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Further MP simulation testing for Indian Ocean skipjack tuna

Prepared for the Indian Ocean Tuna Commission

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CESCAPE Client Report

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Project Objectives

Work on an updated Management Procedure for Indian Ocean skipjack tuna has been ongoing since 2019. The current phase of the work is from October 2023 to June 2024.

The overall objective is to:

- Develop a Management Procedure for Indian Ocean skipjack tuna, including specification of the data inputs, that has been fully tested using a Management Strategy Simulation framework.

Specific objectives defined at the 6th Session of the TCMP (2023) include:

1. Re-visit the possibility of using a model-based Management Procedure based on the updated CPUE indices to be presented at WPTT25;
2. Propose a set of candidate Management Procedures to the TCMP (2024) for potential adoption by the Commission.

Item (1) was addressed at the 25th Session of the IOTC-WPTT in October 2023, with evidence presented that a model-based approach to setting management catch limits was not viable. At the preceeding 14th Session of the IOTC-WPM, a further set of objectives for the work were proposed:

4. Update the Operating Model to the most recent skipjack stock assessment, presented at the 25th Session of the IOTC-WPTT in October 2023;
5. Impose a minimum recommended catch of approximately 66 thousand tonnes;
6. Include a temporal correlation in the projected recruitment timeseries;
7. Evaluate the effect of different catch change limits.

Items (2), (4) and (5) were addressed by work at the 7th TCMP (2024). However, evaluation of the candidate MPs was considered incomplete and a further set of refinements requested:

9. Include the full grid of 36 assessment models as operating models;
10. Include an HCR with tuning parameters that correspond to 10% and 40% depletion;
11. Explore the consequence of two- or three-year data lags when setting the TAC;
12. Evaluate symmetric (15%) and asymmetric (10% down, 15% up) TAC-change constraints;
13. Include in the robustness testing a 20% or 30% overcatch and a sustained drop in recruitment for 5 – 10 years at the lowest historic recruitment level.

The current report provides a review of work to date for discussion by the WPM (MSETF) and in preparation for the 8th TCMP in May 2024.

Introduction

Following recent presentation of candidate empirical MPs to the TCMP and the WPM in 2023 and 2024 (Edwards, 2023b,a,c, 2024), the following work has been scheduled (IOTC, 2023d,a,b, 2024):

1. Evaluate the performance of data-based (empirical) MPs that use as input the mean of the log of the standardised PL and PSLS indices and which output a recommended catch limit (TAC);
2. Use as a set of operating models the 36 stock synthesis assessment model runs constructed by Fu (2023);
3. Use as tuning criteria the probability of being in the target quadrant defined by $B_y > B_{40\%}$ and $E_y < E_{40\%}$;
4. Tune according to the 50%, 60% or 70% probability of being in the target quadrant assuming:
   - no limit to the TAC change per MP implementation;
   - a symmetric 15% TAC-change limit for each MP implementation;
   - an asymmetric 10% reduction and 15% increase limit in the TAC change for each MP implementation;
5. Include index-based tuning parameters that correspond to depletion values of 10% and 40% in the set of candidate MPs;
6. Assume a 2-year lag between the availability of standardised catch rate indices and the setting of the TAC;
7. Include as robustness testing:
   - an overcatch of 20% or 30% above the recommended TAC for all projection years;
   - an unacknowledged 1% per annum increase in the catchability (i.e., an overestimation of the abundance by the MP);
   - a drop in recruitment for a period of 5-10 years to a level equal to the minimum estimated recruitment level from the stock assessment;
   - a 3-year lag in the availability of catch rate input data.

The current report outlines developmental work in partial fulfillment of these objectives. Unfortunately, given computational and time constraints, MPs with an asymmetric TAC-change limit have not yet been included. Robustness of tuned MPs to overcatch is included in this report but the remaining robustness tests will be presented in later work.

Management procedure design

Data inputs

The proposed MPs currently under development are based on standardised CPUE indices from the Maldivian PL (Medley et al., 2020b,a, 2023) and European PSLS fleets (Guery et al., 2020, Guery, 2020, Kaplan et al., 2023). These indices are both used routinely in Indian Ocean SKJ assessments (Fu, 2017, 2020, 2023).

The log-transformed PL and PSLS indices, offset by the mean and averaged across all four seasons within the year, show similar trends over time when plotted for overlapping years (1995 to 2021 inclusive; Figure 1). On this basis, the index in Equation 1, with notation a_y, has been proposed as in input value for the MP (Edwards, 2021b), with the reference value (a^{REF}) calculated, in the current case, from the 1995 to 2021 period.

Figure 1: Time series of the log-trasformed PL (blue) and PSLS (orange) indices between 1995 and 2021 (Fu, 2023), offset by their respective mean values. The grey line illustrates the arithmetic mean of the two log-trasformed indices (Equation 1).

$$a^{REF} = \frac{1}{2 \cdot n_s \cdot n_y} \cdot \left\{ \sum_{y=1995}^{2021} \sum_s \log\left(CPUE_{y,s}^{PSLS}\right) + \sum_{y=1995}^{2021} \sum_s \log\left(CPUE_{y,s}^{PL}\right) \right\} \tag{1a}$$

$$a_y = \frac{1}{2 \cdot n_s} \cdot \left\{ \sum_s \log\left(CPUE_{y-3,s}^{PSLS}\right) + \sum_s \log\left(CPUE_{y-3,s}^{PL}\right) \right\} - a^{REF} \tag{1b}$$

The stock assessment results from Fu (2023) can be used to estimate the relationship between a_y and the depletion. This relationship is shown in Figure 2. Also shown are values for a_y that correspond to depletions of 10% and 40% respectively. These depletion values were used in Res. 16/02 and the corresponding values of $a_X = -1.2$ and $a_T = -0.1$ have been used to guide development of the data-based MP.

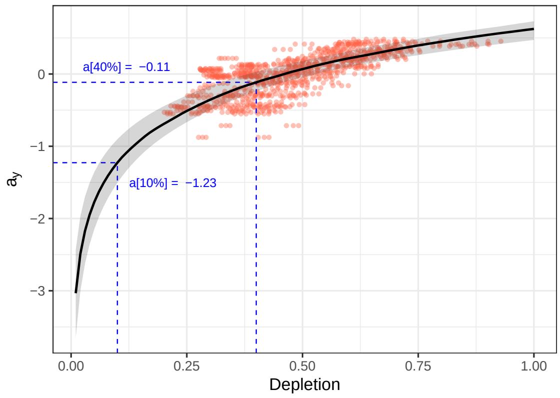


Figure 2: Relationship between the mean of the log-transformed PL and PSLS indices (a_y) and biomass depletion estimated by the 36 single-area stock assessment model runs of Fu (2023). Each data point (red) represents a value for a_y estimated from the empirical data, and the depletion estimated by the stock assessment. The fitted value line is shown, which is a median across relationships obtained from the different model runs.

Harvest Control Rule

The proposed MPs contain an HCR of the form:

$$C^{INIT} = \begin{cases} C_{max} & \text{for} \quad a_y \geq a_T \\ (C_{max} - C_{min}) \times \frac{a_y - a_X}{a_T - a_X} + C_{min} & \text{for} \quad a_X < a_y < a_T \\ C_{min} & \text{for} \quad a_y \leq a_X \end{cases} \tag{2}$$

For values $a_y \leq a_X$, the recommended catch is equal to C_{min}. As a_y increases, the recommended catch also increases, until for values of $a_y \geq a_T$ the recommended catch is equal to C_{max} (Figure 3). In addition, there are tuning parameters Δ_{min}^{TAC} and Δ_{max}^{TAC}, which denote the upper and lower percentage change limits for the TAC. These tuning parameters (a_X, a_T, C_{min}, C_{max}, Δ_{min}^{TAC} and Δ_{max}^{TAC}) are a fixed part of the MP, allowing simulation testing of it's performance with different tuning parameter values.

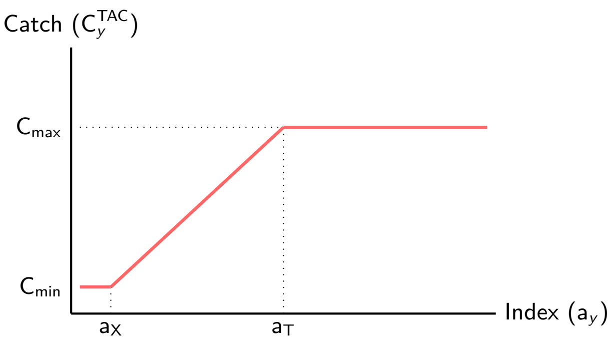


Figure 3: Schematic representation of the empirical Harvest Control Rule (Equation 2) that was proposed as part of a data-based MP (Edwards, 2021b,a). Tuning parameters are a_X, a_T, C_{max}, $\Delta_{min}^{TAC} and \Delta_{max}^{TAC}$, where Δ_{min}^{TAC} and Δ_{max}^{TAC} denote the upper and lower percentage change limits for the TAC. The C_{min} parameter was fixed.

Tuning

When tuning, MPs are selected using the simulated probability of the stock being in the management-target quadrant when averaged across projection years 11 to 15 (2033 to 2037 inclusive). The target quadrant is defined as: $B_y > B_{40\%}$ and $E_y < E_{40\%}$ (Edwards, 2023b, IOTC, 2023a). Tuning criteria equal to 50%, 60% and 70% probabilities of being in this target quadrant were adopted. In common with other IOTC stocks, if an MP matched one of these criteria then it would be selected for further consideration.

Simuation testing

Operating model

The management strategy simulation framework makes use of the current skipjack stock assessment, which represents our best understanding of the resource (Fu, 2023). The grid of 36 assessment models represent structural uncertainty in our understanding of the dynamics. These were used as operating models to simulation test the performance of candidate MPs over an 18 year projection period (2023 to 2040 inclusive). The recommended catch from 2023 to 2026 was fixed based on outputs from the current HCR (Table 1), with candicate MPs being implemented to recommend the catch from 2027 onwards, at three year intervals. Catch rate data was assumed to be available to the MP with a two-year lag. For example, the candidate MP being tested is first implemented in 2026, using simulated catch rate data up to and including 2025, to set the TAC for 2027.

Table 1: Recommended catch from current HCR and realised catches used by Fu (2023) in tonnes. *Note that the 2023 catch is predicted by the stock assessment based on current exploitation rates and is not an empirical value.

Year	Recommended catch	Realised catch	Overcatch
2018	470,029	606,134	29%
2019	470,029	590,388	26%
2020	470,029	547,258	16%
2021	513,572	655,115	28%
2022	513,572	648,697	26%
2023	513,572	*596,511	*16%
2024	628,606	–	–
2025	628,606	–	–
2026	628,606	–	–

The realised catch from 2023 onwards was assumed to be a symmetric deviation around the recommended TAC, with the magnitude of this deviation consistent with known annual deviations in the total catch. Despite the large overcatch observed in the fishery (Table 1), implementation error is not included in the tuning process (IOTC, 2023a). Rather, it is treated as part of the robustness testing.

Candidate Management procedures

Following recommendations by the TCMP, the value for C_{min} was fixed at 66 thousand tonnes. The value for C_{max} was informed by estimates for $C_{40\%}$ of approximately 528 thousand tonnes (Edwards, 2024). Values for a_X and a_T were informed by the relationship between a_y and the depletion (Figure 2). In particular we assumed that $\{a_X, a_T\} = \{-1.2, -0.1\}$, and referred to these MPs as "TARGET," because a_T corresponds to a depletion of approximately 40% (Figure 2). An alternative MP design assumed $\{a_X, a_T\} = \{-1.4, -0.3\}$, which was referred to as "STABLE," because it is expected to lead to a more stable TAC timeseries (Edwards, 2024). The MP's either had a TAC change limit of 15% or no limit (the asymmetric change limits could not be included given computational and time constraints, and is reserved for future work). If a change limit was included the MP was referred to as "buffered" and given the "B" suffix.

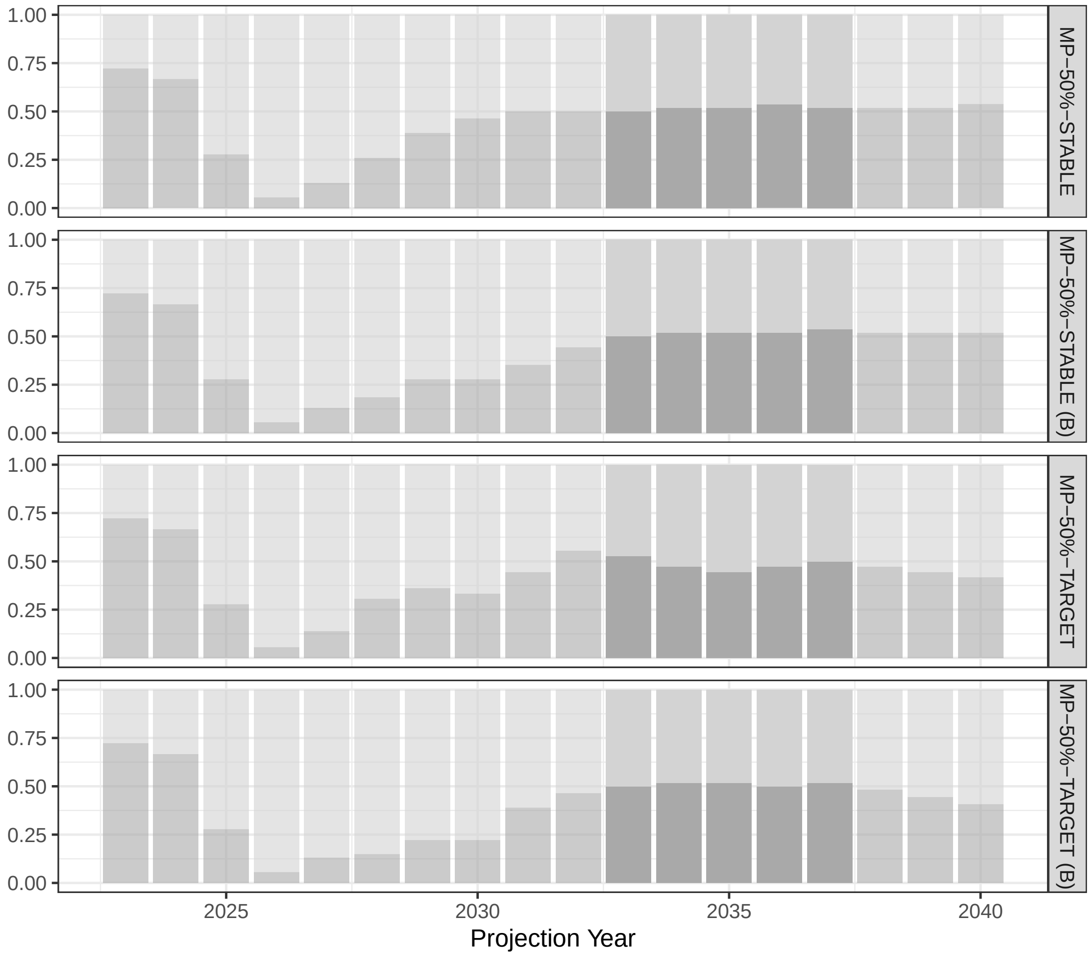
Following tuning, the MPs listed in Table 2 were selected. The associated tuning timeseries are illustrated in Figure 4, which shows the target probabilities over time for each MP.

Table 2: Tuning parameters for MPs tuned to the 50%, 60% and 70% tuning criteria. Tuning parameters a_X and a_T for the TARGET MPs correspond to a depletion of approximately 10% and 40% respectively. For the STABLE MPs, a_X and a_T correspond to depletions of approximately 8% and 32% respectively. MPs that are buffered with a 15% TAC change limit are given the "B" suffix. Values for C_{max} and C_{min} are given in units of 1000 tonnes.

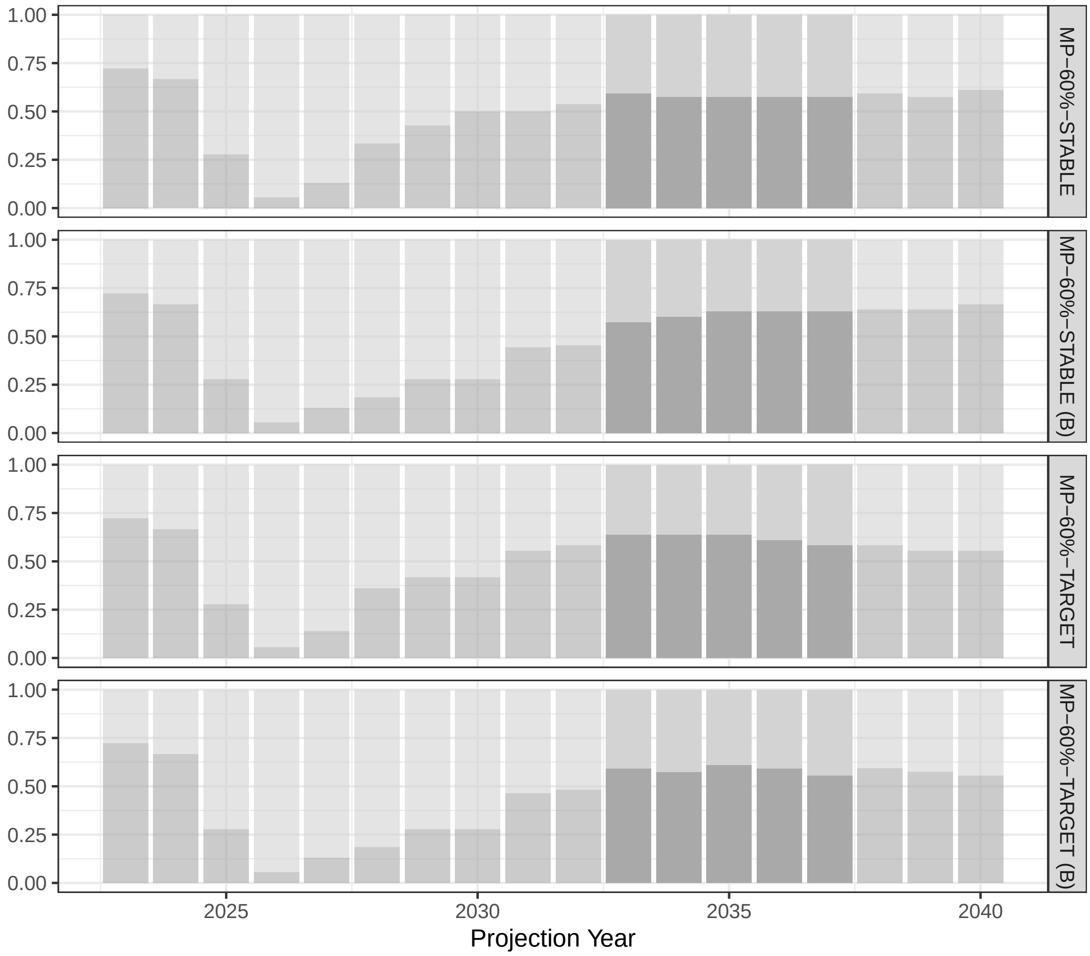
MP	C_{min}	C_{max}	a_X	a_T	Δ^{TAC}_{min}	Δ^{TAC}_{max}
MP-50%-STABLE	65.80	526.36	-1.40	-0.30	0	∞
MP-50%-STABLE (B)	65.80	526.36	-1.40	-0.30	85%	115%
MP-50%-TARGET	65.80	557.94	-1.20	-0.10	0	∞
MP-50%-TARGET (B)	65.80	557.94	-1.20	-0.10	85%	115%
MP-60%-STABLE	65.80	515.84	-1.40	-0.30	0	∞
MP-60%-STABLE (B)	65.80	510.57	-1.40	-0.30	85%	115%
MP-60%-TARGET	65.80	536.89	-1.20	-0.10	0	∞
MP-60%-TARGET (B)	65.80	536.89	-1.20	-0.10	85%	115%
MP-70%-STABLE	65.80	505.31	-1.40	-0.30	0	∞
MP-70%-STABLE (B)	65.80	494.78	-1.40	-0.30	85%	115%
MP-70%-TARGET	65.80	526.36	-1.20	-0.10	0	∞
MP-70%-TARGET (B)	65.80	515.84	-1.20	-0.10	85%	115%

Robustness testing

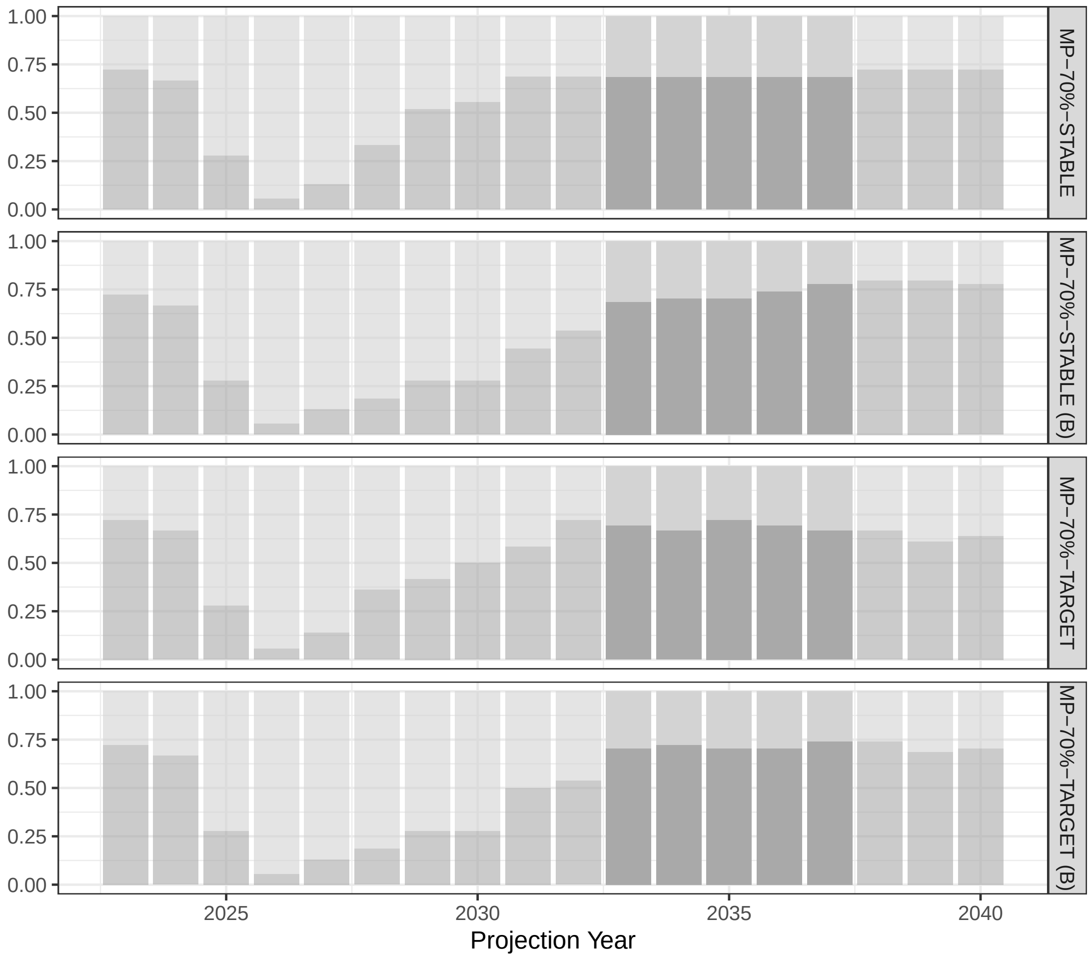
A range of robustness tests are scheduled for the tuned MP. Arguably the most important are the overcatch (Table 1) and the possibility of recruitment failure, given the likelihood that productivity is environmentally driven. In the current work, robustness of each tuned MP to overcatch values of 20% and 30% are presented.



(a) MP's tuned to 50% probability of being in the target quadrant.



(b) MP's tuned to 60% probability of being in the target quadrant.



(c) MP's tuned to 70% probability of being in the target quadrant.

Figure 4: Simulated probabilities of being in the target quadrant over time, per MP (Table 2). Between 2023 and 2026 the TAC was fixed at known values (Table 1), after which the TAC was set by the MP. Each MP was tuned using the target quadrant probabilities between 2033 and 2037 inclusive.

Simulation results

Reference case

The relationships between the projected indices and the recommended catches are shown in Figure 5 for each MP. In general, the TARGET MPs have a higher C_{max}, but a lower probability of the recommended TAC being equal to C_{max}, meaning that the TAC timeseries will be less stable.

Tables 4 to 6 (see also Figures 6 and 7) show that the tuning criteria is the most important consideration, with the 50% tuning yielding a higher catch but also lower stock biomass compared to the 60% and 70% criteria. A secondary consideration is selection of the TARGET or STABLE MPs, with the STABLE MP improving stability of the catch by reducing both the number of TAC changes and the magnitude of each change. This result is common across all tuning criteria. It is also noteworthy that even though the TARGET MPs have a higher value for C_{max} (Table 2) they do not typically yield a higher overall TAC compared to their STABLE counterparts, because the stock is less frequently above a_T (i.e., on the plateau). Overall catches are similar and the stock status between TARGET and STABLE MPs is comparable.

Finally, we can considered whether it is advantageous to buffer the TAC change with a change limit. Results indicate that te presence of a TAC change limit does not necessarily lead to a more stable TAC timeseries. Rather the buffered MPs can have a lower probability of the TAC being equal to C_{max} (Figure 5), and this observation is reflected in Tables 4 to 6, which show that when the TAC change is limited, the number of changes recommended by the MP can be increased. This result is most clearly illustrated in Figure 8, which shows the improved TAC stability of the STABLE MPs, but also the effect of buffering the TAC change. There is an improvement in the catch stability for TARGET MPs, which typically have a much higher degree of instability, but not for the STABLE MPs, which are already more stable.

Further illustrations of the simulation results are provided in Figures A1 to A2. Finally, the Kobe and Majuro phase plots are provided in Figure 9, indicating that none of the MPs are predicted to lead to overfishing of the stock, under the assumptions currently represented by the operating model. It is anticipated that the next phase of the work will investigate these assumptions through robustness testing.

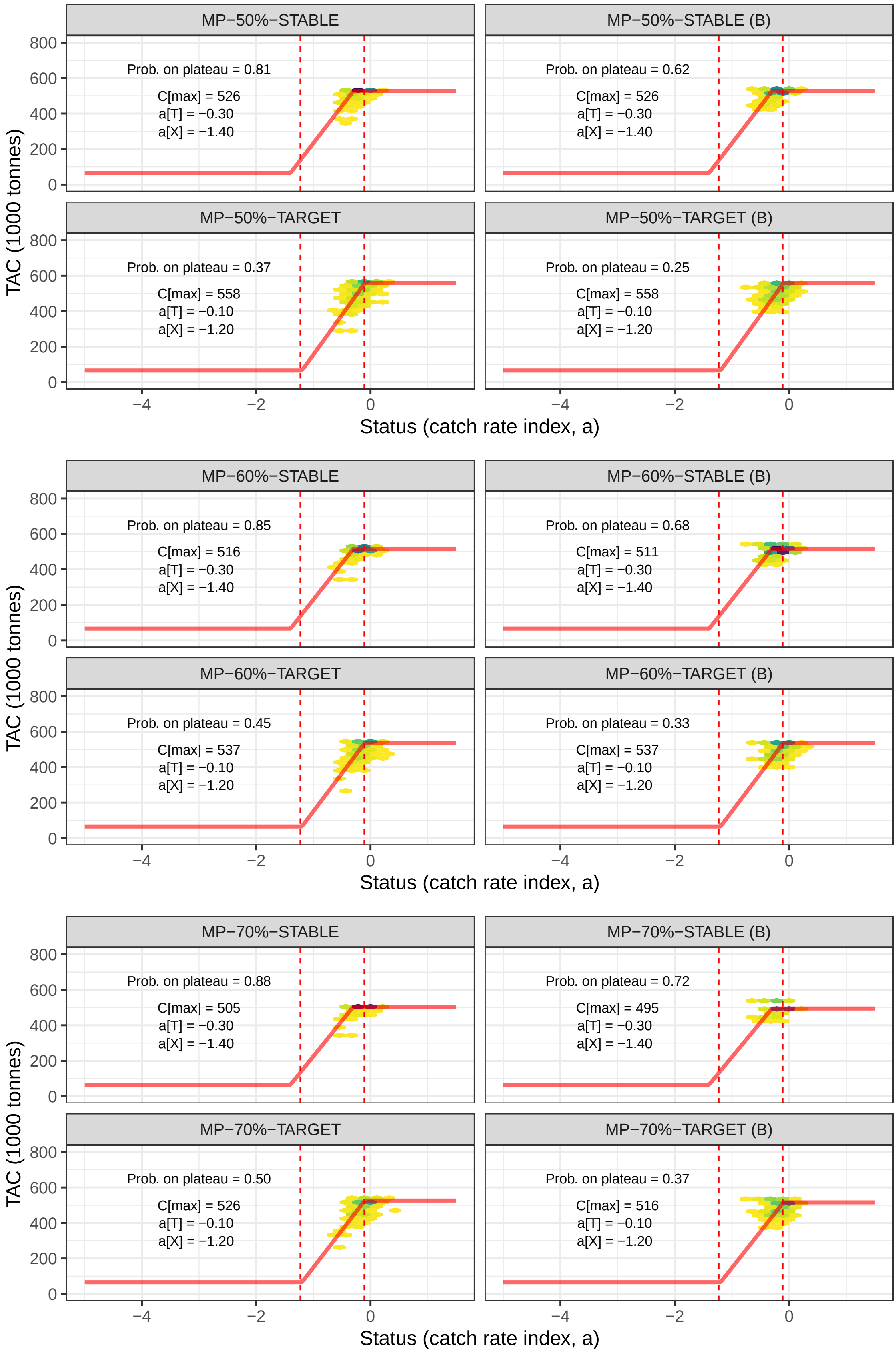


Figure 5: Relationship between the stock status, as measured by the catch rate index value a_y, and the TAC for each MP (Table 2). The HCR for each MP is shown schematically in red, and the distribution of states as a two-dimensional histogram with darker colours indicating a higher frequency.

Table 3: Diagnostic outputs for MP evaluations over 14 year projection period (2027 to 2040). Each performance statistic is generated by first calculating the summary statistic per run and iteration across projection years, and then reporting the median and 80% quantiles across those values – unless the statistic is a probability, in which case it is calculated as a proportion across all projection years, runs and iterations simultaneously. For catch stability statistics, only five TAC implementation years (2027, 2030, 2033, 2036 and 2039 inclusive) were used, and were calculated relative to the previous TAC.

Performance Statistic	Description	Summary statistic
Catch		
C_y^{TAC}	Total Allowable Catch (three years)	Mean
C	Total realised catch	Mean
$C_{[PL]}$	Catch for PL fleet	Mean
$C_{[PSLS]}$	Catch for PSLS fleet	Mean
$C_{[PSFS]}$	Catch for PSFS fleet	Mean
$C_y/C_{40\%}$	Catch rel. to target	Geometric mean
C_y/C_{MSY}	Catch rel. to MSY	Geometric mean
Catch stability (TAC years only)		
$C_y^{TAC} \neq C_{y-1}^{TAC}$	n. TAC changes	Count
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	TAC change	Mean % change
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	TAC change $> 10\%$	Probability
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	TAC change $> 5\%$	Probability
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	TAC change at limit	Probability
Catch rate		
$CPUE_{[PL]}$	CPUE for PL fleet	Geometric mean
$CPUE_{[PSLS]}$	CPUE for PSLS fleet	Geometric mean
Exploitation rate		
E_y	Exploitation rate	Geometric mean
$E_y/E_{40\%}$	Exploitation rel. to target	Geometric mean
E_y/E_{MSY}	Exploitation rel. to MSY	Geometric mean
Stock biomass		
B_y	Stock biomass	Mean
B_y/B_0	Depletion rel. to B_0	Geometric mean
B_y/B_{MSY}	Depletion rel. to B_{MSY}	Geometric mean
B_{MIN}/B_0	Min. depletion	Minimum
Pr. $> B_{40\%}$	$B_y > B_{40\%}$	Probability
Pr. $> B_{MSY}$	$B_y > B_{MSY}$	Probability
Pr. $> B_{20\%}$	$B_y > B_{20\%}$	Probability
Pr. $> B_{10\%}$	$B_y > B_{10\%}$	Probability
Target Quadrant		
Pr. Target Quadrant	$B_y > B_{40\%}$ and $E_y < E_{40\%}$	Probability
Kobe Quadrants		
Pr. Kobe Red	$B_y < B_{MSY}$ and $E_y > E_{MSY}$	Probability
Pr. Kobe Green	$B_y > B_{MSY}$ and $E_y < E_{MSY}$	Probability
Majuro Quadrants		
Pr. Majuro Red	$B_y < B_{20\%}$	Probability
Pr. Majuro White	$B_y > B_{20\%}$ and $E_y < E_{40\%}$	Probability

Table 4: Diagnostic outputs for evaluation of index-based MPs with a target tuning probability of 50% (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	MP-50%-STABLE	MP-50%-STABLE (B)	MP-50%-TARGET	MP-50%-TARGET (B)
C_y^{TAC}	10^3 tonnes	524.42 (502.65 - 526.36)	525.51 (510.41 - 528.07)	517.66 (492.44 - 536.40)	522.34 (494.47 - 538.90)
C	10^3 tonnes	524.12 (502.45 - 526.70)	525.46 (509.75 - 528.40)	517.32 (492.97 - 536.22)	521.49 (494.56 - 538.46)
$C_{[PL]}$	10^3 tonnes	105.91 (101.11 - 111.13)	106.18 (102.42 - 111.29)	105.25 (98.76 - 110.90)	105.68 (99.23 - 111.00)
$C_{[PSLS]}$	10^3 tonnes	137.17 (128.08 - 142.47)	137.86 (128.19 - 144.24)	135.25 (127.15 - 144.21)	136.31 (126.90 - 145.61)
$C_{[PSFS]}$	10^3 tonnes	25.55 (24.40 - 26.30)	25.62 (24.45 - 26.34)	25.33 (23.89 - 26.36)	25.37 (23.94 - 26.45)
$C_y/C_{40\%}$	Proportion	1.00 (0.89 - 1.10)	1.00 (0.89 - 1.10)	1.00 (0.86 - 1.08)	1.00 (0.90 - 1.07)
C_y/C_{MSY}	Proportion	0.90 (0.78 - 1.01)	0.91 (0.78 - 1.01)	0.89 (0.77 - 0.98)	0.90 (0.79 - 0.99)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	2.00 (1.00 - 4.00)	3.00 (2.00 - 5.00)	4.00 (3.00 - 5.00)	5.00 (4.00 - 5.00)
$\|C_y^{TAC}/C_{y-1}^{TAC} - 1\|$	Percent	3.95 (3.25 - 8.60)	4.21 (3.30 - 9.14)	10.12 (4.58 - 18.00)	9.75 (6.88 - 12.38)
Pr. $\|C_y^{TAC}/C_{y-1}^{TAC} - 1\| > 10\%$	Prob.	0.25	0.28	0.46	0.56
Pr. $\|C_y^{TAC}/C_{y-1}^{TAC} - 1\| > 5\%$	Prob.	0.33	0.36	0.60	0.77
Pr. $\|C_y^{TAC}/C_{y-1}^{TAC} - 1\|$ at limit	Prob.	0.00	0.23	0.00	0.31
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.08)	0.07 (0.07 - 0.08)	0.08 (0.07 - 0.08)	0.08 (0.07 - 0.08)
$CPUE_{[PSLS]}$	Rate	18.95 (16.88 - 20.08)	18.72 (16.75 - 20.02)	19.00 (17.95 - 19.98)	18.71 (17.64 - 19.85)
E_y	Rate	0.55 (0.46 - 0.77)	0.57 (0.47 - 0.77)	0.53 (0.46 - 0.70)	0.56 (0.48 - 0.69)
$E_y/E_{40\%}$	Proportion	1.01 (0.78 - 1.45)	1.02 (0.79 - 1.47)	1.02 (0.75 - 1.40)	1.03 (0.79 - 1.38)
E_y/E_{MSY}	Proportion	0.58 (0.37 - 0.88)	0.60 (0.37 - 0.90)	0.57 (0.38 - 0.81)	0.60 (0.37 - 0.82)
B_y	10^3 tonnes	855.26 (617.31 - 989.89)	820.65 (614.44 - 985.17)	888.48 (660.01 - 980.76)	846.09 (657.37 - 966.24)
B_y/B_0	Proportion	0.40 (0.30 - 0.46)	0.38 (0.30 - 0.46)	0.40 (0.31 - 0.47)	0.38 (0.31 - 0.46)
B_y/B_{MSY}	Proportion	1.59 (1.13 - 2.38)	1.59 (1.11 - 2.37)	1.63 (1.25 - 2.35)	1.61 (1.20 - 2.39)
Pr. $> B_{40\%}$	Prob.	0.47	0.42	0.47	0.43
Pr. $> B_{MSY}$	Prob.	0.95	0.94	0.97	0.96
Pr. $> B_{20\%}$	Prob.	1.00	1.00	1.00	1.00
Pr. $> B_{10\%}$	Prob.	1.00	1.00	1.00	1.00
Pr. Target Quadrant	Prob.	0.46	0.42	0.42	0.39
Pr. Kobe Red	Prob.	0.05	0.05	0.02	0.03
Pr. Kobe Green	Prob.	0.93	0.93	0.96	0.95
Pr. Majuro Red	Prob.	0.00	0.00	0.00	0.00
Pr. Majuro White	Prob.	0.94	0.94	0.96	0.96

Table 5: Diagnostic outputs for evaluation of index-based MPs with a target tuning probability of 60% (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	MP-60%-STABLE	MP-60%-STABLE (B)	MP-60%-TARGET	MP-60%-TARGET (B)
C_y^{TAC}	10^3 tonnes	514.85 (499.63 - 515.84)	511.52 (500.56 - 519.79)	507.60 (485.19 - 519.70)	512.55 (491.09 - 526.02)
C	10^3 tonnes	514.58 (499.20 - 516.31)	511.38 (500.53 - 519.74)	507.92 (485.12 - 520.07)	512.47 (491.07 - 525.50)
$C_{[PL]}$	10^3 tonnes	104.00 (100.91 - 109.08)	103.74 (100.90 - 108.58)	103.05 (97.14 - 107.90)	103.59 (99.06 - 108.59)
$C_{[PSLS]}$	10^3 tonnes	134.71 (126.59 - 139.62)	134.85 (125.71 - 141.93)	132.72 (125.16 - 139.92)	133.66 (125.19 - 143.11)
$C_{[PSFS]}$	10^3 tonnes	25.08 (24.13 - 25.83)	24.95 (24.16 - 25.69)	24.80 (23.43 - 25.77)	24.96 (23.69 - 25.87)
$C_y/C_{40\%}$	Proportion	0.98 (0.87 - 1.09)	0.98 (0.88 - 1.09)	0.98 (0.84 - 1.07)	0.98 (0.88 - 1.07)
C_y/C_{MSY}	Proportion	0.88 (0.76 - 0.99)	0.89 (0.75 - 1.00)	0.87 (0.75 - 0.97)	0.88 (0.78 - 0.98)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	2.00 (1.00 - 3.00)	3.00 (2.00 - 4.00)	4.00 (0.00 - 5.00)	5.00 (4.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	3.93 (3.59 - 8.27)	4.27 (3.69 - 8.25)	8.93 (0.00 - 15.77)	9.42 (5.74 - 12.15)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.24	0.28	0.38	0.53
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.30	0.41	0.48	0.67
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.00	0.23	0.00	0.30
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.09)	0.08 (0.07 - 0.08)	0.08 (0.08 - 0.09)	0.08 (0.07 - 0.08)
$CPUE_{[PSLS]}$	Rate	19.34 (17.52 - 20.45)	19.11 (17.38 - 20.36)	19.57 (18.59 - 20.49)	19.08 (18.06 - 20.21)
E_y	Rate	0.53 (0.45 - 0.73)	0.55 (0.45 - 0.72)	0.50 (0.43 - 0.67)	0.53 (0.46 - 0.66)
$E_y/E_{40\%}$	Proportion	0.97 (0.75 - 1.36)	0.98 (0.75 - 1.39)	0.95 (0.71 - 1.31)	0.98 (0.76 - 1.31)
E_y/E_{MSY}	Proportion	0.56 (0.35 - 0.84)	0.57 (0.34 - 0.85)	0.53 (0.35 - 0.75)	0.57 (0.35 - 0.78)
B_y	10^3 tonnes	879.53 (648.12 - 1011.36)	846.32 (651.18 - 1010.83)	920.59 (697.87 - 1020.05)	865.80 (690.13 - 1002.90)
B_y/B_0	Proportion	0.41 (0.32 - 0.47)	0.40 (0.31 - 0.47)	0.41 (0.33 - 0.49)	0.40 (0.32 - 0.47)
B_y/B_{MSY}	Proportion	1.64 (1.18 - 2.43)	1.65 (1.15 - 2.48)	1.70 (1.30 - 2.43)	1.66 (1.27 - 2.43)
Pr. $> B_{40\%}$	Prob.	0.53	0.49	0.56	0.49
Pr. $> B_{MSY}$	Prob.	0.97	0.95	0.98	0.98
Pr. $> B_{20\%}$	Prob.	1.00	1.00	1.00	1.00
Pr. $> B_{10\%}$	Prob.	1.00	1.00	1.00	1.00
Pr. Target Quadrant	Prob.	0.51	0.48	0.52	0.46
Pr. Kobe Red	Prob.	0.03	0.05	0.01	0.01
Pr. Kobe Green	Prob.	0.96	0.94	0.97	0.97
Pr. Majuro Red	Prob.	0.00	0.00	0.00	0.00
Pr. Majuro White	Prob.	0.96	0.94	0.98	0.98

Table 6: Diagnostic outputs for evaluation of index-based MPs with a target tuning probability of 70% (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	MP-70%-STABLE	MP-70%-STABLE (B)	MP-70%-TARGET	MP-70%-TARGET (B)
C_y^{TAC}	10^3 tonnes	505.31 (493.20 - 505.31)	503.25 (494.55 - 503.25)	501.83 (479.39 - 511.63)	503.34 (483.99 - 512.14)
C	10^3 tonnes	504.90 (492.65 - 505.84)	502.69 (493.85 - 503.78)	501.99 (479.32 - 512.09)	503.07 (484.01 - 512.73)
$C_{[PL]}$	10^3 tonnes	102.01 (98.96 - 106.96)	101.54 (99.24 - 106.14)	101.74 (96.09 - 106.51)	101.72 (98.09 - 106.09)
$C_{[PSLS]}$	10^3 tonnes	132.15 (124.36 - 136.77)	131.44 (123.81 - 139.40)	130.80 (123.52 - 137.67)	131.14 (122.62 - 139.92)
$C_{[PSFS]}$	10^3 tonnes	24.56 (23.77 - 25.31)	24.45 (23.69 - 25.12)	24.52 (23.14 - 25.42)	24.57 (23.44 - 25.26)
$C_y/C_{40\%}$	Proportion	0.96 (0.86 - 1.07)	0.96 (0.85 - 1.07)	0.97 (0.83 - 1.07)	0.96 (0.86 - 1.05)
C_y/C_{MSY}	Proportion	0.87 (0.75 - 0.98)	0.87 (0.75 - 0.97)	0.86 (0.74 - 0.96)	0.86 (0.76 - 0.96)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	1.00 (1.00 - 3.00)	2.50 (2.00 - 4.00)	3.00 (0.00 - 5.00)	5.00 (3.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	3.92 (3.92 - 8.00)	4.48 (4.48 - 7.79)	8.47 (0.00 - 15.27)	8.72 (5.96 - 11.51)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.22	0.26	0.32	0.51
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.29	0.46	0.44	0.66
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.00	0.24	0.00	0.35
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.09)	0.08 (0.07 - 0.09)	0.08 (0.08 - 0.09)	0.08 (0.08 - 0.09)
$CPUE_{[PSLS]}$	Rate	19.77 (18.05 - 20.79)	19.63 (17.79 - 20.81)	19.95 (18.92 - 20.75)	19.58 (18.57 - 20.61)
E_y	Rate	0.50 (0.43 - 0.68)	0.52 (0.43 - 0.69)	0.49 (0.42 - 0.64)	0.50 (0.44 - 0.64)
$E_y/E_{40\%}$	Proportion	0.93 (0.73 - 1.28)	0.95 (0.72 - 1.27)	0.92 (0.69 - 1.26)	0.94 (0.74 - 1.25)
E_y/E_{MSY}	Proportion	0.54 (0.34 - 0.80)	0.55 (0.34 - 0.79)	0.52 (0.34 - 0.72)	0.54 (0.34 - 0.75)
B_y	10^3 tonnes	903.36 (689.69 - 1032.53)	869.24 (674.56 - 1030.78)	937.28 (712.85 - 1037.88)	887.56 (720.59 - 1023.64)
B_y/B_0	Proportion	0.42 (0.33 - 0.48)	0.41 (0.33 - 0.48)	0.42 (0.34 - 0.49)	0.41 (0.33 - 0.48)
B_y/B_{MSY}	Proportion	1.71 (1.22 - 2.47)	1.70 (1.21 - 2.48)	1.73 (1.33 - 2.47)	1.71 (1.31 - 2.47)
Pr. $> B_{40\%}$	Prob.	0.61	0.56	0.62	0.57
Pr. $> B_{MSY}$	Prob.	0.98	0.95	0.99	0.98
Pr. $> B_{20\%}$	Prob.	1.00	1.00	1.00	1.00
Pr. $> B_{10\%}$	Prob.	1.00	1.00	1.00	1.00
Pr. Target Quadrant	Prob.	0.61	0.56	0.58	0.54
Pr. Kobe Red	Prob.	0.02	0.04	0.01	0.01
Pr. Kobe Green	Prob.	0.97	0.95	0.99	0.97
Pr. Majuro Red	Prob.	0.00	0.00	0.00	0.00
Pr. Majuro White	Prob.	0.98	0.95	0.99	0.98

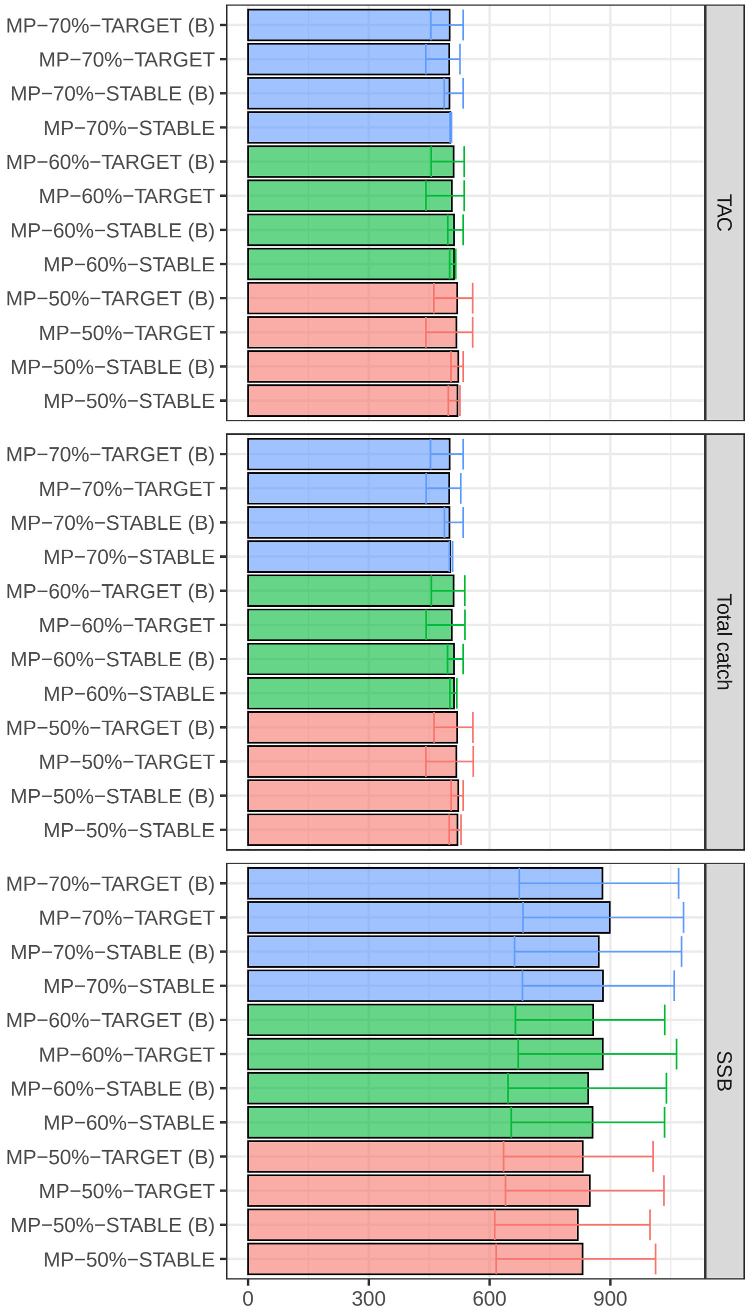


Figure 6: Absolute diagnostic values per MP, averaged over all operating models and iterations for the projection period from 2027 to 2040.

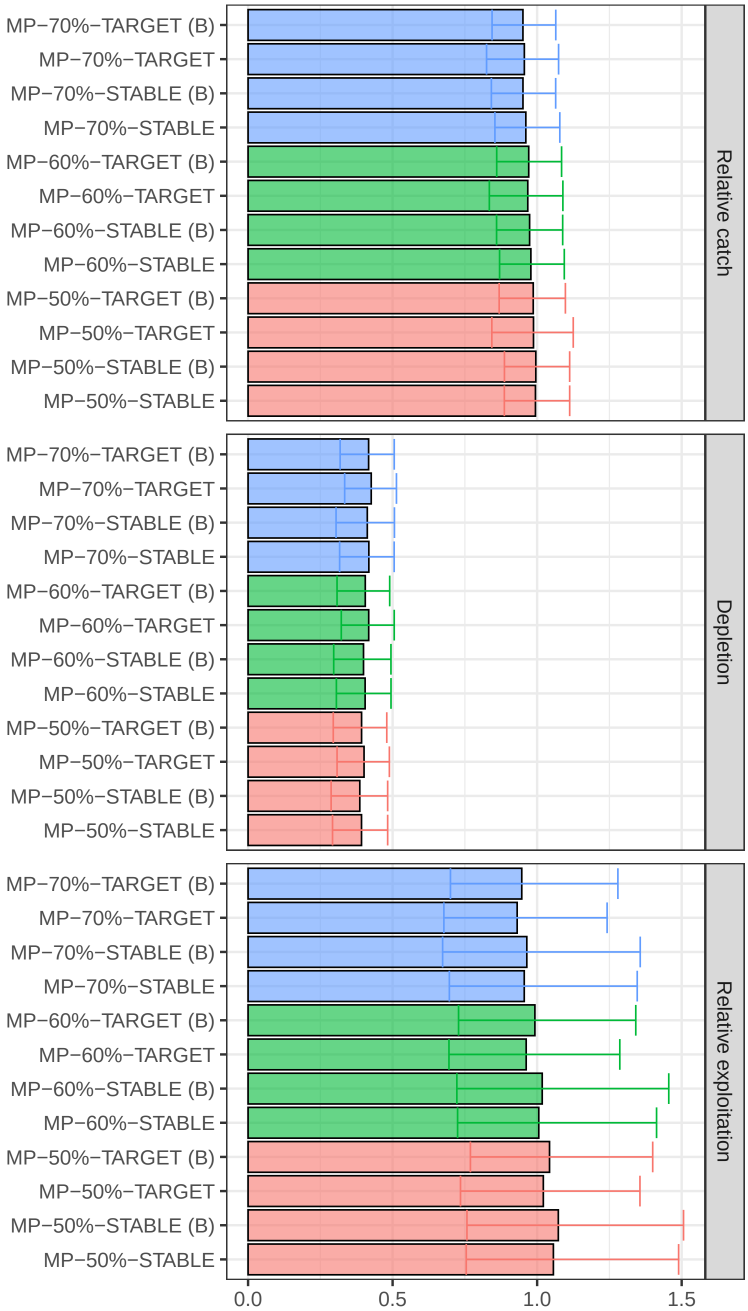


Figure 7: Relative diagnostic values per MP, averaged over all operating models and iterations for the projection period from 2027 to 2040.

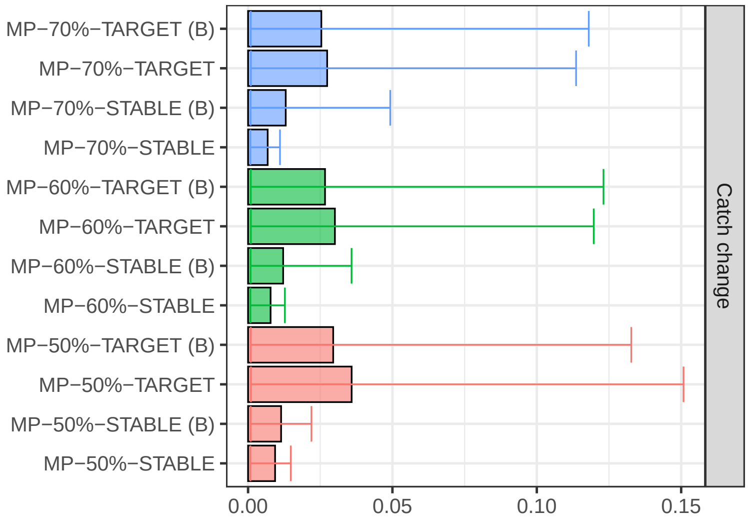
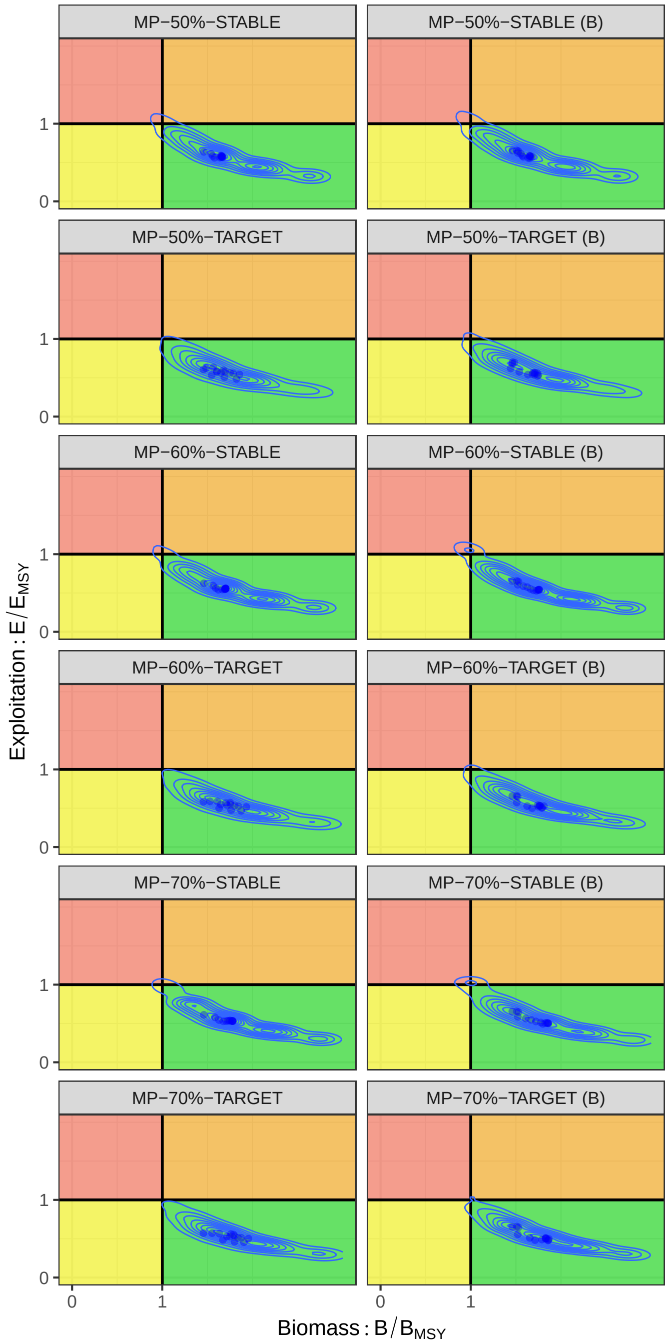
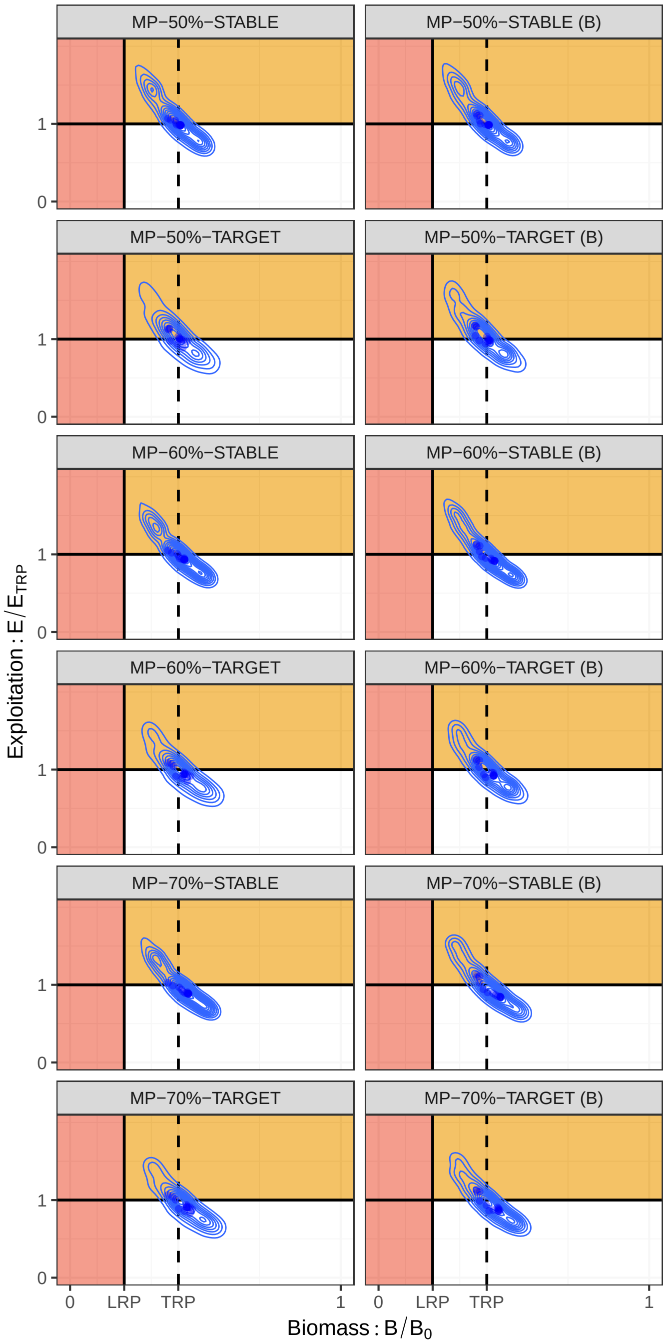


Figure 8: Catch stability ($|C_y^{TAC}/C_{y-1}^{TAC} - 1|$) per MP, averaged over all operating models and iterations for the projection period from 2027 to 2040.



(a) Kobe phase plots



(b) Majuro phase plots

Figure 9: Kobe phase plots (top panel) and Majuro phase plots (bottom panel) for tuned MPs listed in Table 2. Contours show a two-dimensional histogram of stock status across all years for which the MP was used to set catches (i.e. 2027 to 2040), 18 operating model runs and three stochastic iterations for each run. Blue points show the median values per year and MP for each MP. The Kobe and Majuro matrices differ in the reference points used to diagnose stock status. The Kobe matrix is defined using MSY-based reference points B_{MSY} and E_{MSY}, whereas the Majuro plot uses Target and Limit Reference Points (TRP and LRP) equal to $B_{40\%}$ and $B_{20\%}$ respectively.

Robustness to overcatch

Simulation results per MP are provided in Tables 7 to 18, and summarised graphically in Figures 10 to 11. Results are largely as expected, in that overcatch substantially impedes performance of all MPs. This overcatch would argue for choosing more conservative MPs tuned to the 70% criteria. For example, MP-50%-TARGET when overcatch is up to 30%, has a realised probability of being in the target quadrant that drops to 12% (Table 9). For MP-70%-TARGET, the realised probability of being in the target quadrant drops to 16% (Table 17). The 70% turning criteria is therefore more robust, although in both cases the drop in performance is significant.

Another feature of the simualtion testing results is the relationship between design of the MP and robustness to overcatch. Typically, the more stable MPs are less robust to overcatch; i.e., both the “STABLE” and “B” MP types perform worse than the “TARGET” MPs without buffering. This suggests that a responsive MP is advantageous when overcatch is present.

Table 7: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-50%-STABLE (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	524.42 (502.65 - 526.36)	483.66 (449.59 - 506.33)	463.96 (422.49 - 497.20)
C	10^3 tonnes	524.12 (502.45 - 526.70)	549.41 (485.44 - 594.54)	543.41 (465.02 - 600.33)
$C_{[PL]}$	10^3 tonnes	105.91 (101.11 - 111.13)	113.78 (98.06 - 121.20)	112.18 (93.02 - 122.65)
$C_{[PSLS]}$	10^3 tonnes	137.17 (128.08 - 142.47)	144.77 (123.18 - 161.05)	144.01 (118.83 - 163.74)
$C_{[PSFS]}$	10^3 tonnes	25.55 (24.40 - 26.30)	27.10 (23.62 - 29.12)	26.86 (22.63 - 29.30)
$C_y/C_{40\%}$	Proportion	1.00 (0.89 - 1.10)	1.03 (0.95 - 1.08)	1.02 (0.92 - 1.05)
C_y/C_{MSY}	Proportion	0.90 (0.78 - 1.01)	0.93 (0.87 - 0.98)	0.92 (0.85 - 0.96)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	2.00 (1.00 - 4.00)	5.00 (4.00 - 5.00)	5.00 (4.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	3.95 (3.25 - 8.60)	15.99 (8.73 - 35.39)	21.53 (10.20 - 39.80)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.25	0.62	0.70
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.33	0.77	0.81
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.00	0.00	0.00
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.08)	0.06 (0.06 - 0.06)	0.06 (0.05 - 0.06)
$CPUE_{[PSLS]}$	Rate	18.95 (16.88 - 20.08)	15.93 (14.24 - 16.69)	15.35 (13.79 - 16.35)
E_y	Rate	0.55 (0.46 - 0.77)	0.74 (0.61 - 0.82)	0.74 (0.66 - 0.82)
$E_y/E_{40\%}$	Proportion	1.01 (0.78 - 1.45)	1.35 (1.04 - 1.58)	1.35 (1.11 - 1.58)
E_y/E_{MSY}	Proportion	0.58 (0.37 - 0.88)	0.73 (0.49 - 1.04)	0.75 (0.54 - 1.03)
B_y	10^3 tonnes	855.26 (617.31 - 989.89)	644.33 (561.85 - 784.79)	622.02 (563.22 - 736.70)
B_y/B_0	Proportion	0.40 (0.30 - 0.46)	0.31 (0.25 - 0.38)	0.29 (0.23 - 0.35)
B_y/B_{MSY}	Proportion	1.59 (1.13 - 2.38)	1.32 (0.88 - 1.99)	1.26 (0.82 - 1.84)
Pr. $> B_{40\%}$	Prob.	0.47	0.12	0.10
Pr. $> B_{MSY}$	Prob.	0.95	0.81	0.75
Pr. $> B_{20\%}$	Prob.	1.00	0.93	0.91
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.46	0.07	0.04
Pr. Kobe Red	Prob.	0.05	0.13	0.15
Pr. Kobe Green	Prob.	0.93	0.76	0.70
Pr. Majuro Red	Prob.	0.00	0.07	0.09
Pr. Majuro White	Prob.	0.94	0.80	0.78

Table 8: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-50%-STABLE (B) (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	525.51 (510.41 - 528.07)	494.81 (464.40 - 510.58)	487.16 (460.25 - 510.02)
C	10^3 tonnes	525.46 (509.75 - 528.40)	551.08 (494.86 - 600.76)	553.95 (485.39 - 608.00)
$C_{[PL]}$	10^3 tonnes	106.18 (102.42 - 111.29)	113.52 (99.21 - 122.31)	113.39 (97.43 - 124.16)
$C_{[PSLS]}$	10^3 tonnes	137.86 (128.19 - 144.24)	145.36 (125.24 - 163.29)	144.27 (121.14 - 166.95)
$C_{[PSFS]}$	10^3 tonnes	25.62 (24.45 - 26.34)	27.24 (24.04 - 29.37)	27.17 (23.56 - 29.54)
$C_y/C_{40\%}$	Proportion	1.00 (0.89 - 1.10)	1.05 (0.98 - 1.08)	1.04 (0.98 - 1.07)
C_y/C_{MSY}	Proportion	0.91 (0.78 - 1.01)	0.94 (0.89 - 1.00)	0.94 (0.88 - 0.98)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	3.00 (2.00 - 5.00)	5.00 (5.00 - 5.00)	5.00 (5.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	4.21 (3.30 - 9.14)	10.46 (7.59 - 13.63)	11.87 (6.66 - 14.10)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.28	0.61	0.66
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.36	0.78	0.83
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.23	0.50	0.51
$CPUE_{[PL]}$	Rate	0.07 (0.07 - 0.08)	0.06 (0.05 - 0.06)	0.06 (0.05 - 0.06)
$CPUE_{[PSLS]}$	Rate	18.72 (16.75 - 20.02)	15.49 (13.74 - 16.52)	14.69 (12.74 - 16.27)
E_y	Rate	0.57 (0.47 - 0.77)	0.79 (0.66 - 0.85)	0.81 (0.72 - 0.84)
$E_y/E_{40\%}$	Proportion	1.02 (0.79 - 1.47)	1.42 (1.11 - 1.70)	1.45 (1.19 - 1.79)
E_y/E_{MSY}	Proportion	0.60 (0.37 - 0.90)	0.76 (0.51 - 1.13)	0.80 (0.54 - 1.20)
B_y	10^3 tonnes	820.65 (614.44 - 985.17)	636.26 (540.65 - 757.19)	610.05 (527.18 - 708.56)
B_y/B_0	Proportion	0.38 (0.30 - 0.46)	0.30 (0.24 - 0.36)	0.29 (0.22 - 0.34)
B_y/B_{MSY}	Proportion	1.59 (1.11 - 2.37)	1.28 (0.85 - 1.93)	1.22 (0.78 - 1.83)
Pr. $> B_{40\%}$	Prob.	0.42	0.05	0.01
Pr. $> B_{MSY}$	Prob.	0.94	0.77	0.73
Pr. $> B_{20\%}$	Prob.	1.00	0.93	0.91
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.42	0.03	0.01
Pr. Kobe Red	Prob.	0.05	0.17	0.19
Pr. Kobe Green	Prob.	0.93	0.73	0.67
Pr. Majuro Red	Prob.	0.00	0.07	0.09
Pr. Majuro White	Prob.	0.94	0.78	0.73

Table 9: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-50%-TARGET (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	517.66 (492.44 - 536.40)	458.69 (426.15 - 484.90)	434.70 (396.34 - 463.38)
C	10^3 tonnes	517.32 (492.97 - 536.22)	533.34 (473.27 - 568.98)	533.26 (444.23 - 571.43)
$C_{[PL]}$	10^3 tonnes	105.25 (98.76 - 110.90)	109.03 (94.88 - 116.50)	107.81 (89.05 - 117.40)
$C_{[PSLS]}$	10^3 tonnes	135.25 (127.15 - 144.21)	141.07 (119.18 - 153.83)	141.13 (112.01 - 156.27)
$C_{[PSFS]}$	10^3 tonnes	25.33 (23.89 - 26.36)	25.98 (22.95 - 27.93)	26.09 (21.57 - 27.84)
$C_y/C_{40\%}$	Proportion	1.00 (0.86 - 1.08)	0.97 (0.90 - 1.05)	0.97 (0.84 - 1.04)
C_y/C_{MSY}	Proportion	0.89 (0.77 - 0.98)	0.90 (0.81 - 0.94)	0.88 (0.78 - 0.94)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	4.00 (3.00 - 5.00)	5.00 (5.00 - 5.00)	5.00 (5.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	10.12 (4.58 - 18.00)	27.19 (16.07 - 57.11)	34.54 (17.61 - 67.56)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.46	0.80	0.83
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.60	0.89	0.91
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.00	0.00	0.00
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.08)	0.07 (0.06 - 0.07)	0.06 (0.06 - 0.07)
$CPUE_{[PSLS]}$	Rate	19.00 (17.95 - 19.98)	16.90 (15.20 - 17.71)	16.14 (14.54 - 16.86)
E_y	Rate	0.53 (0.46 - 0.70)	0.66 (0.54 - 0.75)	0.67 (0.57 - 0.78)
$E_y/E_{40\%}$	Proportion	1.02 (0.75 - 1.40)	1.21 (0.92 - 1.45)	1.22 (0.96 - 1.46)
E_y/E_{MSY}	Proportion	0.57 (0.38 - 0.81)	0.67 (0.45 - 0.90)	0.69 (0.49 - 0.92)
B_y	10^3 tonnes	888.48 (660.01 - 980.76)	703.24 (599.78 - 840.44)	685.37 (588.00 - 802.13)
B_y/B_0	Proportion	0.40 (0.31 - 0.47)	0.33 (0.26 - 0.40)	0.31 (0.25 - 0.38)
B_y/B_{MSY}	Proportion	1.63 (1.25 - 2.35)	1.39 (0.98 - 2.06)	1.31 (0.90 - 1.96)
Pr. $> B_{40\%}$	Prob.	0.47	0.25	0.21
Pr. $> B_{MSY}$	Prob.	0.97	0.84	0.78
Pr. $> B_{20\%}$	Prob.	1.00	0.92	0.90
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.42	0.15	0.12
Pr. Kobe Red	Prob.	0.02	0.10	0.12
Pr. Kobe Green	Prob.	0.96	0.80	0.73
Pr. Majuro Red	Prob.	0.00	0.08	0.10
Pr. Majuro White	Prob.	0.96	0.84	0.80

Table 10: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-50%-TARGET (B) (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	522.34 (494.47 - 538.90)	479.72 (455.60 - 500.08)	469.30 (437.09 - 491.54)
C	10^3 tonnes	521.49 (494.56 - 538.46)	540.59 (489.42 - 580.96)	540.62 (477.28 - 592.01)
$C_{[PL]}$	10^3 tonnes	105.68 (99.23 - 111.00)	110.26 (98.11 - 118.84)	111.07 (95.68 - 120.87)
$C_{[PSLS]}$	10^3 tonnes	136.31 (126.90 - 145.61)	142.32 (124.82 - 158.13)	142.23 (120.45 - 163.03)
$C_{[PSFS]}$	10^3 tonnes	25.37 (23.94 - 26.45)	26.50 (23.78 - 28.32)	26.62 (23.19 - 28.91)
$C_y/C_{40\%}$	Proportion	1.00 (0.90 - 1.07)	1.03 (0.97 - 1.06)	1.02 (0.94 - 1.06)
C_y/C_{MSY}	Proportion	0.90 (0.79 - 0.99)	0.93 (0.87 - 0.97)	0.92 (0.87 - 0.96)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	5.00 (4.00 - 5.00)	5.00 (5.00 - 5.00)	5.00 (5.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	9.75 (6.88 - 12.38)	12.31 (8.69 - 13.84)	12.20 (8.81 - 15.00)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.56	0.71	0.70
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.77	0.83	0.85
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.31	0.57	0.61
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.08)	0.06 (0.06 - 0.07)	0.06 (0.05 - 0.06)
$CPUE_{[PSLS]}$	Rate	18.71 (17.64 - 19.85)	15.94 (14.59 - 16.99)	15.26 (13.53 - 16.48)
E_y	Rate	0.56 (0.48 - 0.69)	0.72 (0.61 - 0.83)	0.77 (0.66 - 0.84)
$E_y/E_{40\%}$	Proportion	1.03 (0.79 - 1.38)	1.29 (1.04 - 1.64)	1.40 (1.10 - 1.66)
E_y/E_{MSY}	Proportion	0.60 (0.37 - 0.82)	0.73 (0.48 - 1.04)	0.75 (0.50 - 1.12)
B_y	10^3 tonnes	846.09 (657.37 - 966.24)	684.08 (552.74 - 800.29)	625.95 (530.22 - 753.37)
B_y/B_0	Proportion	0.38 (0.31 - 0.46)	0.32 (0.24 - 0.38)	0.30 (0.23 - 0.36)
B_y/B_{MSY}	Proportion	1.61 (1.20 - 2.39)	1.32 (0.93 - 2.00)	1.26 (0.84 - 1.93)
Pr. $> B_{40\%}$	Prob.	0.43	0.13	0.06
Pr. $> B_{MSY}$	Prob.	0.96	0.80	0.74
Pr. $> B_{20\%}$	Prob.	1.00	0.94	0.92
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.39	0.12	0.04
Pr. Kobe Red	Prob.	0.03	0.13	0.16
Pr. Kobe Green	Prob.	0.95	0.78	0.71
Pr. Majuro Red	Prob.	0.00	0.06	0.08
Pr. Majuro White	Prob.	0.96	0.83	0.78

Table 11: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-60%-STABLE (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	514.85 (499.63 - 515.84)	475.46 (445.22 - 498.63)	457.33 (419.62 - 488.73)
C	10^3 tonnes	514.58 (499.20 - 516.31)	545.64 (488.76 - 588.46)	544.51 (467.90 - 596.91)
$C_{[PL]}$	10^3 tonnes	104.00 (100.91 - 109.08)	112.90 (98.01 - 120.00)	112.02 (93.31 - 121.81)
$C_{[PSLS]}$	10^3 tonnes	134.71 (126.59 - 139.62)	144.29 (122.72 - 159.46)	143.84 (118.37 - 162.45)
$C_{[PSFS]}$	10^3 tonnes	25.08 (24.13 - 25.83)	26.94 (23.78 - 28.78)	26.86 (22.74 - 29.11)
$C_y/C_{40\%}$	Proportion	0.98 (0.87 - 1.09)	1.02 (0.95 - 1.08)	1.02 (0.92 - 1.05)
C_y/C_{MSY}	Proportion	0.88 (0.76 - 0.99)	0.93 (0.86 - 0.98)	0.92 (0.85 - 0.96)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	2.00 (1.00 - 3.00)	4.50 (4.00 - 5.00)	5.00 (4.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	3.93 (3.59 - 8.27)	15.39 (9.19 - 34.33)	21.72 (10.43 - 39.94)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.24	0.59	0.69
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.30	0.76	0.79
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.00	0.00	0.00
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.09)	0.06 (0.06 - 0.07)	0.06 (0.05 - 0.06)
$CPUE_{[PSLS]}$	Rate	19.34 (17.52 - 20.45)	16.20 (14.45 - 16.91)	15.45 (13.89 - 16.44)
E_y	Rate	0.53 (0.45 - 0.73)	0.73 (0.59 - 0.81)	0.74 (0.65 - 0.81)
$E_y/E_{40\%}$	Proportion	0.97 (0.75 - 1.36)	1.33 (1.00 - 1.56)	1.33 (1.09 - 1.57)
E_y/E_{MSY}	Proportion	0.56 (0.35 - 0.84)	0.71 (0.47 - 1.02)	0.74 (0.53 - 1.03)
B_y	10^3 tonnes	879.53 (648.12 - 1011.36)	654.98 (566.26 - 808.40)	628.71 (567.99 - 745.49)
B_y/B_0	Proportion	0.41 (0.32 - 0.47)	0.31 (0.25 - 0.39)	0.30 (0.23 - 0.36)
B_y/B_{MSY}	Proportion	1.64 (1.18 - 2.43)	1.34 (0.90 - 2.03)	1.27 (0.83 - 1.86)
Pr. $> B_{40\%}$	Prob.	0.53	0.15	0.12
Pr. $> B_{MSY}$	Prob.	0.97	0.81	0.76
Pr. $> B_{20\%}$	Prob.	1.00	0.94	0.91
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.51	0.10	0.06
Pr. Kobe Red	Prob.	0.03	0.13	0.15
Pr. Kobe Green	Prob.	0.96	0.78	0.71
Pr. Majuro Red	Prob.	0.00	0.06	0.09
Pr. Majuro White	Prob.	0.96	0.81	0.78

Table 12: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-60%-STABLE (B) (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	511.52 (500.56 - 519.79)	489.28 (460.96 - 502.56)	481.40 (454.19 - 501.88)
C	10^3 tonnes	511.38 (500.53 - 519.74)	546.63 (492.44 - 593.14)	551.74 (485.39 - 602.49)
$C_{[PL]}$	10^3 tonnes	103.74 (100.90 - 108.58)	112.65 (98.72 - 121.11)	113.34 (97.42 - 123.14)
$C_{[PSLS]}$	10^3 tonnes	134.85 (125.71 - 141.93)	144.52 (125.21 - 161.07)	143.97 (121.22 - 164.90)
$C_{[PSFS]}$	10^3 tonnes	24.95 (24.16 - 25.69)	27.15 (23.93 - 29.04)	27.13 (23.51 - 29.34)
$C_y/C_{40\%}$	Proportion	0.98 (0.88 - 1.09)	1.05 (0.98 - 1.08)	1.04 (0.97 - 1.07)
C_y/C_{MSY}	Proportion	0.89 (0.75 - 1.00)	0.93 (0.88 - 0.99)	0.93 (0.88 - 0.97)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	3.00 (2.00 - 4.00)	5.00 (4.00 - 5.00)	5.00 (5.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	4.27 (3.69 - 8.25)	9.95 (7.54 - 13.25)	11.44 (7.78 - 13.85)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.28	0.60	0.64
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.41	0.77	0.82
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.23	0.43	0.48
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.08)	0.06 (0.05 - 0.06)	0.06 (0.05 - 0.06)
$CPUE_{[PSLS]}$	Rate	19.11 (17.38 - 20.36)	15.66 (14.04 - 16.70)	14.82 (12.78 - 16.33)
E_y	Rate	0.55 (0.45 - 0.72)	0.77 (0.65 - 0.85)	0.80 (0.70 - 0.84)
$E_y/E_{40\%}$	Proportion	0.98 (0.75 - 1.39)	1.37 (1.07 - 1.68)	1.44 (1.17 - 1.77)
E_y/E_{MSY}	Proportion	0.57 (0.34 - 0.85)	0.76 (0.49 - 1.10)	0.79 (0.53 - 1.19)
B_y	10^3 tonnes	846.32 (651.18 - 1010.83)	653.15 (541.76 - 774.65)	612.07 (527.28 - 718.21)
B_y/B_0	Proportion	0.40 (0.31 - 0.47)	0.31 (0.24 - 0.37)	0.29 (0.22 - 0.35)
B_y/B_{MSY}	Proportion	1.65 (1.15 - 2.48)	1.29 (0.87 - 1.97)	1.22 (0.78 - 1.86)
Pr. $> B_{40\%}$	Prob.	0.49	0.08	0.02
Pr. $> B_{MSY}$	Prob.	0.95	0.78	0.74
Pr. $> B_{20\%}$	Prob.	1.00	0.94	0.92
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.48	0.06	0.01
Pr. Kobe Red	Prob.	0.05	0.15	0.18
Pr. Kobe Green	Prob.	0.94	0.75	0.68
Pr. Majuro Red	Prob.	0.00	0.06	0.08
Pr. Majuro White	Prob.	0.94	0.80	0.74

Table 13: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-60%-TARGET (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	507.60 (485.19 - 519.70)	448.73 (421.55 - 472.31)	424.38 (392.49 - 451.06)
C	10^3 tonnes	507.92 (485.12 - 520.07)	528.59 (472.31 - 559.27)	529.50 (448.42 - 566.93)
$C_{[PL]}$	10^3 tonnes	103.05 (97.14 - 107.90)	107.70 (94.94 - 114.79)	108.06 (90.51 - 116.31)
$C_{[PSLS]}$	10^3 tonnes	132.72 (125.16 - 139.92)	139.85 (118.42 - 151.20)	140.36 (112.96 - 154.00)
$C_{[PSFS]}$	10^3 tonnes	24.80 (23.43 - 25.77)	25.83 (22.90 - 27.48)	25.96 (21.75 - 27.66)
$C_y/C_{40\%}$	Proportion	0.98 (0.84 - 1.07)	0.97 (0.90 - 1.04)	0.96 (0.85 - 1.03)
C_y/C_{MSY}	Proportion	0.87 (0.75 - 0.97)	0.89 (0.81 - 0.94)	0.88 (0.78 - 0.94)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	4.00 (0.00 - 5.00)	5.00 (5.00 - 5.00)	5.00 (4.30 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	8.93 (0.00 - 15.77)	25.62 (15.52 - 55.68)	33.83 (20.18 - 67.19)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.38	0.75	0.80
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.48	0.86	0.88
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.00	0.00	0.00
$CPUE_{[PL]}$	Rate	0.08 (0.08 - 0.09)	0.07 (0.06 - 0.07)	0.06 (0.06 - 0.07)
$CPUE_{[PSLS]}$	Rate	19.57 (18.59 - 20.49)	17.22 (15.49 - 18.16)	16.44 (14.73 - 17.27)
E_y	Rate	0.50 (0.43 - 0.67)	0.64 (0.52 - 0.73)	0.65 (0.55 - 0.76)
$E_y/E_{40\%}$	Proportion	0.95 (0.71 - 1.31)	1.17 (0.89 - 1.42)	1.20 (0.92 - 1.41)
E_y/E_{MSY}	Proportion	0.53 (0.35 - 0.75)	0.65 (0.43 - 0.87)	0.68 (0.47 - 0.91)
B_y	10^3 tonnes	920.59 (697.87 - 1020.05)	728.59 (611.21 - 865.06)	698.76 (597.20 - 822.70)
B_y/B_0	Proportion	0.41 (0.33 - 0.49)	0.34 (0.27 - 0.42)	0.32 (0.25 - 0.39)
B_y/B_{MSY}	Proportion	1.70 (1.30 - 2.43)	1.44 (1.01 - 2.13)	1.34 (0.92 - 2.00)
Pr. $> B_{40\%}$	Prob.	0.56	0.31	0.24
Pr. $> B_{MSY}$	Prob.	0.98	0.85	0.78
Pr. $> B_{20\%}$	Prob.	1.00	0.93	0.91
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.52	0.21	0.15
Pr. Kobe Red	Prob.	0.01	0.09	0.13
Pr. Kobe Green	Prob.	0.97	0.82	0.75
Pr. Majuro Red	Prob.	0.00	0.07	0.09
Pr. Majuro White	Prob.	0.98	0.86	0.81

Table 14: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-60%-TARGET (B) (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	512.55 (491.09 - 526.02)	475.42 (449.54 - 490.66)	463.58 (434.40 - 481.33)
C	10^3 tonnes	512.47 (491.07 - 525.50)	536.49 (483.40 - 574.07)	538.62 (477.65 - 585.53)
$C_{[PL]}$	10^3 tonnes	103.59 (99.06 - 108.59)	109.42 (96.91 - 117.27)	109.55 (95.75 - 119.49)
$C_{[PSLS]}$	10^3 tonnes	133.66 (125.19 - 143.11)	140.87 (123.50 - 157.00)	141.85 (120.45 - 161.32)
$C_{[PSFS]}$	10^3 tonnes	24.96 (23.69 - 25.87)	26.28 (23.49 - 28.07)	26.39 (23.21 - 28.64)
$C_y/C_{40\%}$	Proportion	0.98 (0.88 - 1.07)	1.02 (0.96 - 1.05)	1.01 (0.94 - 1.05)
C_y/C_{MSY}	Proportion	0.88 (0.78 - 0.98)	0.92 (0.86 - 0.96)	0.91 (0.86 - 0.96)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	5.00 (4.00 - 5.00)	5.00 (5.00 - 5.00)	5.00 (5.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	9.42 (5.74 - 12.15)	12.15 (8.89 - 14.20)	11.92 (8.88 - 14.42)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.53	0.71	0.71
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.67	0.84	0.84
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.30	0.57	0.61
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.08)	0.06 (0.06 - 0.07)	0.06 (0.05 - 0.06)
$CPUE_{[PSLS]}$	Rate	19.08 (18.06 - 20.21)	16.22 (14.90 - 17.26)	15.57 (13.81 - 16.62)
E_y	Rate	0.53 (0.46 - 0.66)	0.70 (0.60 - 0.82)	0.75 (0.65 - 0.83)
$E_y/E_{40\%}$	Proportion	0.98 (0.76 - 1.31)	1.26 (1.01 - 1.59)	1.34 (1.07 - 1.66)
E_y/E_{MSY}	Proportion	0.57 (0.35 - 0.78)	0.72 (0.46 - 1.00)	0.74 (0.49 - 1.10)
B_y	10^3 tonnes	865.80 (690.13 - 1002.90)	692.61 (557.38 - 816.02)	633.34 (535.39 - 772.46)
B_y/B_0	Proportion	0.40 (0.32 - 0.47)	0.33 (0.25 - 0.39)	0.30 (0.23 - 0.37)
B_y/B_{MSY}	Proportion	1.66 (1.27 - 2.43)	1.34 (0.95 - 2.05)	1.27 (0.86 - 1.97)
Pr. $> B_{40\%}$	Prob.	0.49	0.16	0.07
Pr. $> B_{MSY}$	Prob.	0.98	0.81	0.76
Pr. $> B_{20\%}$	Prob.	1.00	0.95	0.92
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.46	0.14	0.06
Pr. Kobe Red	Prob.	0.01	0.12	0.15
Pr. Kobe Green	Prob.	0.97	0.79	0.72
Pr. Majuro Red	Prob.	0.00	0.05	0.08
Pr. Majuro White	Prob.	0.98	0.84	0.79

Table 15: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-70%-STABLE (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	505.31 (493.20 - 505.31)	468.84 (440.87 - 492.66)	451.33 (414.46 - 480.44)
C	10^3 tonnes	504.90 (492.65 - 505.84)	541.59 (486.92 - 579.94)	541.24 (469.13 - 591.80)
$C_{[PL]}$	10^3 tonnes	102.01 (98.96 - 106.96)	111.91 (97.87 - 118.25)	111.97 (94.33 - 121.05)
$C_{[PSLS]}$	10^3 tonnes	132.15 (124.36 - 136.77)	143.61 (122.63 - 157.77)	143.76 (117.90 - 161.16)
$C_{[PSFS]}$	10^3 tonnes	24.56 (23.77 - 25.31)	26.71 (23.67 - 28.39)	26.95 (22.75 - 28.92)
$C_y/C_{40\%}$	Proportion	0.96 (0.86 - 1.07)	1.02 (0.95 - 1.08)	1.01 (0.93 - 1.05)
C_y/C_{MSY}	Proportion	0.87 (0.75 - 0.98)	0.92 (0.85 - 0.98)	0.91 (0.84 - 0.96)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	1.00 (1.00 - 3.00)	4.00 (3.00 - 5.00)	5.00 (4.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	3.92 (3.92 - 8.00)	14.95 (8.33 - 33.37)	21.29 (11.77 - 39.52)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.22	0.56	0.67
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.29	0.69	0.77
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.00	0.00	0.00
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.09)	0.06 (0.06 - 0.07)	0.06 (0.05 - 0.06)
$CPUE_{[PSLS]}$	Rate	19.77 (18.05 - 20.79)	16.40 (14.81 - 17.32)	15.66 (14.12 - 16.52)
E_y	Rate	0.50 (0.43 - 0.68)	0.72 (0.57 - 0.79)	0.73 (0.63 - 0.80)
$E_y/E_{40\%}$	Proportion	0.93 (0.73 - 1.28)	1.29 (0.96 - 1.55)	1.32 (1.07 - 1.56)
E_y/E_{MSY}	Proportion	0.54 (0.34 - 0.80)	0.70 (0.46 - 0.99)	0.74 (0.52 - 1.02)
B_y	10^3 tonnes	903.36 (689.69 - 1032.53)	669.83 (571.88 - 827.17)	637.96 (570.74 - 764.31)
B_y/B_0	Proportion	0.42 (0.33 - 0.48)	0.32 (0.26 - 0.40)	0.31 (0.24 - 0.36)
B_y/B_{MSY}	Proportion	1.71 (1.22 - 2.47)	1.36 (0.94 - 2.07)	1.30 (0.85 - 1.88)
Pr. $> B_{40\%}$	Prob.	0.61	0.18	0.14
Pr. $> B_{MSY}$	Prob.	0.98	0.83	0.77
Pr. $> B_{20\%}$	Prob.	1.00	0.94	0.91
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.61	0.13	0.07
Pr. Kobe Red	Prob.	0.02	0.12	0.14
Pr. Kobe Green	Prob.	0.97	0.79	0.72
Pr. Majuro Red	Prob.	0.00	0.06	0.09
Pr. Majuro White	Prob.	0.98	0.82	0.78

Table 16: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-70%-STABLE (B) (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	503.25 (494.55 - 503.25)	484.33 (456.88 - 494.55)	474.75 (449.27 - 489.68)
C	10^3 tonnes	502.69 (493.85 - 503.78)	542.81 (492.80 - 584.06)	548.80 (484.53 - 599.03)
$C_{[PL]}$	10^3 tonnes	101.54 (99.24 - 106.14)	111.47 (98.79 - 119.27)	112.32 (97.14 - 121.84)
$C_{[PSLS]}$	10^3 tonnes	131.44 (123.81 - 139.40)	143.34 (125.07 - 159.09)	143.82 (121.30 - 163.21)
$C_{[PSFS]}$	10^3 tonnes	24.45 (23.69 - 25.12)	26.88 (23.94 - 28.61)	27.04 (23.49 - 29.14)
$C_y/C_{40\%}$	Proportion	0.96 (0.85 - 1.07)	1.04 (0.98 - 1.07)	1.03 (0.97 - 1.06)
C_y/C_{MSY}	Proportion	0.87 (0.75 - 0.97)	0.93 (0.86 - 0.98)	0.93 (0.87 - 0.97)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	2.50 (2.00 - 4.00)	5.00 (3.00 - 5.00)	5.00 (5.00 - 5.00)
$\|C_y^{TAC}/C_{y-1}^{TAC} - 1\|$	Percent	4.48 (4.48 - 7.79)	9.49 (7.67 - 12.47)	10.83 (7.41 - 13.75)
Pr. $\|C_y^{TAC}/C_{y-1}^{TAC} - 1\| > 10\%$	Prob.	0.26	0.51	0.59
Pr. $\|C_y^{TAC}/C_{y-1}^{TAC} - 1\| > 5\%$	Prob.	0.46	0.73	0.81
Pr. $\|C_y^{TAC}/C_{y-1}^{TAC} - 1\|$ at limit	Prob.	0.24	0.44	0.48
$CPUE_{[PL]}$	Rate	0.08 (0.07 - 0.09)	0.06 (0.05 - 0.07)	0.06 (0.05 - 0.06)
$CPUE_{[PSLS]}$	Rate	19.63 (17.79 - 20.81)	15.76 (14.36 - 16.91)	15.01 (12.85 - 16.45)
E_y	Rate	0.52 (0.43 - 0.69)	0.75 (0.63 - 0.84)	0.79 (0.69 - 0.84)
$E_y/E_{40\%}$	Proportion	0.95 (0.72 - 1.27)	1.31 (1.03 - 1.67)	1.41 (1.14 - 1.76)
E_y/E_{MSY}	Proportion	0.55 (0.34 - 0.79)	0.75 (0.48 - 1.07)	0.78 (0.52 - 1.19)
B_y	10^3 tonnes	869.24 (674.56 - 1030.78)	672.77 (543.70 - 787.99)	618.02 (528.31 - 730.21)
B_y/B_0	Proportion	0.41 (0.33 - 0.48)	0.32 (0.25 - 0.38)	0.30 (0.22 - 0.36)
B_y/B_{MSY}	Proportion	1.70 (1.21 - 2.48)	1.29 (0.90 - 2.02)	1.23 (0.79 - 1.89)
Pr. $> B_{40\%}$	Prob.	0.56	0.11	0.03
Pr. $> B_{MSY}$	Prob.	0.95	0.80	0.74
Pr. $> B_{20\%}$	Prob.	1.00	0.94	0.92
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.56	0.09	0.02
Pr. Kobe Red	Prob.	0.04	0.14	0.18
Pr. Kobe Green	Prob.	0.95	0.77	0.69
Pr. Majuro Red	Prob.	0.00	0.06	0.08
Pr. Majuro White	Prob.	0.95	0.81	0.76

Table 17: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-70%-TARGET (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	501.83 (479.39 - 511.63)	443.83 (418.67 - 465.80)	418.98 (389.65 - 445.40)
C	10^3 tonnes	501.99 (479.32 - 512.09)	525.91 (469.39 - 554.74)	526.20 (449.73 - 563.42)
$C_{[PL]}$	10^3 tonnes	101.74 (96.09 - 106.51)	106.87 (94.15 - 113.67)	107.86 (90.77 - 115.58)
$C_{[PSLS]}$	10^3 tonnes	130.80 (123.52 - 137.67)	138.79 (117.95 - 149.56)	139.40 (113.31 - 152.80)
$C_{[PSFS]}$	10^3 tonnes	24.52 (23.14 - 25.42)	25.68 (22.75 - 27.22)	25.87 (21.81 - 27.55)
$C_y/C_{40\%}$	Proportion	0.97 (0.83 - 1.07)	0.96 (0.88 - 1.04)	0.95 (0.85 - 1.03)
C_y/C_{MSY}	Proportion	0.86 (0.74 - 0.96)	0.88 (0.80 - 0.93)	0.87 (0.78 - 0.93)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	3.00 (0.00 - 5.00)	5.00 (4.00 - 5.00)	5.00 (4.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	8.47 (0.00 - 15.27)	24.71 (15.51 - 54.84)	33.04 (20.55 - 66.13)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.32	0.73	0.79
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.44	0.86	0.87
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.00	0.00	0.00
$CPUE_{[PL]}$	Rate	0.08 (0.08 - 0.09)	0.07 (0.06 - 0.07)	0.06 (0.06 - 0.07)
$CPUE_{[PSLS]}$	Rate	19.95 (18.92 - 20.75)	17.39 (15.86 - 18.40)	16.65 (14.88 - 17.45)
E_y	Rate	0.49 (0.42 - 0.64)	0.63 (0.51 - 0.72)	0.64 (0.54 - 0.75)
$E_y/E_{40\%}$	Proportion	0.92 (0.69 - 1.26)	1.15 (0.86 - 1.39)	1.19 (0.91 - 1.38)
E_y/E_{MSY}	Proportion	0.52 (0.34 - 0.72)	0.63 (0.42 - 0.84)	0.67 (0.46 - 0.90)
B_y	10^3 tonnes	937.28 (712.85 - 1037.88)	744.03 (620.16 - 877.88)	699.77 (601.67 - 833.69)
B_y/B_0	Proportion	0.42 (0.34 - 0.49)	0.34 (0.28 - 0.42)	0.32 (0.26 - 0.39)
B_y/B_{MSY}	Proportion	1.73 (1.33 - 2.47)	1.45 (1.04 - 2.17)	1.35 (0.93 - 2.03)
Pr. $> B_{40\%}$	Prob.	0.62	0.33	0.25
Pr. $> B_{MSY}$	Prob.	0.99	0.86	0.80
Pr. $> B_{20\%}$	Prob.	1.00	0.94	0.91
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.58	0.24	0.16
Pr. Kobe Red	Prob.	0.01	0.09	0.12
Pr. Kobe Green	Prob.	0.99	0.83	0.76
Pr. Majuro Red	Prob.	0.00	0.06	0.09
Pr. Majuro White	Prob.	0.99	0.86	0.82

Table 18: Diagnostic outputs per overcatch scenario for evaluation of index-based MP: MP-70%-TARGET (B) (see Table 2 for the list of MP definitions and Table 3 for a description of each diagnostic).

Performance Statistic	Units	REFERENCE	OVERCATCH (20%)	OVERCATCH (30%)
C_y^{TAC}	10^3 tonnes	503.34 (483.99 - 512.14)	469.76 (445.90 - 482.92)	455.70 (427.86 - 475.24)
C	10^3 tonnes	503.07 (484.01 - 512.73)	531.36 (479.09 - 566.32)	534.45 (473.28 - 578.28)
$C_{[PL]}$	10^3 tonnes	101.72 (98.09 - 106.09)	108.54 (96.54 - 115.66)	108.48 (94.88 - 117.96)
$C_{[PSLS]}$	10^3 tonnes	131.14 (122.62 - 139.92)	139.61 (121.88 - 155.61)	141.23 (120.45 - 159.28)
$C_{[PSFS]}$	10^3 tonnes	24.57 (23.44 - 25.26)	26.07 (23.28 - 27.66)	26.08 (23.00 - 28.23)
$C_y/C_{40\%}$	Proportion	0.96 (0.86 - 1.05)	1.01 (0.95 - 1.05)	1.00 (0.93 - 1.05)
C_y/C_{MSY}	Proportion	0.86 (0.76 - 0.96)	0.91 (0.85 - 0.95)	0.91 (0.85 - 0.95)
$C_y^{TAC} \neq C_{y-1}^{TAC}$	Count	5.00 (3.00 - 5.00)	5.00 (5.00 - 5.00)	5.00 (5.00 - 5.00)
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Percent	8.72 (5.96 - 11.51)	11.84 (9.04 - 13.50)	12.33 (9.24 - 14.34)
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	Prob.	0.51	0.70	0.72
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	Prob.	0.66	0.85	0.84
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$ at limit	Prob.	0.35	0.57	0.58
$CPUE_{[PL]}$	Rate	0.08 (0.08 - 0.09)	0.06 (0.06 - 0.07)	0.06 (0.05 - 0.07)
$CPUE_{[PSLS]}$	Rate	19.58 (18.57 - 20.61)	16.45 (14.99 - 17.56)	15.72 (14.04 - 16.90)
E_y	Rate	0.50 (0.44 - 0.64)	0.68 (0.58 - 0.80)	0.73 (0.63 - 0.82)
$E_y/E_{40\%}$	Proportion	0.94 (0.74 - 1.25)	1.23 (0.97 - 1.56)	1.29 (1.03 - 1.62)
E_y/E_{MSY}	Proportion	0.54 (0.34 - 0.75)	0.70 (0.45 - 0.98)	0.73 (0.48 - 1.07)
B_y	10^3 tonnes	887.56 (720.59 - 1023.64)	706.86 (561.48 - 826.73)	650.14 (544.03 - 785.83)
B_y/B_0	Proportion	0.41 (0.33 - 0.48)	0.33 (0.25 - 0.40)	0.31 (0.23 - 0.38)
B_y/B_{MSY}	Proportion	1.71 (1.31 - 2.47)	1.36 (0.95 - 2.09)	1.28 (0.87 - 2.01)
Pr. $> B_{40\%}$	Prob.	0.57	0.20	0.11
Pr. $> B_{MSY}$	Prob.	0.98	0.82	0.77
Pr. $> B_{20\%}$	Prob.	1.00	0.95	0.93
Pr. $> B_{10\%}$	Prob.	1.00	1.00	0.99
Pr. Target Quadrant	Prob.	0.54	0.17	0.08
Pr. Kobe Red	Prob.	0.01	0.12	0.15
Pr. Kobe Green	Prob.	0.97	0.80	0.74
Pr. Majuro Red	Prob.	0.00	0.05	0.07
Pr. Majuro White	Prob.	0.98	0.85	0.80

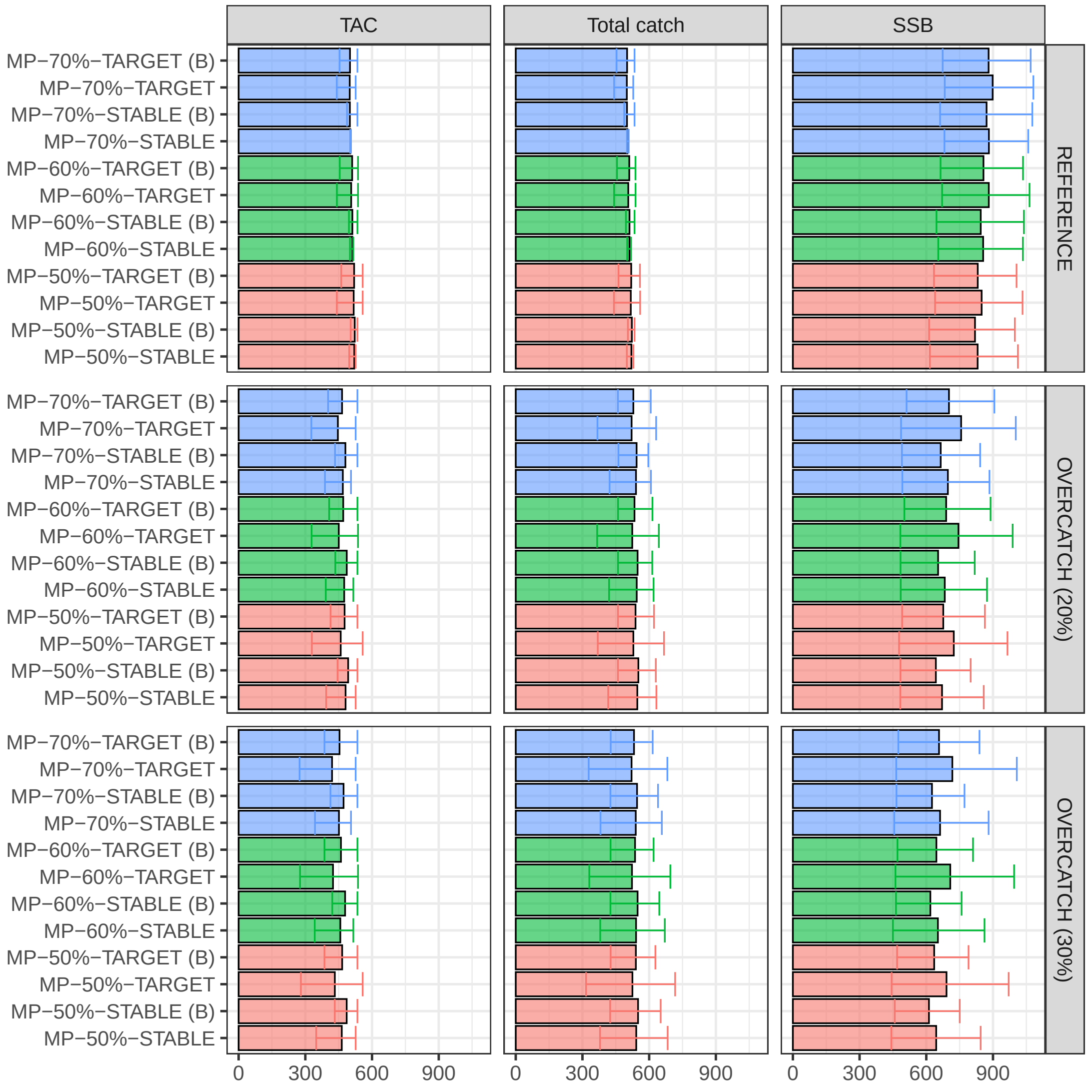


Figure 10: Absolute diagnostic values per MP per overcatch scenario, averaged over all operating models and iterations for the projection period from 2027 to 2040.

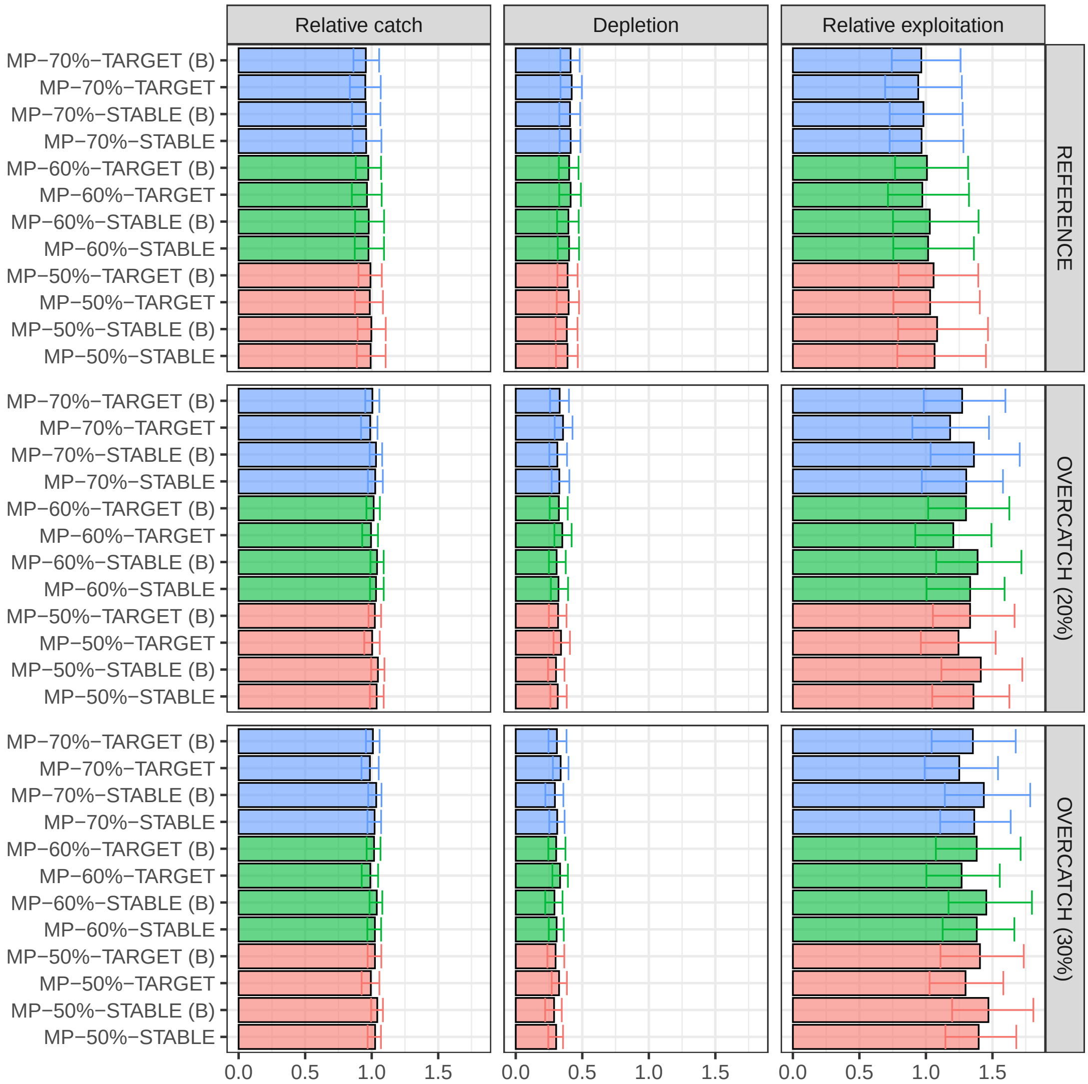


Figure 11: Relative diagnostic values per MP per overcatch scenario, averaged over all operating models and iterations for the projection period from 2027 to 2040.

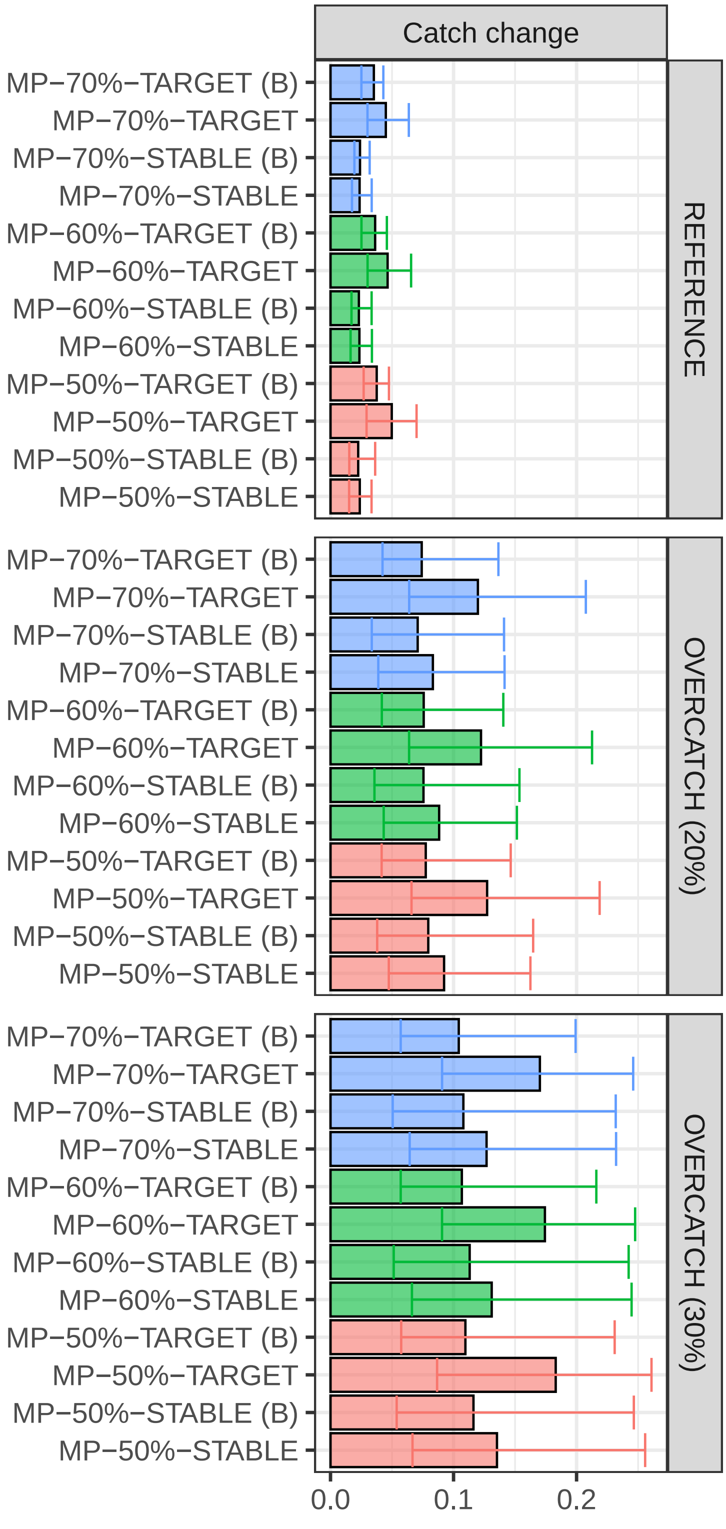


Figure 12: Catch stability ($|C_y^{TAC}/C_{y-1}^{TAC} - 1|$) per MP per overcatch scenario, averaged over all operating models and iterations for the projection period from 2027 to 2040.

Conclusions

Simulation testing allows us to make the following overall conclusions:

- Tuning to a higher probability of being in the target quadrant leads to:
  - lower TAC and catch;
  - higher SSB;
  - lower exploitation rate;
  - higher robustness to overcatch;
- the STABLE MP design leads to:
  - a more stable TAC over time;
  - no appreciable difference in the exploitation rate or stock status.
  - less robustness to overcatch;
- buffering the TAC with a change limit can lead to:
  - more frequent TAC changes.
  - less robustness to overcatch.

In summary, it is possible to construct the qualitative recommendations listed in Table 19, to describe the preferred MP design options depending on broad performance criteria. Overall, the STABLE MPs provide a higher and more stable catch, whilst the stock status is determined by the tuning criteria. Buffering of the TAC change does not appear to provide a clear benefit but can make the MP less robust to overcatch.

Table 19: Qualitative performance criteria and recommendations for MP design.

Criteria	MP-type	Buffered	Preferred Tuning objective (50%, 60%, 70% prob. of being in the target quadrant)
Maximum possible catch	TARGET	–	50%
Maximum average catch	STABLE	–	50%
Catch stability	STABLE	No	70%
Stock status	–	–	70%
Robust to overcatch	TARGET	No	70%

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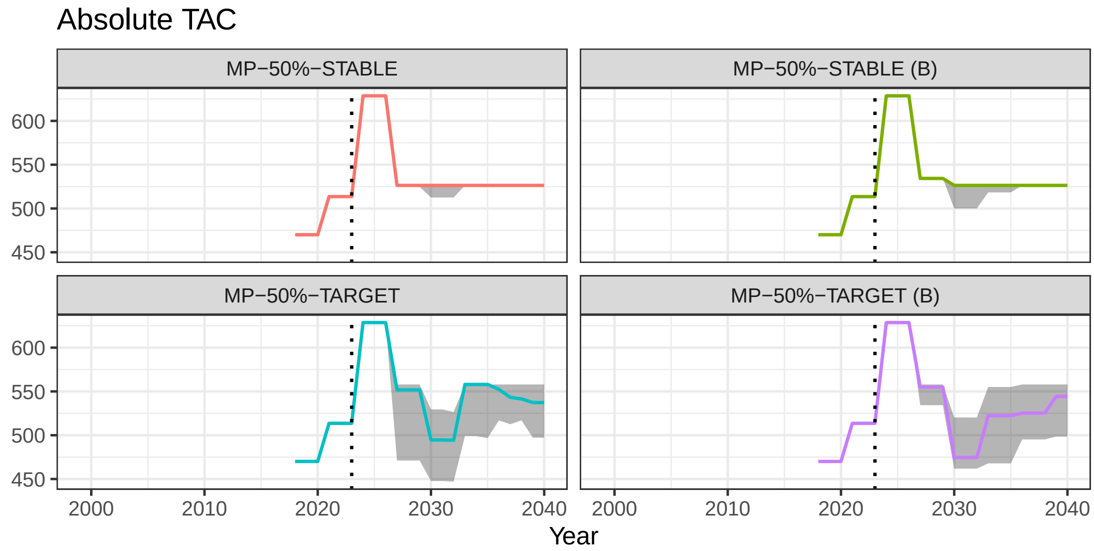
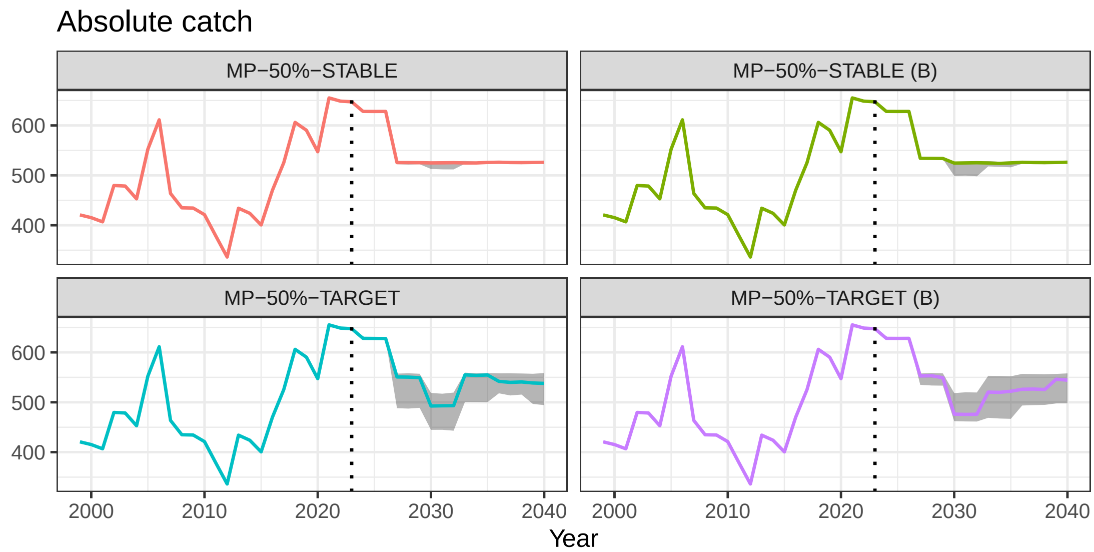
Appendix

MP's tuned to 50%

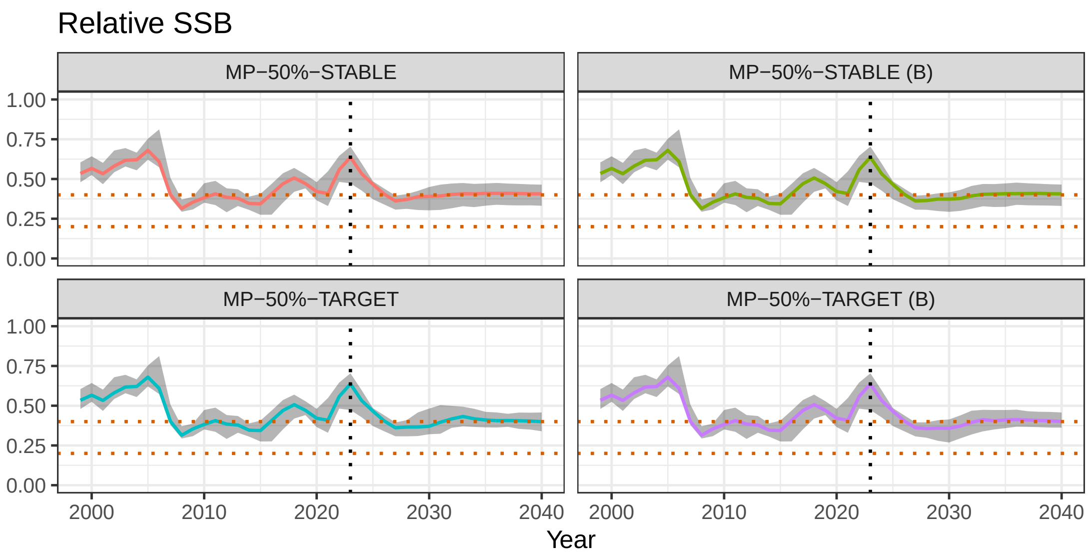


(a) Recommended TAC over time for each MP.

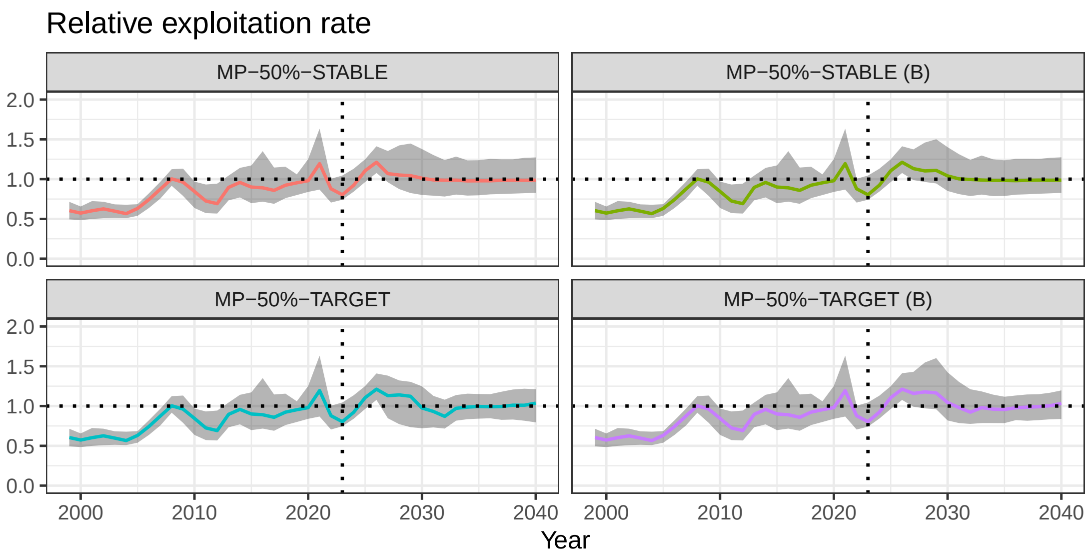


(b) Realised catch over time for each MP.

Figure A1: The recommended TAC and realised catch over time for each MP with a target tuning probability of 50%. The TAC for 2023 to 2026 was fixed at the known values listed in Table 1. No overcatch error was applied for the projection from 2023 onwards, which accounts for the low realised catch in 2023. The median value for each projection is shown as a coloured line, with the 95% quantile across operating models shaded in grey.



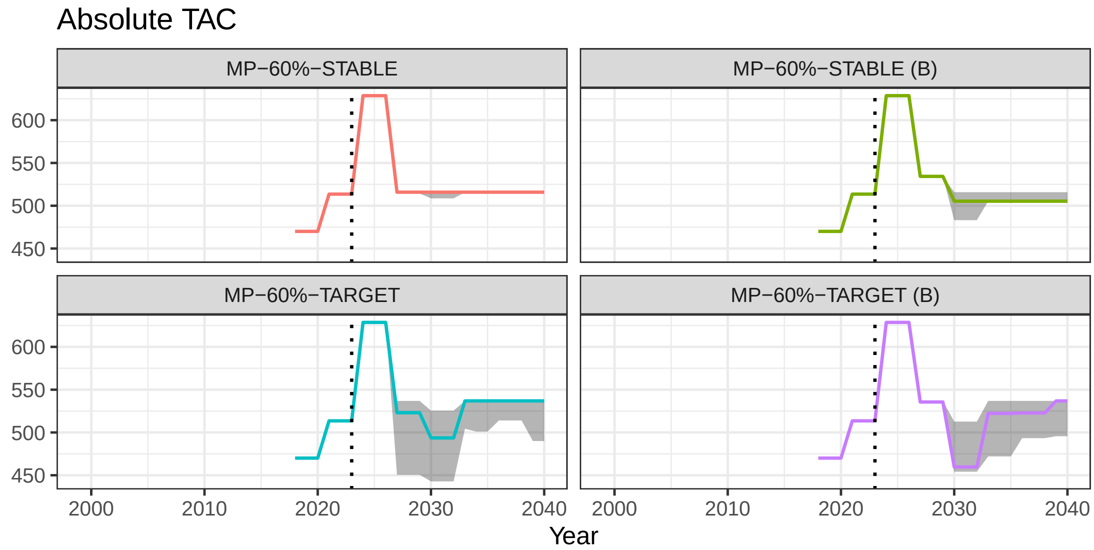
(a) Spawning stock biomass depletion B_y/B_0 relative to the 40% and 20% reference points.



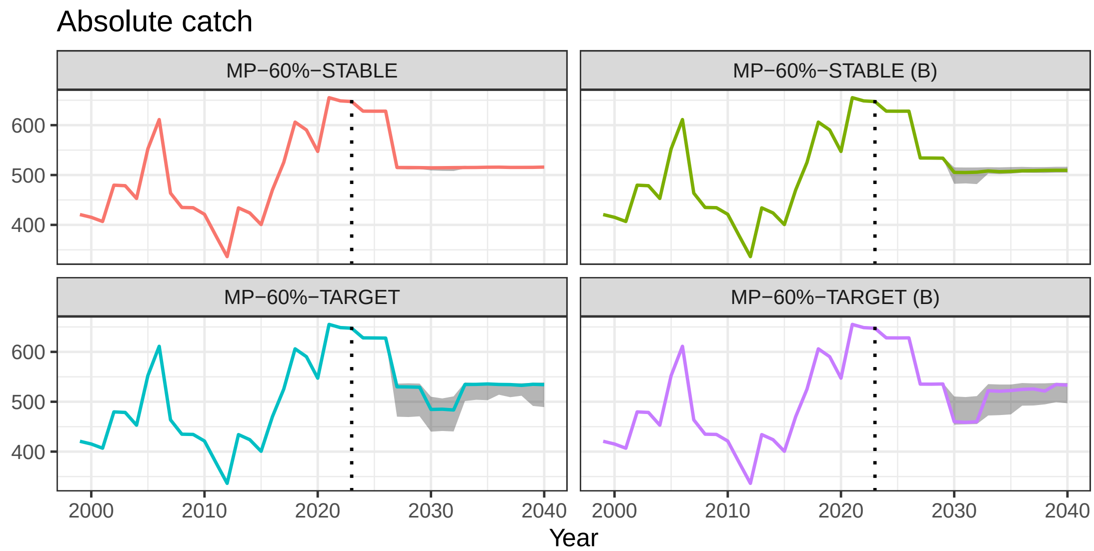
(b) Exploitation rate E_y, measured as a proportion of the 1+ individuals caught, relative to the $E_{40\%}$ reference point.

Figure A2: Stock status projections for each MP with a target tuning probability of 50%. The median value for each projection is shown as a coloured line, with the 95% quantile across operating models shaded in grey.

MP's tuned to 60%

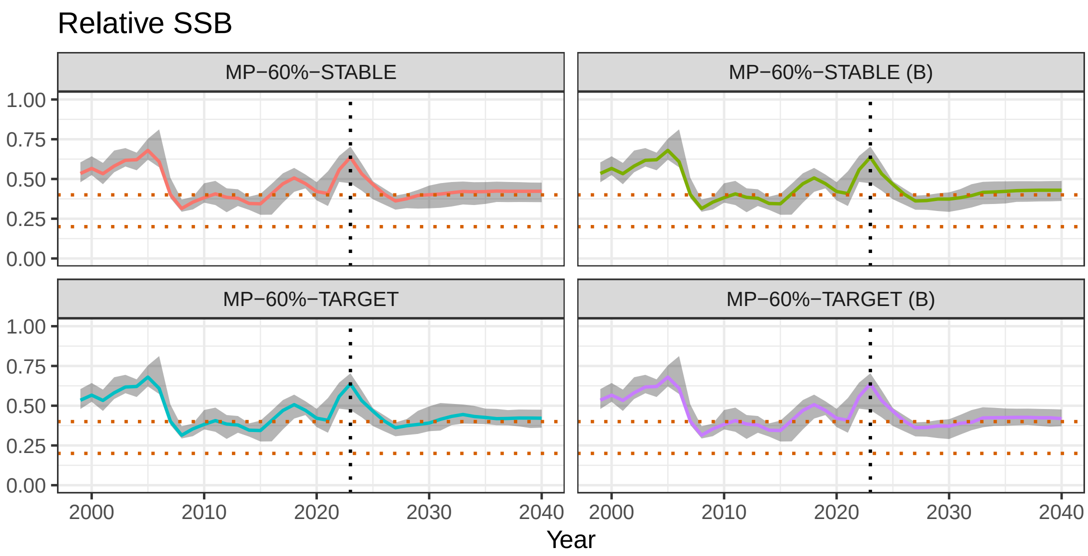


(a) Recommended TAC over time for each MP.

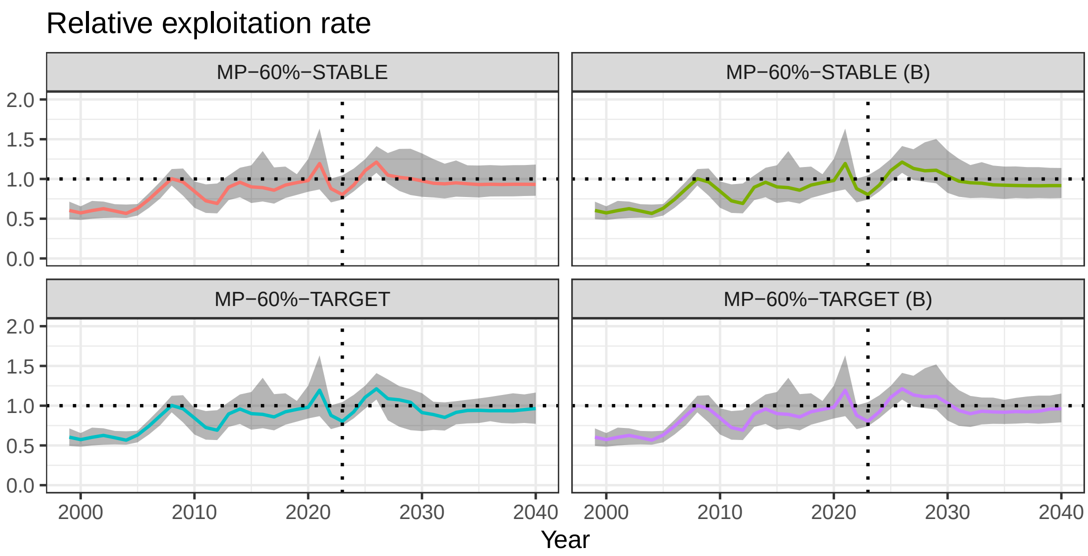


(b) Realised catch over time for each MP.

Figure A3: The recommended TAC and realised catch over time for each MP with a target tuning probability of 60%. The TAC for 2023 to 2026 was fixed at the known values listed in Table 1. No overcatch error was applied for the projection from 2023 onwards, which accounts for the low realised catch in 2023. The median value for each projection is shown as a coloured line, with the 95% quantile across operating models shaded in grey.



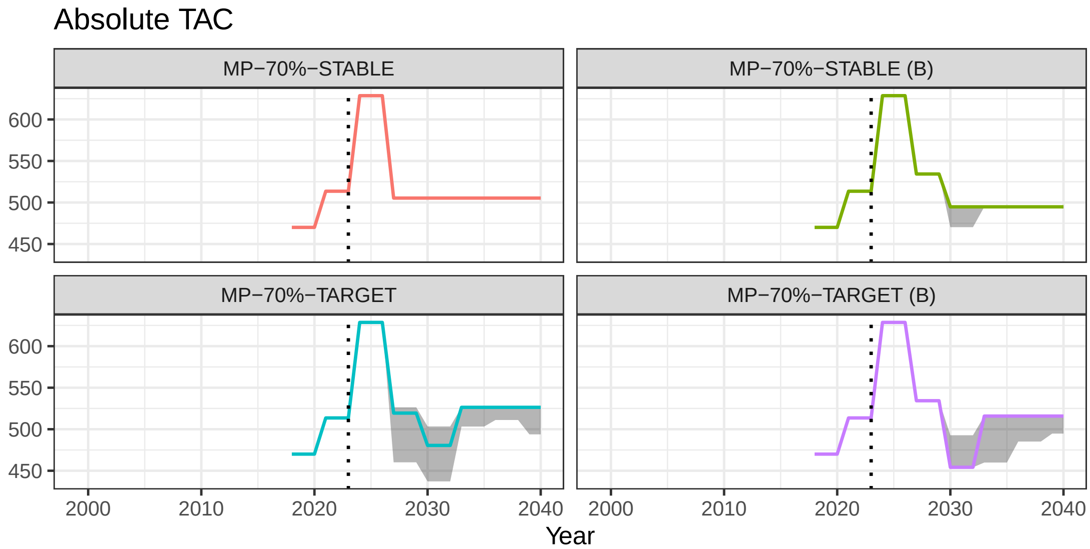
(a) Spawning stock biomass depletion B_y/B_0 relative to the 40% and 20% reference points.



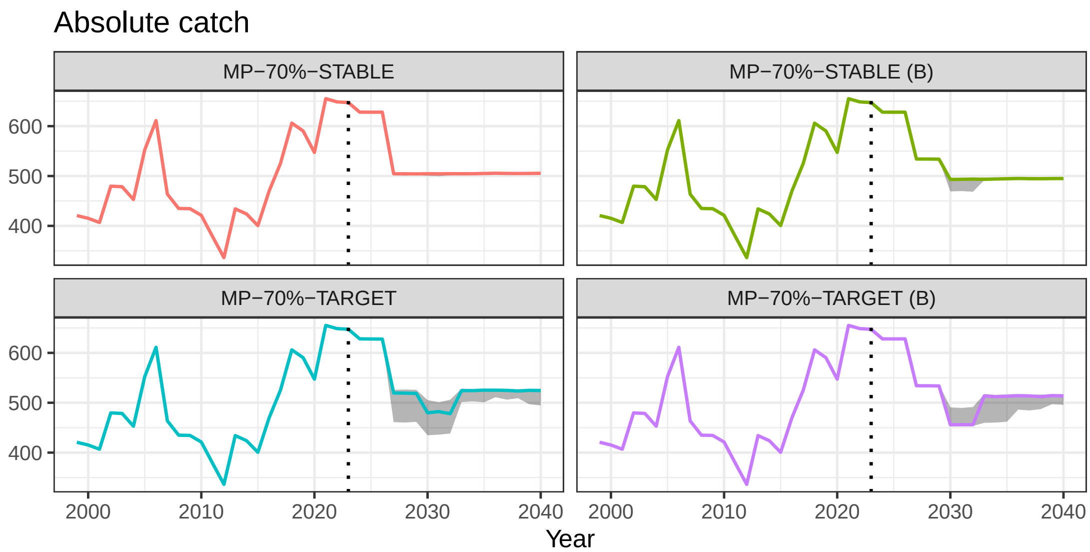
(b) Exploitation rate E_y, measured as a proportion of the 1+ individuals caught, relative to the $E_{40\%}$ reference point.

Figure A4: Stock status projections for each MP with a target tuning probability of 60%. The median value for each projection is shown as a coloured line, with the 95% quantile across operating models shaded in grey.

MP's tuned to 70%

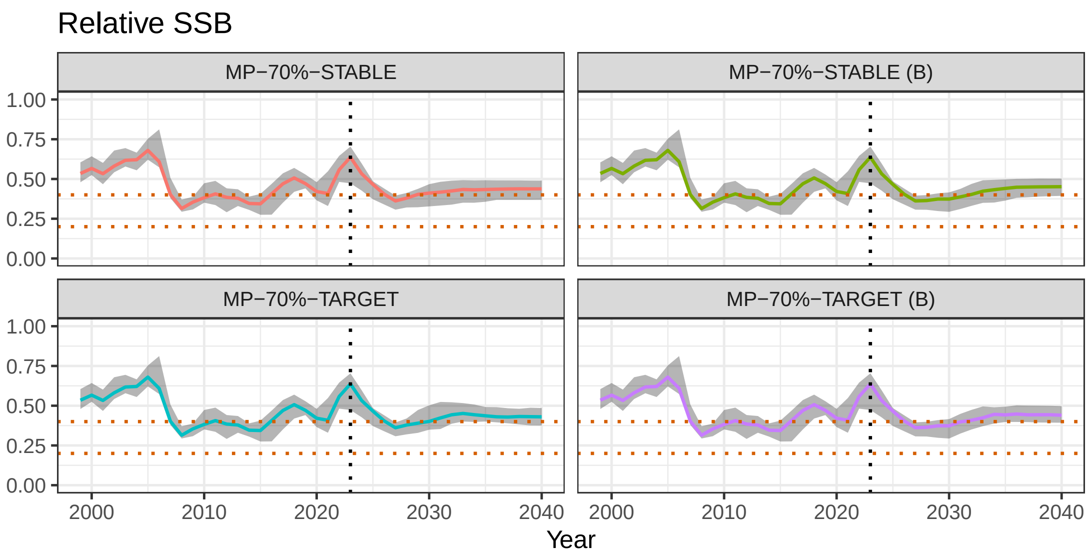


(a) Recommended TAC over time for each MP.

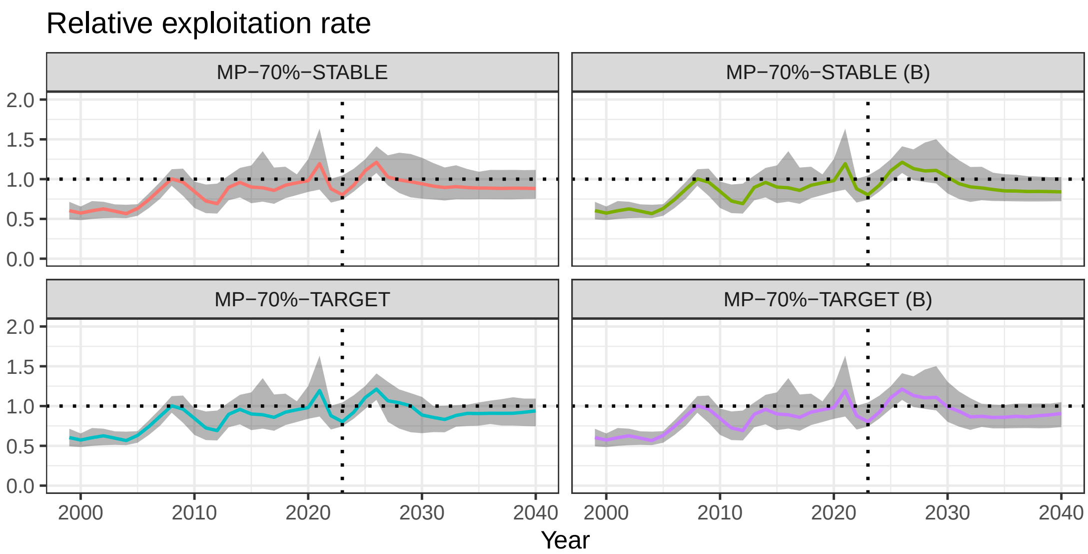


(b) Realised catch over time for each MP.

Figure A5: The recommended TAC and realised catch over time for each MP with a target tuning probability of 70%. The TAC for 2023 to 2026 was fixed at the known values listed in Table 1. No overcatch error was applied for the projection from 2023 onwards, which accounts for the low realised catch in 2023. The median value for each projection is shown as a coloured line, with the 95% quantile across operating models shaded in grey.



(a) Spawning stock biomass depletion B_y/B_0 relative to the 40% and 20% reference points.



(b) Exploitation rate E_y, measured as a proportion of the 1+ individuals caught, relative to the $E_{40\%}$ reference point.

Figure A6: Stock status projections for each MP with a target tuning probability of 70%. The median value for each projection is shown as a coloured line, with the 95% quantile across operating models shaded in grey.