Example of a Stock Synthesis projection approach at alternative fixed total allowable catch (TAC) limits implemented for three previously completed North Atlantic shortfin mako Stock Synthesis model runs

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EXAMPLE OF A STOCK SYNTHESIS PROJECTION APPROACH AT ALTERNATIVE FIXED TOTAL ALLOWABLE CATCH (TAC) LIMITS IMPLEMENTED FOR THREE PREVIOUSLY COMPLETED NORTH ATLANTIC SHORTFIN MAKO STOCK SYNTHESIS MODEL RUNS

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SUMMARY

Projections were implemented for three North Atlantic shortfin mako shark Stock Synthesis model runs previously presented to the ICCAT Shark Working Group during the 2017 ICCAT Shortfin Mako Assessment Meeting. Projections resulted in continued short term population declines, regardless of the TAC level, because it took many years for the surviving recruits to reach maturity (female age at 50% maturity = 21 yr) and begin to contribute to the spawning stock size. MCMC Kobe II risk matrix probabilities indicated that projections at a fixed annual TAC limit of between 800 – 900 t resulted in ≥ 50% probability of being in the Kobe green zone (the joint probability of $F < F_{MSY}$ and $SSF > SSF_{MSY}$) by 2070 (two generations) for preliminary model runs 1 and 2. In contrast, projections at a fixed annual TAC limit of 800 t resulted in the spawning stock size stabilizing below the level required to return the stock to a size that could support MSY by 2070 for model run 3, the base Stock Synthesis model run resulting from the 2017 meeting.

RÉSUMÉ

Des projections ont été mises en œuvre pour trois scénarios du modèle Stock Synthèse pour le requin-taupe bleu de l'Atlantique Nord, précédemment présentés au groupe d'espèces sur les requins de l'ICCAT lors de la réunion d'évaluation 2017 du requin-taupe bleu de l'ICCAT. Les projections ont entraîné la poursuite de la chute de la population à court terme, indépendamment du niveau du TAC, car il a fallu de nombreuses années pour que les recrues survivantes arrivent à maturité (âge des femelles à 50% de maturité = 21 ans) et commencent à contribuer à la taille du stock reproducteur. Les probabilités de la MCMC de la matrice de risque de Kobe 2 indiquaient que les projections à une limite annuelle fixe du TAC comprise entre 800 et 900 t aboutissaient à une probabilité ≥ 50% de se trouver dans la zone verte de Kobe (probabilité conjointe de $F < F_{PME}$ et $SSF > SSF_{PME}$) d'ici 2070 (deux générations) pour les scénarios préliminaires 1 et 2 des modèles. En revanche, les projections à une limite annuelle fixe de TAC de 800 t ont permis de stabiliser la taille du stock reproducteur au-dessous du niveau requis pour ramener le stock à une taille suffisante pour soutenir la PME d'ici 2070 pour le scénario 3 du modèle, le scénario de base du modèle Stock Synthèse résultant de la réunion de 2017.

RESUMEN

Se implementaron proyecciones para tres ensayos del modelo Stock Synthesis para el marrajo dientuso del Atlántico norte presentados anteriormente al Grupo de especies de tiburones de ICCAT durante la reunión de evaluación del stock de marrajo dientuso de ICCAT de 2017. Las proyecciones dieron como resultado descensos continuos a corto plazo de la población, independientemente del nivel del TAC, porque a los reclutas supervivientes les llevó varios años llegar a la madurez (edad de 50 % de madurez de las hembras = 21 años) y comenzar a contribuir al tamaño del stock reproductor. Las probabilidades de la MCMC de la matriz de riesgo de Kobe II indicaban que las proyecciones con un límite de TAC anual fijado de entre 800-900 t daban lugar a un ≥ 50% de probabilidades de encontrarse en la zona verde de Kobe

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(la probabilidad conjunta de que F < F_{RMS} y SSF > SSF_{RMS}) antes de 2070 (dos generaciones) para los ensayos preliminares 1 y 2 del modelo. Por el contrario, las proyecciones con un límite del TAC anual fijado en 800 t daban lugar a un tamaño del stock reproductor estabilizado por debajo del nivel requerido para devolver el stock a un tamaño que podría soportar el RMS antes de 2070 para el ensayo 3 del modelo, el ensayo base de Stock Synthesis de la reunión de 2017.

KEYWORDS

Stock assessment, Shark fisheries, Pelagic environment, Shortfin mako shark

1. Introduction

This working document was produced intersessionally in response to a request from the Shark Working Group (Group) to conduct projections for previously completed 2017 North Atlantic shortfin mako shark Stock Synthesis model runs (Anon. 2017b, their Section 4.3). One example of a Stock Synthesis projection approach is provided here using projections at alternative fixed total allowable catch (TAC) limits, adapted from a recent U.S. domestic sandbar shark stock assessment (Anon. 2017c and 2017d). The Stock Synthesis projection approach was originally implemented for a blue shark stock assessment conducted for the Indian Ocean Tuna Commission (Rice 2017; Anon. 2017a). A separate document is being developed which evaluates the effect of size regulations to protect immature North Atlantic shortfin mako (Kai *et al.* 2019) using the same Stock Synthesis projection approach.

The Stock Synthesis projection approach implemented here provides Markov Chain Monte Carlo (MCMC) projection probabilities at alternative fixed annual TAC levels, as described below, for use in plots and generating Kobe II risk matrix probabilities from the projections. The projection approach was adapted here to provide maximum likelihood estimate (MLE) projection probabilities, as described below, for use in generating approximate Kobe II risk matrix probabilities more quickly than can be obtained with MCMC.

The projection approach was implemented here for three previously completed North Atlantic shortfin mako shark Stock Synthesis model runs presented to the Group during the 2017 ICCAT Shortfin Mako Assessment Meeting (Anon. 2017b, their Section 4.3). Model runs 1 and 2 were preliminary Stock Synthesis model runs presented during the meeting (Courtney et al. 2017; Anon. 2017b, their Section 4.3). Model run 3 was the base Stock Synthesis model run resulting from the meeting (Anon. 2017b, their Section 4.3). The main difference between the Stock Synthesis model runs was that model run 3 utilized a low fecundity stock recruit relationship, while model runs 1 and 2 utilized the Beverton-Holt stock recruit relationship (Anon. 2017b, their Section 4.3).

2. Methods

2.1 Harvest policy and duration

Stock Synthesis projections (**Appendix D**) were implemented from 2016 to 2070. Generation time was about 25 years (Cortés 2017). Consequently, a time horizon of 50+ years (2016 – 2070) was assumed to include two generations. Catch data used in the Stock Synthesis model were from the C1 time series (Anon. 2017b), consistent with projections previously completed for North Atlantic shortfin mako shark using BSP2-JAGS (Anon. 2017b, their page 1469). Updated catch data for the years 2016 and 2017 were obtained from the 2018 SCRS report (SCRS 2018). Updated catch data for 2018 were not available, so the average catch in 2016 and 2017 was used for 2018. Fixed annual TAC levels were implemented in increments of 100 t ranging from 0 to 1,100 t (the value 1,100 t was near MSY) during the years 2019 to 2070. The proportion of catch among fleets in the projection period was assumed to be constant, and was calculated as the average annual proportion of catch by each fleet over the most recent 10 years (2006 – 2015 obtained from Stock Synthesis model output for catch in numbers; **Table 1**). Projected catch was allocated to each fleet based on these proportions (**Table 2**).

Stock Synthesis projections were modified in response to the following intersessional Group recommendations.

1) Use updated catch in the projections for the years 2016, 2017, and 2018. Because catch from 2018 was not available intersessionally; use the average of 2016 and 2017 for 2018.

Year	*Catch (t)*
2016[1]	3351
2017[1]	3112
2018 (Average of 2016 and 2017)	3231.5

[1]Obtained from the 2018 SCRS report by the Shark Working Group Chair

2) Conduct projections for two generations. Generation time was assumed to be 25 years. The projection period (55 years; 2016 – 2070) covered two generations (50 years) plus the intervening years 2016 – 2018 since the end year of data used in the 2017 assessment.
3) Save space in the Kobe II table produced from Stock Synthesis projections by reporting results for every year for the first 5 years, and then every 5 years after that.
4) Conduct projection scenarios in 100 t increments.
5) Evaluate the allocation of projected catch to each fleet under different combinations of catch in numbers and weight [This recommendation was not evaluated here due to time constraints].
6) Report back to the intersessional group with an updated draft after the changes above have been implemented, and then finalize projection methods.
7) Implement the projection approach developed here in a separate SCRS working document to evaluate the 2017 conservation measures recommended by ICCAT to reduce mortality for North Atlantic Shortfin Mako (ICCAT Rec. 17-08) for the 2017 base model run (model run 3).

2.2 Technical description

Projections were implemented with Stock Synthesis (Methot and Wetzel 2013, their Appendix A) at a pre-specified constant harvest policy. A fixed TAC was removed annually in the projection period, as described above. Annual fishing mortality was obtained during the projection period under the specified harvest policy and was compared to the fixed fishing mortality reference point threshold at MSY to determine the probability ($F < F_{MSY}$). Annual spawning stock size, calculated here as spawning stock fecundity (SSF; see Courtney et al. 2017), was obtained during the projection period under the specified harvest policy and was compared to the fixed spawning stock size benchmark quantity at MSY to determine the probability ($SSF > SSF_{MSY}$).

The Stock Synthesis projection approach implemented here (Rice 2017; Anon. 2017a, 2017c and 2017d) utilized estimated recruitment deviations in the projection period (stochastic recruitment) by treating the future projection period as part of the estimation period. Stochastic recruitment uncertainty in the projection period was implemented as an approximation of the recruitment uncertainty that would have been achieved by randomly sampling annual recruitment from a stock recruitment relationship with a statistical distribution (Maunder et al. 2006; Methot and Wetzel 2013). Because there were no data in the projection period, the estimated recruitment deviations shrank to zero, while the estimated variances of the recruitment deviations in the projection period were included in annual Kobe II risk matrix probabilities computed for fishing mortality (F/F_{MSY}) and spawning stock size (SSF/SSF_{MSY}) (See Maunder et al. 2006 and Methot and Wetzel 2013 for details).

Projections were carried out using the Stock Synthesis version 3.24U forecast module (Methot 2015). Stock Synthesis projection results were summarized using the R language for statistical computing version 3.4.4 (R Core Team 2018), and the R library package 'r4ss' version 1.34.0 (Taylor *et al*. 2018).

2.3 Kobe II risk matrix probabilities

MCMC was implemented in AD Model Builder (ADMB; Fournier et al. 2011; Methot 2015; e.g., Anon. 2017c, 2017d) for projections under each harvest policy with both a long and a short MCMC chain as described below. The long MCMC chain included 1 million draws with the first 10,000 draws removed (burn in = 10,000) and then saved every 1,000th draw (thin interval = 1,000). Kobe II risk matrix projection probabilities for $F < F_{MSY}$, $SSF > SSF_{MSY}$, and the joint probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$ were obtained as the median (0.5 quantile) and 95% credible interval (0.025, and 0.975 quantiles) of the thinned MCMC chain. In order to reduce run time, a shorter MCMC chain including 500,000 draws with a burn-in of 10,000 and thinning interval of 1,000 was also evaluated.

2.4 Approximate Kobe II risk matrix probabilities

Model run time for MCMC projections currently limits the number of model runs which can be evaluated using MCMC. In order to reduce run time, two maximum likelihood estimation (MLE) approaches based on a normal and a lognormal distribution, respectively, were also explored to obtain approximate probabilities for $F/F_{MSY} < 1$ and $SSF/\ SSF_{MSY} > 1$ during the projection period. Annual probabilities were calculated using the cumulative normal distribution in R statistical software (R Core Team 2018). Calculations used the Stock Synthesis ADMB output for the parameter estimate (mode) and standard deviation (std) of the derived quantities F/F_{MSY} and $SSF/\ SSF_{MSY}$. Cumulative probabilities of $F/F_{MSY} < 1$ and $SSF/\ SSF_{MSY} > 1$ were calculated analogously to a normal distribution confidence interval (CI) as the proportion of a normal distribution (X%) at the distance x*std from the mode (X% CI = mode ± x*std) for each year of the projection period. A lognormal distribution in F/F_{MSY} and $SSF/\ SSF_{MSY}$ was also evaluated.

3. Results

Kobe II risk matrix probabilities produced with the long MCMC chain (**Tables 3 – 5; Figures 1 – 3)** indicated that a TAC of between 800 – 900 t resulted in ≥ 50% probability of being in the Kobe green zone (the joint probability of $F < F_{MSY}$ and $SSF > SSF_{MSY}$) by 2070 for model runs 1 and 2 (e.g., see **Figures 4 and 5**). In contrast, a fixed annual TAC limit of 800 t for model run 3 indicated that the spawning stock size would likely stabilize below the level required to return the stock to a size that could support MSY by 2070 (**Figure 6**).

The changes made to the stock assessment models during the assessment (Anon. 2017b) may explain the observed differences in MCMC results obtained among the model runs. The result of setting male natural morality equal to that of females (model runs 2 and 3) was, among other things (Anon. 2017b), a higher selectivity of immature females in some fleets (**Figure 7** and **Figures E1 – E5**). This change resulted in a slight difference in MCMC Kobe II risk matrix results for model run 2 (**Table 4**) compared to model run 1 (**Table 3**). In contrast, the result of utilizing the low fecundity stock recruit relationship within the population dynamics for model run 3 was, among other things (Anon. 2017b), a relatively lower initial ratio for SSF/SSF_{MSY} and a relatively lower rate of recovery in SSF/SSF_{MSY} over time during the projection period (**Figures 1 – 3**). This change resulted in a large difference in MCMC Kobe II risk matrix results for model run 3 (**Table 5**) compared to model runs 1 and 2 (**Tables 3 and 4**), especially in the resulting probability that $SSF > SSF_{MSY}$ by 2070 which was much lower for model run 3.

Kobe II risk matrix probabilities produced with the shorter MCMC chain (**Tables A1 – A3)** were similar to those obtained above, especially near the median. In contrast, the approximate Kobe II risk matrix probabilities obtained with MLE and the cumulative normal distribution (**Tables B1 – B3**) differed somewhat from those obtained with MCMC. Kobe II risk matrix probabilities obtained with MLE indicated that a TAC of between 600 – 700 t resulted in ≥ 50% probability of $SSF > SSF_{MSY}$ by 2070 for model run 2, and there was no TAC level which resulted in ≥ 50% probability of $SSF > SSF_{MSY}$ by 2070 for model run 3. MLE probabilities of $F < F_{MSY}$ were slightly lower than MCMC for the all fixed TAC levels. The joint probability of $F < F_{MSY}$ and $SSF > SSF_{MSY}$ (Kobe green zone) was not available from MLE approach. Similar results were obtained for a lognormal distribution (**Tables C1 – C3**).

4. Discussion

All projection scenarios resulted in continued short term population declines regardless of the TAC used in future projections (**Figures 1 – 3)**. This result is consistent with the dome-shaped selectivity estimated in the Stock Synthesis model runs (Anon. 2017b). Dome-shaped selectivity at relatively small lengths (**Figure 7** and **Figures E1 – E5**) resulted in juveniles being removed beginning at age of first capture before reaching maturity. Consequently, spawning stock size in the projections continued to decline for many years after fishing pressure had been reduced because it took many years for the surviving recruits to reach maturity within the modeled population dynamics (female age at 50% maturity = 21 yr; Courtney et al. 2017, their Table 8) and begin to contribute to spawning stock fecundity (SSF) reported in the projections. A maturity ogive (♀) Mat=1/(1+exp(-27.81+9.332*MS)) was used in the Stock Synthesis assessment model (Courtney et al. 2017, their Table 6). Consequently, the female age at 50% maturity reported here (21 yr) is somewhat older than reported for female T50 (♀) and Tmat (♀) (18 yr) (Courtney et al. 2017, their Table 6).
The MSY obtained from Stock Synthesis model runs 1, 2, and 3, as implemented here with projections, was 1095 ± 43.1 t, 1063 ± 39.2 t, and 1019 ± 34.9 t (mode ± SE), respectively. These values were comparable to, but slightly

larger than, those obtained from Stock Synthesis during the assessment meeting for model runs 1 and 3, which were 1075 ± 40.6 t and 1004 ± 33.3 t (mode ± SE), respectively (e.g., see Courtney et al. 2017, their Table 13; Anon. 2017b, their Table 6). The slight differences in MSY may have resulted from some aspect of how the Stock Synthesis projections were implemented here. However, this was not evaluated explicitly. In contrast, activating the forecast module in Stock Synthesis with one forecast year resulted in only minimal differences between estimated model parameters (see Kai and Courtney 2019).

Our expectation was that MCMC projections for Stock Synthesis model runs 1, 2, and 3 at a fixed TAC near MSY would approach a 50% probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$ by 2070. This was the case for Stock Synthesis model runs 1 and 2. Projections with MCMC indicated that a TAC of between 800 – 900 t resulted in ≥ 50% probability of being in the Kobe green zone (the joint probability of $F < F_{MSY}$ and $SSF > SSF_{MSY}$) by 2070 for model runs 1 and 2 (**Tables 3 and 4**). In contrast, this was not the case for Stock Synthesis model run 3. Projections with MCMC indicated a TAC of between 0 and 100 t resulted in ≥ 50% probability of being in the Kobe green zone by 2070 for model run 3 (**Table 5**).

One explanation for this discrepancy may be that model run 3 had a relatively lower rate of recovery in SSF/SSF_{MSY} over time during the projection period (**Figures 1 – 3**) as a result of utilizing the low fecundity stock recruit relationship within the projected population dynamics. MCMC also resulted in slightly skewed distributions (median ± 95% credible interval) for parameter estimates of the derived quantities F/F_{MSY} and SSF/SSF_{MSY} relative to the Stock Synthesis (mode ± SE) (e.g., Courtney *et al.* 2019, their Figures 11 – 13). However, the skew does not appear to be large enough to explain the differences observed in Kobe II risk matrix results among model runs.

MCMC projections at fixed TAC values larger than MSY (>1,100 t) also sometimes produced anomalous results, including large differences in the trajectories of the MCMC chains over time. One explanation for the anomalous results at large TAC may be that the MCMC projections were not properly bounded, although this was not checked explicitly. Instead, the projection scenarios presented here were capped at 1,100 t because this value was near MSY.

An assumption made here was that a very long MCMC chain (one million iterations) with a very high thinning rate (every 1,000th iteration saved) and a very long burn-in (the first 10,000 iterations removed) was sufficient to obtain stable median values from the posterior distributions, which is the main probability of interest (50%) for Kobe II risk matrix. This assumption was consistent with results of MCMC diagnostics conducted separately on the same model runs implemented without projections, which indicated that while a relatively shorter MCMC chain length (500,000 iterations) was sufficient to obtain convergence for most of the derived quantities evaluated for model runs 1 and 2, a very long MCMC chain (one million iterations) was required to obtain convergence for most of the derived quantities evaluated for model run 3 (Courtney *et al.* 2019).

Run time with the long chain was about 21 hrs, and run time with the short chain was about 10 hrs, but run time also depended on the desktop or laptop computer used. In both cases, MCMC run time was reduced by using the same MCMC chain to project at each of the twelve alternative catch scenarios. This was accomplished by replacing the forcast.ss file and then re-running the same MCMC chain for each alternative catch scenario with the ADMB command “ss3.exe -mceval” (run time was about 5 min for each TAC level).

Kobe II risk matrix results produced with MLE assuming either a normal or lognormal distribution for both F/F_{MSY} and SFF/SSF_{MSY} resulted in lower probabilities than those obtained with MCMC. Consequently, Kobe II risk matrix results produced here with both the normal and the lognormal distribution should be interpreted cautiously as only a preliminary approximation exercise. In the future, use of a more sophisticated approximating distribution, such as the multivariate normal (e.g., Walter et al. 2019), may be required to obtain a better approximation to the MCMC results. Run time to obtain Stock Synthesis projection probabilities with MLE was about 15 minutes for each alternative TAC level and about 3 hr to evaluate 12 alternative TAC levels in 100 t increments.

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Table 1. Average proportion of total catch for each fleet (F1 – F12) in numbers (Panel A) and weight (Panel B) observed in the data during the years 2006 – 2015 as obtained from Stock Synthesis model output. Definitions for fleets (F1 – F12) used to represent time series of catch, surveys (S1 – S6) used to represent time series of relative abundance, and length composition data considered for use in the North Atlantic shortfin mako Stock Synthesis model runs (Panel C; Adapted from Courtney *et al.* 2017, their Table 1).

A. Proportion of catch in numbers by fleet[1].

Year	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	Total
2006	0.823	0.000	0.006	0.030	0.001	0.015	0.063	0.059	0.000	0.000	0.000	0.004	1.00
2007	0.836	0.014	0.001	0.043	0.001	0.012	0.038	0.031	0.000	0.000	0.011	0.012	1.00
2008	0.797	0.025	0.004	0.041	0.000	0.008	0.077	0.033	0.000	0.000	0.002	0.012	1.00
2009	0.764	0.016	0.012	0.039	0.004	0.009	0.107	0.028	0.003	0.000	0.003	0.015	1.00
2010	0.759	0.018	0.002	0.037	0.002	0.006	0.137	0.028	0.003	0.000	0.004	0.003	1.00
2011	0.753	0.010	0.009	0.044	0.003	0.008	0.108	0.037	0.010	0.008	0.003	0.007	1.00
2012	0.784	0.009	0.005	0.034	0.003	0.005	0.089	0.040	0.014	0.006	0.003	0.007	1.00
2013	0.676	0.007	0.002	0.041	0.001	0.007	0.179	0.047	0.015	0.015	0.002	0.009	1.00
2014	0.616	0.017	0.003	0.055	0.001	0.014	0.212	0.054	0.000	0.016	0.001	0.009	1.00
2015	0.520	0.011	0.002	0.082	0.001	0.020	0.267	0.046	0.000	0.046	0.000	0.004	1.00
Average proportion 2006 – 2015	0.7328	0.0128	0.0047	0.0447	0.0018	0.0105	0.1277	0.0402	0.0045	0.0091	0.0030	0.0081	1.000

[1]Fleets as defined in Panel C.

B. Proportion of catch in weight by fleet[1].

Year	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	Total
2006	0.795	0.000	0.011	0.036	0.002	0.018	0.061	0.071	0.000	0.000	0.000	0.006	1.00
2007	0.796	0.020	0.001	0.053	0.003	0.015	0.036	0.038	0.000	0.000	0.019	0.020	1.00
2008	0.760	0.034	0.007	0.051	0.000	0.010	0.073	0.041	0.000	0.000	0.004	0.019	1.00
2009	0.725	0.021	0.019	0.047	0.008	0.011	0.102	0.035	0.005	0.000	0.004	0.023	1.00
2010	0.730	0.024	0.003	0.047	0.005	0.008	0.132	0.035	0.006	0.000	0.006	0.005	1.00
2011	0.711	0.014	0.014	0.056	0.005	0.010	0.102	0.047	0.018	0.008	0.005	0.010	1.00
2012	0.740	0.012	0.008	0.044	0.005	0.006	0.084	0.051	0.025	0.006	0.005	0.012	1.00
2013	0.637	0.009	0.004	0.052	0.002	0.009	0.169	0.060	0.027	0.014	0.003	0.014	1.00
2014	0.579	0.024	0.005	0.071	0.003	0.018	0.199	0.069	0.000	0.015	0.002	0.015	1.00
2015	0.488	0.015	0.004	0.106	0.002	0.026	0.250	0.059	0.000	0.043	0.000	0.007	1.00
Average proportion 2006 – 2015	0.6963	0.0172	0.0076	0.0562	0.0033	0.0132	0.1209	0.0505	0.0082	0.0086	0.0048	0.0132	1.00

[1]Fleets as defined in Panel C.

Table 1. Continued.

C. Fleet and survey definitions.

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.
[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).
[3] Index S5 was obtained as CPUE in weight (CV = se on log scale).

Table 2. Projections were conducted at a fixed catch level during the years 2016 – 2018 (Panel A) and then at an alternative fixed annual total allowable catch (TAC) ranging from 0 – 1100 t in 100 t increments (alternative catch scenarios 1 – 12, respectively) during the years 2019 – 2070 (Panel B). Annual TAC was apportioned to the fleets F1 – F12 based on the average annual proportion of catch in numbers observed for these fleets during the years 2006 – 2015 (**Table 1**).

A. Fixed catch level (t) 2016 – 2018

Year	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	Catch
2016	2455.6	42.9	15.7	149.8	6.0	35.2	427.9	134.7	15.1	30.5	10.1	27.1	3350.7
2017	2280.5	39.8	14.6	139.1	5.6	32.7	397.4	125.1	14.0	28.3	9.3	25.2	3111.7
2018	2368.0	41.4	15.2	144.4	5.8	33.9	412.7	129.9	14.5	29.4	9.7	26.2	3231.2

B. Projected TAC (t) 2019 – 2070

Alternative TAC scenario	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	TAC
1	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
2	73.3	1.3	0.5	4.5	0.2	1.1	12.8	4.0	0.5	0.9	0.3	0.8	100
3	146.6	2.6	0.9	8.9	0.4	2.1	25.5	8.0	0.9	1.8	0.6	1.6	200
4	219.8	3.8	1.4	13.4	0.5	3.2	38.3	12.1	1.4	2.7	0.9	2.4	300
5	293.1	5.1	1.9	17.9	0.7	4.2	51.1	16.1	1.8	3.6	1.2	3.2	400
6	366.4	6.4	2.4	22.4	0.9	5.3	63.9	20.1	2.3	4.6	1.5	4.1	500
7	439.7	7.7	2.8	26.8	1.1	6.3	76.6	24.1	2.7	5.5	1.8	4.9	600
8	513.0	9.0	3.3	31.3	1.3	7.4	89.4	28.1	3.2	6.4	2.1	5.7	700
9	586.2	10.2	3.8	35.8	1.4	8.4	102.2	32.2	3.6	7.3	2.4	6.5	800
10	659.5	11.5	4.2	40.2	1.6	9.5	114.9	36.2	4.1	8.2	2.7	7.3	900
11	732.8	12.8	4.7	44.7	1.8	10.5	127.7	40.2	4.5	9.1	3.0	8.1	1000
12	806.1	14.1	5.2	49.2	2.0	11.6	140.5	44.2	5.0	10.0	3.3	8.9	1100

Table 3. Stock Synthesis model run 1 Markov Chain Monte Carlo (MCMC, long chain) Kobe II risk matrix for North Atlantic shortfin mako projection results: Probability that the fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; middle panel), and the probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$ (bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
600	0	0	0	97	99	100	100	100	100	100	100	100	100	100	100
700	0	0	0	82	92	100	100	100	100	100	100	100	100	100	100
800	0	0	0	53	71	98	99	97	95	96	97	98	98	98	99
900	0	0	0	26	41	88	90	85	80	79	83	87	87	87	87
1000*	0	0	0	10	19	63	68	57	49	49	53	55	57	56	58
1100	0	0	0	4	8	35	39	32	24	22	25	28	28	27	25

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	100	99	96	89	81	48	27	23	65	96	100	100	100	100	100
100	100	99	96	89	81	47	26	20	57	93	99	99	100	100	100
200	100	99	96	89	81	47	25	19	51	89	97	98	99	100	100
300	100	99	96	89	81	47	24	17	44	82	94	96	98	99	100
400	100	99	96	89	81	47	24	16	38	75	89	93	95	98	99
500	100	99	96	89	81	47	24	14	33	67	82	87	89	93	97
600	100	99	96	89	81	46	23	13	28	56	72	77	80	84	90
700	100	99	96	89	81	46	23	12	23	46	61	66	68	72	79
800*	100	99	96	89	81	46	22	11	19	38	52	54	56	59	63
900	100	99	96	89	81	45	22	11	17	31	39	42	42	45	48
1000	100	99	96	89	81	45	21	10	14	24	32	32	30	30	34
1100	100	99	96	89	81	45	21	9	13	19	25	23	22	20	21

*Largest TAC interval with ≥ 50% by 2070.

C. Probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	89	81	48	27	23	65	96	100	100	100	100	100
100	0	0	0	89	81	47	26	20	57	93	99	99	100	100	100
200	0	0	0	89	81	47	25	19	51	89	97	98	99	100	100
300	0	0	0	89	81	47	24	17	44	82	94	96	98	99	100
400	0	0	0	89	81	47	24	16	38	75	89	93	95	98	99
500	0	0	0	89	81	47	24	14	33	67	82	87	89	93	97
600	0	0	0	87	81	46	23	13	28	56	72	77	80	84	90
700	0	0	0	78	79	46	23	12	23	46	61	66	68	72	79
800*	0	0	0	52	65	46	22	11	19	38	52	54	56	59	63
900	0	0	0	26	39	45	22	11	17	31	39	42	42	45	48
1000	0	0	0	10	19	40	21	10	14	23	29	30	28	29	32
1100	0	0	0	4	8	28	19	9	11	13	17	18	16	15	16

*Largest TAC interval with ≥ 50% by 2070.

Table 4. Stock Synthesis model run 2 Markov Chain Monte Carlo (MCMC, long chain) Kobe II risk matrix for North Atlantic shortfin mako projection results: Probability that the fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), the probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; middle panel), and the probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$ (bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	99	100	100	100	100	100	100	100	100	100	100	100
600	0	0	0	94	98	100	100	100	100	100	100	100	100	100	100
700	0	0	0	74	88	100	100	100	99	99	99	100	100	100	100
800	0	0	0	46	63	97	97	95	91	91	95	96	98	97	97
900*	0	0	0	23	36	80	86	77	71	67	74	81	83	80	80
1000	0	0	0	9	18	55	58	50	40	38	44	50	53	51	48
1100	0	0	0	4	6	30	32	26	19	18	21	24	26	24	21

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	100	99	94	87	78	46	24	21	58	94	99	100	100	100	100
100	100	99	94	87	78	46	24	19	52	89	98	99	100	100	100
200	100	99	94	87	78	46	24	18	47	85	96	98	99	100	100
300	100	99	94	87	78	46	23	17	41	77	92	95	97	99	100
400	100	99	94	87	78	46	23	15	37	69	85	91	93	96	98
500	100	99	94	87	78	46	23	14	32	61	78	83	85	90	95
600	100	99	94	87	78	46	22	13	28	53	68	72	75	79	88
700	100	99	94	87	78	46	22	13	24	45	58	62	63	66	74
800*	100	99	94	87	78	46	22	12	20	37	49	52	51	54	59
900	100	99	94	87	78	46	21	11	17	30	39	41	40	41	44
1000	100	99	94	87	78	45	21	10	14	25	31	32	30	30	32
1100	100	99	94	87	78	45	20	10	12	20	25	24	21	20	21

*Largest TAC interval with ≥ 50% by 2070.

C. Probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	87	78	46	24	21	58	94	99	100	100	100	100
100	0	0	0	87	78	46	24	19	52	89	98	99	100	100	100
200	0	0	0	87	78	46	24	18	47	85	96	98	99	100	100
300	0	0	0	87	78	46	23	17	41	77	92	95	97	99	100
400	0	0	0	87	78	46	23	15	37	69	85	91	93	96	98
500	0	0	0	87	78	46	23	14	32	61	78	83	85	90	95
600	0	0	0	84	78	46	22	13	28	53	68	72	75	79	88
700	0	0	0	72	76	46	22	13	24	45	58	62	63	66	74
800*	0	0	0	45	59	46	22	12	20	37	49	52	51	54	59
900	0	0	0	23	36	44	21	11	17	30	38	41	40	41	44
1000	0	0	0	9	18	38	20	10	13	22	28	30	28	28	29
1100	0	0	0	4	6	25	16	9	9	12	16	17	16	15	14

*Largest TAC interval with ≥ 50% by 2070.

Table 5. Stock Synthesis model run 3 Markov Chain Monte Carlo (MCMC, long chain) Kobe II risk matrix for North Atlantic shortfin mako projection results: Probability that the fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), the probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; middle panel), and the probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$ (bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	91	97	100	100	100	100	100	99	100	100	100	100
600	0	0	0	65	78	99	99	96	91	90	93	94	94	92	91
700*	0	0	0	31	45	87	85	75	64	60	65	68	70	63	64
800	0	0	0	11	20	55	55	43	32	28	31	36	36	32	27
900	0	0	0	4	7	25	25	17	12	10	11	15	12	11	9
1000	0	0	0	1	2	10	8	6	4	2	3	5	4	3	3
1100	0	0	0	0	0	3	2	2	1	1	1	1	1	1	1

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0*	24	12	6	3	2	1	0	0	1	9	20	26	33	45	61
100	24	12	6	3	2	1	0	0	1	6	14	19	23	32	46
200	24	12	6	3	2	1	0	0	1	4	10	13	14	21	31
300	24	12	6	3	2	1	0	0	1	2	6	8	9	12	21
400	24	12	6	3	2	1	0	0	0	2	4	6	6	7	12
500	24	12	6	3	2	1	0	0	0	2	3	3	4	4	6
600	24	12	6	3	2	1	0	0	0	1	2	2	2	2	3
700	24	12	6	3	2	1	0	0	0	1	1	2	1	2	2
800	24	12	6	3	2	1	0	0	0	1	1	1	1	1	1
900	24	12	6	3	2	1	0	0	0	0	1	1	0	0	1
1000	24	12	6	3	2	1	0	0	0	0	0	0	0	0	0
1100	24	12	6	3	2	1	0	0	0	0	0	0	0	0	0

*Largest TAC interval with ≥ 50% by 2070.

C. Probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0*	0	0	0	3	2	1	0	0	1	9	20	26	33	45	61
100	0	0	0	3	2	1	0	0	1	6	14	19	23	32	46
200	0	0	0	3	2	1	0	0	1	4	10	13	14	21	31
300	0	0	0	3	2	1	0	0	1	2	6	8	9	12	21
400	0	0	0	3	2	1	0	0	0	2	4	6	6	7	12
500	0	0	0	3	2	1	0	0	0	2	3	3	4	4	6
600	0	0	0	3	2	1	0	0	0	1	2	2	2	2	3
700	0	0	0	3	2	1	0	0	0	1	1	2	1	2	2
800	0	0	0	3	2	1	0	0	0	1	1	1	1	1	1
900	0	0	0	2	2	1	0	0	0	0	1	1	0	0	1
1000	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
1100	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

*Largest TAC interval with ≥ 50% by 2070.

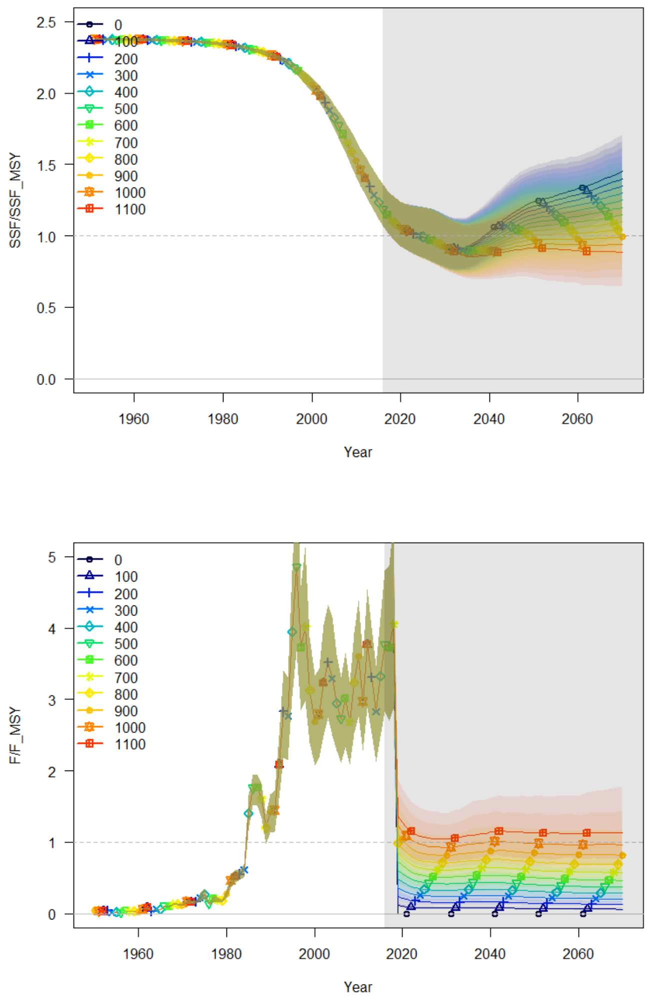


Figure 1. Stock Synthesis model run 1 projections (shaded area) under fixed total allowable catch (TAC 0 – 1100 t), as described above, for the derived quantities SSF/SSF_{MSY} (upper panel) and F/F_{MSY} (lower panel). Each line is the 0.5 quantile (median) and each shaded interval is the 95% credible interval between the 0.025 and 0.975 quantiles obtained from the long Markov Chain Monte Carlo (MCMC) chain, as described above.

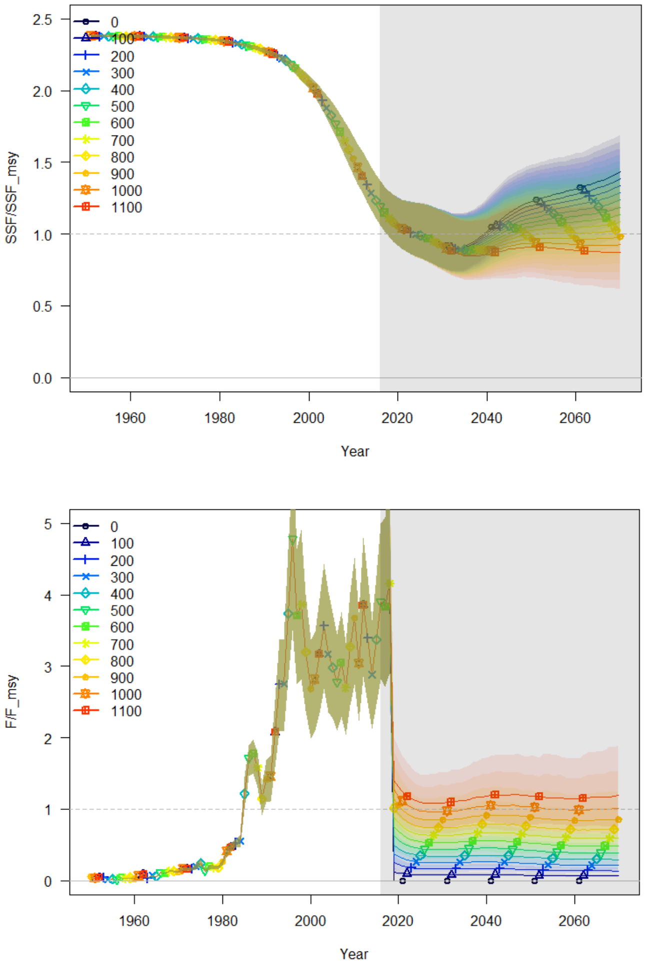


Figure 2. Stock Synthesis model run 2 projections (shaded area) under fixed total allowable catch (TAC 0 – 1100 t), as described above, for the derived quantities SSF/SSF_{MSY} (upper panel) and F/F_{MSY} (lower panel). Each line is the 0.5 quantile (median) and each shaded interval is the 95% credible interval between the 0.025 and 0.975 quantiles obtained from the long Markov Chain Monte Carlo (MCMC) chain, as described above.

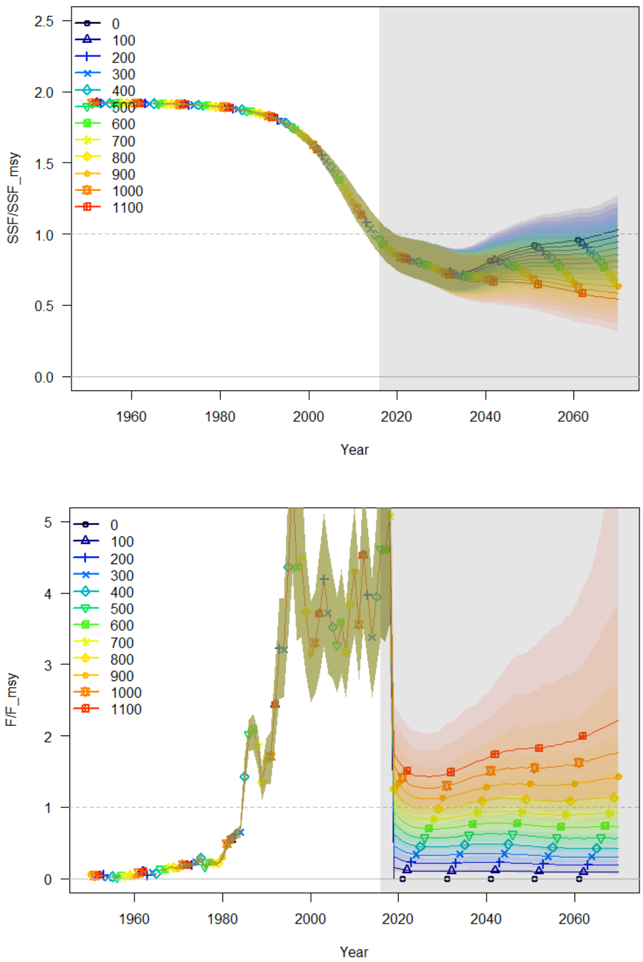


Figure 3. Stock Synthesis model run 3 projections (shaded area) under fixed total allowable catch (TAC 0 – 1100 t), as described above, for the derived quantities SSF/SSF$_{MSY}$ (upper panel) and F/F$_{MSY}$ (lower panel). Each line is the 0.5 quantile (median) and each shaded interval is the 95% credible interval between the 0.025 and 0.975 quantiles obtained from the long Markov Chain Monte Carlo (MCMC) chain, as described above.

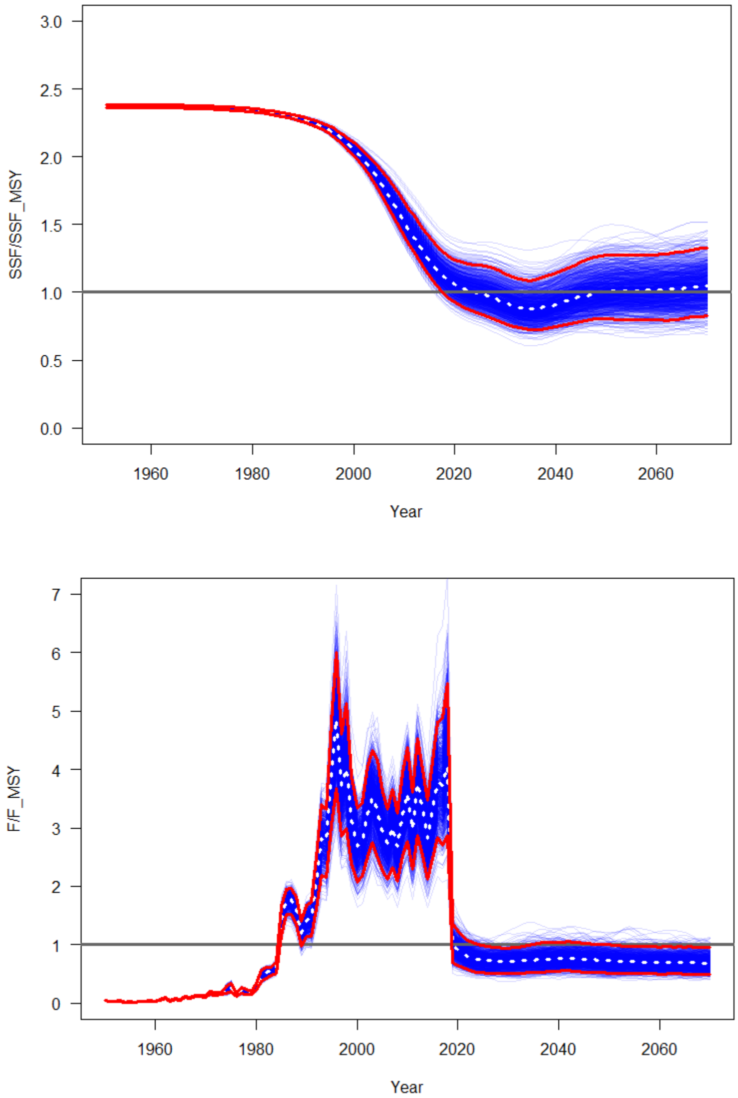


Figure 4. Stock Synthesis model run 1 projection results under the alternative constant catch scenario TAC = 800 t for the derived quantities SSF/SSF_{MSY} (upper panel) and F/F_{MSY} (lower panel). Blue lines are individual runs, the stippled line is the 0.5 quantile (median), and the red lines are the 0.025 and 0.975 quantiles (95% credible interval) obtained from a long Markov Chain Monte Carlo (MCMC) chain, as described above.

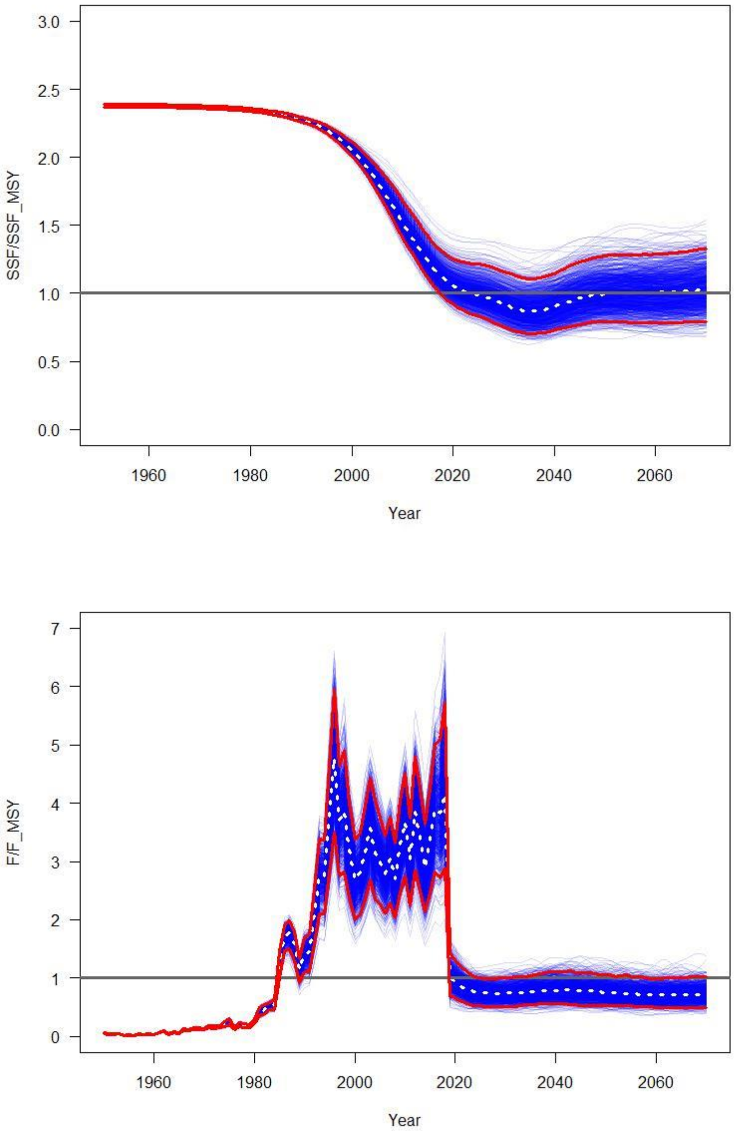


Figure 5. Stock Synthesis model run 2 projection results under the alternative constant catch scenario TAC = 800 t for the derived quantities SSF/SSF_{MSY} (upper panel) and F/F_{MSY} (lower panel). Blue lines are individual runs, the stippled line is the 0.5 quantile (median), and the red lines are the 0.025 and 0.975 quantiles (95% credible interval) obtained from a long Markov Chain Monte Carlo (MCMC) chain, as described above.

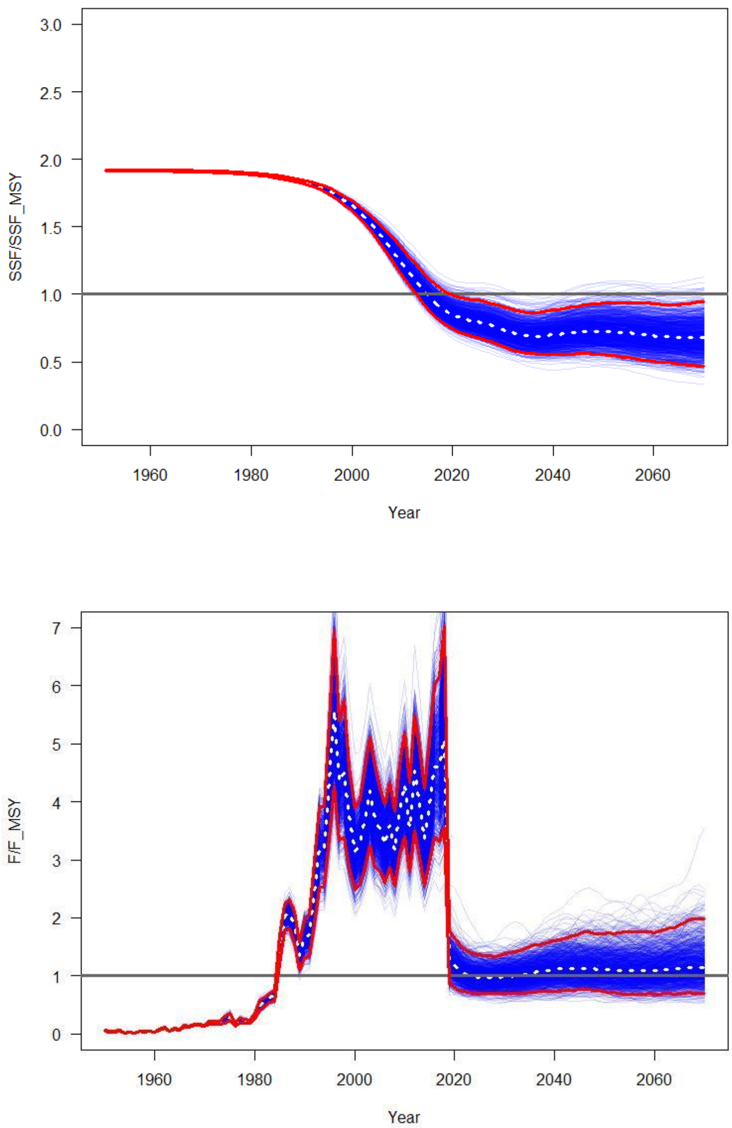
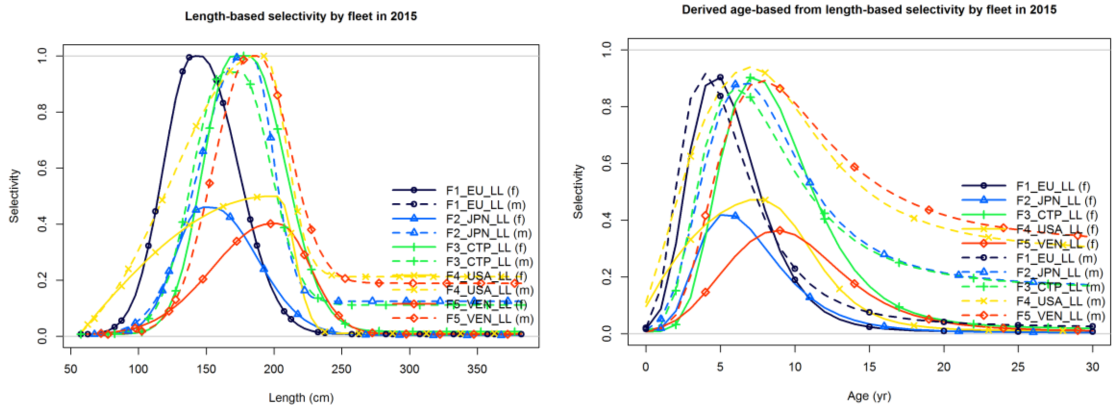
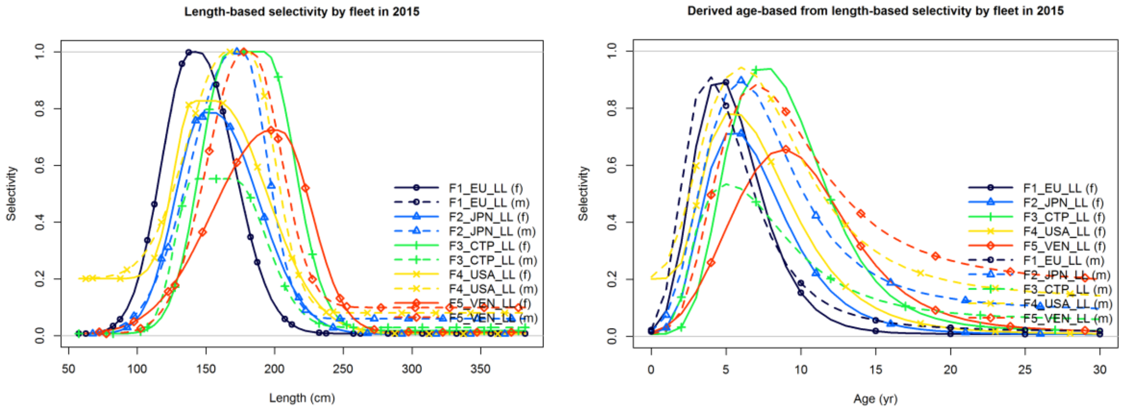


Figure 6. Stock Synthesis model run 3 projection results under the alternative constant catch scenario TAC = 800 t for the derived quantities SSF/SSF$_{MSY}$ (upper panel) and F/F$_{MSY}$ (lower panel). Blue lines are individual runs, the stippled line is the 0.5 quantile (median), and the red lines are the 0.025 and 0.975 quantiles (95% credible interval) obtained from a long Markov Chain Monte Carlo (MCMC) chain, as described above.

A. Stock Synthesis model run 1



B. Stock Synthesis model run 2



C. Stock Synthesis model run 3

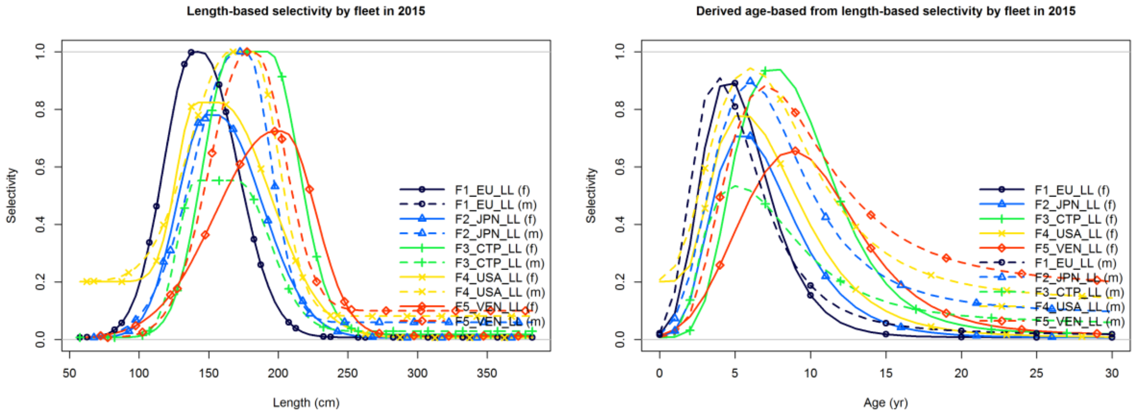


Figure 7. Fleets 1 – 5 (fleets as defined in **Table 1**) length based selectivity estimated for model run 1 (upper left Panel A) model run 2 (middle left Panel B) and model run 3 (lower left Panel C) along with the corresponding derived selectivity at age obtained by transforming selectivity at length through the sex specific von Bertalanffy growth curves for female (f) and male (m) North Atlantic shortfin mako (Courtney et al. 2017) (right panels) (also see **Appendix E**). Selectivity for the remaining fleets, which did not have length data, was set equal to (mirrored) one of the fleets F1 – F5 as defined in **Table 1.**

Appendix A. MCMC short chain results.

Table A1. Stock Synthesis model run 1 Markov Chain Monte Carlo (MCMC, short chain) Kobe II risk matrix for North Atlantic shortfin mako projection results: Probability that the fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; middle panel), and the probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$ (bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
600	0	0	0	97	100	100	100	100	100	100	100	100	100	100	100
700	0	0	0	82	92	100	100	100	100	100	100	100	100	100	100
800	0	0	0	53	72	99	99	97	95	96	97	99	99	98	99
900	0	0	0	25	39	89	91	86	80	79	84	88	88	87	89
1000*	0	0	0	10	17	66	69	58	48	46	52	54	55	55	57
1100	0	0	0	3	7	33	39	31	21	20	24	27	26	26	25

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	100	99	97	89	79	46	25	22	65	97	100	100	100	100	100
100	100	99	97	89	79	45	25	20	57	93	99	99	100	100	100
200	100	99	97	89	79	45	24	18	50	90	97	98	99	100	100
300	100	99	97	89	79	45	23	16	42	83	94	96	98	99	100
400	100	99	97	89	79	45	23	15	35	78	91	94	95	97	99
500	100	99	97	89	79	44	23	13	32	69	83	88	90	94	97
600	100	99	97	89	79	43	22	12	26	55	74	79	80	84	91
700	100	99	97	89	79	43	22	11	22	44	62	67	69	72	80
800*	100	99	97	89	79	43	21	10	18	36	51	53	55	58	62
900	100	99	97	89	79	42	21	9	16	30	38	40	41	43	47
1000	100	99	97	89	79	42	21	8	13	23	30	30	28	28	32
1100	100	99	97	89	79	41	20	7	11	17	23	22	20	19	19

*Largest TAC interval with ≥ 50% by 2070.

C. Probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	89	79	46	25	22	65	97	100	100	100	100	100
100	0	0	0	89	79	45	25	20	57	93	99	99	100	100	100
200	0	0	0	89	79	45	24	18	50	90	97	98	99	100	100
300	0	0	0	89	79	45	23	16	42	83	94	96	98	99	100
400	0	0	0	89	79	45	23	15	35	78	91	94	95	97	99
500	0	0	0	89	79	44	23	13	32	69	83	88	90	94	97
600	0	0	0	87	79	43	22	12	26	55	74	79	80	84	91
700	0	0	0	78	77	43	22	11	22	44	62	67	69	72	80
800*	0	0	0	51	66	43	21	10	18	36	51	53	55	58	62
900	0	0	0	25	38	42	21	9	16	30	38	40	40	42	47
1000	0	0	0	10	17	39	20	8	12	21	27	28	25	27	30
1100	0	0	0	3	7	26	18	7	9	12	17	17	15	15	16

*Largest TAC interval with ≥ 50% by 2070.

Table A2. Stock Synthesis model run 2 Markov Chain Monte Carlo (MCMC, short chain) Kobe II risk matrix for North Atlantic shortfin mako projection results: Probability that the fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), the probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; middle panel), and the probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$ (bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	99	100	100	100	100	100	100	100	100	100	100	100
600	0	0	0	94	98	100	100	100	100	100	100	100	100	100	100
700	0	0	0	75	89	100	100	100	100	100	100	100	100	100	100
800	0	0	0	46	64	98	98	97	92	92	96	97	98	98	98
900*	0	0	0	21	38	82	89	79	70	68	74	81	83	80	81
1000	0	0	0	9	17	54	57	50	42	39	43	49	52	48	49
1100	0	0	0	2	4	29	33	27	19	16	20	22	27	22	20

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	100	99	95	89	79	48	23	19	60	96	100	100	100	100	100
100	100	99	95	89	78	48	23	18	53	91	99	100	100	100	100
200	100	99	95	89	78	47	22	17	47	86	98	99	100	100	100
300	100	99	95	89	78	47	22	16	40	79	94	97	98	100	100
400	100	99	95	89	78	47	22	14	36	71	87	93	94	97	99
500	100	99	95	89	78	47	22	13	32	62	80	85	87	92	95
600	100	99	95	89	78	47	21	12	27	53	69	73	75	79	89
700	100	99	95	89	78	47	21	12	21	44	58	62	63	66	73
800*	100	99	95	89	78	47	20	11	19	36	48	52	52	54	58
900	100	99	95	89	78	47	19	10	16	29	39	41	41	42	45
1000	100	99	95	89	78	47	19	9	13	23	31	32	30	30	31
1100	100	99	95	89	78	46	18	9	12	18	24	23	19	17	19

*Largest TAC interval with ≥ 50% by 2070.

C. Probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	89	79	48	23	19	60	96	100	100	100	100	100
100	0	0	0	89	78	48	23	18	53	91	99	100	100	100	100
200	0	0	0	89	78	47	22	17	47	86	98	99	100	100	100
300	0	0	0	89	78	47	22	16	40	79	94	97	98	100	100
400	0	0	0	89	78	47	22	14	36	71	87	93	94	97	99
500	0	0	0	88	78	47	22	13	32	62	80	85	87	92	95
600	0	0	0	85	78	47	21	12	27	53	69	73	75	79	89
700	0	0	0	72	75	47	21	12	21	44	58	62	63	66	73
800*	0	0	0	46	59	47	20	11	19	36	48	52	52	54	58
900	0	0	0	21	36	45	19	10	16	29	38	41	41	42	44
1000	0	0	0	9	17	39	19	9	12	20	27	29	28	27	28
1100	0	0	0	2	4	24	15	8	8	10	14	15	15	13	12

*Largest TAC interval with ≥ 50% by 2070.

Table A3. Stock Synthesis model run 3 Markov Chain Monte Carlo (MCMC, short chain) Kobe II risk matrix for North Atlantic shortfin mako projection results: Probability that the fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), the probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; middle panel), and the probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$ (bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	89	96	100	100	100	99	99	99	100	100	100	100
600	0	0	0	59	73	99	98	95	91	88	93	93	93	90	89
700*	0	0	0	26	39	83	82	74	61	55	61	63	65	57	58
800	0	0	0	8	15	47	50	36	26	23	27	29	30	26	22
900	0	0	0	2	4	20	19	12	9	7	8	11	8	7	8
1000	0	0	0	1	1	6	5	4	3	1	2	3	3	2	1
1100	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0*	18	8	3	2	2	1	0	0	1	4	15	20	27	38	56
100	18	8	3	2	2	1	0	0	0	3	9	13	18	26	41
200	18	8	3	2	2	1	0	0	0	2	6	9	10	16	25
300	18	8	3	2	2	1	0	0	0	1	3	6	6	9	16
400	18	8	3	2	2	1	0	0	0	1	2	3	4	5	8
500	18	8	3	2	2	1	0	0	0	1	2	2	2	2	4
600	18	8	3	2	2	1	0	0	0	0	1	1	1	1	2
700	18	8	3	2	2	1	0	0	0	0	0	1	1	1	1
800	18	8	3	2	2	1	0	0	0	0	0	1	1	0	1
900	18	8	3	2	2	1	0	0	0	0	0	0	0	0	0
1000	18	8	3	2	2	1	0	0	0	0	0	0	0	0	0
1100	18	8	3	2	2	1	0	0	0	0	0	0	0	0	0

*Largest TAC interval with ≥ 50% by 2070.

C. Probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0*	0	0	0	2	2	1	0	0	1	4	15	20	27	38	56
100	0	0	0	2	2	1	0	0	0	3	9	13	18	26	41
200	0	0	0	2	2	1	0	0	0	2	6	9	10	16	25
300	0	0	0	2	2	1	0	0	0	1	3	6	6	9	16
400	0	0	0	2	2	1	0	0	0	1	2	3	4	5	8
500	0	0	0	2	2	1	0	0	0	1	2	2	2	2	4
600	0	0	0	2	2	1	0	0	0	0	1	1	1	1	2
700	0	0	0	2	2	1	0	0	0	0	0	1	1	1	1
800	0	0	0	2	2	1	0	0	0	0	0	1	1	0	1
900	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
1100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*Largest TAC interval with ≥ 50% by 2070.

Appendix B. Approximate Kobe II risk matrix obtained with maximum likelihood estimation (MLE) assuming a normal distribution for both F/F_{MSY} and SSF/SSF_{MSY}.

Table B1. Stock Synthesis model run 1 maximum likelihood estimate (MLE) Kobe II risk matrix for North Atlantic shortfin mako projection results assuming a normal distribution for both F/F_{MSY} and SSF/SSF_{MSY}: Probability that fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), and probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
600	0	0	0	96	100	100	100	100	100	100	100	100	100	100	100
700	0	0	0	73	90	100	100	100	100	100	100	100	100	100	100
800	0	0	0	40	61	99	99	97	94	94	97	98	99	99	99
900*	0	0	0	18	31	84	86	77	67	67	75	80	81	81	81
1000	0	0	0	7	14	54	56	45	34	34	40	44	45	44	44
1100	0	0	0	3	6	26	27	20	15	15	17	19	20	19	19

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	100	97	91	81	69	31	11	9	51	91	98	99	100	100	100
100	100	97	91	81	69	31	11	8	44	86	96	98	99	100	100
200	100	97	91	81	69	31	10	7	37	80	93	96	98	99	100
300	100	97	91	81	69	30	10	6	31	72	88	92	95	97	99
400	100	97	91	81	69	30	10	5	25	63	81	86	89	93	97
500	100	97	91	81	69	30	9	4	20	53	71	77	80	86	92
600	100	97	91	81	69	30	9	4	16	44	61	66	68	75	82
700	100	97	91	81	69	30	9	3	12	35	49	53	55	60	68
800*	100	97	91	81	69	29	9	3	9	26	38	40	40	44	51
900	100	97	91	81	69	29	8	2	7	19	28	29	28	30	34
1000	100	97	91	81	69	29	8	2	5	14	19	19	18	18	20
1100	100	97	91	81	69	29	8	2	4	9	13	12	10	10	11

*Largest TAC interval with ≥ 50% by 2070.

Table B2. Stock Synthesis model run 2 maximum likelihood estimate (MLE) Kobe II risk matrix for North Atlantic shortfin mako projection results assuming a normal distribution for both F/F_{MSY} and SSF/SSF_{MSY}: Probability that fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), and probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	99	100	100	100	100	100	100	100	100	100	100	100
600	0	0	0	85	97	100	100	100	100	100	100	100	100	100	100
700	0	0	0	50	73	100	100	99	98	99	100	100	100	100	100
800	0	0	0	22	38	93	94	87	78	80	87	91	93	93	93
900*	0	0	0	8	16	64	66	53	41	42	51	57	58	58	58
1000	0	0	0	3	6	32	32	23	17	17	21	24	25	24	24
1100	0	0	0	1	2	13	13	9	6	7	8	9	10	10	10

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	99	93	80	61	45	12	2	2	27	80	95	98	99	100	100
100	99	93	80	61	45	12	2	1	21	72	91	95	97	99	100
200	99	93	80	61	45	11	2	1	16	62	84	90	94	97	99
300	99	93	80	61	45	11	2	1	12	52	75	82	87	93	97
400	99	93	80	61	45	11	2	1	9	41	64	72	77	85	92
500	99	93	80	61	45	11	2	1	7	32	52	59	64	72	82
600*	99	93	80	61	45	11	2	1	5	23	40	45	48	56	67
700	99	93	80	61	45	11	2	0	3	16	29	32	34	39	49
800	99	93	80	61	45	11	2	0	2	11	19	21	21	25	31
900	99	93	80	61	45	11	2	0	2	7	12	13	12	14	17
1000	99	93	80	61	45	10	1	0	1	4	7	7	6	7	8
1100	99	93	80	61	45	10	1	0	1	3	4	4	3	3	4

*Largest TAC interval with ≥ 50% by 2070.

Table B3. Stock Synthesis Model run 3 maximum likelihood estimate (MLE) Kobe II risk matrix for North Atlantic shortfin mako projection results assuming a normal distribution for both F/F_{MSY} and SSF/SSF_{MSY}: Probability that fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), and probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	80	94	100	100	100	99	99	100	100	100	100	100
600*	0	0	0	37	57	97	96	88	75	76	82	85	84	81	78
700	0	0	0	13	22	70	65	47	33	33	38	41	39	36	34
800	0	0	0	4	7	31	26	17	11	11	13	15	14	13	12
900	0	0	0	1	2	10	9	5	4	4	5	6	6	6	6
1000	0	0	0	0	1	3	3	2	1	2	2	3	3	4	4
1100	0	0	0	0	0	1	1	1	1	1	1	2	3	3	5

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0*	3	0	0	0	0	0	0	0	0	1	3	5	8	16	33
100	3	0	0	0	0	0	0	0	0	0	1	2	4	8	18
200	3	0	0	0	0	0	0	0	0	0	1	1	1	3	8
300	3	0	0	0	0	0	0	0	0	0	0	0	1	1	3
400	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1
500	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
700	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1100	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*Largest TAC interval with ≥ 50% by 2070.

Appendix C. Approximate Kobe II risk matrix obtained with maximum likelihood estimation (MLE) assuming a lognormal distribution for both F/F_{MSY} and SSF/SSF_{MSY}.

Table C1. Stock Synthesis model run 1 maximum likelihood estimate (MLE) Kobe II risk matrix table for North Atlantic shortfin mako projection results assuming a lognormal distribution for both F/F_{MSY} and SSF/SSF_{MSY}: Probability that fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), and probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
600	0	0	0	94	99	100	100	100	100	100	100	100	100	100	100
700	0	0	0	72	88	100	100	100	99	99	100	100	100	100	100
800	0	0	0	40	60	97	98	95	91	92	95	97	97	97	98
900*	0	0	0	16	30	83	84	76	66	67	74	78	80	79	79
1000	0	0	0	5	11	54	56	44	34	34	40	44	45	44	43
1100	0	0	0	1	3	25	26	19	12	12	15	17	17	17	16

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	100	98	92	82	70	31	12	10	51	93	99	100	100	100	100
100	100	98	92	82	70	31	12	9	44	88	97	99	100	100	100
200	100	98	92	82	70	31	12	8	37	81	94	97	99	100	100
300	100	98	92	82	70	31	11	7	31	73	89	93	96	98	100
400	100	98	92	82	70	30	11	6	26	63	82	87	90	95	98
500	100	98	92	82	69	30	11	6	21	53	72	78	81	87	93
600	100	98	92	82	69	30	10	5	17	44	61	66	69	75	83
700	100	98	92	82	69	30	10	5	14	35	49	53	55	60	68
800*	100	98	92	82	69	30	10	4	11	27	38	40	41	44	51
900	100	98	92	82	69	30	10	4	8	20	28	29	28	30	34
1000	100	98	92	82	69	29	9	3	7	15	21	20	19	19	21
1100	100	98	92	82	69	29	9	3	5	11	14	14	12	12	13

*Largest TAC interval with ≥ 50% by 2070.

Table C2. Stock Synthesis model run 2 maximum likelihood estimate (MLE) Kobe II risk matrix for North Atlantic shortfin mako projection results assuming a lognormal distribution for both F/F_{MSY} and SSF/SSF_{MSY}: Probability that fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), and probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	98	100	100	100	100	100	100	100	100	100	100	100
600	0	0	0	83	95	100	100	100	100	100	100	100	100	100	100
700	0	0	0	50	72	99	99	98	97	97	99	99	100	100	100
800	0	0	0	20	38	91	92	85	76	78	85	89	90	90	91
900*	0	0	0	6	14	64	65	53	41	42	51	57	58	58	58
1000	0	0	0	1	4	31	31	22	15	15	19	23	23	23	22
1100	0	0	0	0	1	10	10	6	4	4	5	6	7	6	6

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	99	94	80	61	45	13	3	3	27	81	96	99	100	100	100
100	99	94	80	61	45	13	3	2	22	72	92	96	98	100	100
200	99	94	80	61	45	12	3	2	17	62	85	92	95	98	100
300	99	94	80	61	45	12	3	2	14	52	76	84	89	95	98
400	99	94	80	61	45	12	3	1	10	41	64	72	78	86	94
500	99	94	80	61	45	12	3	1	8	32	52	59	64	73	83
600*	99	94	80	61	45	12	3	1	6	24	40	45	48	56	67
700	99	94	80	61	45	12	3	1	5	17	29	32	34	40	49
800	99	94	80	61	45	12	3	1	3	12	20	22	22	25	31
900	99	94	80	61	45	12	2	1	3	9	14	14	14	15	19
1000	99	94	80	61	45	12	2	1	2	6	9	9	8	9	10
1100	99	94	80	61	45	11	2	1	1	4	6	6	5	5	6

*Largest TAC interval with ≥ 50% by 2070.

Table C3. Stock Synthesis Model run 3 maximum likelihood estimate (MLE) Kobe II risk matrix for North Atlantic shortfin mako projection results assuming a lognormal distribution for both F/F_{MSY} and SSF/SSF_{MSY}: Probability that fishing mortality (F) will be below the fishing mortality rate at MSY ($F < F_{MSY}$; top panel), and probability that the spawning stock fecundity (SSF) will exceed the level that will produce MSY ($SSF > SSF_{MSY}$; bottom panel).

A. Probability that $F < F_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
100	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
200	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
300	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100
400	0	0	0	99	100	100	100	100	100	100	100	100	100	100	100
500	0	0	0	79	91	100	100	99	98	98	99	99	99	99	99
600*	0	0	0	37	57	96	94	86	74	74	81	83	82	79	77
700	0	0	0	10	21	69	65	47	32	32	38	41	39	35	33
800	0	0	0	2	5	30	25	14	8	8	10	11	11	9	8
900	0	0	0	0	1	8	6	3	1	1	2	2	2	2	2
1000	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
1100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*Largest TAC interval with ≥ 50% by 2070.

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0*	4	1	0	0	0	0	0	0	0	1	4	6	9	17	33
100	4	1	0	0	0	0	0	0	0	1	2	3	5	9	19
200	4	1	0	0	0	0	0	0	0	0	1	2	2	5	10
300	4	1	0	0	0	0	0	0	0	0	1	1	1	2	5
400	4	1	0	0	0	0	0	0	0	0	0	0	1	1	2
500	4	1	0	0	0	0	0	0	0	0	0	0	0	0	1
600	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
700	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
800	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
900	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1100	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0

*Largest TAC interval with ≥ 50% by 2070.

Appendix D. Example of a Stock Synthesis forecast file (forecast.ss_new) used to implement projections from 2016 to 2070 for model run 1 under a constant annual TAC = 800 t.

C:\000\1004_ICCAT_SFM_2019\01_2019_Meeting\SSv324U_01_Projections\Projections_02_SS\2019_02_ATL_SMA_run_1_proj\2019_run_1_try_09_projections_ss\Projections\SMA_run_1_try_09_1\Grid1\9_TAC800
forecast.ss_new

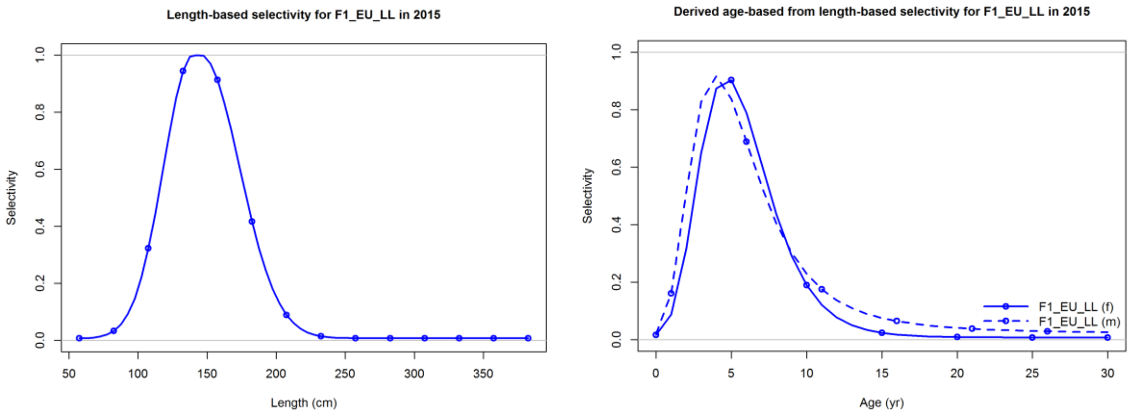
```
#V3.24U
#C SS3_Control_NA_SFM_2017_05.xlsx                                                    =
# for all year entries except rebuilder; enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
1 # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2 # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt); 4=set to F(endyr)
0.68894 # SPR target (e.g. 0.40)
0.368408 # Biomass target (e.g. 0.40)
#_Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_relF (enter actual year, or values of 0 or -integer to be rel. endyr)
 0 0 0 0 0 0
#  2015 2015 2015 2015 2015 2015 # after processing
1 #Bmark_relF_Basis: 1 = use year range; 2 = set relF same as forecast below
#
2 # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt); 4=Ave F (uses first-last relF yrs); 5=input annual F scalar
55 # N forecast years
1 # F scalar (only used for Do_Forecast==5)
#_Fcast_years:  beg_selex, end_selex, beg_relF, end_relF  (enter actual year, or values of 0 or -integer to be rel. endyr)
 0 0 0 0
#  2015 2015 2015 2015 # after processing
1 # Control rule method (1=catch=f(SSB) west coast; 2=F=f(SSB) )
1 # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40); (Must be > the no F level below)
0.1 # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
1 # Control rule target as fraction of Flimit (e.g. 0.75)
3 #_N forecast loops (1=OFL only; 2=ABC; 3=get F from forecast ABC catch with allocations applied)
3 #_First forecast loop with stochastic recruitment
0 #_Forecast loop control #3 (reserved for future bells&whistles)
0 #_Forecast loop control #4 (reserved for future bells&whistles)
0 #_Forecast loop control #5 (reserved for future bells&whistles)
2071  #FirstYear for caps and allocations (should be after years with fixed inputs)
0 # stddev of log(realized catch/target catch) in forecast (set value>0.0 to cause active impl_error)
0 # Do West Coast gfish rebuilder output (0/1)
1999 # Rebuilder:  first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
2016 # Rebuilder:  year for current age structure (Yinit) (-1 to set to endyear+1)
1 # fleet relative F:  1=use first-last alloc year; 2=read seas(row) x fleet(col) below
# Note that fleet allocation is used directly as average F if Do_Forecast=4
2 # basis for fcast catch tuning and for fcast catch caps and allocation  (2=deadbio; 3=retainbio; 5=deadnum; 6=retainnum)
# Conditional input if relative F choice = 2
# Fleet relative F:  rows are seasons, columns are fleets
#_Fleet:  F1_EU_LL F2_JPN_LL F3_CTP_LL F4_USA_LL F5_VEN_LL F6_CAN_LL F7_MOR_LL F8_USA_RR F9_BEL_LL
F10_MOR_PS F11_CPR_LL F12_OTH
#  0.520932 0.0160159 0.00233231 0.0779858 0.00191031 0.0192496 0.26692 0.0434458 0.000157099 0.0463058 0.000311851
0.00443423
# max totalcatch by fleet (-1 to have no max) must enter value for each fleet
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
# max totalcatch by area (-1 to have no max); must enter value for each fleet
 -1
# fleet assignment to allocation group (enter group ID# for each fleet, 0 for not included in an alloc group)
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
#_Conditional on >1 allocation group
# allocation fraction for each of: -1 allocation groups
# no allocation groups
660 # Number of forecast catch levels to input (else calc catch from forecast F)
-1 # code means to read fleet/time specific basis (2=dead catch; 3=retained catch; 99=F)  as below (units are from fleetunits; note new codes
in SSV3.20)
# Input fixed catch values
#Year Seas Fleet Catch(or_F) Basis
 2016 1 1 2455.61 2
 2016 1 2 42.8928 2
 2016 1 3 15.7497 2
 2016 1 4 149.79 2
 2016 1 5 6.0318 2
 2016 1 6 35.1855 2
 2016 1 7 427.923 2
 2016 1 8 134.71 2
 2016 1 9 15.0795 2
 2016 1 10 30.4941 2
 2016 1 11 10.053 2
 2016 1 12 27.1431 2
```

```
 2017 1 1 2280.47 2
 2017 1 2 39.8336 2
 2017 1 3 14.6264 2
 2017 1 4 139.106 2
 2017 1 5 5.6016 2
 2017 1 6 32.676 2
 2017 1 7 397.402 2
 2017 1 8 125.102 2
 2017 1 9 14.004 2
 2017 1 10 28.3192 2
 2017 1 11 9.336 2
 2017 1 12 25.2072 2
 2018 1 1 2368.04 2
 2018 1 2 41.3632 2
 2018 1 3 15.1881 2
 2018 1 4 144.448 2
 2018 1 5 5.8167 2
 2018 1 6 33.9308 2
 2018 1 7 412.663 2
 2018 1 8 129.906 2
 2018 1 9 14.5418 2
 2018 1 10 29.4066 2
 2018 1 11 9.6945 2
 2018 1 12 26.1751 2
 2019 1 1 586.24 2
 2019 1 2 10.24 2
 2019 1 3 3.76 2
 2019 1 4 35.76 2
 2019 1 5 1.44 2
 2019 1 6 8.4 2
 2019 1 7 102.16 2
 2019 1 8 32.16 2
 2019 1 9 3.6 2
 2019 1 10 7.28 2
 2019 1 11 2.4 2
 2019 1 12 6.48 2
 …
 2070 1 1 586.24 2
 2070 1 2 10.24 2
 2070 1 3 3.76 2
 2070 1 4 35.76 2
 2070 1 5 1.44 2
 2070 1 6 8.4 2
 2070 1 7 102.16 2
 2070 1 8 32.16 2
 2070 1 9 3.6 2
 2070 1 10 7.28 2
 2070 1 11 2.4 2
 2070 1 12 6.48 2
#
999 # verify end of input
```

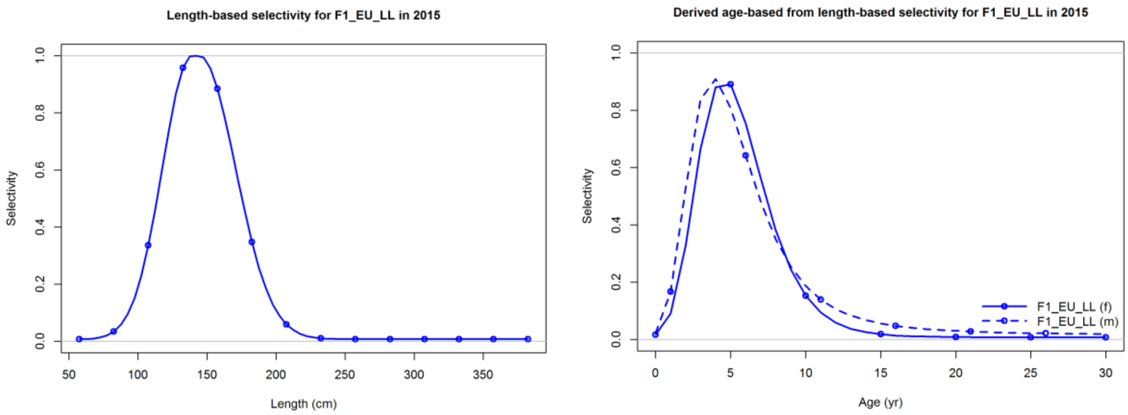
Appendix E. Estimated length based selectivity along with the corresponding selectivity at age.

Length based selectivity estimated in projections was plotted for fleets 1 – 5 (fleets as defined in **Table 1**) along with the corresponding derived selectivity at age obtained through the sex specific von Bertalanffy growth curves for female and male North Atlantic shortfin mako (Courtney et al. 2017) (**Figures E1 – E5**). Selectivity for the remaining fleets, which did not have length data, was set equal to (mirrored) one of the fleets F1-F5 as defined in **Table 1**.

A. Stock Synthesis model run 1



B. Stock Synthesis model run 2



C. Stock Synthesis model run 3

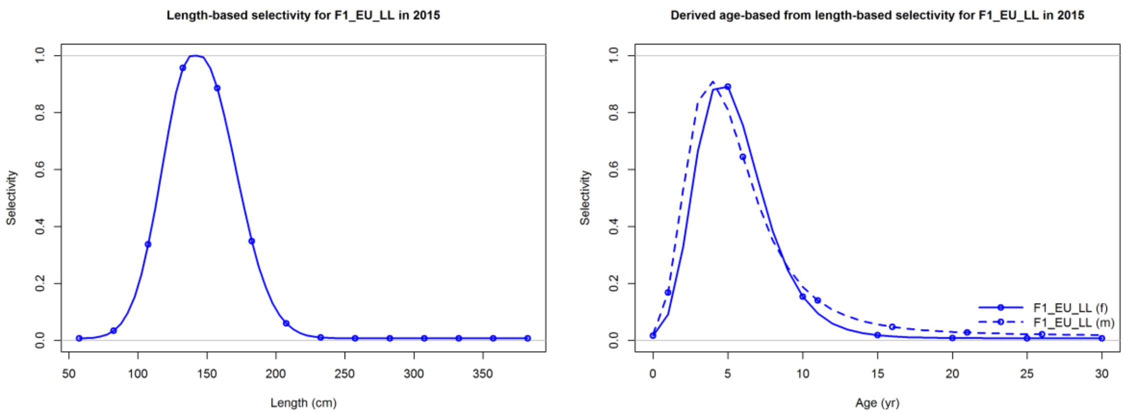
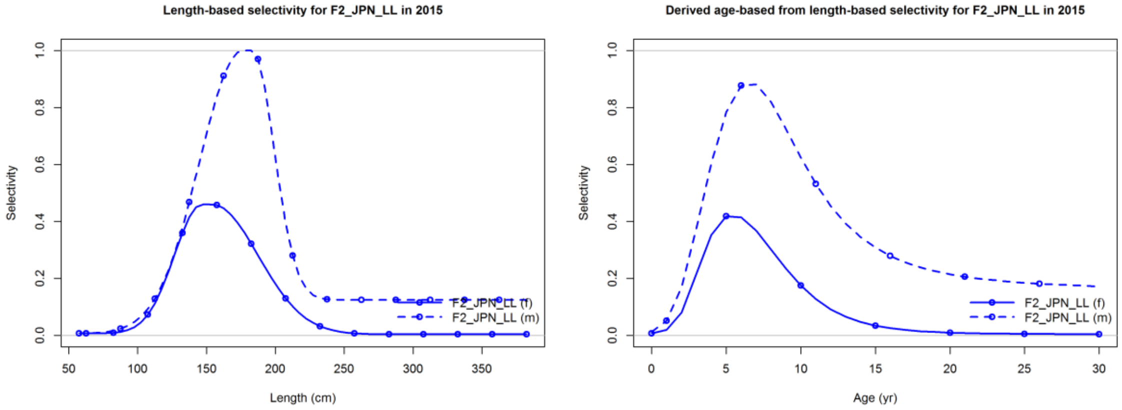
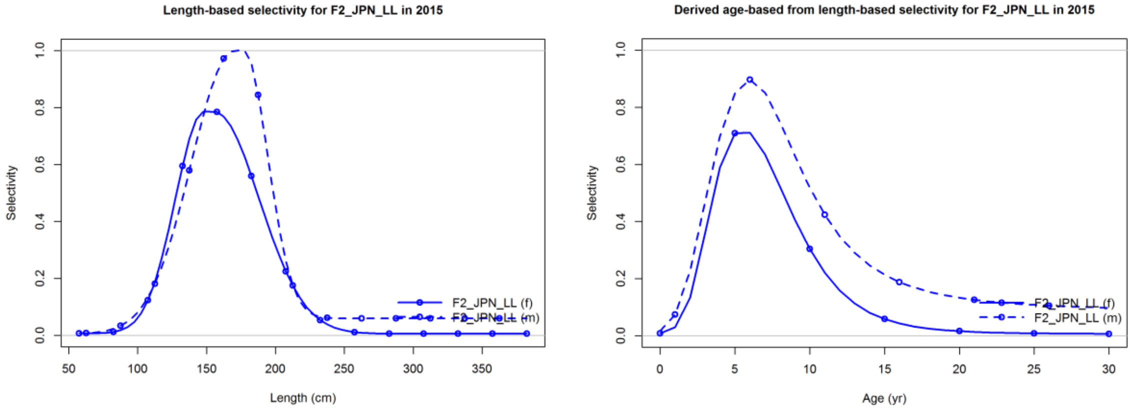


Figure E1. Fleet 1 (fleets as defined in **Table 1**) sex combined length based selectivity estimated for model run 1 (upper left Panel A) model run 2 (middle left Panel B) and model run 3 (lower left Panel C) along with the corresponding derived selectivity at age obtained by transforming selectivity at length through the sex specific von Bertalanffy growth curves for female (f) and male (m) North Atlantic shortfin mako (Courtney *et al*. 2017) (right panels).

A. Stock Synthesis model run 1



B. Stock Synthesis model run 2



C. Stock Synthesis model run 3

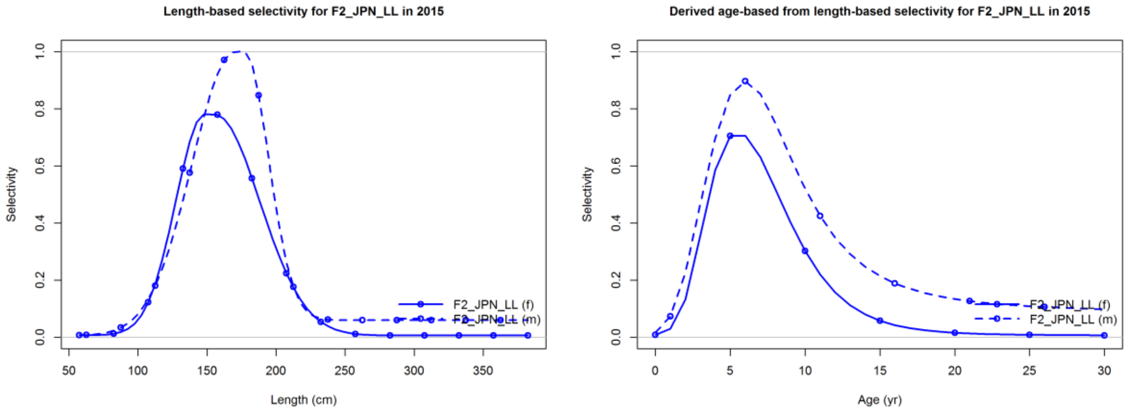
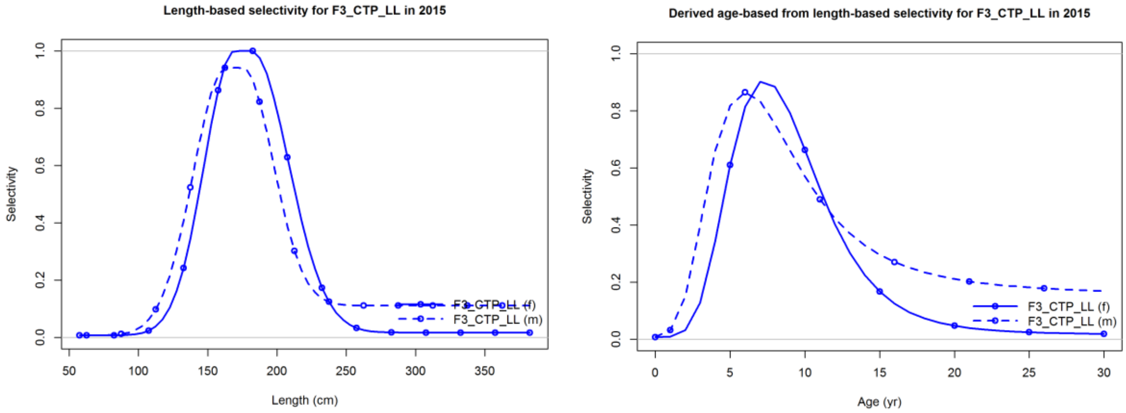
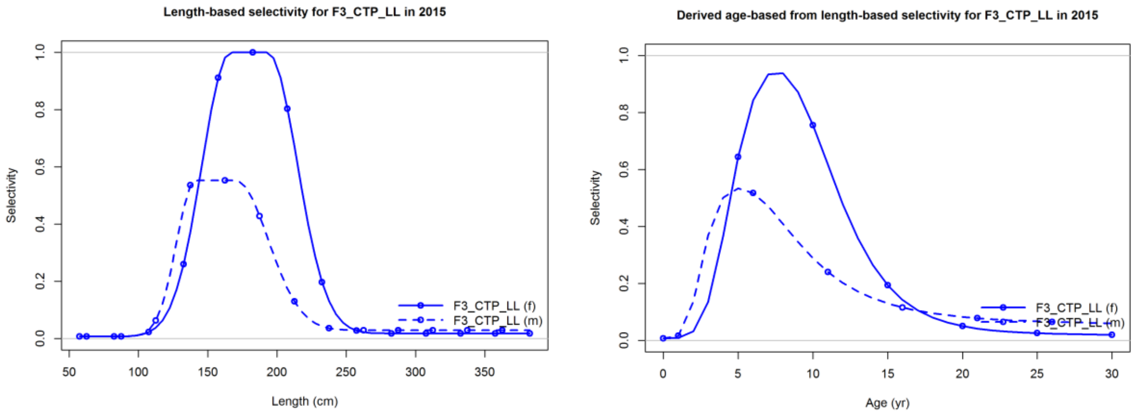


Figure E2. Fleet 2 (fleets as defined in **Table 1**) sex combined length based selectivity estimated for model run 1 (upper left Panel A) model run 2 (middle left Panel B) and model run 3 (lower left Panel C) along with the corresponding derived selectivity at age obtained by transforming selectivity at length through the sex specific von Bertalanffy growth curves for female (f) and male (m) North Atlantic shortfin mako (Courtney *et al.* 2017) (right panels).

A. Stock Synthesis model run 1



B. Stock Synthesis model run 2



C. Stock Synthesis model run 3

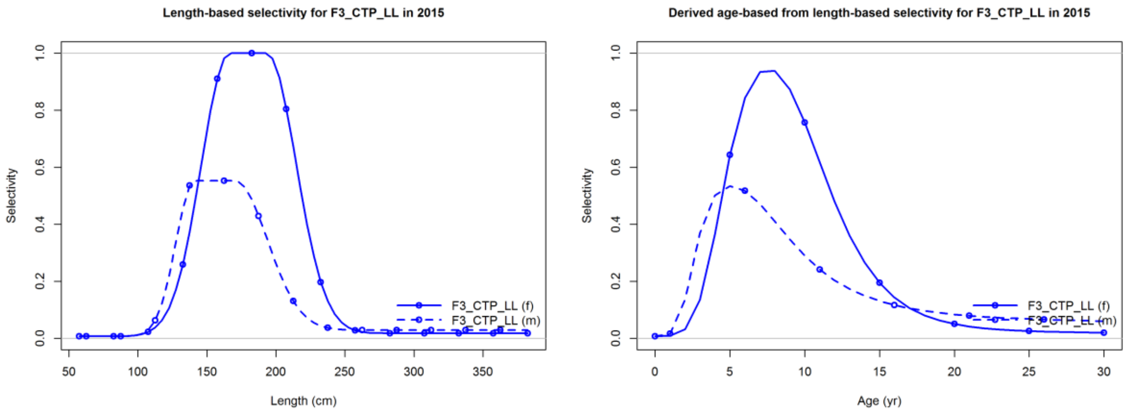
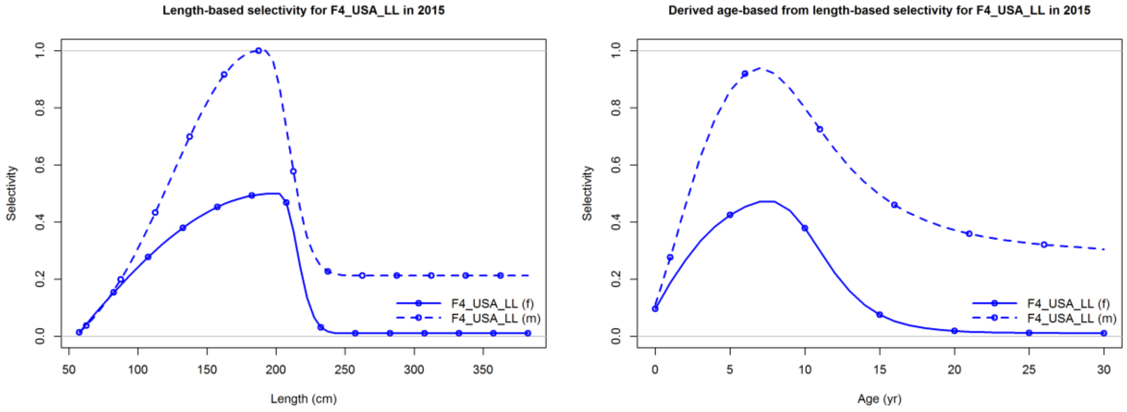
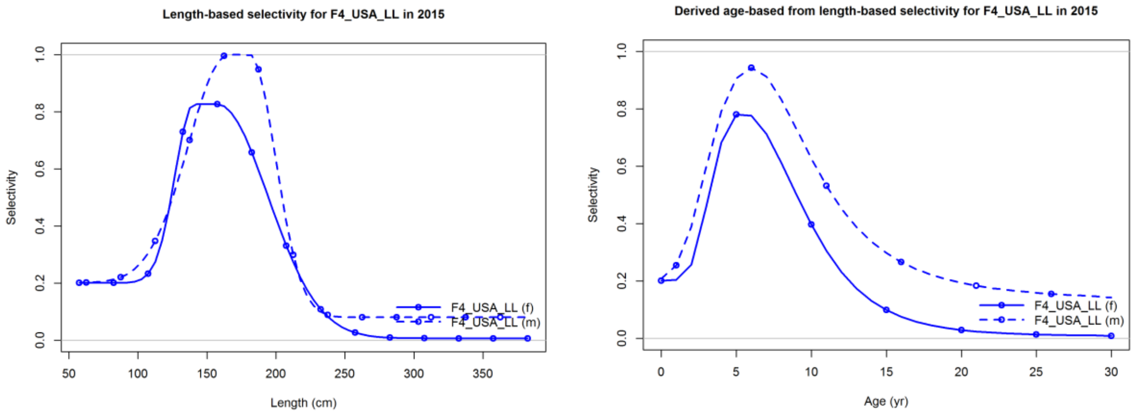


Figure E3. Fleet 3 (fleets as defined in **Table 1**) sex combined length based selectivity estimated for model run 1 (upper left Panel A) model run 2 (middle left Panel B) and model run 3 (lower left Panel C) along with the corresponding derived selectivity at age obtained by transforming selectivity at length through the sex specific von Bertalanffy growth curves for female (f) and male (m) North Atlantic shortfin mako (Courtney *et al.* 2017) (right panels).

A. Stock Synthesis model run 1



B. Stock Synthesis model run 2



C. Stock Synthesis model run 3

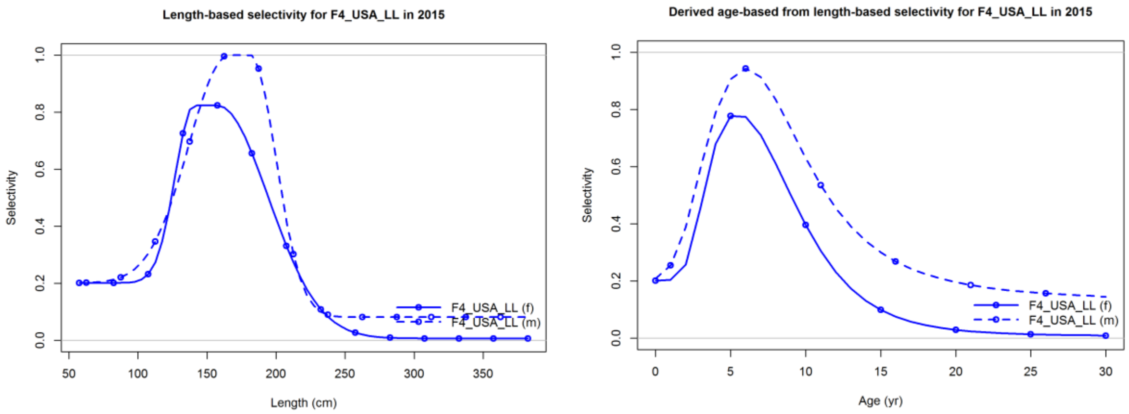
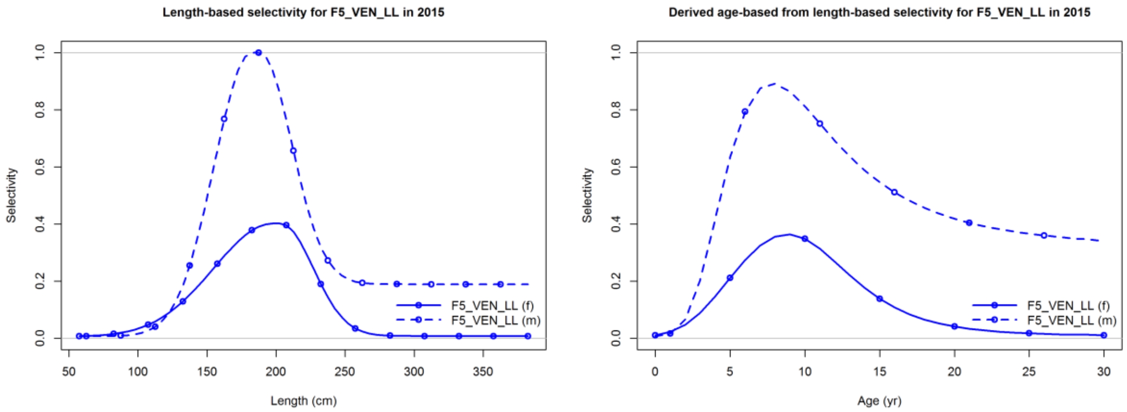
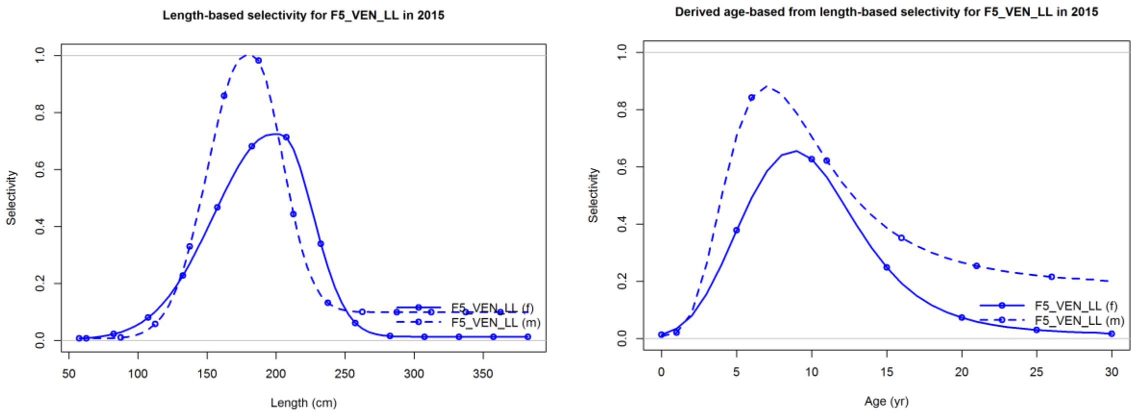


Figure E4. Fleet 4 (fleets as defined in **Table 1**) sex combined length based selectivity estimated for model run 1 (upper left Panel A) model run 2 (middle left Panel B) and model run 3 (lower left Panel C) along with the corresponding derived selectivity at age obtained by transforming selectivity at length through the sex specific von Bertalanffy growth curves for female (f) and male (m) North Atlantic shortfin mako (Courtney *et al.* 2017) (right panels).

A. Stock Synthesis model run 1



B. Stock Synthesis model run 2



C. Stock Synthesis model run 3

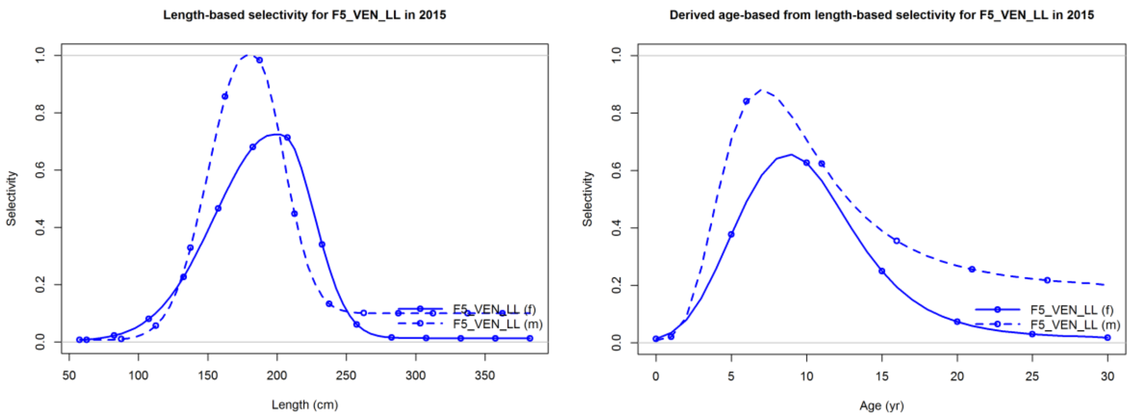


Figure E5. Fleet 5 (fleets as defined in **Table 1**) sex combined length based selectivity estimated for model run 1 (upper left Panel A) model run 2 (middle left Panel B) and model run 3 (lower left Panel C) along with the corresponding derived selectivity at age obtained by transforming selectivity at length through the sex specific von Bertalanffy growth curves for female (f) and male (m) North Atlantic shortfin mako (Courtney *et al*. 2017) (right panels).