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SEDAR 65 REVIEW WORKSHOP DOCUMENT

Projections Conducted for the Atlantic Blacktip Shark Stock Synthesis Base Model Configuration at Alternative Fixed Total Allowable Catch (TAC) Limits

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Summary

Projections were implemented for two generations at alternative fixed annual total allowable catch, TAC, limits ranging from 0 – 200% of the average annual commercial landings and recreational catches (2014 – 2018) in increments of 10%. A risk matrix of projected spawning stock fecundity (SSF) relative to SSF at MSY (SSF_{MSY}) indicated that fixed TACs equal to 100% and 110% of the average annual removals (2014 – 2018) resulted in cumulative normal projection probabilities for $SSF_y > SSF_{MSY}$ of 75% and 69%, respectively, in two generations (2043). A linear interpolation of the projection results indicated that a 70% cumulative normal probability of $SSF_y > SSF_{MSY}$ in 2043 was achieved at a TAC of 108% of the average removals (2014 – 2018). 108% of the average annual commercial landings (2014 – 2018) is 115.0 mt ww for fleet F1 (Bottom Longlines), 33.3 mt ww for fleet F2 (Gillnets) and 2.2 mt ww for fleet F3 (Other Gears). 108% of the average smoothed recreational catches (2014 – 2018) is 62,416 sharks for fleet F4 (Recreational A + B1 + B2-Dead). In comparison, a risk matrix of projected fishing mortality (F) indicated that fixed TACs of 100% and 110% of the average annual removals (2014 – 2018) resulted in cumulative normal projection probabilities for $F_y < F_{MSY}$ of 66% and 51%, respectively, in 2043. TACs of 100% and 110% of average removals (2014 – 2018) resulted in an 86% and 81% probability, respectively, of $SSF_y >$ the Minimum Stock Size Threshold (MSST) in 2043.

Introduction

Stock Synthesis projections at alternative fixed total allowable catch (TAC) limits are provided for the SEDAR 65 Stock Synthesis base model configuration. Projections were carried out using the forecast module internal to Stock Synthesis. The projection approach was adapted from projections previously implemented in Stock Synthesis for a blue shark stock assessment conducted for the Indian Ocean Tuna Commission (Rice 2017; Anon. 2017c), a recent SEDAR 54 domestic sandbar shark stock assessment update (Anon. 2017a, 2018a), and a recent ICCAT North Atlantic shortfin mako assessment projections update provided in SEDAR 65 RD14 (Courtney and Rice 2020).

However, in contrast to the previous Stock Synthesis projections cited above, the projection approach implemented here uses maximum likelihood estimation (MLE) to provide approximate annual projection probabilities based on a normal distribution assumption (Anon. 2018a). The MLE projection approach generates approximate risk matrix probabilities more quickly than can be obtained with Markov Chain Monte Carlo (MCMC). Comparisons of MLE and MCMC projection results using the alternative fixed TAC limit approach are available from the SEDAR 54 domestic sandbar shark stock assessment update (Anon. 2017a, their Figure EX 3; Anon. 2018a, their Figure A9) and from the recent ICCAT North Atlantic shortfin mako projections update provided in SEDAR 65 RD14 (Courtney and Rice 2020). MCMC projections are not available for this report because of time constraints resulting from the Covid-19 crisis including a lack of IT resources necessary to perform MCMC projections while on mandatory telework during the assessment.

Methods

Harvest Policy and Duration

Projections are implemented from 2019 to 2043. Generation time is assumed to be 12.5 years (Cortés 2020). Consequently, a time horizon of 25 years (2019 to 2043) is assumed to include two generations.

Projections are implemented with average commercial landings and with average recreational catches (A + B1 + B2-Dead) for the first three projection years (2019 – 2021).

Average commercial landings by fleet (**Table 1**) are obtained from commercial landings of blacktip sharks in the U.S. Atlantic in metric tons whole weight (mt ww; SEDAR 65 Stock Assessment Report, SAR, their Table 2.2) during the most recent five years of data available in the assessment (2014 – 2018**)**. Similarly, average recreational catches (A + B1 + B2-Dead; **Table 2**) are obtained from annual smoothed recreational catch estimates in numbers (1000s, reported as a 3-year moving average in SEDAR 65 SAR, their Table 2.3) for blacktip sharks in the Atlantic during the most recent five years of data available in the assessment (2014 – 2018**)**.

Projections are implemented at alternative fixed annual total allowable catch, TAC, limits for the remaining projection years (2022 – 2043). Twenty one alternative fixed TAC levels are evaluated ranging from 0 – 200% of the average annual commercial landings and recreational catches in increments of 10%. The selectivity of each fleet and the proportion of catch among fleets during the projection period are assumed to be constant and equal to the values obtained during the final year of the assessment (2018).

Projection Benchmarks and Reference Points

Projection benchmarks and MSY reference points are the same as those provided in the SEDAR 65 SAR (their section 3.3.1.13). Projection benchmarks are provided for spawning stock fecundity, SSF, and fishing mortality, F, in each projection year (SSF_y, and F_y, respectively) obtained from Stock Synthesis output as ratios relative to their equilibrium MSY reference points (SSF_y/SSF_{MSY}, and F_y/F_{MSY}, respectively). The derivations and definitions of SSF and F are the same as those provided in the SEDAR 65 SAR. The spawning stock fecundity, SSF, is a derived parameter obtained from Stock Synthesis, calculated as the sum of female numbers at age (in 1,000s) multiplied by annual pup production at age at the beginning of each calendar year assuming a 1:1 ratio of male to female pups (SEDAR 65 SAR, their Section 3.3.1.3). The fishing mortality rate, F, is also a derived parameter obtained from Stock Synthesis output, calculated as the total annual fishing mortality rate experienced by the population ($F = Z - M$ for ages 0-28; SEDAR 65 SAR, their Section 3.3.1.13; Methot et al. 2020).

Overfishing and overfished stock status determinations in the projections are the same as those provided in the SEDAR 65 SAR (their section 3.3.1.13). The Atlantic blacktip shark stock is defined to be in an overfishing condition in projection year y if $F_y > F_{MSY}$. The Atlantic blacktip shark stock is defined to be in an overfished condition in projection year y if $SSF_y <$

$\left(1-\bar{M}_a\right)$*SSF$_{MSY}$, where $\left(1-\bar{M}_a\right)$*SSF$_{MSY}$ is the Minimum Stock Size Threshold (MSST) defined in the SEDAR 65 SAR (their section 3.3.1.13) consistent with Restrepo et al. (1998) and Restrepo and Powers (1999). Spawning stock fecundity, SSF, is used as a proxy for female biomass, B, and $\bar{M}_a$ is calculated as the arithmetic mean of the female age-specific values of natural mortality obtained from the base model configuration (0.139; SEDAR 65 SAR, their Table 2.13) .

Characterizing Projection Uncertainty

The projection approach implemented here utilizes 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 is 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). Because there are no observation data in the projection period, the estimated recruitment deviations shrink to zero in the projection period, while the estimated variances of the recruitment deviations in the projection period are included in the projection uncertainty obtained from Stock Synthesis output for the annual ratios of SSF_y/SSF_{MSY} and F_y/F_{MSY} during the projection period.

Maximum likelihood estimation (MLE) of uncertainty during the projection period is obtained as the asymptotic normal standard errors reported in Stock Synthesis output for the annual ratios of SSF_y/SSF_{MSY} and F_y/F_{MSY} during the projection period. Cumulative probabilities (70%) of $SSF_y/ SSF_{MSY} > 1$ and $F_y/F_{MSY} < 1$ are calculated in R using the cumulative normal distribution.

Projections are implemented using the Stock Synthesis version 3.30.15.00 forecast module (Methot et al. 2020). Stock Synthesis projection results are summarized using the R language for statistical computing version 4.0.0 (R Core Team 2020), and the R library package ‘r4ss’ version 1.38.0 (Taylor et al. 2020).

Results

The 70% projection probabilities (30% of the cumulative normal distribution) obtained each year for SSF_y/SSF_{MSY} with MLE are provided in **Figure 1**. The projection model at 180% of average annual removals crashed for unknown reasons and, consequently, is not available in the results.

A risk matrix of cumulative normal projection probabilities for $SSF_y/SSF_{MSY} > 1$ (**Table 3**) indicates that a TAC of 100% of the average removals (2014 – 2018) results in a 75% probability of $SSF_y > SSF_{MSY}$ in 2043. In contrast, the risk matrix (**Table 3**) indicates that a TAC of 110% of the average removals (2014 – 2018) results in a 69% probability of $SSF_y > SSF_{MSY}$ in 2043.

A linear interpolation of the cumulative normal probability of SSF_y/SSF_{MSY} in 2043 obtained at each TAC is provided in **Figure 2** and is summarized in **Table 4**. The linear interpolation indicates that a 70% cumulative normal probability of $SSF_y > SSF_{MSY}$ in 2043 is achieved at a fixed TAC of 108% of average removals (2014 – 2018). 108% of average commercial landings (2014 – 2018) is 115.0 (mt ww) for fleet F1 (Bottom Longlines), 33.3 (mt ww) for fleet F2 (Gillnets), and 2.2 (mt ww) for fleet F3 (Other Gears) **(Table 4 Panel B).** Similarly, 108% of average recreational catch (2014 – 2018) is 62.416 (1000s) for fleet F4 (Recreational A + B1 + B2-Dead) **(Table 4 Panel C).**

In comparison, a risk matrix of cumulative normal projection probabilities for $F_y/F_{MSY} < 1$ indicates that TACs of 100% and 110% of the average removals (2014 – 2018) result in a 66% and 51% probability, respectively, of $F_y < F_{MSY}$ in 2043 (**Table 5**). In addition, a risk matrix of cumulative normal projection probabilities for $SSF_y/SSF_{MSY} > \left(1-\bar{M}_a\right)$ indicates that TACs of 100% and 110% of average removals (2014 – 2018) result in an 86% and 81% probability, respectively, of $SSF_y >$ MSST in 2043 (**Table 6**).

Discussion

Figure 1 shows lines representing the 70% MLE probability of SSF_y/SSF_{MSY} for the SEDAR 65 Stock Synthesis base model configuration at each fixed TAC during both the assessment period (1981 – 2018) and the projection period (2019 – 2043). During the assessment period, the line representing the 70% MLE probability of SSF_y/SSF_{MSY} was below 1.0 in some years (1981 – 2018; **Figure 1)**. This result indicates there was less than a 70%

probability of $SSF_y > SSF_{MSY}$ during those years of the assessment period. In contrast, the line representing the 70% MLE probability of SSF_y/SSF_{MSY} was above the MSST value during the entire assessment period (1981 – 2018; **Figure 1)**. This result indicates that there was greater than a 70% probability of $SSF_y >$ MSST during the entire assessment period.

During the projection period (2019 – 2043), the lines representing the 70% MLE probability of SSF_y/SSF_{MSY} at each fixed TAC diverged (**Figure 1)**. Fixed TACs ≤ 100% of the average annual removals from 2014 – 2018 (in increments of 10%) resulted in at least a 70% MLE projection probability of $SSF_y > SSF_{MSY}$ in 2043 (**Figure 1**; **Table 3**). In comparison, fixed TACs ≥ 110% of the average annual removals from 2014 – 2018 (in increments of 10%) resulted in less than a 70% MLE projection probability MLE of $SSF_y > SSF_{MSY}$ in 2043 (**Figure 1**; **Table 3**).

Figure 2 shows results of a linear interpolation of the MLE probability of SSF_y/SSF_{MSY} obtained at each TAC in the final year of the projection period (2043) for the SEDAR 65 Stock Synthesis base model configuration. The linear interpolation indicated that a 70% MLE probability of $SSF_y > SSF_{MSY}$ in 2043 was achieved at a fixed TAC of 108% of the average removals (2014 – 2018) (**Figure 2; Table 4 Panel A)**. The projected TAC at 108% of the average annual commercial landings (2014 – 2018) was 115.0 mt ww for fleet F1 (Bottom Longlines), 33.3 mt ww for fleet F2 (Gillnets) and 2.2 mt ww for fleet F3 (Other Gears) **(Table 4 Panel B)**. The projected TAC at 108% of the average smoothed recreational catches (2014 – 2018) was 62,416 sharks for fleet F4 (Recreational A + B1 + B2-Dead) **(Table 4 Panel C).**

The SEDAR 65 Stock Synthesis base model configuration predicted that the stock was not overfished ($SSF_{2018} >$ MSST) and that the stock was not experiencing overfishing ($F_{2018} > F_{MSY}$) in the terminal year of the assessment (SEDAR 65 SAR, their Tables 3.10 and 3.11; SEDAR 65 SAR, their Figures 3.9 and 3.10). Consequently, projections are provided here in response to the SEDAR 65 SAR TORs 9c and 9d: "c. If [the] stock is neither overfished nor undergoing overfishing, then utilize projections to determine: i. The F needed and corresponding removals associated with a 70% probability of overfishing not occurring (analogous to a P* = 0.3 approach). d If data-limitations preclude classic projections (i.e. a, b, and c above), explore alternate projection models to provide management advice." Projections are based on the pre-specified acceptable probability of the 70% MLE probability of $SSF_y/SSF_{MSY} > 1$ and $F_y/F_{MSY} < 1$ as a proxy to a typical P* approach where P* = 0.3; < 0.5 (e.g., Courtney et al. 2014) under the SEDAR 65 SAR TORs 9c and 9d.

The projections implemented here utilized the asymptotic standard errors obtained from ADMB (Fournier et al. 2012). This approach is consistent with previous projections

implemented for HMS sharks in a State Space Age Structured Production Model (SSASPM) (Anon. 2011, 2012a, 2012b, 2013a, 2013b, 2018b, 2018c). A difference is that projections for SSASPM utilized the asymptotic standard errors obtained from ADMB in Monte Carlo simulation implemented with R statistical software.

Projections implemented here at alternative fixed TAC limits are consistent with the projection approach used by the International Commission for the Conservation of Atlantic Tunas (ICCAT) Standing Committee on Research and Statistics (SCRS) in their Kobe II strategy matrices and Kobe plots (e.g., SCRS 2012, their Tables 16-18, and their Figures 36-38). A difference is that Kobe II matrices are based on bootstrap resampling and report combined probabilities $SSF_y/SSF_{MSY} > 1$ and $F_y/F_{MSY} < 1$.

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Table 1. Annual commercial landings of blacktip sharks in the U.S. Atlantic in metric tons whole weight (mt ww; 2014 – 2018; adapted from the SEDAR 65 SAR, their Table 2.2).

Year	F1 Bottom Longlines (mt ww)	F2 Gillnets (mt ww)	F3 Other Gears (mt ww)
2014	130.126	41.000	6.678
2015	121.858	22.712	0.333
2016	110.737	44.723	1.202
2017	110.825	26.754	1.105
2018	58.961	18.886	1.047
Average (2014 – 2018)	106.501	30.815	2.073

Table 2. Annual smoothed recreational catch estimates (1000s, reported as a 3-year moving average in SEDAR 65 SAR, their Table 2.3) of blacktip sharks in the Atlantic (2014 – 2018). Type A is the number of sharks killed or kept seen by the interviewer, type B1 is the number of sharks killed or kept reported to the interviewer by the angler, and type B2-Dead is the number of sharks released alive reported by the fisher multiplied by a post-release mortality rate of 18.5%. Total-Dead is A + B1 + B2-Dead.

		F4	
		Recreational catch (1000s)	
Year	**A + B1**	**B2-Dead**	**Total-Dead**
2014	3.437	81.810	85.247
2015	4.701	68.243	72.944
2016	4.451	51.887	56.338
2017	2.849	34.367	37.216
2018	2.849	34.367	37.216
Average (2014 – 2018)			57.792

Table 3. Risk matrix of cumulative normal projection probabilities for $SSF_y/SSF_{MSY} > 1$ in the SEDAR 65 base model configuration at alternative fixed levels of total annual removals due to fishing (TAC; 0-200% of average annual removals from 2014 – 2018 in increments of 10%), as described above. The $Pr(SSF_y > SSF_{MSY})$ is color coded to represent $Pr \geq 0.70$ (green), $0.50 \leq Pr < 0.70$ (yellow), and $Pr < 0.50$ (red).

TAC (0-200%)	2019	2020	2021	2022	2023	2025	2030	2035	2040	2043
0	77	80	83	83	83	85	92	98	100	100
10%	77	80	83	83	83	84	91	97	99	100
20%	77	80	83	83	83	84	90	96	99	100
30%	77	80	83	83	83	84	89	95	98	99
40%	77	80	83	83	83	83	88	93	97	98
50%	77	80	83	83	83	83	87	91	95	96
60%	77	80	83	83	83	82	86	89	92	94
70%	77	80	83	83	82	82	84	87	89	90
80%	77	80	83	83	82	82	83	84	85	86
90%	77	80	83	83	82	81	81	81	81	81
100%	77	80	83	83	82	81	80	77	76	75
110%	77	80	83	83	82	81	78	74	71	69
120%	77	80	83	83	82	80	76	70	65	62
130%	77	80	83	83	82	80	75	66	60	56
140%	77	80	83	83	82	79	73	63	54	50
150%	77	80	83	83	82	79	71	59	49	44
160%	77	80	83	83	81	79	69	55	44	39
170%	77	80	83	83	81	78	67	51	39	34
180%[1]										
190%	77	80	83	83	81	77	63	44	31	26
200%	77	80	83	83	81	77	61	41	27	22

[1]Model run crashed.

Table 4. Linear interpolation of the cumulative normal probability of $SSF_y > SSF_{MSY}$ in 2043 (**Figure 2**) indicates that a TAC = 1.08*Average removals (2014 – 2018) achieves a 70% asymptotic normal probability of $SSF_y/SSF_{MSY} > 1$ in 2043 (**Panel A**). The resulting projected commercial TAC (mt ww) = 1.08 * (average annual commercial landings 2014 – 2018) is provided in **Panel B**. The resulting projected recreational TAC (1,000s) = 1.08 * (average annual smoothed recreational catch 2014 – 2018) is provided in **Panel C**.

A. Interpolated TAC = 1.08*Average removals (2014 – 2018).

Projection scenario	Model configuration	Example of fixed removals
Base	SEDAR 65 Base model configuration	108% of average removals (2014 – 2018)

B. 108% of average commercial landings (2014 – 2018; **Table 1**).

Projected Commercial TAC	F1 Bottom Longlines (mt ww)	F2 Gillnets (mt ww)	F3 Other Gears (mt ww)
Average removals (2014 – 2018)	106.501	30.815	2.073
1.08*Average	115.0	33.3	2.2

C. 108% of average recreational catch (2014 – 2018; **Table 2**).

Projected Recreational TAC	A + B1	F4 Recreational catch (1000s) B2-Dead	Total-Dead
Average removals (2014 – 2018)	3.6574	54.1348	57.7922
1.08*Average			62.416

Table 5. Risk matrix of cumulative normal projection probabilities for $F_y/F_{MSY} < 1$ in the SEDAR 65 base model configuration at alternative fixed levels of total annual removals due to fishing (TAC; 0-200% of average annual removals from 2014 – 2018 in increments of 10%), as described above. The Pr($F_y < F_{MSY}$) is color coded to represent Pr ≥ 0.70 (green), 0.50 ≤ Pr < 0.70 (yellow), and Pr < 0.50 (red).

TAC (0-200%)	2019	2020	2021	2022	2023	2025	2030	2035	2040	2043
0	71	70	70	100	100	100	100	100	100	100
10%	71	70	70	100	100	100	100	100	100	100
20%	71	70	70	100	100	100	100	100	100	100
30%	71	70	70	100	100	100	100	100	100	100
40%	71	70	70	100	100	100	100	100	100	100
50%	71	70	70	100	100	100	100	100	100	100
60%	71	70	70	100	100	100	100	100	100	100
70%	71	70	70	97	98	98	99	99	99	99
80%	71	70	70	91	91	92	93	94	94	95
90%	71	70	70	81	81	81	82	82	82	82
100%	71	70	70	70	70	69	69	68	67	66
110%	71	70	70	59	58	57	56	54	52	51
120%	71	70	70	49	48	47	45	43	41	40
130%	71	70	70	41	40	38	36	35	33	32
140%	71	70	70	34	33	32	30	29	28	27
150%	71	70	70	28	28	27	25	24	24	24
160%	71	70	70	24	23	22	22	21	22	22
170%	71	70	70	21	20	19	19	19	20	22
180%[1]										
190%	71	70	70	15	15	15	15	17	20	22
200%	71	70	70	14	13	13	14	16	20	24

[1]Model run crashed.

Table 6. Risk matrix of cumulative normal projection probabilities for $SSF_y/SSF_{MSY} > \left(1-\bar{M}_a\right)$ in the SEDAR 65 base model configuration at alternative fixed levels of total annual removals due to fishing (TAC; 0-200% of average annual removals from 2014 – 2018 in increments of 10%), as described above. Projection results are provided as the probability of spawning stock fecundity in projection year y (SSF_y) being above the Minimum Stock Size Threshold (MSST), where MSST is defined as $\left(1-\bar{M}_a\right)$ *SSF_{MSY}, as described above. The Pr(SSF_y > MSST) is color coded to represent Pr ≥ 0.70 (green), 0.50 ≤ Pr < 0.70 (yellow), and Pr < 0.50 (red).

TAC (0-200%)	2019	2020	2021	2022	2023	2025	2030	2035	2040	2043
0	90	91	92	92	93	93	97	100	100	100
10%	90	91	92	92	93	93	97	99	100	100
20%	90	91	92	92	92	93	96	99	100	100
30%	90	91	92	92	92	93	96	98	99	100
40%	90	91	92	92	92	93	95	98	99	99
50%	90	91	92	92	92	92	94	97	98	99
60%	90	91	92	92	92	92	94	95	97	98
70%	90	91	92	92	92	92	93	94	95	96
80%	90	91	92	92	92	92	92	92	93	93
90%	90	91	92	92	92	91	91	90	90	90
100%	90	91	92	92	92	91	90	88	87	86
110%	90	91	92	92	92	91	89	86	83	81
120%	90	91	92	92	92	91	88	83	78	76
130%	90	91	92	92	92	91	86	80	74	70
140%	90	91	92	92	92	90	85	77	69	64
150%	90	91	92	92	92	90	84	73	64	58
160%	90	91	92	92	91	90	82	70	58	52
170%	90	91	92	92	91	89	81	66	53	47
180%[1]										
190%	90	91	92	92	91	89	78	59	44	37
200%	90	91	92	92	91	89	76	56	39	32

[1]Model run crashed.

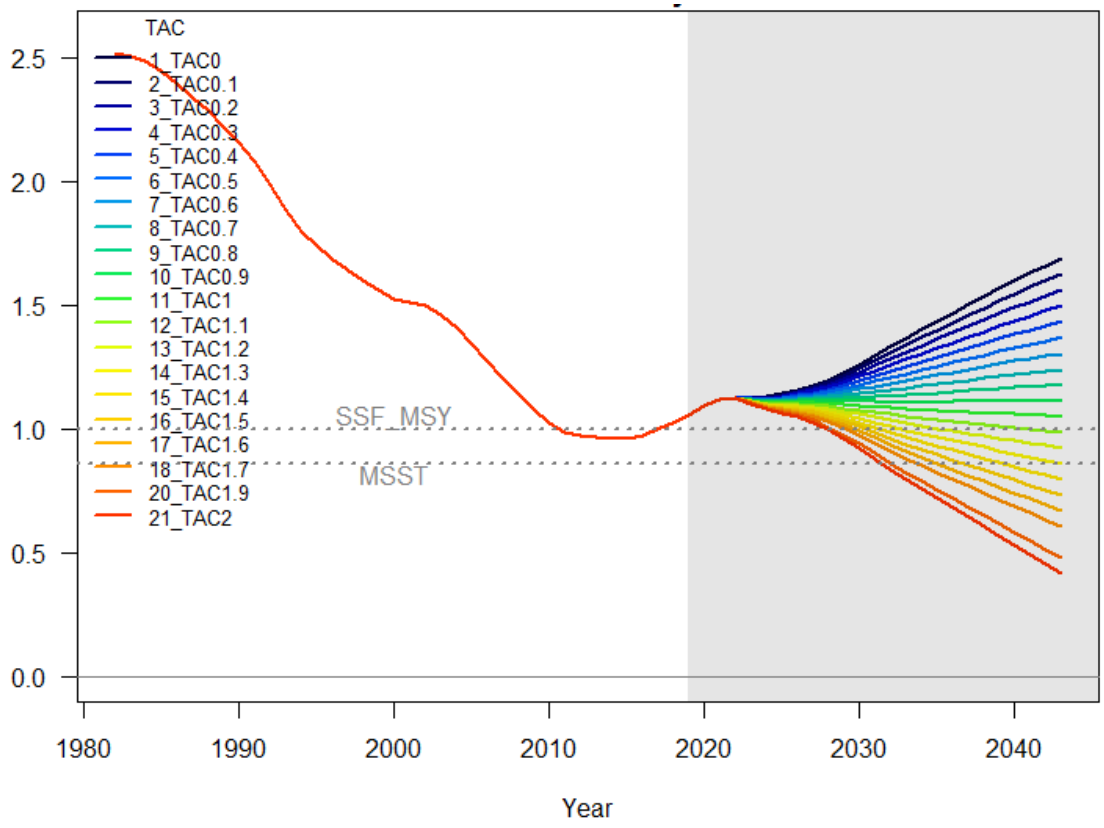

Figure 1. Projection results (shaded area) for the SEDAR 65 base model configuration at alternative fixed levels of total annual removals due to fishing (TAC; 0-200% of the average annual removals from 2014 – 2018 in increments of 10%), as described above. Projection results are provided for the ratio of spawning stock fecundity in projection year *y* relative to spawning stock fecundity at equilibrium maximum sustainable yield (SSF_y/SSF_{MSY}; y-axis). Lines represent the 70% projection probabilities (30% of the cumulative normal distribution) obtained with MLE at each TAC, as described above. The minimum stock size threshold (MSST) is $\left(1-\bar{M}_a\right)$ *SSF_{MSY}, as described above.

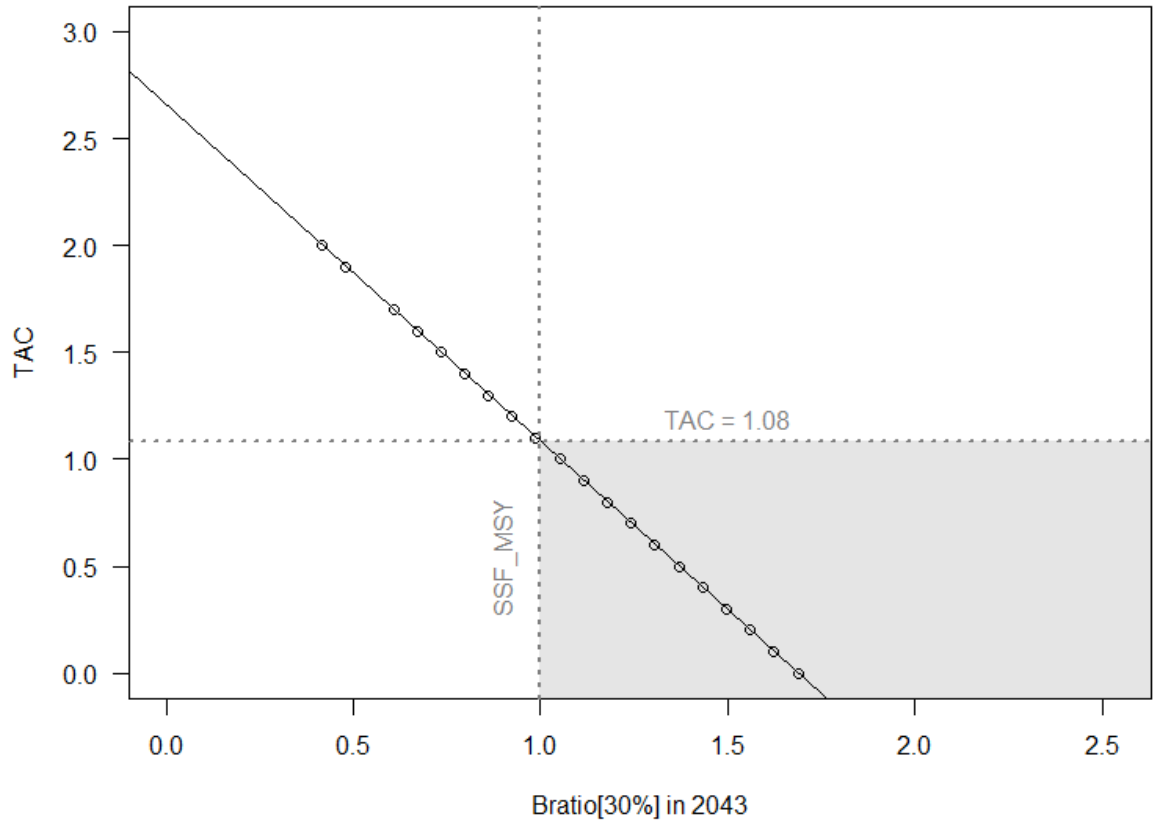

Figure 2. Linear interpolation of TAC at 70% cumulative normal probability for $SSF_y/SSF_{MSY} > 1$ in 2043 (Bratio[30%] in 2043) indicates that a 70% asymptotic normal probability of $SSF_y/SS_{FMSY} > 1$ in 2043 is achieved at TAC = 1.08*Average removals (2014 – 2018).