothesis for the reconstruction of time series of catches for North and South Atlantic stocks of shortfin mako shark	Coelho R. and Rosa D.
SCRS/2017/111	Age and growth of shortfin mako in the North Atlantic, with revised parameters for consideration to use in the stock assessment	Rosa D., Mas F., Mathers A., Natanson L.J., Domingo A., Carlson J. and Coelho R.
SCRS/2017/125	Stock synthesis (SS3) model runs conducted for North Atlantic shortfin mako shark	Courtney D., Cortés E. and Zhang X.
SCRS/2017/126	Estimates of maximum population growth rate and steepness for shortfin makos in the North and South Atlantic Ocean	Cortes E.
SCRS/2017/129	Anomalous ratios of blue and shortfin mako shark landings from individual north-Atlantic longline fishing vessels	Queiroz N., Mucientes G., Sousa L.L., Sims D.W.
SCRS/2017/130	Highly spatially resolved catch records of shortfin mako in the Central North Atlantic	Queiroz N., Mucientes G., Sousa L.L., Sims D.W.
SCRS/2017/132	Proposal of implementation of low-fecundity spawner-recruitment relationship for shortfin mako in the North Atlantic	Kai M. and Carvalho F.
SCRS/2017/135	Initial stock assessment results for the North and South Atlantic shortfin mako (*Isurus oxyrinchus*) using a Bayesian Surplus Production Model and the Catch-Resilience method CMSY	Winker H, Carvalho F., Sharma R., Parker D. and Kerwath S.
SCRS/P/2017/017	Fishing the RFMO boundary: South African shortfin mako data	Winker H., Kerwath S. and Parker D.
SCRS/P/2017/020	Linking age-structured (SS3) and surplus production models	Winker H. and Carvalho F.
SCRS/P/2017/021	CMSY and a fitted SPMs: Lessons learned from Mediterranean albacore with application to South Atlantic shortfin mako	Winker H. and Parker D.
SCRS/P/2017/022	Using Satellite Telemetry to Quantify Fisheries Interaction and Survival of Shortfin Mako Sharks	Byrne M.

Appendix 4

SCRS Document Abstracts

SCRS/2017/108 – Standardized catches per unit of effort (in number and weight) were obtained for the shortfin mako (*Isurus oxyrinchus*) using General Linear Modeling procedures based on trip data from the Spanish surface longline fleet targeting swordfish in the North and South Atlantic Ocean over the period 1990-2015. A base case and two GLM sensitivity analyses were carried out including a MIXED procedure. Area was identified to be the most relevant factor in explaining CPUE variability in all cases. The base case models explained between 40-46% of CPUE variability. The comparison of the standardized CPUEs obtained from the base case and the two sensitivity models show a very similar and stable general trend over time regardless of the model used for the North Atlantic stock. The base case and sensitivity analysis using a mixed model also show very similar trends over time in the case of the South Atlantic stock. All scenarios tested suggest overall stable CPUE trends or a slightly increase trend, in the North and South Atlantic stocks, respectively, during the 26-year period analyzed.

SCRS/2017/110 – The reconstruction of shark catch time series is particularly important for stock assessments, as the nominal catch data on sharks is usually very limited and a major source of uncertainty. This document provides an alternative hypothesis for the reconstruction of shark catches in the Atlantic (ICCAT fisheries) based on a method developed for the EUPOA-Sharks (EU Plan of Action for Sharks). The estimation method is based on ratios of sharks:main species catches, obtained from observer programs, literature revision and/or personnel communications. In this paper we present the average estimations by fleet/métier for the Atlantic (2000-2015) as well as time series for 1971-2015. A specific estimation for shortfin mako by stock is also presented. In this specific case, the main differences in the declared vs. estimated catches are more relevant in the earlier years of the series, which is consistent with more underreporting and lack of species specific information in the earlier years. These time series (North and South stocks) can be considered for use as alternative catch histories in the 2017 ICCAT SMA stock assessment.

SCRS/2017/111 – The shortfin mako, *Isurus oxyrinchus* (Lamnidae), is regularly caught as bycatch in pelagic longline fisheries and is among the most vulnerable sharks to this fishery. The age and growth of *I. oxyrinchus* was studied along a wide North Atlantic region. Data from 375 specimens ranging in size from 57 to 366 cm fork length (FL) for females and 52 to 279 cm FL for males were analysed. Growth models were fitted using the von Bertalanffy growth equation re-parameterised to calculate L0, instead of t0, and a modification of this equation using the known size at birth. Growth models were compared using the Akaike information criterion (AIC) and Bayesian Information Criterion (BIC). The von Bertalanffy growth equation with fixed L0 (size at birth = 63 cm FL) seemed to adequately model growth in this species, with resulting growth parameters of Linf = 241.8 cm FL, k = 0.136 year-1 for males and Linf = 350.3 cm FL, k = 0.064 year-1 for females. This study adds to knowledge of the vital life-history parameters of shortfin mako in the Atlantic Ocean, which can be used in future stock assessments for producing scientific advice to promote the management and conservation of this species.

SCRS/2017/125 – Stock Synthesis model runs were conducted for the North Atlantic shortfin mako shark based on the available catch, CPUE, length composition, and life history data compiled by the Shark Working Group. A sex-specific model was implemented in order to allow for observed differences in growth between sexes. Beverton-Holt stock-recruitment was assumed. The steepness of the stock recruitment relationship and natural mortality at age were fixed at independently estimated values. A two-stage data weighting approach was implemented to iteratively tune (re-weight) variance adjustment factors for fleet-specific relative abundance indices (CPUE) externally to the model (Stage 1) and fleet-specific size data distributions (length composition) within the Stock Synthesis model (Stage 2). Ending year (2015) stock status relative to maximum sustainable yield (MSY) reference points obtained from the final SS3 model run following the two stage data weighting approach indicated that the fishing mortality rate in 2015 was above the fishing mortality rate at maximum sustainable yield (F_2015/F_MSY = 3.7) and that F_2015/F_MSY first exceeded 1.0 in 1985. The final SS3 model run also indicated that spawning stock size in 2015, calculated here as spawning stock fecundity (SSF, 1,000s), was very close to being below the spawning stock size at MSY (SSF_2015/SSF_MSY = 1.005).

SCRS/2017/126 – Maximum population growth rates and steepness values of the Beverton-Holt stock-recruitment relationship were computed for North and South Atlantic stocks of shortfin mako (*Isurus oxyrinchus*) based on the biological information provided at the 2017 Shortfin Mako Data Preparatory meeting and soon thereafter. I used a dual life table/Leslie matrix approach to obtain estimates of productivity (r_{max}), net reproductive rate (R_0), generation time (μ_1), and derived steepness analytically. To encompass a plausible range of biological values, I considered parameters from the von Bertalanffy growth function obtained in a recently completed study by the Shark Species Group and those from a previous study for the North Atlantic, and from two published studies for the South Atlantic. I also considered a female size vs. litter size relationship or constant fecundity. Finally, natural mortality at age was obtained from the minimum of five estimates obtained through different life history invariant methods to approximate a maximum population growth rate. Estimated productivity ranged from r_{max}=0.031 to 0.060 yr^{-1} for the North Atlantic stock and from r_{max}=0.066 to 0.123 yr^{-1} for the South Atlantic stock. Analytically derived values of steepness corresponding to these productivities ranged from h=0.34 to 0.52 for the North Atlantic stock and h=0.44 to 0.72 for the South Atlantic stock. These estimates can be used to formulate informative priors of r_{max} and h in production and age-structured stock assessment models, respectively.

SCRS/2017/129 – Here we examine the verified landings of shortfin mako and blue sharks made by 21 individual European longline fishing vessels in 2008. Catches of shortfin mako typically comprise 3–13% of blue shark catches in the same longline or gill-net fishery, hence large deviations from this ratio may represent overreporting of mako landings that can affect scientific stock assessments. For the 21 vessels operating in the North Atlantic in 2008 the catches of shortfin mako were between 27.8 and 6481 % of blue shark catches. The average of mako was 725 % (± 1611.2 S.D.) of blue shark catches. Considering only 9 vessels for which the percentage was less than 100, the catches of mako were on average 48.6 % (± 18.9 S.D.) of blue shark catches. Although some discarding of blues may have affected the higher percentage makos observed, it seems likely that the majority of blue shark catches were retained and implies that the excess 'mako' could have been a regulated species such as swordfish. The scale of this problem prior to 2013 may already have affected data used in assessing shortfin mako populations in the Atlantic.

SCRS/2017/130 – Here we examine highly-spatially resolved catch records of individual shortfin mako detailed in personal logbooks from two longline-vessel captains over a 16 year period. Logbooks comprised data recording time, location (latitude/longitude), water temperature, gear type and setting practice (exact hook number, type, depth) and numbers of sharks and total biomass per species captured on each longline set. Results show median fishing trip duration increased from 29 days pre-2005 to 37 post-2005, with fishing areas expanded spatially by as much as 5º further west and between 2o and 20º further south from pre- to post-2005, together with a general shift in density distribution of sets. The expansion overlapped key areas of shark habitat use not previously exploited by those vessels, resulting in CPUE and biomass of shortfin mako being generally higher at the expanding edges of the core fishing areas post-2005. Whether fishing patterns responded to lower biomass of shortfin mako being available within higher use shark habitat remains an open question, but our results argue for detailed spatially-referenced catch data to be analysed in relation to new telemetry of oceanic shark space-use and fishing vessel movements to obtain a greater understanding of how CPUE varies through time.

SCRS/2017/132 – This document paper presents the short review of low-fecundity spawner-recruitment relationship (LFSR) to give a motivation of the implementation of the LFSR in the stock synthesis model. The parameter values of the LFSR are also computed using the preliminary value of the steepness for shortfin mako in the North Atlantic.

SCRS/2017/135 – We present results of two alternative stock assessment modeling frameworks applied to the North Atlantic (NA) and South Atlantic (SA) shortfin mako shark catch and CPUE data series. First we applied a Bayesian State-Space Surplus Production Model (Just Another Bayesian Biomass Assessment: JABBA), which estimates process variance and additional observation variance simultaneously and was fitted to primary catch time series and all provided standardized CPUE time series for the NA and SA. Based on the JABBA base-case fits, the MSY estimate for North Atlantic base-case was 1134.1 metric tons (479.9 – 3324.5 95% C.I.) and at 1130.5 metric tons (325.3 – 2274.1 95% C.I.) for the South Atlantic. Stock status trajectory of over time showed a typical anti-clockwise pattern for the NA shortfin mako shark stock status moving from underexploited through a period of unsustainable fishing, leading to a 99% posterior probability of being over-exploited in 2015. In contrast, the South Atlantic stock reveals a clockwise pattern moving from an underexploited state to a recovery as result of decreasing biomass under sustainable fishing, which is followed by a short period of overfishing. For the SA shortfin mako shark population, the resulting stock status posterior for 2015 therefore appears somewhat implausible and ambiguous. Model diagnostics in for evaluating forecasting, retrospective patterns and sensitivity to dropping on CPUE series at a time (jackknife) indicated overall good performance for the NA stock, but highlighted that stock biomass estimates must be treated with extreme caution. This was further corroborated by the good match between the catch-only method CMSY for NA, but strong discrepancies between CMSY and fitted models for SA. The latter can be attributed to the apparent contradiction between the observation process (i.e. CPUE) and process equation, which is informed by the catch and resilience (r) information.

Appendix 5

Additional results using the Visual BASIC Bayesian Surplus Production Software (BSP1 and BSP2), and the equivalent in JAGS (BSP2-JAGS)

This appendix presents results of the BSP1, BSP2 and BSP2-JAGS runs that were discussed at the assessment meeting, but not included in the main text. This includes the detailed results of BSP1 and BSP2 continuity runs, as well as some sensitivity analyses done with BSP2-JAGS.

The continuity runs using the BSP1 VisualBASIC model were set up using the same catch data and indices as all the other BSP models (Section 3.1). We ran three models for the North Atlantic (**Table Appendix 1a**) and three models for the South Atlantic (**Table Appendix 1b**) using data through 2015. For the North and the South the first run (na1, sa1) was the C1 catch starting in 1950 and 1971 respectively. Both second runs (na2, sa2) used the C2 catch series both starting in 1971. The final run (na3, sa3) applied a generalized production model and the alternative catch series both starting in 1971. Runs na2 and sa1 are continuity runs for comparison to the 2012 assessment methods. All BSP1 models were able to converge adequately, with percent maximum weight less than 0.5% and similar values of the log(weights) and log(likelihood*priors). However, without process error they were not able to fit the zigzag pattern in the CPUE series in the North Atlantic (**Figure Appendix 1**), or the increasing trend in the South Atlantic (**Figure Appendix 2**). All BSP1 results had high K values and were fairly optimistic (**Table Appendix 2, Table Appendix 3, Figure Appendix 3, Figure Appendix 4, Figure Appendix 5**).

Although the BSP2 VisualBASIC model with process error (BSP2) was able to estimate the mode of the posterior distribution, the SIR algorithm did not converge on the posterior distribution. For the North Atlantic, the authors were able to estimate the mode of the posterior distribution, and the fit at the mode (**Figure Appendix 6**) was similar to the fits from the BSP2-JAGS models with the same data (**Figure Appendix 7**).

Additional sensitivity analyses of the BSP1, BSP2 and BSP2-JAGS models were presented using slightly different priors and weighting methods, with the same catch and CPUE data through 2015. These models were presented at the beginning of the meeting, and they have different priors than the runs used for the assessment. The models were used in part to explore the differences between BSP VisualBASIC and BSP2-JAGS implementations (Babcock and Cortés (in press)). They were based on the runs conducted during the 2012, except where noted (**Table Appendix 4**). While the starting year was 1971 for the North Atlantic in the 2012 assessment, these runs used the first year of the catch series, which was 1950. The indices used in the north Atlantic were US-Log, JPLL-N, POR-LL-N, ESP-LL-N, and CH-TA-LLN. In a sensitivity run, the US-Obs series was also included. Catches were either the catches from the data preparatory meeting (C1), or the alternative catch scenario based on ratios (C2). In the north, the C1 catches were used for 1950 to 1970 in the C1 catch scenario. In one run, catches from 1950 to 1996 were predicted from effort using an estimated constant of proportionality. For the south Atlantic, the indices were UR-LL-Log, JPLL-S, BR-L, UR-LL-Obs, ESP-LL-S, and CH-TA-LLS.

For both the North and the South, a lognormal informative prior was used for r, in which the mean of r was set to the mean of the newly calculated values of r from several different methods life history methods. The log-standard deviation of r was the same as the 2012 assessment (log-sd=0.12). The means were 0.046 for the north and 0.073 for the south (corresponding to log-means of -3.09 in the north and -2.62 in the south). In one sensitivity analysis the log-sd of r was doubled. The other priors were the same as in 2012. The starting biomass relative to K was lognormal with a mean of one and log-standard deviation of 0.2, bounded between 0.2 and 1.1. K was uniform on log-K, bounded between 0.01 and 5,000,000. In the BSP1 and BSP2 runs, q was estimated using the MLE shortcut. For the BSP2-JAGS runs, for each series was estimated with a uniform prior between 1.0E-10 and 10. In most model runs, the error standard deviation was assumed to be the same for all points and was estimated with a uniform prior between 0.01 and 10. In the "catch weighting" runs, the error standard deviation in each data point was estimated from the proportion of catch in each year in each series. In the BSP2 runs, it is not possible to estimate the error standard deviation, so error standard deviation was set equal to a value slightly larger than the mean MLE sigma (0.4 in the north, and 0.45 in the south). Process error was zero in all the BSP1 runs, and fixed at either log-sd=0.05 or log-sd=0.005 in BSP2 and BSP2-JAGS. We also conducted post-model pre-data runs to evaluate the impact of the priors on the posterior distribution. These runs included only a single CPUE data point so that the results are driven entirely by the priors and the catch time series.

In the north Atlantic, the BSP1 alternative models were all able to converge adequately, with percent maximum weight less than 0.5% and similar values of the log(weights) and log(likelihood*priors). For the BSP2 runs, none of the importance functions produced good convergence; the final percent maximum weight was 1.97% for run n5, above the target of 0.5%. The BSP1 and BSP2 models generally produced fits that were quite optimistic, with biomass above B_{MSY} and F below F_{MSY} (**Table Appendix 5**, **Figure Appendix 5, Figure Appendix 8, Figure Appendix 9**). The BS2-JAGS alternative models for the north Atlantic also suffered from convergence problems, but generally had Gelman Rubin diagnostics less than 1.05 (**Table Appendix 6**). Like the BSP runs, the BSP2-JAGS runs returned values of r that were very similar to the priors. However, the BSP2-JAGS runs produced lower estimate of K, and were generally more pessimistic (**Table Appendix 6, Figure Appendix 10, Figure Appendix 11**). Process error improved the model fits.

For the south Atlantic, the BSP1 alternative models converged adequately, but the BSP2 model did not. The percent maximum weight was13.5% for run s2, above the target of 0.5%. The BSP2-JAGS runs all converged adequately. All models produced posterior distributions that were similar to the priors for r. However, the BSP2-JAGS models estimated higher values of K, so that they were more optimistic than the BSP2-JAGS models (**Table Appendix 7, Table Appendix 8, Figure Appendix 12, Figure Appendix 13**). The BSP2-JAGS runs estimated an increasing trend during the years with CPUE data (**Figure Appendix 14**).

Finally, **Figure Appendix 15** shows the Kobe plot for the main assessment model results described in section 3.1 for the South Atlantic.

Table Appendix 1. Inputs for the BSP1 and BSP2 continuity runs.

(a) North BSP1

Run	*Weighting*	*Catch*	*Catch start date*	*B0/K prior*	*r prior*	*Name*	*Shape*
na1	equal	C1	1950	lnorm(1)	lnorm(log(0.0254), 0.434)	N 1950	n=2
na2	equal	alt	1971	lnorm (.85)	lnorm(log(0.0254), 0.434)	N continuity	n=2
na3	equal	alt	1971	lnorm(.85)	lnorm(log(0.0254), 0.434)	N 1971 gen	n=5

b) South BSP1

Run	*Weighting*	*Catch*	*Catch start date*	*B0/K prior*	*r prior*	*Name*	*Shape*
sa1	equal	C1	1971	lnorm	lnorm(log(0.052), 0.275)	S continuity	n=2
sa2	equal	alt	1971	lnorm	lnorm(log(0.052), 0.275)	S alt cat	n=2
sa3	equal	alt	1971	lnorm	lnorm(log(0.052), 0.275)	S alt cat gen	n=5

(c) North BSP2

Run	*Area*	*Weighting*	*Catch*	*Process error*	*Catch start date*	*B0/K prior*	*r prior*	*Name*	*Shape*
na4	North	input CV	C1	0.05	1950	lnorm(1)	lnorm(log(0.0254), 0.434)	N 1950	n=2
na5	North	input CV	alt	0.05	1971	lnorm (.85)	lnorm(log(0.0254), 0.434)	N continuity	n=2
na6	North	input CV	alt	0.05	1950	lnorm(.85)	lnorm(log(0.0254), 0.434)	N 1971 gen	n=5

(d) South BSP2

Run	*Area*	*Weighting*	*Catch*	*Process error*	*Catch start date*	*B0/K prior*	*r prior*	*Name*	*Shape*
sa4	South	input CV	C1	0.05	1971	lnorm	lnorm(log(0.052), 0.275)	S continuity	n=2
sa5	South	input CV	alt	0.05	1971	lnorm	lnorm(log(0.052), 0.275)	S alt cat	n=2
sa6	South	input CV	alt	0.05	1971	lnorm	lnorm(log(0.052), 0.275)	S alt cat gen	n=5

Table Appendix 2. Expected values (CVs) of estimated parameters for the BSP1 continuity model runs for North Atlantic mako sharks.

Variable	*mako17Na1*	*mako17Na2*	*mako17Na3*
K (1000)	1755.63(0.70)	1967.08(0.6)	1670.76(0.76)
r	0.03(0.46)	0.03(0.5)	0.03(0.48)
MSY (1000)	10.98(0.88)	11.93(0.8)	22.95(0.97)
Bcur (1000)	1620.98(0.74)	1713.97(0.7)	1595.70(0.79)
Binit (1000)	1603.58(0.71)	1663.14(0.7)	1451.19(0.78)
Bcur/Binit	0.99(0.12)	1.01(0.1)	1.09(0.14)
Ccur/MSY	0.55(0.83)	0.61(0.8)	0.39(0.85)
Bcur/Bmsy	1.77(0.09)	1.67(0.1)	1.38(0.09)
Fcur/Fmsy	0.34(0.99)	0.40(0.9)	0.31(1.03)

Table Appendix 3. Expected values (CVs) of estimated parameters for the BSP1 model continuity runs for South Atlantic mako sharks.

Variable	*mako17Sa1*	*mako17Sa2*	*mako17Sa3*
K (1000)	2547.55(0.50)	2473.56(0.52)	1842.71(0.72)
r	0.06(0.21)	0.06(0.21)	0.04(0.18)
MSY (1000)	35.02(0.54)	34.24(0.56)	37.99(0.72)
Bcur (1000)	2317.55(0.51)	2243.62(0.53)	1792.91(0.73)
Binit (1000)	1360.17(0.55)	1318.90(0.57)	711.75(0.77)
Bcur/Binit	1.75(0.19)	1.75(0.19)	2.60(0.19)
Ccur/MSY	0.11(0.79)	0.11(0.78)	0.13(0.91)
Bcur/Bmsy	1.81(0.05)	1.80(0.05)	1.44(0.03)
Fcur/Fmsy	0.06(0.85)	0.06(0.86)	0.09(0.97)

Table Appendix 4. Inputs for the BSP and BSP2-JAGS sensitivity runs using alternative priors.

(a) North Atlantic

Run	*Weighting*	*Catch*	*Indices*	*Est Cat*	*Proc. error*	*Software*	*Cat start date*	*B0/K prior*	*r prior*	*Name*
n1	equal, estimated	C1	base	no	0	BSP	1950	lnorm (mean 1, CV 0.2)	lnorm, mean 0.046	N equal wt
n2	equal, estimated	C1	base	effort	0	BSP	1997	uniform (0.2, 1.1)	lnorm,mean 0.046	N effort fit
n3	catch wt	C1	base	no	0	BSP	1950	lnorm	lnorm,mean 0.046	N catch wt
n4	equal, estimated	C1	base	no	0	BSP	1950	lnorm	lnorm,mean 0.046, double sd	N double r sd
n1pmpd	NA	C1	NA	no	0	BSP	1950	lnorm	lnorm,mean 0.046	N pmpd
n5	equal, estimated	C1	base	no	0.05	BSP2	1950	lnorm	lnorm,mean 0.046	N process error
n6	by series	C1	base	no	0	BSP	1950	lnorm	lnorm,mean 0.046	N series wt
n7	equal, estimated	C2	base	no	0	BSP	1950	lnorm	lnorm,mean 0.046	N alt catch
n8	equal, estimated	C1	base+US obs	no	0	BSP	1950	lnorm	lnorm,mean 0.046	N alt index
jn1	equal, estimated	C1	base	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N equal wt
jn2	equal, estimated	C1	base	effort	0.005	JAGS	1997	uniform	lnorm,mean 0.046	N effort fit
jn3	catch wt	C1	base	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N catch wt
jn4	equal, estimated	C1	base	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046, double sd	N double r sd
n1pmpd	NA	C1	NA	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N pmpd
jn5	equal, estimated	C1	base	no	0.05	JAGS	1950	lnorm	lnorm,mean 0.046	N process error
jn6	by series	C1	base	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N series wt
jn7	equal, estimated	C2	base	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N alt catch
jn8	equal, estimated	C1	base+US obs	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N alt index
jn1s1	estimated	C1	1	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N index 1
jn1s2	estimated	C1	2	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N index 2
jn1s3	estimated	C1	3	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N index 3
jn1s4	estimated	C1	4	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N index 4
jn1s5	estimated	C1	5	no	0.005	JAGS	1950	lnorm	lnorm,mean 0.046	N index 5

(b) South Atlantic

Run	*Weighting*	*Catch*	*Indices*	*Est cat*	*Proc. error*	*Software*	*Catch start date*	*B0/K prior*	*r prior*	*Name*
s1	equal, estimated	C1	base	no	0	BSP	1971	lnorm	lnorm, mean 0.073	S equal wt
s2	equal, fixed	C1	base	no	0.05	BSP2	1971	lnorm	lnorm, mean 0.073	S process error
s1pm pd	NA	C1	NA	no	0	BSP	1971	lnorm	lnorm, mean 0.073	S pmpd
js1	equal, estimated	C1	base	no	0.005	JAGS	1971	lnorm	lnorm, mean 0.073	S equal wt
js2	equal, estimated	C1	base	no	0.05	JAGS	1971	lnorm	lnorm, mean 0.073	S process error
js1p mpd	NA	C1	NA	no	0.005	JAGS	1971	lnorm	lnorm, mean 0.073	S pmpd

Table Appendix 5. Expected values (CVs) of estimate parameters for the BSP1 and BSP2 model alternative runs for North Atlantic mako sharks.

Variable	*mako17 N1*	*mako17N2*	*mako17N3*	*mako17N4*	*mako17N5*	*mako 17N6*	*mako 17N7*	*mako17 N8*	*mako17N1P MPD*
	equal wt	*effort fit*	*catch wt*	*double r sd*	*process error*	*series wt*	*C2 catch*	*alt index*	
K (1000)	1592.96 (0.78)	446.71(1.0)	1395.38(0.9)	1594.17(0.78)	1160.38(0.8)	1088. 96(1. 0)	1810. 40(0. 70)	1756.9 6(0.70)	1245.22(1.0)
r	0.05(0. 12)	0.05(0.1)	0.05(0.1)	0.05(0.24)	0.05(0.1)	0.05(0.1)	0.05(0.12)	0.05(0. 12)	0.05(0.1)
MSY (1000)	18.20(0 .80)	5.20(1.0)	16.04(0.9)	18.16(0.84)	13.54(0.8)	12.54 (1.0)	20.68 (0.71)	20.11(0 .71)	14.32(1.0)
Bcur (1000)	1515.92 (0.82)	302.00(1.6)	1316.91(1.0)	1514.94(0.82)	1020.82(0.8)	1013. 84(1. 1)	1715. 90(0. 73)	1678.8 8(0.73)	1165.04(1.1)
Binit (1000)	1455.62 (0.80)	294.65(1.5)	1260.14(0.9)	1456.44(0.80)	1058.20(0.8)	1004. 30(1. 0)	1655. 66(0. 71)	1596.0 0(0.71)	1122.33(1.0)
Bcur/Bin it	1.02(0. 14)	1.04(0.4)	0.97(0.2)	1.02(0.14)	0.91(0.2)	0.95(0.2)	1.02(0.14)	1.04(0. 14)	0.90(0.3)
Ccur/MS Y	0.34(0. 82)	0.78(0.3)	0.50(0.9)	0.35(0.82)	0.53(0.7)	0.53(0.7)	0.36(0.78)	0.28(0. 78)	0.70(1.0)
Bcur/Bm sy	1.82(0. 08)	1.17(0.3)	1.73(0.2)	1.82(0.08)	1.64(0.2)	1.72(0.1)	1.82(0.08)	1.85(0. 06)	1.59(0.3)
Fcur/Fms y	0.20(0. 96)	0.79(0.5)	0.37(1.4)	0.21(0.97)	0.37(0.8)	0.34(0.8)	0.21(0.94)	0.16(0. 90)	1.27(4.3)

Table Appendix 6. BSP2-JAGS alternative model expected values and CVs for north Atlantic mako sharks.

Parameter	*1N equal wt*	*2N effort fit*	*3N catch wt*	*4N double r sd*	*5N pmpd*	*6N process error*	*7N series wt*	*8N C2 catch*	*9N alt index*
Rhat	1.01	1.17	1.02	1.04	1.15	1	1.01	1.02	1.02
n.eff	280	15	87	110	24	2100	180	520	110
K(1000)	251.57(0.29)	256.72(0.17)	342.33(0.08)	252.16(0.29)	493.29(1.87)	159.99(0.26)	227.14(0.24)	304.17(0.3)	265.69(0.27)
r	0.05(0.12)	0.05(0.13)	0.05(0.06)	0.05(0.12)	0.05(0.12)	0.05(0.12)	0.05(0.12)	0.05(0.12)	0.05(0.12)
B0/Bmsy	1.75(0.16)	1.82(0.13)	0.41(0.03)	1.79(0.14)	1.82(0.13)	1.81(0.13)	1.81(0.13)	1.77(0.14)	1.77(0.14)
Bcur.Bmsy	1.36(0.12)	0.88(0.24)	1.3(0.04)	1.37(0.12)	0.73(1.12)	1.09(0.21)	1.32(0.11)	1.35(0.13)	1.42(0.1)
HRcur.HRmsy	0.88(0.34)	1.22(0.25)	0.57(0.08)	0.88(0.34)	2441.6(1.23)	1.75(0.32)	0.97(0.29)	0.99(0.37)	0.78(0.32)

Table Appendix 7. Expected values (CVs) of model outputs from BSP1 and BSP2 alternative model runs for the South Atlantic.

Variable	*mako17S1*	*mako17s2*	*mako17S1PMPD*
	equal wt	*process error*	*pmpd*
K (1000)	2416.85(0.53)	1489.99(0.51)	1079.86(1.1)
r	0.07(0.11)	0.07(0.09)	0.07(0.1)
MSY (1000)	42.86(0.54)	26.21(0.47)	19.70(1.2)
Bcur (1000)	2288.62(0.54)	1594.18(0.52)	1039.75(1.2)
Binit (1000)	1238.15(0.58)	922.35(0.60)	976.59(1.2)
Bcur/Binit	1.90(0.20)	1.82(0.13)	0.93(0.3)
Ccur/MSY	0.09(0.82)	0.13(0.47)	0.60(1.2)
Bcur/Bmsy	1.88(0.03)	2.13(0.08)	1.66(0.3)
Fcur/Fmsy	0.05(0.88)	0.06(0.47)	1.05(4.6)

Table Appendix 8. Expected values (CVs) or model outputs from BSP2-JAGS alternative model runs for the South Atlantic.

Parameter	*10S equal wt*	*11S process error*	*12S pmpd*
Rhat	1	1	1.21
n.eff	1400	3600	13
K(1000)	236.69(0.44)	161.93(0.43)	352.39(2.28)
r	0.07(0.11)	0.07(0.11)	0.07(0.12)
B1.K	1.07(0.22)	1.1(0.2)	1.83(0.12)
Bcur.Bmsy	1.58(0.09)	2.04(0.15)	0.7(1.2)
HRcur.HRmsy	0.47(0.47)	0.55(0.43)	4363.62(1.19)

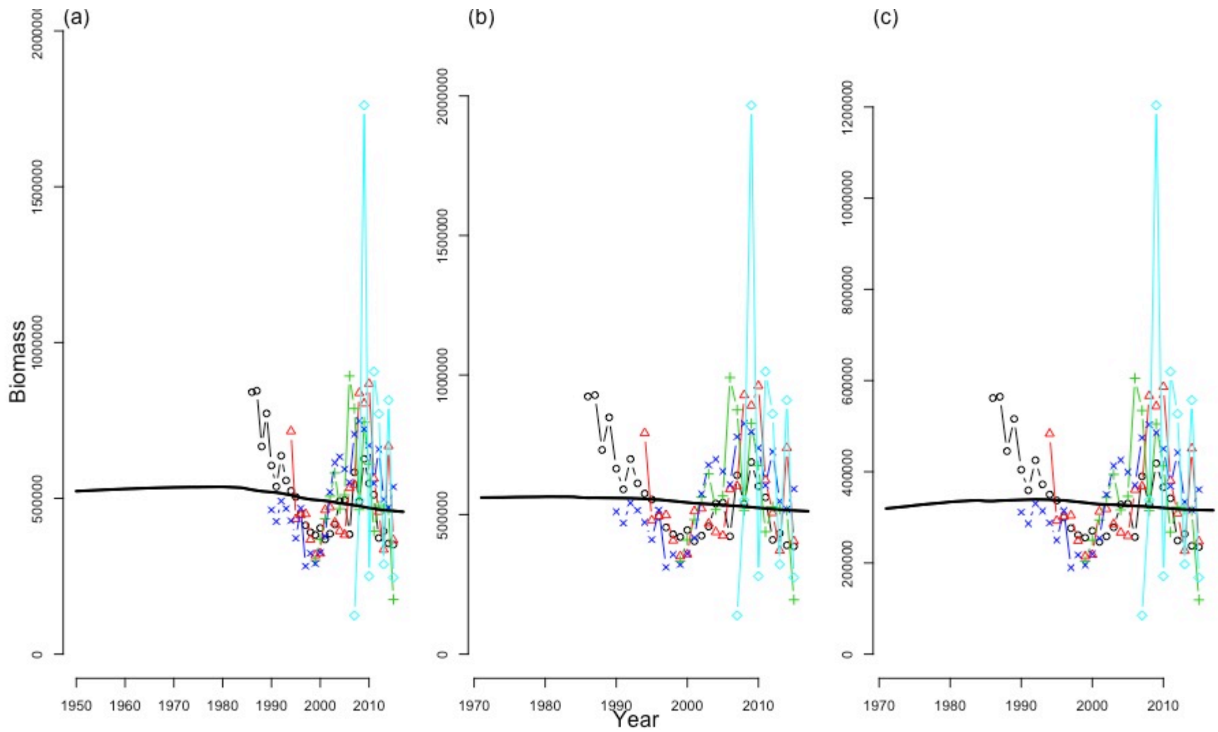

Figure Appendix 1. BSP1 model fits for the North Atlantic, for the runs described in **Table Appendix 1a**.

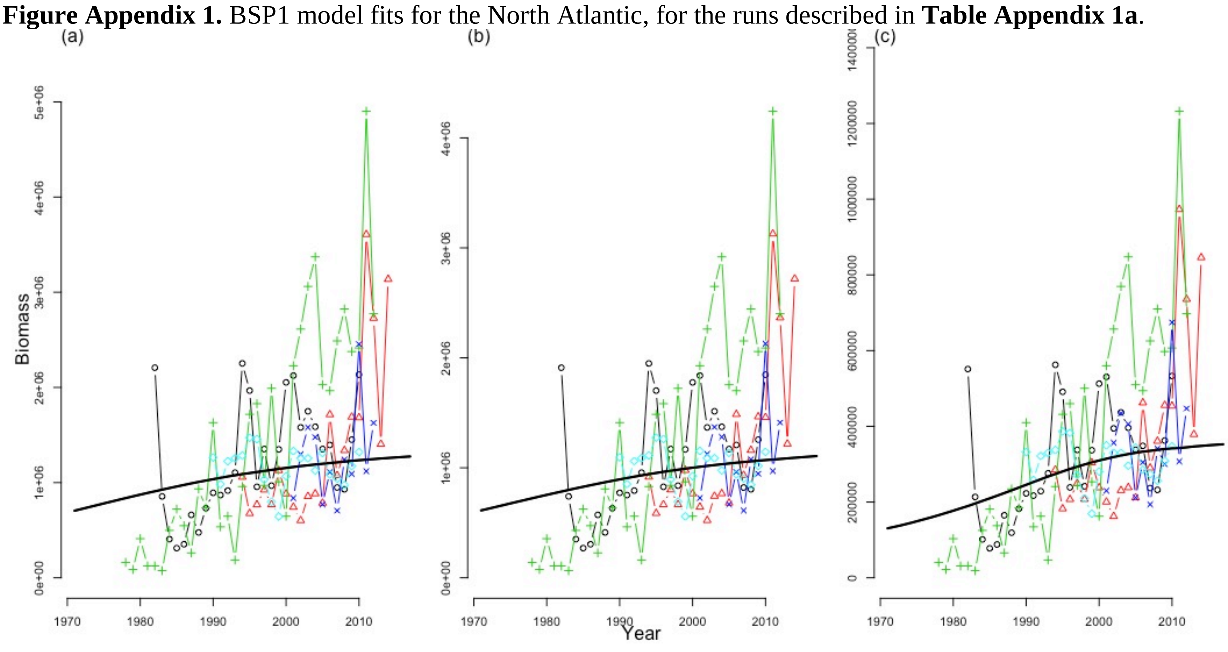

Figure Appendix 2. BSP1 continuity model fits for the South Atlantic for the runs described in **Table Appendix 1b**.

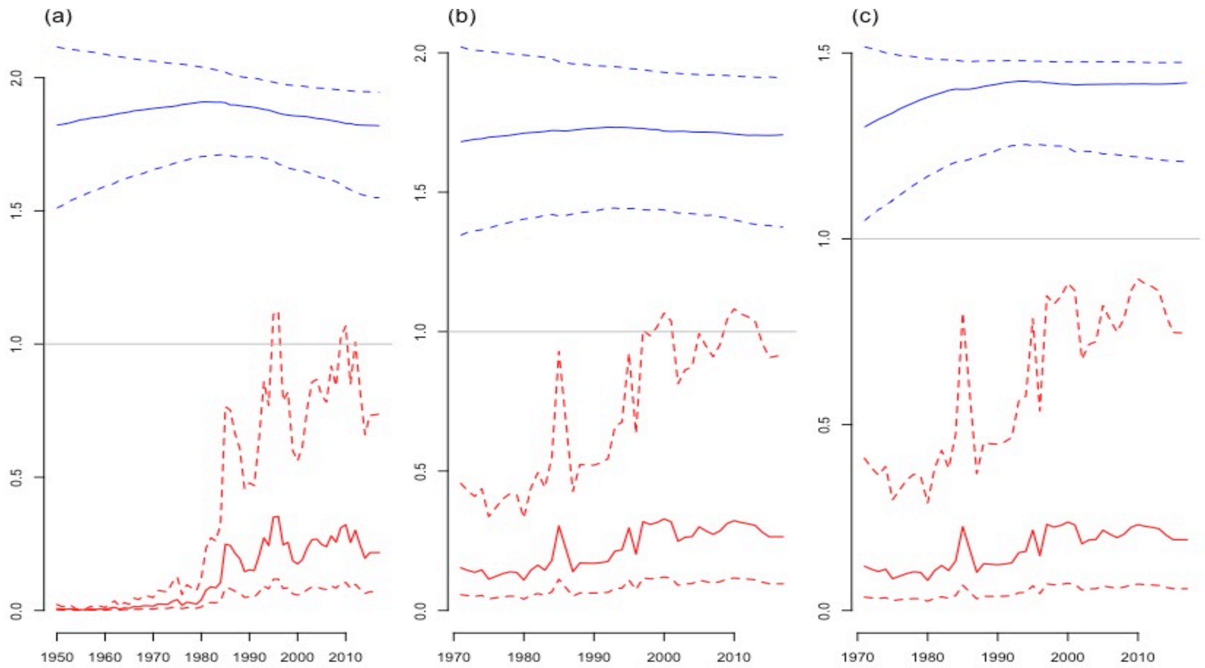

Figure Appendix 3. B/B_{MSY} (blue) and H/H_{MSY} (red) with 80% credible intervals for north Atlantic mako BSP1 continuity runs (a) C1 catch, (b) C2 catch, and (c) generalized model with C1 catch.

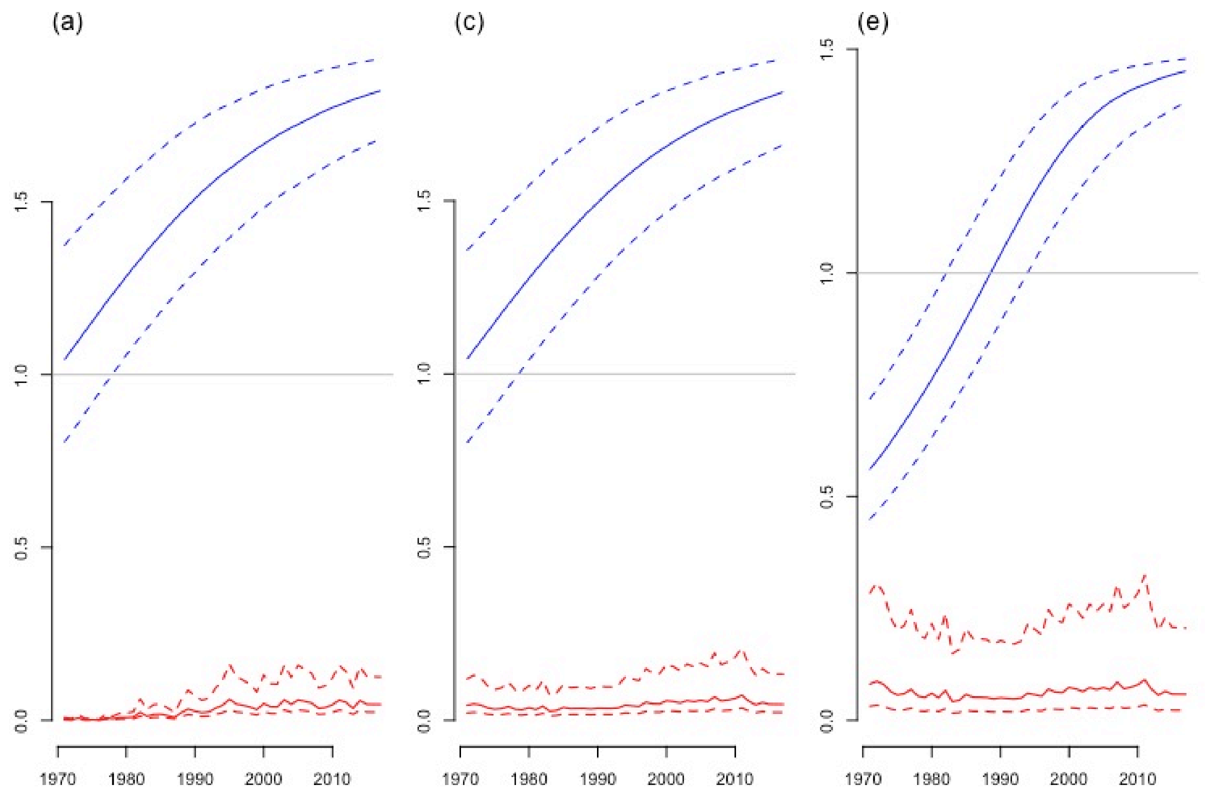

Figure Appendix 4. B/B_{MSY} (blue) and F/F_{MSY} (red) with 80% credible intervals for south Atlantic mako BSP1 continuity runs (a) C1 catch , (b) C2 catch, and (c) generalized model with C1 catch.

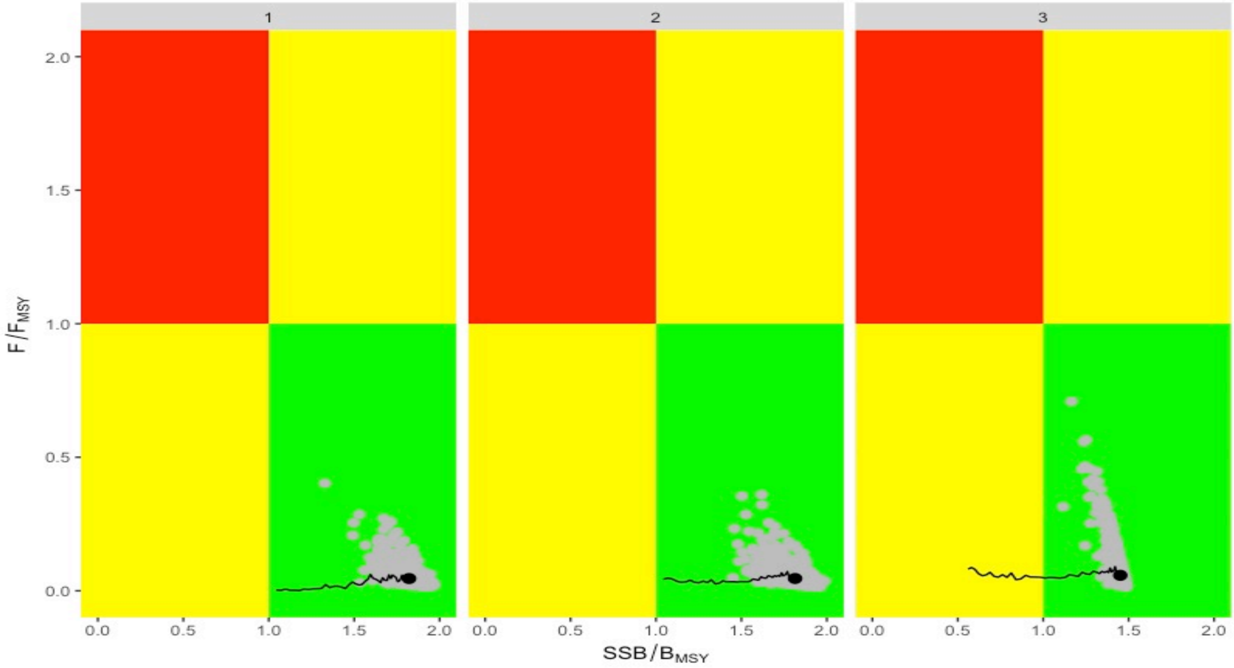

Figure Appendix 5. Kobe plots for south Atlantic mako BSP1 runs (a) C1 catch, (b) C2 catch, (c) generalized model.

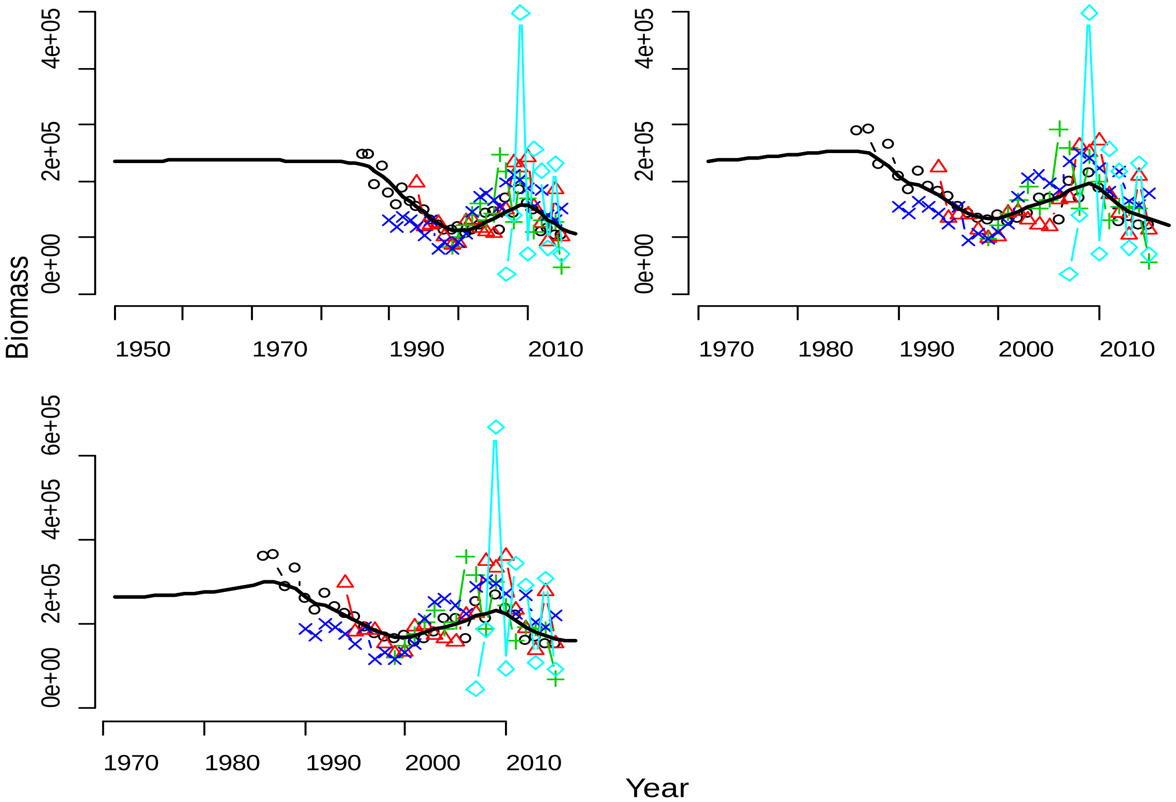

Figure Appendix 6. Mode of the posterior biomass trend for the BSP2 runs in the North Atlantic, with CPUE fits, for (a) C1 catch Schaefer, (b) C2 catch Schaefer, (c) C2 catch generalized production model.

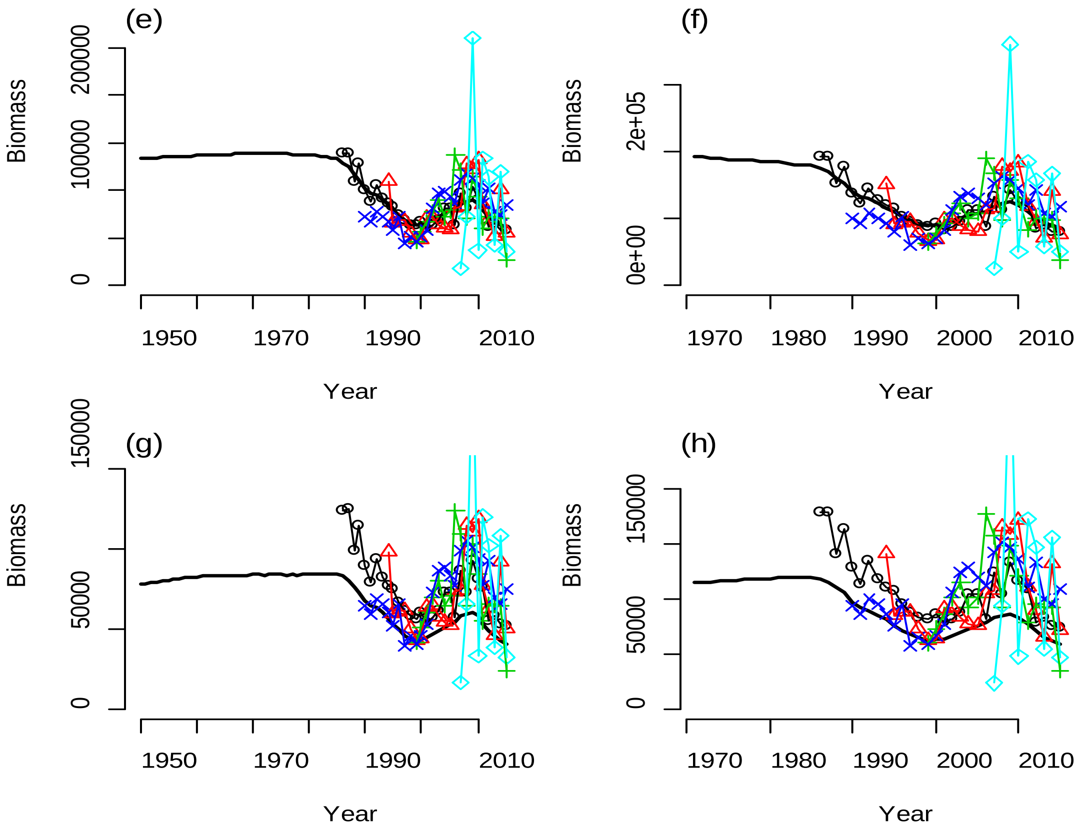

Figure Appendix 7. Median biomass trajectory from the BSP2-JAGS runs described in section 3.1 for the North Atlantic, for (a) the C1 catch Schaefer model, (b) C2 catch Schaefer model, (c) C1 catch generalized production model, and (d) C2 catch generalized production model.

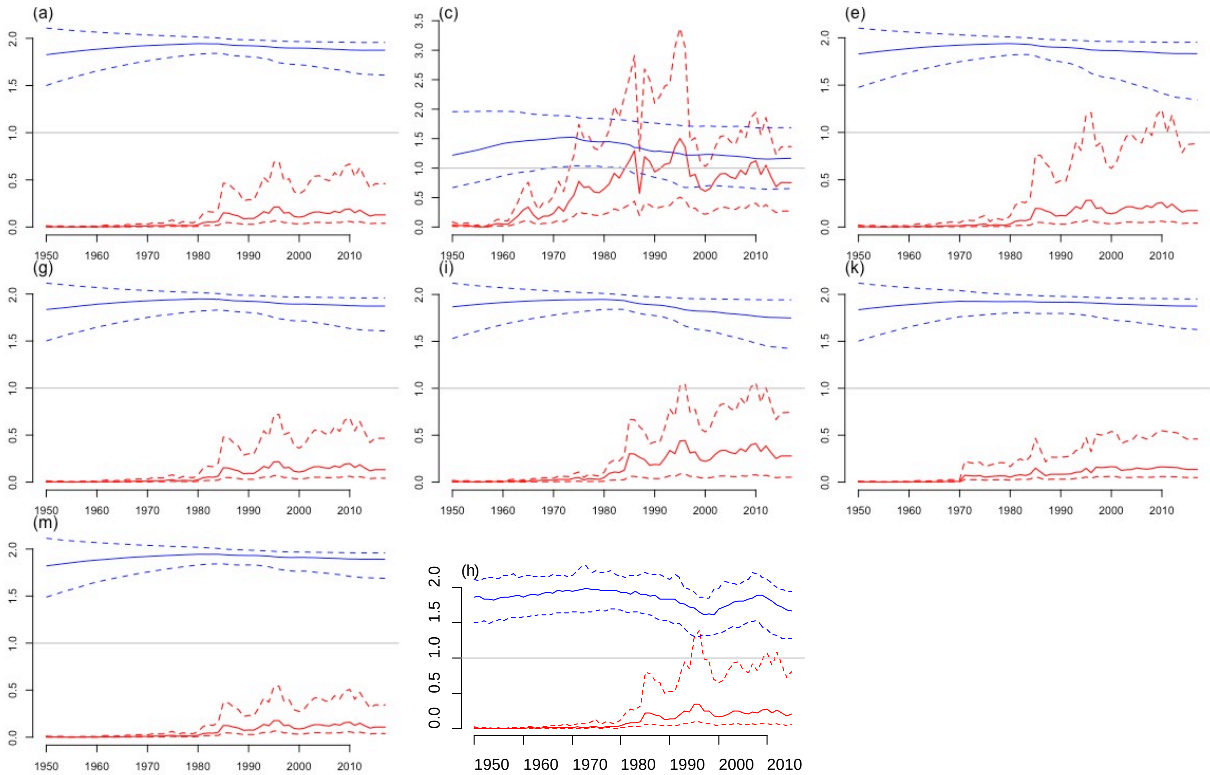

Figure Appendix 8. History of B/B_{MSY} (blue) and H/H_{MSY} (red) with 80% credible intervals for north Atlantic mako BSP1 and BSP2 alternative runs (a) equal weighting, (b) fitted to effort, (c) catch weighting, (d) double r standard deviation, (e) series weighting, (f) catch C2, (g) alternative index, and (h) BSP2 with process error.

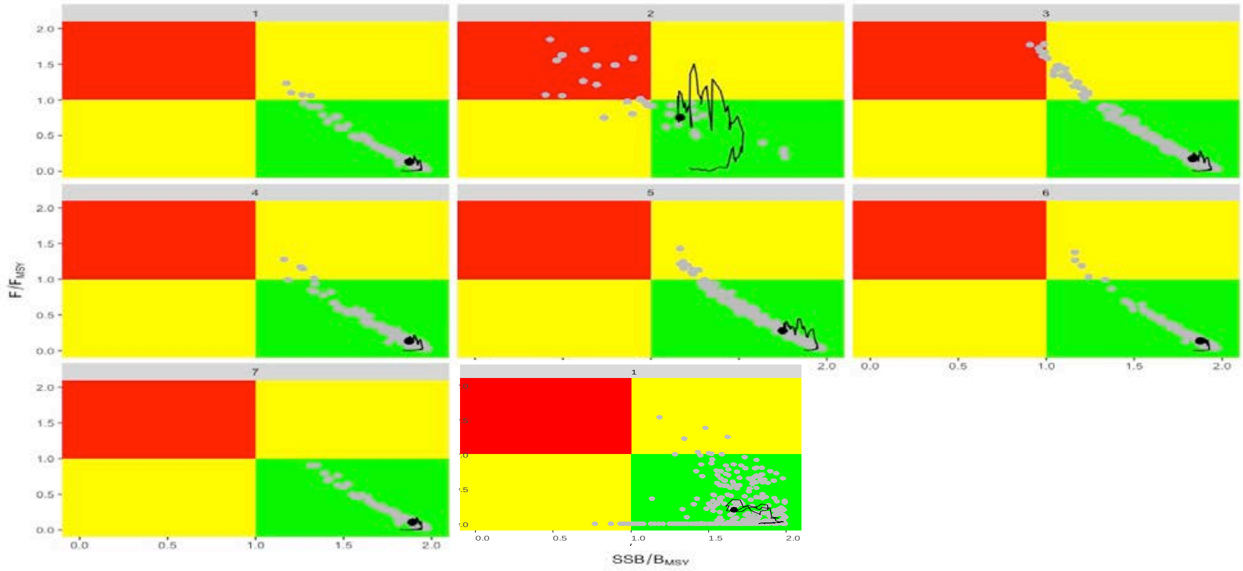

Figure Appendix 9. Kobe plots for north Atlantic mako BSP1 and BSP2 alternative runs (1) equal weighting, (2) fitted to effort, (3) catch weighting, (4) double r standard deviation, (5) series weighting, (6) C2 catch, (7) alternative index, and BSP 2. Current year is 2015.

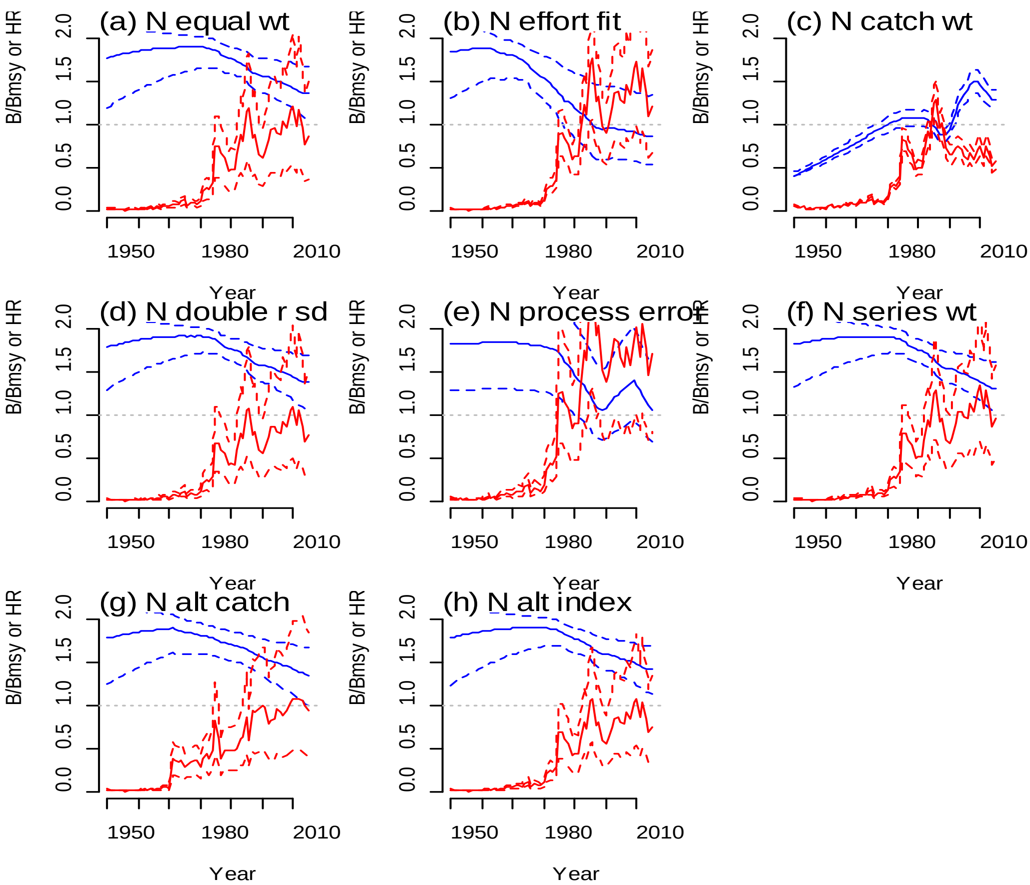

Figure Appendix 10. Biomass and harvest rate trends from BSP2-JAGS alternative models for North Atlantic mako sharks.

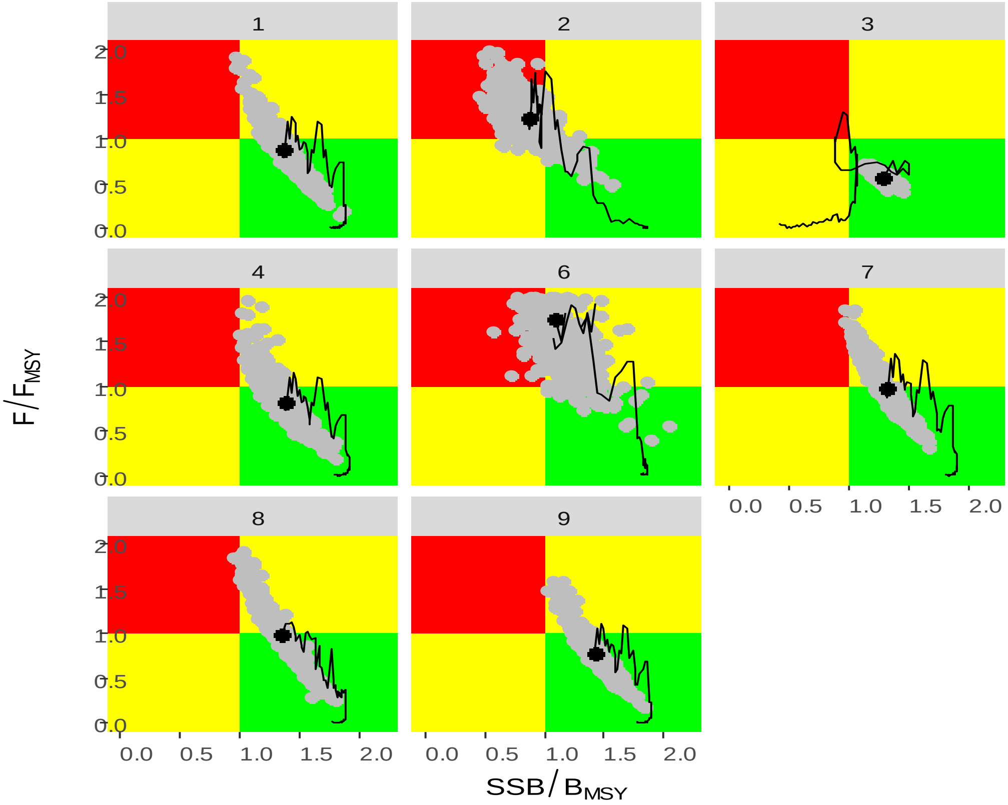

Figure Appendix 11. Kobe plots from BSP2-JAGS alternative models for North Atlantic mako sharks. Current year is 2015 (solid black dot).

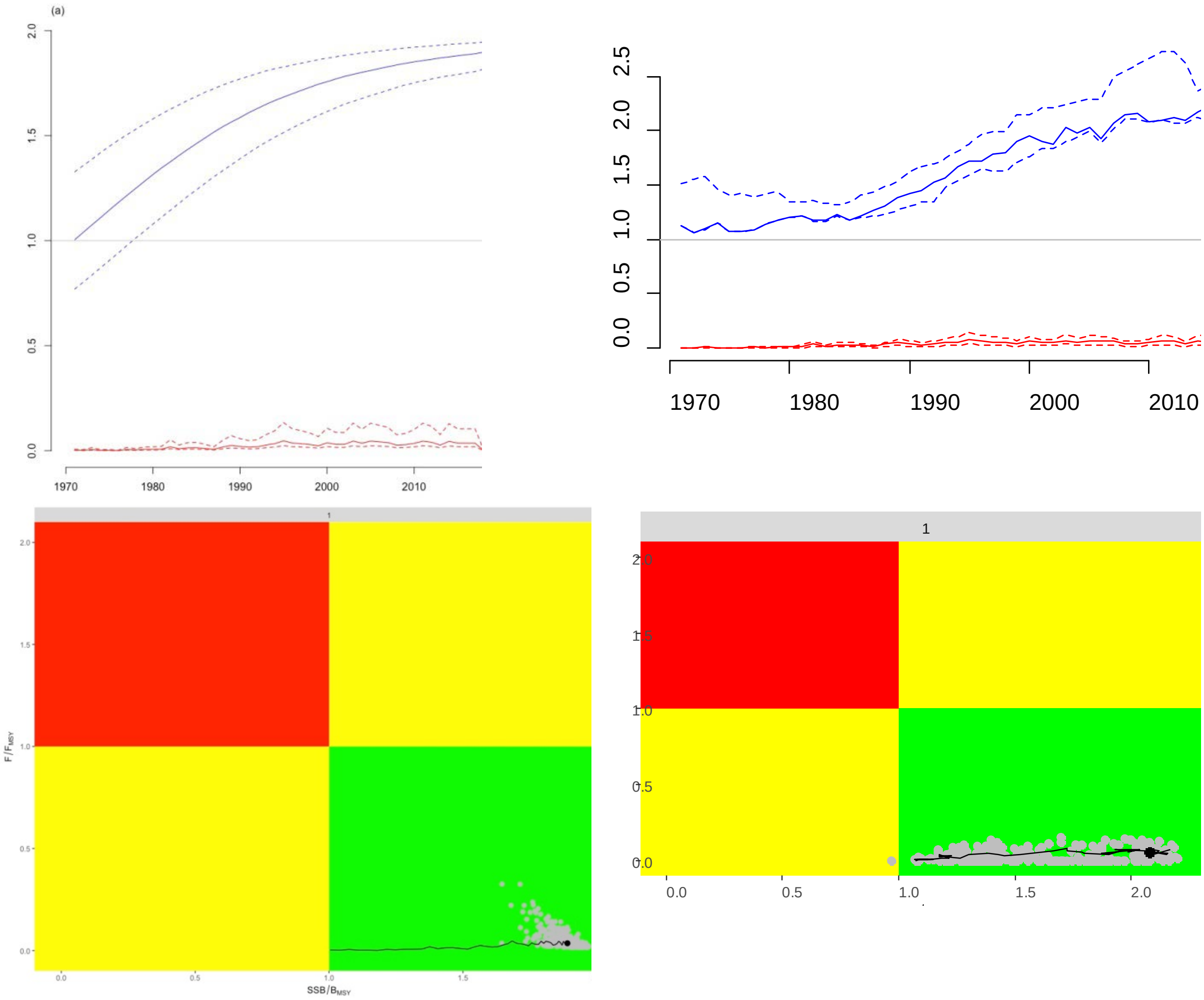

Figure Appendix 12. Biomass and harvest rate trends (top) and Kobe plots (bottom) for South Atlantic mako sharks obtained with the BSP1 (left) and BSP2 (right) results.

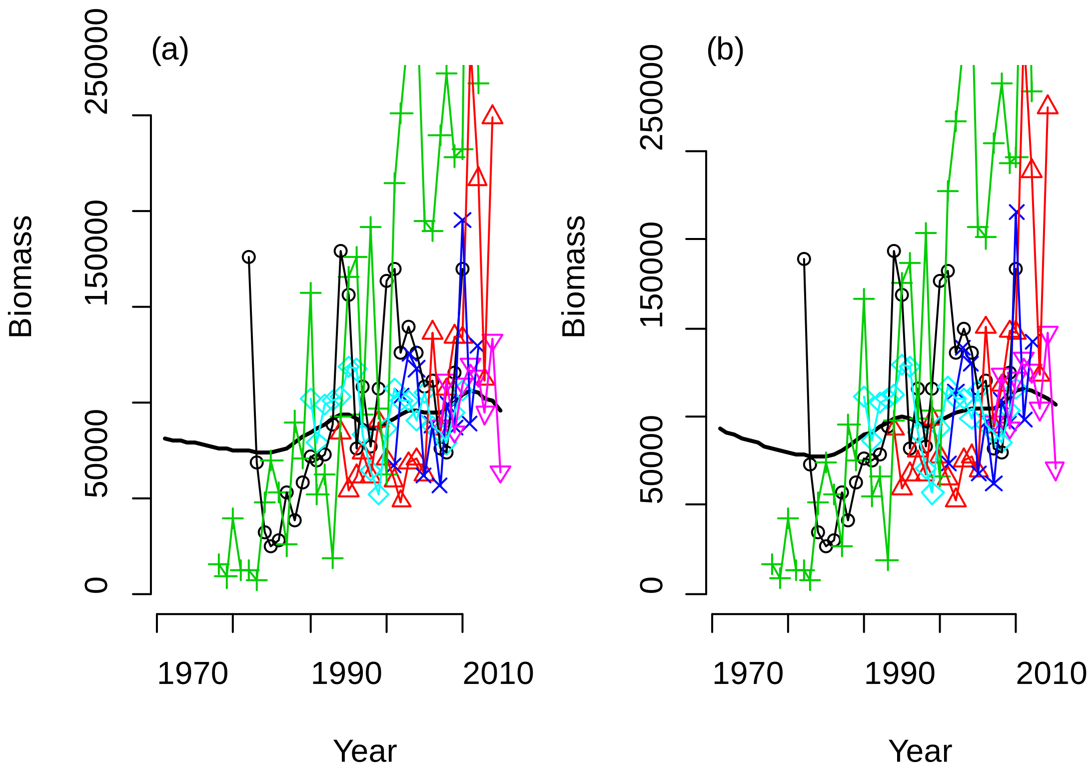

Figure Appendix 13. Median biomass trajectory from the BSP2-JAGS runs for the South Atlantic.

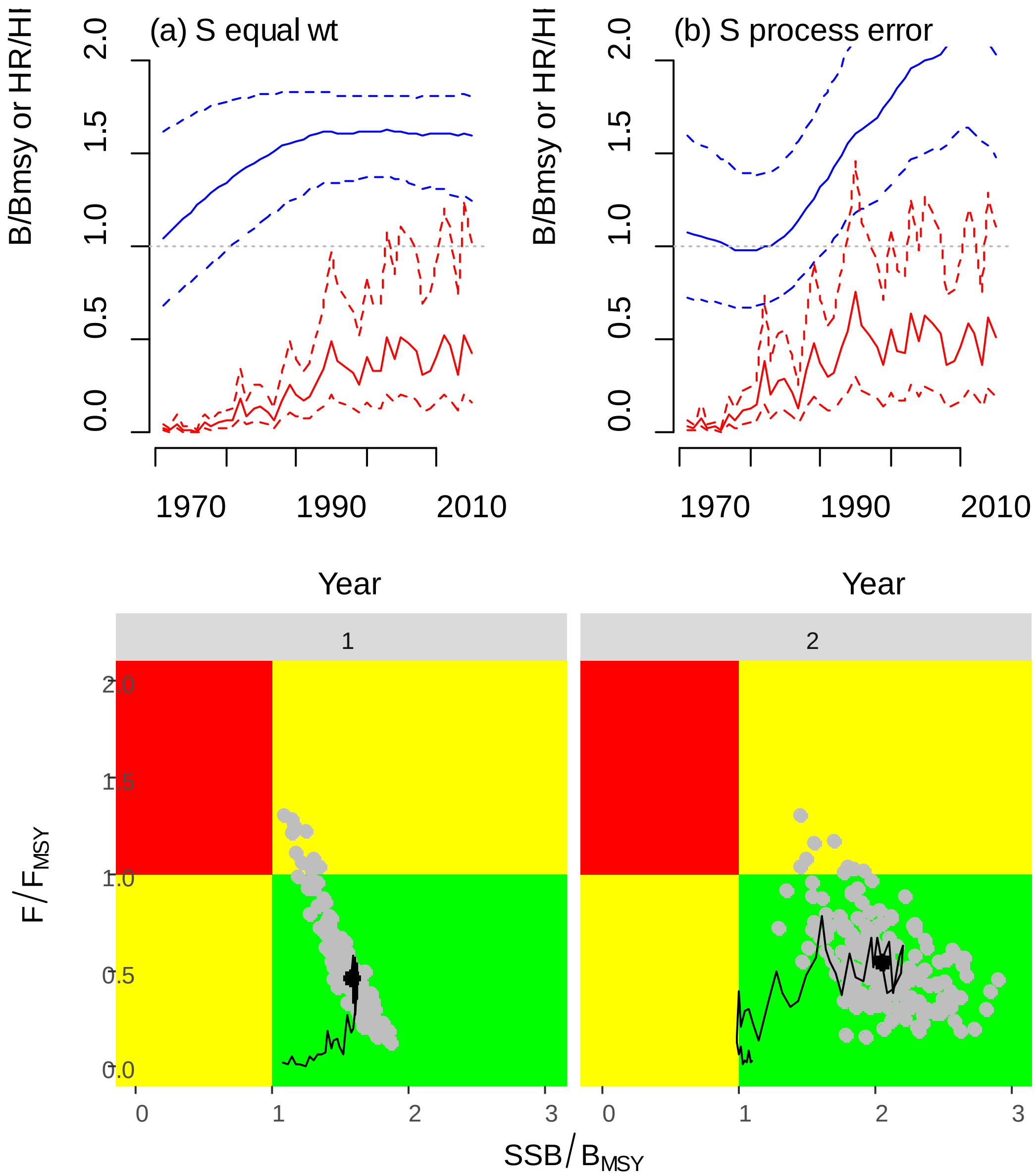

Figure Appendix 14. South Atlantic BSP2-JAGS results without process error (left) and with process error (right), using the priors described in **Table Appendix 1**.

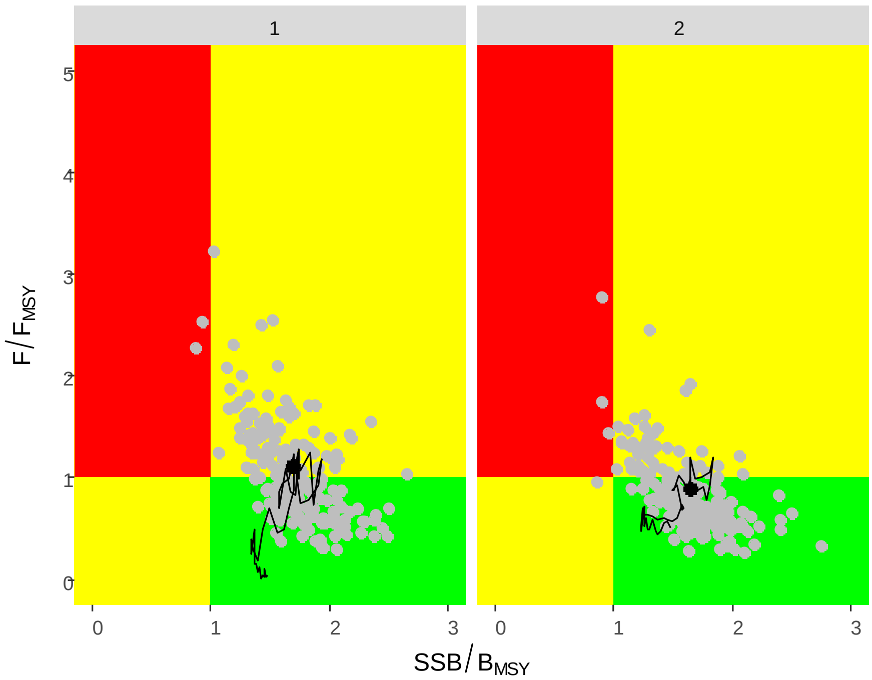

Figure Appendix 15. South Atlantic BSP2-JAGS results from the process error Schaefer models described in section 3.1, using catch C1 (left) or catch C2 (right).