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North Atlantic Swordfish MSE: Final Results, Decision Guide, and CMP Specifications

This document presents the final results of the North Atlantic swordfish management strategy evaluation (MSE), which address feedback received from Panel 4 in October 2023. The intention is to facilitate decision-making for adoption of a management procedure (MP) at the 28th Regular Meeting of the Commission in November 2023.

Management Objectives

The N-SWO MSE includes 10 key performance metrics as a benchmark for evaluation of the Commission's selected management objectives. **Appendix A** shows the current management objectives and performance metrics based on input received from Panel 4 intersessionally in 2023, most recently in October.

Importantly, all yield performance metrics calculate the TAC as landings plus dead discards.

Candidate Management Procedures

The SCRS Swordfish Species Group has worked collaboratively to develop and test a number of CMPs. Five CMP types remain, as agreed by Panel 4. In addition to representing both model-based and empirical CMPs, the five remaining CMP types are SCRS-recommended because they cover a wide 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. **Appendix D** contains detailed specifications for each CMP and **Appendix E** contains key terminology.

This table describes the CMP types:

	CE	MCC5	MCC7	SPSSFox	SPSSFox2
Type	Empirical	Empirical	Empirical	Model	Model
Index	Combined	Combined	Combined	Combined	Combined
Steps	N/A	4	7	N/A	N/A
Minimum TAC	10% of reference historical exploitation	4000 t	50% of base TAC (~5000-5500t)	10%*E_{MSY}	10%*E_{MSY}
PGK Tuning	60%	60%, 70%	60%, 70%	60%	60%
Stability Limit	±25% cap	None	None	±25% cap	±25% cap, with no cap on TAC decreases if the MP's estimated B<B_{MSY}
Reference Period	2016-2020	2017-2019	2017-2019	N/A	N/A
Detailed Description	Attempts to maintain a constant exploitation rate in the projection period, based on the mean exploitation rate in the recent historical years.	Provides relative stability in TAC by using a base TAC that can increase by 1 step or decrease by up to 2 steps. Steps occur once thresholds in the abundance indicator are breached. Steps	Like MCC5 but the base TAC can increase by 4 small steps or decrease by 2 steps. A smoother is applied to the 3-year average of the Combined	A Fox surplus production model with a hockey-stick HCR where fishing mortality decreases linearly from 100*B_{MSY} to 40*B_{MSY}.	Like SPSSFox but with a bifurcated stability restriction as described above in "Stability Limit".

		are selected depending on the value of the current 3-year average of the Combined Index compared to a 3-year historical average (2017-2019). The minimum TAC is used when the 3-year average of the Combined Index is less than half of the 3-year historical average.	Index to buffer effects of interannual variability in the index.		

All '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. In addition, 'c-tunings' for MCC5 and MCC7 are tuned to 70% probability of being in the Kobe green quadrant for the short time period (years 1-10; denoted as 'c' CMPs). There are therefore a total of seven final CMPs.

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. All CMPs achieve the Safety minimum threshold, achieving 97% or greater probability of not breaching the LRP. Performance against other objectives is then compared.

CMPs use a 3-year management cycle and in testing, did not produce TAC changes of less than 200 t between management cycles.

Final CMP Performance Results

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

	MP	AvTAC_long	AvTAC_med	AvTAC_short	nLRP	PGK	PGK_long	PGK_med	PGK_short	PNOF	VarC
1	CE_b	11628.6	11298.28	12726.57	0.97	0.61	0.63	0.6	0.61	0.74	0.15
2	MCC5_b	11029.56	13235.47	13235.47	1	0.62	0.62	0.6	0.63	0.72	0.06
3	MCC5_c	12854.07	12854.07	12854.07	1	0.7	0.71	0.68	0.7	0.8	0.06
4	MCC7_b	12454.65	12454.65	12973.59	1	0.61	0.62	0.6	0.62	0.73	0.09
5	MCC7_c	12505.21	12005	12505.21	1	0.7	0.72	0.69	0.7	0.81	0.09
6	SPSSFox_b	11683.41	11602.68	12751.04	0.99	0.63	0.68	0.62	0.6	0.75	0.16
7	SPSSFox2_b	11802	11383.2	12797.41	1	0.67	0.74	0.68	0.6	0.76	0.2

Figure 1. Quilt plot showing results for the 7 remaining CMPs (each with up to two Status tuning options: PGK=60% - 'b', or 70% - 'c') against key performance metrics for the reference set of operating models. CMPs are listed in alphabetical order. See **Appendix A** for performance metric descriptions. The nLRP performance metric is the probability of not breaching the limit reference point; this modification of the LRP performance metric means that higher values are better for all metrics except VarC. Darker shading indicates better performance, but some of the values are very similar, despite different shading.

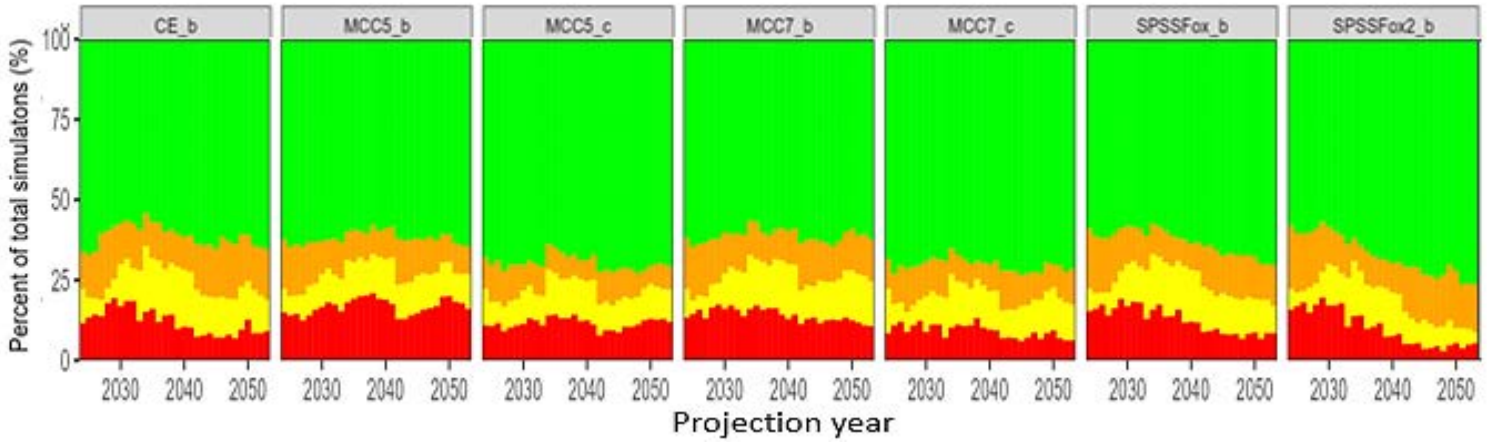

Figure 2. Kobe time plot showing the median percentage (vertical axis) of simulations across all reference operating models that fall in each of the Kobe quadrants in each projection year (horizontal axis). Green indicates that the stock is neither overfished nor subject to overfishing. Orange means 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 continued overfishing.

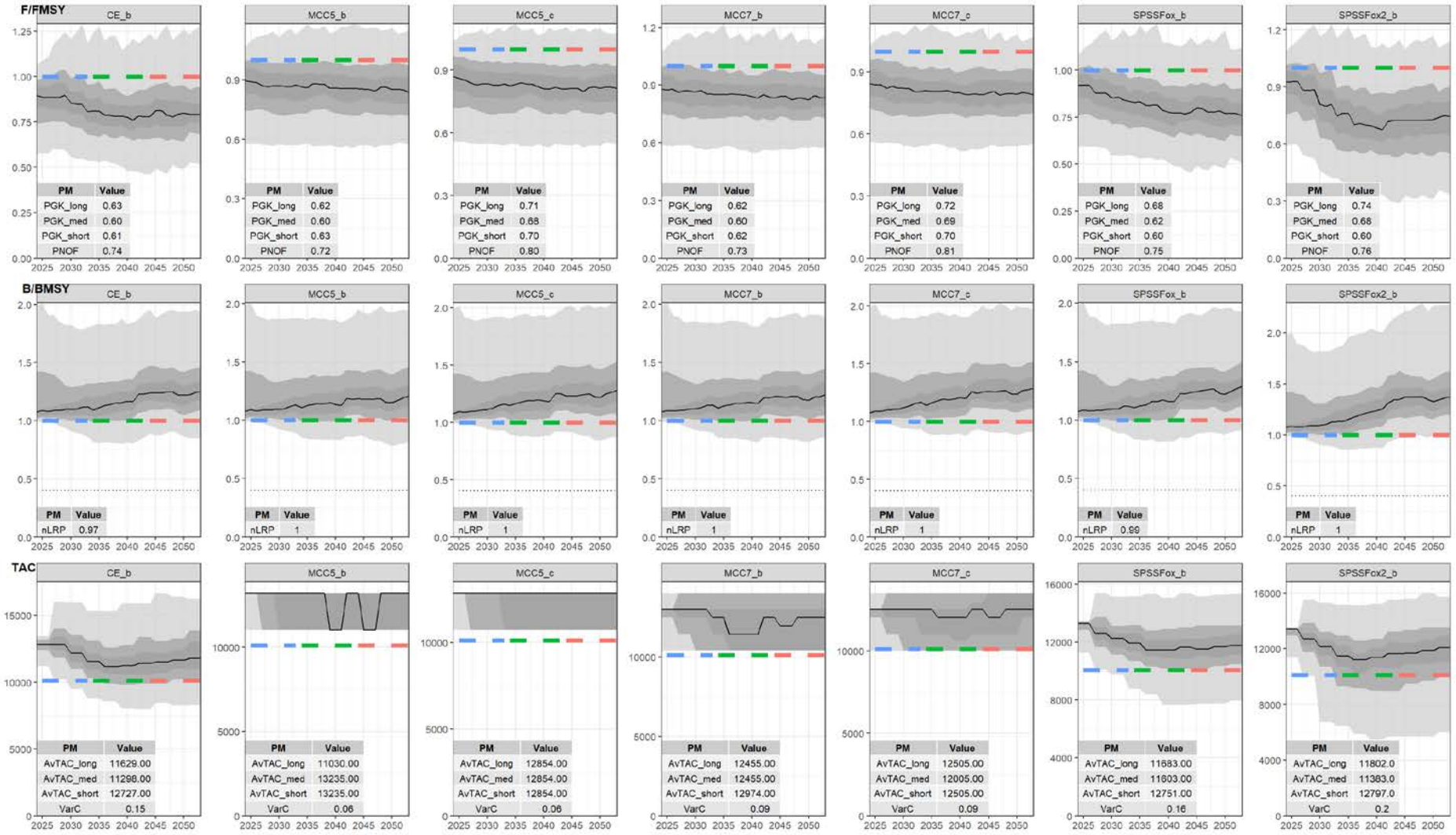

Figure 3. Trajectory of a) fishing mortality (F) relative to F_{MSY} (top row), b) spawning stock biomass (SSB) relative to SSB_{MSY} (middle row), and c) TAC (in tons, bottom row) for the 7 final CMPs. Note that the scale is not the same for all axes across a row. Results are summarized across all reference operating models. Blue bars show the short time period, while green depicts medium and red long.

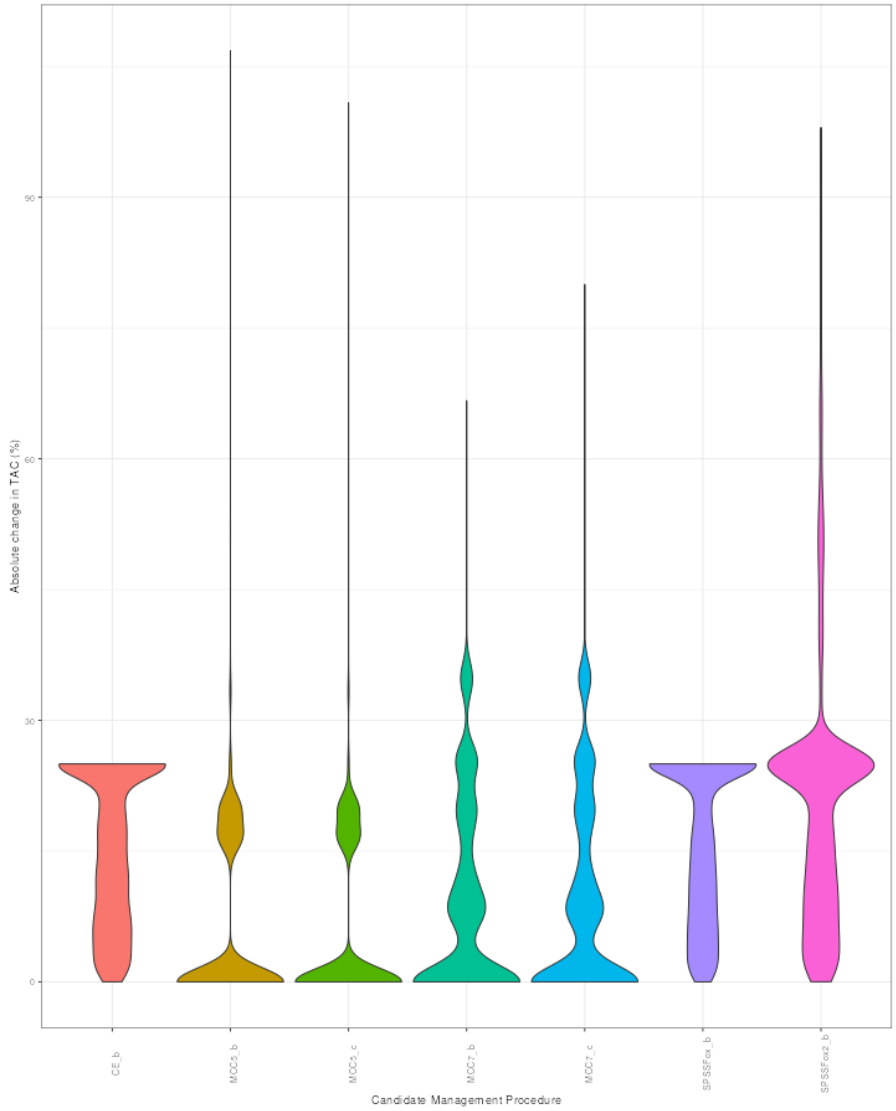

Figure 4. Violin plot for the change in TAC between management cycles. The width of the violin plot indicates the proportion of data points that are in each region of the plot (i.e., wide areas of the plot indicate a relatively large number of data points in that region, while narrow areas of the plot indicate few data points).

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. Options are 60% or 70% probability of occurring in the green quadrant of the Kobe matrix.

- Minimum acceptable threshold for the Safety objective. Options are 85%, 90% or 95% probability of the stock *not* falling below B_{LIM} ($0.4*B_{MSY}$) at any point during the 30-year evaluation period.

    - Note that all CMPs in the short-list meet the most stringent safety objective threshold (95%).

- Maximum percent allowable change in TAC between management periods. Options are 25% (CE, SPSSFox), 25% with no limit on TAC decreases when the MP's estimated $B<B_{MSY}$ (SPSSFox2), or no limit (MCC5, MCC7).

- Results for CMP relative performance are provided above in **Figures 1-4** and may help to inform these decisions.

b) Final CMP type

- There are seven remaining CMPs – CE_b, MCC5_b, MCC5_c, MCC7_b, MCC7_c, SPSSFox_b and SPSSFox2_b.

- 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 (years 1-10).

- 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 1-4**. **Appendix B** contains CMP results for robustness scenario 3b (climate change effects on recruitment).

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 metrics based on input received at the March, June and October 2023 Panel 4 meetings. Importantly, all yield performance metrics calculate the TAC as landings plus dead discards.

Management objectives	*Corresponding key performance metrics*
Status The stock should have a [60, 70]% 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., $SSB \geq SSB_{MSY}$ and $F < F_{MSY}$) in years 1-10 **PGK_{MED}**: Probability of being in the Kobe green quadrant (i.e., $SSB \geq SSB_{MSY}$ and $F < F_{MSY}$) in years 11-20 **PGK_{ALL}**: Probability of being in the Kobe green quadrant (i.e., $SSB \geq SSB_{MSY}$ 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 [5, 10, 15]% or less probability of the stock falling below B_{LIM} ($0.4*B_{MSY}$) at any point during the 30-year evaluation period.	**LRP_{ALL}**[1]: Probability of breaching the limit reference point (i.e., $SSB < 0.4*SSB_{MSY}$) in any of years 1-30
Yield Maximize overall catch levels.	**TAC1**[2]: TAC in the first management cycle (years 1-3) **$AvTAC_{SHORT}$**: 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]%. [Also test no stability limitation and bifurcated stability when $B < B_{MSY}$.]	**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 metrics to indicate a 'safer' outcome, such as in trade-off plots. For example, a 15% LRP threshold is equivalent to a nLRP threshold of 85%.
[2] TAC1 values have been removed from the CMP performance results and will be replaced by a separate table containing the TAC recommendation values for the first management cycle (years 2024 – 2026) for each CMP.

CMP results for Robustness Scenario 3b – climate change effects on recruitment

	MP	AvTAC_long	AvTAC_med	AvTAC_short	nLRP	PGK	PGK_long	PGK_med	PGK_short	PNOF	VarC
1	CE_b	4821.7	5921.37	11892.86	0.4	0.22	0.56	0.03	0.07	0.48	0.22
2	MCC5_b	11029.56	8272.17	11029.56	0.2	0.08	0.17	0	0.07	0.39	0.23
3	MCC5_c	10711.72	8033.79	10711.72	0.22	0.09	0.17	0	0.09	0.4	0.2
4	MCC7_b	7784.15	7784.15	11416.76	0.2	0.08	0.16	0	0.06	0.37	0.17
5	MCC7_c	10004.17	7503.13	12005	0.34	0.1	0.22	0	0.09	0.44	0.16
6	SPSSFox_b	5289.65	5824.01	11876.97	0.46	0.22	0.58	0.03	0.04	0.5	0.22
7	SPSSFox2_b	6204.46	3436.36	11890.47	0.78	0.4	0.91	0.22	0.06	0.73	0.29

Figure C1. Quilt plot showing results for the 7 remaining CMPs (each with up to two Status tuning options: PGK=60% - 'b', or 70% - 'c') against key performance metrics for robustness operating model 3b (climate change effects on recruitment). CMPs are listed in alphabetical order. See **Appendix A** for performance metric descriptions. The nLRP performance metric is the probability of not breaching the limit reference point; this modification of the LRP performance metric means that higher values are better for all metrics except VarC. Darker shading indicates better performance, but some of the values are very similar, despite different shading.

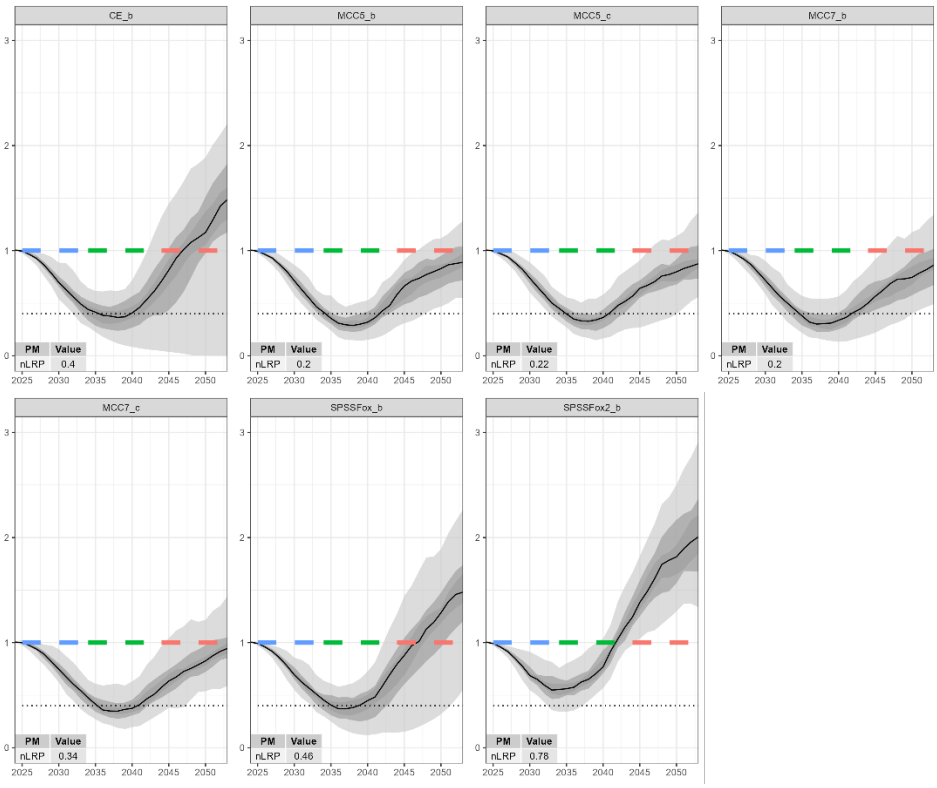

Figure C2. Trajectory of spawning stock biomass (SSB) relative to SSB_{MSY} for all CMPs under the climate change robustness test 3b (features a decline in recruitment in the first fifteen years, followed by a return to average recruitment for the remainder of the projection period). This robustness operating model, R3b, presents the biggest challenge to CMPs compared to all other OMs. The 'b' CMPs are tuned to achieve at least 60% PGK for all three decades in the projection period and the 'c' CMPs are tuned to 70% PGK for the short time period in the projection years (years 1-10). The small-dashed black horizontal line indicates the LRP of $0.4*SSB_{MSY}$. The coloured horizontal line shows the SSB_{MSY} target over the short (blue), medium (green) and long (red) terms. The dark black trend line shows the median value of SSB, while the increasingly lighter shades of grey show the 50th, 60th, and 90th percentiles, respectively.

Appendix C

Proposed schedule for data provision, updating MPs and stock assessments.

		Activity					***Data inputs***	
Year	Management cycle	MP run	MP advice implemented	Stock assessment	MSE Review	Exceptional circumstances evaluated	Combined index[3]	Exceptional circumstance indicators
2023		x					x	x
2024	1		x			x		x
2025						x		x
2026		x				x	x	x
2027	2		x	[x]		x		x
2028				[x]		x		x
2029		x			[x]	x	x	x
2030	3		x			x		x
2031						x		x
2032		x				x	x	x

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

Detailed specifications for short-listed CMPs

CE

The CE management procedure aims to keep a fixed exploitation rate in the projection years. The Combined Index is used to track relative changes in the population. A smoothed index is generated by applying Tukey's Running Median Smoother (stats::smooth R function).

The historical relative exploitation rate is calculated as:

$$E_{\text{hist}} = \frac{\bar{C}_{\text{hist}}}{\bar{I}_{\text{hist}}}$$

where $\bar{C}_{\text{hist}}$ and $\bar{I}_{\text{hist}}$ are the mean reported landings and smoothed index respectively over a fixed 5 year historical period (2016 – 2020).

The current relative exploitation rate is calculated as:

$$E_{\text{curr}} = \frac{\bar{C}_{\text{curr}}}{\bar{I}_{\text{curr}}}$$

where $\bar{C}_{\text{curr}}$ and $\bar{I}_{\text{curr}}$ are the mean reported landings and smoothed index respectively over the 3 most recent projection years.

The target relative exploitation rate is set to E_{hist} but subject to a harvest control rule based on the ratio of the current to historical smoothed index (I_{ratio}) (calculated over same years as above):

$$E_{\text{targ}} = \begin{cases} E_{\text{hist}} & \text{if } I_{\text{ratio}} \geq 0.8 \\ E_{\text{hist}}(-1.4 + 3I_{\text{ratio}}) & \text{if } 0.8 > I_{\text{ratio}} > 0.5 \\ 0.1E_{\text{hist}} & \text{otherwise} \end{cases}$$

The ratio of the target to current relative exploitation rate is calculated:

$$E_{\text{ratio}} = \frac{E_{\text{targ}}}{E_{\text{curr}}}$$

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

$$TAC_{y+1} = \theta E_{\text{ratio}} TAC_y$$

where θ is a tuning parameter, subject to a constraint where it cannot change by more than 25% from one management cycle to the next.

MCC

The goal of the MCC (Mostly Constant Catch) CMPs is to have the catch remain as constant as possible and only increase if the Combined Index increases substantially and only decrease if the Combined Index declined substantially. The base TAC (constant catch) would be 12,600 t, this is an approximation of the constant catch that would result in PGK60 and also achieve LRP <15%.

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 (currently tested at 51%, 60%, and 70%).

$\mathrm{TAC}_{\mathrm{base}}$ 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}):

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

The value of I_{rat} was then used to determine how much $\mathrm{TAC}_{\mathrm{base}}$ should be increased or decreased if at all.

The total allowable catch (TAC) for the following management cycle was then calculated as:

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

where Δ_{TAC} is determined by a set of CMP-specific rules described below.

MCC5

I_{base} is calculated as the average of the Combined Index from 2017-2019, and Δ_{TAC} calculated as below, but TAC is set to 4,000 t when $I_{\mathrm{rat}} < 0.5$.:

$$\Delta_{\mathrm{TAC}} = \begin{cases} 1.2 & \text{if } I_{\mathrm{rat}} \geq 1.2 \\ 1 & \text{if } 0.75 \leq I_{\mathrm{rat}} < 1.2 \\ 0.75 & \text{if } 0.5 \leq I_{\mathrm{rat}} < 0.75 \\ 0.5 & \text{if } I_{\mathrm{rat}} < 0.5 \end{cases}$$

MCC7

I_{base} is calculated as the average of the Combined Index from 2017-2019, and Δ_{TAC} calculated as:

$$\Delta_{\mathrm{TAC}} = \begin{cases} 1.35 & \text{if } I_{\mathrm{rat}} \geq 1.35 \\ 1.25 & \text{if } 1.25 \leq I_{\mathrm{rat}} < 1.35 \\ 1.20 & \text{if } 1.20 \leq I_{\mathrm{rat}} < 1.25 \\ 1.10 & \text{if } 1.15 \leq I_{\mathrm{rat}} < 1.20 \\ 1 & \text{if } 0.75 \leq I_{\mathrm{rat}} < 1.15 \\ 0.75 & \text{if } 0.5 \leq I_{\mathrm{rat}} < 0.75 \\ 0.5 & \text{if } I_{\mathrm{rat}} < 0.5 \end{cases}$$

SPSSFox

The SPSSFox and SPSSFox2 management procedures use a state-space surplus production model to set the TAC. The two CMPs assume a Fox production curve.

The Combined Index is used to track relative changes in the population. A smoothed index is generated by applying Tukey's Running Median Smoother.

The state-space surplus production model from the SAMtool package (SAMtool::SP_SS) is used to fit to the smoothed index and the reported landings.

For the SPSSFox CMP, the following harvest control rule is used to set the target exploitation rate $\left(E_{\mathrm{targ}}\right)$:

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

where E_{prop} is the proposed harvest rate, calculated as $\theta 0.15$ where θ is the tuning parameter, 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 management cycle is then calculated as:

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

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

For SPSSFox2, the TAC is subject to a constraint where it cannot change by more than 25% from one management cycle to the next, except when the MP's estimated $B<B_{MSY}$, in which case there is no limit on the reduction in TAC between management cycles.

Appendix E

Key terminology used in this document

Limit reference point (LRP): A benchmark for an indicator that defines an undesirable biological state of the stock such as the BLIM or the biomass limit which is undesirable to be below. To keep the stock safe, the probability of violating an LRP should be very low. In many cases, nLRP (not breaching the LRP) is used when it is more appropriate for higher values of performance metrics to indicate a 'safer' outcome, such as in trade-off plots. For example, a 15% LRP threshold is equivalent to an nLRP threshold of 85%.

Management objectives: Formally adopted social, economic, biological, ecosystem, and political (or other) goals for a stock and fishery. They include high-level or conceptual objectives often expressed in legislation, conventions or similar documents. They must also include operational objectives that are specific and measurable, with associated timelines. When management objectives are referenced in the context of management procedures, the latter, more specific definition applies, but sometimes conceptual objectives are adopted first (e.g., Rec. 19-14 for SWO-N).

Management procedure (MP): Some combination of monitoring, assessment, harvest control rule and management action designed to meet the stated objectives of a fishery, and which has been simulation tested for performance and adequate robustness to uncertainties. Also known as a harvest strategy.

Management strategy evaluation (MSE): A simulation-based, analytical framework used to evaluate the performance of multiple management procedures relative to the pre-specified management objectives.

Operating model (OM): A model representing a plausible scenario for stock and fishery dynamics that is used to simulation test the management performance of CMPs. Multiple models will usually be considered to reflect the uncertainties about the dynamics of the resource and fishery, thereby testing the robustness of management procedures.

Performance statistic: A quantitative expression of a management objective used to evaluate how well an objective is being achieved by determining the proximity of the current value of the statistic to the objective. Also known as a performance metric or performance indicator.

Reference Grid: The operating models that represent the most important uncertainties in stock and fishing dynamics, which are used as the principal basis for evaluating CMP performance. The reference operating models are specified according to factors (e.g., natural mortality rate) that have multiple levels (possible scenarios for each factor, e.g., high / low natural mortality rate). Reference OMs are usually organized in a fully crossed orthogonal 'grid' of all factors and levels.

Robustness Set: Other potentially important uncertainties in stock and fishing dynamics may be included in a Robustness Set of tests that provide additional tests of CMP performance robustness. They can be used to further discriminate between CMPs. Compared to the Reference Grid operating models, the Robustness Set will be typically less plausible and/or influential on performance.