IOTC-2024-TCMP07-06

Updated candidate MPs 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 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.

The current report provides a review of work to date, and proposed future directions, for discussion by the TCMP.

Introduction

In 2016, the IOTC adopted Resolution 16/02 (IOTC, 2016), which described a harvest control rule (HCR) to be used for setting a recommended exploitation rate for skipjack (SKJ), based on outputs from the stock assessment (Figure 1). This stock assessment is conducted in the same year that the HCR is implemented, using catch data up to and including the previous year. Each associated catch recommendation is valid for the subsequent three year period. Using outputs from the 2017 assessment (Fu, 2017), the HCR was first implemented at the end of that year to give a recommended catch limit for 2018–2020 of 470 thousand tonnes (SC, 2017). A second implementation of the HCR was conducted in 2020 (SC, 2020), based on an updated stock assessment by Fu (2020). The outputs were used to calculate a recommended catch limit for 2021–2023 of 514 thousand tonnes (IOTC, 2021a). The stock assessment was repeated in 2023 (Fu, 2023), yielding a recommended catch limit for 2024–2026 of 629 thousand tonnes (SC, 2023). The realised catch from the fishery consistently exceeds the recommended limit by 15% – 30% each year (Table 1).

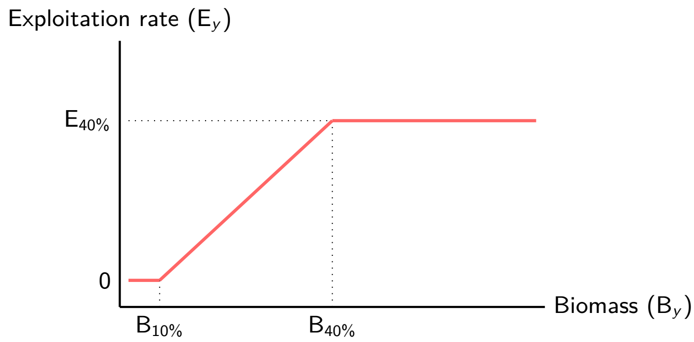


Figure 1: Schematic representation of the current Harvest Control Rule, which relates the estimated spawning stock biomass (B_y) to an exploitation rate (E_y). The recommended catch is obtained by multiplieing the exploitation rate with the estimated spawning stock biomass.

Table 1: Recommended catch from Resolution 16/02 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	–	–

As part of CMM 16/02 and 21/03 the IOTC has committed to a programme of development and refinement of the HCR, and to subject it to simulation-based evaluation. An HCR that has the data inputs specified and which has been simulation tested is referred to as a Management Procedure (MP). This work has been on-going since 2019 (see Edwards, 2023c, for a review of progress). The MP being considered is empirical, or data-based, meaning that it uses a descriptive rather than process-based representation of stock depletion to set the catches. For example, estimation of the spawning stock biomass requires a process-based representation of the dynamics, whereas a slope in the catch rate index over time does not, and would be considered a data-based indicator of stock status.

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

1. Re-visit the possibility of using a model-based Management Procedure based on the updated CPUE indices to be presented at WPTT-25;
2. Propose a set of candidate Management Procedures to the TCMP (2024) for potential adoption by the Commission.
3. Update the Operating Model to the most recent skipjack stock assessment, presented at WPTT-25;
4. Impose a minimum recommended catch of approximately 67 thousand tonnes;
5. Include a temporal correlation in the projected recruitment timeseries;
6. Evaluate the effect of different catch change limits.

Item (1) was addressed at WPTT-25 in 2023, with evidence presented that a model-based approach to setting management catch limits was not viable (IOTC, 2023c). The current report adresses items (2), (3) and (4), for discussion by the TCMP.

Management procedure design

Data inputs

An empirical or data-based MP utilises a descriptive rather than process based model. Initial work towards development of this approach was presented to the TCMP by Edwards (2021b), with an MP that was 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). Given the apparent utlity of the approach it has continued to be developed in subsequent work.

Within the traditional stock assessment paradigm, the natural logarithm of the exploitable biomass is typically assumed to follow a linear relationship with the natural logarithm of the CPUE (or survey) index. Assuming this to be a valid assumption, we can therefore consider the log-abundance as an index of the log-depletion and use it to set a suitable catch limit. One advantage of using the logarithm is that it introduces a convex shape to the relationship between the recommended catch and the true depletion, the effect of which is to make the harvest control rule increasingly aggressive in reducing catches as the depletion approaches zero. A second advantage is that the log-abundance has a more symmetrical error distribution around its true value, making it less susceptible as an index to the extreme values that may occur due to observation error.

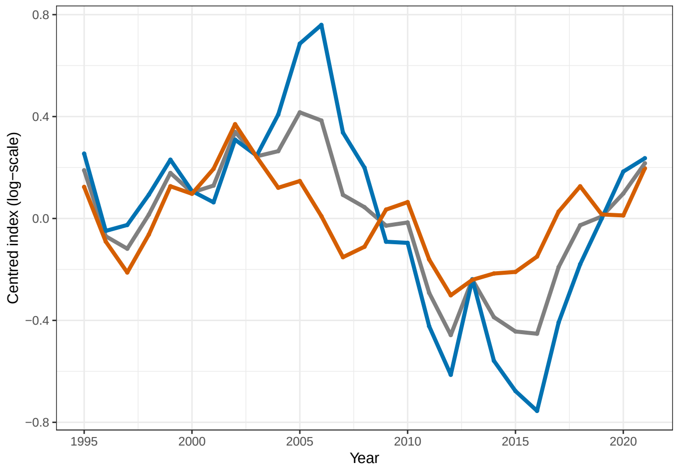


Figure 2: Time series of the log-trasformed PL and PSLS indices between 1995 and 2021 (Fu, 2023), offset by the mean value.

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 2). 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. For the 2023 assessment, 2021 is the most recent year for which both PL and PSLS CPUE's are available, meaning that there is a three year lag between the data and the year for which the catch is being recommended. The value for a_y is therefore calculated using data from year $y - 3$. It would be possible to stabalise the a_y index by taking the average over more years, but this was not explored further here. Instead, it was assumed that the standardisation process used to generate the CPUE indices will have already provided sufficient smoothing.

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

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

For purposes of illustration, the stock assessment results from Fu (2023) can be used to estimate the relationship between a_y and the depletion. The results are shown in Figure 3. This illustrates how the index becomes increasingly sensitive at lower depletion values, which is a property that is used implicitly by the HCR to recommend more severe reductions in the recommended catch as the stock biomass declines.

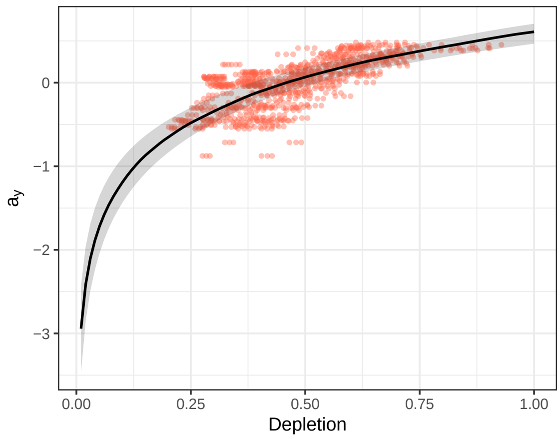


Figure 3: Relationship between the mean of the log-transformed PL and PSLS indices (a_y) and biomass depletion estimated by the 36 single-area stock assessment model runs of Fu (2023). Each data point (red) represents a value for a_y estimated from the empirical data, and the depletion estimated by the 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 MP contains an HCR of the form:

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

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 4). In addition, there are tuning parameters $\Delta^{TAC}_{\text{min}}$ and $\Delta^{TAC}_{\text{max}}$, which denote the upper and lower percentage change limits for the TAC. These tuning parameters (a_X, a_T, C_{min}, C_{max}, $\Delta^{TAC}_{\text{min}}$ and $\Delta^{TAC}_{\text{max}}$) are a fixed part of the MP, allowing simulation testing of it's performance with different tuning parameter values.

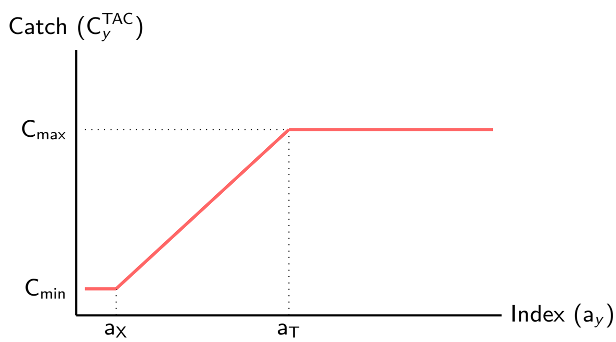


Figure 4: Schematic representation of the empirical Harvest Control Rule (Equation 2) that was proposed as part of a data-based MP (Edwards, 2021b,a). Tuing parameters are a_X, a_T, C_{min}, C_{max}, $\Delta^{\text{TAC}}_{\text{min}} and \Delta^{\text{TAC}}_{\text{max}}$, where $\Delta^{TAC}_{\text{min}}$ and $\Delta^{TAC}_{\text{max}}$ denote the upper and lower percentage change limits for the TAC.

Tuning

Within the IOTC, "tuning" is conducted with reference to pre-defined performance criteria, namely biomass status and the rate of exploitation, which define managment objectives for the stock (IOTC, 2015). Specifically, 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 $B_y > B_{40\%} \cap E_y < E_{40\%}$ (Edwards, 2023b, IOTC, 2023a). Tuning criteria defined as 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. If more than one MP matched the same tuning criteria, then the MP with an average TAC closest to C_{max} was selected.

Table 2: Median and 80% CI reference point estimates across 36 model runs Fu (2023), estimated using SS3.30.22. Catch and biomass values are given in units of 1000 tonnes. The assessment uses data up to 2022, and the 2023 values are obtained from a one-year projection at E_{2022}. Note that these outputs were re-estimated from the assessment input files used by Fu (2023) and may differ slightly from the published results.

Quantity	Median	(80% quantiles)
B_0	2169.945	(1912.66 - 2427.17)
$B_{40\%}$	867.979	(765.066 - 970.868)
B_{MSY}	519.871	(382.606 - 676.942)
B_{2023}	1229.435	(883.647 - 1530.985)
$C_{40\%}$	528.133	(475.914 - 594.267)
C_{MSY}	580.528	(519.6 - 671.156)
C_{2023}	596.511	(569.755 - 632.312)
$E_{40\%}$	0.55	(0.472 - 0.643)
E_{MSY}	0.981	(0.7 - 1.432)
E_{2023}	0.453	(0.379 - 0.615)
B_{2023}/B_0	0.572	(0.404 - 0.7)
$B_{2023}/B_{40\%}$	1.43	(1.009 - 1.749)
B_{2023}/B_{MSY}	2.383	(1.649 - 3.303)
$C_{2023}/C_{40\%}$	1.14	(0.972 - 1.289)
C_{2023}/C_{MSY}	1.024	(0.862 - 1.19)
$E_{2023}/E_{40\%}$	0.828	(0.676 - 1.088)
E_{2023}/E_{MSY}	0.484	(0.325 - 0.686)

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. Model runs that assume a changing catchability over time were excluded from the reference set (IOTC, 2023c), which was therefore reduced to 18 models. 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 three-year lag, as per current management. For example, the candidate MP being tested is first implemented in 2026, using simulated catch rate data up to and including 2024, to set the TAC for 2027.

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 will be treated as a robustness test in subsequent work.

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 (Table 2). Previous work has focused on tuning the MP through adjustments in C_{max}. In the current work we also explore adjustments in a_X and a_T.

The following tuning parameter values were explored:

- $C_{max} = \{505, 516, 526, 537, 547, 558, 568, 590\}$
- $C_{min} = 66$
- $a_T = \{-0.5, -0.3, -0.1\}$
- $a_X = \{-1.2, -1.0, -0.8, -0.6\}$
- $\Delta^{TAC}_{min} = 0$
- $\Delta^{TAC}_{max} = \infty$

with C_{max} and C_{min} in units of 1000 tonnes. The Δ^{TAC}_{min} and Δ^{TAC}_{max} parameters represent upper and lower percentage change limits for the TAC. Possible values were defined by the WPM (IOTC, 2023b), and the effect of these will be explored in future work.

Tuning of the MP is based on the probability of the stock being in the target quadrant between years between 2033 and 2037. Figure 5 shows the relationship between C_{max} and this probability (left panel), and the marginal probability at different values of $\{a_T, a_X\}$ (right panel). An increasing value for C_{max} decreases the probability of being in the target quadrant, however this relationship depends on $\{a_T, a_X\}$. At smaller values of $\{a_T, a_X\}$, the probabilty is decreased, because the MP is less responsive to downward fluctuations in the stock biomass. This means that for any given tuning, multiple values of C_{max} can yield the same probabilty if appropriate values for $\{a_T, a_X\}$ are selected. It is likely that these choices will also affect other diagnostics, in particularly those related to stability of the catch. In response to this property, two MPs have been selected for each tuning probabilty, with high and low values for $\{a_T, a_X\}$, giving a total of six MPs. These are listed in Table 3. The target probabilities over time, used in the tuning process, is shown in Figure 6.

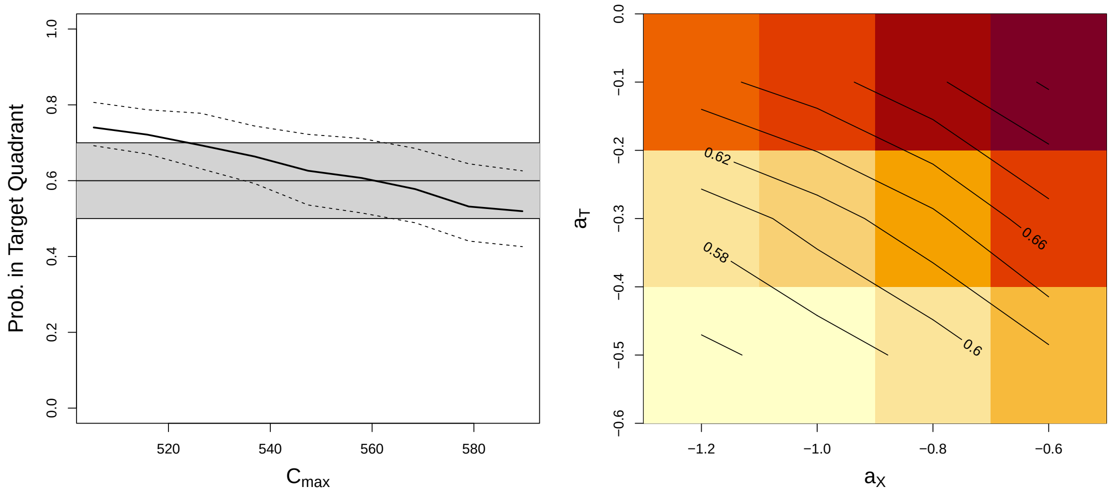


Figure 5: Simulated probabilities of being in the target quadrant between 2033 and 2037 for different values of C_{max}, a_T and a_X. Left panel: relationship between C_{max} and the target probability. For any given C_{max} the target probability is dependent on the values of a_T and a_X, and the mean, upper and lower probabilities are shown. Grey shading represents the tuning probabilities of 50%, 60% and 70%. Right panel: target probability for each combination of a_T and a_X, averaged over values for C_{max}.

Table 3: MP tuning parameters (Equation 2 and Figure 4). The MP label indicates the tuning probability and choice of values for $\{a_X, a_{max}\}$.

MP label	C_{min}	C_{max}	a_X	a_{max}
MP-50%-A	65.80	568.47	-1.20	-0.50
MP-50%-B	65.80	589.53	-1.00	-0.30
MP-60%-A	65.80	536.89	-1.20	-0.50
MP-60%-B	65.80	547.42	-1.00	-0.30
MP-70%-A	65.80	505.31	-1.20	-0.50
MP-70%-B	65.80	515.84	-1.00	-0.30

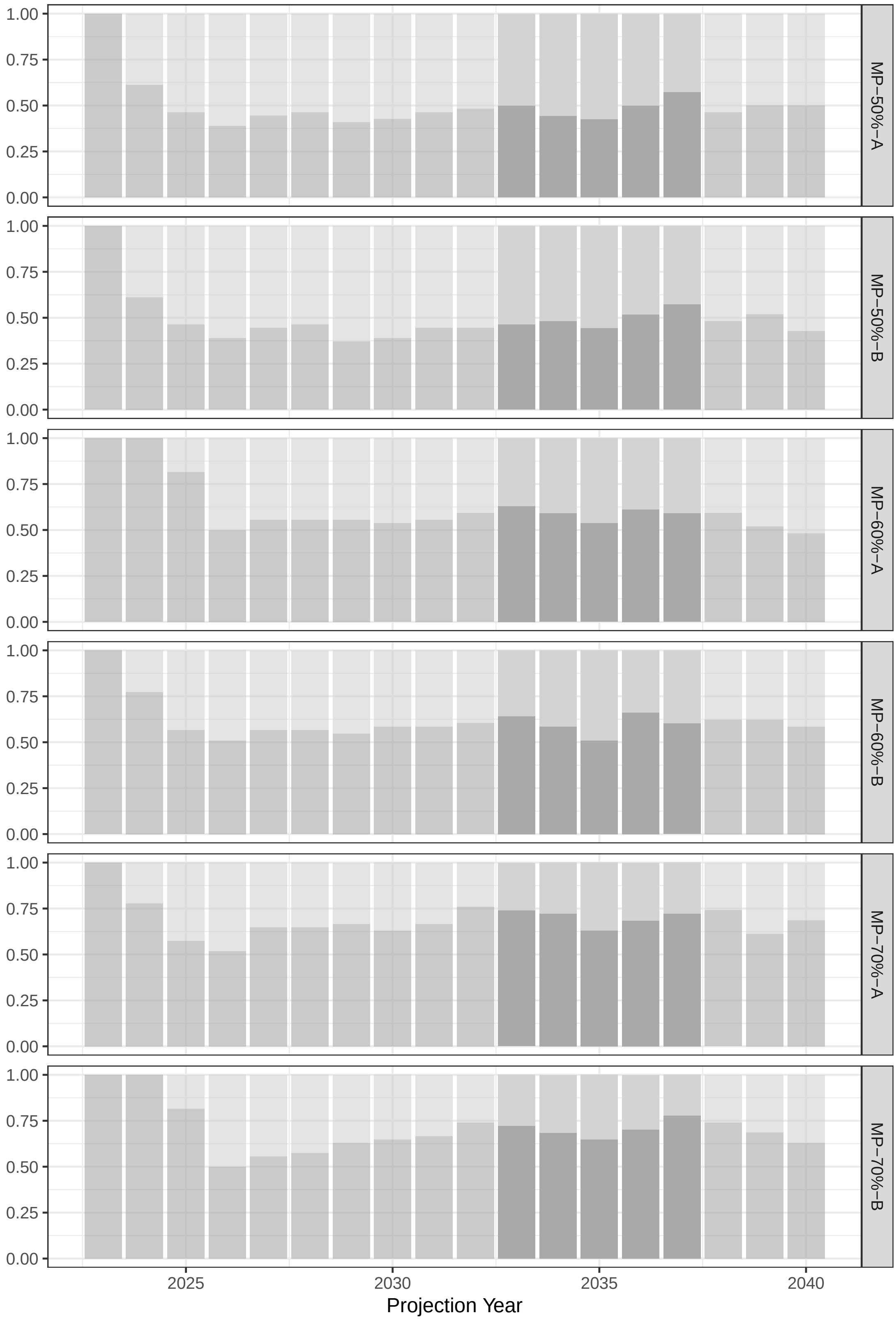


Figure 6: Simulated probabilities of being in the target quadrant over time, per MP (Table 3). Between 2023 and 2026 the TAC was fixed at known values (Table 1), after which the TAC was set by the MP. Each MP was tuned using the target quadrant probabilities between 2033 and 2037 inclusive.

Simulation results

Projections of the stock status index a_y over time are shown in Figure 7. The relationships between this projected value and the recommended catches are shown in Figure 8 for each MP. MPs with a higher C_{max}, and higher $\{a_T, a_X\}$, have a lower probability of the recommended TAC being equal to C_{max}, meaning that the TAC timeseries will be less stable. For example, it is estimated that MP-50%-B will recommend a TAC of 590 thousand tonnes with a probability of less than 70%, whereas MP-70%-A will recommend a TAC of 505 thousand tonnes with a probability of more than 90%. This contrast illustrates the trade-off that exists when selecting an MP for managemet. The catch stability of each MP is further illustrated in Figure 9, which shows the TAC and realised catch values over time.

Projected stock biomass and exploitation dynamics are shown in Figure 10. In this case, it can be seen that the tuning probability will determine status relative to the reference points, but there is no relationship between the stock status and stability of the catch time series observed in Figures 8 and 9. This is to be expected, since a higher but less stable TAC will yield a similar overall stock dynamic compared to a lower but more stable TAC. For example, MP-60%-A will generate a TAC of 537 thousand tonnes with a probability of 88%, whilst MP-60%-B will generate a TAC of 547 thousand tonnes with a probability of 76% (Figure 8). In these two instances the dynamics are indistinguishable (Figure 10).

More detailed diagnostics are listed in Table 4 and reported in Tables 5, 7 and 7, for consideration by the TCMP. As expected, more conservative tuning is associated with a lower catch and a higher biomass. Within each tuning, it is possible to adjust the stability of the TAC (the $|C_y^{TAC}/C_{y-1}^{TAC} - 1|$ diagnostic) using the a_T and a_X tuning parameters. Interestingly, higher values for $\{a_T, a_X\}$ allow a higher TAC for the 70% tuning, with an associated decrease in the catch stability (Table 5). But for the 50% tuning, higher values for $\{a_T, a_X\}$ are associated with a reduction in the average TAC (Table 7), even though the C_{max} parameter is higher (Table 3). This is similarly true to a lesser degree for the 60% tuning (Table 6). This overall pattern would indicate that for the 50% and 60% tunings, the smaller $\{a_T, a_X\}$ appear to be preferable (i.e., MP-60%-A and MP-50%-A).

Finally, the Kobe and Majuro phase plots are provided in Figure 11, 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.

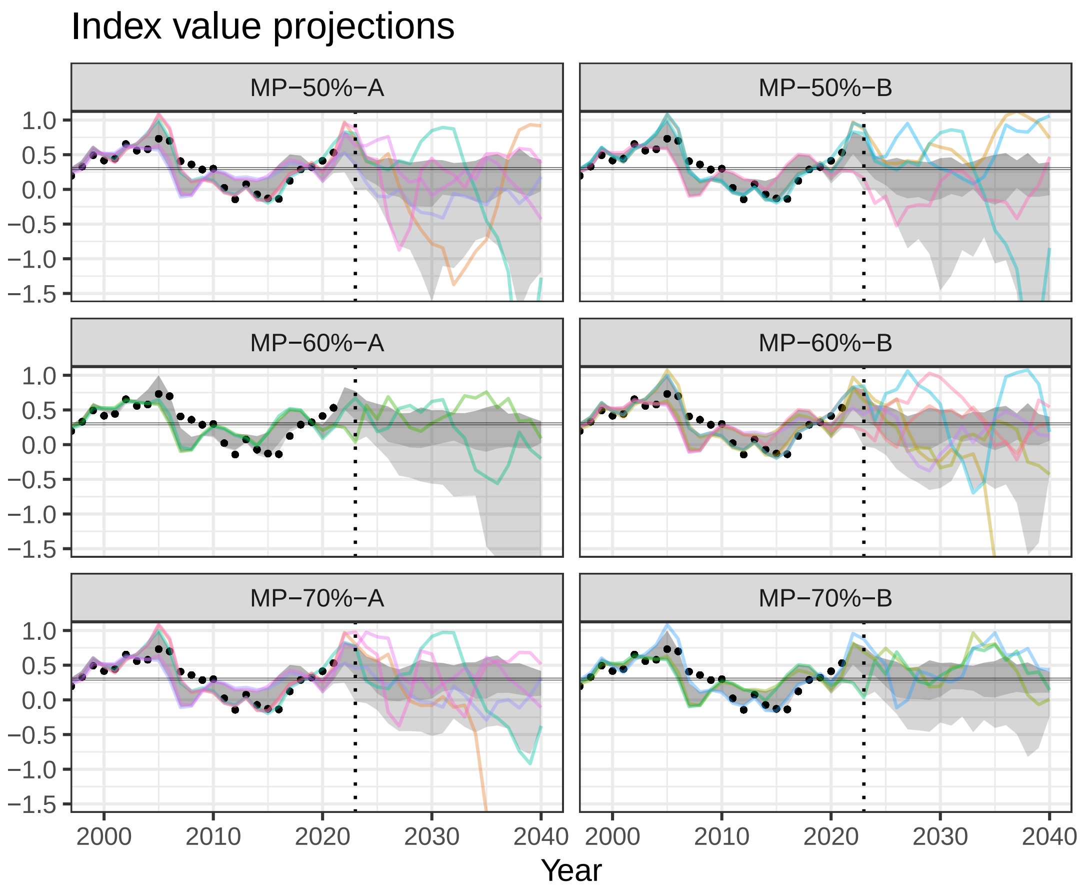


Figure 7: Values for a_y calculated from the fitted CPUE values (prior to 2023) and projected forward over time (2023 onwards). The 75% and 95% quantiles of a_y across operating models are shown as light and dark grey shadings respectively, with a random sample of individual trajectories shown in colour. The points prior to 2023 are calculated directly from the CPUE input time series. Also shown as a horizontal line is the reference value $a^{REF} = 0.314$ (Equation 1a), against which changes in the stock status are measured by the MP.

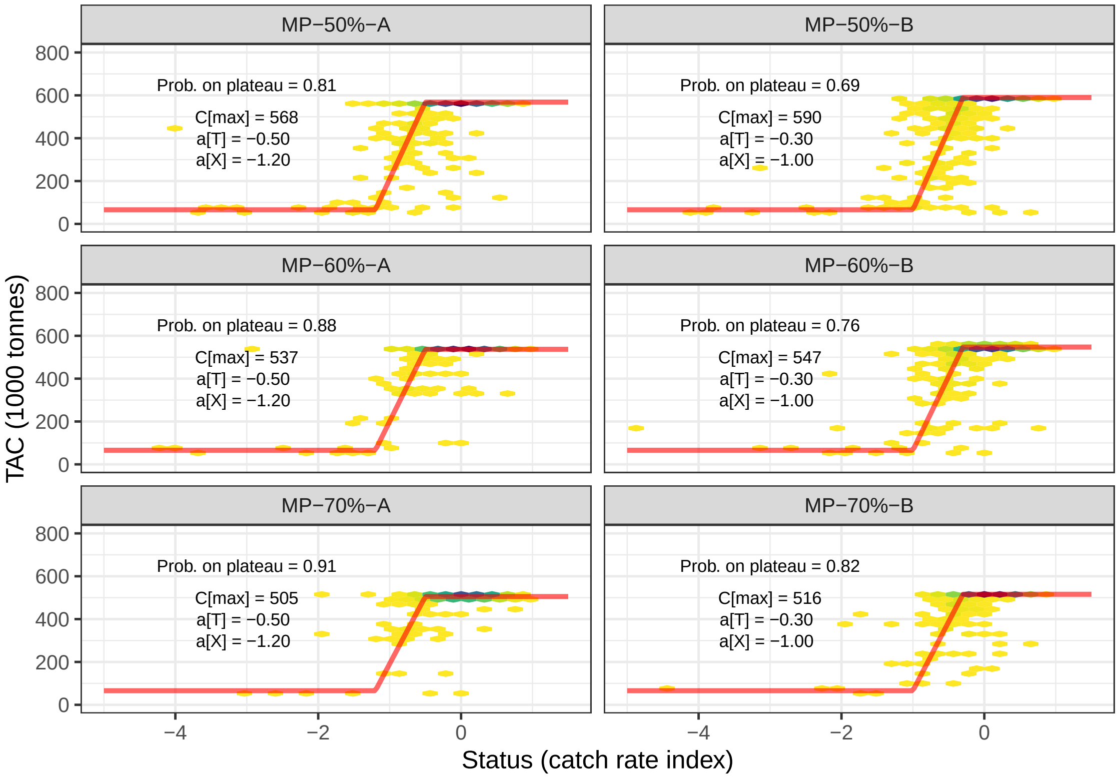
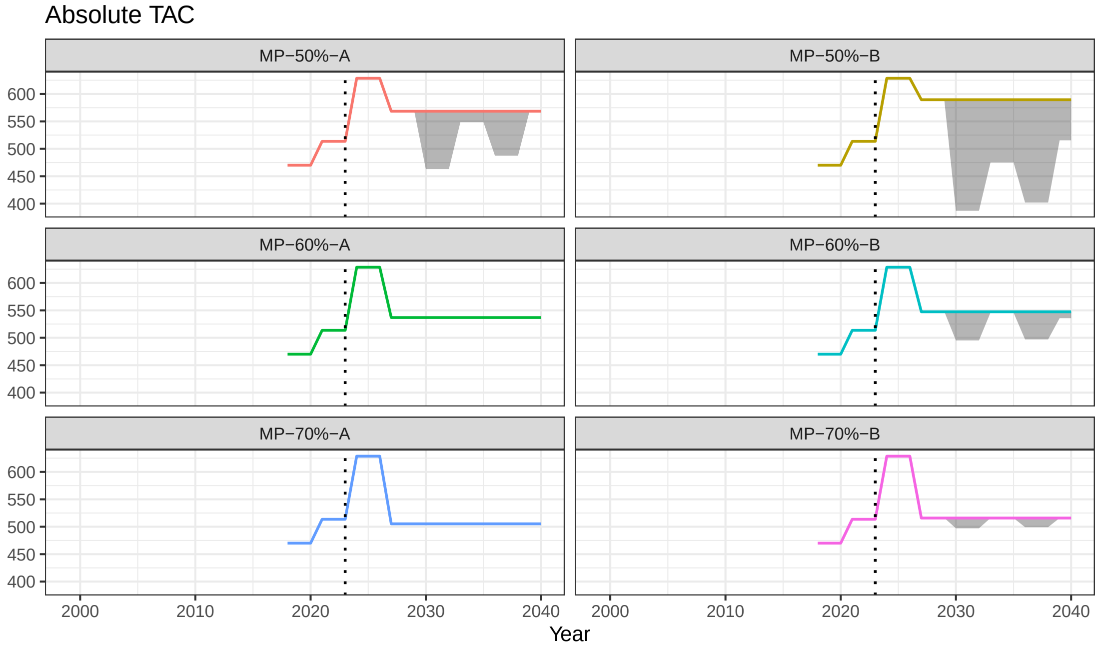
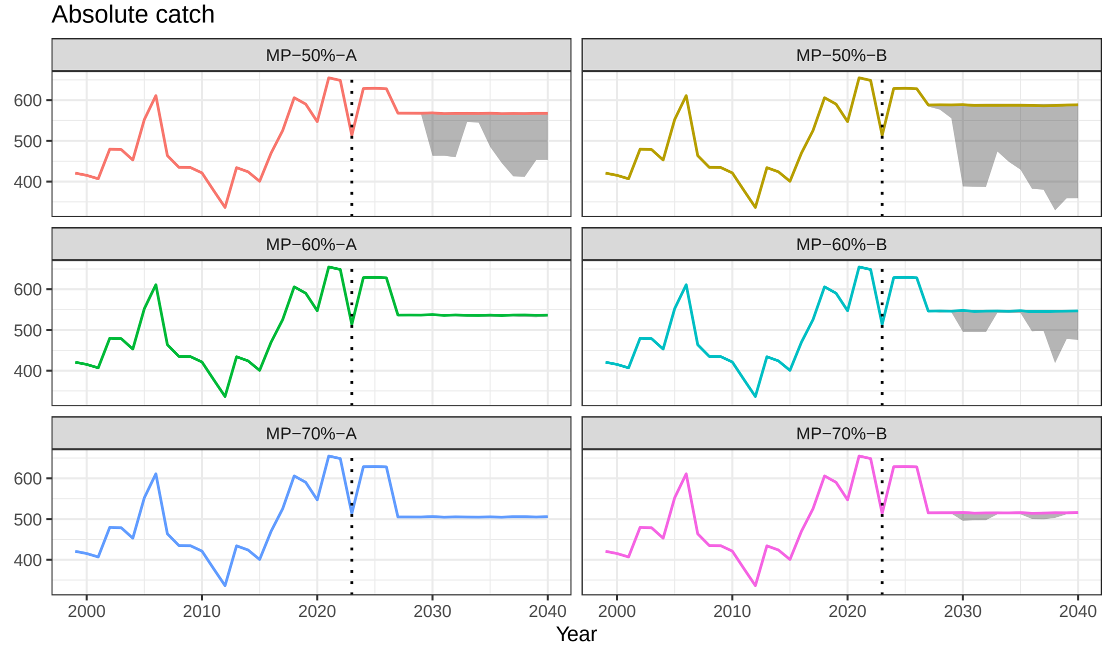


Figure 8: Relationship between the stock status, as measured by the catch rate index value a_y, and the TAC for each of the MPs in Table 3. The HCR for each MP is shown schematically in red, and the distribution of states as a two-dimensional histogram with darker colours indicating a higher frequency. In all cases the TAC per year is most often on the plateau (i.e., equal to C_{max}), but this probability differs between MPs, depending on the values of C_{max} and $\{a_T, a_X\}$.

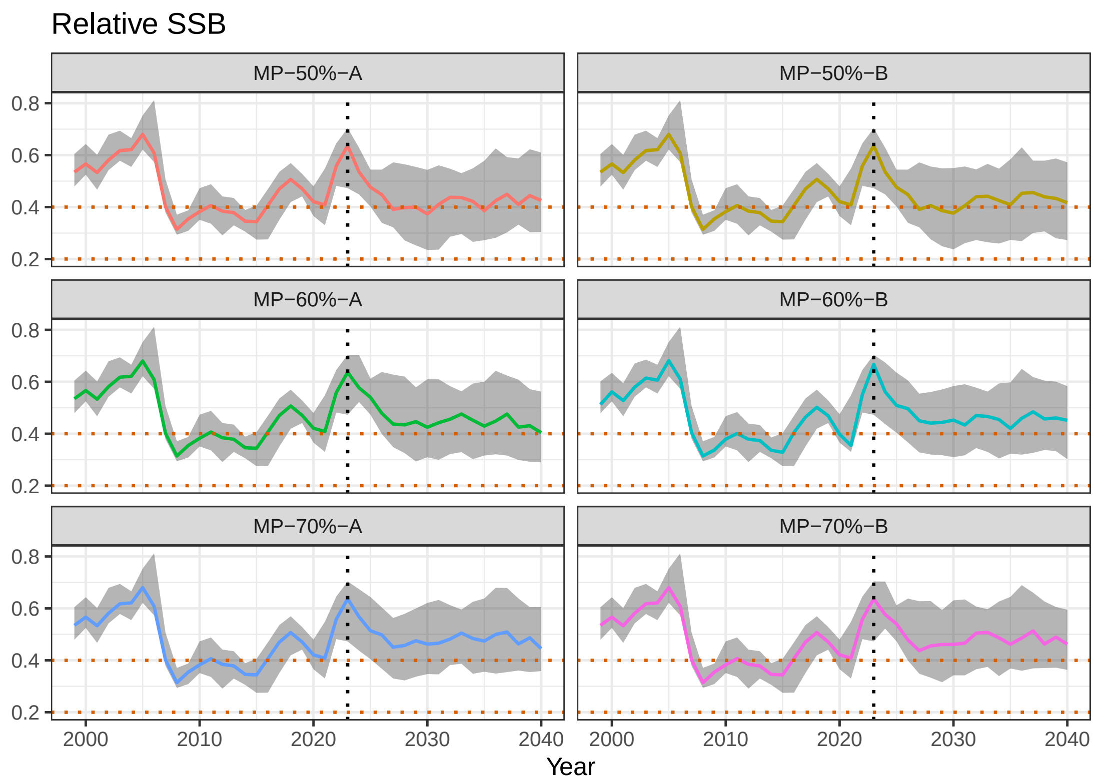


(a) Recommended TAC over time for each MP.

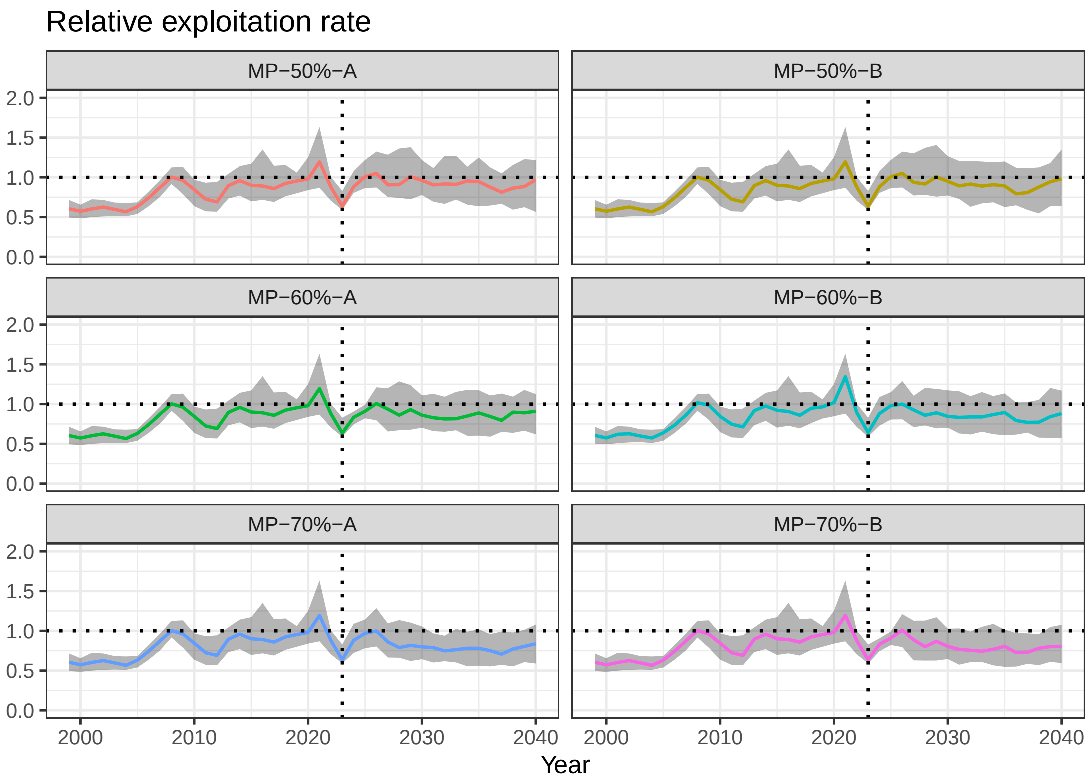


(b) Realised catch over time for each MP.

Figure 9: The recommended TAC and realised catch over time for each MP. 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.

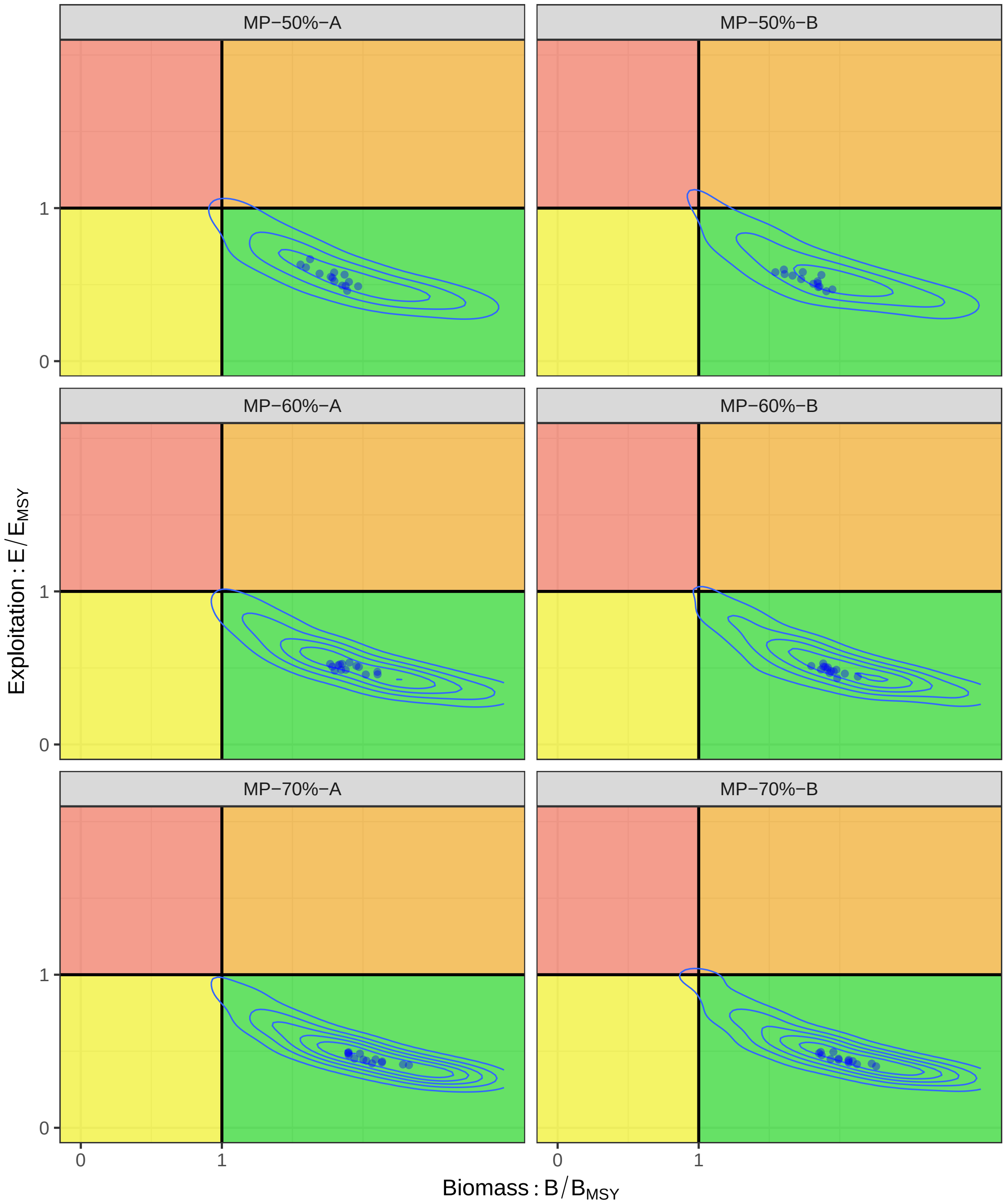


(a) Spawning stock biomass depletion B_y/B_0 relative to the 40% and 20% reference points.

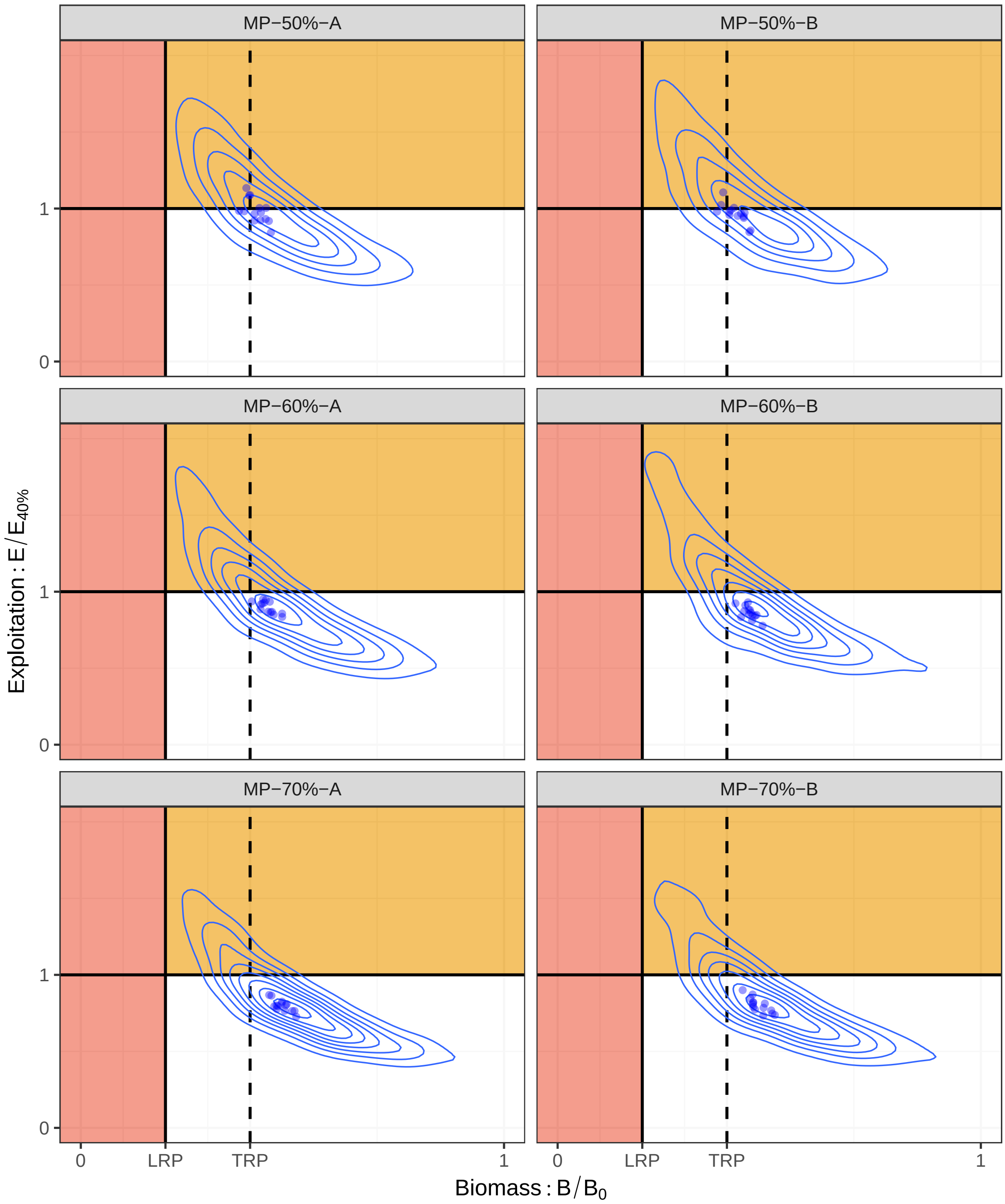


(b) Exploitation rate E_y, measured as a proportion of the 1+ individuals caught, relative to the $E_{40\%}$ reference point.

Figure 10: Stock status projections for each MP. The median value for each projection is shown as a coloured line, with the 95% quantile across operating models shaded in grey.



(a) Kobe phase plots



(b) Majuro phase plots

Figure 11: Kobe phase plots (top panel) and Majuro phase plots (bottom panel) for tuned MPs listed in Table 3. 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. Estimates for $B_{40\%}$, $B_{20\%}$ and B_{MSY}, and associated exploitation rates, were obtained from the stock assessment and are listed in Table 2.

Table 4: 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
Max. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Max. TAC change	Max. % 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. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert = 15\%$	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. $> B_{20\%}$	$B_y > B_{20\%}$	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 5: Diagnostic outputs for evaluation of index-based MPs with a target tuning probability of 70% (see Table 3 for the list of MP definitions and Table 4 for a description of each diagnostic).

Performance Statistic	Units	MP-70%-A	MP-70%-B
$C^{TAC}_{y+1:3}$	10^3 tonnes	526.32 (494.46 - 526.32)	531.49 (480.12 - 534.50)
C	10^3 tonnes	526.21 (493.73 - 526.72)	531.44 (479.73 - 534.82)
$C_{[PL]}$	10^3 tonnes	106.20 (99.92 - 108.32)	106.66 (97.25 - 109.63)
$C_{[PSLS]}$	10^3 tonnes	135.19 (129.42 - 148.20)	134.17 (125.61 - 148.66)
$C_{[PSFS]}$	10^3 tonnes	25.56 (24.45 - 25.92)	25.55 (23.73 - 26.25)
$C_y/C_{40\%}$	Proportion	0.98 (0.86 - 1.11)	0.97 (0.84 - 1.12)
C_y/C_{MSY}	Proportion	0.90 (0.75 - 1.01)	0.87 (0.75 - 1.02)
$C^{TAC}_y \neq C^{TAC}_{y-1}$	Count	1.00 (1.00 - 3.00)	2.00 (1.00 - 4.00)
$\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert$	Percent	3.92 (3.92 - 20.43)	5.02 (3.59 - 38.86)
Pr. $\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert > 10\%$	Prob.	0.29	0.37
Pr. $\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert > 5\%$	Prob.	0.30	0.40
Pr. $\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert = 15\%$	Prob.	0.00	0.00
$CPUE_{[PL]}$	Rate	0.09 (0.07 - 0.12)	0.09 (0.08 - 0.12)
$CPUE_{[PSLS]}$	Rate	21.32 (17.50 - 27.41)	21.76 (17.88 - 26.73)
E_y	Rate	0.46 (0.37 - 0.56)	0.44 (0.38 - 0.55)
$E_y/E_{40\%}$	Proportion	0.82 (0.65 - 1.04)	0.79 (0.66 - 1.07)
E_y/E_{MSY}	Proportion	0.47 (0.30 - 0.70)	0.47 (0.30 - 0.68)
B_y	10^3 tonnes	1063.14 (851.82 - 1343.93)	1082.38 (881.95 - 1300.29)
B_y/B_0	Proportion	0.48 (0.35 - 0.60)	0.49 (0.38 - 0.58)
B_y/B_{MSY}	Proportion	2.01 (1.46 - 2.84)	2.10 (1.43 - 2.85)
Pr. $> B_{20\%}$	Prob.	0.96	0.96
Pr. $> B_{10\%}$	Prob.	0.98	0.98
Pr. Target Quadrant	Prob.	0.69	0.71
Pr. Kobe Red	Prob.	0.05	0.04
Pr. Kobe Green	Prob.	0.93	0.93
Pr. Majuro Red	Prob.	0.04	0.04
Pr. Majuro White	Prob.	0.94	0.94

Table 6: Diagnostic outputs for evaluation of index-based MPs with a target tuning probability of 60% (see Table 3 for the list of MP definitions and Table 4 for a description of each diagnostic).

Performance Statistic	Units	MP-60%-A	MP-60%-B
$C^{TAC}_{y+1:3}$	10^3 tonnes	550.88 (497.13 - 550.88)	544.99 (485.24 - 559.07)
C	10^3 tonnes	550.59 (497.21 - 551.28)	544.09 (473.37 - 559.33)
$C_{[PL]}$	10^3 tonnes	110.63 (102.78 - 113.27)	109.11 (95.78 - 114.55)
$C_{[PSLS]}$	10^3 tonnes	138.99 (128.38 - 155.11)	140.03 (117.73 - 151.34)
$C_{[PSFS]}$	10^3 tonnes	26.60 (24.77 - 27.11)	26.01 (23.41 - 27.42)
$C_y/C_{40\%}$	Proportion	1.01 (0.88 - 1.12)	0.99 (0.72 - 1.10)
C_y/C_{MSY}	Proportion	0.90 (0.77 - 1.03)	0.88 (0.68 - 1.02)
$C^{TAC}_y \neq C^{TAC}_{y-1}$	Count	1.00 (1.00 - 3.00)	2.00 (1.00 - 4.00)
$\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert$	Percent	2.92 (2.92 - 22.69)	9.02 (2.58 - 60.36)
Pr. $\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert > 10\%$	Prob.	0.31	0.43
Pr. $\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert > 5\%$	Prob.	0.33	0.45
Pr. $\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert = 15\%$	Prob.	0.00	0.00
$CPUE_{[PL]}$	Rate	0.09 (0.07 - 0.11)	0.09 (0.07 - 0.12)
$CPUE_{[PSLS]}$	Rate	20.42 (16.10 - 25.88)	20.39 (16.46 - 26.21)
E_y	Rate	0.48 (0.40 - 0.64)	0.47 (0.40 - 0.58)
$E_y/E_{40\%}$	Proportion	0.85 (0.70 - 1.26)	0.85 (0.68 - 1.14)
E_y/E_{MSY}	Proportion	0.51 (0.32 - 0.82)	0.49 (0.33 - 0.68)
B_y	10^3 tonnes	1019.34 (822.50 - 1267.61)	1011.07 (813.26 - 1272.43)
B_y/B_0	Proportion	0.46 (0.35 - 0.57)	0.45 (0.35 - 0.56)
B_y/B_{MSY}	Proportion	1.97 (1.28 - 2.77)	1.95 (1.28 - 2.72)
Pr. $> B_{20\%}$	Prob.	0.94	0.94
Pr. $> B_{10\%}$	Prob.	0.97	0.98
Pr. Target Quadrant	Prob.	0.62	0.62
Pr. Kobe Red	Prob.	0.08	0.07
Pr. Kobe Green	Prob.	0.90	0.90
Pr. Majuro Red	Prob.	0.06	0.06
Pr. Majuro White	Prob.	0.91	0.91

Table 7: Diagnostic outputs for evaluation of index-based MPs with a target tuning probability of 50% (see Table 3 for the list of MP definitions and Table 4 for a description of each diagnostic).

Performance Statistic	Units	MP-50%-A	MP-50%-B
$C^{TAC}_{y+1:3}$	10^3 tonnes	561.60 (483.76 - 575.44)	543.80 (478.81 - 591.82)
C	10^3 tonnes	555.22 (445.76 - 575.80)	536.35 (464.91 - 591.90)
$C_{[PL]}$	10^3 tonnes	112.02 (89.92 - 118.31)	109.41 (93.03 - 119.55)
$C_{[PSLS]}$	10^3 tonnes	144.16 (110.31 - 157.49)	142.07 (117.84 - 158.68)
$C_{[PSFS]}$	10^3 tonnes	26.81 (23.19 - 28.31)	26.44 (22.78 - 28.85)
$C_y/C_{40\%}$	Proportion	0.98 (0.62 - 1.12)	0.97 (0.69 - 1.14)
C_y/C_{MSY}	Proportion	0.89 (0.57 - 1.03)	0.86 (0.62 - 1.04)
$C^{TAC}_y \neq C^{TAC}_{y-1}$	Count	2.50 (1.00 - 3.70)	3.00 (1.00 - 4.70)
$\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert$	Percent	7.39 (1.91 - 61.03)	18.25 (1.24 - 94.10)
Pr. $\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert > 10\%$	Prob.	0.24	0.33
Pr. $\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert > 5\%$	Prob.	0.44	0.54
Pr. $\lvert C^{TAC}_y/C^{TAC}_{y-1} - 1\rvert = 15\%$	Prob.	0.00	0.00
$CPUE_{[PL]}$	Rate	0.08 (0.06 - 0.10)	0.08 (0.06 - 0.11)
$CPUE_{[PSLS]}$	Rate	18.82 (13.94 - 24.20)	18.92 (15.03 - 23.88)
E_y	Rate	0.53 (0.41 - 0.68)	0.52 (0.43 - 0.67)
$E_y/E_{40\%}$	Proportion	0.95 (0.68 - 1.40)	0.92 (0.70 - 1.38)
E_y/E_{MSY}	Proportion	0.52 (0.33 - 0.85)	0.52 (0.35 - 0.86)
B_y	10^3 tonnes	944.39 (740.49 - 1210.01)	945.82 (725.51 - 1207.86)
B_y/B_0	Proportion	0.43 (0.27 - 0.55)	0.42 (0.28 - 0.54)
B_y/B_{MSY}	Proportion	1.79 (0.96 - 2.63)	1.77 (1.08 - 2.60)
Pr. $> B_{20\%}$	Prob.	0.90	0.91
Pr. $> B_{10\%}$	Prob.	0.96	0.96
Pr. Target Quadrant	Prob.	0.50	0.50
Pr. Kobe Red	Prob.	0.11	0.11
Pr. Kobe Green	Prob.	0.85	0.83
Pr. Majuro Red	Prob.	0.10	0.09
Pr. Majuro White	Prob.	0.86	0.85

Conclusions and further work

In this report, performance diagnostics for six candidate MPs have been presented, following simulations with an updated set of operating models. These MPs have been tuned to the 50%, 60% and 70% target quadrant tuning criteria. Which tuning criteria is used will largely determine the long term status of the stock. However, within each criteria, two MPs have been presented with more or less stable TAC dynamics. These six MPs represent initial candidates for potential managment of the skipjack fishery, pending further robustness testing.

Robustness testing

The two primary uncertainties related to performance of the skipjack MP are overcatch (i.e. catches higher than the recommendation), and potential recruitment failure. Overcatch is a persistent concern (Table 1) that needs to be addressed either at the governence level, or through temperance of the scientific advice (i.e., reduction in the recommended catch). Recruitment failure is a concern because of suspected correlations between skipjack recruitment and environmental conditions in the Indian Ocean (Marsac, 2023a,b), which may become unfavourable in the future.

Based on discussions by the WMP (IOTC, 2023a), the approach adopted by Edwards (2023a) was to tune MPs without including any overcatch error, and then to test the impact of overcatch in subsequent robustness testing. This approach was presented to the TCMP (IOTC, 2023d), and it was recommended that future testing should assume overcatch errors of between 20% – 30%. The TCMP further requested that temporally correlated changes in recruitment should be included as a robustness test. This would be to examine the consequences of a sustained decline in skipjack recruitment as a result of unfavourable environmental conditions. Both of these robustness tests are scheduled to be presented to the TCMP in May 2024.

A final robustness test, which includes an increase in the catchability for the PSLS fleet over time, was discussed by the WPTT IOTC (2023c). An increase in the catchability would dampen any observed change in the CPUE index that has occured as a result of stock decline, making the index increasingly unreliable over time. It therefore has the potential to undermine performance of the MPs tested here. It was agreed at the WPTT that the consequence of changes in the catchability should be examined as a robustness test.

Further MP development

In addition to the robustness testing described above, further developmental work is required. First, the influence of different percentage change limits should be explored (the $\Delta^{\mathrm{TAC}}_{\mathrm{min}}$ and $\Delta^{\mathrm{TAC}}_{\mathrm{max}}$ tuning parameters), as defined by the WPM (IOTC, 2023b). Also requested by the WPM, was that the CPUE standardisation process, by which the PL and PSLS indices are generated, should be specified as part of the MP definition. Any substantial changes to the standardisation process could then be used to invoke exceptional circumstances. Finally, the exceptional circumstances should themselves be fully described. This additional work is scheduled to be presented at the TCMP in May 2024.

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