STOCK SYNTHESIS (SS3) MODEL RUNS CONDUCTED FOR NORTH ATLANTIC SHORTFIN MAKO SHARK

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STOCK SYNTHESIS (SS3) MODEL RUNS CONDUCTED FOR NORTH ATLANTIC SHORTFIN MAKO SHARK

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SUMMARY

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. 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 = 3.5) and that F_2015/F_MSY first exceeded 1.0 in 1985. The final SS3 model run indicated that spawning stock size in 2015, calculated here as spawning stock fecundity (SSF, 1,000s), was above the spawning stock size at MSY (SSF_2015/SSF_MSY = 1.217).

RÉSUMÉ

*Des scénarios du modèle Stock synthèse ont été réalisés pour le requin-taupe bleu de l'Atlantique Nord basés sur les données disponibles de capture, CPUE, composition par taille et cycle vital qui ont été compilées par le Groupe d'espèces sur les requins. Un modèle sexo-spécifique a été mis en œuvre afin de pouvoir observer des différences de croissance entre les sexes. On a postulé une relation stock-recrutement de Beverton-Holt. La pente à l'origine de la relation stock-recrutement (*steepness*) et la mortalité naturelle par âge ont été fixées à des valeurs estimées de façon indépendante. Une approche de pondération des données en deux étapes a été mise en œuvre. L'état du stock de l'année finale (2015) par rapport aux points de référence de la production maximale équilibrée (PME) obtenu à partir du scénario final du modèle SS3 suivant l'approche de pondération des données en deux étapes indiquait que le taux de mortalité par pêche en 2015 était supérieur à la production maximale équilibrée (F_2015/F_PME= 3,5) et que F_2015/F_PME avait dépassé 1,0 pour la première fois en 1985. Le scénario final du modèle SS3 indiquait que la taille du stock reproducteur en 2015, calculée comme la fécondité du stock reproducteur (SSF, 1000s), était supérieure à la taille du stock reproducteur au niveau de la PME (SSF_2015/SSF_PME= 1,217).*

RESUMEN

Se llevaron a cabo ensayos del modelo Stock Shynthesis para el marrajo dientuso del Atlántico norte basados en los datos disponibles de captura, CPUE, composición por tallas y ciclo vital recopilados por el Grupo de especies de tiburones. Se implementó un modelo específico del sexo para tener en cuenta las diferencias específicas del sexo observadas en el crecimiento. Se asumió una relación stock reclutamiento de Beverton-Holt. La inclinación de la relación stock reclutamiento y la mortalidad natural por edad se fijaron en valores estimados independientemente. Se utilizó un enfoque de ponderación de los datos en dos etapas: el año final (2015) del estado del stock en relación a los puntos de referencia del rendimiento máximo sostenible (RMS) obtenidos en el ensayo final del modelo SS3 siguiendo el enfoque de ponderación de los datos en dos etapas indicaba que la tasa de mortalidad por pesca en 2015 era superior a la tasa de mortalidad por pesca en el rendimiento máximo sostenible (F_2015/F_RMS = 3,5) y que F_2015/F_RMS superó por primera vez el 1,0 en 1985. El ensayo final del modelo SS3 indicaba que el tamaño del stock reproductor en 2015, calculado aquí como fecundidad del stock reproductor (SSF, 1000s) era superior al tamaño del stock reproductor en RMS (SSF_2015/SSF_RMS = 1,217).

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KEYWORDS

Stochastic models, Stock assessment, Shark fisheries, Pelagic fisheries, Shortfin mako shark

1. Introduction

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. Stock Synthesis is an integrated modeling approach (Maunder and Punt 2013) and was proposed to take advantage of available length composition data sources. An advantage of the integrated modeling approach is that the development of statistical methods which combine several sources of information into a single analysis allows for consistency in assumptions and permits the uncertainty associated with multiple data sources to be propagated to final model outputs (Maunder and Punt 2013). A disadvantage of the integrated modeling approach is the increased model complexity. Because of the model complexity and because this is the first time that Stock Synthesis will be applied to shortfin mako in ICCAT, its application was limited to the North Atlantic stock.

A sex-specific model was implemented to allow for observed differences in length at age between sexes. Sex-specific length composition and life history inputs were obtained and input, where available. Sex-specific natural mortality and growth were implemented, and sex-specific selectivity was implemented for fleets with sex-specific length composition data.

A two-stage Francis (2011) 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). Francis (2011) describes a two-stage approach to assign variance adjustment factors to different data inputs (e.g., first to fleet-specific relative abundance indices, and second to fleet-specific size data distributions) within an integrated stock assessment model. In stage one, variance adjustment factors are applied to the fleet-specific relative abundance indices externally to the integrated stock assessment model. In stage two, variance adjustment factors are applied to fleet-specific size data distributions within the integrated stock assessment model. An example of this approach was previously investigated for North Atlantic blue shark and described in SCRS/2016/066 (Courtney et al. 2017).

Ending year (2015) stock status relative to maximum sustainable yield (MSY) reference points is provided for the final SS3 model run following the two-stage data weighting approach described above.

2. Materials and methods

The model was fitted to the available catch, CPUE, and length composition data compiled during the 2017 Shortfin Mako Shark Data Preparatory meeting. Life history inputs were obtained from data first assembled at the 2014 Intersessional meeting of the Shark Species Group (Anon. 2015), plus updated information provided during the 2016 Intersessional meeting of the Shark Species Group (Anon. 2017), the 2017 Shortfin Mako Shark Data Preparatory meeting (Anon. In Prep.), and thereafter, as summarized below. A sex-specific model was implemented to allow for observed differences in growth between sexes.

2.1 Time series data

Available time series of catch, abundance, and length composition data considered for use in the SS3 model runs were assigned to “fleets” and “surveys” as summarized in **Table 1**. The start year of the model was 1950, and the end year was 2015.

2.1.1 Catch

Catch in metric tons (t) by major flag for North Atlantic mako was obtained from data compiled during the 2017 Shortfin Mako Data Preparatory meeting (**Table 2, Figure 1**) and assigned to fleets F1 – F12 for use in SS3 model runs as described in **Table 1**.

2.1.2 Indices of abundance

Indices of abundance for North Atlantic shortfin mako and their corresponding coefficients of variation (CV) were obtained from data compiled during the 2017 Shortfin Mako Data Preparatory meeting (**Tables 3 and 4, Figure 2**; Anon. In Prep.), except for EU España Longline (EU ESP LL) which was obtained separately from SCRS/2017/108. The available abundance indices and their associated CVs were assigned to surveys S1 – S6 for use in the SS3 model runs as described in **Table 1**.

2.1.3 Length composition

A sex-specific model was implemented in order to allow for observed differences in length at age between sexes, as described below. Sex-specific (♀, ♂) and sex unknown (Unknown) length composition data, 30 – 350 cm fork length (FL) in 10 cm FL bins, were obtained for North Atlantic shortfin mako from data compiled during the 2017 Shortfin Mako Data Preparatory meeting as reported in document SCRS/2017/048 (**Figure 3**; Coelho et al. In Prep.). Length composition data were assigned to fleets F1 – F5 as described in **Table 1**. Length composition data for USA LL were updated here to remove estimated lengths. Sex-combined length composition data (♀, ♂, Unknown) were entered in SS3 for fleet F1 (EU LL), because the available sex-specific data for F1 (♀, ♂) were limited (13% of the combined data were sex specific) (**Table 5**). Sex-specific length composition data were entered in SS3 for fleets F2 (JPN LL), F3 (CTP LL), F4 (USA LL), and F5 (VEN LL), because sex-specific data made up higher proportions of the combined data for the other fleets (92%, 100%, 100%, and 100%, respectively) (**Table 5**). A 10 cm FL bin width was chosen for the length composition data bin width and 21 data length bins (55 – 255+ cm FL, 10 cm FL bins) were defined for use in SS3. A jagged pattern was apparent in some of the length composition data sources at a higher 5 cm FL bin width, which suggested that some lengths were estimated or were not measured at more than 10 cm resolution. In the Stock Synthesis model, a finer resolution can be established for the internal calculations of numbers at length (population length bins) than is used to enter the data (data length bins). For this assessment, a total of 66 population length bins were implemented (55 – 380+ cm FL in 5 cm FL bins).

2.2 Life history

Sex-specific life history inputs were obtained from data first assembled at the 2014 Intersessional meeting of the Shark Species Group (Anon. 2015), plus updated information provided during the 2016 Intersessional meeting of the Shark Species Group (Anon. 2017), the 2017 Shortfin Mako Shark Data Preparatory meeting (Anon. In Prep.), and thereafter, as summarized in document SCRS/2017/126 (Cortés In Prep.; **Table 6**). The maximum age in SS3 was fixed at 30 yr based on the approximate maximum age observed in the population (**Table 6**). In SS3, maximum age is modelled as a "plus" group that accumulates ages greater than or equal to the maximum age.

2.2.1 Growth

Growth in length at age was assumed to follow a von Bertalanffy growth (VBG) relationship, and sex-specific growth was implemented in SS3 by modelling female and male VBG with updated parameters provided separately in SCRS/2017/111 (**Table 7 and Figure 4**). VBG length at age-0 (L_{Amin}) was fixed at 63.0 cm FL for both females and males. VBG asymptotic length (L_{inf}) was 350.6 cm FL for females and 241.8 cm FL for males. VBG growth coefficient (*k*) was 0.064 for females and 0.136 for males. The resulting VBG intercept (t_0) was estimated here as -3.1 for females and -2.2 for males.

A normal distribution in mean length at each age was assumed and was implemented in SS3 separately for females and males (**Figure 5**). The CV in mean length at age was assumed to be a linear function of length. Values for the CVs in length at each age were obtained here from the raw data used for document SCRS/2017/111 (R. Coelho, Pers. Comm.). The sample standard deviation in observed length at each age was divided by the mean in observed length at each age. The CV for L_{Amin} was computed as the average CV for ages <= 8 yr. The CV for L_{inf} was computed as the average CV for ages > 8 yr. The resulting CVs for L_{Amin} were 0.093 for females and 0.097 for males. The resulting CVs for L_{inf} were 0.090 for females and 0.082 for males. CVs were linearly interpolated between L_{Amin} and L_{inf}. The break point at age (8 yr) was chosen because this was the approximate age after which male and female growth began to differ noticeably (e.g., see **Figure 4**)

A combined-sex length-weight relationship, weight (kg) = 5.2432E-06*(cm FL)^3.1407 (**Table 6**) was implemented in SS3 to convert body length (cm FL) to body weight (kg) for both males and females.

2.2.2 Pup production

Annual pup production at each age (**Table 8**) was implemented in SS3 model runs, and was calculated as follows. Growth in cm FL at each age was assumed to follow the female VBG relationship from **Table 7**. Growth in cm TL was obtained as (growth in cm FL + 1.7101)/ 0.9286 from **Table 6**. Litter size (LS) was obtained as 0.81 * (growth in m TL)^ 2.346 from **Table 6**. Female fraction mature (Mat) at m TL was obtained as 1/(1+exp-(-27.81+9.332*MS)) from **Table 6,** where MS was maternal size (m TL). Annual pup production was obtained by assuming a three year reproductive cycle (**Table 6**) and calculated as [(LS) * (Mat)]/3 (**Table 8**). For sensitivity analyses, a more conservative estimate of the annual pup production at parturition at age *a* was modeled as the annual pup production at age *a* - 2, based on an assumed gestation period of 18 months (**Table 6)** plus an additional 6 months to allow for mating.

2.3 Model structure

2.3.1 Natural mortality

Sex-specific natural mortality rates at each age (M_a) were fixed at values obtained independently with life history invariant methods, as described in document SCRS/2017/126 (Cortés In Prep.; **Table 9, Figure 6**). The VBG parameters utilized to derive sex-specific natural mortality rates were obtained from document SCRS/2017/111 (Rosa et al. In Prep), and were the same as those used in the SS3 model runs (**Table 7**).

2.3.2 Stock recruitment

A Beverton-Holt stock-recruitment relationship was assumed and implemented in SS3. In Stock Synthesis, the Beverton-Holt stock-recruitment model is parameterized with three parameters, the log of unexploited equilibrium recruitment (R_0), the steepness parameter (h) and a parameter representing the standard deviation in recruitment (σ_R) (Methot and Wetzel 2013; e.g., Wetzel and Punt 2011a, 2011b). Parameter estimation for ln(R_0) utilized a normal prior with a large standard deviation (Pr_SD) along with independent minimum and maximum boundary conditions (Min, Max). Implementation of a normal prior is described in the manual for Stock Synthesis (Methot 2015). The steepness parameter, *h*, describes the fraction of the unexploited recruits produced at 20% of the equilibrium spawning biomass level. For these SS3 model runs, the stock-recruit steepness parameter was fixed at a value obtained analytically based on life history, h = 0.345 (**Table 9)**, as described in document SCRS/2017/126 (Cortés In Prep.). The VBG parameters utilized to derive the stock-recruit steepness parameter were obtained from document SCRS/2017/111 (Rosa et al. In Prep), and were the same as those used to derive sex specific natural mortality rates, as described above, and as those used in the SS3 model runs (**Table 7**). The parameter representing the standard deviation in recruitment, σ_R, was fixed initially at a value of 0.4 and updated as described below.

Spawning stock size in the stock-recruitment relationship was modelled as spawning stock fecundity (SSF), and calculated here as the sum of female numbers at age (in 1,000s) multiplied by annual female pup production at age (male and female pups, assuming a 1:1 ratio of male to female pups) at the beginning of each calendar year.

An examination of preliminary SS3 output with the program r4ss (Taylor et al. 2014) indicated that there was little recruitment information in the data prior to about 1985, that there was a ramp up in recruitment information by about 1990 consistent with availability of length composition data beginning about that time (**Table 5** and **Figure 7**; e.g., see **Figure 11** – lower panel), and a ramp back down after about 2012 consistent with the decreasing influence of length composition data on recruitment with proximity to the terminal year of the model. Consequently, main recruitment deviations were estimated in these SS3 model runs for the years 1990 – 2012, with early recruitment deviations beginning 5 years prior to the main recruitment in 1985. Main recruitment deviations are zero centered. The estimation of early recruitment deviations allows for recruitment in early periods without biasing recruitment estimates in the main period. Recruitment deviations are estimated on the log scale in Stock Synthesis. Consequently, the expected recruitments require a bias adjustment so that the resulting recruitment level on the standard scale is mean unbiased. The years chosen for bias adjustment, and the maximum bias adjustment parameter value were obtained from Stock Synthesis output with the program r4ss.

2.3.3 Selectivity

A double normal selectivity function (Stock Synthesis selectivity pattern 24; Methot 2015) was implemented in SS3 for fleets F1 – F5 (**Table 1**) and fit to the available length composition data (10 cm FL bin width; **Figure 3**). The double normal selectivity function includes six parameters: p1 - Peak value, p2 - Top logistic, p3 - Ascending width, p4 - Descending width, p5 - Selectivity at initial size bin, and p6 - Selectivity at final size bin.

Initial values for all parameters were obtained by fitting the selectivity curve by eye to the available length composition data separately for each fleet within a Microsoft Excel spreadsheet provided with Stock Synthesis. Selectivity at the first bin (p5) was subsequently fixed at its value determined by eye, and the remaining parameters were estimated within SS3 with initial values set to those obtained by eye. This approach allowed for either asymptotic selectivity or dome-shaped selectivity depending upon the data. Parameter estimation for double normal selectivity parameters utilized a diffuse symmetric beta prior (Pr_SD = 0.05) scaled between parameter bounds. A diffuse symmetric beta prior imposed larger penalty near minimum and maximum boundary conditions (Min, Max) and is described in the manual for Stock Synthesis (Methot 2015). Because there was no prior information – other than the fit by eye, the priors were set equal to the initial values.

Sex-specific selectivity was implemented for fleets with sex-specific length composition data (F2 – F5; **Tables 1 and 5**). Sex-specific selectivity was implemented as a parameter offset to the double normal selectivity and included the estimation of five additional parameters per fleet: p1-offset (peak), p3-offset (ascending width), p4-offset (descending width), p6-offset (selectivity at final size bin), and sex specific apical selectivity. Parameter offsets to double normal selectivity were estimated with minimum and maximum boundary conditions (Min, Max) for each parameter (no prior). For each fleet, male selectivity was first calculated as an offset from the female parameters (option 3), followed by calculating female selectivity as an offset from the male parameters (option 4). The option which resulted in maximum selectivity equal to one was chosen so that the resulting apical *F* (the *F* that would be obtained when multiplied by maximum selectivity) was comparable among fleets. Initial values for selectivity offset parameters along with their minimum and maximum boundary conditions were adjusted by trial and error in preliminary model runs to insure that parameter estimates were not hitting upper or lower bounds.

2.3.4 Data weighting

A two-stage Francis (2011) data weighting approach was implemented. In stage one, a minimum average standard error (SE; on the natural log scale) was implemented in SS3 for each CPUE series. The minimum SE was based on fitting a simple smoother to the CPUE data (on the natural log scale) outside the model and estimating the residual variance[2] (e.g., Francis 2011; Lee et al. 2014a, 2014b; Courtney et al. 2017). In stage two, the Francis (2011) method was applied to estimate the effective sample size of each length composition data set from the residuals of the Stock Synthesis model fit to the data, based on Stock Synthesis output (Methot and Wetzel 2013; Methot 2015) obtained with the program r4ss (Taylor et al. 2014). The McAllister and Ianelli (1997) method (using the harmonic mean) was also evaluated to estimate the effective sample size of each length composition data from the residuals of the Stock Synthesis model fit to the data, based on Stock Synthesis output (Methot and Wetzel 2013; Methot 2015). The Francis (2011) and McAllister and Ianelli (1997) methods are reviewed in Punt et al. (2014).

Stage 1. The CVs for each CPUE series were obtained externally to the Stock Synthesis model and adjusted externally to the model before being input in Stock Synthesis as follows. The annual CVs for each CPUE series were assumed to be equal to the SE on the log scale and adjusted based on our expectation that the stock assessment model would fit each CPUE data **at best** as well as a smoother (e.g., Francis 2011; Lee et al. 2014a, 2014b; Courtney et al. 2017). The average annual SE (SE.in; on the log scale) was calculated for each CPUE series. The square root of the residual variance was calculated based on the fit of a simple smoother to each CPUE series on the log scale as

$$\mathrm{RMSE}_{smoother} = \sqrt{\left(\tfrac{1}{N}\right)\sum_{t=1}^{N}\left(Y_t - \hat{Y}_t\right)^2}$$

where Y_t is the observed CPUE in year *t* on the log scale, $\hat{Y}_t$ is the predicted CPUE in year *t* from the smoother fit to the data on the log scale, and N is the number of CPUE observations—rather than the degrees of freedom used in the estimation of the smoother fit— (e.g., Francis 2011; Lee et al. 2014a, 2014b; Courtney et al. 2017). For these model runs, a LOESS smoother was fit to each CPUE data on the log scale (**Appendix A**). If SE.in for a CPUE series was less than $\mathrm{RMSE}_{smoother}$ for that CPUE series, then the input SE for the CPUE series was

[2] Carvalho, F. and H. Winker. Withdrawn. Stock assessment of south Atlantic blue shark (*Prionace glauca*) through 2013. (ICCAT SCRS/2015/153).

adjusted (SE.adj) in Stock Synthesis before running the model so that the new average SE was equal to $\mathrm{RMSE}_{smoother}$ (SE.in + SE.adj = $\mathrm{RMSE}_{smoother}$). If SE.in for a CPUE series was greater than or equal to the $\mathrm{RMSE}_{smoother}$ for that CPUE series then the SE of the CPUE series was not adjusted in the Stock Synthesis model. The resulting variance adjustment factors for surveys S1 – S6 were 0.0000, 0.0000, 0.1459, 0.0578, 0.0886, and 0.2510, respectively.

Stage 2. The Francis (2011) method (Francis method Stage 2) was applied to estimate the effective sample size of each length composition data set after an initial model run with the input CVs adjusted for each CPUE as described in Stage 1 above. The input sample sizes for the length composition data for fleets F1 – F5 were adjusted two times with variance adjustment multiplication factors so that the sample size entered for each length composition data set (fleets F1 – F5) was equal to the effective sample size obtained using the Francis method. The resulting variance adjustment factors for fleets F1 – F5 were 0.048, 0.057, 0.040, 0.100, and 0.254, respectively.

Stage 2 *VarAdj (1st time)	**Stage 2 *VarAdj (2nd time)**	**Percent Difference**	**Relative Difference**
0.063	0.048	0.77	23% (Lower)
0.083	0.057	0.69	31% (Lower)
0.041	0.040	0.96	4% (Lower)
0.119	0.100	0.84	16% (Lower)
0.626	0.254	0.41	59% (Lower)

Additional iterative adjustments to the effective sample size obtained using the Francis method were not attempted because the estimates appeared to stabilize (i.e., within 6% of the previous estimate). This is consistent with CAPAM Data Weighting Workshop (Pers. Obs., D, Courtney, see footnote 3) that the Francis method variance adjustment factors for length composition data tend to stabilize after one (or in this case two) iterative adjustments.

The effective sample size for length composition obtained with the Francis method is based on the number of years with length composition data and can be uncertain if the number of years is small (Courtney, D. Pers. Observation from CAPAM Data Weighting Workshop; see footnote 3). For this reason, the McAllister and Ianelli (1997) method (using the harmonic mean) was also explored for obtaining the effective sample size of each length composition data set in Stage 2. The resulting variance adjustment factors obtained with the McAllister and Ianelli (1997) method (using the harmonic mean) for fleets F1 – F5 resulted in relatively more weight being given to the length data than the Francis method. Consequently, variance adjustments that would be applied to length data from the McAllister and Ianelli (1997) method (using the harmonic mean) were considered to be intermediate between those that would be applied under the raw length data sample size and those that would be applied under the Francis method, and were not implemented in the final SS3 model runs presented here due to time constrains. However, variance adjustments obtained with the McAllister and Ianelli (1997) method (using the harmonic mean) would be appropriate for use in sensitivity analyses at a later time.

The parameter representing the standard deviation in recruitment, σ_R, was adjusted one time from the initial value of 0.4 to the value of 0.28 in order match the RMSE of recruitment variability obtained in SS3 during the main recruitment deviation period (1990 – 2012). Additional iterative adjustments for the standard deviation in recruitment, σ_R, based on the RMSE of recruitment variability obtained in SS3 were not attempted because the adjustments may tend to zero (Courtney, D. Pers. Observation from the CAPAM Data Weighting Workshop[3]). In addition, lower values for the standard deviation in recruitment, evaluated in preliminary model runs resulted in a noticeable trend in recruitment (matching the trend in CPUE), which did not seem plausible. For example, a similar trend in recruitment, matching the CPUE trends, was observed in preliminary model runs when estimation of early recruitment deviations began in either 1951 (near start year of the model) or in 1966 (the first year for which early recruitment deviations were correlated with other data in the assessment).

[3] Personal observation based on presentations and discussions during a Center for the Advancement of Population Assessment Methodology (CAPAM) Data Weighting Workshop (October 19-23, 2015, La Jolla, California).

The expected recruitments require a bias adjustment so that the resulting recruitment level on the standard scale is mean unbiased. The years chosen for bias adjustment, and the maximum bias adjustment parameter value were obtained from Stock Synthesis output with the program r4ss and implemented in SS3:

1981.6 #_last_early_yr_nobias_adj_in_MPD
1991.5 #_first_yr_fullbias_adj_in_MPD
2012.0 #_last_yr_fullbias_adj_in_MPD
2019.2 #_first_recent_yr_nobias_adj_in_MPD
0.377 #_max_bias_adj_in_MPD

2.3.5 Initial fishing mortality

Initial fishing mortality was not estimated because the model started in 1950 and fishing mortality was assumed to be negligible prior to 1950. In addition, preliminary attempts to estimate initial fishing mortality within these model runs resulted in parameter estimates at the lower boundary (zero). Implementation of initial fishing mortality is described in the manual for Stock Synthesis (Methot 2015). Parameter estimation for initial fishing mortality utilized a normal prior with a large standard deviation (Pr_SD) along with independent minimum and maximum boundary conditions (Min, Max). The poor performance of the initial *F* estimate (hitting a lower bound) contrasts with results from model runs previously completed for North Atlantic blue shark, for which the model was started in 1970 and initial fishing mortality was estimable (Courtney 2016; Courtney et al. 2017). One difference between the SS3 model runs implemented here for North Atlantic shortfin mako and those implemented previously for North Atlantic blue sharks, is that the previously completed runs for North Atlantic blue sharks included some fleets with logistic (asymptotic) selectivity, while those completed for North Atlantic shortfin mako did not include any fleets with logistic (asymptotic) selectivity.

2.3.6 Model convergence and diagnostics

Model convergence was based on whether or not the Hessian inverted (i.e., the matrix of second derivatives of the likelihood with respect to the parameters, from which the asymptotic standard error of the parameter estimates is derived). Other convergence diagnostics were also evaluated. Excessive CVs on estimated quantities (>> 50%) or a large final gradient (>1.00E-05) were indicative of uncertainty in parameter estimates or assumed model structure. The correlation matrix was also examined for highly correlated (> 0.95) and non-informative (< 0.01) parameters. Parameters estimated at a bound were a diagnostic for possible problems with data or the assumed model structure. Fits to CPUE and patterns in Pearson's residuals of fits to length composition data were examined as diagnostics for problems with data or the assumed model structure.

2.3.7 Uncertainty and measures of precision

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. In SS3 asymptotic standard errors are obtained for derived quantities by including the derived parameters in the inverted Hessian matrix calculation.

2.4 Evaluation of stock status

Derived quantities and their associated asymptotic standard errors were obtained for time series of annual spawning stock size (calculated in fecundity; SSF) relative to spawning stock size at MSY (SSF/SSF_MSY) and for annual fishing mortality relative to fishing mortality at MSY (*F*/*F*_MSY).

3. Results

Model results are presented below for the final SS3 model run obtained by applying the two-stage data weighting approach described above to the available data for North Atlantic shortfin mako (**Figure 7**)

3.1 Convergence diagnostics

The Hessian matrix inverted and was presumably positive definite. The final gradient was reasonably small (< 1.00E-05) and no parameters were estimated above the maximum correlation threshold *(cormax = 0.95)* or below the minimum correlation threshold (*cormin* = 0.01).

Parameter estimates, their asymptotic standard errors and resulting CV, and their priors and status relative to imposed boundary conditions are provided in **Table 10.** None of the parameters were estimated at a boundary. The CV of many (20) selectivity parameters was >> 50%. However, repeated examination of selectivity parameter estimation in preliminary and final runs indicated that despite the high uncertainty in individual parameters, the overall shape of the selectivity curves that resulted from the parameter estimation in the final SS3 model run (**Figure 8**) were relatively stable across model runs. In contrast, and as expected, the location of peak selectivity shifted slightly across model runs in response to model changes (Not shown).

3.2 Model fits

3.2.1 Indices of abundance

Model predicted and observed standardized indices of relative abundance are provided in **Figure 9** for each standardized index of relative abundance as defined in **Table 1**. Fits on the nominal scale and on the log scale are provided. Index S2 (USA LL Obs) was not fit in the model likelihood (lambda = 0) because of high variability in the index and because S2 describes the same fishery as S1 (USA LL Log) (Anon. In Prep.).

3.2.2 Length compositions

Model predicted and observed aggregated length compositions (female + male; for fleet F1 and sex-specific for fleets F2 – F5) (as defined in **Tables 1 and 5)** are provided in **Figure 10** for the final SS3 model run. Fits to aggregate length compositions appeared to be reasonably accurate – indicating that the estimated selectivity curves removed sharks from the modelled population in aggregate at comparable length to that observed in the data.

Observed and predicted annual length compositions by fleet (as defined in **Tables 1 and 5)** are provided in **Appendix B**. Fits to the annual length compositions by fleet were poor (**Figure B1**), but there were few obvious systematic patterns observed in the residuals (e.g., patterns of positive or negative residuals) making it difficult to objectively determine how to improve the fits. This may be an important area for future model development. For example, more flexible selectivity curves (or time blocks in selectivity) in combination with alternative binning of length composition data could be examined in the future to account for the jagged distributions observed in annual length compositions. Alternatively, different area stratification of fleets could be explored in the future to either increase sample size or smooth the length-frequency distributions.

Diameter of Pearson residuals was relatively larger for fleet F1 (Max > 10) than fleets F2 – F5 (Max < 3) indicating a relatively poorer fit to fleet F1 (**Figure B1**), and/or relatively larger sample size, and consequently, relatively more influence on model results if in conflict with other data in the model. Length data for fleet F1 was the only fleet modelled with sex-combined length composition. Length-specific data were available but were not fit in the model because there were only a limited number of sex-specific length data relative to the sex-combined data. However, given the poor fit, an examination of sex-specific length data may be appropriate for use in sensitivity analyses at a later time. Additional length composition data were also available for fleet F1 from EU España (**Appendix C**) which were not included in the current model due to time constraints. A preliminary examination of the sex-combined length composition data available for fleet F1 from EU España indicated a similar distribution to EU Portugal but with a peak at slightly smaller lengths for EU España (**Figure C.1**). Interestingly, a peak at slightly smaller lengths than those observed for EU Portugal was also predicted by the SS3 model for fleet F1 (EU LL) in aggregate (**Figure 10**).

3.3 Estimated time series

3.3.1 Recruitment

Expected recruitment from the stock-recruitment relationship and the bias adjustment applied to the stock-recruitment relationship (**Figure 11**), along with estimated log recruitment deviations and estimated annual recruitment (**Figure 12**), are provided for the final SS3 model run. Estimation of early recruitment deviations was limited to 5 years before the start of main recruitment because preliminary model runs which allowed earlier recruitment deviations resulted in an early recruitment pattern that was strongly influenced by the common trend in CPUE (not shown).

3.3.2 Fishing mortality

Two calculations of exploitation rate were obtained from Stock Synthesis model output for the final SS3 model run. First, instantaneous annual fishing mortality rates (Continuous *F*) were estimated for each fleet F1 – F12 (**Figure 13**). Estimated total annual fishing mortality for all fleets combined (*F*) was then calculated as the sum of continuous *F* obtained for each fleet (**Table 11)** and reported relative to total annual fishing mortality at MSY (*F*/*F*_MSY) (**Tables 12 and 13; Figure 14**). Second, the total annual exploitation rate in numbers (*U*) (**Table 11**) was obtained for ages 1+ from Stock Synthesis output for comparison with other assessment methods.

3.3.3 Spawning stock biomass

Estimated **s**pawning stock size (spawning stock fecundity, SSF in 1,000s) along with approximate 95% asymptotic standard errors (± 2*s.e.) relative to spawning stock size at MSY (SSF_MSY) are provided from Stock Synthesis model output for the final SS3 model run in **Table 11** and **Figure 14**.

3.3.4 Evaluation of uncertainty

Sensitivity runs were not implemented in SS3 due to time constraints, but may be important to explore at a later time.

3.4 Stock status

Stock status is provided from the final SS3 model run obtained by applying the two-stage data weighting approach described above.

Annual estimates of total biomass (*B*, 1,000s kg), spawning stock fecundity (SSF, 1,000s), recruits (*R*, 1,000s), total fishing mortality (*F*, calculated as the sum of continuous *F* obtained for each fleet; see **Figure 13**), and the total exploitation rate in numbers (*U*, obtained for ages 1+) are provided in **Table 11**.

Annual estimates of total fishing mortality relative to total fishing mortality at MSY (*F*/*F*_MSY) and **s**pawning stock size (spawning stock fecundity, SSF) relative to spawning stock size at MSY (SSF/SSF_MSY) are provided in **Table 12 and Figure 14**.

Estimates of ending year (2015) stock status relative to maximum sustainable yield (MSY) are provided in **Table 13** including spawning stock fecundity (SSF_2015, 1,000s), fishing mortality (*F*_2015), and recruits (*R*_2015, 1,000s) along with equilibrium SSF (SSF_0) and *R* (*R*_0), maximum sustainable yield (MSY, *t*), 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 (S.E.) calculated from the maximum likelihood estimates of parameter variances at the converged solution and CVs based on the S.E. (where available) are also provided for the parameter estimates.

Model results for the final SS3 model run indicated that the fishing mortality rate in 2015 was above the fishing mortality rate at maximum sustainable yield (*F*_2015/*F*_MSY = 3.5) and that *F*_2015/*F*_MSY first exceeded 1.0 in 1985 (**Tables 12 and 13, Figures 14 and 15**).

Model results for the final SS3 model run indicated that spawning stock size in 2015, calculated here as spawning stock fecundity (SSF, 1,000s), was above the spawning stock size at MSY (SSF_2015/SSF_MSY = 1.217) (**Tables 12 and 13, Figures 14 and 15**).

4. Discussion

Two calculations of total exploitation rate were obtained from Stock Synthesis. The first was the total annual fishing mortality for all fleets combined, *F*, calculated as the sum of continuous *F* obtained for each fleet. The second was the total annual exploitation rate in numbers, *U*, obtained for ages 1+. The two calculations of exploitation rates were similar in trend but not in absolute magnitude (**Table 11; Figure 16**). For comparisons with other assessment methods, the total annual exploitation rate in numbers, *U*, obtained for ages 1+ may be most appropriate, because the sum of continuous *F* may not be comparable across models with different selectivity, especially if maximum selectivity is not equal to one for all fleets.

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Table 1. Time series of catch, relative abundance, and length composition data considered for use in the North Atlantic shortfin mako SS3 model runs.

Time series #	Symbol	Catch (t) and abundance (numbers or biomass)	Name	Definition	Length composition (10 cm FL bins)
1	F1	Catch (t)	EU LL	EU España + Portugal Longline (1950-2015)	EU España + Portugal LL (1997-2015)
2	F2	Catch (t)	JPN LL	Japan Longline(1971-2015)	Japan LL (1997-2015)
3	F3	Catch (t)	CTP LL	Chinese Taipei Longline (1981-2015) [1]	Chinese Taipei LL (2004-2015)
4	F4	Catch (t)	USA LL	USA Longline (1982-2015)	USA LL (1992-2015)
5	F5	Catch (t)	VEN LL	Venezuela Longline (1986-2015)	Venezuela LL (1994-2013)
6	F6	Catch (t)	CAN LL	Canada Longline (1995-2015)	Mirror USA LL (F4)
7	F7	Catch (t)	MOR LL	Morocco Longline (1961-2015) [1]	Mirror EU LL (F1)
8	F8	Catch (t)	USA RR	USA Recreational (1981-2015)	Mirror USA LL (F4)
9	F9	Catch (t)	BEL LL	Belize Longline (2009-2015)	Mirror VEN LL (F5)
10	F10	Catch (t)	MOR PS	Morocco Purse Seine (2011-2015)	Mirror EU LL (F1)
11	F11	Catch (t)	CPR LL	China PR Longline (2000-2015)	Mirror CTP LL (F3)
12	F12	Catch (t)	OTH	Other (1982-2015)	Mirror CTP LL (F3)
13	S1	Relative abundance (numbers)	USA LL Log	USA Longline-Logbook (1986-2015)	Mirror USA (F4)
14	S2	Relative abundance (numbers)	USA LL Obs	USA Longline-Observer (1992-2015) [2]	Mirror USA (F4)
15	S3	Relative abundance (numbers)	JPN LL	Japan Longline (1994-2015)	Mirror JPN (F2)
16	S4	Relative abundance (biomass)	EU POR LL	EU Portugal Longline (1999-2015)	Mirror EU (F1)
17	S5	Relative abundance (biomass)	EU ESP LL	EU España Longline (1990-2015) [3]	Mirror EU (F1)
18	S6	Relative abundance (numbers)	CTP LL	Chinese Taipei Longline (2007-2015)	Mirror CTP (F3)

1. Not ICCAT Task I - Finalized catch data for this assessment was obtained from the 2017 Shortfin Mako Data Preparatory meeting (Anon. In Prep.)
2. Index S2 (USA LL Obs) was not fit in the model likelihood (lambda = 0) because of high variability in the index and because S2 describes the same fishery as S1 (USA LL Log) (Anon. In Prep.).
3. Index S5 was obtained from SCRS/2017/108 - CPUE in weight (CV = se on log scale).

Table 2. North Atlantic shortfin mako catch in metric tons (t) was obtained from data compiled during the 2017 Shortfin Mako Data Preparatory meeting and assigned here to "fleets" F1 – F12 for use in SS3 model runs as defined below.

Fleet	F1	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Flag	EU España [1,2]	EU Portugal [1]	Japan	Chinese Taipei [3]	U.S.A.	Venezuela	Canada	Morocco [3]	U.S.A.	Belize	Morocco	China PR	Other
Gear	LL	LL	LL	LL	LL	LL	LL	LL	SP + RR	LL	PS	LL	Combined
1950	105.6												
1951	70.6												
1952	70.6												
1953	87.9												
1954	22.3												
1955	45.2												
1956	27.3												
1957	73.1												
1958	60.8												
1959	80.4												
1960	52.8												
1961	124.3							4.0					
1962	168.1							7.9					
1963	73.1							4.0					
1964	131.6							11.9					
1965	104.8							9.3					
1966	219.2							7.9					
1967	196.6							7.3					
1968	259.6							8.6					
1969	256.0							10.6					
1970	231.0							9.3					
1971	247.373		112.0					13.880					
1972	234.7		115.0					9.9					
1973	280.2		61.0					6.6					
1974	211.5		307.0					7.9					
1975	273.9		344.0					9.9					
1976	205.9		84.0					7.9					
1977	241.9		236.0					4.0					
1978	264.0		153.0					7.3					
1979	188.7		45.0					137.5					
1980	278.5		246.0					89.9					
1981	293.4		387.0	32.0				82.0	384.960				
1982	332.9		273.0	52.0	42.1			60.1	613.1				0.04
1983	600.5		159.0	59.0	42.2			82.6	368.1				0.00
1984	389.2		141.0	70.0	42.5			52.2	929.0				0.00
1985	543.2		142.0	71.0	51.9			90.6	2947.5				1.34

Table 2. Continued.

Fleet	F1	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Flag	EU España [1,2]	EU Portugal [1]	Japan	Chinese Taipei [3]	U.S.A.	Venezuela	Canada	Morocco [3]	U.S.A.	Belize	Morocco	China PR	Other
Gear	LL	LL	LL	LL	LL	LL	LL	LL	SP + RR	LL	PS	LL	Combined
1986	2097.4		120.0	78.0	64.0	2.8		117.6	1295.9				0.79
1987	2404.5		218.0	22.0	86.1	1.7		126.9	461.7				0.46
1988	1851.3		113.0	4.0	105.9	2.6		128.9	794.6				0.54
1989	1078.5		207.0	2.0	122.8	8.1		144.7	670.4				10.73
1990	1537.2	193.0	221.0	9.0	93.0	1.5		15.9	268.4				9.08
1991	1390.1	314.0	157.0	39.0	112.7	2.1		60.8	210.0				6.78
1992	2145.4	220.0	318.0	16.0	160.8	0.7		27.1	250.3				7.61
1993	1964.1	796.0	425.0	9.0	301.9	0.6		17.8	666.7				4.06
1994	2163.6	649.0	214.0	29.0	331.8	3.5		4.6	317.8				17.35
1995	2209.5	657.0	592.0	32.0	309.7	4.2	93.4	18.5	1421.5				38.92
1996	3293.8	691.0	790.0	45.0	234.1	11.7	56.1	23.1	232.1				21.13
1997	2415.6	354.0	258.0	42.0	242.1	3.4	99.0	158.0	163.9				18.57
1998	2223.1	307.0	892.0	47.0	195.0	0.8	54.6		148.4				27.52
1999	2050.9	327.4	120.0	75.0	89.5	2.0	53.8	23.1	69.2				30.63
2000	1560.7	317.5	138.0	56.0	163.8	2.2	58.7	25.1	290.5			0.2	40.26
2001	1684.5	377.6	105.0	47.0	180.5	20.3	59.6	174.5	214.5			0.0	32.72
2002	2046.6	414.7	438.0	53.0	166.8	16.0	61.1	101.8	248.0			0.0	24.31
2003	2067.6	1248.6	267.0	37.0	141.4	21.9	63.4	147.4	0.2			0.0	29.00
2004	2087.6	398.7	572.0	70.0	187.8	58.0	69.4	168.5	332.6			0.0	100.14
2005	1751.3	1109.3	0.0	68.0	186.9	19.6	73.9	214.8	282.1			0.0	36.61
2006	1918.0	950.6	0.0	40.0	129.3	6.3	64.5	220.1	256.7			0.0	22.34
2007	1815.6	1539.7	82.4	6.0	222.4	11.1	63.7	151.4	158.3			80.5	84.53
2008	1895.3	1033.1	130.9	27.0	196.5	1.8	38.9	282.9	156.0			15.5	74.11
2009	2216.2	1169.3	98.4	89.0	221.0	35.1	50.3	475.9	162.7	23.1		19.0	109.23
2010	2090.7	1431.9	116.3	14.0	225.7	21.9	38.6	636.5	167.8	28.1		28.6	23.68
2011	1667.1	1044.6	53.3	54.0	212.9	18.0	37.2	390.0	178.2	69.2	30.0	17.7	40.01
2012	2308.0	1022.6	56.1	35.0	198.4	24.3	27.6	380.0	229.5	113.8	26.0	24.0	52.71
2013	1508.8	817.4	32.7	13.0	190.0	5.8	34.7	616.0	219.4	98.5	50.7	11.5	52.34
2014	1480.9	208.6	69.2	16.0	206.9	7.5	53.1	580.0	201.4	1.2	44.0	5.0	42.31
2015	1361.7	213.3	47.1	11.4	341.1	7.5	84.2	807.0	190.0	0.6	140.0	1.5	21.61

1. EU España + EU Portugal catch was combined into a single fleet (F1) because length comps were similar.
2. Start year of the model was 1950 (first year of catch EU España).
3. Not ICCAT Task I - Finalized catch data for this assessment was obtained from the 2017 Shortfin Mako Data Preparatory meeting (Anon. In Prep.)

Table 3. Indices of relative abundance for North Atlantic shortfin mako were obtained from data compiled during the 2017 Shortfin Mako Data Preparatory meeting (Anon. In Prep.), except for EU España Longline (EU ESP LL) which was obtained from SCRS/2017/108; the available abundance indices were assigned here to “surveys” S1 – S6 for use in SS3 model runs as defined below.

Survey Units	S1 USA LL Log Numbers	S2 USA LL Obs[1] Numbers	S3 JPN LL Numbers	S4 EU POR LL Biomass	S5 EU ESP LL[2] Biomass	S6 CTP-LL Numbers
1986	1.157					
1987	1.163					
1988	0.917					
1989	1.063					
1990	0.833				43.036	
1991	0.740				42.583	
1992	0.876	1.121			51.414	
1993	0.767	0.857			48.400	
1994	0.721	0.576	0.179		41.193	
1995	0.694	0.890	0.108		36.534	
1996	0.618	0.511	0.112		43.529	
1997	0.569	0.668	0.113		26.479	
1998	0.538	0.493	0.092		28.965	
1999	0.526	0.531	0.079	18.263	28.055	
2000	0.557	0.807	0.081	22.394	28.181	
2001	0.507	0.674	0.116	26.385	29.554	
2002	0.532	0.815	0.118	30.805	41.898	
2003	0.573	0.678	0.106	35.330	51.190	
2004	0.676	0.996	0.099	28.353	51.084	
2005	0.680	0.711	0.096	31.037	46.739	
2006	0.529	0.770	0.133	54.240	41.612	
2007	0.803	0.870	0.136	47.896	53.941	0.014
2008	0.675	0.638	0.210	28.184	58.258	0.056
2009	0.862	1.350	0.201	45.236	57.967	0.200
2010	0.754	0.883	0.217	36.996	52.512	0.028
2011	0.704	1.261	0.141	23.998	42.635	0.103
2012	0.513	1.105	0.114	28.914	51.525	0.088
2013	0.543	0.777	0.084	28.422	38.824	0.033
2014	0.489	0.811	0.167	28.181	37.383	0.093
2015	0.484	0.630	0.091	10.675	42.780	0.028

1. Index S2 (USA LL Obs) was not fit in the model likelihood (lambda = 0) because of high variability in the index and because S2 describes the same fishery as S1 (USA LL Log) (Anon. In Prep.).
2. Index S5 was obtained from SCRS/2017/108 - CPUE in weight.

Table 4. Coefficients of variation (CV) corresponding to indices of relative abundance for North Atlantic shortfin mako were obtained from data compiled during the 2017 Shortfin Mako Data Preparatory meeting (Anon. In Prep.), except for EU España Longline (EU ESP LL) which was obtained from SCRS/2017/108.

Survey	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
	USA	**USA**	**JPN**	**EU POR LL**	**EU ESP LL[2]**	**CTP**
	LL Log	**LL Obs[1]**	**LL**			**LL**
Units	**Numbers**	**Numbers**	**Numbers**	**Biomass**	**Biomass**	**Numbers**
1986	0.137					
1987	0.084					
1988	0.083					
1989	0.08					
1990	0.082				0.046	
1991	0.084				0.046	
1992	0.082	0.199			0.047	
1993	0.083	0.165			0.045	
1994	0.082	0.182	0.055		0.044	
1995	0.081	0.169	0.049		0.041	
1996	0.084	0.46	0.038		0.039	
1997	0.086	0.225	0.057		0.039	
1998	0.088	0.300	0.052		0.039	
1999	0.09	0.237	0.061	0.157	0.043	
2000	0.09	0.191	0.040	0.140	0.043	
2001	0.092	0.235	0.053	0.153	0.043	
2002	0.093	0.231	0.060	0.136	0.042	
2003	0.094	0.206	0.057	0.123	0.046	
2004	0.091	0.171	0.046	0.124	0.048	
2005	0.092	0.188	0.037	0.155	0.050	
2006	0.097	0.184	0.059	0.132	0.055	
2007	0.092	0.169	0.060	0.144	0.057	0.555
2008	0.09	0.157	0.070	0.156	0.057	0.308
2009	0.09	0.145	0.060	0.142	0.055	0.111
2010	0.091	0.166	0.054	0.172	0.054	0.297
2011	0.091	0.154	0.061	0.148	0.054	0.126
2012	0.092	0.165	0.063	0.141	0.054	0.128
2013	0.093	0.148	0.073	0.183	0.057	0.373
2014	0.095	0.162	0.063	0.185	0.054	0.200
2015	0.099	0.176	0.067	0.178	0.054	0.268

1. Index S2 (USA LL Obs) was not fit in the model likelihood (lambda = 0) because of high variability in the index and because S2 describes the same fishery as S1 (USA LL Log) (Anon. In Prep.).
2. Index S5 was obtained from SCRS/2017/108 (CV on the nominal scale = standard error on log scale obtained from CPUE in weight).

Table 5. Observed sample sizes (number of sharks measured) for available length composition assigned to fleets F1 – F5 (**Table 1**) in the SS3 model runs; Years with small sample size (total number of sharks measured < 30) were excluded from the fit in the model likelihood (see **Appendix B** for model fits to annual length composition).

Year	**F1 (EU LL)[1] (♀,♂,Unknown)**	**F2 (JPN LL) (♀)**	**F2 (JPN LL) (♂)**	**F3 (CTP LL) (♀)**	**F3 (CTP LL) (♂)**	**F4 (USA LL) (♀)**	**F4 (USA LL) (♂)**	**F5 (VEN LL) (♀)**	**F5 (VEN LL) (♂)**
1992						9	9		
1993						95	74		
1994						54	63	5	3
1995						85	106	27	19
1996						12	13	10	7
1997	19	175	145			71	71	12	5
1998	26	92	78			14	39	10	5
1999	18	2	8			38	34	2	0
2000	334	2	5			73	84	2	0
2001	301	26	26			28	40	3	5
2002	545	6	28			63	62	2	2
2003	164	2	9			59	76	9	4
2004	629	2	21	20	17	136	203	1	5
2005	292	4	20	9	2	52	84	0	0
2006	172	6	42	228	122	103	146	1	3
2007	494	9	33	3	2	90	135	1	5
2008	249	34	56	6	7	97	114	1	0
2009	499	28	44	44	68	174	225	1	1
2010	925	21	55	4	5	142	170	1	5
2011	713	11	74	22	39	106	163	7	36
2012	1042	29	37	31	37	81	89	66	67
2013	682	24	19	0	14	86	132	23	63
2014	277	34	75	2	0	73	108		
2015	273	1	5	4	2	95	110		

1. Sex-combined length composition data (♀, ♂, Unknown) were input in SS3 for fleet F1 (EU LL), because the available sex-specific data for F1 (♀, ♂) was only a small portion (13%) of the combined data. Sex-specific length composition data were input in SS3 for fleets F2 (JPN LL), F3 (CTP LL), F4 (USA LL), and F5 (VEN LL), because sex-specific data made up higher proportions (92%, 100%, 100%, and 100%, respectively) of the combined data for the other fleets.

Table 6. Life history inputs were obtained from data first assembled at the 2014 Intersessional meeting of the Shark Species Group (Anon. 2015), plus updated information provided during the 2016 Intersessional meeting of the Shark Species Group (Anon. 2017), the 2017 Shortfin Mako Shark Data Preparatory meeting (Anon. In Prep.), and thereafter. Highlighted values are used in the current SS3 model runs. Cited references in the table are provided separately in the references above, except as noted below.

	NA	SA	References
Reproduction			
L_{mat} (♂)		180	Mas et al. (2017) [SCRS]
L_{50} (♂)	180-185 FL	166	Natanson et al. (2006) Maia et al. (2006) Mas et al. (2017) [SCRS]
T_{mat} (♂)	8	6-8*	Campana et al. (2005) Barreto et al. (2016) Doño et al. (2015)
T_{50} (♂)	8		Natanson et al. (2006)
L_{mat} (♀)			
L_{50} (♀)	275-298 FL		Mollet et al. (2000), Natanson et al. (2006)
T_{mat} (♀)	18	12-18*	Campana et al. (2005) Barreto et al. (2016) Doño et al. (2015)
T_{50} (♀)	18		Natanson et al. (2006)
Sex ratio	1:1		Mollet et al. (2000)
Cycle	3		Mollet et al. (2000)
GP (months)	16.5 (15-18)		Mollet et al. (2000)
L_0	70 TL (63 FL)	81M-88F (FL)*	Natanson et al. (2006) Mollet et al. (2000) Doño et al. (2015)
Mean litter size (LS)	12.5		Mollet et al. 2000 (n=24)
Min LS	2		Mollet et al. 2000 (n=24)
Max LS	30		Mollet et al. 2000 (n=24)
LS vs MS relation	LS=0.81*(m TL)^2.346		Mollet et al. 2000 (n=24)
Maturity ogive (♀)	Mat=1/(1+exp-(-27.81+9.332*MS))	Use fit to clasper index (♂)	Mollet et al. 2000 (n=24); SCRS/2017/058
Age & Growth			
L_{inf} (♀)[1]	366 (393) [350.6]**	244*; 408	Natanson et al. (2006) Doño et al. (2015) Barreto et al. (2016)
k (♀)[1]	0.087 (0.054) [0.064]**	0.04	Natanson et al. (2006) Barreto et al. (2016)
T_o / L_o (♀)[1]	88.4 (70 TL fixed) [63 FL] **	-7.08	Natanson et al. (2006) Barreto et al. (2016)
T_{max} (♀)	32	23-28*	Natanson et al. (2006) Barreto et al. (2016) Doño et al. (2015)
L_{inf} (♂)[1]	253 ***	261*; 329	Natanson et al. (2006) Doño et al. (2015) Barreto et al. (2016)
k (♂)[1]	0.125	0.08	Natanson et al. (2006) Barreto et al. (2016)
T_o / L_o (♂)[1]	71.6	-4.47	Natanson et al. (2006) Barreto et al. (2016)
T_{max} (♂)	29	11-18*	Natanson et al. (2006) Doño et al. (2015) Barreto et al. (2016)
Conversion Factors			
Length-length [cm]	FL=0.9286TL-1.7101	TL=1.127FL+0.358	Megalofonou et al. (2005) Kohler (1995)
	W=5.2432E-06FL^3.1407	W=3.1142E-05FL^2.7243	Kohler (1995) García-Cortes & Mejuto (2002)
Length-weight (b) [cm,kg]		HG=7.5443×10^{-6}x (FL ^{2,9568})****	Mas et al. (2017) [SCRS]

* Derived with the Schnute model; ** Gompertz (VBGF in parentheses) [Coelho et al. VBGF in brackets]; *** VBGF with Lo; **** HG is eviscerated weight

1. Sex-specific growth in length at age was assumed to follow von Bertalanffy growth (VBG), with updated parameters provided separately from document SCRS/2017/111 (Rosa et al. In Prep.) as described in the text, **Table 7, and Figure 4**.

Table 7. Sex-specific VBG parameters and CVs in mean length at age were obtained from document SCRS/2017/111 (Rosa et al. In Prep.) as described in the text.

Age (yr)	**Female cm FL predicted from VBG parameters below**	**Male cm FL predicted from VBG parameters below**
0	62.9	63.0
1	80.7	85.7
2	97.5	105.6
3	113.2	122.9
4	127.9	138.0
5	141.7	151.2
6	154.6	162.7
7	166.8	172.8
8	178.2	181.6
9	188.9	189.2
10	198.9	195.9
11	208.3	201.7
12	217.1	206.8
13	225.4	211.3
14	233.2	215.2
15	240.4	218.6
16	247.3	221.5
17	253.7	224.1
18	259.7	226.3
19	265.3	228.3
20	270.6	230.0
21	275.6	231.5
22	280.2	232.8
23	284.6	234.0
24	288.7	235.0
25	292.5	235.8
26	296.1	236.6
27	299.5	237.3
28	302.7	237.8
29	305.6	238.3
30	308.4	238.8

VBG parameters	**Female**	**Male**
L_{inf}	350.6	241.8
k	0.064	0.136
t_0	-3.09	-2.2
CV implemented for L_{Amin}	0.093	0.097
CV implemented for L_{inf}	0.090	0.082

Table 8. Annual pup production at age used i5n SS3 model runs.

Age (yr)	Length (cm FL)[1]	Length (cm TL) [2]	Length (m TL)	Litter size (LS) [3]	Fraction mature (Mat) [4]	Pup production (LS) * (Mat)	Annual pup production [5]	Annual pup production at parturition [6]
0	62.9	69.6	0.7	0.3	0.0	0.0	0.00	0.00
1	80.7	88.8	0.9	0.6	0.0	0.0	0.00	0.00
2	97.5	106.8	1.1	0.9	0.0	0.0	0.00	0.00
3	113.2	123.7	1.2	1.3	0.0	0.0	0.00	0.00
4	127.9	139.6	1.4	1.8	0.0	0.0	0.00	0.00
5	141.7	154.4	1.5	2.2	0.0	0.0	0.00	0.00
6	154.6	168.4	1.7	2.8	0.0	0.0	0.00	0.00
7	166.8	181.5	1.8	3.3	0.0	0.0	0.00	0.00
8	178.2	193.7	1.9	3.8	0.0	0.0	0.00	0.00
9	188.9	205.2	2.1	4.4	0.0	0.0	0.00	0.00
10	198.9	216.0	2.2	4.9	0.0	0.0	0.00	0.00
11	208.3	226.2	2.3	5.5	0.0	0.0	0.00	0.00
12	217.1	235.7	2.4	6.1	0.0	0.0	0.01	0.00
13	225.4	244.6	2.4	6.6	0.0	0.0	0.01	0.00
14	233.2	252.9	2.5	7.1	0.0	0.1	0.03	0.01
15	240.4	260.8	2.6	7.7	0.0	0.2	0.08	0.01
16	247.3	268.1	2.7	8.2	0.1	0.5	0.16	0.03
17	253.7	275.0	2.8	8.7	0.1	0.9	0.30	0.08
18	259.7	281.5	2.8	9.2	0.2	1.6	0.54	0.16
19	265.3	287.6	2.9	9.7	0.3	2.6	0.88	0.30
20	270.6	293.3	2.9	10.1	0.4	4.0	1.32	0.54
21	275.6	298.6	3.0	10.5	0.5	5.4	1.81	0.88
22	280.2	303.6	3.0	11.0	0.6	6.9	2.29	1.32
23	284.6	308.3	3.1	11.4	0.7	8.2	2.74	1.81
24	288.7	312.7	3.1	11.8	0.8	9.4	3.13	2.29
25	292.5	316.8	3.2	12.1	0.9	10.3	3.45	2.74
26	296.1	320.7	3.2	12.5	0.9	11.1	3.71	3.13
27	299.5	324.4	3.2	12.8	0.9	11.8	3.93	3.45
28	302.7	327.8	3.3	13.1	0.9	12.4	4.12	3.71
29	305.6	331.0	3.3	13.4	1.0	12.8	4.28	3.93
30	308.4	334.0	3.3	13.7	1.0	13.3	4.42	4.12

1 Growth in length at age was assumed to follow the female von Bertalanffy growth (VBG) relationship from **Table 7**.
2. cm TL = (cm FL + 1.7101)/ 0.9286 (**Table 6**).
3. Litter size (LS) = 0.81 * (m TL)^ 2.346 (**Table 6**).
4. Fraction mature (Mat)=1/(1+exp-(-27.81+9.332*MS)) (**Table 6**), where MS is maternal size (m TL).
5. Annual pup production was obtained here by assuming a three year reproductive cycle (**Table 6**) and calculated as [(LS) * (Mat)]/3.
6. Annual pup production at maternity (parturition) was obtained here by assuming a two year gestation period (18 months, **Table 6**, plus 6 months for mating), for use in sensitivity analyses [(Annual pup production at parturition)$_a$= (Annual pup production)$_{a-2}$].

Table 9. The stock-recruit steepness parameter, *h*, and the sex-specific natural mortality at each age (M_a) were fixed at values obtained independently with life history invariant methods, as described in document SCRS/2017/126 (Cortés In Prep.).

Age (yr)	Female	Male
0	0.080	0.157
1	0.080	0.157
2	0.080	0.157
3	0.080	0.157
4	0.080	0.149
5	0.080	0.139
6	0.080	0.131
7	0.080	0.125
8	0.080	0.120
9	0.080	0.116
10	0.080	0.113
11	0.080	0.111
12	0.080	0.108
13	0.080	0.107
14	0.080	0.105
15	0.080	0.104
16	0.080	0.103
17	0.080	0.102
18	0.080	0.101
19	0.080	0.100
20	0.080	0.100
21	0.080	0.099
22	0.080	0.099
23	0.080	0.098
24	0.080	0.098
25	0.079	0.098
26	0.079	0.097
27	0.078	0.097
28	0.077	0.097
29	0.076	0.097
30+	0.075	0.097

Stock-recruit steepness parameter (*h*)
0.345

Table 10. Non-recruitment parameter estimates are provided for the final SS3 model run obtained by applying the two-stage data weighting approach described in the text of the main document above. Parameters with a negative phase were fixed at their initial value. CV is calculated as the asymptotic standard error (Parm_StDev) divided by the estimated value (Value). Num is the parameter number within the SS3 model run.

Num	Label	Value	Active_Cnt	Phase	Min	Max	Init	Status	Parm_StDev	PR_type	Prior	Pr_SD	CV (%)
23	SR_LN(R0)	5.589	1	1	2.300	13.820	7.040	OK	0.0507	Normal	7.040	1000	0.91
69	SizeSel_1P_1_F1_EU_LL	139.86	30	2	63	298	131.76	OK	4.104	Sym_Beta	135.54	0.05	2.93
70	SizeSel_1P_2_F1_EU_LL	-5.55	31	3	-6	4	-5.91	OK	1.669	Sym_Beta	-6.00	0.05	30.09
71	SizeSel_1P_3_F1_EU_LL	6.81	32	3	-1	9	6.63	OK	0.226	Sym_Beta	6.70	0.05	3.32
72	SizeSel_1P_4_F1_EU_LL	7.33	33	3	-1	9	7.29	OK	0.198	Sym_Beta	7.25	0.05	2.69
73	SizeSel_1P_5_F1_EU_LL	-5.00	_	-2	-5	9	-5.00	NA	_	Sym_Beta	-5.00	0.05	NA
74	SizeSel_1P_6_F1_EU_LL	-4.96	_	-2	-5	9	-4.96	NA	_	Sym_Beta	-5.00	0.05	NA
75	SizeSel_2P_1_F2_JPN_LL	176.02	34	2	63	298	142.77	OK	14.228	Sym_Beta	148.87	0.05	8.08
76	SizeSel_2P_2_F2_JPN_LL	-4.36	35	3	-6	4	-4.74	OK	4.366	Sym_Beta	-4.56	0.05	100.04
77	SizeSel_2P_3_F2_JPN_LL	7.56	36	3	-1	9	6.83	OK	0.510	Sym_Beta	7.25	0.05	6.75
78	SizeSel_2P_4_F2_JPN_LL	6.19	37	3	-1	9	7.54	OK	1.510	Sym_Beta	7.61	0.05	24.40
79	SizeSel_2P_5_F2_JPN_LL	-5.00	_	-2	-5	9	-5.00	NA	_	Sym_Beta	-5.00	0.05	NA
80	SizeSel_2P_6_F2_JPN_LL	-1.95	38	2	-5	9	-3.21	OK	0.876	Sym_Beta	-5.00	0.05	44.96
81	SzSel_2Fem_Peak_F2_JPN_LL	-29.35	39	4	-60	200	17.20	OK	20.085	No_prior	0.00	0	68.42
82	SzSel_2Fem_Ascend_F2_JPN_LL	-0.88	40	4	-15	15	0.91	OK	1.006	No_prior	0.00	0	114.15
83	SzSel_2Fem_Descend_F2_JPN_LL	1.51	41	4	-15	15	-0.64	OK	1.651	No_prior	0.00	0	109.59
84	SzSel_2Fem_Final_F2_JPN_LL	-3.70	42	4	-15	15	0.57	OK	2.247	No_prior	0.00	0	60.79
85	SzSel_2Fem_Scale_F2_JPN_LL	0.46	43	5	-15	15	0.73	OK	0.158	No_prior	0.00	0	34.46
86	SizeSel_3P_1_F3_CTP_LL	169.36	44	2	63	298	155.77	OK	20.717	Sym_Beta	159.98	0.05	12.23
87	SizeSel_3P_2_F3_CTP_LL	-3.28	45	3	-6	4	-2.26	OK	5.104	Sym_Beta	-6.00	0.05	155.58
88	SizeSel_3P_3_F3_CTP_LL	6.85	46	3	-1	9	6.49	OK	0.967	Sym_Beta	6.81	0.05	14.12
89	SizeSel_3P_4_F3_CTP_LL	7.25	47	3	-1	9	7.32	OK	1.471	Sym_Beta	7.08	0.05	20.30
90	SizeSel_3P_5_F3_CTP_LL	-5.00	_	-2	-5	9	-5.00	NA	_	Sym_Beta	-5.00	0.05	NA
91	SizeSel_3P_6_F3_CTP_LL	-4.08	48	2	-5	9	-3.35	OK	2.047	Sym_Beta	-5.00	0.05	50.16
92	SzSel_3Male_Peak_F3_CTP_LL	-6.31	49	4	-200	200	-19.99	OK	35.944	No_prior	0.00	0	569.48
93	SzSel_3Male_Ascend_F3_CTP_LL	0.15	50	4	-15	15	-0.74	OK	1.611	No_prior	0.00	0	1078.14
94	SzSel_3Male_Descend_F3_CTP_LL	-0.42	51	4	-15	15	-0.08	OK	3.097	No_prior	0.00	0	740.22
95	SzSel_3Male_Final_F3_CTP_LL	2.00	52	4	-15	15	-0.57	OK	3.286	No_prior	0.00	0	163.95
96	SzSel_3Male_Scale_F3_CTP_LL	0.94	53	5	-15	15	0.47	OK	0.525	No_prior	0.00	0	55.75

Table 10. Continued.

Num	Label	Value	Active_Cnt	Phase	Min	Max	Init	Status	Parm_StDev	PR_type	Prior	Pr_SD	CV (%)
97	SizeSel_4P_1_F4_USA_LL	187.61	54	2	63	298	147.05	OK	6.313	Sym_Beta	127.99	0.05	3.36
98	SizeSel_4P_2_F4_USA_LL	-5.56	55	3	-6	4	-5.16	OK	1.623	Sym_Beta	-5.84	0.05	29.18
99	SizeSel_4P_3_F4_USA_LL	8.98	_	-3	-1	9	8.98	NA	_	Sym_Beta	7.33	0.05	NA
100	SizeSel_4P_4_F4_USA_LL	6.18	56	3	-1	9	7.54	OK	0.948	Sym_Beta	8.08	0.05	15.34
101	SizeSel_4P_5_F4_USA_LL	-4.32	57	2	-5	9	-2.50	OK	1.538	Sym_Beta	-2.50	0.05	35.58
102	SizeSel_4P_6_F4_USA_LL	-1.30	58	2	-5	9	-3.38	OK	0.563	Sym_Beta	-5.00	0.05	43.24
103	SzSel_4Fem_Peak_F4_USA_LL	10.29	_	-4	-20	200	10.29	NA	_	No_prior	0.00	0	NA
104	SzSel_4Fem_Ascend_F4_USA_LL	1.89	59	4	-15	15	3.42	OK	2.045	No_prior	0.00	0	108.46
105	SzSel_4Fem_Descend_F4_USA_LL	-0.60	60	4	-15	15	-0.46	OK	0.954	No_prior	0.00	0	158.08
106	SzSel_4Fem_Final_F4_USA_LL	-3.31	61	4	-15	15	0.63	OK	0.945	No_prior	0.00	0	28.58
107	SzSel_4Fem_Scale_F4_USA_LL	0.50	62	5	-15	15	0.74	OK	0.082	No_prior	0.00	0	16.34
108	SizeSel_5P_1_F5_VEN_LL	182.01	63	2	63	298	191.87	OK	9.802	Sym_Beta	167.54	0.05	5.39
109	SizeSel_5P_2_F5_VEN_LL	-4.96	64	3	-6	4	-5.50	OK	3.310	Sym_Beta	-6.00	0.05	66.78
110	SizeSel_5P_3_F5_VEN_LL	7.26	65	3	-1	9	8.33	OK	0.431	Sym_Beta	6.81	0.05	5.93
111	SizeSel_5P_4_F5_VEN_LL	6.97	66	3	-1	9	7.00	OK	1.593	Sym_Beta	7.08	0.05	22.84
112	SizeSel_5P_5_F5_VEN_LL	-5.00	_	-2	-5	9	-5.00	NA	_	Sym_Beta	-5.00	0.05	NA
113	SizeSel_5P_6_F5_VEN_LL	-1.46	67	2	-5	9	-2.70	OK	1.904	Sym_Beta	-5.00	0.05	130.50
114	SzSel_5Fem_Peak_F5_VEN_LL	15.39	68	4	-200	200	-19.66	OK	20.053	No_prior	0.00	0	130.33
115	SzSel_5Fem_Ascend_F5_VEN_LL	0.93	69	4	-15	15	-1.00	OK	0.693	No_prior	0.00	0	74.60
116	SzSel_5Fem_Descend_F5_VEN_LL	0.01	70	4	-15	15	-0.42	OK	2.135	No_prior	0.00	0	22673.67
117	SzSel_5Fem_Final_F5_VEN_LL	-3.44	71	4	-15	15	0.76	OK	3.333	No_prior	0.00	0	96.86
118	SzSel_5Fem_Scale_F5_VEN_LL	0.40	72	5	-15	15	0.94	OK	0.127	No_prior	0.00	0	31.69

Table 11. 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; see **Figure 13**), and total exploitation rate in numbers (*U*, for ages 1+) for the final SS3 model run obtained by applying the two-stage data weighting approach described in the text of the main document above.

Year	*B* (t)	SSF (1,000s)	*R* (1,000s)	*F*	*U*
Virg		1,366	267		
Init		1,366	267		
1950	265,971	1,366	267	0.003	0.001
1951	265,848	1,366	267	0.002	0.001
1952	265,755	1,366	267	0.002	0.001
1953	265,655	1,366	267	0.003	0.001
1954	265,531	1,366	267	0.001	0.000
1955	265,477	1,366	267	0.001	0.000
1956	265,400	1,366	267	0.001	0.000
1957	265,345	1,366	267	0.002	0.001
1958	265,240	1,366	267	0.002	0.001
1959	265,148	1,366	267	0.003	0.001
1960	265,033	1,366	267	0.002	0.001
1961	264,949	1,366	267	0.004	0.001
1962	264,780	1,365	267	0.006	0.002
1963	264,550	1,365	267	0.002	0.001
1964	264,425	1,365	267	0.005	0.001
1965	264,227	1,364	267	0.004	0.001
1966	264,059	1,363	267	0.007	0.002
1967	263,761	1,363	267	0.007	0.002
1968	263,480	1,362	267	0.009	0.003
1969	263,118	1,361	267	0.009	0.003
1970	262,747	1,361	267	0.008	0.002
1971	262,399	1,360	267	0.012	0.003
1972	261,901	1,359	267	0.011	0.003
1973	261,414	1,358	267	0.011	0.003
1974	260,936	1,357	267	0.016	0.004
1975	260,266	1,356	266	0.020	0.005
1976	259,482	1,355	266	0.010	0.003
1977	259,063	1,353	266	0.015	0.004
1978	258,458	1,352	266	0.014	0.004
1979	257,926	1,350	266	0.012	0.004
1980	257,460	1,348	266	0.020	0.006
1981	256,735	1,346	266	0.033	0.010
1982	255,389	1,343	265	0.036	0.011
1983	253,813	1,340	265	0.038	0.012
1984	252,269	1,337	265	0.042	0.013
1985	250,287	1,334	230	0.094	0.031
1986	245,730	1,330	216	0.119	0.037
1987	240,889	1,325	209	0.121	0.036
1988	236,166	1,320	210	0.109	0.033
1989	231,519	1,314	217	0.082	0.024
1990	227,550	1,309	219	0.098	0.028
1991	223,356	1,303	214	0.100	0.028
1992	219,085	1,296	194	0.145	0.040
1993	213,746	1,287	200	0.196	0.054
1994	207,080	1,277	195	0.191	0.052
1995	200,677	1,266	177	0.276	0.072
1996	192,281	1,252	174	0.344	0.084
1997	183,718	1,236	223	0.261	0.065
1998	177,040	1,219	279	0.290	0.067
1999	170,466	1,200	264	0.220	0.054

Table 11. Continued.

Year	***B*** **(t)**	**SSF (1,000s)**	***R*** **(1,000s)**	***F***	***U***
2000	165,537	1,179	316	0.190	0.050
2001	161,412	1,157	322	0.196	0.055
2002	157,442	1,132	233	0.230	0.065
2003	153,362	1,105	343	0.248	0.079
2004	149,323	1,076	370	0.238	0.072
2005	145,744	1,044	356	0.207	0.068
2006	142,863	1,011	293	0.190	0.065
2007	140,275	977	210	0.211	0.075
2008	137,148	941	238	0.187	0.070
2009	134,403	904	250	0.228	0.084
2010	130,611	867	191	0.251	0.089
2011	126,339	830	169	0.209	0.073
2012	122,877	795	165	0.264	0.090
2013	118,514	760	194	0.232	0.078
2014	114,904	728	189	0.197	0.064
2015	112,050	698	184	0.230	0.073

Table 12. Annual estimates of total fishing mortality (*F*, calculated as the sum of continuous F obtained for each fleet; see **Figure 13**) relative to total fishing mortality at MSY (*F*/*F*_MSY) and **s**pawning stock fecundity (SSF 1,000s) relative to spawning stock fecundity at MSY (SSF/SSF_MSY) for the final SS3 model run obtained by applying the two-stage data weighting approach described in the text of the main document above.

Year	*F*/*F*_MSY	SSF/SSF_MSY
1950	0.052	2.384
1951	0.035	2.384
1952	0.035	2.384
1953	0.043	2.384
1954	0.011	2.384
1955	0.022	2.384
1956	0.013	2.384
1957	0.036	2.384
1958	0.030	2.384
1959	0.039	2.384
1960	0.026	2.383
1961	0.063	2.383
1962	0.087	2.382
1963	0.038	2.382
1964	0.071	2.381
1965	0.056	2.380
1966	0.112	2.379
1967	0.101	2.378
1968	0.133	2.377
1969	0.133	2.375
1970	0.120	2.374
1971	0.181	2.373
1972	0.174	2.371
1973	0.171	2.370
1974	0.249	2.368
1975	0.300	2.366
1976	0.147	2.364
1977	0.232	2.361
1978	0.208	2.359
1979	0.186	2.355
1980	0.300	2.352
1981	0.501	2.348
1982	0.553	2.344
1983	0.581	2.339
1984	0.637	2.334
1985	1.435	2.328
1986	1.816	2.320
1987	1.841	2.312
1988	1.664	2.303
1989	1.258	2.293
1990	1.499	2.284
1991	1.527	2.273
1992	2.205	2.261
1993	2.986	2.246
1994	2.920	2.228
1995	4.211	2.209
1996	5.244	2.184
1997	3.977	2.157
1998	4.422	2.127
1999	3.354	2.094

Table 12. Continued.

Year	*F*/F_MSY	SSF/SSF_MSY
2000	2.891	2.058
2001	2.985	2.019
2002	3.507	1.976
2003	3.779	1.929
2004	3.635	1.877
2005	3.152	1.823
2006	2.894	1.765
2007	3.218	1.704
2008	2.858	1.641
2009	3.470	1.578
2010	3.829	1.513
2011	3.184	1.449
2012	4.032	1.387
2013	3.541	1.326
2014	3.008	1.270
2015	3.501	1.217

Table 13. 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; see **Figure 13**), 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 (S.E.) calculated from the maximum likelihood estimates of parameter variances at the converged solution and CVs based on the S.E. (where available) are also provided for the parameter estimates.

Ending year (2015) stock status relative to MSY reference points	**Estimate**	**S.E.**	**CV**
SSF_2015 (1,000s)	698	69	10%
*F*_2015	0.230	---	---
*R*_2015 (1,000s)	184	15	8%
SSF_0	1,366	69	5%
*R*_0	267	14	5%
MSY (t)	1,075	40.60	4%
SSF_MSY	573	29	5%
*F*_MSY	0.066	0.003	4%
SSF_2015/SSF_MSY	1.217	---	---
*F*_2015/*F*_MSY	3.501	0.41	12%

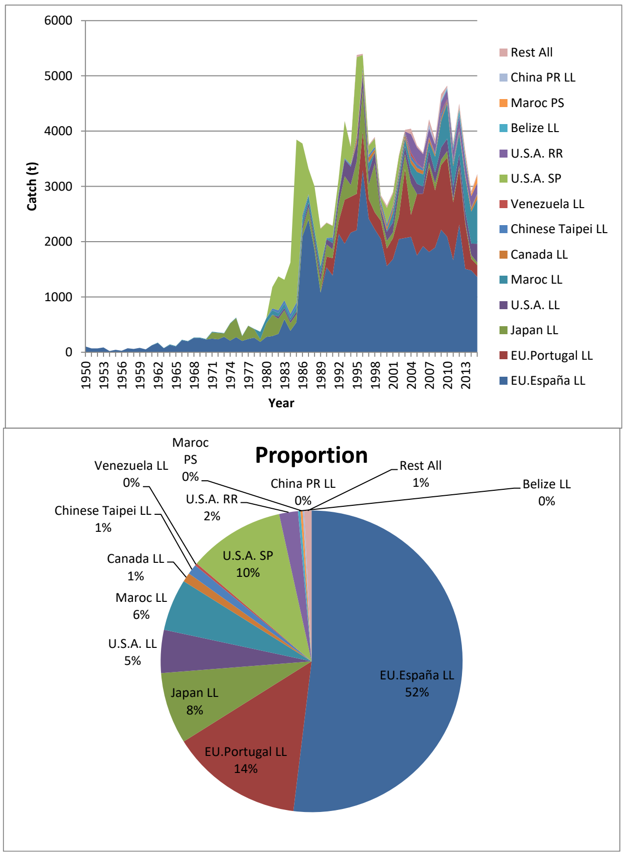


Figure 1. Catch in metric tons (t) by major flag obtained from data compiled during the 2017 Shortfin Mako Data Preparatory meeting and presented here as annual time series (upper panel) and as the proportion of the total catch (lower panel).

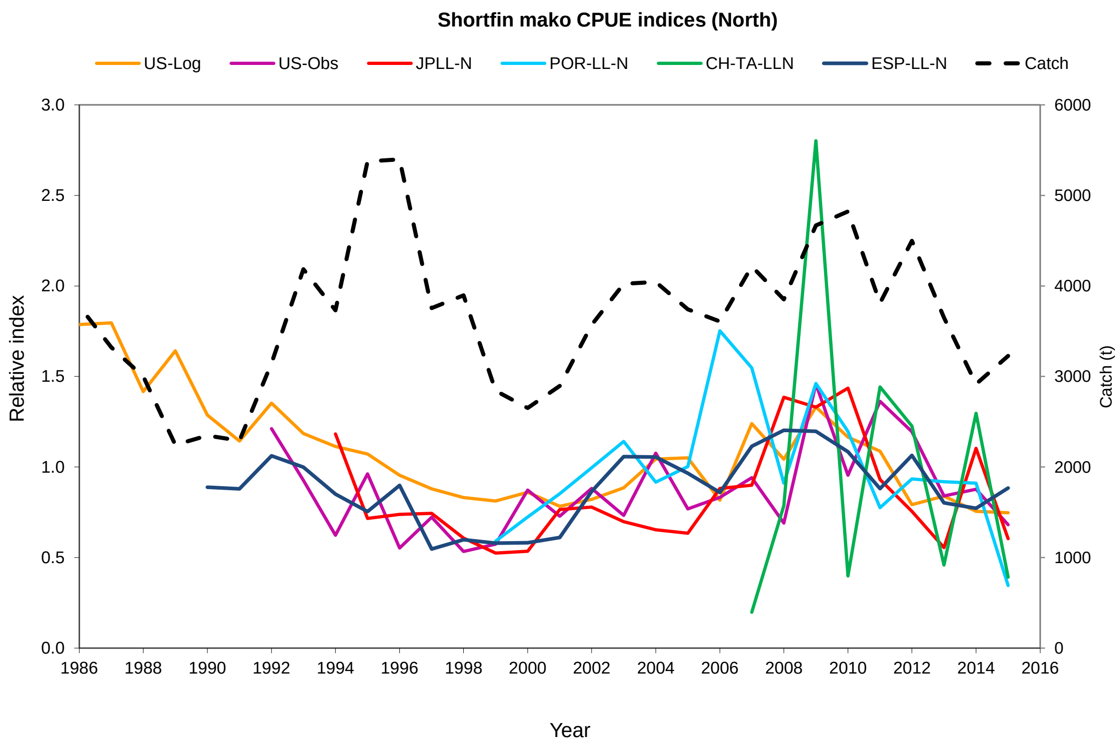


Figure 2. Indices of relative abundance for North Atlantic shortfin mako obtained from **Table 3**, divided here by the mean of the overlapping years among series (2007 – 2015) for plotting purposes, along with total catches (t) obtained from **Table 2** for overlapping years with survey data (1986 – 2015).

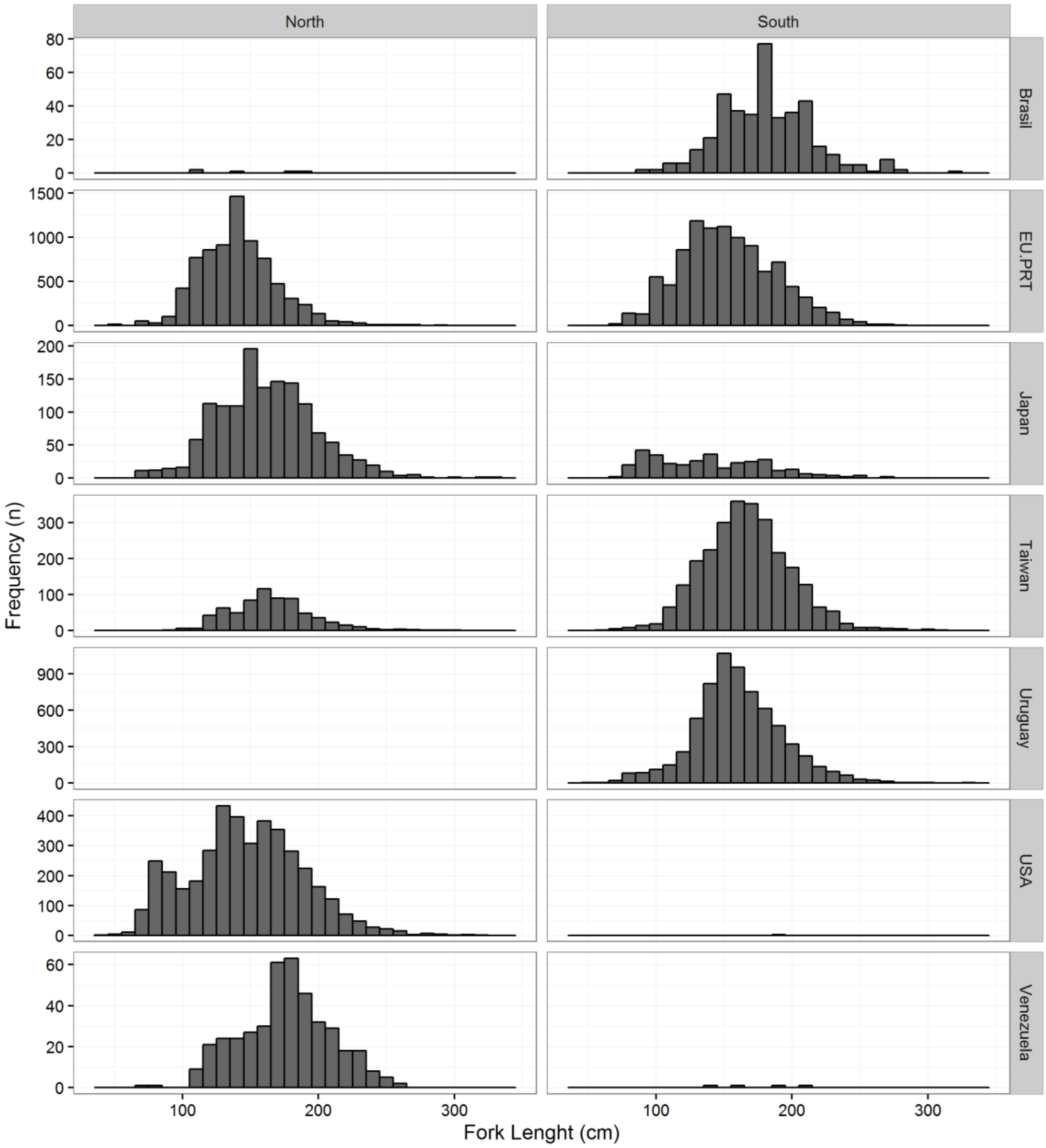


Figure 3. Available length composition data for North and South Atlantic shortfin mako (30 – 350 cm FL in 10 cm bins) were obtained from data compiled during the 2017 Shortfin Mako Data Preparatory meeting, as reported in document SCRS/2017/048 (Coelho et al. In Prep.). Only data for North Atlantic shortfin mako were used in the SS3 model runs. Plots of fits to annual North Atlantic shortfin mako length composition by fleet are provided in **Appendix B**).

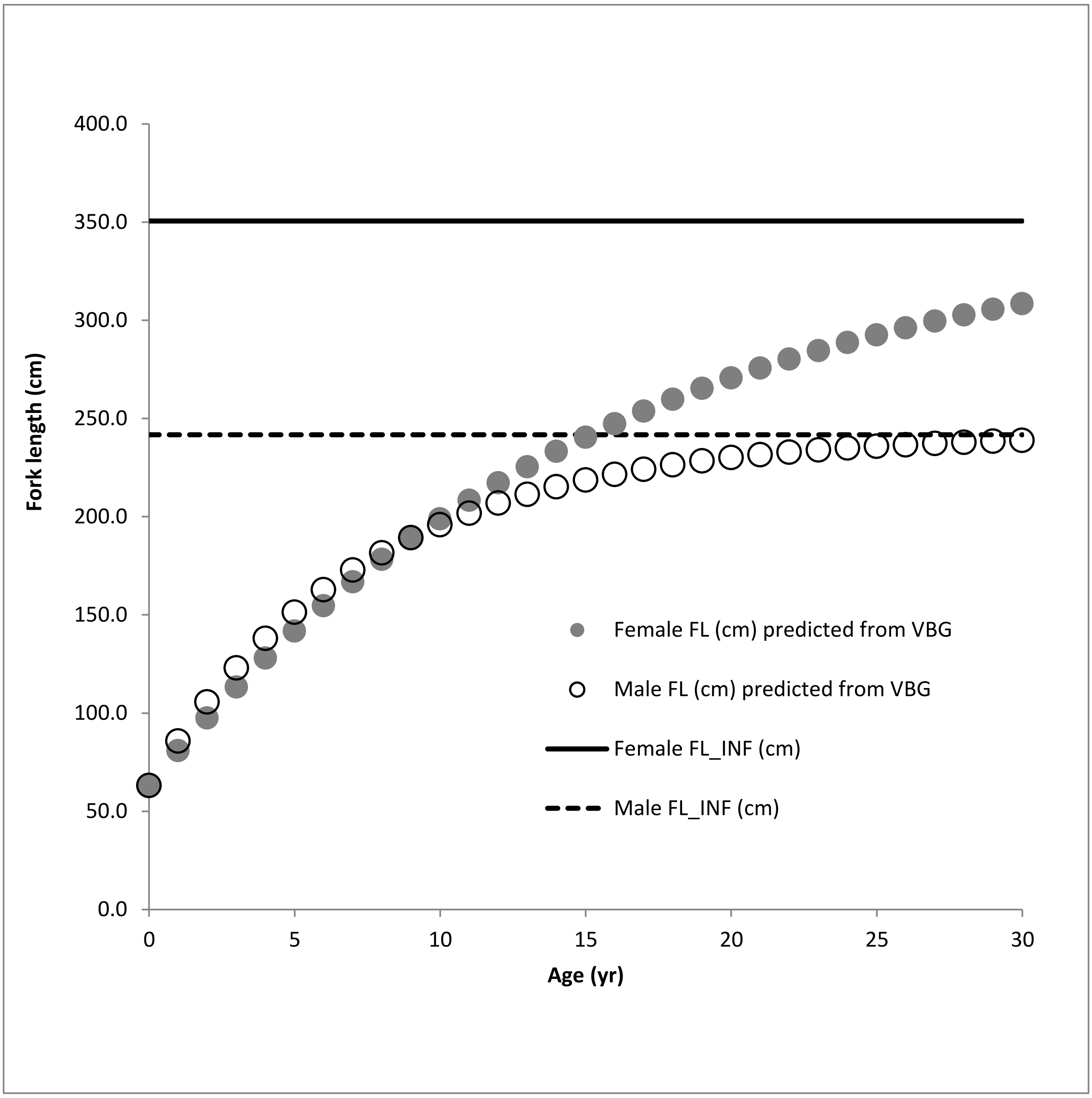
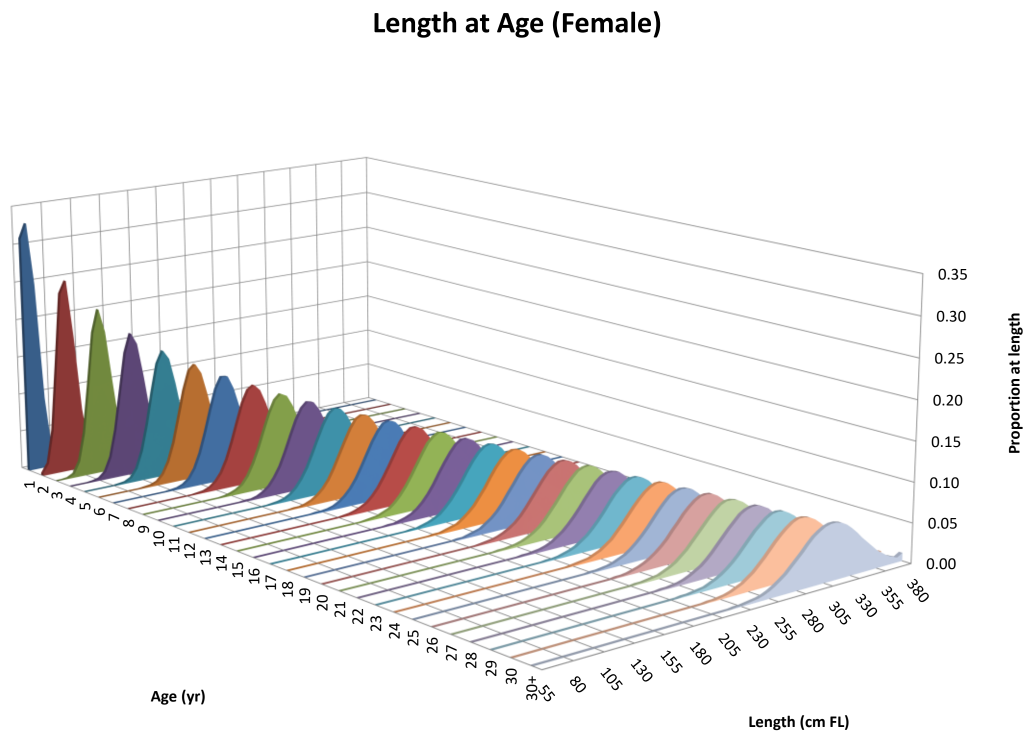


Figure 4. Sex-specific VBG parameters were obtained from SCRS/2017/111 as described in the text and **Table 7**.



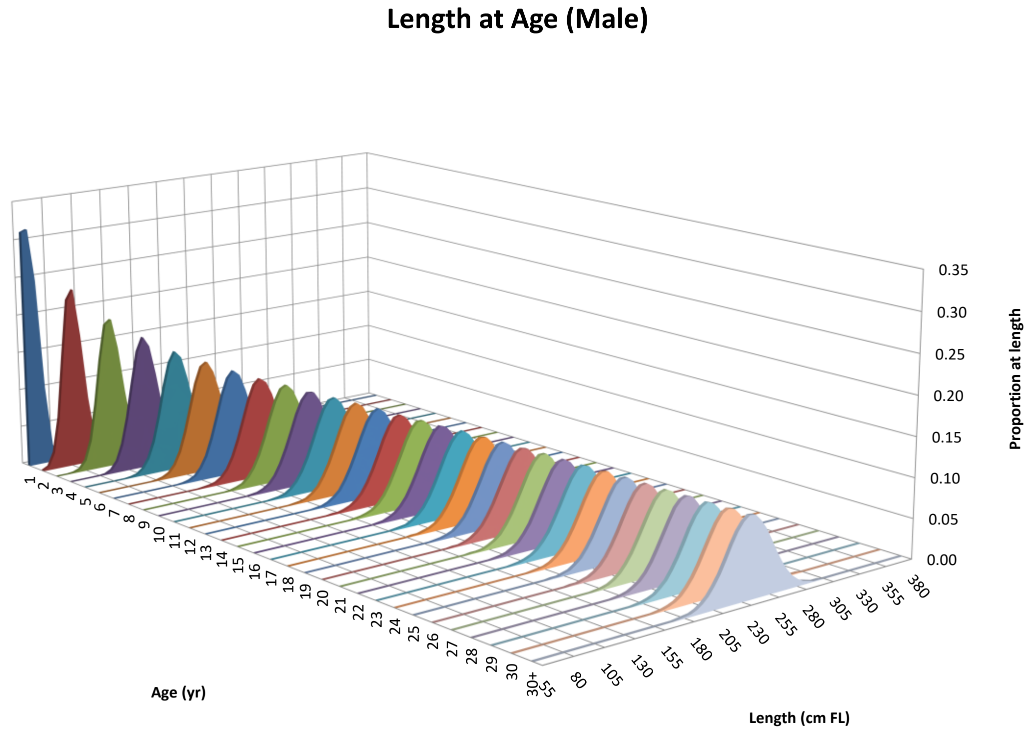


Figure 5. The assumed distribution of mean length at each age implemented in SS3 separately for females (upper panel) and males (lower panel) as described in the text of the main document and in **Table 7**.

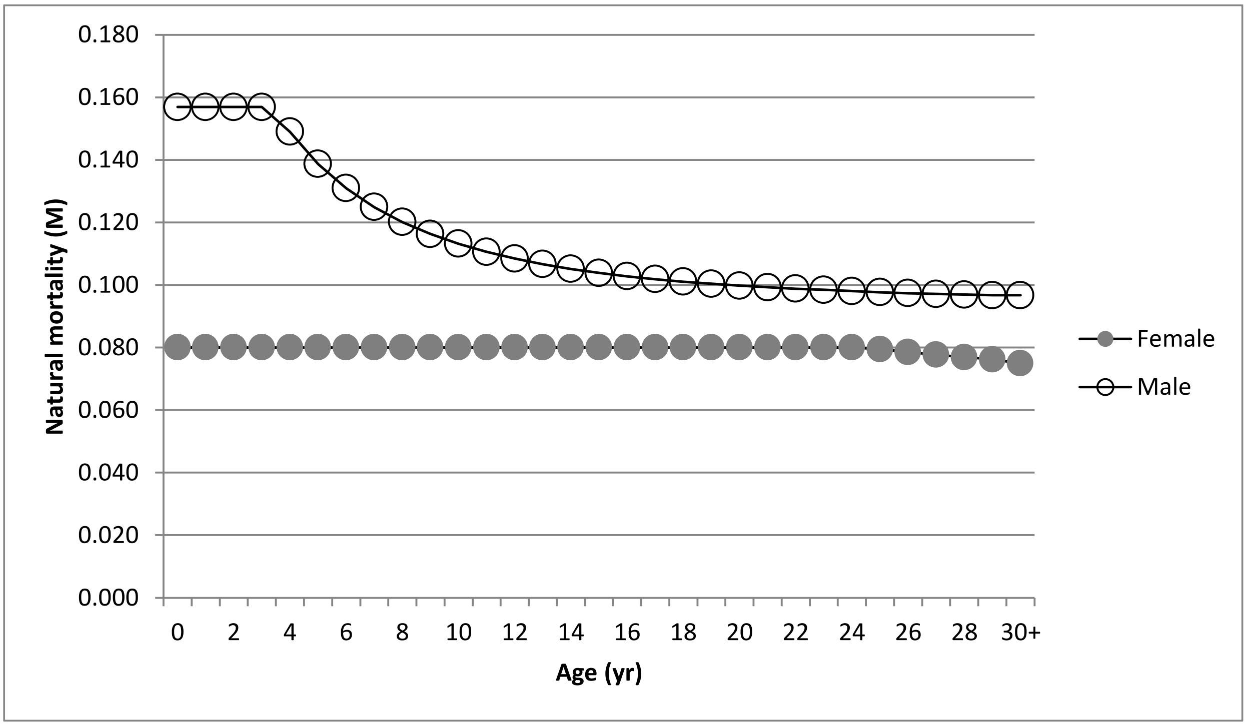


Figure 6. Sex-specific natural mortality at each age was fixed at values obtained independently with life history invariant methods, as described in document SCRS/2017/126 (Cortés In Prep.).

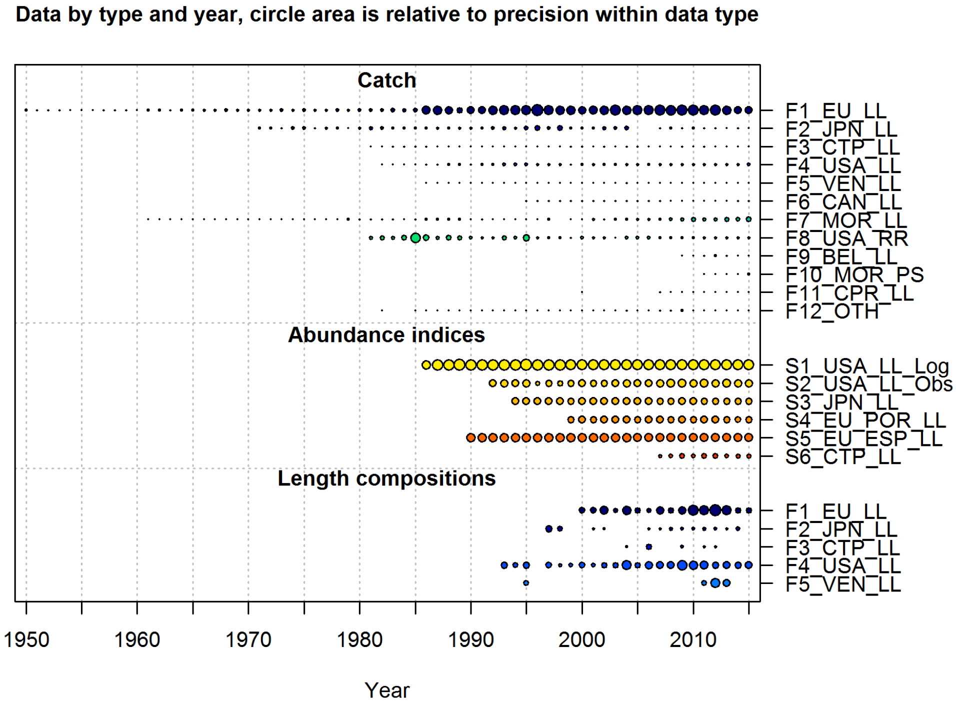


Figure 7. North Atlantic shortfin mako time series of catch, relative abundance, and length composition data used in the final SS3 model runs.

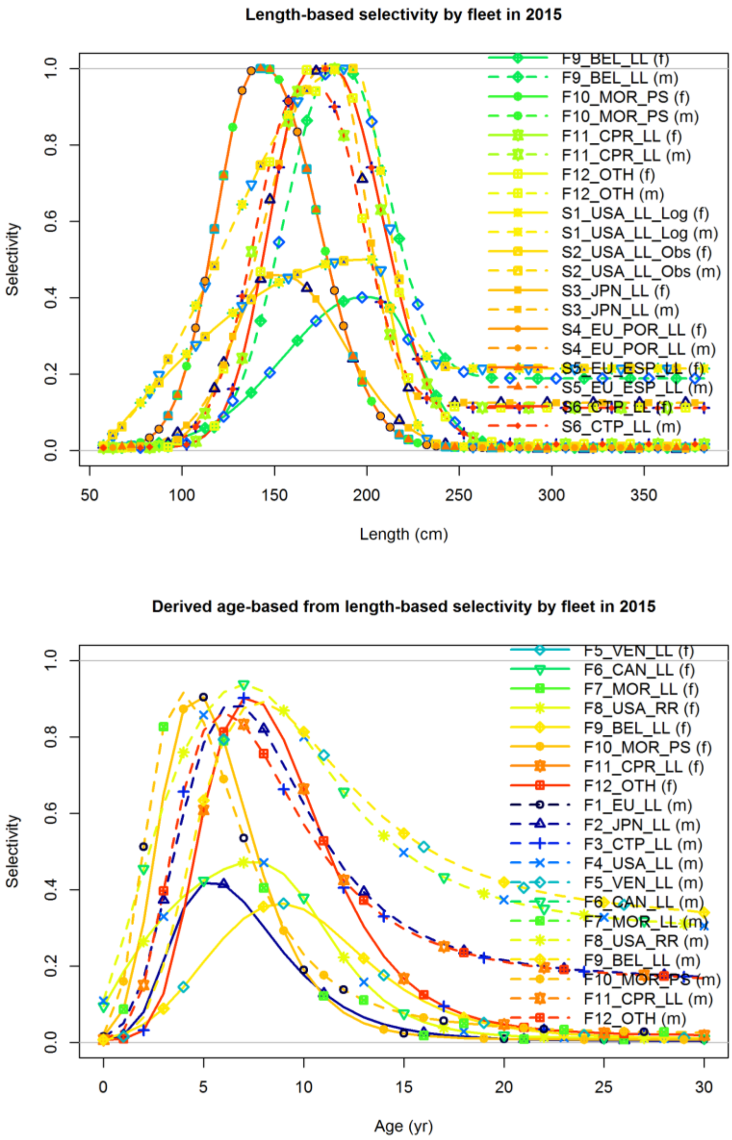
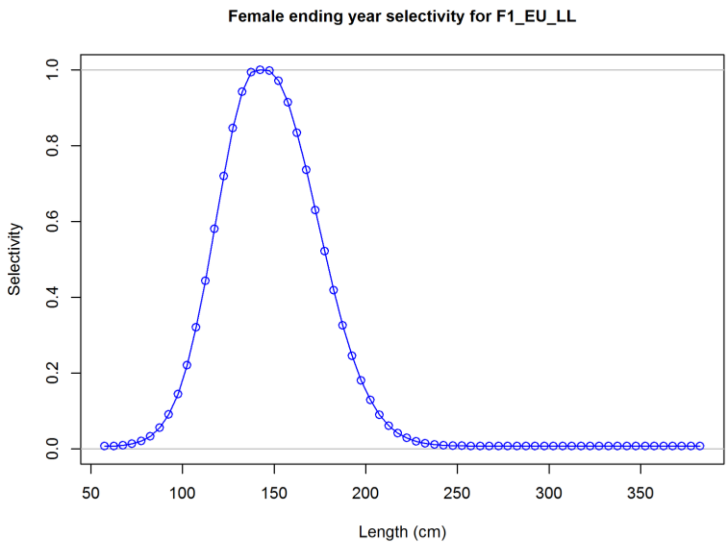


Figure 8. Selectivity at length (cm FL; upper panel) and corresponding derived selectivity at age (lower panel) obtained for the final SS3 model. Selectivity was estimated for fleets F1-F5 based on fit to length composition data. Selectivity for the remaining fleets and surveys mirrored the estimated selectivity of Fleets F1 – F5 as defined in **Table 1**. Sex-combined selectivity was estimated for fleet F1 based on sex-combined length composition data. Sex- specific selectivity was estimated for fleets F2 – F5 based on sex-specific length composition data.



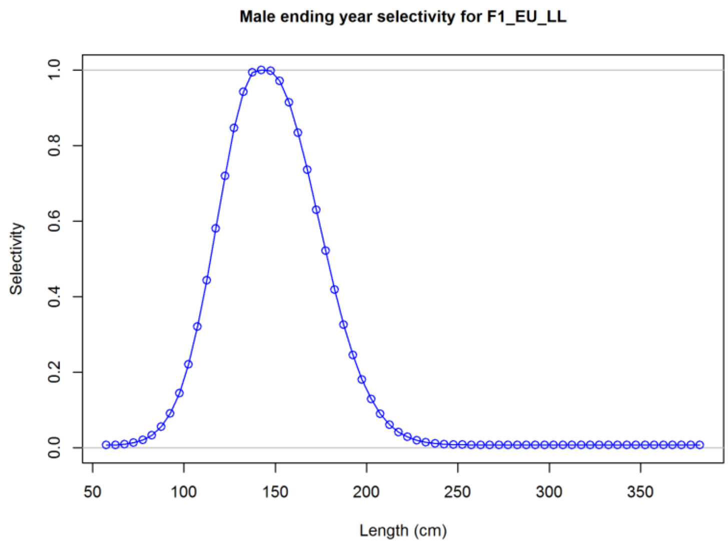
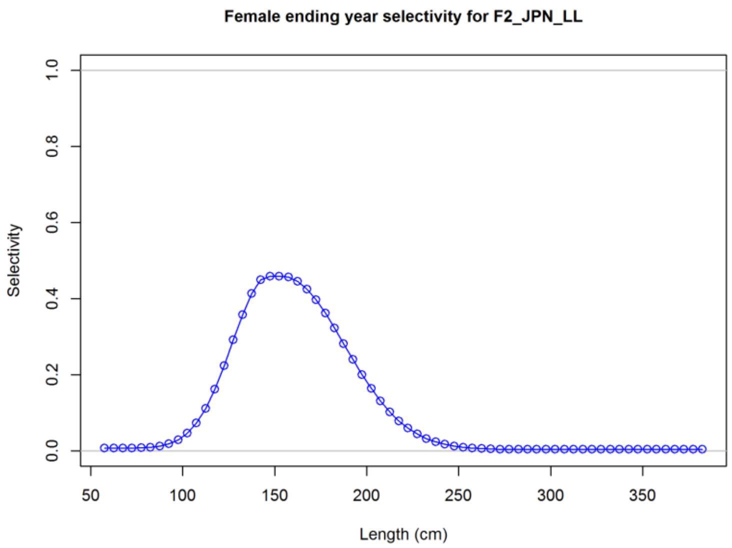


Figure 8. Continued.



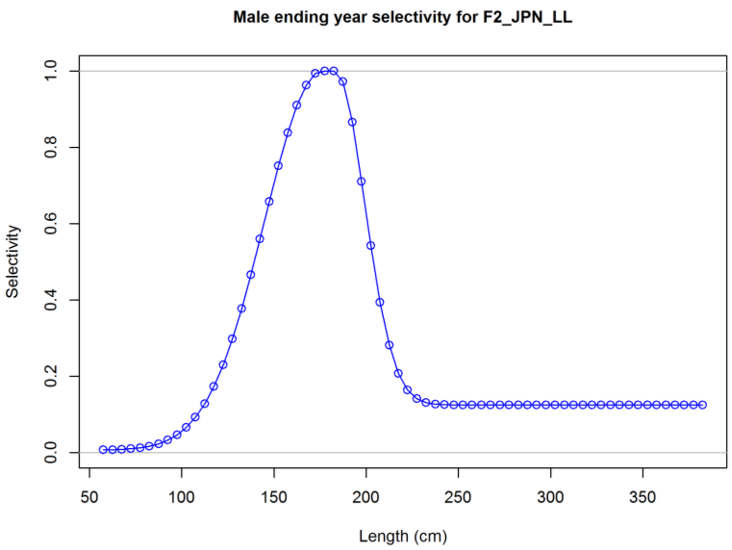
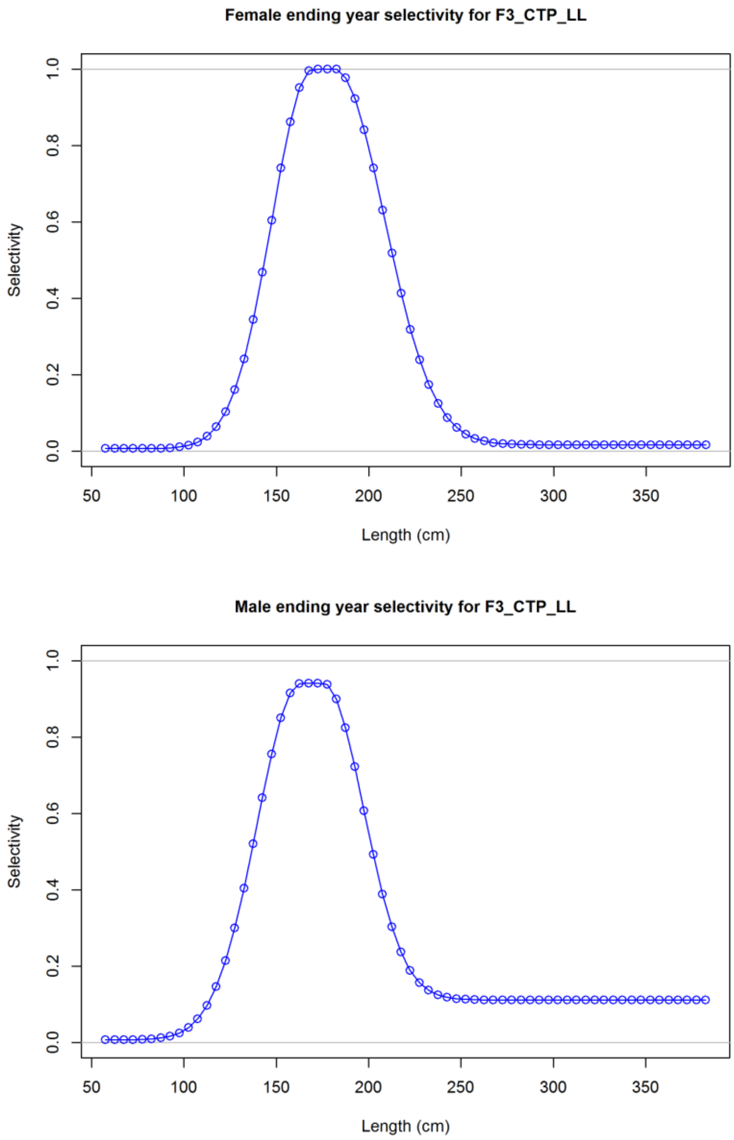


Figure 8. Continued.



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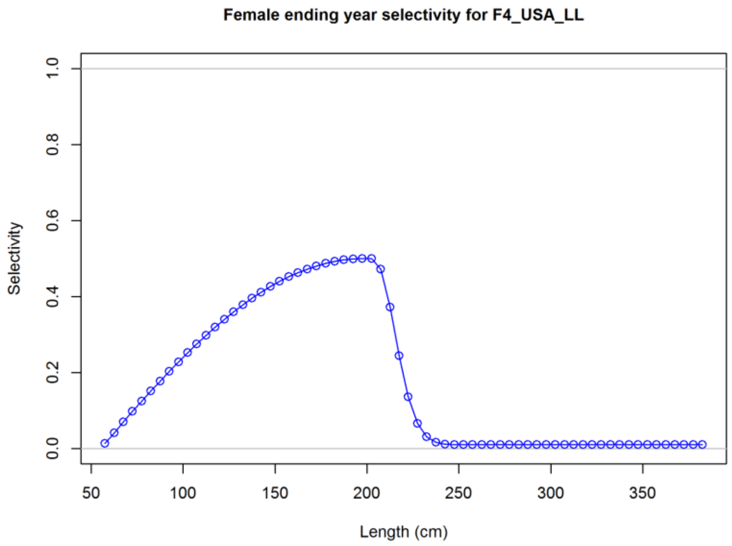

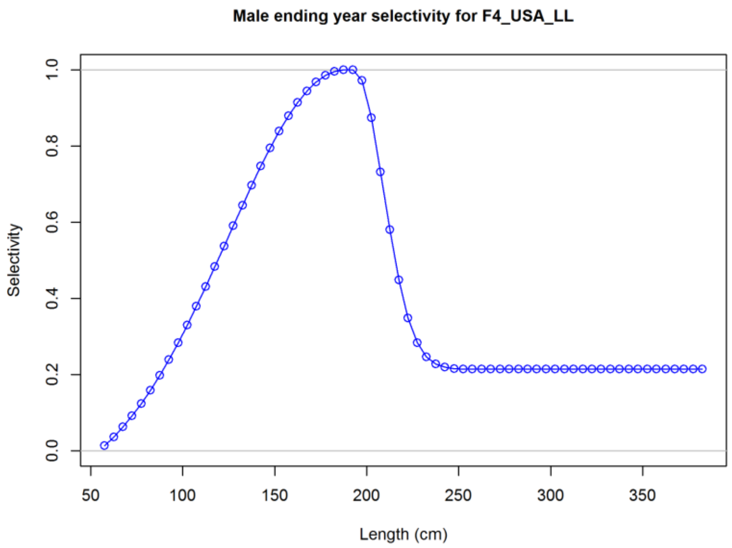

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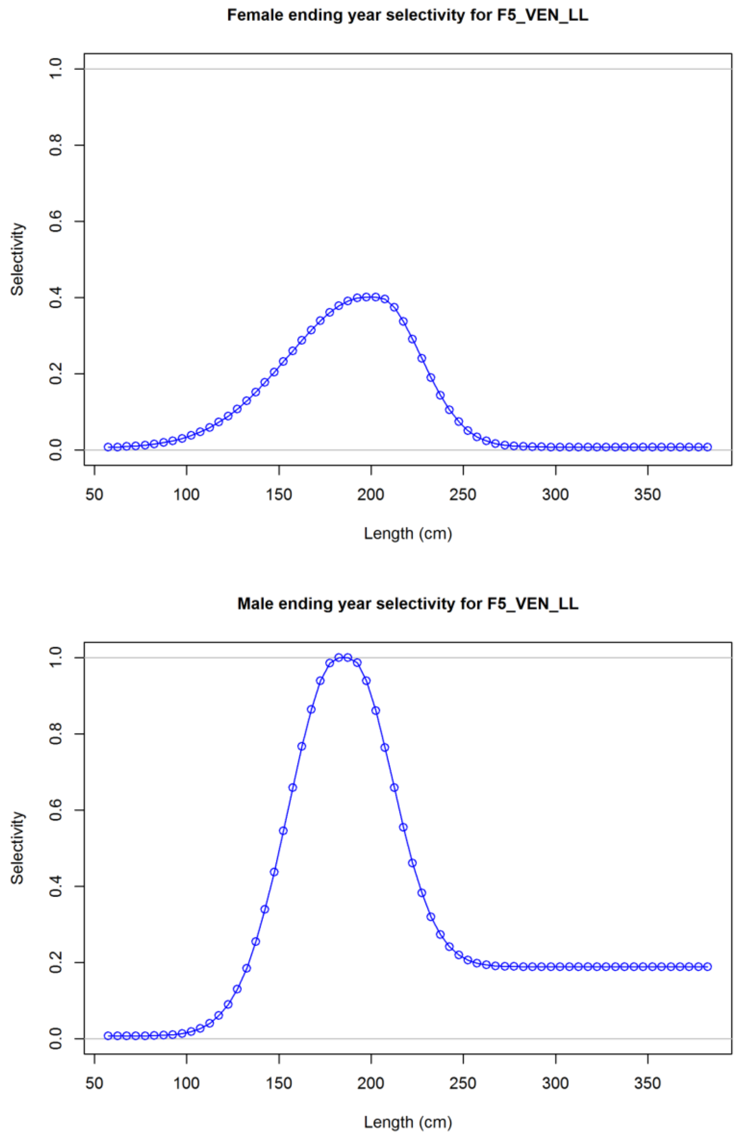

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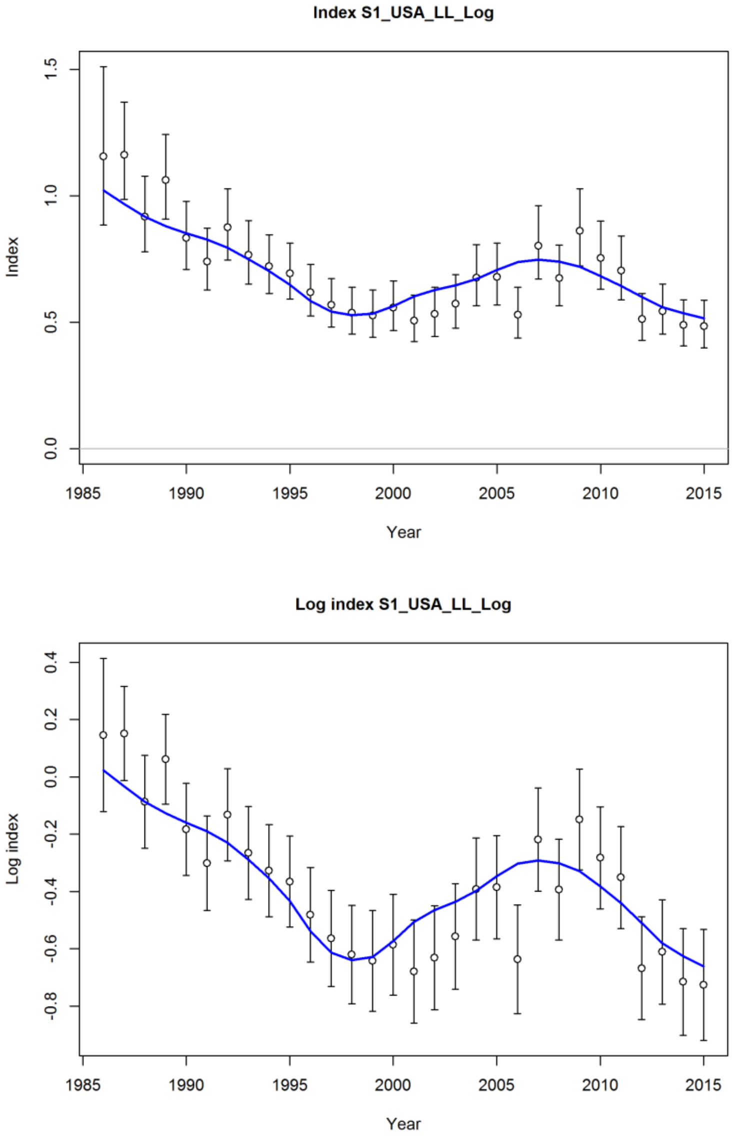


Figure 9. Predicted (blue line) and observed (open circles with 95% confidence intervals assuming lognormal error) for each standardized index of relative abundance as defined in **Table 1** obtained for the final SS3 model. Fits on the nominal scale are provided in the upper panel and fits on the log scale are provided in the lower panel. Index S2 (USA LL Obs) was not fit in the model likelihood (lambda = 0) because of high variability in the index and because S2 describes the same fishery as S1 (USA LL Log) (Anon. In Prep.).

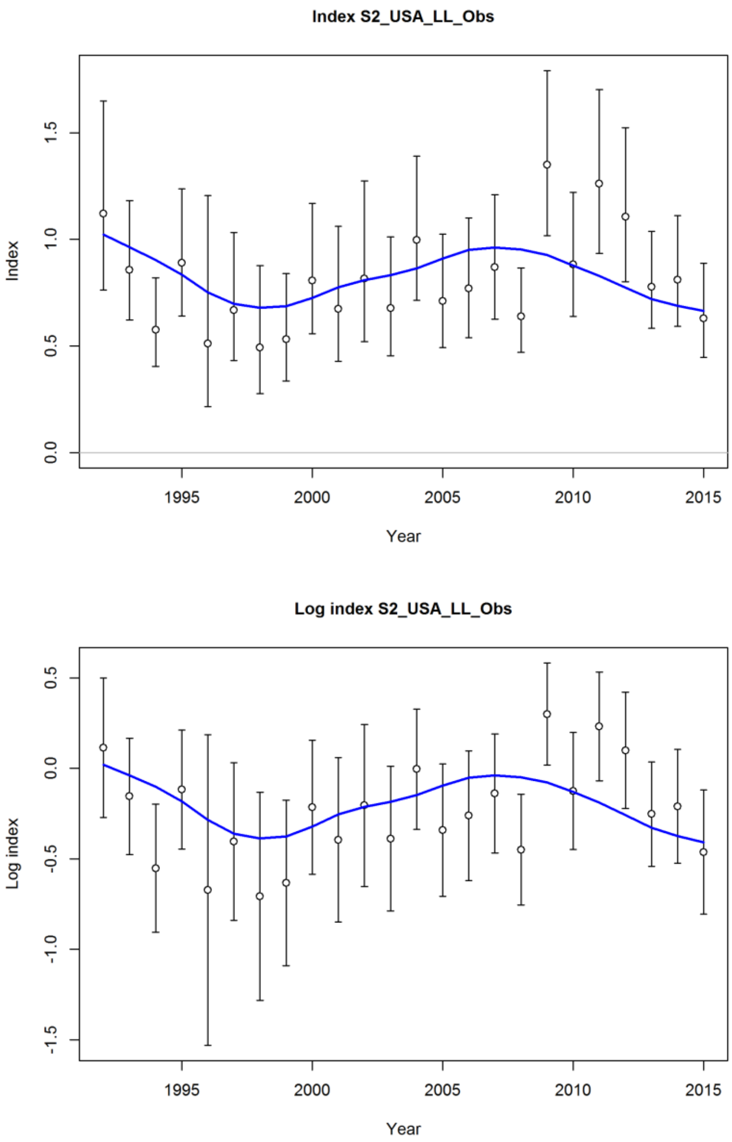
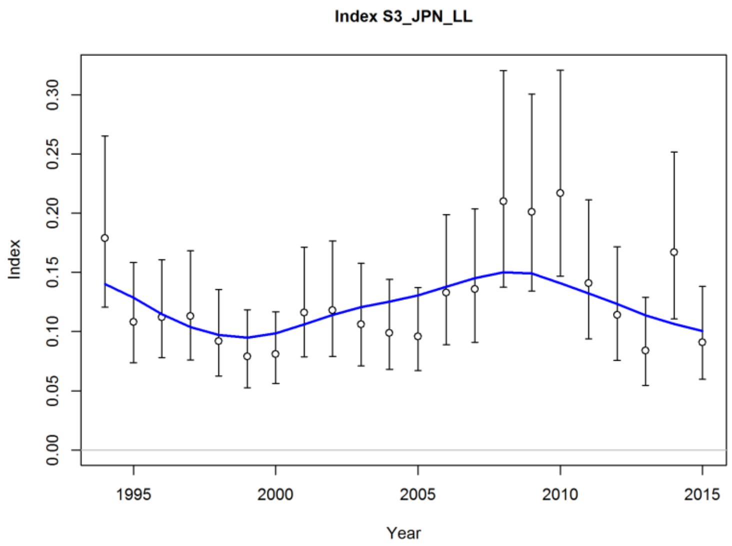
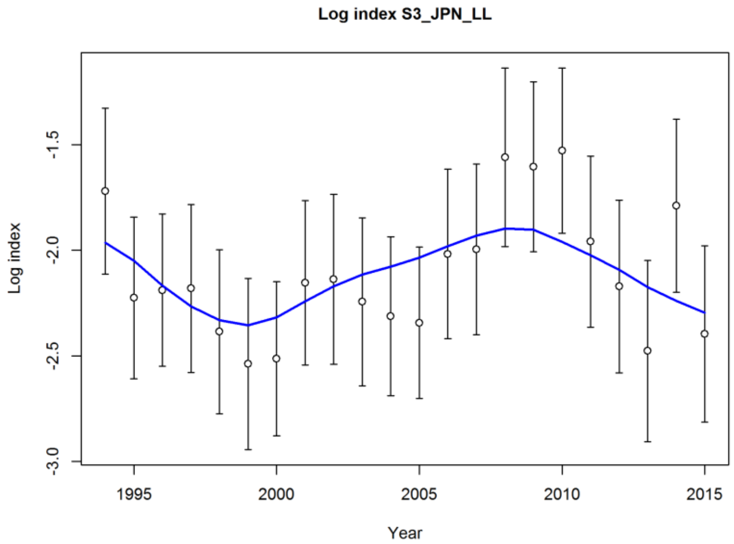


Figure 9. Continued.





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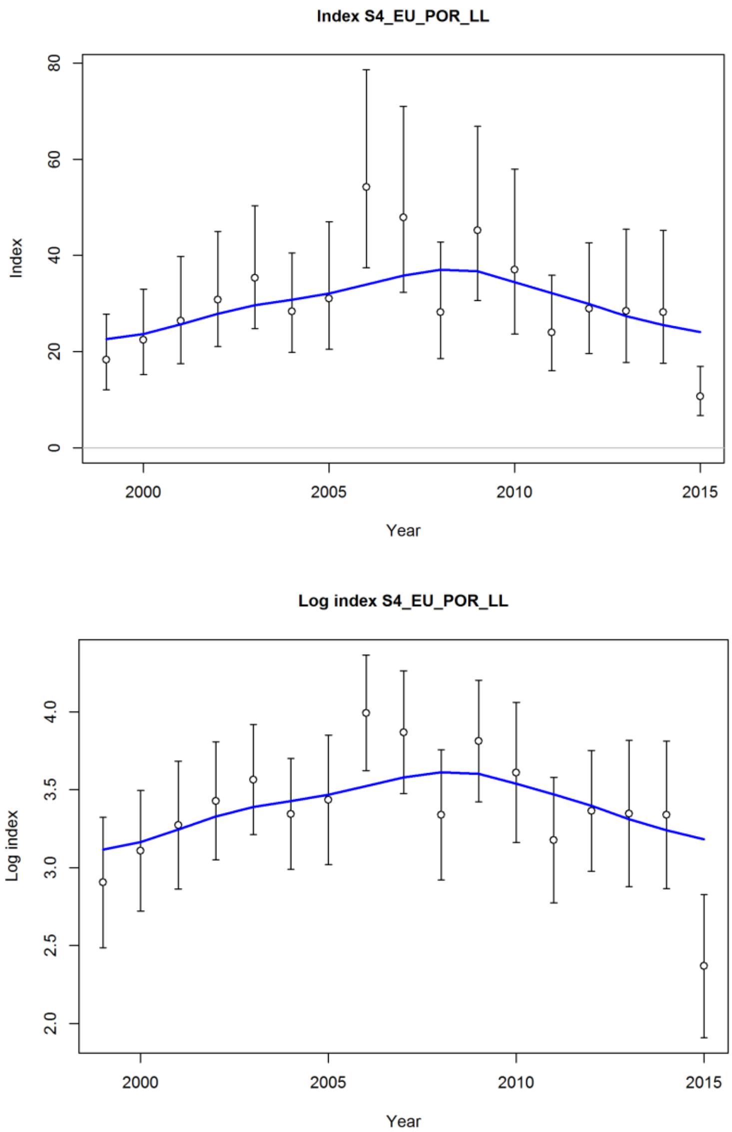

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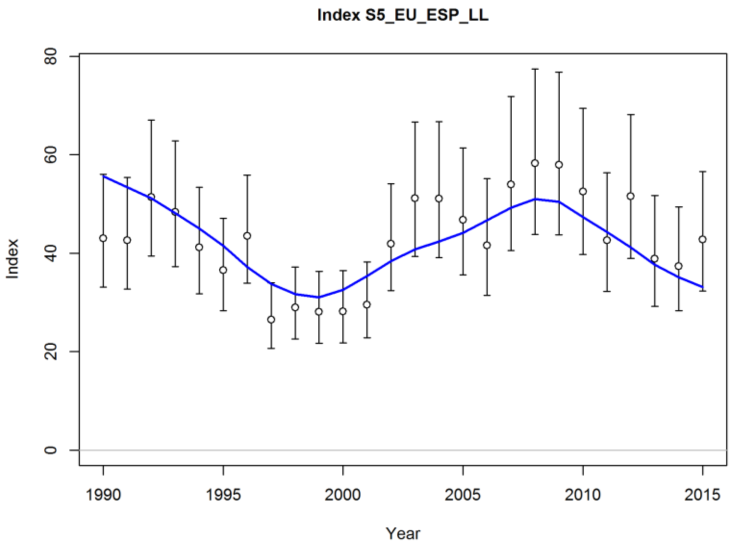

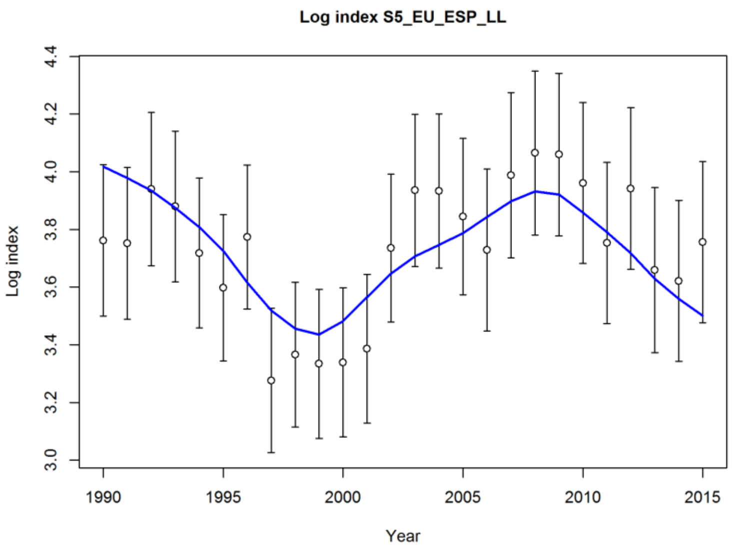

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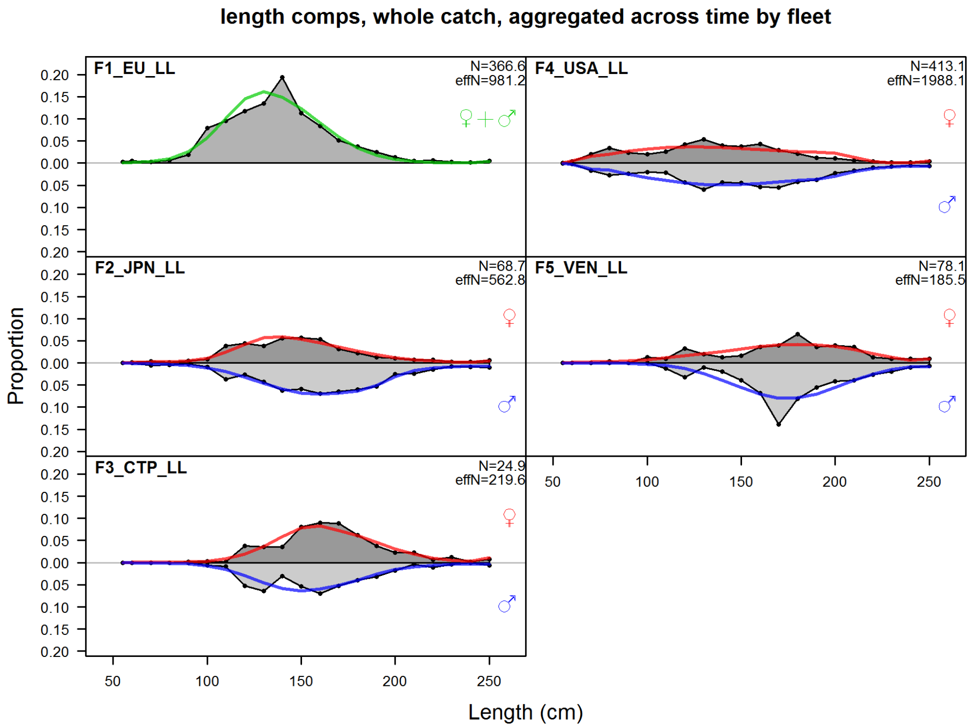
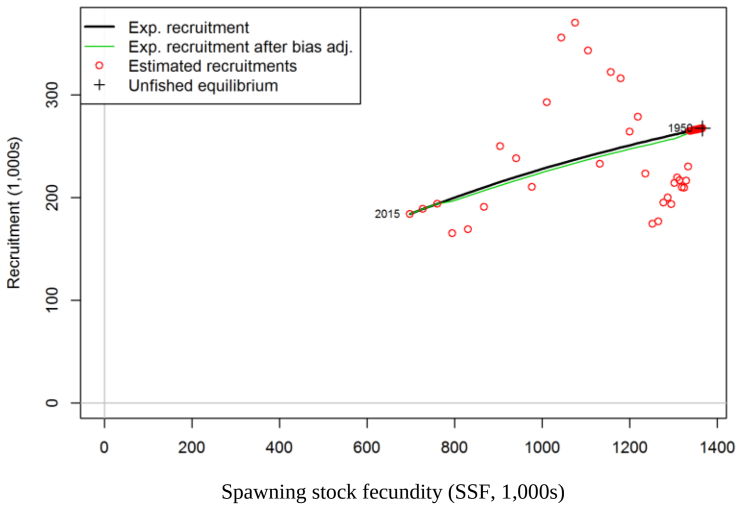


Figure 10. Model predicted (line) and observed (shaded) aggregated length compositions (female + male; for fleet F1 and sex specific for fleets F2 – F5) obtained for the final SS3 model. N is the input effective sample size using the Francis method (Stage 2) as described in the text of the main document above, and effN is the effective sample size estimated in Stock Synthesis. Plots of annual fits to length composition data by fleet along with plots of Francis method (Stage 2) length composition variance adjustments are provided in **Appendix B**.



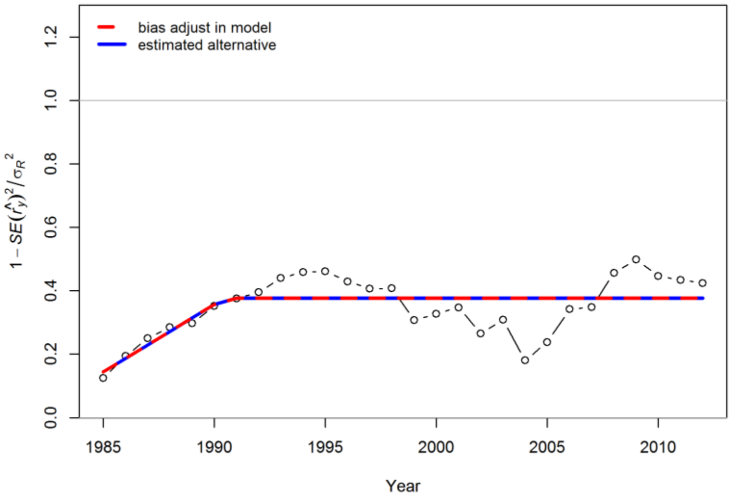
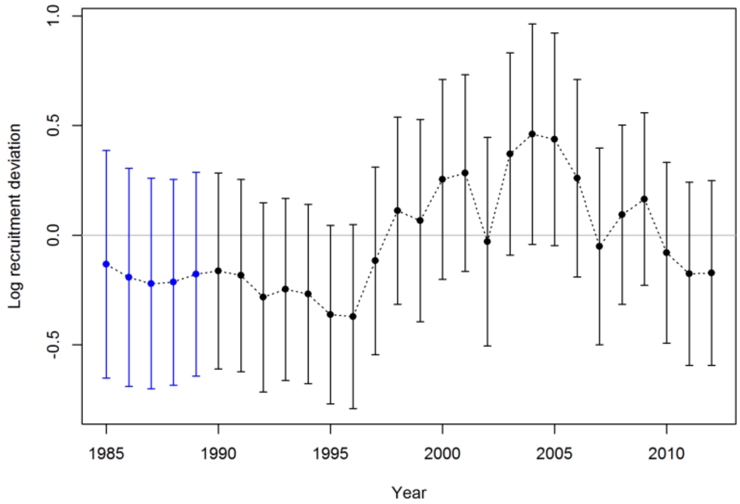


Figure 11. Upper panel is the expected recruitment from the stock-recruitment relationship (black line), expected recruitment after implementing the bias adjustment correction (green line), estimated annual recruitments (circles), unfished equilibrium (plus), and first (1950) and last (2015) years along with years with log deviations > 0.5. Note the different scales on the Y-axis (number of recruits in 1,000s) and X-axis (spawning stock fecundity, SSF, in 1,000s). Lower panel is bias adjustment applied to the stock-recruitment relationship (red stippled line) and the estimated alternative (blue line) obtained from the r4ss output.



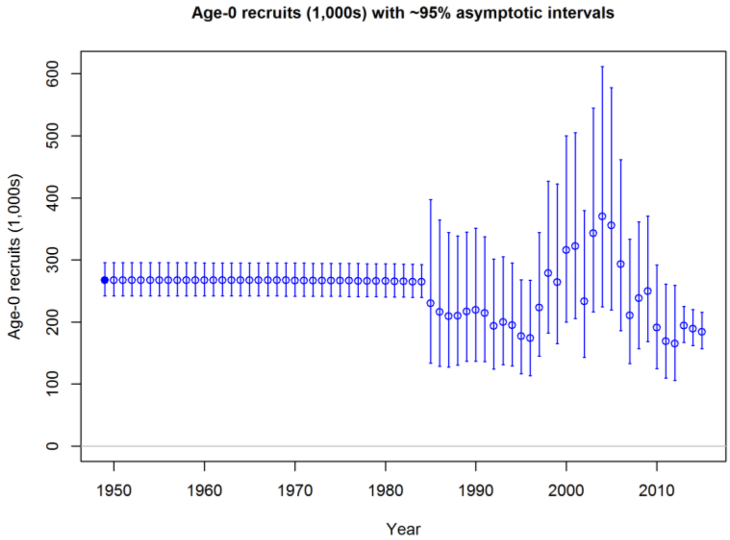


Figure 12. Upper panel is the estimated log recruitment deviations for the early (1985 – 1989, blue) and main (1990 – 2012, black) recruitment periods with associated 95% asymptotic confidence intervals, lower panel is the estimated annual age-0 recruitment (circles) with 95% asymptotic confidence intervals; recruitment in years prior to 1985 and after 2012 follows the stock recruitment relationship exactly.

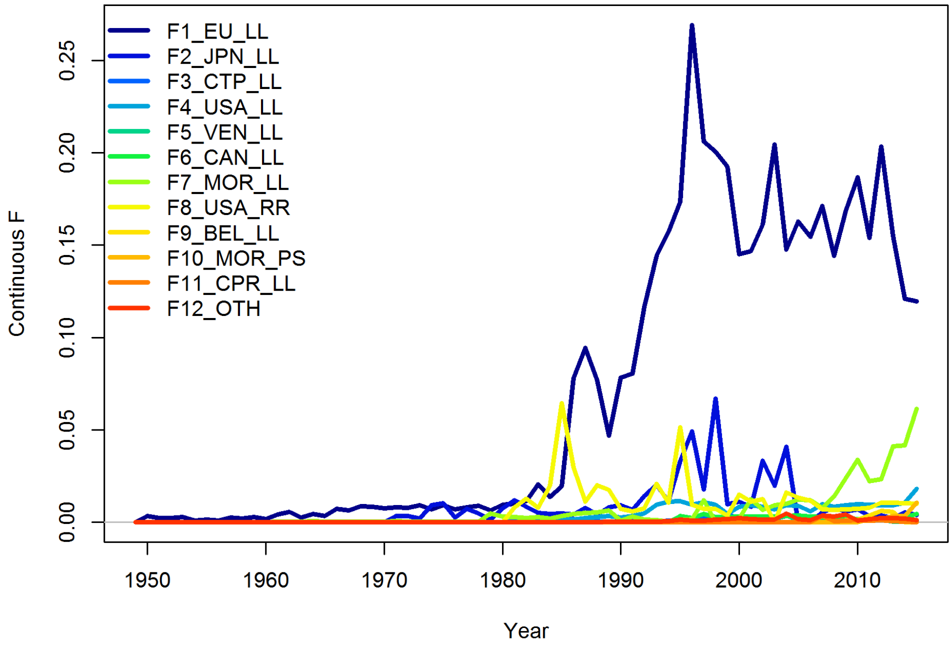
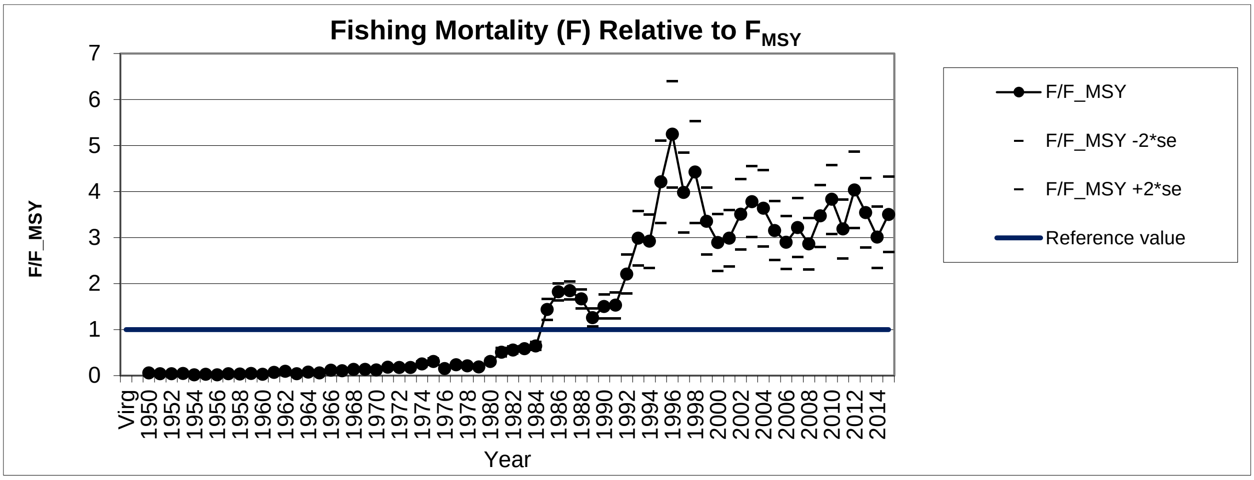


Figure 13. Estimated instantaneous fishing mortality rates (Continuous *F*) for each fleet (F1 – F12) obtained for the final SS3 model.



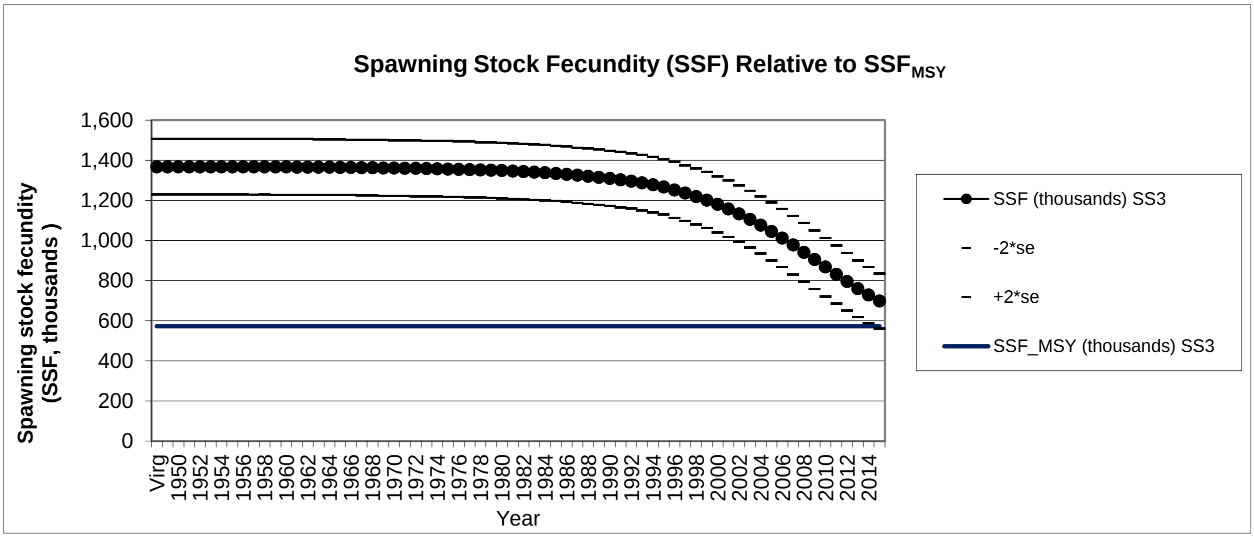


Figure 14. Upper panel is the estimated total annual fishing mortality for all fleets combined, calculated as the sum of continuous F obtained for each fleet (see **Figure 13**), relative to total annual fishing mortality at MSY (F/F_MSY) and lower panel is the estimated **s**pawning stock size (spawning stock fecundity, SSF) and spawning stock size at MSY (SSF_MSY). Approximate 95% asymptotic standard errors (± 2*s.e.) are based on asymptotic standard errors obtained for derived quantities from SS3.

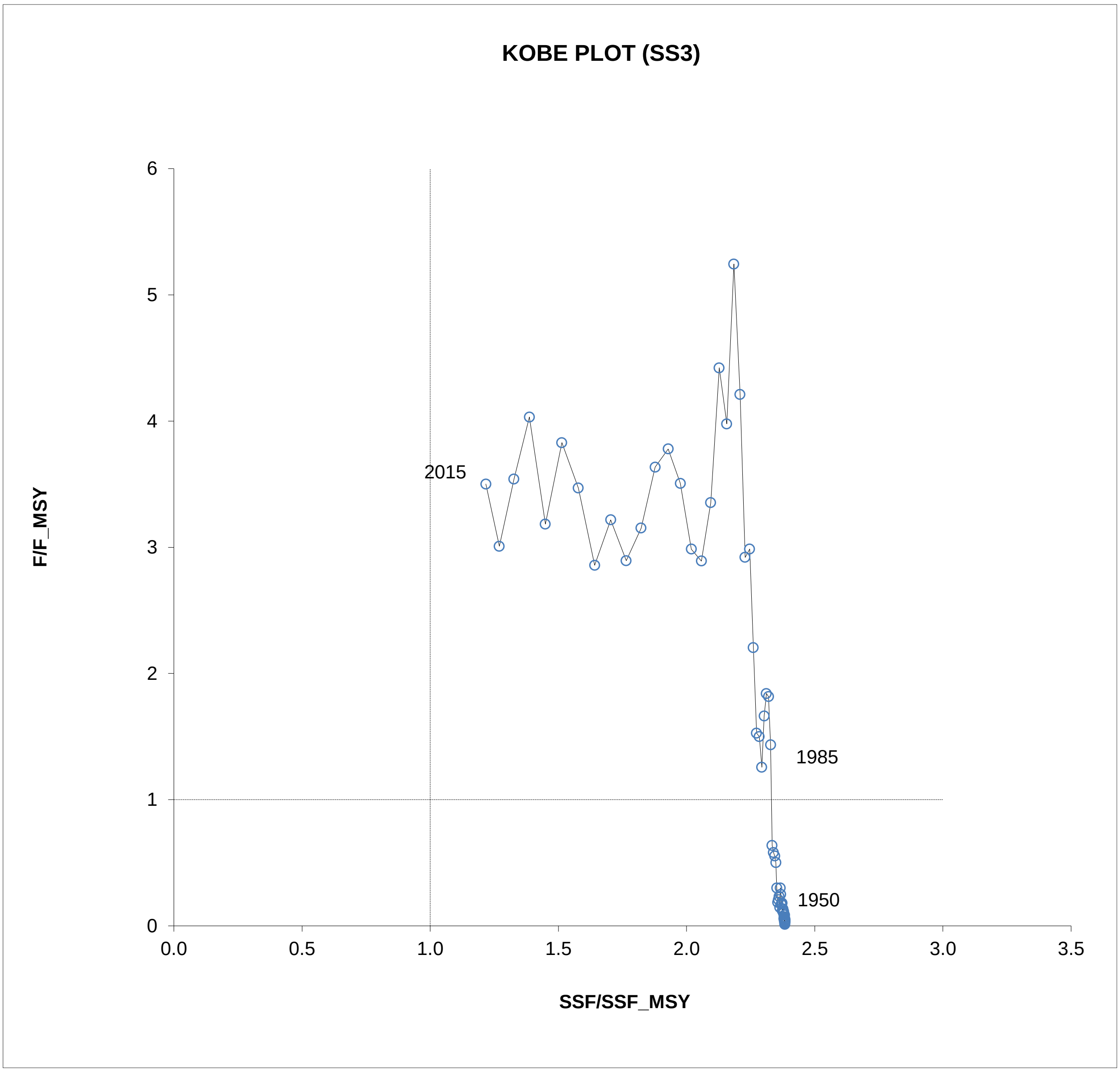
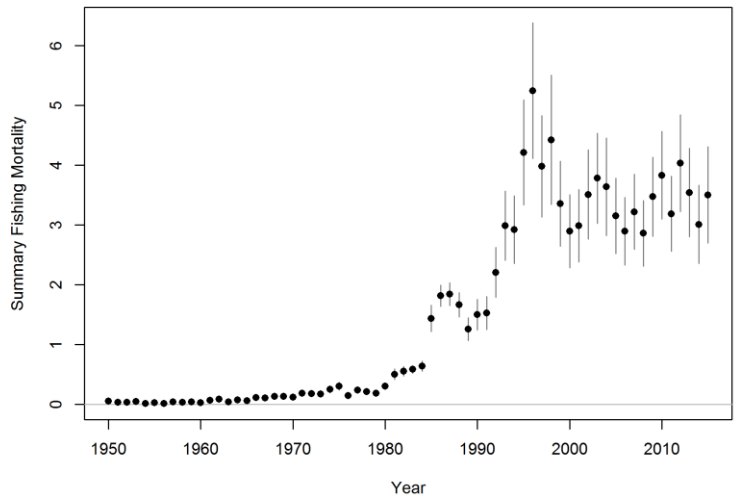


Figure 15. Kobe plot of the estimated total annual fishing mortality for all fleets combined, calculated as the sum of continuous *F* obtained for each fleet (see **Figure 13**), relative to total annual fishing mortality at MSY (*F*/*F*_MSY) and estimated **s**pawning stock size (spawning stock fecundity, SSF 1,000s) relative to spawning stock size at MSY (SSF/SSF_MSY).



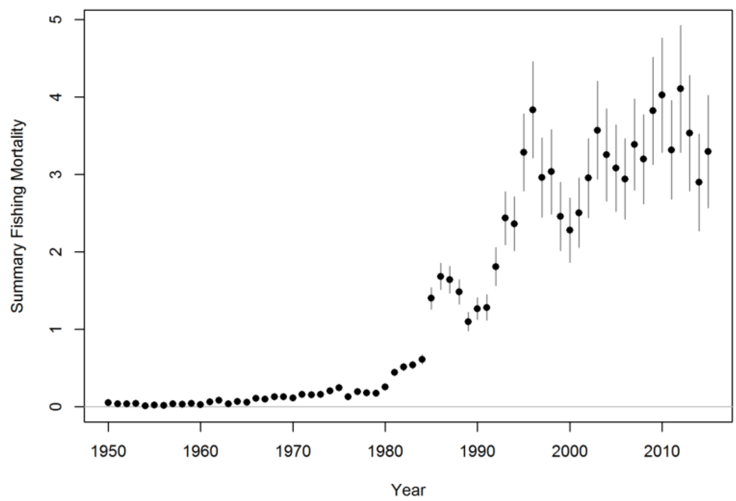


Figure 16. Upper panel is estimated total annual fishing mortality for all fleets combined (calculated as the sum of continuous *F* obtained for each fleet; see **Figure 13**) relative to fishing mortality at MSY, and lower panel is the annual exploitation rate in numbers (*U*, calculated for age 1+) relative to the annual exploitation rate at MSY.

Appendix A

Francis Method (Stage 1) CPUE Variance Adjustments.

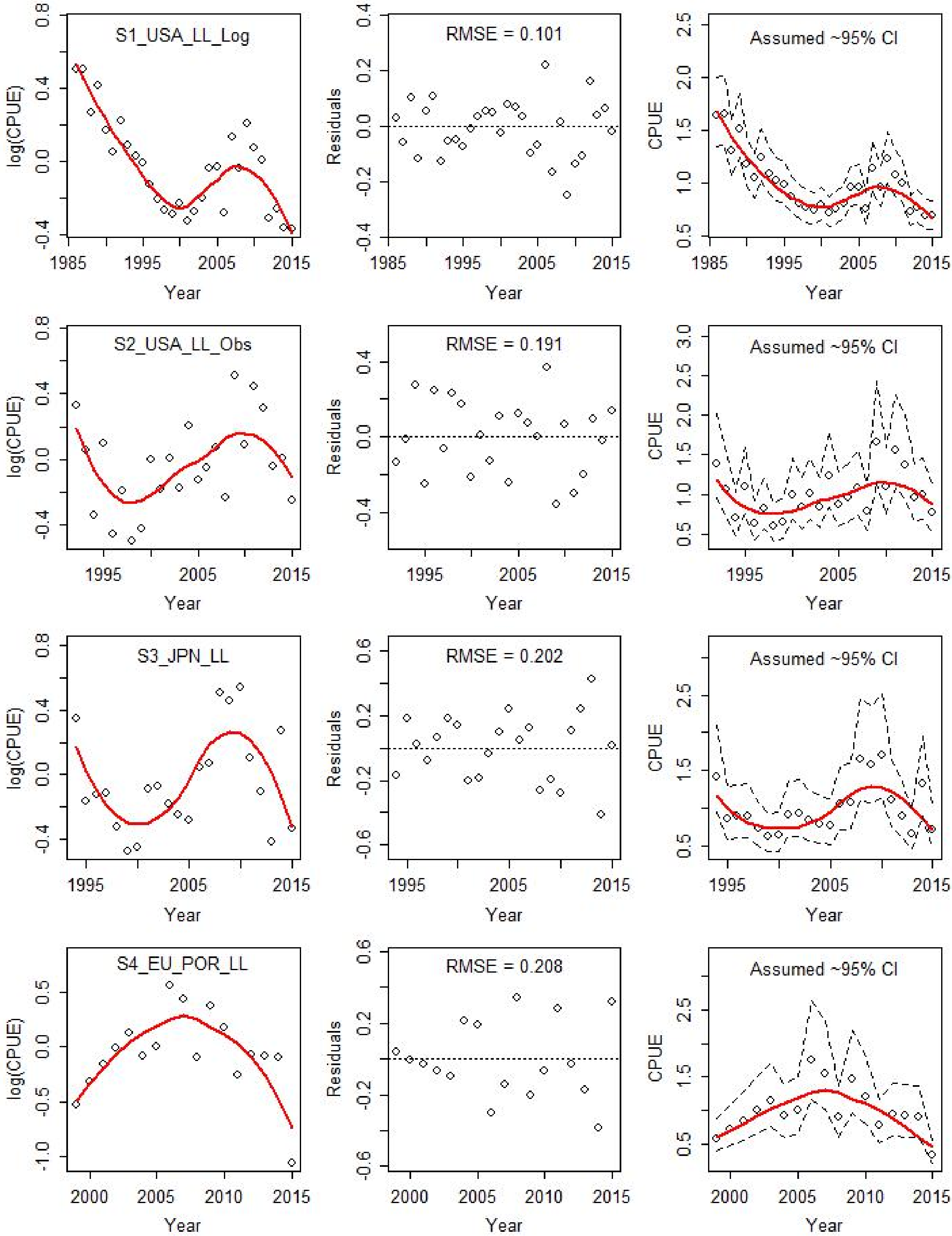


Figure A.1. LOESS smoother fits used to estimate the $RMSE_{smoother}$ for each CPUE series; Left panel: Smoother fits to log (CPUE) data; Middle panel: Residual plots and estimated RMSE for each CPUE series; Right panel: LOESS smoother fits illustrated for CPUE indices along with approximate 95% confidence intervals after applying the variance adjustment.

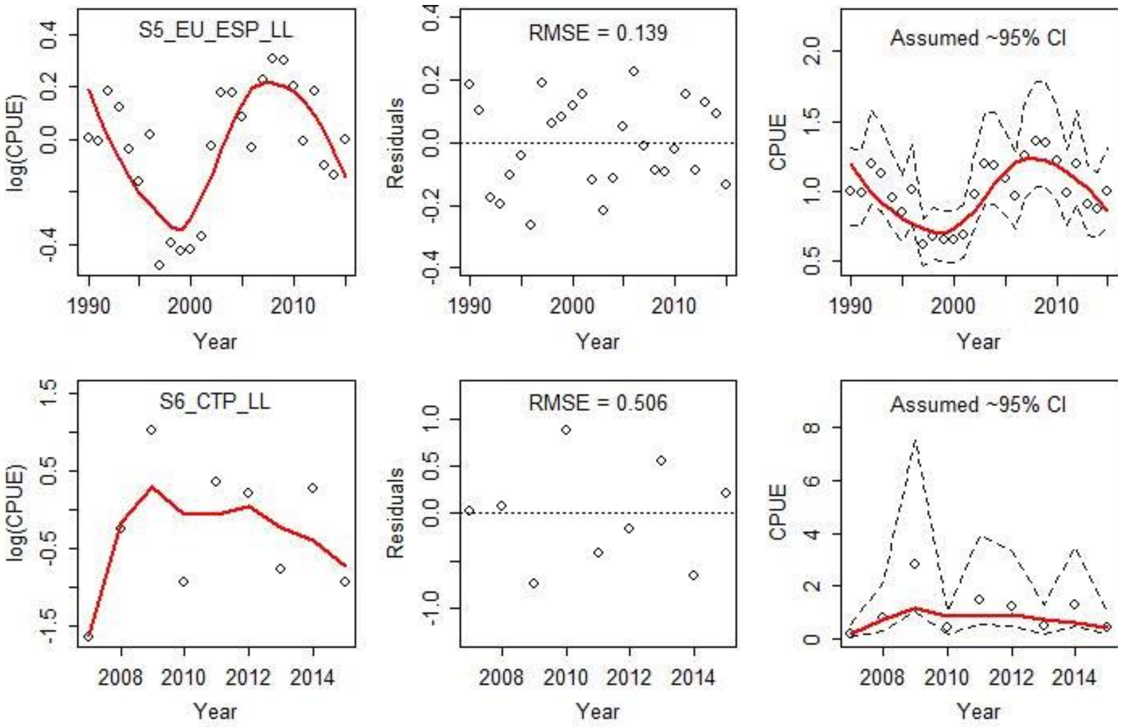


Figure A.1. Continued.

Annual Length Composition Fits and Francis Method (Stage 2) Length Composition Variance Adjustments

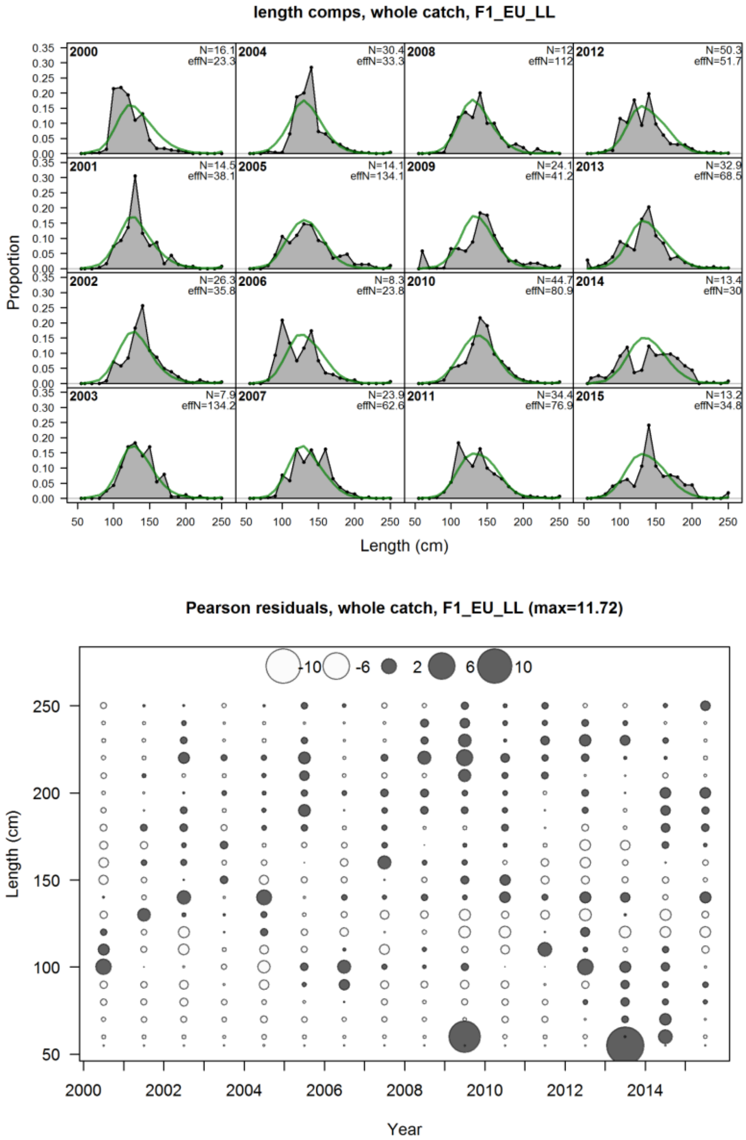
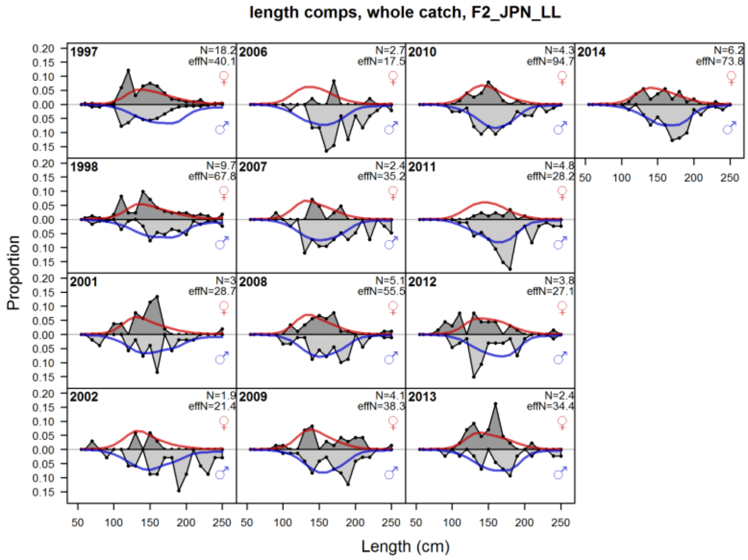


Figure B.1. Observed and predicted annual length compositions (upper panel) by fleet (as defined in **Table 1** of the main document) obtained for the final SS3 model. Diameter of Pearson residuals (lower panel, circles) indicates relative error; predicted < observed (solid), predicted > observed (transparent). The maximum diameter width of the plot for Pearson residuals (max) is an indication of relative fit. N is the input effective sample size using the Francis Method (Stage 2) as described in the main document, and effN is the effective sample size estimated in Stock Synthesis. Years with small sample size (total number of sharks measured < 30) were excluded from the fit (input sample sizes of raw length data are provided in **Table 5** of the main document).



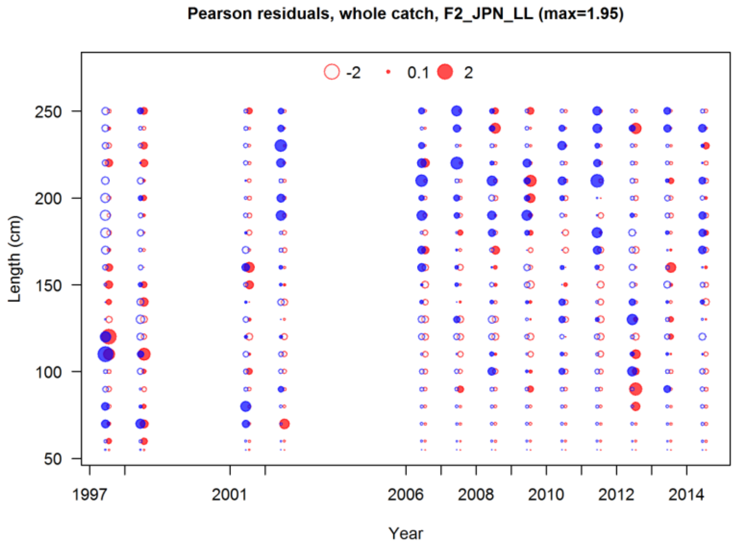
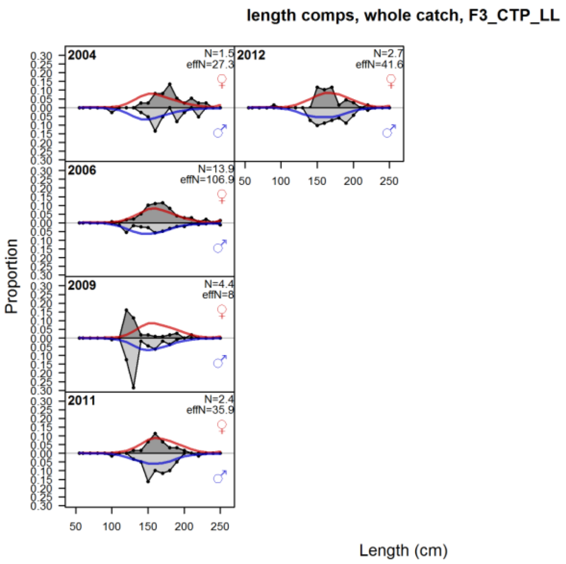


Figure B.1. Continued.



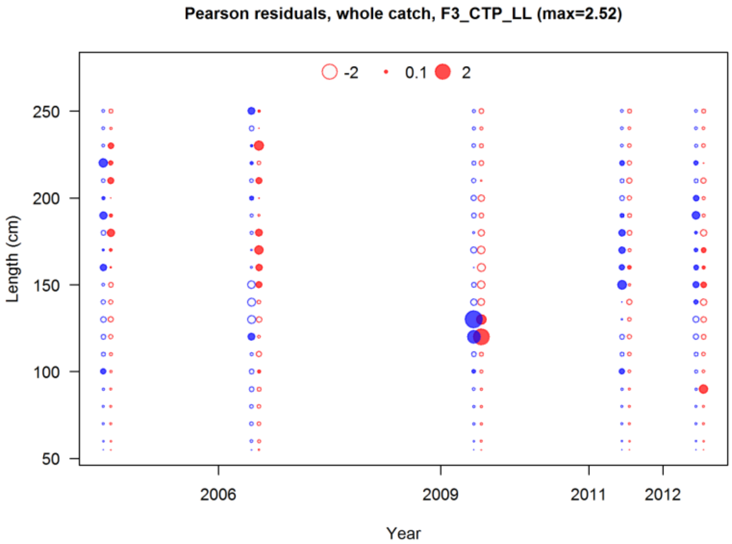
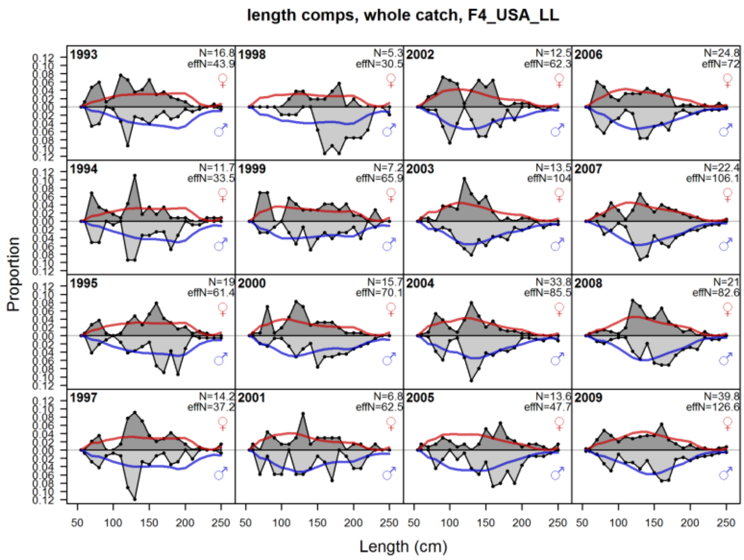
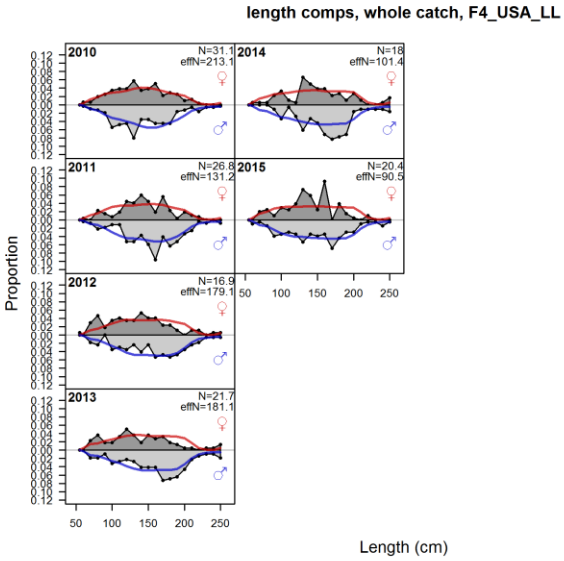


Figure B.1. Continued.





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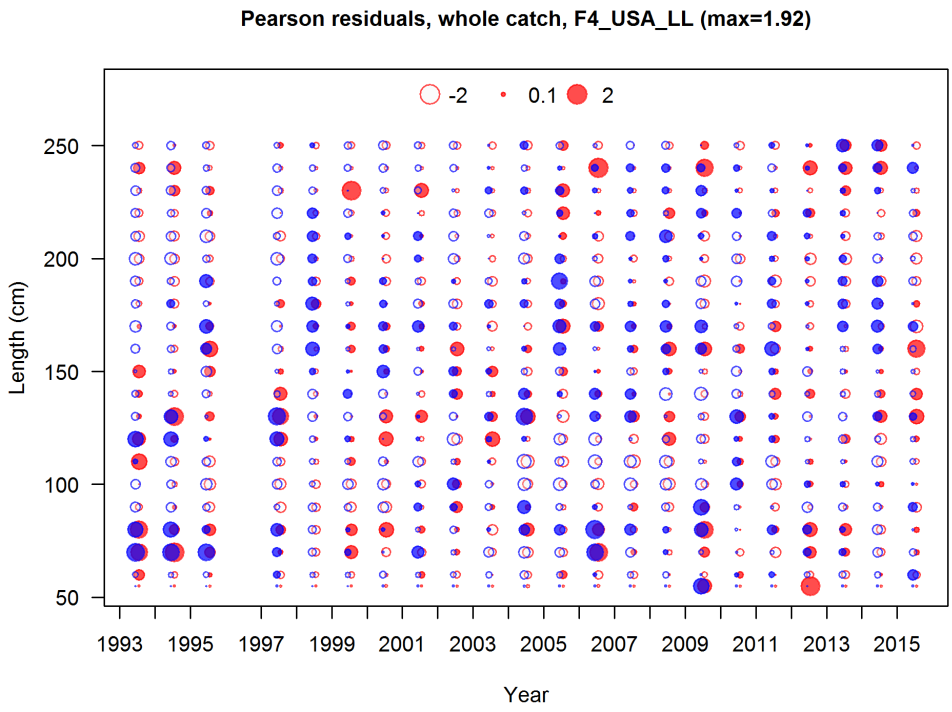
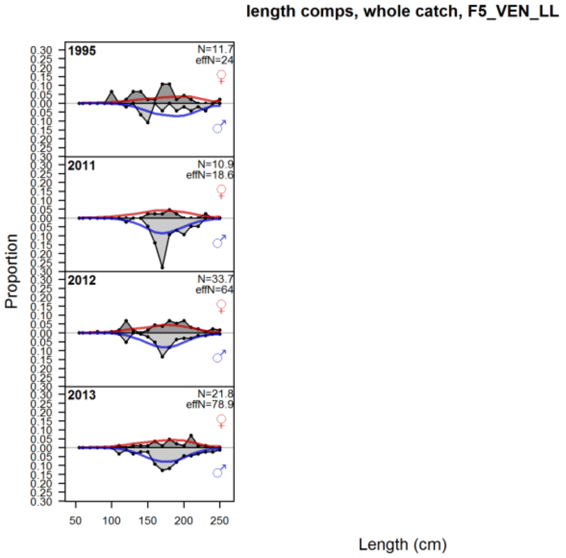


Figure B.1. Continued.



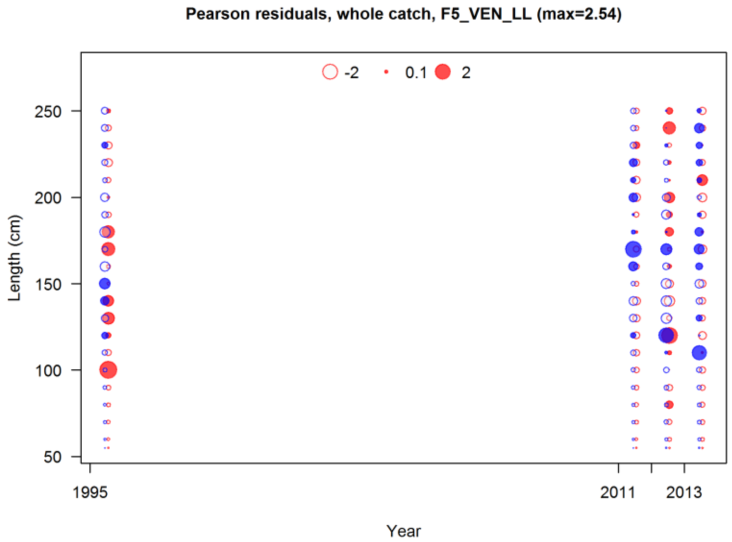


Figure B.1. Continued.

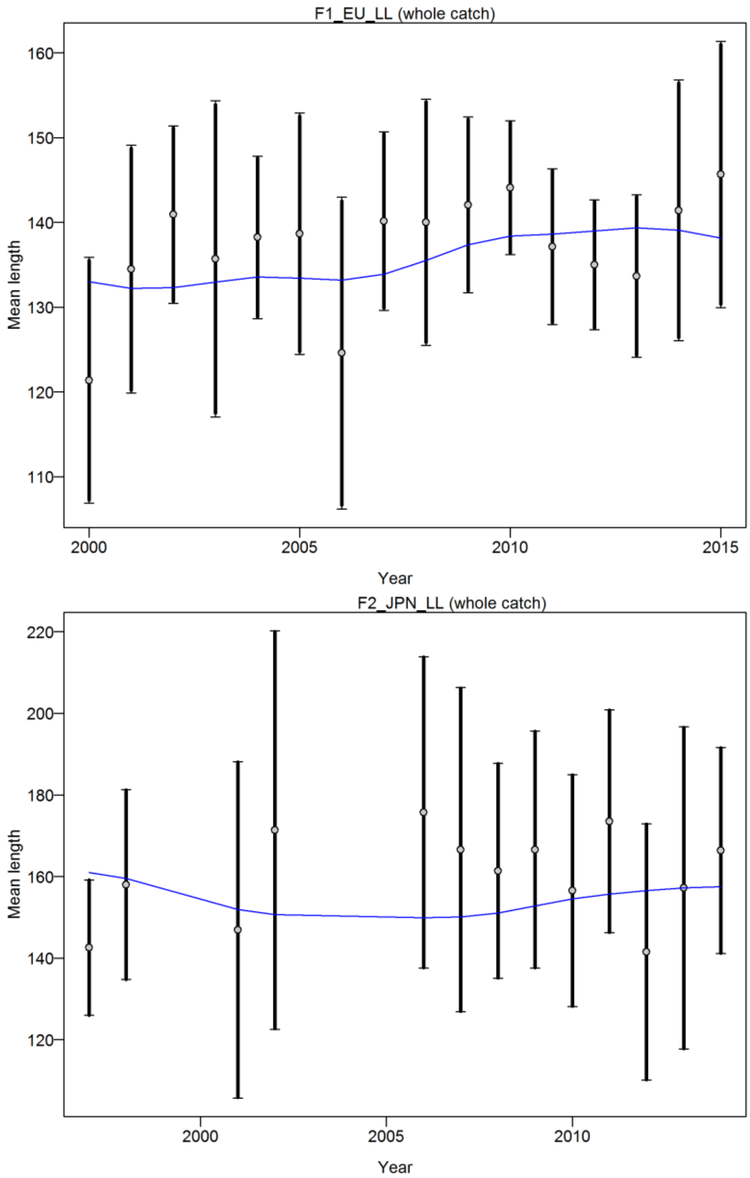


Figure B.2. Observed mean length (cm FL, open circle and 95% confidence intervals) and predicted mean length (blue line) by fleet (as defined in **Table 1** of the main document) obtained for the final SS3 model run; Confidence intervals are calculated using the input effective sample size (N) obtained from the Francis Method (Stage 2) as described in the main document and should include the predicted (blue line) mean annual length composition in about 95% of the observations (years). Years with total number of sharks measured < 30 were excluded from the fit (input sample sizes of raw length data are provided in **Table 5** of the main document).

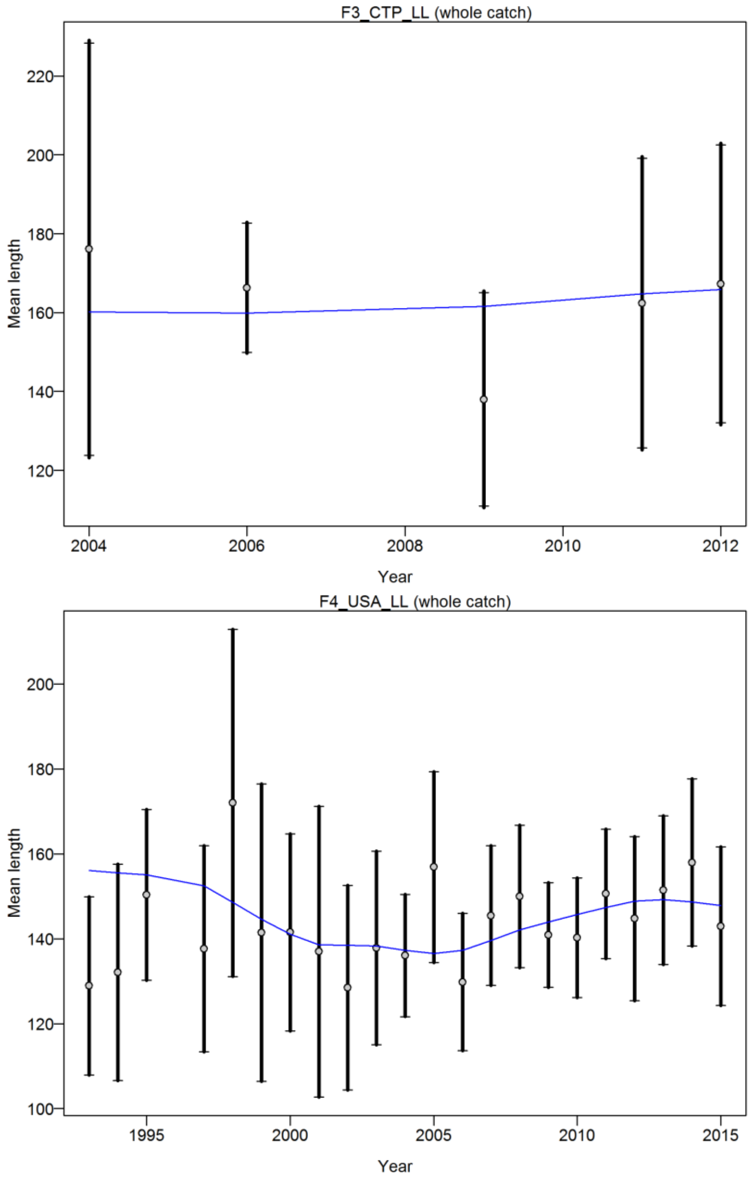


Figure B.2. Continued.

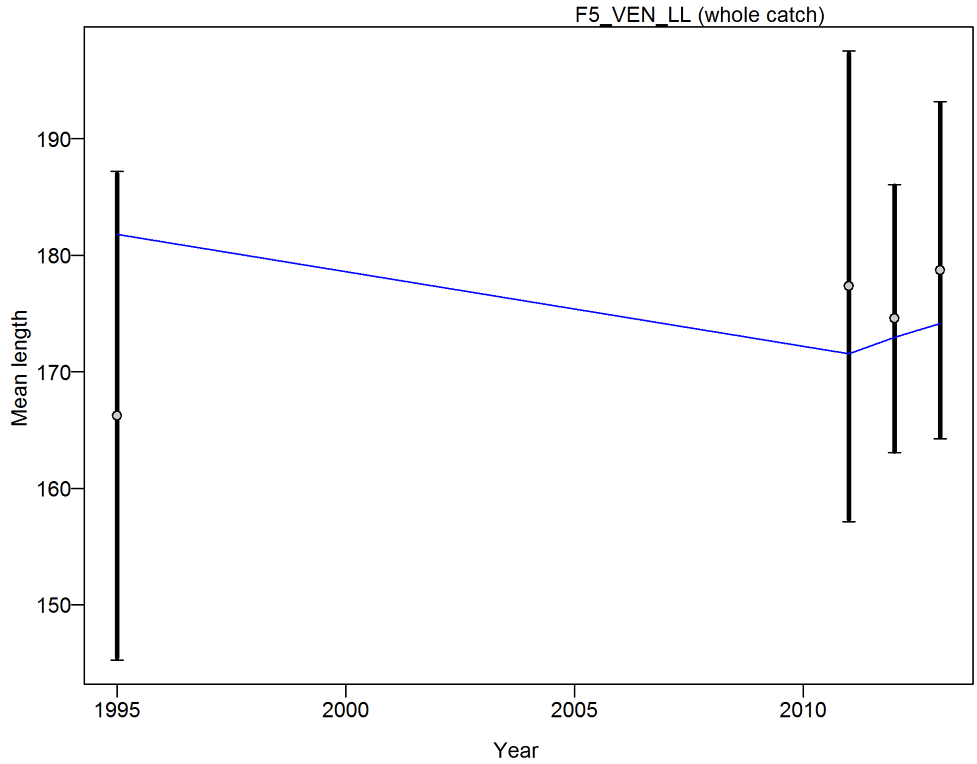


Figure B.2. Continued.

Appendix C. Additional Length Composition Data Available for Fleet F1.

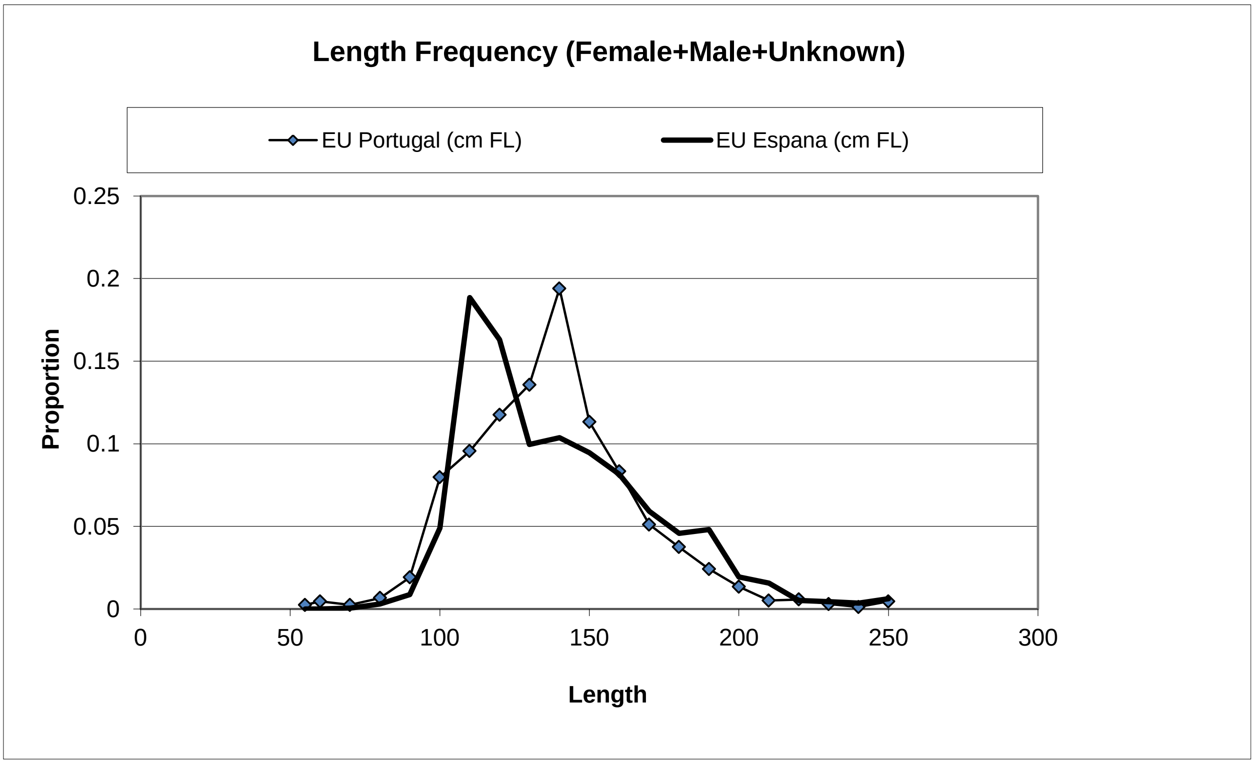


Figure C.1. Additional length composition data available for fleet F1 from EU España were not included in the current model due to time constraints.