IOTC Swordfish

Management Strategy Evaluation

8th Session IOTC TCMP – 10 & 11 May 2024

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Executive summary

- This document presents the outcome of the Indian Ocean swordfish MSE, in which three different Management Procedures (MP) were tested using simulation.
- The operating model (OM) used in these simulations has been developed over the last four years and has been endorsed by the IOTC scientific committee. The OM is based on the 2020 WPB assessment, and covered the dynamics of the swordfish until the year 2018. This OM was updated to the year 2023 by projecting the stock forward based on the IOTC catch estimates for the period 2019 to 2022 and assuming a fishing mortality in 2023 at the 2022 level. A comparison of the OM with the new 2023 swordfish stock assessment shows that the OM remains appropriate to describe the dynamics of the Indian Ocean swordfish stock, as well as its current status.
- The MPs tested are of two types : model-based (using a surplus production model combined with a harvest control rule) and data-based (based on the recent trend and value in a CPUE index). Two versions of the data-based one were investigated, one reacting faster to the changes in the CPUE index than the other.
- The appropriate configuration of these MPs was obtained by tuning (i.e. defining the MP parameters that achieve a certain management goal on average) for a range of management objectives over the next 11 to 15 years.
- Robustness tests were conducted to investigate how the performance of the MPs is impacted in situations where i) the catches exceed the TAC, ii) the TACs are implemented two years after the advice, instead of one year in the base case, and iii) a recruitment failure occurs.
- The performance of the tuned MPs is presented in this document. The different types of MPs maintain the stock well within safe biological limits. Model-based MPs

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achieve very stable catches with low associated uncertainty, while the data-based MPs achieve higher but more uncertain levels of catches, with higher interannual variations.

- The MPs appear to be robust to the two TAC overshoot scenarios tested, with a performance that is only marginally affected. The management objectives (used when tuning the MPs) are, however, no longer met in one of the two scenarios tested. The MPs are furthermore robust to an 2 year lag between the computation of the TAC advice and the implementation of the TAC (compared to 1 year in the base case). The MPs tuned for a more conservative management objective achieve a higher robustness to a recruitment failure, and for a given management objective, the faster reacting version of the data based MP is the most robust, while the model-based MP is the less robust.

Introduction

The IOTC, at its 15th Session in 2011, endorsed the development of a management strategy evaluation (MSE) process and the Scientific Committee endorsed a roadmap for its development later that year. In addition, a meeting of all tuna RFMOs (i.e., Kobe III) in 2011 recognised that an MSE process needs to be widely implemented in the tuna RFMOs in line with implementing a precautionary approach for tuna fisheries management. In 2016, the IOTC established the Technical Committee on Management Procedures (TCMP) specifically to "enhance the decision making response of the Commission in relation to management procedures".

The MSE process for the swordfish has been in progress since 2019. The development of the simulation framework has been mainly carried out by Wageningen Marine Research (funded by FAO) with regular presentations to the IOTC Working Party on Methods, and in particular the MSE task force. Feedback and technical advice from this group have largely guided the development of this work. The development of the work has also regularly been presented to the TCMP, and the necessary work to answer the requests from the TCMP was also (for the most part) conducted.

This document describes the structure and core concepts of the swordfish MSE and summarises the results from the evaluation of six MPs. The intention is to provide sufficient knowledge to facilitate the decision-making processes of the Commission in relation to the adoption of a MP in the IOTC.

MSE framework

Operating model

The basis for the current swordfish OM was presented at the TCMP, and both at the Working party on Billfish and Working party on Methods. The working document presented at TCMP (IOTC 2023) included a revision of the OM grid that decreased the number of factors considered, by identifying those having little impact on initial stock status and productivity in the OM. This resulted in a new grid containing 648 combinations, of which 175 were selected by factorial design optimization (vs 2592 and 108 respectively for the earlier OM). The SS3 stock assessment was run for these 175 parameter combinations, and 130 runs were ultimately considered acceptable (based on model convergence, biomass index prediction skill, and credibility of B0 estimates) and used as a basis for the OM (vs 67 for the original OM).

The basis for the OM are SS3 runs based on data used for the 2020 stock assessment for the Indian ocean swordfish stock, that covered the development of the stock until the year 2018. In order to conduct simulations starting with a stock status as close as possible to the current status, the OM was projected forward over the years 2019-2023 using the IOTC catch estimates for the years 2019 to 2022, and assuming a status quo fishing mortality for 2023 ($F_{2023}=F_{2022}$).

During WPB 2023 an updated SS3 assessment was presented. It consists of an ensemble of 47 SS3 model runs covering a grid of input parameters for the main uncertainty related to assumptions on the CPUE configuration options, stock-recruitment steepness, recruitment deviations, growth, and effective sample sizes of the length composition data. The factors and levels included are similar to the ones used to build the uncertainty grid of the swordfish OM.

The distribution of the population dynamics parameters from the update assessment is narrower and is generally well within the distribution of the parameters of the OM. Likewise, the historical stock status from the 2023 assessment is comprised within the envelop of the OM (figure 1). The distribution of SB/SB_{MSY} and F/F_{MSY} from the assessment in its final year, 2021, are well within the OM.

By definition, more sources of uncertainty are considered when building an OM for an MSE than when assembling the model runs for a stock assessment. In the case of swordfish, the structural uncertainty grid for the OM includes 7 parameters and the OM is based on 130 SS3 runs, while the grid for the assessment considers 5 parameters that lead to 48 combinations. This explains the wider distribution envelop for the OM on figure 1.

Overall, the new 2023 assessment does not drastically change the perception of the dynamics and current status of the stock, and the OM build based on the previous assessment is still considered appropriate to describe the current stock status and its associated uncertainty, as well as uncertainty in the stock dynamics parameters.

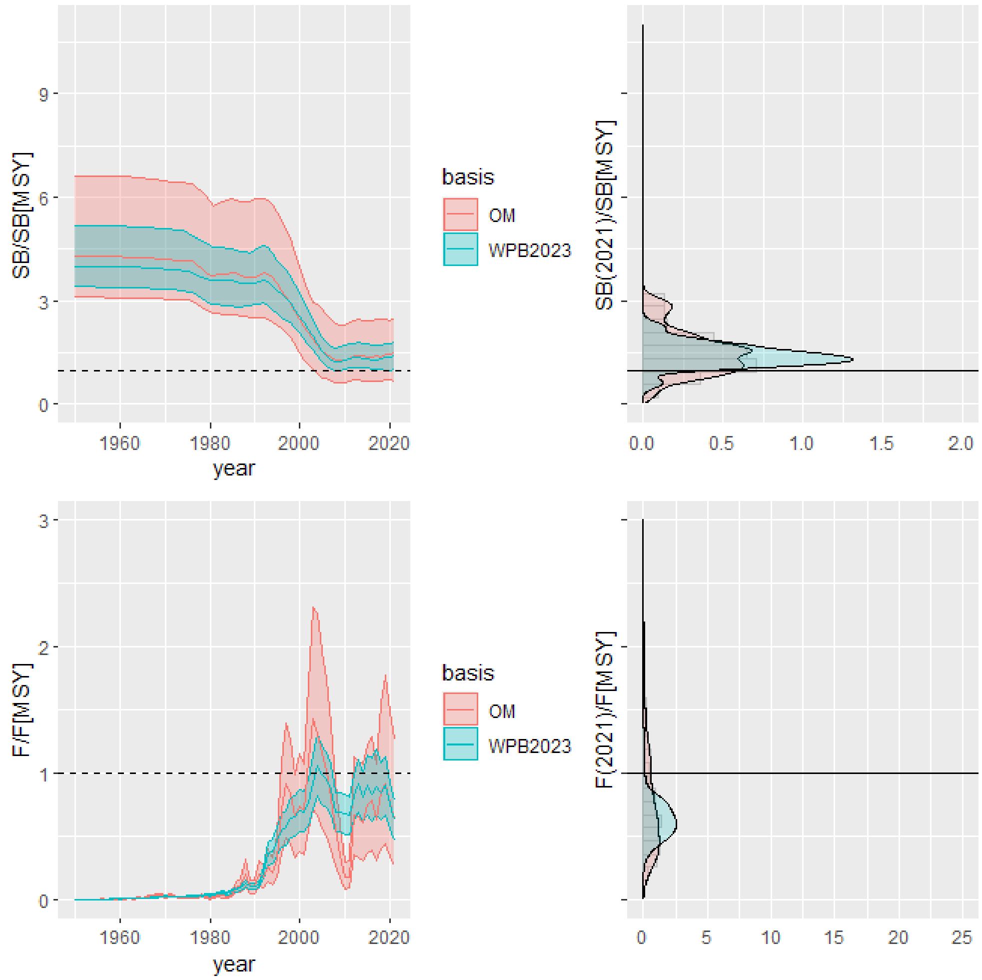


Figure 1: Historical swordfish stock development (left) and stock status in 2021 (right) in the Operating Model developed for the MSE (red) and in the WPB 2023 swordfish assessment (blue).

Management Procedures

Model-based MP

The model-based MPs (figure 3) involve two steps:

- 1) fitting a surplus production model to estimate current depletion rate, and
- 2) applying a Harvest Control Rule (HCR) to the model estimates of current depletion. The shape of the HCR (hockey-stick) is defined by three control parameters :
    - CP1: minimum stock level below which no fishing (or the least possible) should take place,
    - CP2: trigger stock level below which catch advice should be decreased proportionally to current depletion
    - CP3: maximum catch that can be taken when the stock is estimated to be

above the trigger level.

The surplus production model JABBA was fitted to the total catches time series and the Japanese longline and the Taiwanese longline CPUE indices. It provided estimates of the depletion rate, calculated as SB/SB0 (SB0=virgin biomass), in the last year of the assessment period. The limit and trigger depletion rates were set at CP1 = 0.1 and CP2 = 0.4. The maximum catch, CP3, was obtained by tuning the MP to achieve the particular management objectives.

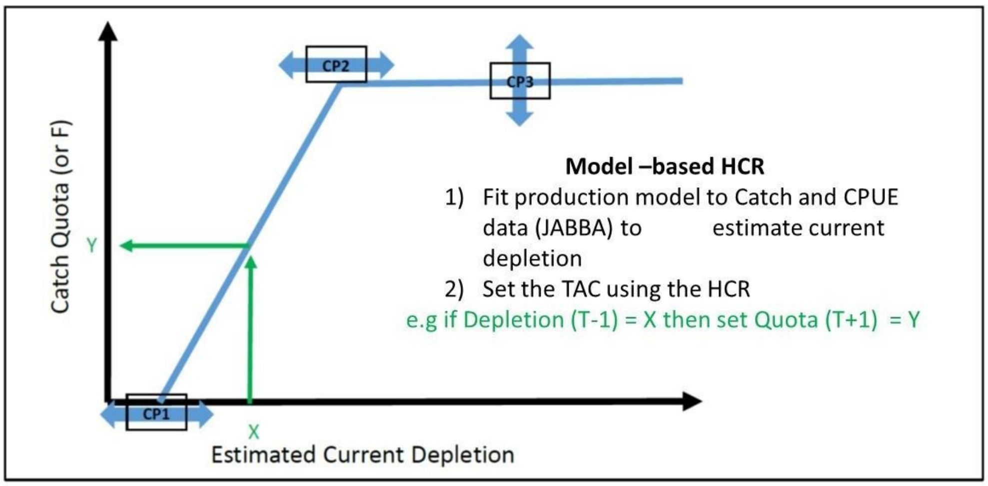


Figure 2. Harvest control rules used in the model-based MPs.

Data-based

The data-based MPs attempt to manage the fishery to achieve a target value of catch rates over a chosen CPUE series. The next TAC is increased relative to the current TAC if current CPUE is above the target CPUE and the CPUE trend is increasing. Conversely, the next TAC is decreased relative to the current TAC if current CPUE is below the target CPUE and the CPUE trend is decreasing. If the CPUE location relative to the target and CPUE slope are in opposite directions, the TAC change could be in either direction, depending on the magnitude of these indicators, and the associated control parameters. Formally, the future TAC is calculated as a proportion, TAC_{mult}, of the current TAC, which is defined as

$$TAC_{mult} = 1 + k_a Sl + k_b D$$

with

$$k_a = k_1 if Sl > 0 \vee k_a = k_2 if Sl \leq 0$$

and

$$k_b = k_3 if D > 0 \vee k_b = k_4 if D \leq 0$$

Where Sl is the slope of the log CPUE over the last 5 years, D is the difference between recent CPUE value (average over the last 3 years) and the target CPUE value, and k_a and k_b

are parameters of the relative weight assigned to the previous two quantities (figure 4), controlling the responsiveness of the MP. Control parameters include: CP1 and 2) responsiveness to CPUE slope (k1 and k2), CP3 and 4) responsiveness to CPUE target deviation (k3 and k4) and CP5) the CPUE target value.

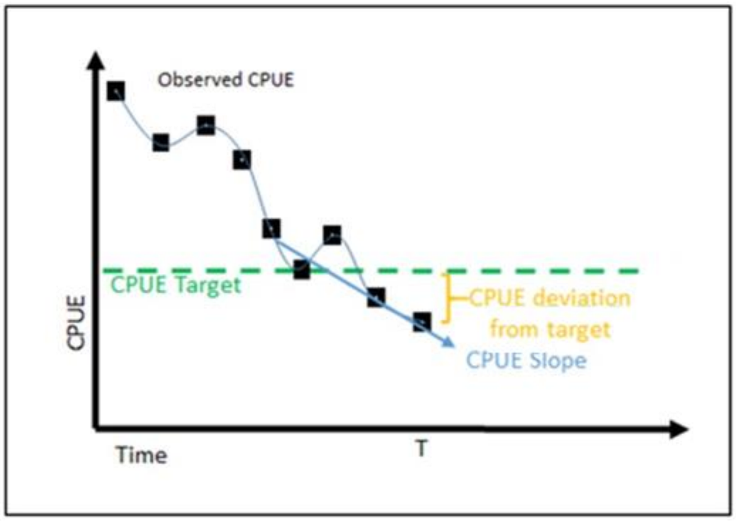


Figure 3 : The CPUE rule is based on the recent slope in the CPUE index and the distance to the target index value.

The CPUE index used for this rule was the Japanese longline CPUE index. The control parameters defining the responsiveness of the MP to both the current distance from the target CPUE and to the slope of the CPUE over the recent years were all set.

Based on analyses presented at the TCMP (IOTC, 2023) it was shown that management objectives could be achieved for a range of k (k1-4) value combinations, corresponding to a range of MPs reacting more or less rapidly to the year-to-year changes in the CPUE index. The choice of these k-values had an impact on different MP performance metrics other that the tuning criteria (e.g. catch variability). In order to propose two contrasting data-based MP options, two data-based MPs implementations are proposed, having respectively low (k1 & k2 = 0.1 and K3 & k4 = 0.3) and high (k1 & k2 = 2.1 and K3 & k4 = 1.2) reactiveness parameters. They are thereafter referred to as slow and fast reacting data-based MPs.

The MPs were tuned to estimate the target CPUE value for the each management objectives as for the model based MPs.

MP implementation

All MPs were implemented using a two-year time difference between the latest year for which information on the stock is available, and the year the TAC is implemented (one-year data lag and one- year management lag). For example, in the first simulation year (2023), the information available on the stock up to 2022 is considered to set the TAC for 2024.

Further, a triennial advice scheme is applied (TAC set for 2024 also applies in 2025 and 2026).

All MPs were run with TAC change limits, by which the TAC cannot increase by more than 15% or decrease by more than 10%.

Management objectives

The management objectives are those set by the TCMP in 2023, and were used to tune the MPs :

- 60% probability of fishing mortality being less than FMSY (not overfishing) and biomass being greater than BMSY (not overfished) (i.e., being in the Kobe green zone) by 2034-2038.
- 70% probability of fishing mortality being less than FMSY (not overfishing) and biomass being greater than BMSY (not overfished) (i.e., being in the Kobe green zone) by 2034-2038.

The performance of the MPs tuned for each of these two objectives is presented in this report and the commission will need to select which one of these two tuning objectives it wishes to use.

Scenario list

Based on the requests from the February 2024 meeting of the TCMP, the following list of scenarios has been defined.

Tuned MP

The MPs for which tuning should be carried out cover the 2 types of MP, model based and data based (both with fast and slow reactiveness). The list of the tuned MP is presented in the table 1.

Table 1 : list of tuned MPs for the Indian Ocean swordfish

MP name	*descriptor*	*MPtype*	*Tuning objective P(Green)=*	*TAC stabilizer (max up- max down)*
MP1	CPUE_Fast_60%_15-10	Faster reacting data-based	60%	15-10
MP2	CPUE_Fast_70%_15-10	Faster reacting data-based	70%	15-10
MP3	CPUE_Slow_60%_15-10	Slower reacting data-based	60%	15-10
MP4	CPUE_Slow_70%_15-10	Slower reacting data-based	70%	15-10
MP5	Modelbased_60%_15-10	Model based	60%	15-10
MP6	Modelbased_70%_15-10	Model based	70%	15-10

Robustness Tests

The purpose of the robustness tests is to see how the MPs react when events occur that were not considered in the base case scenarios used when tuning the MPs. The aim is to see the effects on the TAC set by the MPs and the consequences for stock biomass.

- Implementation error

Additional runs have been requested to test the robustness of the tuned MPs to catches greater than the TACs delivered by the MP are taken. Two scenarios are considered :

  - catches exceeding the TAC by 10% (fixed rate) over a whole simulation period.
  - catches exceeding the TAC by 15% for the first management cycle (2024-2026) and then full compliance with the TAC.

- Management lag

The MPs were tuned assuming that the TAC would be implemented in the year following its calculation (1 year management lag). In practice, there might be a requirement to add a second year of lag for the scientific advice to be considered by the Commission before its implementation in the following year. The MPs were therefore re-run with a 2 year management lag and their performance compared with the base-case runs.

- Recruitment failure

In order to examine how the different tuned MPs perform in protecting the stock in case of an unfavourable event, a robustness test was conducted in which a recruitment failure was simulated at the start of the projection period. A series of poor recruitments were imposed by setting all deviations from the stock-recruitment model to 0.1 for the period 2024-2026. This purely fictive scenario was chosen in order to produce a substantial decrease in stock size, and does not attempt reproduce any event observed in the history of the stock or considered likely to happen. The results of this test should be used to rank the MPs, but not accept or discards MPs.

Summary of Swordfish MP Performance

Detailed performance indicators are given in figure 4 and table 2. Additional performance plots, time series of past and simulated stock trajectories and summary tables of these indicators on different time scales are provided in appendix 1.

We highlight the following key points:

- All tuned MPs lead to similar levels of spawning biomass (for a given tuning objective). The model-based MPs lead to a wider distribution of values across simulation replicates. The slow reacting data-based MPs also lead to slightly wider distributions than the fast reacting ones, but differences are overall minimal.

- For all tuned MPs, the probability that the stock remains above SB_{lim} is very high (average values above 99%).
- The data-based MP leads to larger average TAC values over the period 2024-2038 (end of the tuning period) than the model-based one, but the difference is small.
- Future TAC is more uncertain with the data-based MPs than with the model-based ones. The fast reacting data-based MPs also leads to more uncertainty about future TAC than the slow reacting ones. For the model-based MPs, the TAC is consistent across iterations (no uncertainty in future values), reflecting the fact that it is most of the time equal to the plateau of the hockey stick harvest control rule.
- The TAC in the short term (2024-2027) is higher for the model-based MPs, also with a narrower distribution of values. The TAC in the short term with the fast reacting data-based MP is more uncertain than for the slow reacting one.
- Year-to-year variability in future TACs is very low for the model-based MPs. For the data based MPs, the slow reacting MPs (MP3-4) have a less variable TAC than the fast reacting MPs.
- The choice of the tuning criteria has more impact than the choice of the MP type regarding stock size and average TAC value (larger stock and lower TAC when tuning for 70% probability of being in Kobe green). Tuning criteria has less impact on TAC variability that the choice of MP type.

The main trade-off (figure A1-1, appendix 1) amongst MPs tested appears to be between MP type, with higher catches but larger interannual variation (and overall uncertainty) for the data-based MP, and lower but very stable catches for the model-based MP. The same trade-off is also found between the slow and fast reacting data-based MP, but with smaller differences compared to the trade-off across MP types.

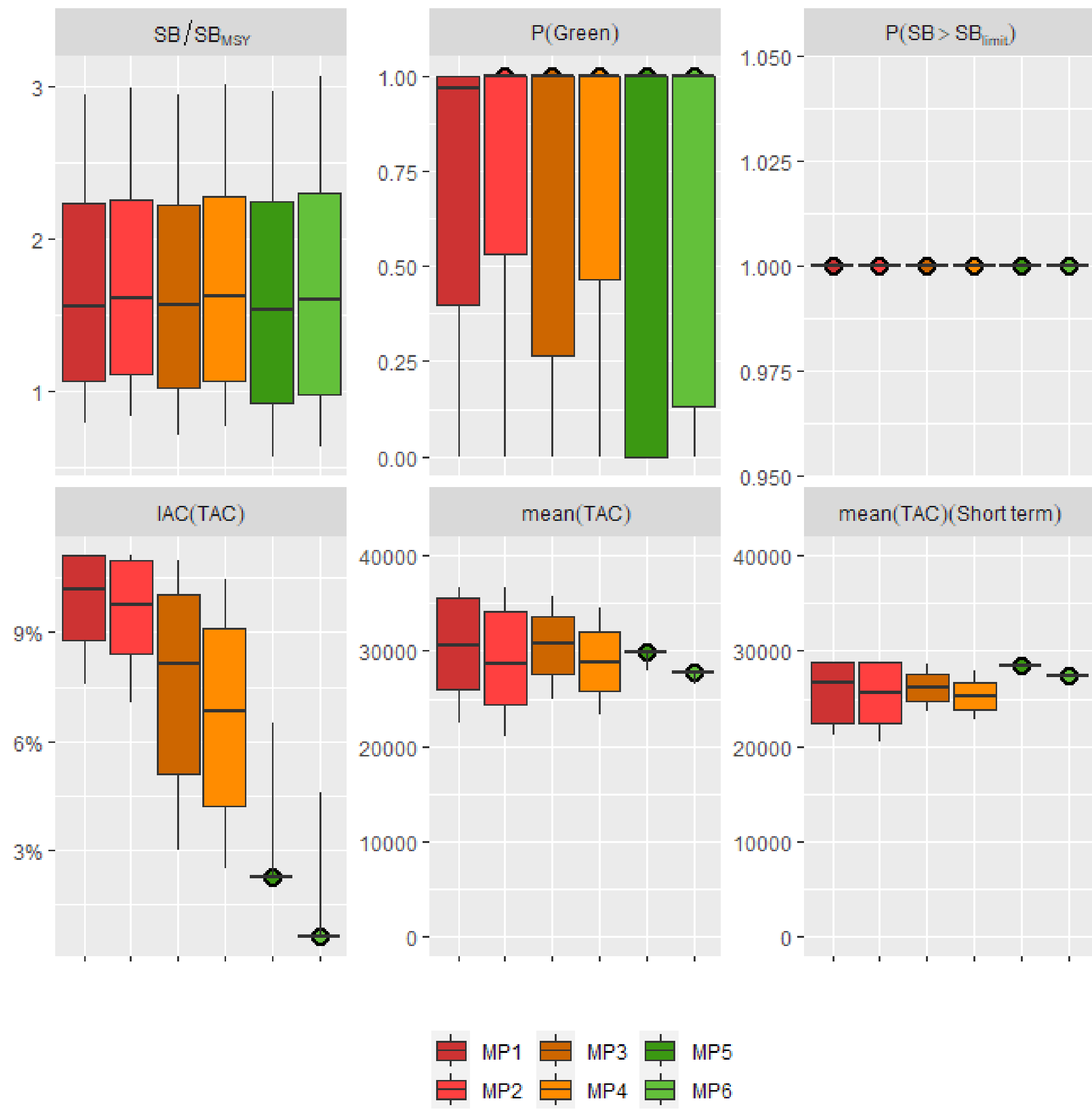


Figure 4. Boxplots comparing candidate MPs with respect to key performance measures (see definition in table 3) averaged over the period 2024-2038 (except for mean(TAC)ST which is average for 2024-2027). Horizontal line is the median, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. The data-based MPs are depicted in red (fast reacting) and orange (slow reacting) and model-based MPs are depicted in green.

Table 2 : summary of MP performance with respect to key performance indicators (median across stock replicates, with the limits of the envelop representing 80% of the distribution in parentheses).

MP	SB/SB_{MSY}	P(SB>=SBMSY)	P(SB>SBLIM)	P(GREEN)	MEAN(TAC)	C/MSY	IAC(TAC)	MAX TAC DECREASE	MAX TAC INCREASE	TIMES TAC CHANGES
MP1	1.55 (0.8-3)	1.00 (0.0-1)	1.00 (1.0-1)	0.61 (0.0-1)	30561 (22351-36599)	0.95 (0.7-1)	10.16 (7.5-11)	0.00 (-3179.7-0)	4845.72 (3186.1-6192)	4.00 (4.0-4)
MP2	1.62 (0.8-3)	1.00 (0.0-1)	1.00 (1.0-1)	0.69 (0.0-1)	28642 (21063-36599)	0.90 (0.7-1)	9.75 (7.1-11)	-1479.65 (-3124.4-0)	4609.28 (2882.4-6192)	4.00 (4.0-4)
MP3	1.57 (0.7-3)	1.00 (0.0-1)	1.00 (1.0-1)	0.59 (0.0-1)	30802 (24993-35729)	0.97 (0.7-1)	8.13 (3.0-11)	0.00 (-474.2-0)	4277.95 (1360.0-5865)	4.00 (4.0-4)
MP4	1.62 (0.8-3)	1.00 (0.0-1)	1.00 (1.0-1)	0.70 (0.0-1)	28808 (23277-34506)	0.92 (0.7-1)	6.84 (2.5-10)	0.00 (-913.1-0)	3821.02 (851.6-5491)	4.00 (4.0-4)
MP5	1.54 (0.6-3)	1.00 (0.0-1)	1.00 (1.0-1)	0.62 (0.0-1)	29828 (28012-29828)	0.93 (0.6-1)	2.25 (2.2-7)	0.00 (-3050.0-0)	3358.82 (3358.7-3359)	1.00 (1.0-4)
MP6	1.60 (0.6-3)	1.00 (0.0-1)	1.00 (1.0-1)	0.69 (0.0-1)	27828 (26580-27828)	0.87 (0.6-1)	0.62 (0.6-5)	0.00 (-2720.5-0)	858.84 (858.8-859)	1.00 (1.0-3)

SB/SB_{MSY} : ratio of the spawning biomass over spawning biomass corresponding to MSY (average over 2024-2038)
P(SB>=SBMSY) : proportion of the years with spawning biomass larger than the spawning biomass corresponding to MSY (calculated over 2024-2038)
P(SB>SBLIM) : proportion of the years with spawning biomass larger than the limit spawning biomass (calculated over 2024-2038)
P(GREEN) : proportion of the years where the stock is in the green quadrant of the Kobe plot (calculated over the tuning period, 2034-2038)
MEAN(TAC) : average TAC in tonnes (average over 2024-2038)
C/MSY : ratio of the annual catch over MSY (average over 2024-2038)
IAC(TAC) : percentage of change between successive TACs (average, calculated every 3 years over the period 2024-2038)
MAX TAC DECREASE AND MAX TAC INCREASE : largest TAC increase and decrease (in tonnes, over the period 2024-2038)
TIMES TAC CHANGES : number of times the TAC value changes (over the period 2024-2038, varies between 0 and 4)

Robustness Tests

- TAC overcatch

The performance of the MPs for the two scenarios in which catches exceed the TAC can be compared in table 3 to the performance of the MPs without implementation error. The corresponding performance plots are given in appendix 2 and 3.

With a constant overcatch of 10%, the tuning objective is no longer met, with probabilities of being in the green quadrant of the Kobe plot 8-9% lower than objective for the model-based MPs and between 12-14% lower for the data-based MPs. Similarly, the average level of spawning biomass is lower with implementation error (1.4-1.5 compared to 1.6-1.8). The stock however remains with a high probability above SB_{lim} and even SB_{msy} in all cases.

As expected, due to the systematic 10% overcatch, higher catches are achieved (C/MSY), although lower TACs are being set, due to the lower stock sizes.

The differences in performance are slightly smaller for the model-based MPs (no decrease in TAC, smaller decrease in p(Green), but larger decrease in stock size). There is, overall, no large differences between the MPs.

A 15% overcatch over single management cycle has similar effect on the performance of the MPs, but the magnitude of the differences is much smaller.

- Two-year management lag

The performance of the MPs for the scenario with a two-year management lag can be compared in table 4 to the performance of the MPs with a single year management lag. The corresponding performance plot is given in appendix 4.

The main impact of implementing a two-year management lag is that it postpones the first implementation of the MPs by one year. Since most MPs increase the TAC over time and lead to a decrease in stock size, the runs with the two-year lag lead to lower TACs and higher stock sizes in average. This impact is slightly smaller for the model based MPs, as they increase the catches in the short-term faster than the data-based ones which partially compensates for the delay in the first implementation of the MP.

Table 3 : summary of MP performance with respect to key performance indicators (median across stock replicates, with the limits of the envelop representing 80% distribution in parentheses) for the base case (no overshoot) and the two scenarios with overcatch. See table 2 for a definition of the performance indicators.

mp	Overcatch scenario	SB/SB_{MSY}	$P(SB>=SB_{MSY})$	$P(SB>SB_{lim})$	p(Green)	C/MSY	mean(TAC)	IAC(TAC)	Times TAC changes
MP1	none	1.55	1	1	0.61	0.95	30561	10.16	4
	10% whole period	1.46	1	1	0.48	1.02	30152	9.9	4
	15% (2024-2026)	1.52	1	1	0.6	0.93	30322	9.94	4
MP2	none	1.62	1	1	0.69	0.9	28643	9.75	4
	10% whole period	1.52	1	1	0.57	0.96	28643	9.45	4
	15% (2024-2026)	1.57	1	1	0.69	0.88	28643	9.56	4
MP3	none	1.57	1	1	0.59	0.97	30802	8.13	4
	10% whole period	1.48	1	1	0.45	1.05	30338	7.46	4
	15% (2024-2026)	1.53	1	1	0.59	0.96	30464	7.79	4
MP4	none	1.62	1	1	0.7	0.92	28809	6.84	4
	10% whole period	1.53	1	1	0.57	1	28399	6.09	4
	15% (2024-2026)	1.57	1	1	0.7	0.91	28524	6.43	4
MP5	none	1.54	1	1	0.62	0.93	29828	2.25	1
	10% whole period	1.42	1	1	0.53	1.02	29828	2.25	1
	15% (2024-2026)	1.48	1	1	0.61	0.93	29828	2.25	1
MP6	none	1.6	1	1	0.69	0.87	27828	0.62	1
	10% whole period	1.49	1	1	0.61	0.96	27828	0.62	1
	15% (2024-2026)	1.55	1	1	0.66	0.87	27828	0.62	1

Table 4 : summary of MP performance with respect to key performance indicators (median across stock replicates, with the limits of the envelop representing 80% distribution in parentheses) for the base case (1 year lag) and the scenarios with a two year management lag. See table 2 for a definition of the performance indicators.

mp	Management lag	SB/SB_{MSY}	$P(SB>=SB_{MSY})$	$P(SB>SB_{lim})$	p(Green)	C/MSY	mean(TAC)	IAC(TAC)	Times TAC changes
MP1	1	1.55	1	1	0.61	0.95	30561	10.16	4
	2	1.59	1	1	0.63	0.93	30037	10.22	4
MP2	1	1.62	1	1	0.69	0.9	28643	9.75	4
	2	1.64	1	1	0.72	0.89	28100	9.8	4
MP3	1	1.57	1	1	0.59	0.97	30802	8.13	4
	2	1.6	1	1	0.62	0.95	30039	8.25	4
MP4	1	1.62	1	1	0.7	0.92	28809	6.84	4
	2	1.64	1	1	0.72	0.9	28236	6.98	4
MP5	1	1.54	1	1	0.62	0.93	29828	2.25	1
	2	1.57	1	1	0.63	0.92	29409	2.25	1
MP6	1	1.6	1	1	0.69	0.87	27828	0.62	1
	2	1.62	1	1	0.69	0.87	27580	0.62	1

- Recruitment failure

The performance of the MPs for the scenario with a recruitment failure can be compared in table 5 to the performance of the MPs for the base case. The corresponding performance plot is given in appendix 5. The figure 5 shows the temporal development of spawning biomass following the recruitment failure.

The central tendency of the simulation envelop (median) shows a decline in the spawning stock from 2027 to 2032, followed by a recovery, for all MPs. The lower part of the distribution of the simulated SB/SB_{MSY} values (10% quantile) however decreases faster, remains low or continues to decrease, and for some MPs, reaches values lower than 1 (indicating that in these years there is at least a 10% probability of $SB<SB_{lim}$ for the stock).

The MPs tuned with a more conservative management objective (p(Green)= 70%) recover faster, and there is overall a lower risk for the stock to fall below SB_{lim} (bottom panel compared to top panel). For a given tuning criteria, the model-based MPs (MP5 and MP6) have a clearly poorer robustness than the data-based MPs, with a lower median SB/SB_{lim}, and a higher risk of falling below SB_{lim} (the 10% quantile falls under 1 earlier, and remains lower). The fast reacting data-based MP has a similar trend as the slow-reacting one for the median of the distribution, but the lowest part of the distribution remains higher (above 1) indicating a lower risk of SB falling below SB_{lim} (which can also be seen on the performance indicator plot, appendix 5). This indicates that a faster reacting data-base MP is indeed more efficient to react to a decrease in stock size.

Table 5 : summary of MP performance with respect to key performance indicators for the base case and the scenario with a recruitment failure. See table 2 for a definition of the performance indicators), except Risk($SB<SB_{lim}$) which is defined the probability (proportion of stock replicates) of $SB<SB_{lim}$ (maximum value over the period 2024-2038).

mp	*Recr. Failure*	*SB/SB_{MSY}*	*$P(SB>=SB_{MSY})$*	*$P(SB>SB_{lim})$*	*Risk(SB<SBlim)*	*p(Green)*	*C/MSY*	*mean(TAC)*	*IAC(TAC)*
MP1	no	1.55	1	1	0.02	0.61	0.95	30561	10.16
	yes	1.19	0.63	1	0.07	0.5	0.79	25372	9.22
MP2	no	1.62	1	1	0.02	0.69	0.9	28643	9.75
	yes	1.21	0.73	1	0.07	0.54	0.77	24318	9.03
MP3	no	1.57	1	1	0.03	0.59	0.97	30802	8.13
	yes	1.14	0.57	1	0.12	0.48	0.82	26160	5.42
MP4	no	1.62	1	1	0.02	0.7	0.92	28809	6.84
	yes	1.19	0.67	1	0.09	0.52	0.77	24460	5.23
MP5	no	1.54	1	1	0.05	0.62	0.93	29828	2.25
	yes	1.02	0.4	1	0.24	0.41	0.84	27641	7.66
MP6	no	1.6	1	1	0.04	0.69	0.87	27828	0.62
	yes	1.08	0.47	1	0.19	0.46	0.8	26337	5.12

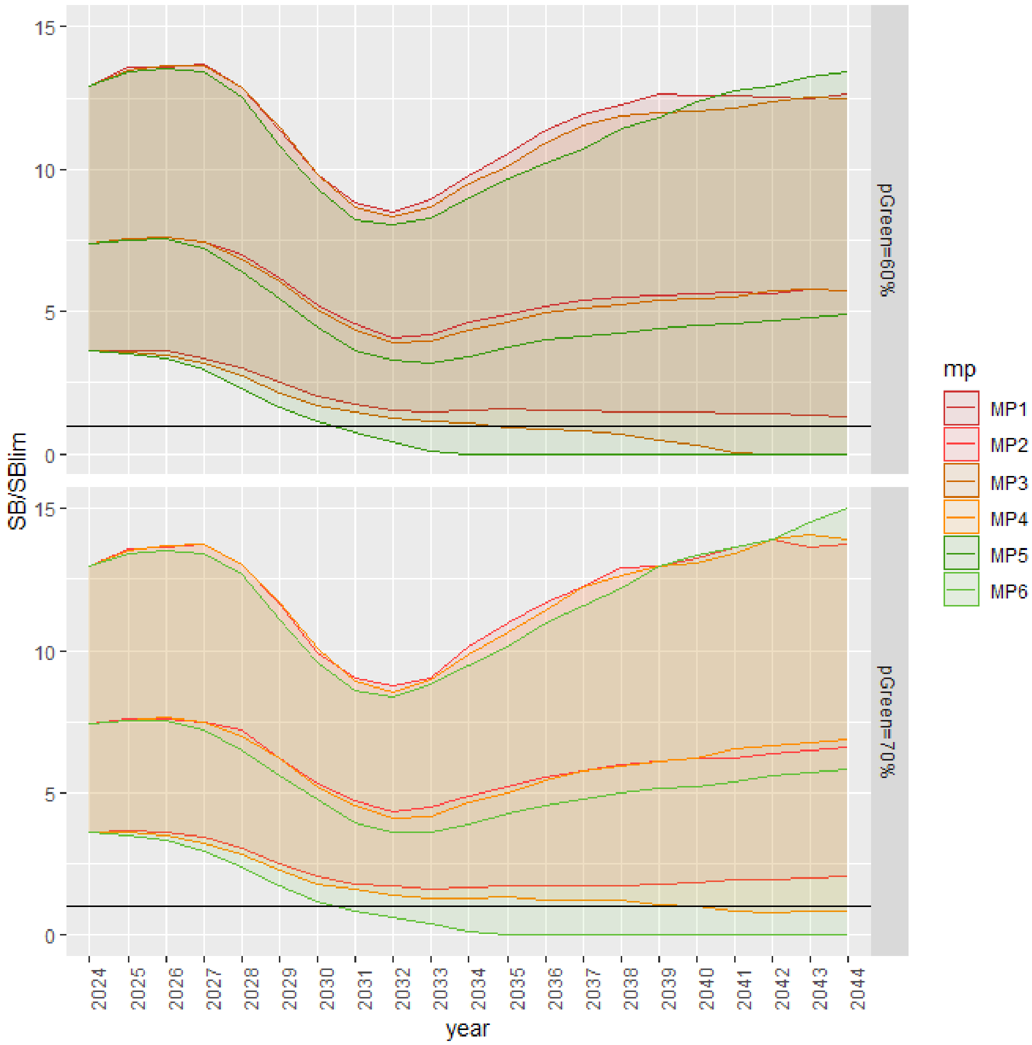


Figure 5 : change in spawning biomass relative to SB_{lim} over time for the runs with a recruitment failure occurring between 2024 and 2026, showing the position of the median, upper (90%) and lower (10%) bound of the distribution of the values with respect to $SB=SB_{lim}$ (black horizontal line).

Conclusions

The table 6 provides a qualitative summary of the performance of the six MPs based on the main performance indicators and robustness tests presented above.

All the MPs tested have a similar performance, and there are only subtle differences. The only main difference is the high TAC stability achieved with the model-based MPs compared to the data-based ones, but at the cost of the slightly lower average TAC. The model-based MPs show however the poorest robustness to a succession of poor recruitments. The robustness of this MP type can potentially be improved by choosing a higher value for the breakpoint, but this would change the performance of the MP and likely result in a more variable TAC (stock more frequently on the slope of the harvest control rule).

The faster-reacting data-based MP offers a better robustness in the case of a poor recruitment event, but otherwise does not present a clear advantage compared to the slow-reacting one and even leads to slightly more variable TACs.

Finally, the performance of the MPs is described here for the short to mid-term (until 2038). The choice of the MP type have different implications for the longer term : while the model-based MPs lead to stable stock after 2038, the data-based ones set the stock on a declining trend (figure A1-4, appendix 1). This mean that if a data-based MP is chosen, a revision of the MP should be envisaged earlier than with a model-based MP.

Table 6 : qualitative comparison of the MPs performance

Performance metrics	MP1-MP2 Data-based fast	MP3-MP4 Data-based slow	MP5-MP6 Model based	Note
Probability of $SB>SB_{lim}$ until the end of the tuning period (2038)		No difference		
Average stock size		No difference		
Uncertainty about stock biomass in 2038	Lower uncertainty	Intermediate	Higher uncertainty	Only minimal differences
Average TAC	Intermediate	Higher	Lower	Only minimal differences
TAC variability	More variable	Intermediate	Less variable	
Decrease in prob. of being in Kobe green when catch exceed TAC by 10% (robustness test)	Intermediate	Higher decrease	Smaller decrease	Only minimal differences
Decrease in average TAC when implemented with a 2 year lag between advice and TAC (in robustness test)	Intermediate	Higher decrease	Smaller decrease	Only minimal differences
Risk of $SB<SB_{lim}$ after a poor recruitment period (robustness test)	Lowest risk	Intermediate	Highest risk	

References

IOTC, 2023. IOTC Swordfish Management Strategy Evaluation Update 6th Session IOTC TCMP – 5 & 6 May 2023. IOTC-2023-TCMP06-09

IOTC, 2024. IOTC Swordfish Management Strategy Evaluation Update 7th Session IOTC TCMP – 19-21 February 2024. IOTC-2024-TCMP07-07

Appendix 1 : additional performance plot for the 6 MPs proposed

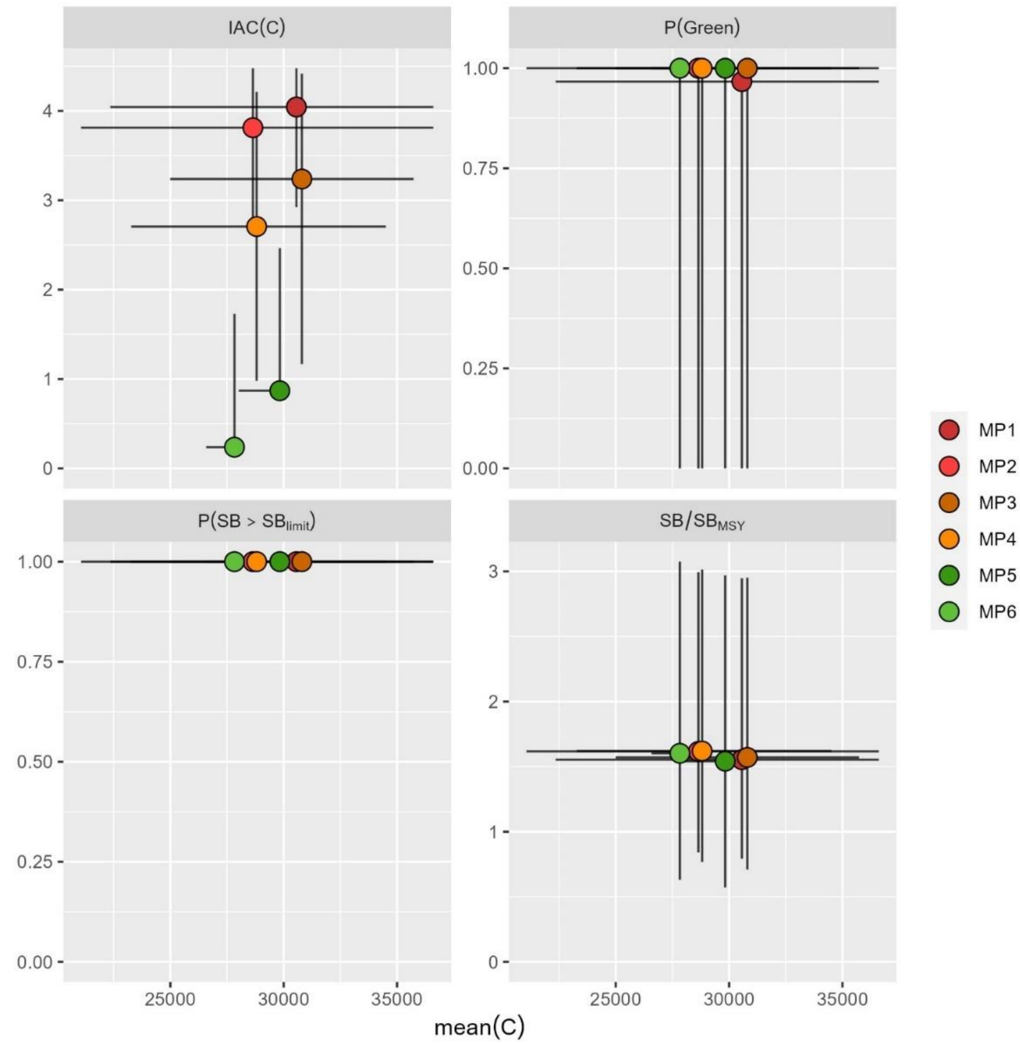


Figure A1-1. Trade-off plots comparing candidate MPs with respect to catch on the X-axis, and 4 other key performance measures on the Y- axis, each averaged over the period 2024-38. Circle is the median, lines represent 10th-90th percentiles.

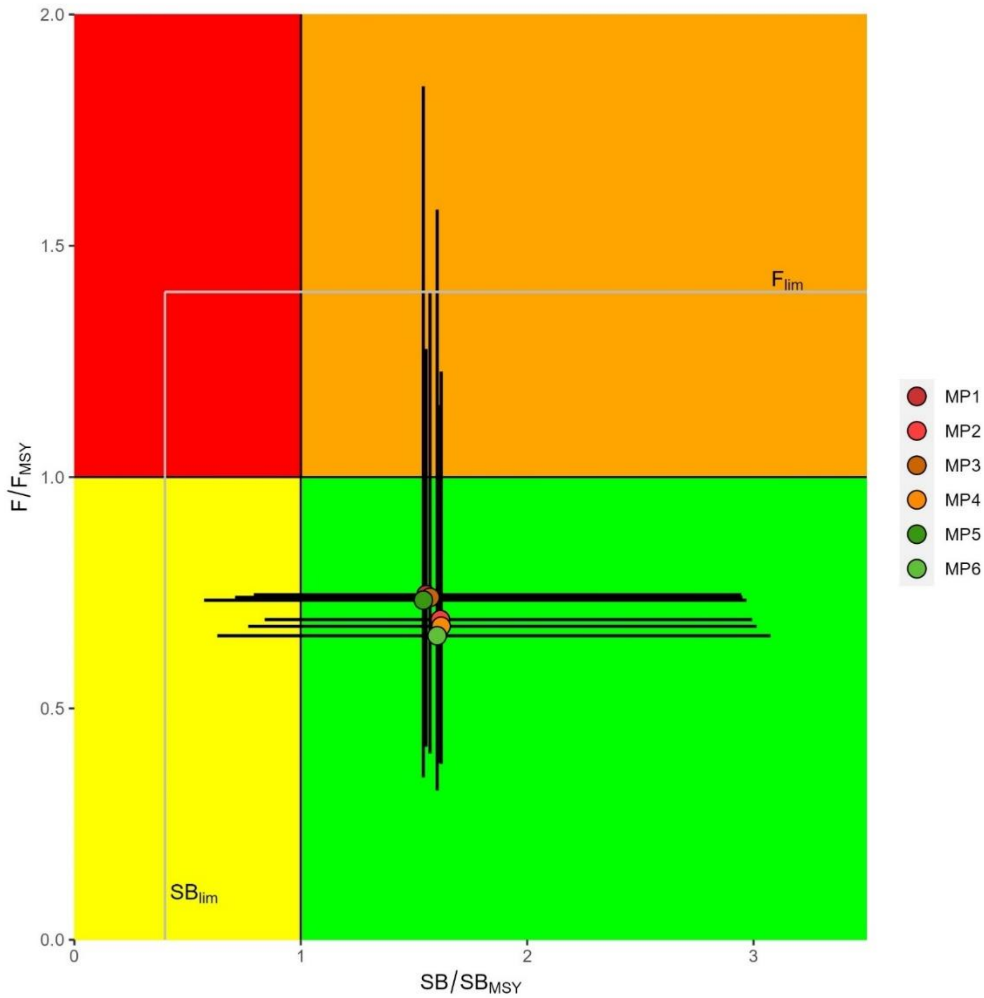


Figure A1-2. Kobe plot comparing candidate MPs on the basis of the expected 2024-2038 average performance. Circle is the median, lines represent 10th-90th percentiles.

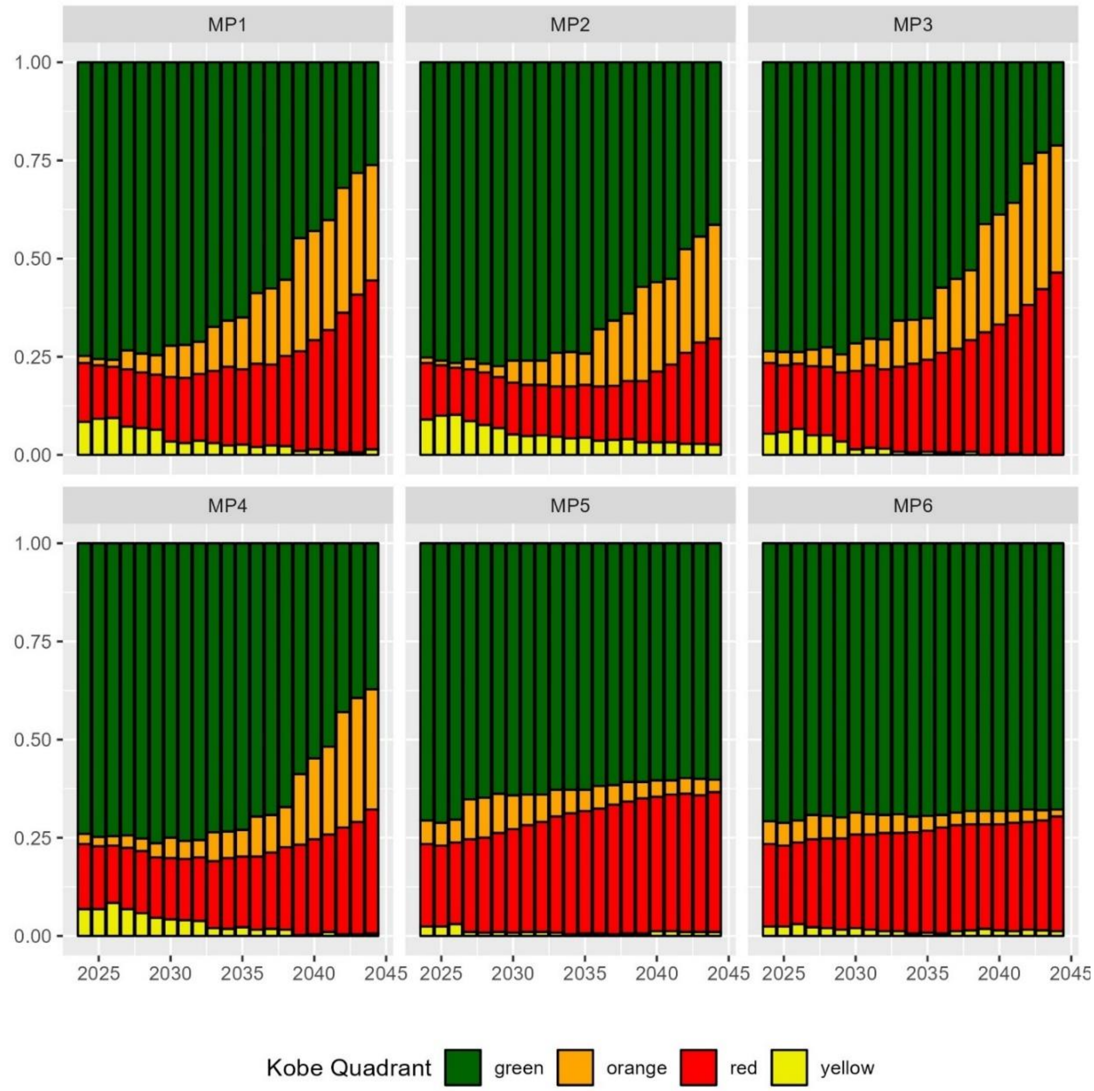


Figure A1-3. Proportion of simulations in each of the Kobe quadrants over time for each of the candidate MPs.

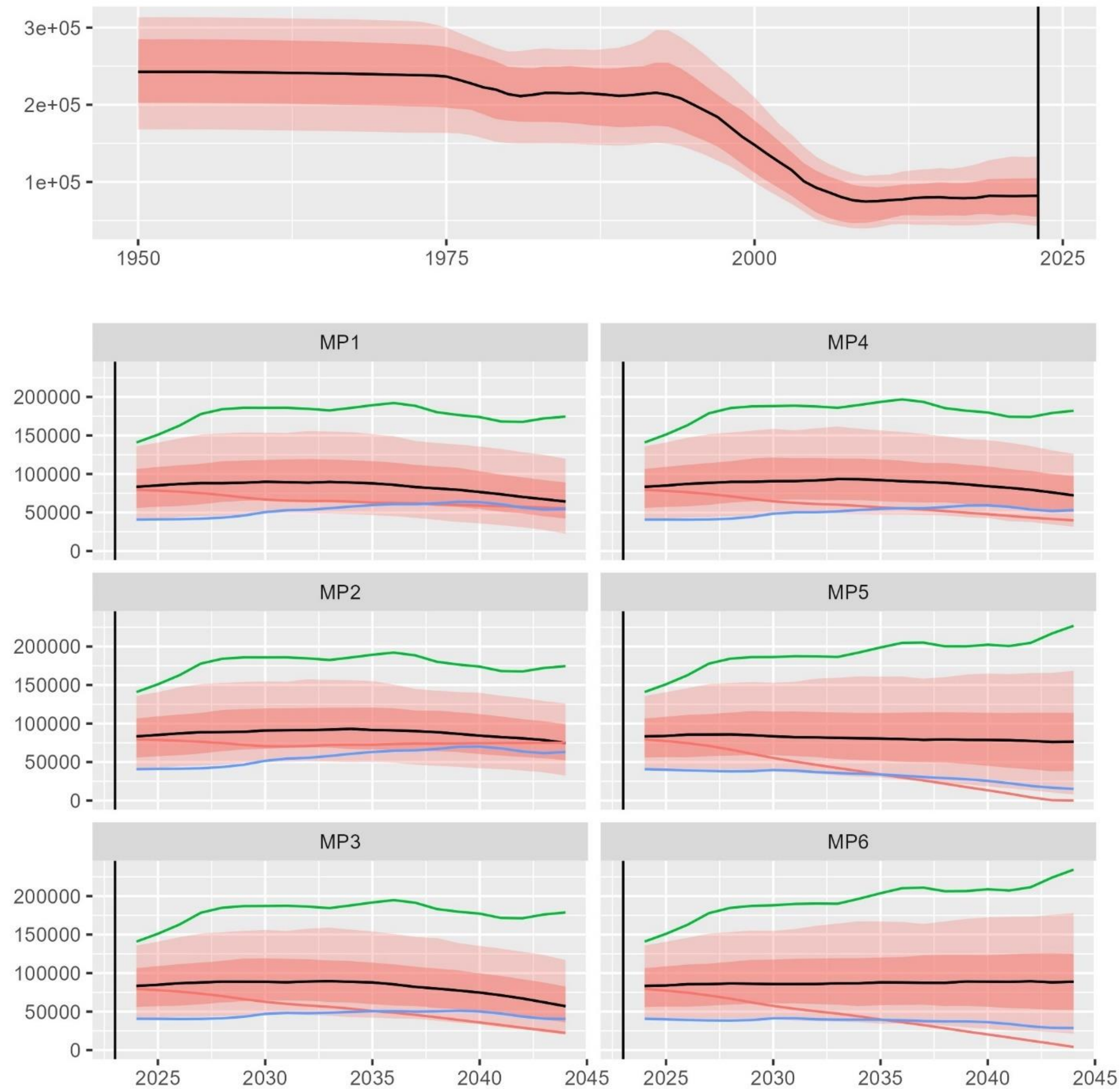


Figure A1-4. Time series of spawning stock size for the candidate MPs. The top panel represents the historical estimates from the reference case operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The median is represented by the bold black line, the darker red shaded ribbon represents the 25th-75th percentiles, the lighter red shaded ribbon represents the 10th-90th percentiles. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate the range of expected realizations in stock trajectory.

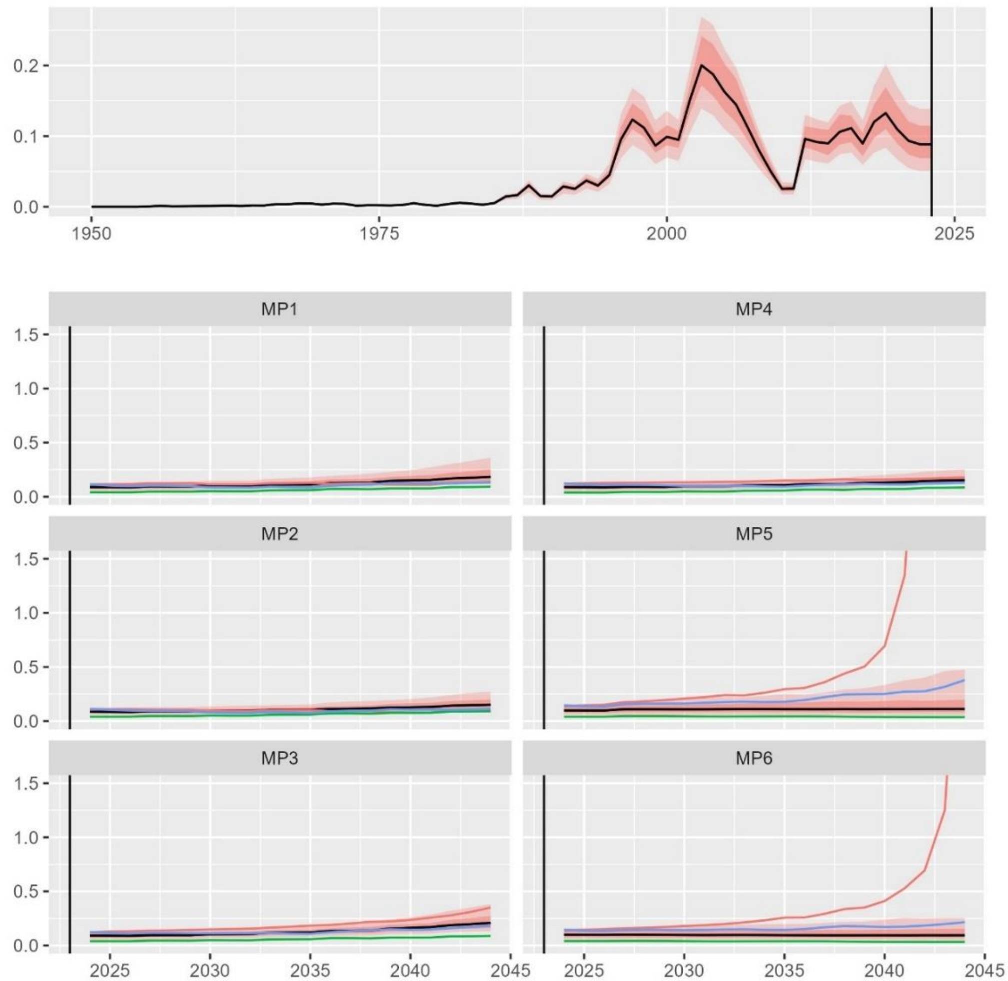


Figure A1-5. Time series of fishing mortality for the candidate MPs

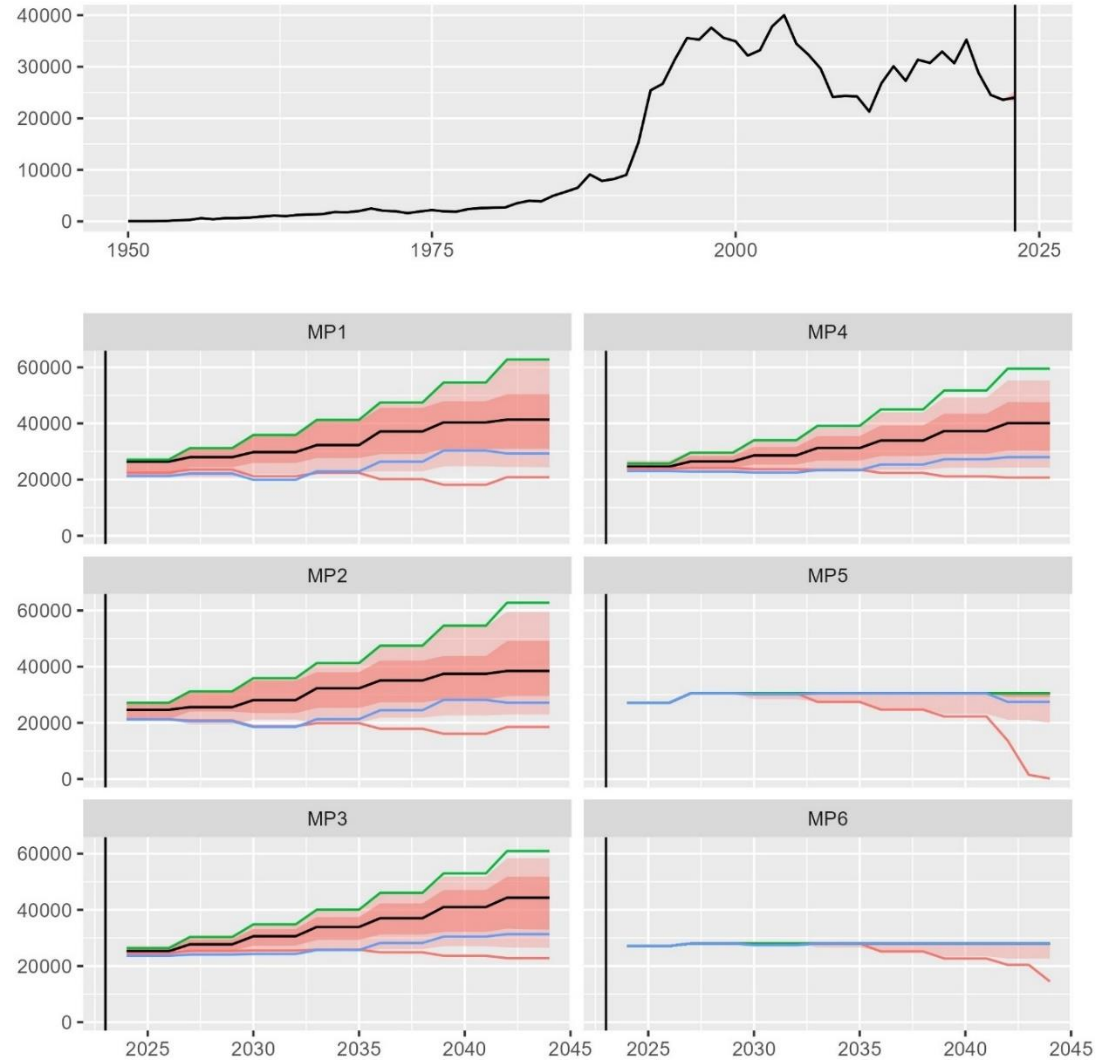


Figure A1-6. Time series of catches for the candidate MPs

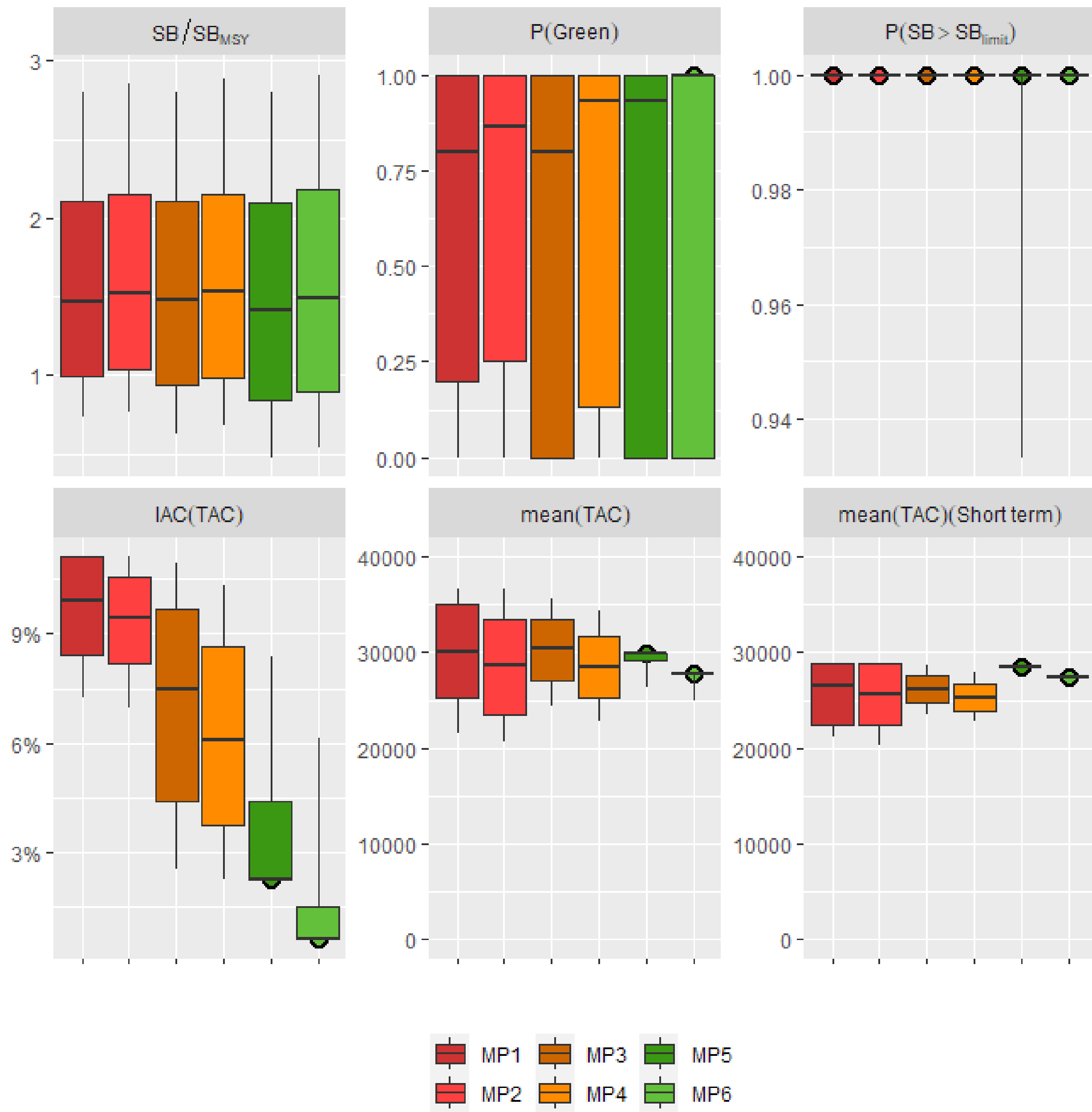
Table A1-1 : Candidate MP performance for standard IOTC performance measures over the short term (2024-2028), Medium term (2024-2038) and long term (2024-2044)
2024-2038

Short-term (2024-2027)							
name	**units**	**MP1**	**MP2**	**MP3**	**MP4**	**MP5**	**MP6**
Average annual variability in catch	proportion	0.03	0.03	0.02	0.02	0.03	0.01
ICES Risk 1, mean probability that spawner biomass is below Blim	probability	0.01	0.01	0.01	0.01	0.01	0.01
ICES Risk 2, probability that spawner biomass is above Blim once	probability	0.01	0.01	0.01	0.01	0.01	0.01
ICES Risk 3, max probability that spawner biomass is above Blim	probability	0.02	0.02	0.02	0.02	0.02	0.02
Maximum decrease in the TAC	tonnes	-349.18	-460.7	-55.64	-115.18	-97.49	-145.21
Maximum increase in the TAC	tonnes	2824.21	2492.01	2327.07	1843.15	3172.98	817.28
Mean fishing mortality relative to FMSY	proportion	0.71	0.69	0.74	0.71	0.86	0.82
Mean fishing mortality relative to target	proportion	0.71	0.69	0.74	0.71	0.86	0.82
Mean proportion of MSY	proportion	0.81	0.79	0.83	0.8	0.91	0.88
Mean spawner biomass relative to unfished	proportion	0.36	0.36	0.36	0.36	0.36	0.36
Mean spawnwer biomass relative to SBMSY	proportion	1.65	1.66	1.65	1.66	1.63	1.63
Minimum spawner biomass relative to unfished	proportion	0.34	0.34	0.34	0.34	0.33	0.33
Number of years with TAC change	years	1	1	1	1	1	1
Probability of SB greater or equal to SBMSY	probability	0.78	0.78	0.77	0.77	0.76	0.76
Probability of being in Kobe green quadrant	probability	0.75	0.76	0.73	0.75	0.68	0.7
Probability of being in Kobe red quadrant	probability	0.14	0.13	0.17	0.16	0.22	0.22
Probability of fishery shutdown	probability	0	0	0	0	0	0
Probability that spawner biomass is above 20% SB[0]	probability	0.91	0.91	0.91	0.91	0.9	0.9
Probability that spawner biomass is above SBlim	probability	0.99	0.99	0.99	0.99	0.99	0.99

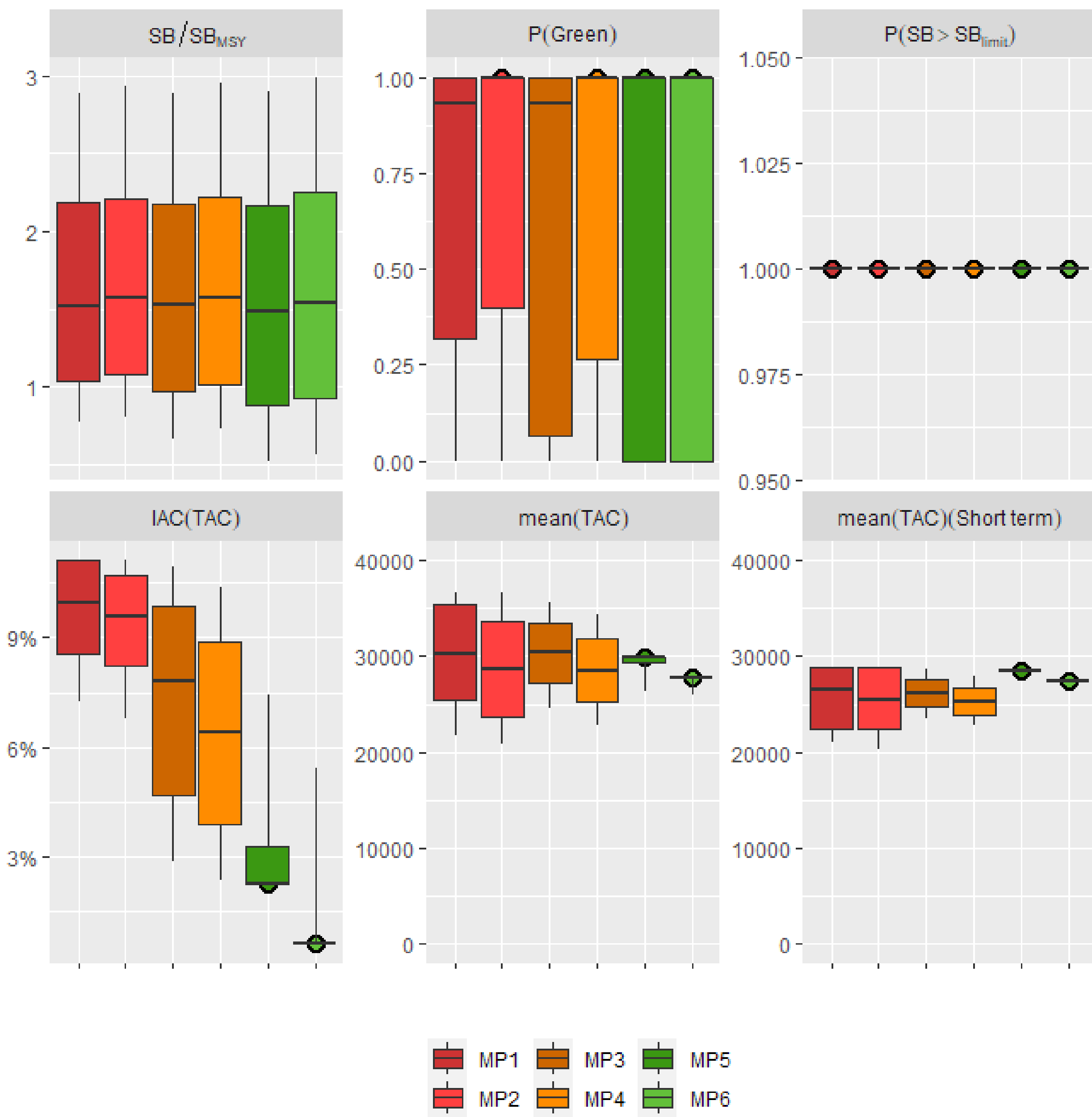
Mid-term (2024-2038)							
name	**units**	**MP1**	**MP2**	**MP3**	**MP4**	**MP5**	**MP6**
Average annual variability in catch	proportion	0.09	0.09	0.13	0.12	0.15	0.12
ICES Risk 1, mean probability that spawner biomass is below Blim	probability	0.02	0.02	0.02	0.02	0.03	0.02
ICES Risk 2, probability that spawner biomass is above Blim once	probability	0.02	0.02	0.02	0.02	0.03	0.02
ICES Risk 3, max probability that spawner biomass is above Blim	probability	0.02	0.02	0.03	0.02	0.05	0.04
Maximum decrease in the TAC	tonnes	-1342.5	-1490.87	-339.36	-402.25	-1023.87	-682.54
Maximum increase in the TAC	tonnes	4679.49	4389.12	3948.5	3461.12	3231.5	932.49
Mean fishing mortality relative to FMSY	proportion	0.98	0.92	1.12	0.99	1.42	1.21
Mean fishing mortality relative to target	proportion	0.98	0.92	1.12	0.99	1.42	1.21
Mean proportion of MSY	proportion	0.94	0.9	0.95	0.9	0.93	0.87
Mean spawner biomass relative to unfished	proportion	0.37	0.38	0.37	0.38	0.36	0.37
Mean spawnwer biomass relative to SBMSY	proportion	1.71	1.75	1.69	1.74	1.65	1.72
Minimum spawner biomass relative to unfished	proportion	0.31	0.32	0.31	0.32	0.3	0.31
Number of years with TAC change	years	4.06	4.06	4.09	4.08	1.61	1.49
Probability of SB greater or equal to SBMSY	probability	0.78	0.81	0.76	0.79	0.72	0.74
Probability of being in Kobe green quadrant	probability	0.69	0.74	0.68	0.73	0.65	0.69
Probability of being in Kobe red quadrant	probability	0.17	0.13	0.21	0.17	0.27	0.24
Probability of fishery shutdown	probability	0	0	0.01	0.01	0.01	0.01
Probability that spawner biomass is above 20% SB[0]	probability	0.92	0.92	0.9	0.91	0.84	0.86
Probability that spawner biomass is above SBlim	probability	0.98	0.98	0.98	0.98	0.97	0.98

Long-term (2024-2041)							
name	**units**	**MP1**	**MP2**	**MP3**	**MP4**	**MP5**	**MP6**
Average annual variability in catch	proportion	0.11	0.11	0.12	0.11	0.18	0.13
ICES Risk 1, mean probability that spawner biomass is below Blim	probability	0.02	0.02	0.02	0.02	0.03	0.03
ICES Risk 2, probability that spawner biomass is above Blim once	probability	0.02	0.02	0.02	0.02	0.03	0.03
ICES Risk 3, max probability that spawner biomass is above Blim	probability	0.03	0.02	0.04	0.02	0.08	0.05
Maximum decrease in the TAC	tonnes	-1731.37	-1852.16	-416.24	-430.15	-1319.26	-838.66
Maximum increase in the TAC	tonnes	5138.55	4831.79	4329.65	3835.68	3242.66	957.68
Mean fishing mortality relative to FMSY	proportion	1.09	1.01	1.26	1.07	1.65	1.36
Mean fishing mortality relative to target	proportion	1.09	1.01	1.26	1.07	1.65	1.36
Mean proportion of MSY	proportion	0.98	0.93	0.99	0.93	0.92	0.87
Mean spawner biomass relative to unfished	proportion	0.37	0.38	0.36	0.38	0.36	0.37
Mean spawnwer biomass relative to SBMSY	proportion	1.67	1.73	1.66	1.73	1.65	1.73
Minimum spawner biomass relative to unfished	proportion	0.29	0.3	0.28	0.31	0.29	0.31
Number of years with TAC change	years	5.08	5.08	5.11	5.09	1.91	1.69
Probability of SB greater or equal to SBMSY	probability	0.77	0.8	0.75	0.78	0.71	0.74
Probability of being in Kobe green quadrant	probability	0.65	0.71	0.63	0.7	0.64	0.69
Probability of being in Kobe red quadrant	probability	0.19	0.14	0.23	0.18	0.28	0.25
Probability of fishery shutdown	probability	0.01	0.01	0.01	0.01	0.02	0.01
Probability that spawner biomass is above 20% SB[0]	probability	0.91	0.92	0.88	0.91	0.82	0.85
Probability that spawner biomass is above SBlim	probability	0.98	0.98	0.98	0.98	0.97	0.97

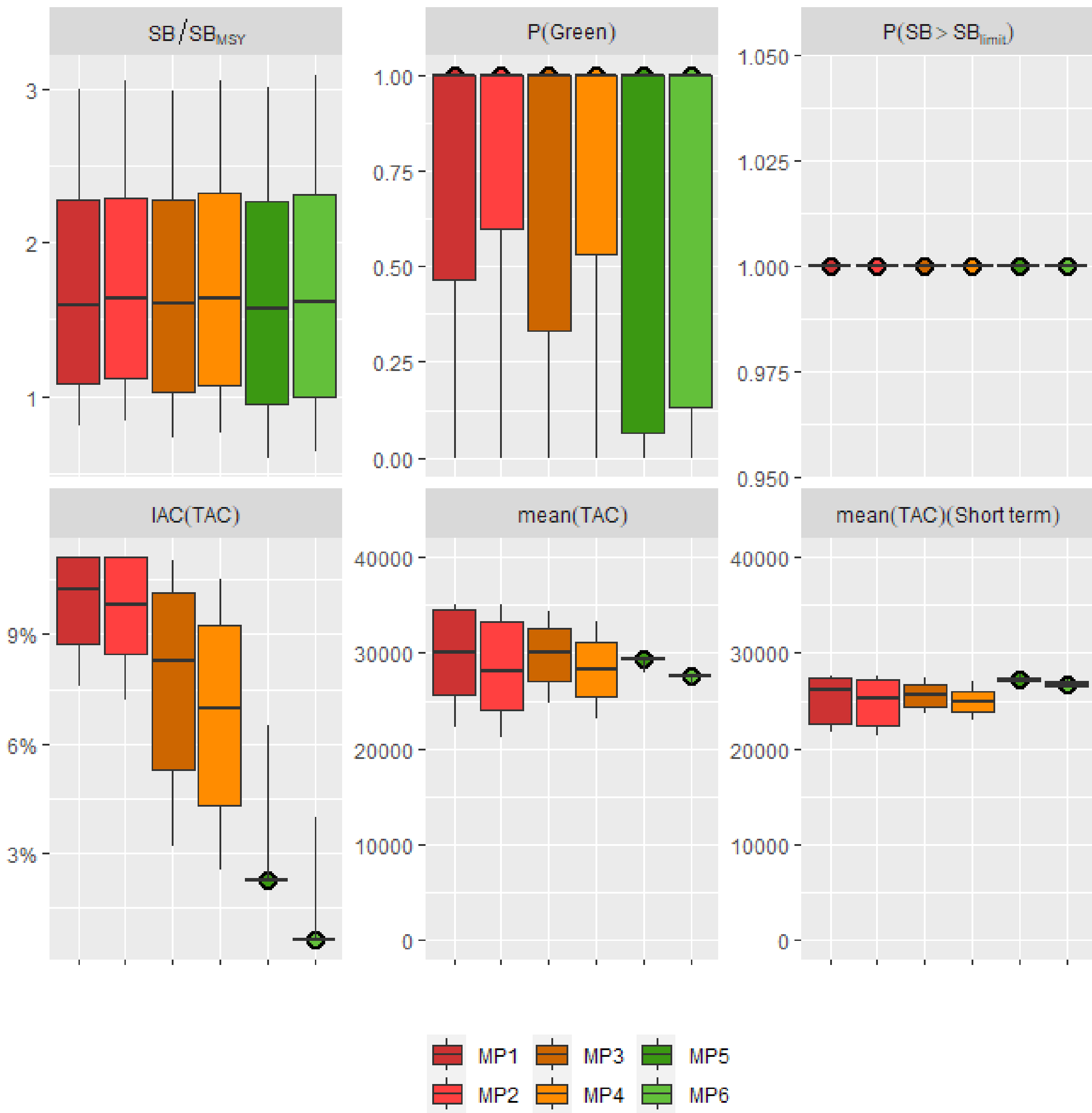
Appendix 2 : performance plots for the robustness test with a consistent 10% overcatch



Appendix 3 : performance plots for the robustness test with a 15% overcatch from 2024 to 2026



Appendix 4 : performance plots for the robustness test with a 2 year management lag



Appendix 5 : performance plots for the robustness test to a recruitment failure