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SUMMARY OF INTERSESSIONAL WORK COMPLETED WITH STOCK SYNTHESIS PROJECTIONS TO EVALUATE A SUBSET OF THE 2017 CONSERVATION MEASURES RECOMMENDED BY ICCAT, RELATED TO TAC AND SIZE LIMITS, TO REDUCE MORTALITY FOR NORTH ATLANTIC SHORTFIN MAKO

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SUMMARY

Stock Synthesis projections at alternative fixed total allowable catch (TAC) limits were implemented for the base case model (run 3) to evaluate the effectiveness of a subset of the 2017 conservation and management measures, size limits to protect immature shortfin mako, recommended by ICCAT to reduce North Atlantic shortfin mako shark mortality in association with ICCAT fisheries and to rebuild the stock to the MSY level. The projected recovery of spawning stock size was accelerated under size limits, but did not reach the MSY level by 2070 (two generations) even with size limits and a fixed TAC set to zero. These results suggest that while TAC and size limits are useful to reduce mortality, these management measures may be insufficient to rebuild the stock to the target level within the ICCAT time frame. In consideration of the nature of the fisheries for shortfin mako (i.e. bycatch species) and recent high level of the annual catches (around 3000 t), other proposed management measures, such as live release, may be practical measures to reduce fishing mortality.

RÉSUMÉ

Les projections de Stock Synthèse à des limites du total des prises admissibles (TAC) fixées de manière alternative ont été mises en œuvre pour le cas de base du modèle (scénario 3) afin d'évaluer l'efficacité d'un sous-ensemble de mesures de conservation et de gestion de 2017, de limites de taille visant à protéger le requin-taupe bleu immature, recommandées par l'ICCAT afin de de réduire la mortalité du requin-taupe bleu de l'Atlantique Nord en association avec les pêcheries de l'ICCAT et de rétablir le stock au niveau de la PME. Le rétablissement projeté de la taille du stock reproducteur a été accéléré en vertu des limites de taille, mais n'a pas atteint le niveau de la PME d'ici 2070 (deux générations), même avec des limites de taille et un TAC fixé à zéro. Ces résultats suggèrent que si le TAC et les limites de taille sont utiles pour réduire la mortalité, ces mesures de gestion risquent de ne pas être suffisantes pour rétablir le stock au niveau cible dans les délais impartis par l'ICCAT. Compte tenu de la nature des pêcheries de requin-taupe bleu (c.-à-d. des espèces de captures accessoires) et du récent niveau élevé des captures annuelles (environ 3.000 t), d'autres mesures de gestion proposées, telles que la remise à l'eau de spécimens vivants, pourraient être des mesures pratiques pour réduire la mortalité par pêche.

RESUMEN

Se implementaron proyecciones de Stock Synthesis en límites del total admisible de captura (TAC) fijados alternativamente para el caso base del modelo (ensayo 3) para evaluar la eficacia de un subconjunto de medidas de conservación y ordenación de 2017, límites de talla para proteger al marrajo dientuso inmaduro, recomendadas por ICCAT para reducir la mortalidad del marrajo dientuso del Atlántico norte en asociación con las pesquerías de ICCAT y recuperar el stock hasta el nivel de RMS. La recuperación proyectada del tamaño del stock reproductor

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se aceleraba con los límites de talla, pero no alcanzaba el nivel del RMS antes de 2070 (dos generaciones) incluso con límites de talla y una TAC fijado en cero. Estos resultados sugieren que, aunque el TAC y los límites de talla son útiles para reducir la mortalidad, estas medidas de ordenación podrían ser insuficientes para recuperar el stock hasta el nivel objetivo en el plazo de ICCAT. Considerando la naturaleza de las pesquerías de marrajo dientuso (es decir, especie de captura fortuita) y el elevado nivel reciente de las capturas anuales (aproximadamente 3000 t), otras medidas de ordenación propuestas, como la liberación de ejemplares vivos, podrían ser medidas prácticas para reducir la mortalidad por pesca.

KEYWORDS

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

1. Introduction

At its 2017 annual Commission meeting, ICCAT recommended several conservation and management measures intended to reduce North Atlantic shortfin mako shark mortality in association with ICCAT Fisheries (SMA Rec 17-08; Anon. 2017b). The commission also tasked the SCRS by 2019 with reviewing the effectiveness of the measures. Since it was unlikely that sufficient data would be available by 2019 to conduct a new stock assessment, it was determined after the 2018 meeting (Anon 2018) that projections based upon the 2017 assessment with additional annual catches in 2016 and 2017 would be developed intersessionally to determine the probability based on projection results that measures contained in the ICCAT recommendations would be expected to prevent the population from decreasing further, stop overfishing and begin to rebuild the stock by 2019.

A projection approach was developed intersessionally in Stock Synthesis (Methot and Wetzel 2013) after the 2018 meeting to implement fixed annual total allowable catch (TAC) limits (Courtney and Rice 2019) for the previously completed 2017 North Atlantic shortfin mako shark stock assessment model runs (Anon. 2017a). The Stock Synthesis projection approach at fixed TAC levels was then adapted intersessionally (Kai *et al*. 2019) to evaluate the effect of a subset of the 2017 conservation and management measures recommended by ICCAT related to size limits.

The objective of this working document was to summarize the intersessional work completed after the 2018 meeting (Anon 2018) by Courtney and Rice (2019) and Kai *et al.* (2019). The conservation and management measures related to TAC and size limits were: A) TAC limits evaluated by conducting projections under alternative constant catch scenarios in 100 t increments (Courtney and Rice 2019); and B) Size limits evaluated for the retention of shortfin mako of a minimum size of at least 180 cm fork length for males and of at least 210 cm fork length for females (**Figure 1**) (Kai *et al.*. 2019).

2. Projection approach

Stock Synthesis projections were developed in response to the following intersessional 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 intersessionally due to time constraints].

6) Utilize the Stock Synthesis base case model (run 3) to evaluate conservation measures recommended by ICCAT, and include Stock Synthesis preliminary model runs 1 and 2, if time allows.

7) Update the base model (run 3) from Stock Synthesis version 3.24U to Stock Synthesis version 3.30 to evaluate conservation measures recommended by ICCAT, because Stock Synthesis version 3.24U does not allow for a change in selectivity during the projection period.

8) Utilize the point estimates obtained from maximum likelihood estimation (MLE) to evaluate conservation measures recommended by ICCAT, because preliminary runs using MCMC did not converge for the updated base model (run 3) in Stock Synthesis version 3.30.

9) Evaluate the conservation measure recommended by ICCAT pertaining to the retention of shortfin mako of a minimum size of at least 180 cm fork length for males and of at least 210 cm fork length for females (size limits) by implementing a change in age-based selectivity in the projection period (2019 – 2070) using the base model (run 3) in Stock Synthesis version 3.30.

3. Results

The projection approach (items 1 – 6) was implemented intersessionally in Courtney and Rice (2019) and summarized here in **Table 1** and **Figure 2**. Item 5 was not completed intersessionally due to time constraints. Projections were conducted at a fixed catch level during the years 2016 – 2018 and then at an alternative TAC level ranging from 0 to 1100 t in 100 t increments during the years 2019 – 2070. TAC was apportioned to the fleets during the projection period based on the proportion of average catch in numbers observed for these fleets during the years 2006 – 2015 (Courtney and Rice 2019, their Tables 1 and 2).

All projection scenarios for the base case model (run 3) resulted in continued short term population declines regardless of the fixed TAC level used in future projections (**Figure 2**). Spawning stock size in the projections, spawning stock fecundity (SSF), continued to decline after fishing pressure had been reduced because it took many years for the surviving recruits to reach maturity (age at 50% maturity = 21 yr) and begin to contribute to the SSF (Courtney and Rice 2019). For the base case, the ratio of SSF/SSF_{MSY} appeared to stabilize at a stock size below MSY by 2070 with a fixed TAC of 800 t, to result in a declining trend by 2070 for fixed TAC levels > 800 t, and to result in an increasing trend by 2070 for fixed TAC levels < 800 t (**Figure 2**). A Kobe II risk matrix for the base case indicated that the SSF would be likely to reach the level required to return the stock to a size that could support MSY by 2070 (around two mean generation times) with greater than 50% probability only at a fixed annual TAC limit of <100 t (**Table 1**).

3.1 Item 7

The effect of transforming the base model from Stock Synthesis version 3.24U to version 3.30, was evaluated in Kai and Courtney (2019). It was concluded that there was only a minimal impact of the version update on the stock status of North Atlantic shortfin mako. Consequently, the new version (3.30.12 beta) was used for future projection of the base case model. In general, use of a beta version is not recommended, and although a newer version of Stock Synthesis (3.30.13) was available (https://vlab.ncep.noaa.gov/web/stock-synthesis/home), it was not evaluated here due to time constraints.

3.2 Items 8 and 9

The effect of size limits was evaluated by implementing a change in age-based selectivity in the projection period (beginning in the year 2019) for the base model (run 3) in Stock Synthesis version 3.30 (Kai *et al.*. 2019) and summarized here in **Table 2**. Preliminary Markov Chain Monte Carlo (MCMC) projections conducted in version 3.30 did not converge (Kai *et al.*. 2019). Consequently, projections conducted with version 3.30 utilized the MLE point estimates of SSF/SSF_{MSY} obtained from Stock Synthesis AD Model Builder (ADMB) output (Kai *et al.*. 2019). The annual fishing mortality (*F*) was not considered in this analysis because *F* is influenced by the assumptions of selectivity. Projections of SSF relative to SSF_{MSY} indicated that although the TAC with size regulation accelerated the recovery of the SSF, the SSF did not reach the MSY level by 2070 even if the TAC was set to zero and size limits were implemented (**Table 2**).

4. Discussion

The projection results suggest that while the TAC and size limit regulation are useful to reduce mortality, these management measures may be insufficient to rebuild the stock to the target level within the ICCAT time frame (two generations).

The projection approach used to evaluate TAC limits (Items 1 – 6 above; Courtney and Rice 2019) implicitly assumed that sharks above the TAC limit were not encountered by the fishing gear during the projection period (2019 – 2070). In contrast, and in consideration of the nature of the fisheries for shortfin mako (i.e., bycatch species), it may be more likely that sharks above the TAC limit would still be encountered by the gear during the projection period, but that they would not be retained. In this case, the expectation is that TAC limits could be somewhat less effective at recovering the SSF to SSF_{MSY} than reported in Courtney and Rice (2019) because of the additional at-vessel and post-release mortality of sharks above the TAC limit that could be encountered by the gear but not retained.

Similarly, the projection approach used to evaluate size limits (Items 7 – 9 above; Kai *et al.*. 2019), implicitly assumed sharks below the size limit were not encountered by the fishing gear during the projection period (2019 – 2070). As above, it may be more likely that sharks below the size limit would still be encountered by the gear during the projection period (2019-2070) but that they would not be retained. In this case, the expectation is that the size regulation could be somewhat less effective at accelerating the recovery of SSF to SSF_{MSY} than reported in Kai *et al.*. (2019) because of additional at-vessel and post-release mortality of sharks below the size limit that could be encountered by the gear but not retained.

In consideration of the nature of the fisheries for shortfin mako (i.e. bycatch species), the recent high level of the annual catches (around 3000 t), and the limitations of the projection scenarios discussed above, other recommendations (SMA Rec 17-08; Anon. 2017b), such as retention of shortfin mako if dead when brought along side for taking on board the vessel (live release) may be practical measures to reduce fishing mortality, because sharks subject to at-vessel mortality would be kept. However, projections for the live release management scenario would require implementing an annual reduction in fishing mortality (*F* based projections) during the projection period, which was not evaluated intersessionally due to time constraints.

Recommendations associated with the effects of circle hooks (SMA Rec 17-08; Anon. 2017b) were not evaluated intersessionally. Information regarding the effects of circle hooks on shark bycatch was presented during the 2018 meeting (Anon 2018). However, it was not clear how to model the effects of circle hooks within a projection scenario.

Model uncertainty should also be considered when interpreting projection results. The use of different model assumptions or the use of different modeling frameworks may lead to different projection outcomes. For example, the range of outcomes obtained from projections of North Atlantic shortfin mako shark ignores large uncertainties in the assumptions of fixed biological parameters within the Stock Synthesis model such as growth, age at maturity, natural mortality, and the stock-recruitment relationship, which were not explicitly evaluated in these projections. In addition, alternative model settings for the shape of the selectivity curves by fleet or changes in the proportion of catch by fleet (item 5) may also have a large effect on projection results, which were not evaluated in these projections.

5. Conclusions

Projection results for the base case Stock Synthesis model run suggested that the TAC and size regulations evaluated here are useful tools to reduce fishing mortality, but these management measures may be insufficient to rebuild the stock to the target level within the ICCAT time frame. In consideration of the nature of the fisheries for shortfin mako (i.e. bycatch) and recent high level of the annual catches (around 3000 t), live release may be a practical measure to reduce fishing mortality. However, the effects of implementing a live release management measure were not evaluated intersessionally with projections due to time constraints. The effect of circle hooks was also not evaluated intersessionally. Model uncertainty should also be considered when interpreting these projection results. The use of different model assumptions or the use of different modeling frameworks may lead to different projection outcomes.

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Table 1. Markov Chain Monte Carlo **(**MCMC) and Maximum Likelihood Estimation (MLE) probabilities that SSF > SSF_{MSY} by 2070 (relative to SSF at the MSY level of 588 x1000 in number) obtained from Stock Synthesis projections at alternative fixed total allowable catch (TAC) limits for the Stock Synthesis base case model (run 3), as described in Courtney and Rice (2019).

	Spawning Stock Fecundity (SSF)		Probability that SSF > SSF_{MSY}			
TAC(t)	SSF (thousands)	SSF/SSF_{MSY}	MCMC long chain[1]	MCMC short chain[2]	MLE normal[3]	MLE lognormal[4]
0*	564	0.96	61	56	33	33
100	537	0.91	46	41	18	19
200	510	0.87	31	25	8	10
300	483	0.82	21	16	3	5
400	456	0.78	12	8	1	2
500	429	0.73	6	4	0	1
600	401	0.68	3	2	0	0
700	373	0.63	2	1	0	0
800	346	0.59	1	1	0	0
900	317	0.54	1	0	0	0
1000	289	0.49	0	0	0	0
1100	260	0.44	0	0	0	0

* Largest TAC interval with ≥ 50% MCMC probability (long chain) that SSF > SSF_{MSY} by 2070 (Courtney and Rice 2019, their Table 5 Panel B).

[1] (Courtney and Rice 2019, their Table 5 Panel B).

[2] (Courtney and Rice 2019, their Table A3 Panel B).

[3] (Courtney and Rice 2019, their Table B3 Panel B).

[4] (Courtney and Rice 2019, their Table C3 Panel B).

Table 2. Effect of size limit recommendations for the Stock Synthesis base case model (run 3) on spawning stock fecundity (SSF) at the final year (2070), as described in Kai *et al.* (2019). Size limits were implemented in projections with both a combined sex age-limit of 9.5 yr and a sex specific age-limit of 7.8 yr for males and 11.2 yr for females as described in **Figure 1**. SSF_s denotes SSF under the minimum size limit, SSF_s/SSF_{MSY} denotes the SSF_s relative to SSF at the MSY level (588 x1000 in number), and SSF_s/SSF_{TAC} denotes the performance of size regulation to accelerate the recovery of the SSF relative the SSF obtained at the alternative fixed TAC levels indicated by the final year (2070) (SSF_{TAC}).

	Combined sex size limits [1]			Sex specific size limits [2]		
TAC (t)	SSF_s (thousands)	SSF_s/SSF_{MSY}	SSF_s/SSF_{TAC}	SSF_s (thousands)	SSF_s/SSF_{MSY}	SSF_s/SSF_{TAC}
0	564	0.96	1.00	564	0.96	1.00
100	545	0.93	1.01	547	0.93	1.02
200	525	0.89	1.03	529	0.90	1.03
300	505	0.86	1.04	511	0.87	1.06
400	484	0.82	1.06	493	0.84	1.08
500	464	0.79	1.08	474	0.81	1.11
600	444	0.75	1.11	455	0.77	1.13
700	423	0.72	1.13	436	0.74	1.17
800	402	0.68	1.16	417	0.71	1.21
900	381	0.65	1.20	397	0.68	1.25
1000	360	0.61	1.24	377	0.64	1.31
1100	338	0.57	1.30	357	0.61	1.37
1200	316	0.54	1.37	336	0.57	1.45
1300	294	0.50	1.46	315	0.54	1.56
1400	272	0.46	1.58	293	0.50	1.70
1500	249	0.42	1.82	271	0.46	1.98

[1] (Kai *et al.*. 2019, their Table 1).
[2] (Kai *et al.*. 2019, their Table 2).

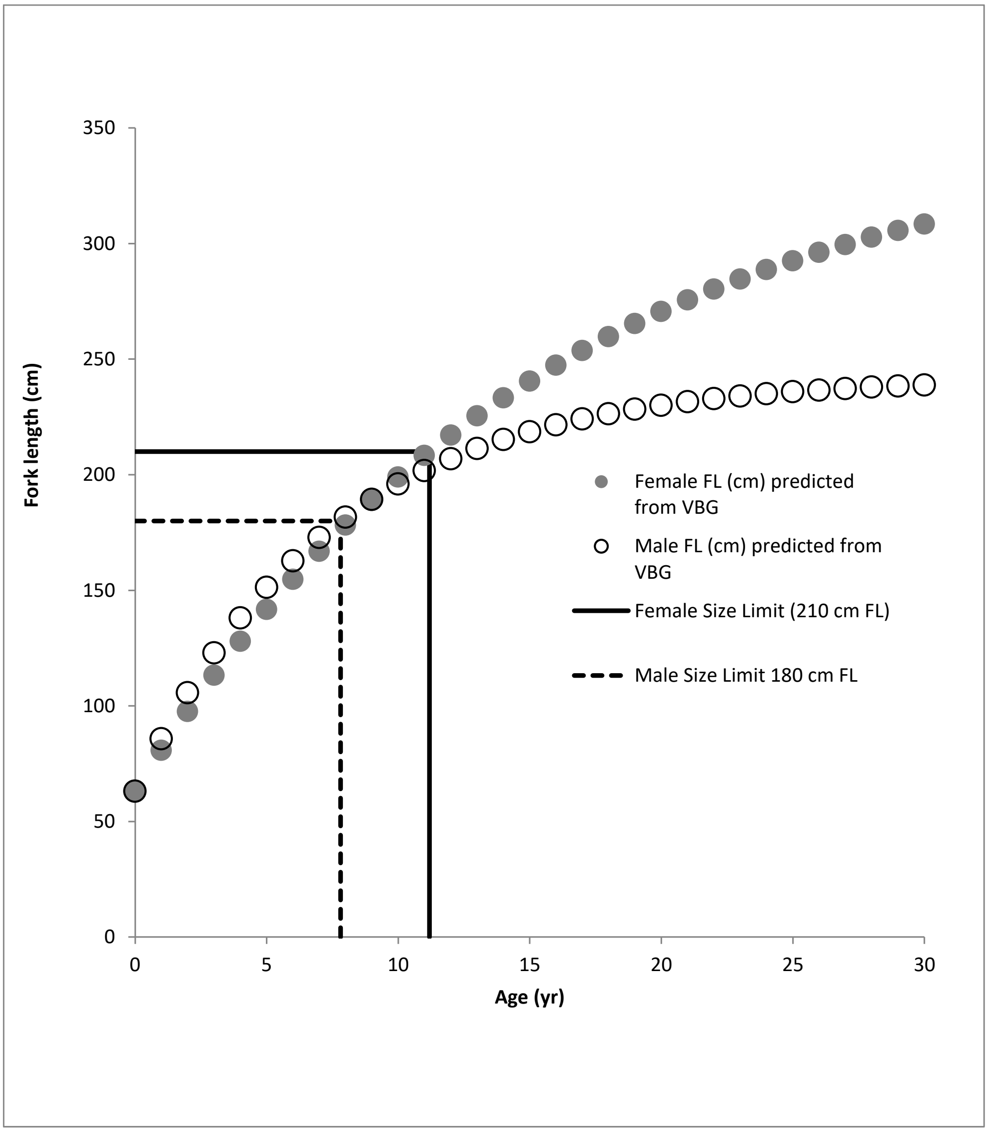

Figure 1 (Adapted from Courtney *et al.* 2018, their Figure 1). Implementation of a conservation measure to limit retention of shortfin mako of a minimum size of at least 180 cm fork length for males and of at least 210 cm fork length for females (assumed here to be applied to all North Atlantic fleets used in the Stock Synthesis model; Anon. 2017a) in forward projection: Convert length to age for males (180 cm FL = age 7.8 yr.) and females (210 cm FL = age 11.2 yr.) through the von Bertalanffy growth curve (VBG) used in the Stock Synthesis model (Courtney *et al.*. 2017; Anon. 2017a), then fix selectivity in forward projections to reflect non retention of sharks below age 7.8 yr (males) and 11.2 (females) or age 9.5 yr (males and females combined).

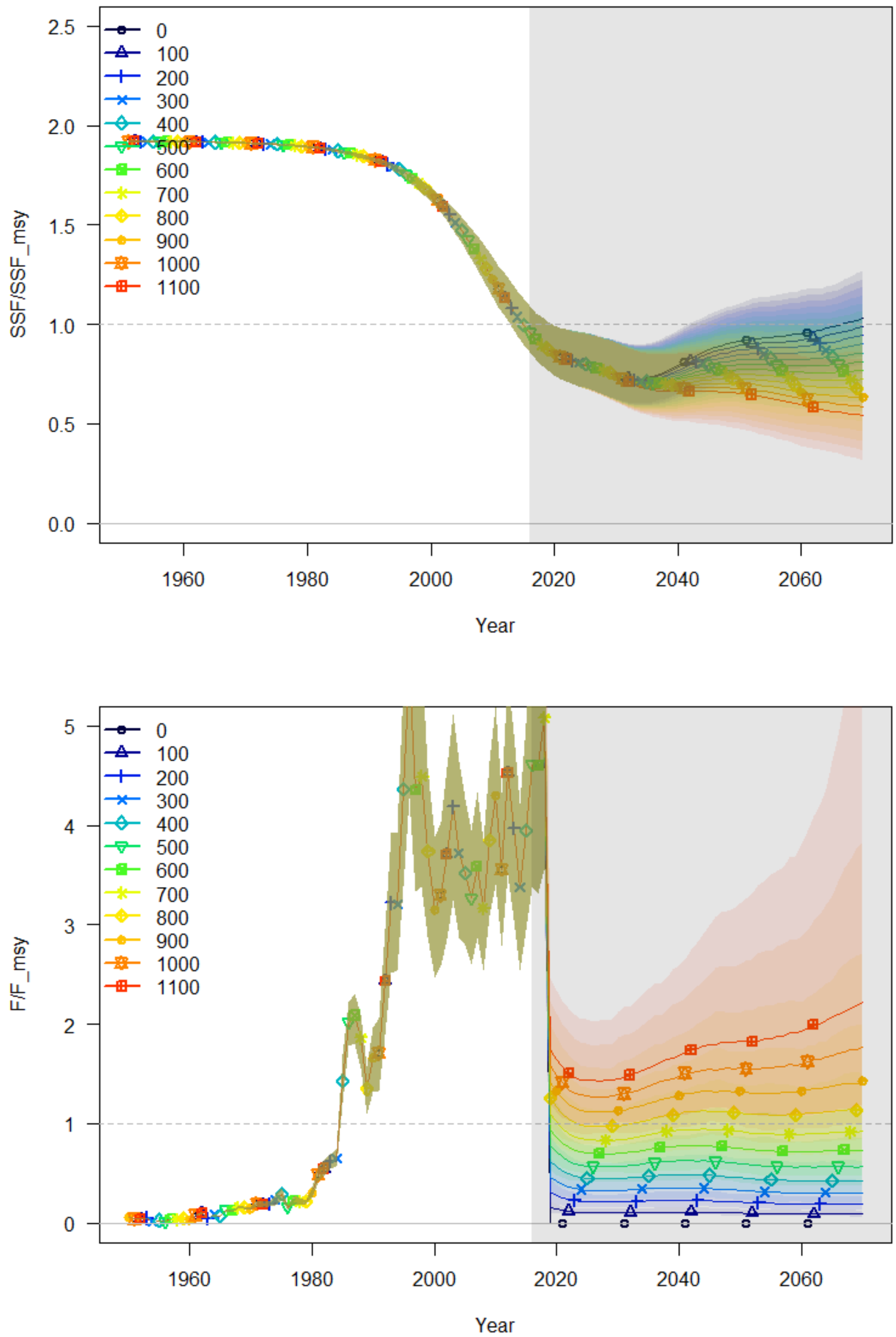

Figure 2. Projection results (shaded area) under a range of fixed TAC limits (0 – 1100 t) for the Stock Synthesis base case model (run 3) for the derived quantities SSF/SSF_{MSY} (upper panel) and F/F_{MSY} (lower panel) (adapted from Courtney and Rice 2019, their Figure 3). Each line is the 0.5 quantile (median) and each shaded interval is the 95% credible interval between the 0.025 and 0.975 quantiles obtained from a Markov Chain Monte Carlo (MCMC) long chain.