North Atlantic Swordfish MSE:
Final Results & Decision Guide

This document presents the final results of the North Atlantic swordfish management strategy evaluation (MSE). The intention is to facilitate discussions and decision-making for adoption of a management procedure (MP) at the 24th Special Meeting of the Commission in November 2024.

2024 Updates

The SCRS Swordfish Species Group has made a number of updates and improvements to the North Atlantic swordfish management strategy evaluation (MSE) in 2024. These include revising the combined index, reconditioning the operating models (OMs) based on updated catch data and indices, developing additional robustness OMs (for a total of 7 robustness OMs), and modifying the candidate management procedures (CMPs) to improve performance.

Management Objectives & Performance Indicators (PIs)

The N-SWO MSE includes 10 key performance indicators (PIs) as a benchmark for evaluation of the Commission's selected management objectives. **Appendix A** shows the current management objectives and performance indicators based on input received from Panel 4 in 2023.

Importantly, all yield performance indicators consider the total allowable catch (TAC) to be landings plus dead discards.

Candidate Management Procedures

The SCRS Swordfish Species Group has worked collaboratively to develop and test a number of CMPs. Three CMP types remain, as agreed by Panel 4 in October 2024. MCC9 and MCC11 are modified versions of the MCC CMPs developed in 2023, updated to include more steps to improve performance relative to the new combined index. The SPSSFox CMP remains unchanged. In addition to representing both model-based and empirical approaches, remaining CMPs are SCRS-recommended because they cover a range of the performance tradeoff space, use a variety of TAC-setting rules, and because they use the combined index, which includes data from the broadest geographic and fleet coverage. Detailed CMP descriptions and formulae for calculating TACs are included in Appendix D.

This table describes the CMP types:

	[...]	MCC9	MCC11	SPSSFox	[...]
Type	[...]	Empirical	Empirical	Model	[...]
Index	[...]	Combined	Combined	Combined	[...]
Steps	[...]	9	11	N/A	[...]
Minimum TAC	[...]	4000 t	4609 t	N/A	[...]
Stability Limit (maximum allowed change between management cycles)	[...]	None	None	±25% cap	[...]
Reference Period	[...]	2017-2019	2017-2019	N/A	[...]
Description	[...]	Aims to maintain a mostly constant catch (MCC). The TAC is adjusted between a set of 9 steps based on the ratio of the mean index over the 3 most recent years compared to the mean index from 2017-2019.	Similar to MCC9 but the TAC is adjusted between a set of 11 steps and there is a different minimum TAC.	A Fox surplus production model with a hockey-stick HCR where fishing mortality decreases linearly from 100*SB_{MSY} to 40*SB_{MSY}.	[...]

The MCC CMPs have b and c tuning variants. The 'b-tuning' CMPs are tuned to meet at least 60% probability of being in the Kobe green quadrant for each decade across the 30-year projection period. The 'c-tuning' CMPs are tuned to meet at least 70%, probability of being in the Kobe green quadrant for the first decade of the projection period and at least 60% PGK for the subsequent two decades of the projection. For the SPSSFox CMP, only the 'b-tuning' remains. There are therefore a total of five final CMP variants.

The Safety minimum threshold requires that CMPs have greater than 85% probability of not breaching the limit reference point (LRP, i.e., 0.4*B_{MSY}) at any point in the projection period. The 90% probability option is also available, however, all CMPs achieve the Safety minimum threshold with 100% probability of not breaching the LRP.

CMPs use a 3-year management cycle and in testing, did not produce TAC changes of between 1 and 200 t between management cycles (0 t TAC changes were common for remaining CMPs). All CMPs use a two-year data lag, meaning that the TAC calculated for the first management cycle (2025-2027) uses data up to and including 2022.

Final CMP Performance Results

Included here are the key performance results for the five final CMP variants. The full suite of results is available in the online interactive application (see, Other resources below).

Reference Operating Models (OMs)

For the Reference OMs, all CMPs had Probability of green Kobe (PGK) >= 60% in the Short (2025-2034), Medium (2035-2044) and Long (2044-2054) time periods, and 100% probability of not breaching the limit reference point (LRP) (**Figures 1-4**).

[…]

[…]

[…]

Robustness Tests

Robustness OM 5, which evaluated a potential impact of climate change by simulating lower than expected recruitment deviations for first 15 years of projection period, was the most challenging test for the CMPs.

[…]

	MP	AvTAC_long	AvTAC_med	AvTAC_short	nLRP	PGK	PGK_med	PGK_short	PNOF	VarC	TAC1
1	MCC9_b	12,258	11,315	14,144	1.00	0.73	0.78	0.60	0.80	0.12	15,087
2	MCC9_c	11,794	10,887	13,609	1.00	0.80	0.84	0.70	0.85	0.12	14,516
3	MCC11_b	11,911	10,958	14,769	1.00	0.71	0.74	0.60	0.78	0.12	14,769
4	MCC11_c	11,523	11,523	14,289	1.00	0.77	0.80	0.70	0.83	0.12	14,289
5	SPSSFox_b	11,557	11,397	13,869	1.00	0.73	0.75	0.60	0.79	0.14	15,629

Figure 1. Quilt table showing results for the 5 remaining CMPs against key performance indicators for the reference set of operating models. CMPs are listed in alphabetical order. See **Appendix A** for performance indicator descriptions. The nLRP performance indicator is the probability of not breaching the limit reference point; this modification of the LRP performance indicator means that higher values are better for all indicators except VarC. Darker shading indicates better performance, but some of the values are very similar, despite different shading.

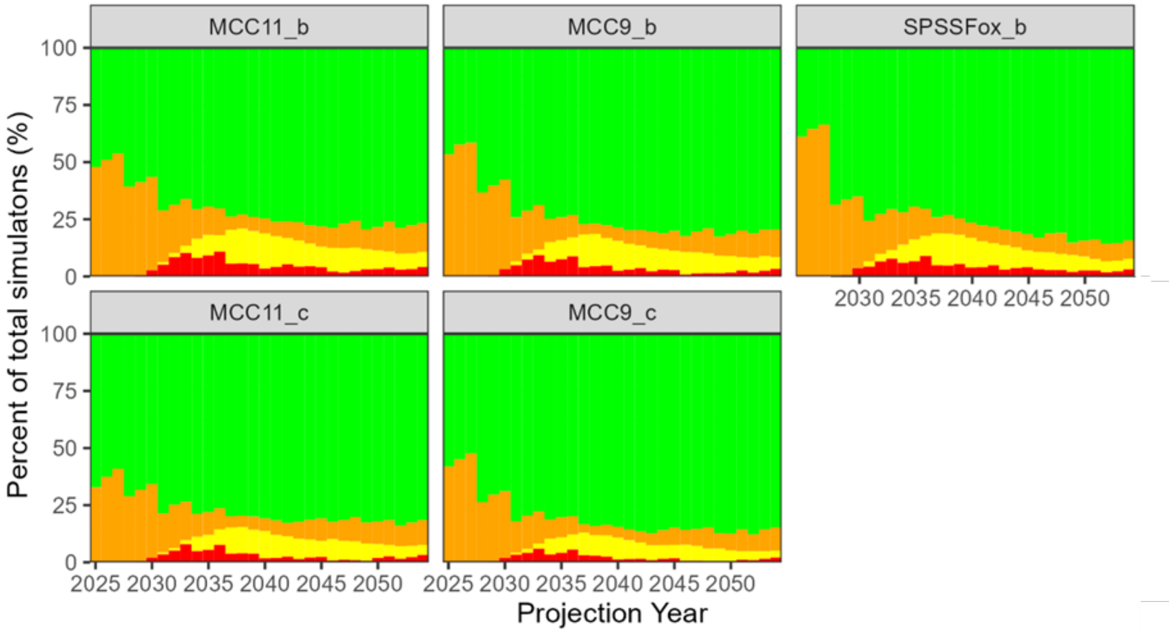

Figure 2. Kobe time plot showing the percentage (vertical axis) of simulations across all reference operating models that fall in each of the Kobe quadrants in each projection year (horizontal axis). Green indicates that the stock is neither overfished nor subject to overfishing. Orange means that the stock is subject to overfishing but not overfished. Yellow indicates that the stock is overfished but not subject to overfishing. Red means that the stock is both overfished and subject to overfishing.

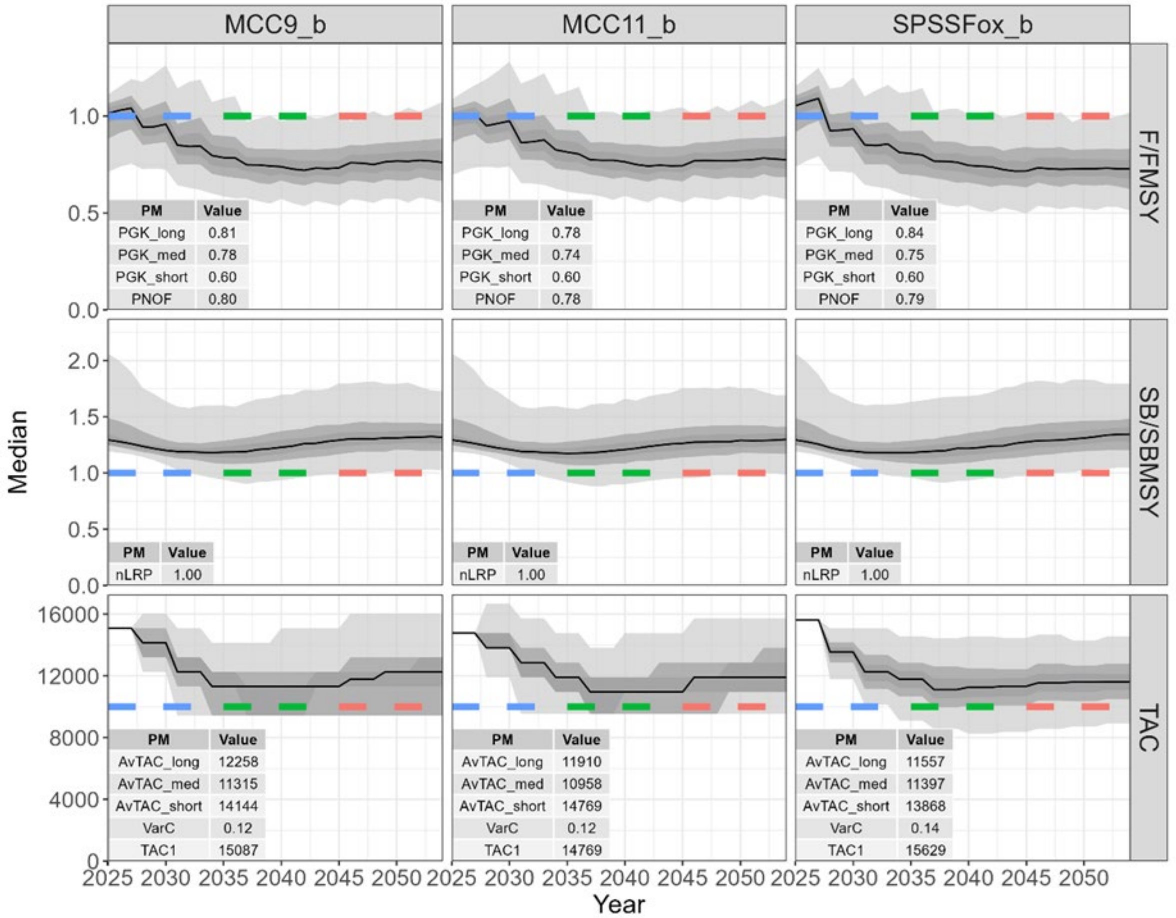

Figure 3. Trajectory of a) fishing mortality (F) relative to F_{MSY} (top row), b) spawning biomass (SB) relative to SB_{MSY} (middle row), and c) TAC (in tons, bottom row) for the 'b' tunings of the final CMPs. Results are summarized across all reference operating models. Blue bars show the short time period, while green depicts medium and red long.

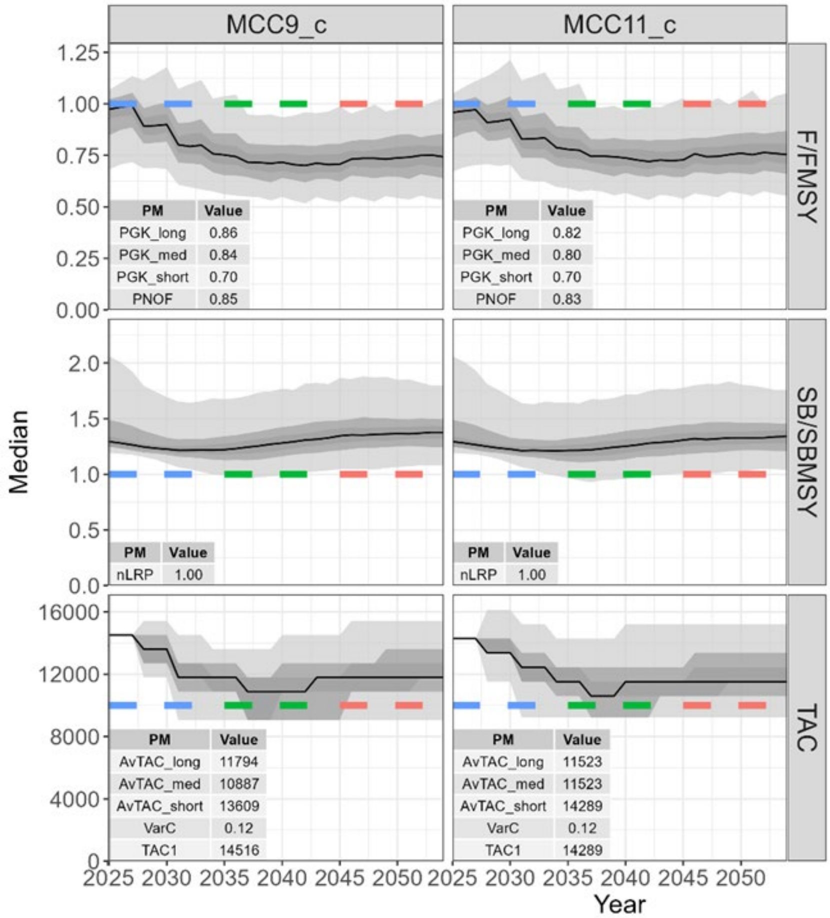

Figure 4. Trajectory of a) fishing mortality (F) relative to F_{MSY} (top row), b) spawning biomass (SB) relative to SB_{MSY} (middle row), and c) TAC (in tons, bottom row) for the 'c' tunings of the final MCC CMPs. Results are summarized across all reference operating models. Blue bars show the short time period, while green depicts medium and red long.

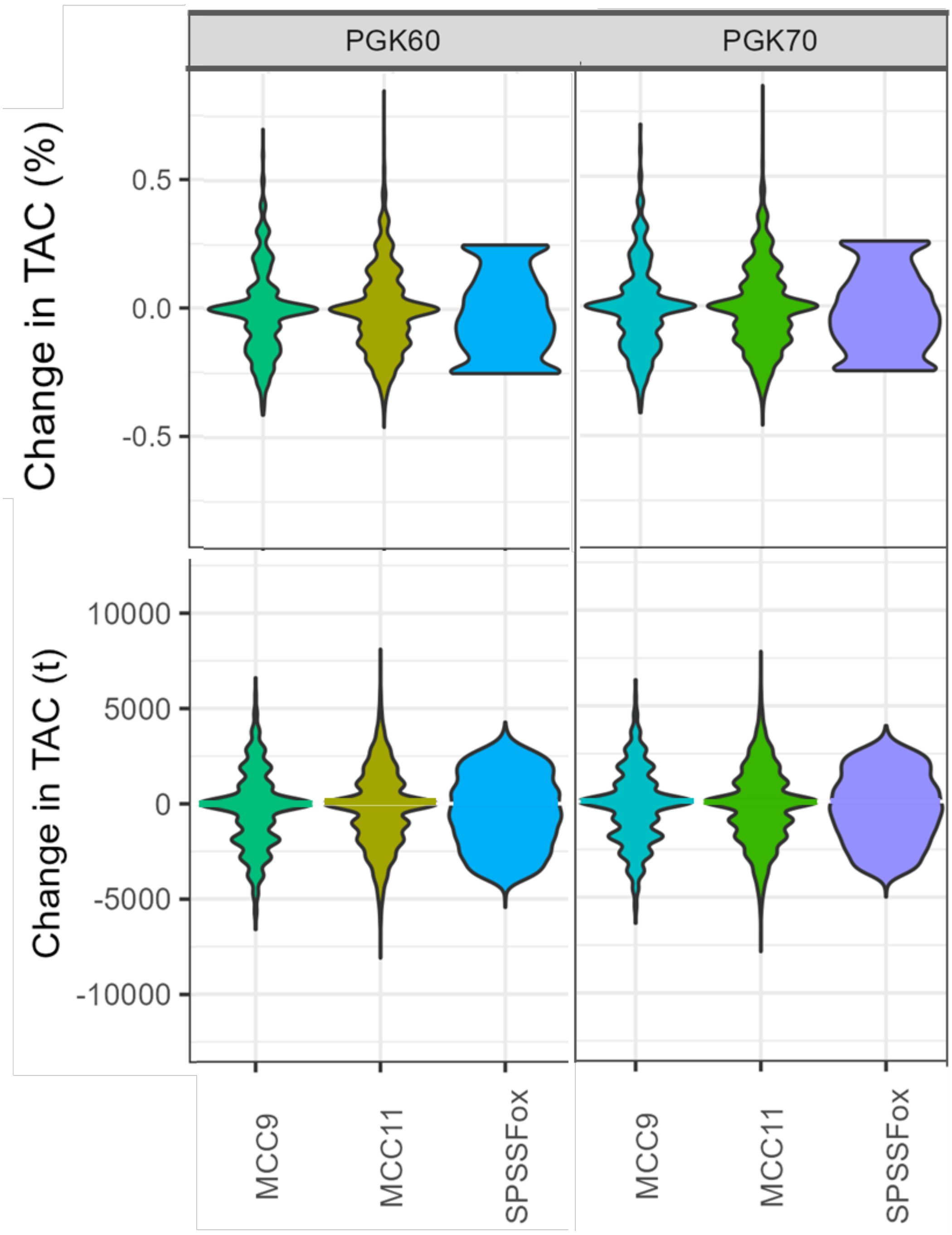

Figure 5. Violin plot for the change in TAC between management cycles. The width of the violin plot indicates the proportion of data points that are in each region of the plot (i.e., wide areas of the plot indicate a relatively large number of data points in that region, while narrow areas of the plot indicate few data points). The top row is TAC change expressed as a percentage and the bottom row as change in tonnage.

Decision Guide

The following points should be reflected in the final MP adopted by the Commission in November:

a) Final operational management objectives (See Appendix A), including:

- Minimum acceptable threshold for the Status objective. Panel 4 has indicated that the minimum threshold should be at least 60%—the 70% options are still available for the MCC CMPs.
- Minimum acceptable threshold for the Safety objective. Options are 85% or 90% probability of the stock not falling below B_{LIM} (0.4*B_{MSY}) at any point during the 30-year evaluation period. These equate to a 15% or 10% maximum probability, respectively, of breaching B_{LIM}, per the phrasing of the management objective.
    - Note that all CMPs in the short-list have a 100% chance of not falling below the limit reference point across the reference set of OMs.
- Maximum percent allowable change in TAC between management periods. Options are 25% (SPSSFox) or no limit (MCC9, MCC11).
- Results for CMP relative performance are provided above in **Figures 1-5** and may help to inform these decisions.

b) Final CMP type

- There are three remaining CMPs, two of which have two tunings available ('b' and 'c') – MCC9 and MCC11. The SPSSFox CMP has one tuning available (the 'b' tuning).
- The 'b' CMP variants are tuned to 60% PGK for each decade over the 30-year projection period, while the 'c' CMP variants are tuned to 70% PGK for the short time period and must have at least 60% PGK for the medium and long time periods.
- Each CMP uses the combined index.
- All CMPs meet the minimum operational objectives for Status and Safely but with varying performance on the Yield and Stability tradeoffs.
- The relative performance results are provided above in **Figures 1-5**. **Appendix B** contains CMP results for robustness scenario R5 (climate change effects on recruitment, called 'R3b in 2023). Because performance for all CMPs is strong for the reference set of OMs, Panel 4 may wish to pay close attention to the more challenging robustness OMs, like R5.

c) MP implementation schedule

- A key element of the process of management procedure implementation is the process of its review. Such a review can occur at regular, prescheduled intervals or following the declaration of exceptional circumstances. In most cases, such a review would not constitute a wholesale revision to the operating model structure, full reconditioning of the OMs or substantial changes to the CMPs, though it offers that opportunity should the need arise. In most cases, such reviews could implement index revisions or relatively minor improvements to the operating models or MPs; indeed, the outcome may leave the MP unchanged. The proposed MP implementation schedule is included in **Appendix C** for Panel 4's review and approval. It includes data requirements for each step, as well as a schedule for review of the MSE model assumptions.

Other Resources

North Atlantic Swordfish MSE splash page
North Atlantic Swordfish MSE interactive Shiny App (includes final results)
Harveststrategies.org MSE outreach materials (multiple languages)

Appendix A

Current management objectives and corresponding performance indicators based on input received at the Panel 4 meetings in 2023. Importantly, all yield performance indicators calculate the TAC as landings plus dead discards. Bracketed text notes remaining decision points.

Management objectives	***Corresponding key performance indicators***
Status The stock should have a 60% or greater probability of occurring in the green quadrant of the Kobe matrix.	**PGK_{SHORT}**: Probability of being in the Kobe green quadrant (i.e., $SB \geq SB_{MSY}$ and $F<F_{MSY}$) in years 1-10 **PGK_{MED}**: Probability of being in the Kobe green quadrant (i.e., $SB \geq SB_{MSY}$ and $F<F_{MSY}$) in years 11-20 **PGK_{ALL}**: Probability of being in the Kobe green quadrant (i.e., $SB \geq SB_{MSY}$ and $F<F_{MSY}$) over years 1-30 **PNOF:** Probability of not overfishing ($F<F_{MSY}$) over years 1-30
Safety There should be a [10, 15]% or less probability of the stock falling below B_{LIM} ($0.4*SB_{MSY}$) at any point during the 30-year evaluation period.	**LRP_{ALL}**[1]: Probability of breaching the limit reference point (i.e., $SB<0.4*SB_{MSY}$) in any of years 1-30.
Yield Maximize overall catch levels.	**TAC1**: TAC in the first management cycle (2025-27) **$AvTAC_{SHORT}$**: Median TAC (t) over years 1-10 **$AvTAC_{MED}$**: Median TAC (t) over years 11-20 **$AvTAC_{LONG}$**: Median TAC (t) over years 21-30
Stability [Any increase or decrease in TAC between management periods should be less than 25%. There is no stability limitation on TAC changes between management cycles.]	**VarC**: Mean variation in TAC (%) between management cycles over years 1-30

[1] nLRP (not breaching the LRP) is used when it is more appropriate for higher values of performance indicators to indicate a 'safer' outcome, such as in trade-off plots. For example, a 10% LRP threshold is equivalent to a nLRP threshold of 90%.

CMP results for Robustness Scenario R5 – climate change effects on recruitment

	MP	AvTAC_long	AvTAC_med	AvTAC_short	nLRP	PGK	PGK_med	PGK_short	PNOF	VarC	TAC1
1	MCC9_b	9,429	7,072	14,144	0.39	0.13	0.00	0.01	0.47	0.22	15,087
2	MCC9_c	9,072	6,804	13,609	0.51	0.16	0.00	0.04	0.50	0.20	14,516
3	MCC11_b	7,146	7,146	14,769	0.34	0.10	0.00	0.02	0.44	0.19	14,769
4	MCC11_c	9,219	6,914	14,289	0.46	0.15	0.00	0.07	0.48	0.19	14,289
5	SPSSFox_b	4,327	6,426	13,668	0.40	0.21	0.00	0.00	0.49	0.21	15,629

Figure B1. Quilt table showing results for the 5 remaining CMPs against key performance indicators for robustness operating model 5 (climate change effects on recruitment). CMPs are listed in alphabetical order. See **Appendix A** for performance indicator descriptions. The nLRP performance indicator is the probability of not breaching the limit reference point; this modification of the LRP performance indicator means that higher values are better for all indicators except VarC. Darker shading indicates better performance, but some of the values are very similar, despite different shading.

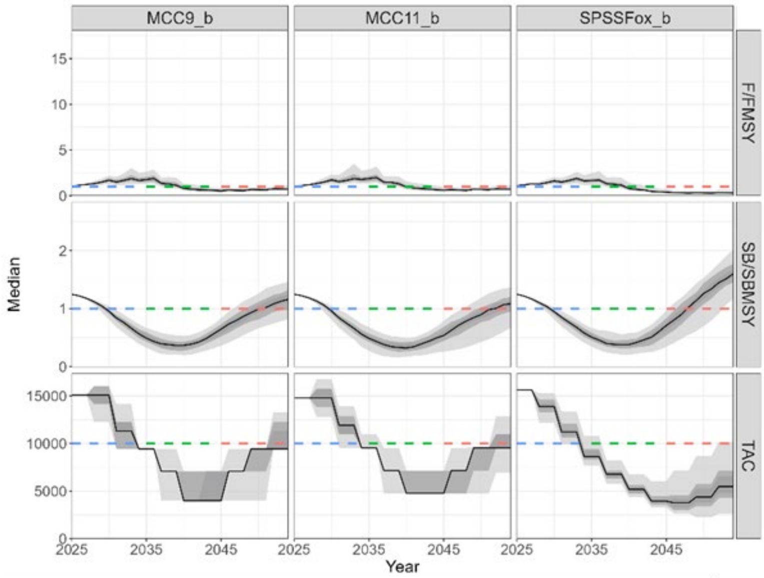

Figure B2. Trajectory of fishing mortality (F) relative to F_{MSY} (top), spawning stock biomass (SB) relative to SB_{MSY} (middle) and the TAC for 'b' tunings of the CMPs under the climate change robustness test R5 (features a decline in recruitment in the first fifteen years, followed by a return to average recruitment for the remainder of the projection period). The dark black trend line shows the median value of SB, while the increasingly lighter shades of grey show the 50^{th}, 60^{th}, and 90^{th} percentiles, respectively. The coloured horizontal line shows the SB_{MSY} target over the short (blue), medium (green) and long (red) terms.

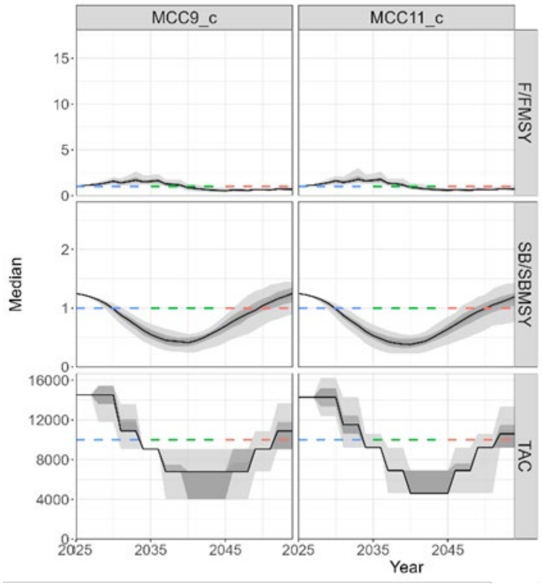

Figure B3. Trajectory of fishing mortality (F) relative to F_{MSY} (top), spawning biomass (SB) relative to SB_{MSY} (middle) and the TAC for 'c' tunings of the CMPs under the Climate Change robustness test R5 (features a decline in recruitment in the first fifteen years, followed by a return to average recruitment for the remainder of the projection period). The dark black trend line shows the median value of SB, while the increasingly lighter shades of grey show the 50th, 60th, and 90th percentiles, respectively. The coloured horizontal line shows the SB_{MSY} target over the short (blue), medium (green) and long (red) terms.

Appendix C

Proposed schedule for data provision, updating MPs, evaluating for exceptional circumstances (EC), stock assessments, and MP/MSE review

		Activity					***Data inputs***	
Year	Management cycle	MP run	MP advice implemented	Stock assessment	MSE Review	Exceptional circumstances evaluated	Combined index[2]	Exceptional circumstance indicators
2024		x					x	
2025	1		x			x		x
2026						x		x
2027		x				x	x	x
2028	2		x	[x]		x		x
2029				[x]		x		x
2030		x			[x]	x	x	x
2031	3		x			x		x
2032						x		x
2033		x				x	x	x

[2] The combined index may be updated every year, depending on the requirements set out in the exceptional circumstances protocol (ECP).

Appendix D

Description and formulae for calculating TACs for North Atlantic swordfish using the [MCC9, MCC11, SPSSFox] MP

MCC9

The MCC9 (Mostly Constant Catch with 9 levels) management procedure is empirical and uses a single input—the North Atlantic Swordfish combined index of abundance (the Combined Index). The goal of the MCC9 MP is to have the catch remain as constant as possible and only increase the TAC if the Combined Index increased substantially and only decrease the TAC if the Combined Index declined substantially. This MP is tuned to achieve a [60%, 70%] PGK (i.e. $SB \geq SB_{MSY}$ and $F \leq F_{MSY}$) in [each of the three 10 year projection time periods (short = years 1-10; medium = years 11-20; long = years 21-30) / the short time period (years 1-10) and at least 60% in the medium (years 11-20) and long (years 21-30) time periods].

Abundance index

The Combined Index uses catch and effort data from 7 ICCAT CPCs and draws from both Task 2 catch and effort data and detailed catch and effort records obtained directly from some CPCs—totaling over 95% of the annual catch in the North Atlantic. The initial year of the index is 1963. The index values are in kilograms of swordfish catch per 1,000 hooks. This model-based index uses a Tweedie error distribution and categorical explanatory variables: year, quarter, spatial zone, a targeting variable, and a size class variable.

The predicted year values are then standardized to a mean of 1 over the whole time series. These values are defined as I.

MP specifications

This MP uses a 3-year management cycle length. The base TAC (constant catch) is 12,600 mt—this is an approximation of the constant catch that would result in at least 60% PGK and also achieve nLRP <[15%, 10%].

A base TAC (TAC_{base}) is calculated as:

$$\mathrm{TAC}_{\mathrm{base}} = \theta 12{,}600$$

where θ is the tuning parameter that results in achieving the desired short-term PGK. The tuning parameter for MCC9 at [60% PGK is 0.7483 / 70% PGK is 0.7200].

TAC_{base} is modified by comparing the ratio of the current 3-year average of the Combined Index (I_{curr}) to a historical 3-year average of the Combined Index (I_{base}):

$$I_{\mathrm{rat}} = \frac{I_{\mathrm{curr}}}{I_{\mathrm{base}}}$$

I_{base} is calculated as the average of the Combined Index from 2017-2019. The value of I_{rat} is used to determine how much TAC_{base} should be increased or decreased if at all.

If I_{rat} is below 0.5, the total allowable catch (TAC) is set to 4,000 mt, otherwise TAC for the following management cycle is calculated as:

$$TAC_{y+1} = \mathrm{TAC}_{\mathrm{base}} \Delta_{\mathrm{TAC}}$$

where Δ_{TAC} is calculated as:

$$\Delta_{TAC} = \begin{cases} 1.7 & \text{if } I_{rat} \geq 1.7 \\ 1.6 & \text{if } 1.6 \leq I_{rat} < 1.7 \\ 1.5 & \text{if } 1.5 \leq I_{rat} < 1.6 \\ 1.4 & \text{if } 1.4 \leq I_{rat} < 1.5 \\ 1.3 & \text{if } 1.3 \leq I_{rat} < 1.4 \\ 1.2 & \text{if } 1.2 \leq I_{rat} < 1.3 \\ 1.0 & \text{if } 0.75 \leq I_{rat} < 1.2 \\ 0.75 & \text{if } 0.5 \leq I_{rat} < 0.75 \end{cases}$$

MCC11

The MCC11 (Mostly Constant Catch with 11 levels) management procedure is empirical and uses a single input—the North Atlantic Swordfish combined index of abundance (*"the Combined Index"*). The goal of the MCC11 MP is to have the catch remain as constant as possible and only increase the TAC if the Combined Index increased substantially and only decrease the TAC if the Combined Index declined substantially. This MP is tuned to achieve a [60%, 70%] probability of being in the Kobe green quadrant (i.e. $SB \geq SB_{MSY}$ and $F \leq F_{MSY}$) in [each of the three 10 year projection time periods (short = years 1-10; medium = years 11-20; long = years 21-30) / the short time period (years 1-10) and at least 60% in the medium (years 11-20) and long (years 21-30) time periods].

Abundance index

The Combined Index uses catch and effort data from 7 ICCAT CPCs and draws from both Task 2 catch and effort data and detailed catch and effort records obtained directly from some CPCs—totaling over 95% of the annual catch in the North Atlantic. The initial year of the index is 1963. The index values are in kilograms of swordfish catch per 1000 hooks. This model-based index uses a Tweedie error distribution and categorical explanatory variables: year, quarter, spatial zone, a targeting variable, and a size class variable.

The predicted year values are then standardized to a mean of 1 over the whole time series. These values are defined as *I*.

MP specifications

This MP uses a 3-year management cycle length. The base TAC (constant catch) is 12,600 mt—this is an approximation of the constant catch that would result in at least 60% PGK and also achieve nLRP <[15%, 10%].

A base TAC (TAC_{base}) is calculated as:

$$TAC_{base} = \theta 12{,}600$$

where θ is the tuning parameter that results in achieving the desired short-term PGK. The tuning parameters for MCC11 at [60% PGK is 0.7562 / 70% PGK is 0.7316].

TAC_{base} is modified by comparing the ratio of the current 3-year average of the Combined Index (I_{curr}) to a historical 3-year average of the Combined Index (I_{base}):

$$I_{rat} = \frac{I_{curr}}{I_{base}}$$

I_{base} is calculated as the average of the Combined Index from 2017-2019. The value of I_{rat} is used to determine how much TAC_{base} should be increased or decreased if at all.

The TAC for the following management cycle is calculated as:

$$TAC_{y+1} = TAC_{base} \Delta_{TAC}$$

where Δ_{TAC} is calculated as:

$$\Delta_{\text{TAC}} = \begin{cases} 1.85 & \text{if } I_{\text{rat}} \geq 1.85 \\ 1.75 & \text{if } 1.75 \leq I_{\text{rat}} < 1.85 \\ 1.65 & \text{if } 1.65 \leq I_{\text{rat}} < 1.75 \\ 1.55 & \text{if } 1.55 \leq I_{\text{rat}} < 1.65 \\ 1.45 & \text{if } 1.45 \leq I_{\text{rat}} < 1.55 \\ 1.35 & \text{if } 1.35 \leq I_{\text{rat}} < 1.45 \\ 1.25 & \text{if } 1.25 \leq I_{\text{rat}} < 1.35 \\ 1.15 & \text{if } 1.15 \leq I_{\text{rat}} < 1.25 \\ 1.00 & \text{if } 0.75 \leq I_{\text{rat}} < 1.15 \\ 0.75 & \text{if } 0.5 \leq I_{\text{rat}} < 0.75 \\ 0.5 & \text{if } I_{\text{rat}} < 0.5 \end{cases}$$

SPSSFox

The SPSSFox management procedure uses a state-space surplus production model, assuming a Fox production curve, to set the TAC (**Figure D1**). It uses the North Atlantic Swordfish combined index of abundance (*"the Combined Index"*) as an abundance indicator. This MP is tuned to achieve a 60% PGK (i.e. $SB \geq SB_{MSY}$ and $F \leq F_{MSY}$) in each of the three 10 year projection time periods (short = years 1-10; medium = years 11-20; long = years 21-30).

Abundance index

The Combined Index uses catch and effort data from 7 ICCAT CPCs and draws from both Task 2 catch and effort data and detailed catch and effort records obtained directly from some CPCs—totaling over 95% of the annual catch in the North Atlantic. The initial year of the index is 1963. The index values are in kilograms of swordfish catch per 1,000 hooks. This model-based index uses a Tweedie error distribution and categorical explanatory variables: year, quarter, spatial zone, a targeting variable, and a size class variable.

The predicted year values are then standardized to a mean of 1 over the whole time series. These values are defined as *I*.

MP specifications

This MP uses a 3-year management cycle length. The Combined Index is used to track to relative changes in the population. A smoothed index is generated by applying Tukey's Running Median Smoother (stats::smooth R function).

The state-space surplus production model from the SAMtool package (SAMtool::SP_SS) is used to fit to the smoothed index and the reported catch. The SP_SS R function is run with the following arguments:

- prior=list(r=c(0.21, 0.1))
- start=list(n=1)
- fix_n=TRUE

The following harvest control rule is used to set the target exploitation rate (E_{targ}):

$$E_{\text{targ}} = \begin{cases} E_{\text{prop}} & \text{if } B_{\text{curr}} \geq B_{\text{thresh}} \\ E_{\text{prop}}\left(-0.367 + 1.167\dfrac{B_{\text{curr}}}{B_{\text{thresh}}}\right) & \text{if } B_{\text{thresh}} > B_{\text{curr}} > B_{\text{lim}} \\ E_{\text{min}} & \text{otherwise} \end{cases}$$

where E_{prop} is the proposed harvest rate, calculated as $\theta 0.15$ where θ is the tuning parameter (θ for 60% PGK is 0.5939), B_{curr} is the estimated biomass from the surplus production model, B_{thresh} is the estimated biomass corresponding with maximum sustainable yield, B_{lim} is $0.4B_{\text{thresh}}$, and E_{min} is $0.1E_{\text{prop}}$.

The total allowable catch (TAC) for the following year is then calculated as:

$$TAC_{y+1} = E_{\text{targ}} B_{\text{curr}}$$

The TAC is subject to a constraint where it cannot change by more than 25% from one management cycle to the next.

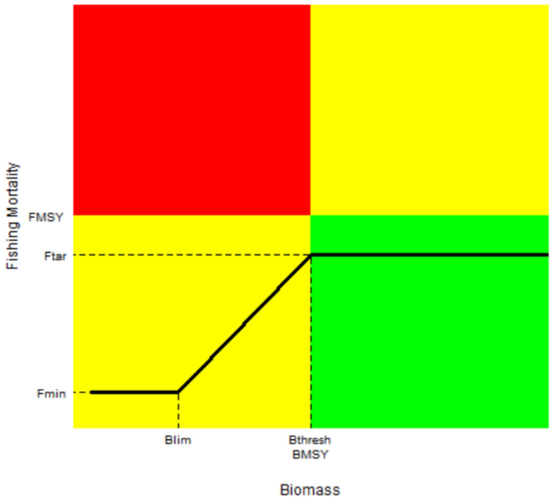

Figure D1. Graphical form of the SPSSFox harvest control rule.