IOTC Swordfish

Management Strategy Evaluation Update

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Status of the MSE work

- The reference operating model for the Indian Ocean swordfish stock has been developed over the last three years and has been endorsed by the IOTC scientific committee. The OM was developed based on the 2020 WPB SS3 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 reported catches for 2019, 2020 and 2021 and assuming a 2022 catch at the 2021 level. A comparison of the OM with the output of the new 2023 stock assessment shows that the OM remains appropriate to describe the dynamics of the Indian Ocean swordfish stock, as well as its current status.
- Further developments to the swordfish MSE included the development and application of two types of candidate MPs, one model-based and one data-based, and the tuning of these MPs (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.
- The main feedback priority for the TCMP-07 is to get agreement on the range of proposed MPs to be fully tested, as well as on the current management objectives to be achieved for the tuning procedure.

Operating model development

The status of the current swordfish OM was presented at the 2023 TCMP, and both at the 2023 Working party on Billfish and 2023 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

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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 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 2019-2022 using the IOTC catch estimates for the years 2019 to 2021, and assuming a status quo fishing mortality for 2022 (F_{2022}=F_{2021}).

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 (figure 1). Likewise, the historical stock status from the 2023 assessment is comprised within the envelop of the OM (figure 2). The distribution of SB/SB_{MSY} from the assessment in its final year, 2021, is well within the OM, while the values for F/F_{MSY} are close to the limit of the envelope of the OM but still remain within it.

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.

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. The OM will therefore not need to be re-conditioned.

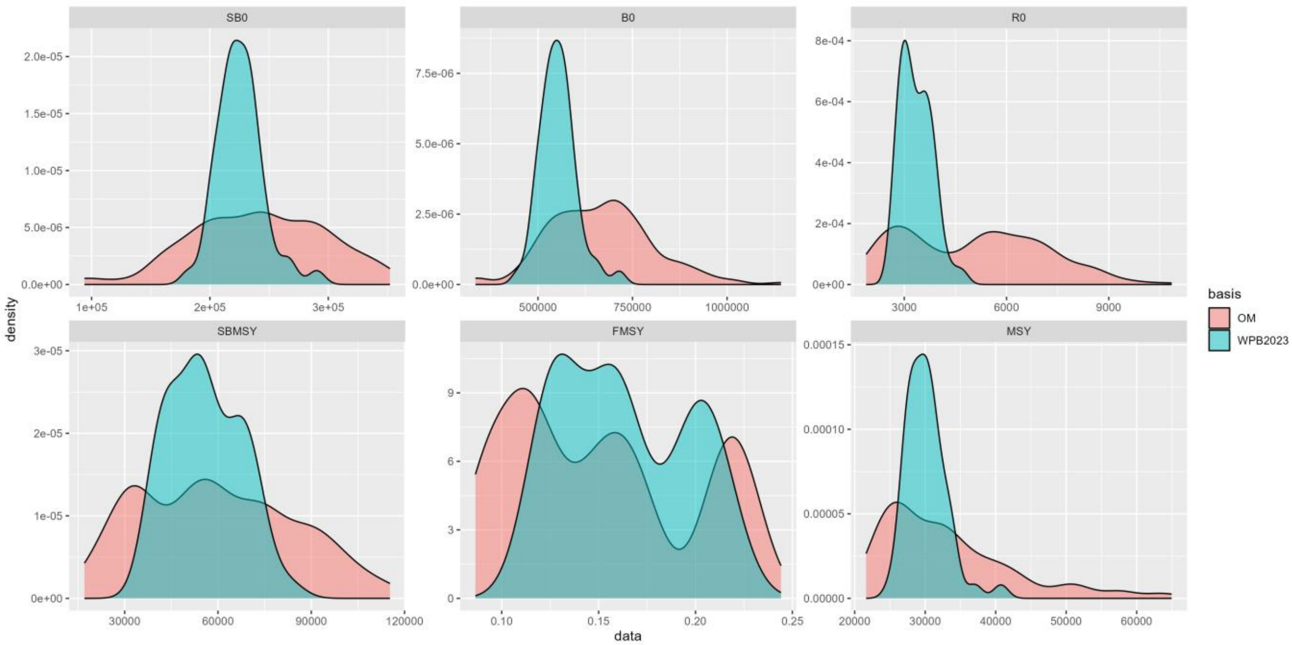

Figure 1 : Comparison of the population dynamics parameters from the WPB 2023 swordfish assessment, and from the Operating Model developed for the MSE analysis from the previous assessment.

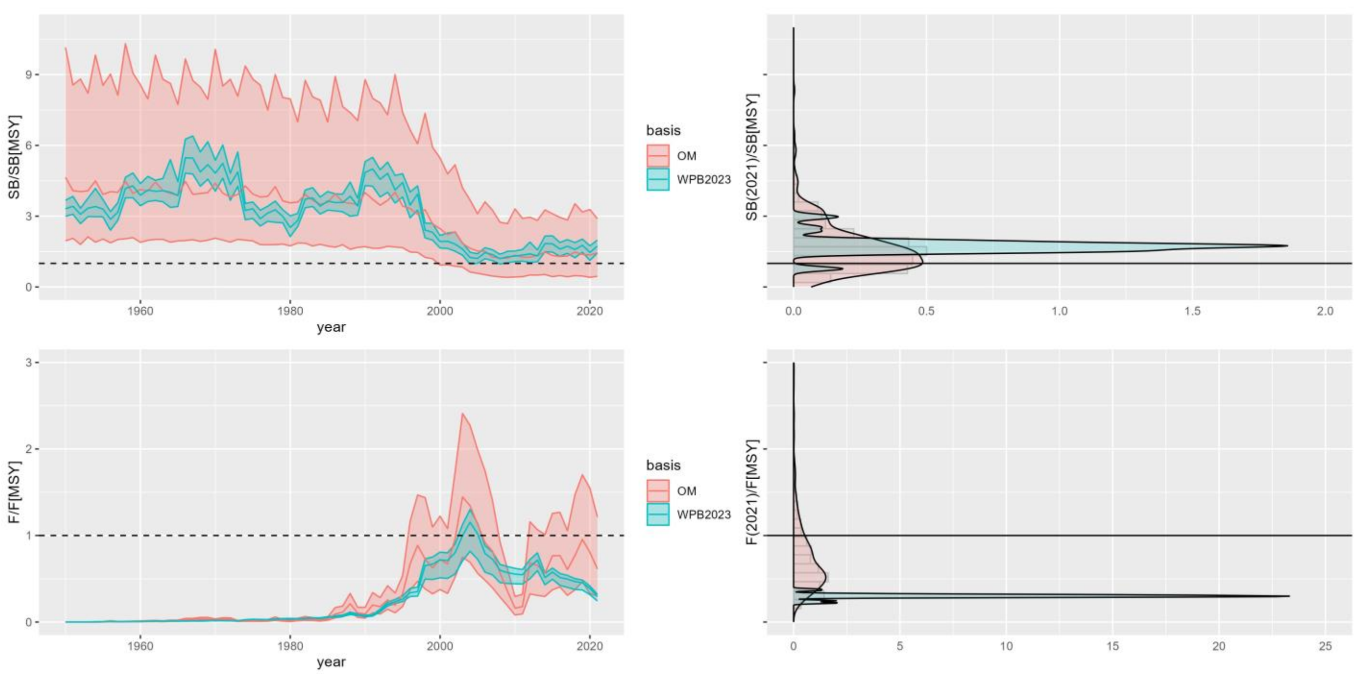

Figure 2 : Comparison of the historical development and current stock status from the WPB 2023 swordfish assessment, and from the Operating Model developed for the MSE.

Candidate Management Procedures

The swordfish MSE analyses presented here have evaluated two types of MPs:

- A model-based one, in which a surplus-production stock assessment model provides an estimate of current stock status, in terms of current biomass depletion, which is then used in a harvest control rule to determine advised catch
- A data-based one in which the advised catch is based on the value and recent trend in a CPUE index.

The two types of MPs are presented below and they were furthermore implemented:

- with a 3 year advice cycle (TAC set for a period of 3 years)
- with an inter-annual TAC variation limit (or TAC stabilizer) for which different options were tested:
  - 15-15 : the maximum increase and decrease in the TAC is 15%
  - 10-10 : the maximum increase and decrease in the TAC is 10%
  - 15-10 : the maximum increase in the TAC is 15% and the maximum decrease in the TAC is 10%
- assuming that in a given year, y, when advice has to be given for the 3 following years, y+1 to y+3, data are available until the previous year, y-1 (i.e. 1 year data lag)

Model-based MP

Definition

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.

Implementation in the swordfish case

The surplus production model JABBA was fitted to the total catches time series and the Japanese longline CPUE index 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 (a proxy for SB=SBlim) and CP2 = 0.4 (a proxy for $SB=SB_{MSY}$). The maximum catch, CP3, was obtained by tuning the MP to achieve the particular management objectives

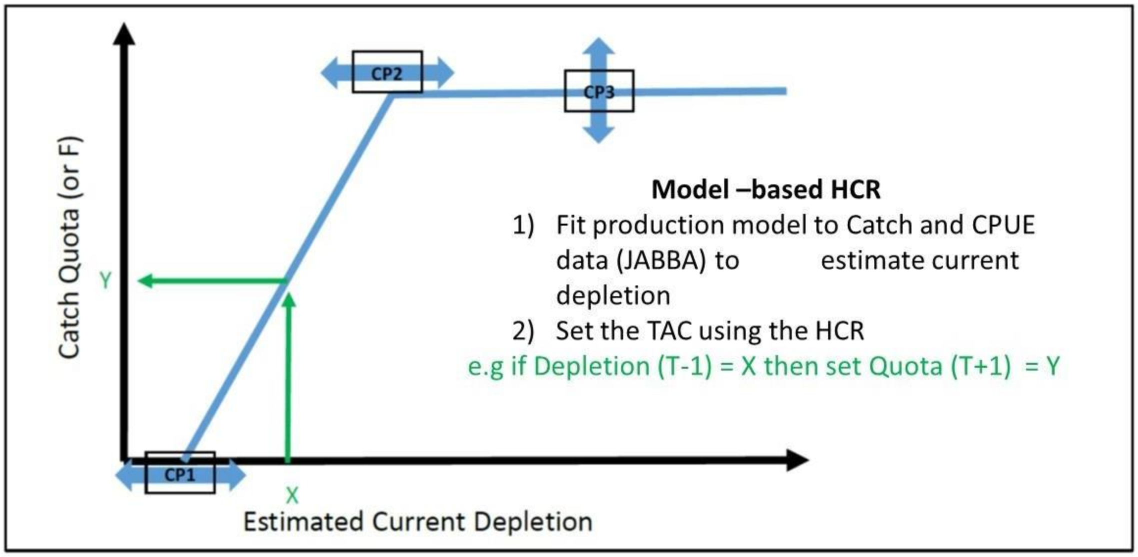

Figure 3. Harvest control rules used in the model-based MP.

Data-based

Definition

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) responsiveness to CPUE slope (k1 and k2), CP3) responsiveness to CPUE target deviation (k3 and k4) and CP4) the CPUE target value.

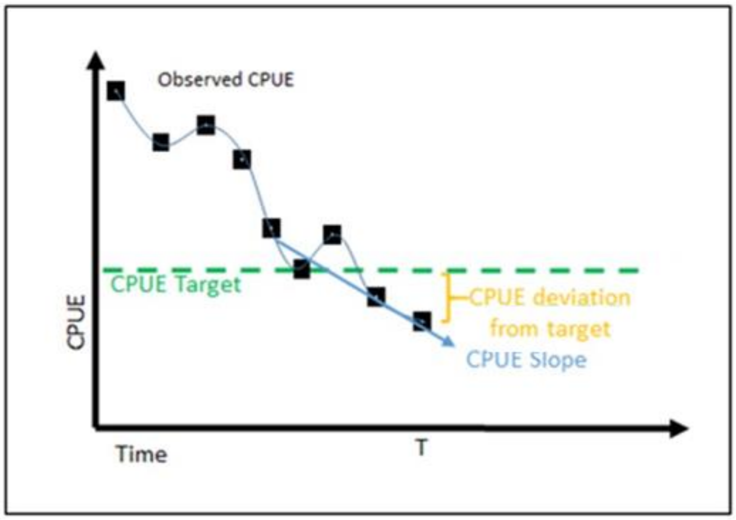

Figure 4 : The CPUE rule is based on the recent slope in the CPUE index and the distance to the target index value.

Implementation in the swordfish case

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 last 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 CPUE 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.

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

Scenario list

Based on the requests from the 2023 TCMP and WPMethods, the following list of scenarios has been defined.

Tunned MP

The MPs for which tuning should be carried out cover the 2 types of MP, model base and data base (both with fast and slow reactiveness). Tuning of these MPs should be done for 2 tunning objectives, namely 60% and 70% probability of being in the green quadrant of the Kobe plot for the period 2034-2038 (i.e. 11 to 15 years into the simulation period). Different options for the TAC stabilizer are also considered. The list of the tuned MP is presented in the table 1.

Table 1 : list of proposed candidate MPs for the Indian Ocean swordfish

MP name	descriptor	MPtype	Tuning objective P(Green)=	TAC stabilizer (max up- max down)
MP1	Modelbased_60%_15-15	Model based	60%	15-15
MP2	Modelbased_60%_10-10	Model based	60%	10-10
MP3	Modelbased_60%_15-10	Model based	60%	15-10
MP4	Modelbased_70%_15-15	Model based	70%	15-15
MP5	Modelbased_70%_45575	Model based	70%	10-10
MP6	Modelbased_70%_15-10	Model based	70%	15-10
MP7	CPUE_Slow_60%_15-15	CPUE_Slow	60%	15-15
MP8	CPUE_Slow_60%_10-10	CPUE_Slow	60%	10-10
MP9	CPUE_Slow_60%_15-10	CPUE_Slow	60%	15-10
MP10	CPUE_Slow_70%_15-15	CPUE_Slow	70%	15-15
MP11	CPUE_Slow_70%_10-10	CPUE_Slow	70%	10-10
MP12	CPUE_Slow_70%_15-10	CPUE_Slow	70%	15-10
MP13	CPUE_Fast_60%_15-15	CPUE_Fast	60%	15-15
MP14	CPUE_Fast_60%_10-10	CPUE_Fast	60%	10-10
MP15	CPUE_Fast_60%_15-10	CPUE_Fast	60%	15-10
MP16	CPUE_Fast_70%_15-15	CPUE_Fast	70%	15-15
MP17	CPUE_Fast_70%_10-10	CPUE_Fast	70%	10-10
MP18	CPUE_Fast_70%_15-10	CPUE_Fast	70%	15-10

Tests

- Implementation error

Additional runs will be conducted to test the robustness of the tuned MPs to different scenarios regarding a possible overshoot of the TACs delivered by the MP. Two scenarios are considered :

  - A maximum implementation error of 15% for a single management cycle, or three years
  - An implementation error of 10% over a longer period of time.

- TAC stabilizer

The subset of the MPs will be tuned again for a situation where the TAC stabilizer is disabled when biomass falls below certain safety values. Their performance will be compared with the MPs with the TAC stabilizer always applied.

Summary of Swordfish Candidate MP Performance

Only a subset of the candidate MP have been tuned so far, due to lack of time (see table 2).

MP rankings against key performance indicators are presented in Table 2 and figs. 5-11 illustrate their performance characteristics. More detailed performance tables are included in Appendix 2 (summarized over different time windows). We highlight the following key points:

- The two types of MP led to similar levels of spawning biomass (for a given tuning objective). The model based MP also led to a wider distribution of values across simulation iterations. No noticeable difference was observed between the slow and fast-reacting data-based MPs.
- For all tuned MPs, the probability that the stock remains above SB_{lim} for the tuning period was very high (average values above 99%).
- The data-based MPs (MP7-10 and MP13-16) led to larger average catches than the model-based one, but a wider distribution of values across simulation iterations. The fast reacting data-based MPs led to slightly higher catches than the slow reacting ones (except when a TAC stabilizer of 10% was applied). The fast reacting data-based MPs also lead to more uncertainty about future catch than the slow reacting ones. For the model-based MPs, the average catch is consistent across iterations (no variability in future values), reflecting the fact that it is most of the time equal to the plateau of the hockey stick harvest control rule.
- This also resulted in a low interannual change in the catch for the model-based MPs. For the data based MPs, the slow reacting MPs (MP7-10) have a lower interannual change in catches than the fast reacting MPs. For the fast reacting MPs, the MP with a TAC stabilizer of maximum 10% upwards and downwards had a lower interannual catch variability than the others. In all cases the catch variability is low, due to the application of the TAC stabilizers and to the fact that the advice is given for a period of three years.
- Tuning objectives are achieved (mean P(Kobe=green) at 0.6 or 0.7) but there is a large variability in this probability between simulation iterations (i.e. the 25th-75th quantile interval ranges from 0 to 1). This specific point was investigated for the 2022 WPB. It was explained by the fact that most of the simulation iterations starting in a given quadrant of the Kobe plot, remain in the same quadrant throughout the simulation period, despite the implementation of a MP. This is due to several factors. First the OM has a large range of initial starting conditions, with numerous iterations far

above or far below the SB_{msy}. For these iterations to change quadrant over the tuning period, it would require a MP that imposes a strong change of stock size. This is unlikely to be the case in the present situation, where the initial status for the stock is at p(Kobe=green)=73%, not far from any of the tuning objectives. In addition, due to the high longevity in the stock (31 age-classes), SB is very stable, which reduces the chances of changing quadrant over the tuning period, especially as the tuning period is rather short (5 years).

The main trade-off (figure 6) 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.

Table 2: performance of candidate MPs with respect to key performance measures (averaged over the period 2034-2038).

MP	prob(SB>SB_{limit})	Catch Variability	prob(Green)	Mean Catch	SB/SB_{MSY}
MP1	1.0 (1.0-1)	3.4	0.6	30652 (25633-30652)	1.6
MP4	1.0 (1.0-1)	2.3	0.71	26820. (26249-26821)	1.8
MP7	1.0 (1.0-1)	4.6	0.6	34514. (25185-44188)	1.7
MP9	1.0 (1.0-1)	4.6	0.6	34514. (25185-44188)	1.7
MP8	1.0 (1.0-1)	4.3	0.6	34159. (26171-39626)	1.7
MP10	1.0 (1.0-1)	4.3	0.7	32212 (23338-42297)	1.7
MP14	1.0 (1.0-1)	4.8	0.59	34343 (25087-41100)	1.7
MP15	1.0 (1.0-1)	5.7	0.6	36129 (23835-47534)	1.6
MP13	1.0 (1.0-1)	5.4	0.59	35709 (22703-47996)	1.6
MP16	1.0 (1.0-1)	5.4	0.71	33528 (20718-46394)	1.8

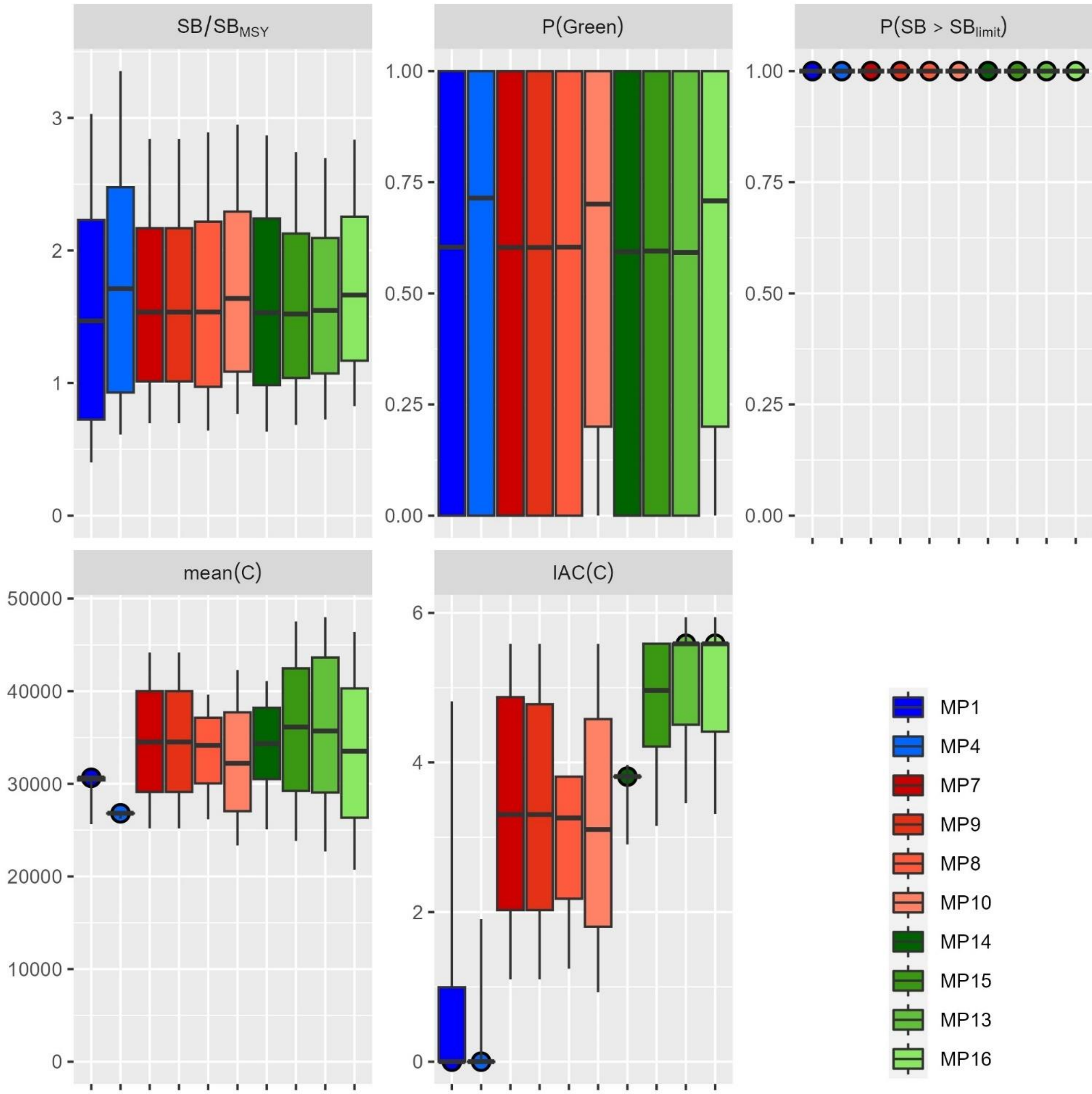

Figure 5. Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2034-2038. Horizontal line is the median (mean for P(Green)), boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. The data-based MPs are depicted in blue and model-based MPs are depicted in red (slow reacting) and green (fast reacting).

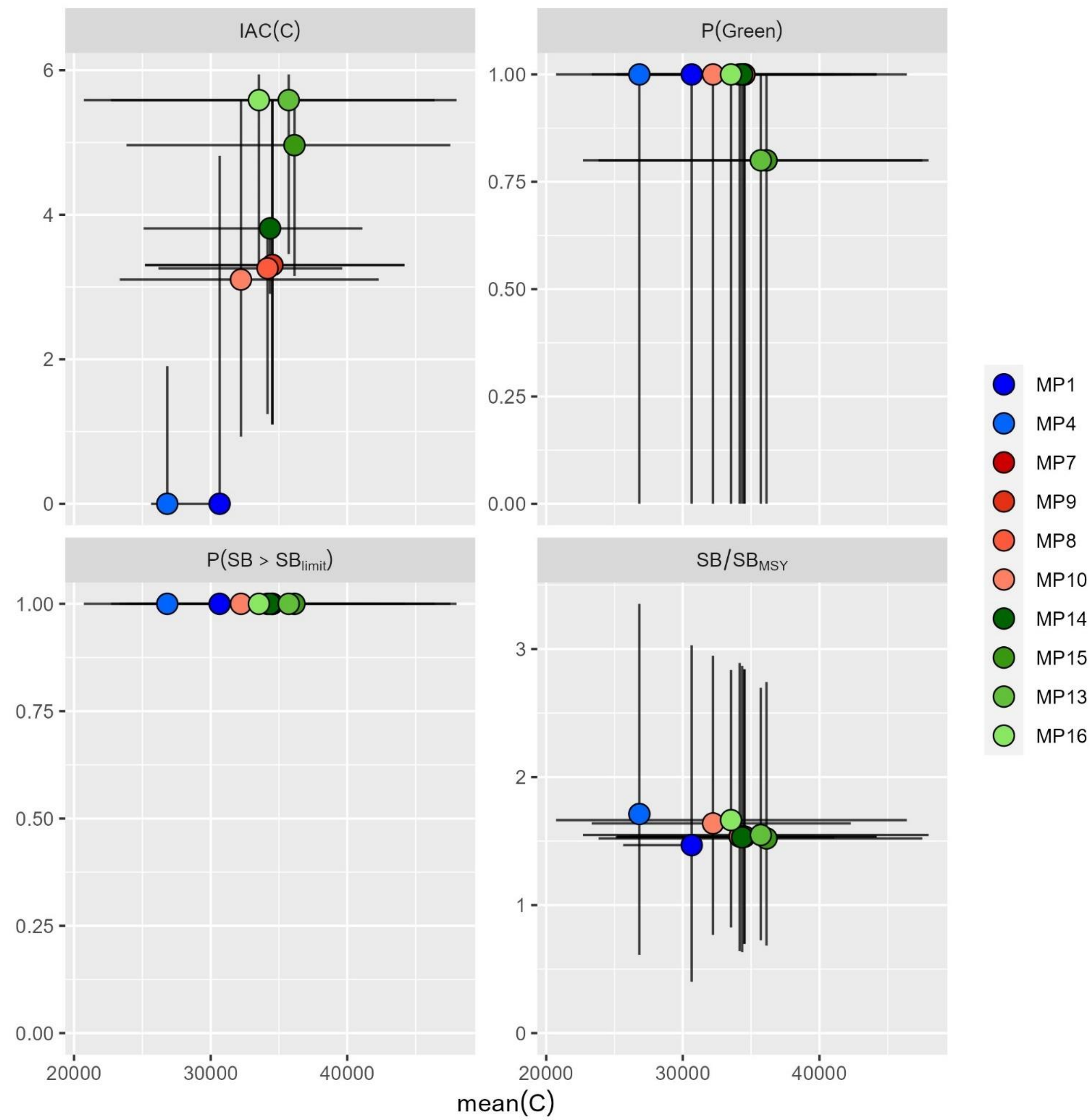

Figure 6. Trade-off plots comparing candidate MPs with respect to catch on the X-axis, and 4 other key performance measures on the Y- axis, each averaged over the period 2034-38. Circle is the median, lines represent 10th-90th percentiles.

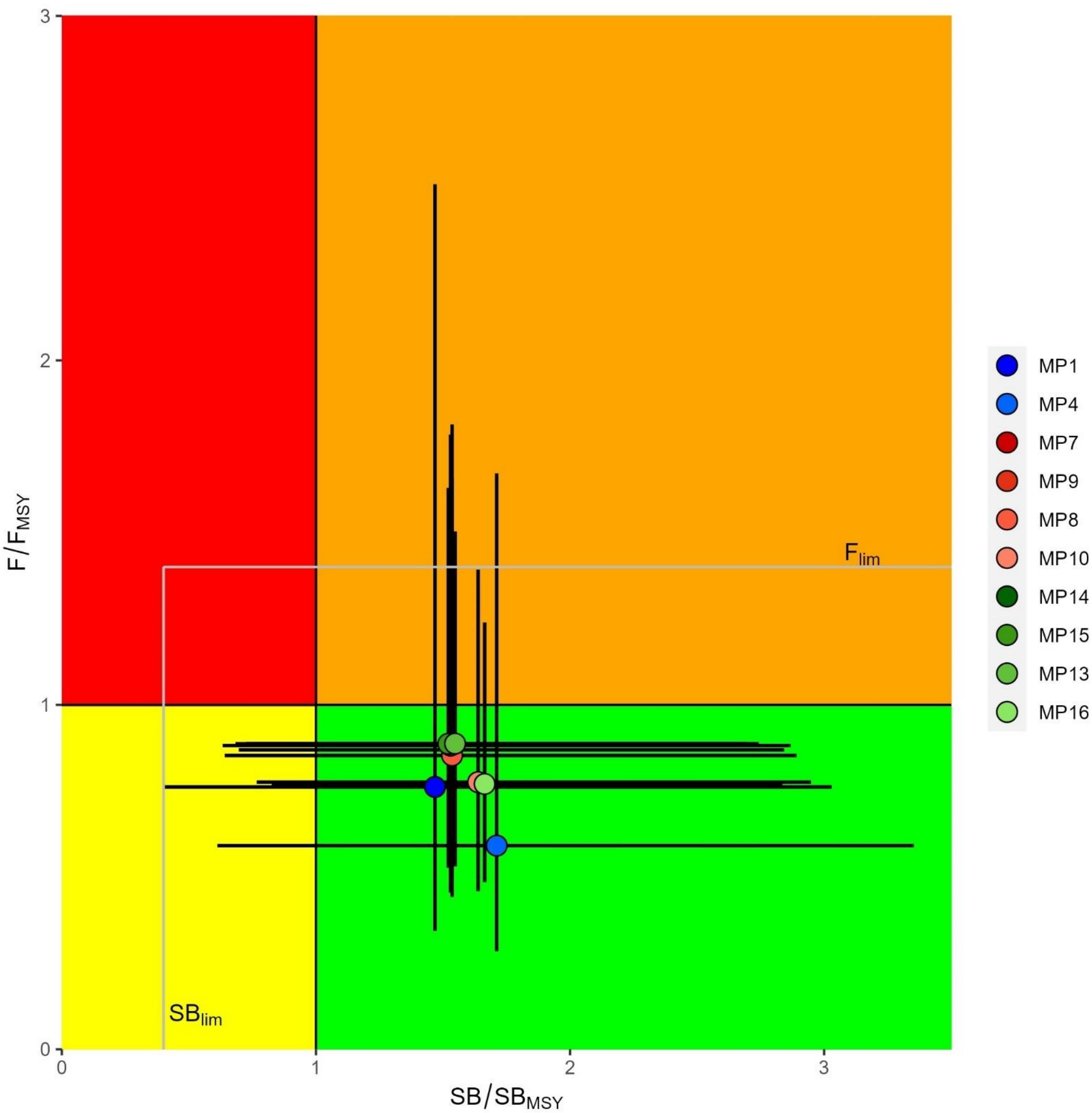

Figure 7. Kobe plot comparing candidate MPs on the basis of the expected 2034-2038 average performance. Circle is the median, lines represent 10th-90th percentiles.

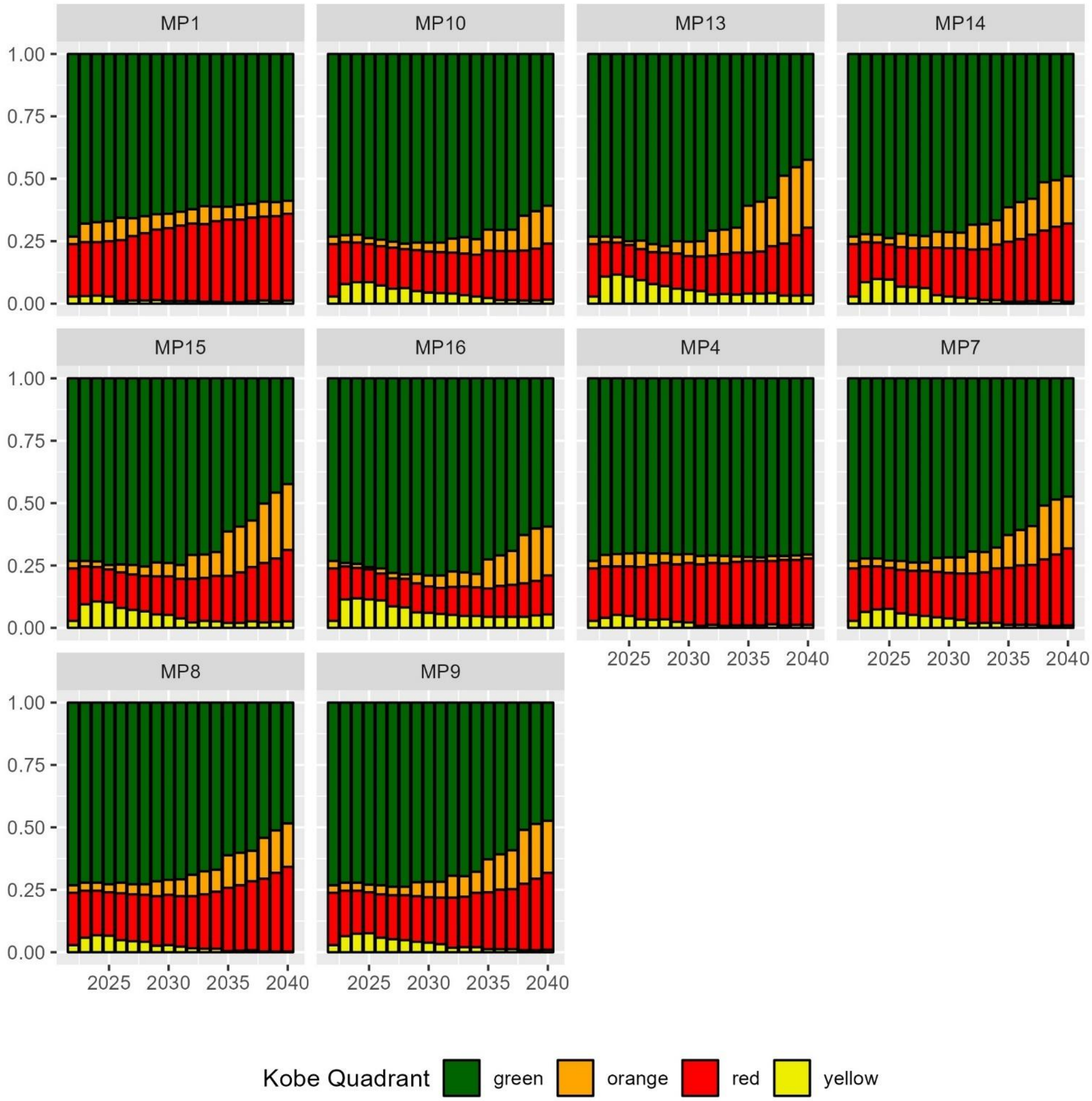

Figure 8. Proportion of simulations in each of the Kobe quadrants over time for each of the candidate MPs.

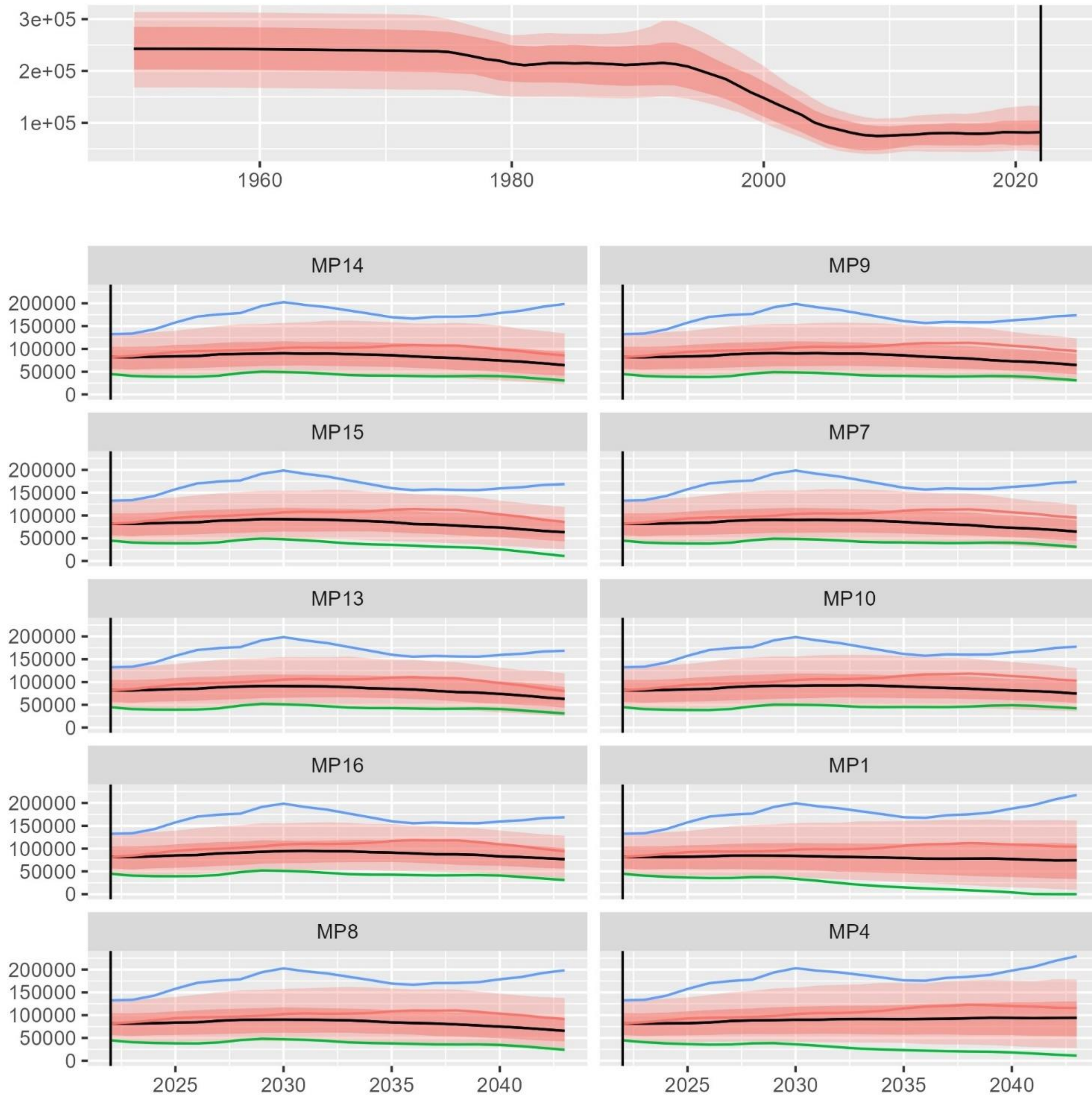

Figure 9. Time series of spawning stock size for the candidate MPs. The top panel represents the historical estimates from the reference case operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The median 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.

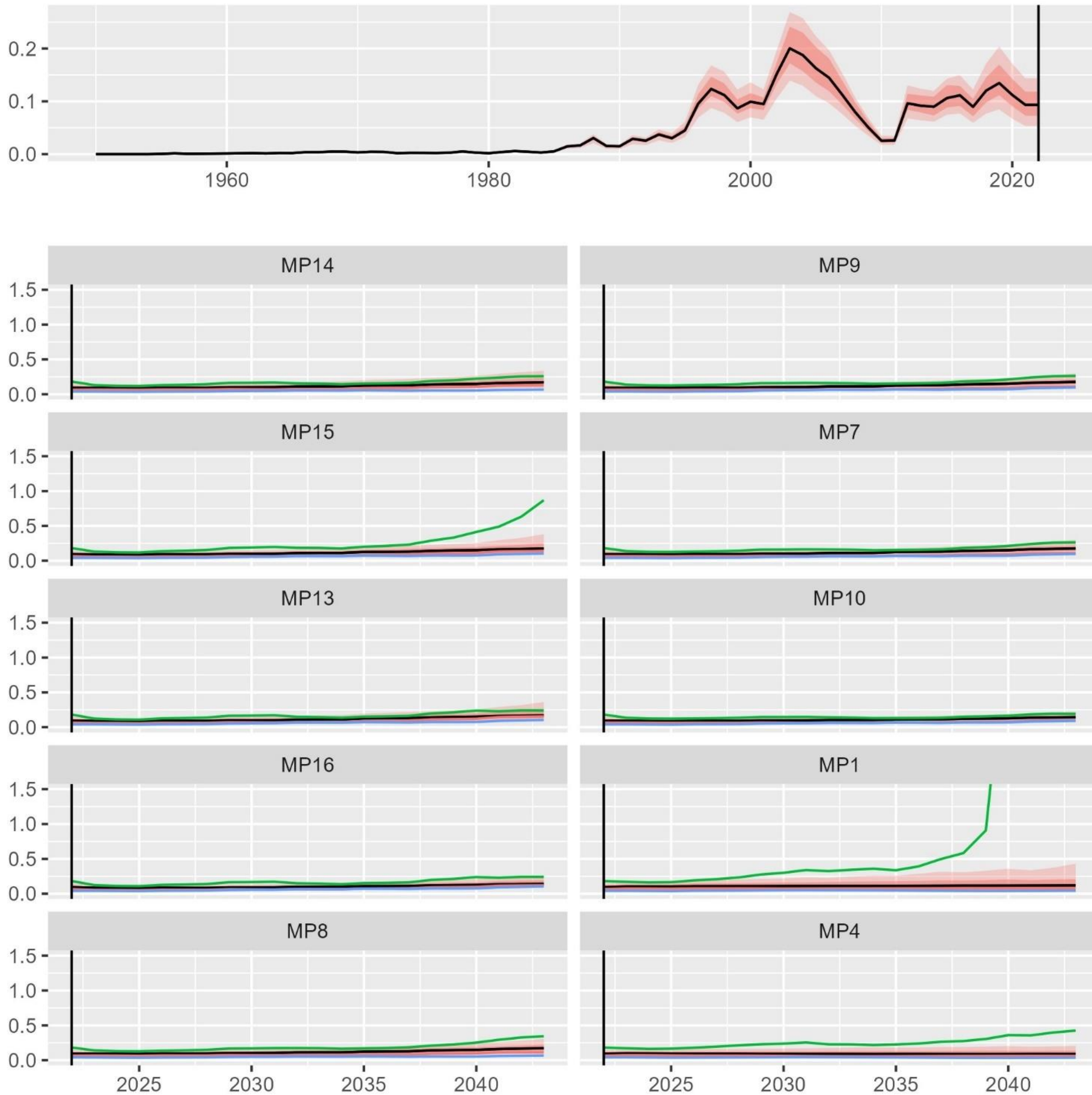

Figure 10. Time series of fishing intensity for the candidate MPs.

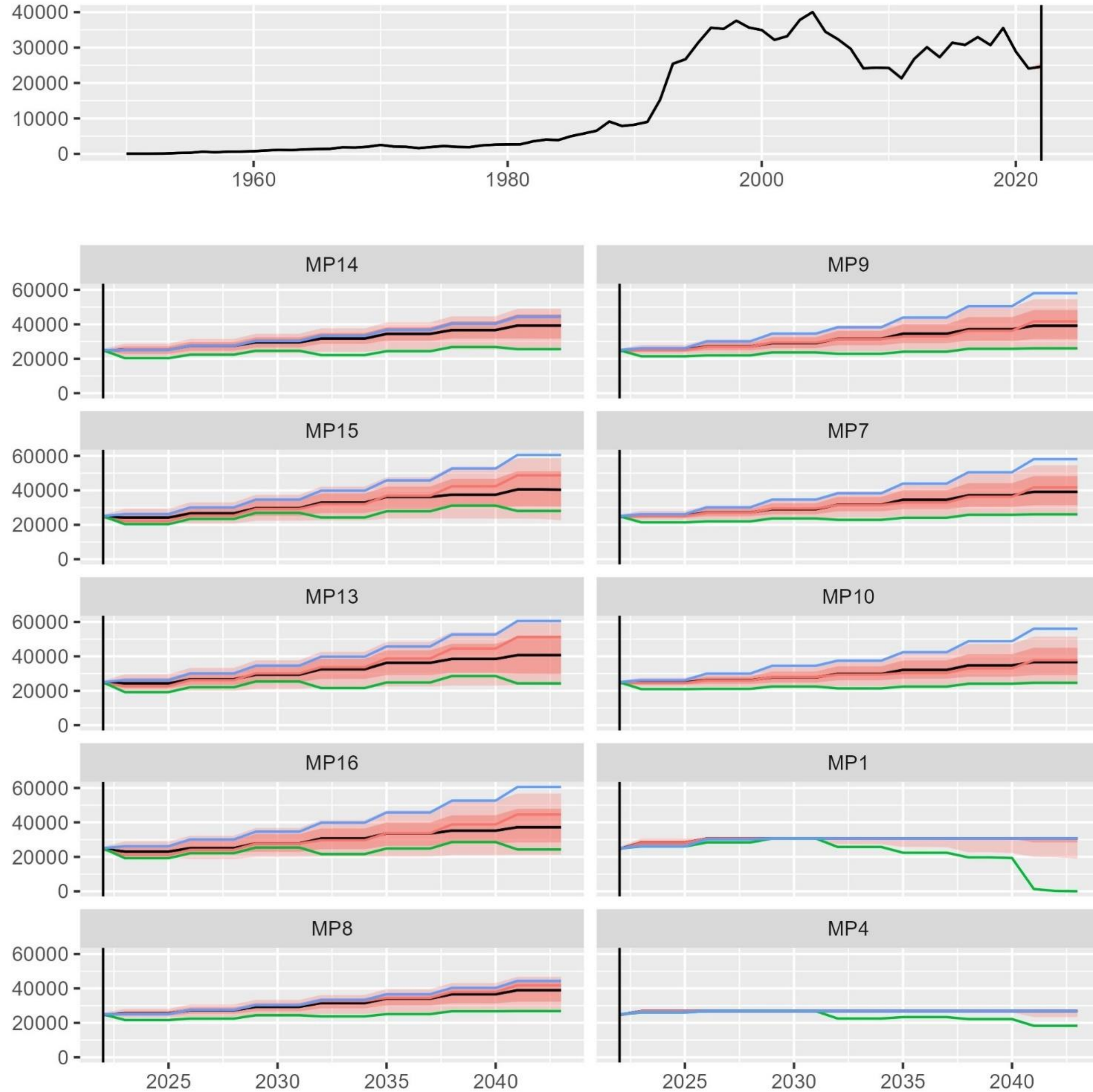

Figure 11. Time series of catch for the candidate MPs

Test runs

The runs to test the robustness of the MPs to an implementation error and to test the suppression of the TAC stabilizer at low biomass have not been carried out yet.

Earlier tests of the impact of an implementation error, presented at the WPM 2023, were considered inconclusive after a coding error was found in the simulation tool. This mistake has been corrected.

The suppression of the stability clause has not been tested yet, but the model developers need some guidance from the TCMP to configure this test (see section below).

Feedback Requests for the TCMP

The following points are provided to suggest the type of feedback that would be most useful for scientists for the next iteration:

1) The developers would welcome any feedback on the list of MP proposed (table 1), and whether it is considered relevant to tests two versions of the data based MP (slow and fast reactiveness).
2) Are the tuning objectives agreed upon in previous TCMPs still considered relevant?
3) Are the tests of robustness to an implementation error (TAC overshoot) considered relevant, and does the TCMP have any guideline with regard to the years (which management cycle) in which the single 15% implementation error should be applied?
4) When testing the suspension of the stability clause, does the TCMP have any suggestion regarding the biomass level below which the clause should be lifted?

   For the model-based MP, candidate values could be a depletion rate estimated by Jabba of 0.40 (current trigger point of the hockey stick rule) or of 0.10 (current limit point).

   For the data-based MP, value should be a CPUE index value that is considered to correspond to a low biomass level.

References

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

Appendix 2. Candidate Management Procedure summary performance tables for a range of time periods (aggregated over regions and fisheries).

Table 2a. Candidate MP performance for standard IOTC performance measures for the year 2023-2027.

Performance metrics	name	MP1	MP10	MP13	MP14	MP15	MP16	MP4	MP7	MP8	MP9
Mean catch over years	mean(C)	27787.72	25198.18	25022.64	25451.9	25180.18	24398.96	26158.91	25643.71	25719.53	25643.88
Mean fishing mortality relative to FMSY	F/FMSY	0.84	0.73	0.7	0.73	0.71	0.68	0.78	0.74	0.75	0.74
Mean fishing mortality relative to target	F/Ftarget	0.84	0.73	0.7	0.73	0.71	0.68	0.78	0.74	0.75	0.74
Mean proportion of MSY	C/MSY	0.89	0.8	0.79	0.81	0.8	0.77	0.84	0.82	0.82	0.82
Mean spawner biomass relative to unfished	SB/SB0	0.34	0.34	0.35	0.34	0.35	0.35	0.34	0.34	0.34	0.34
Mean spawner biomass relative to SBMSY	SB/SBMSY	1.54	1.56	1.56	1.56	1.56	1.57	1.55	1.56	1.56	1.56
Minimum spawner biomass relative to unfished	min(SB/SB0)	0.32	0.33	0.33	0.33	0.33	0.33	0.32	0.33	0.33	0.33
Percentage inter-annual change in catch	IAC(C)	4.06	2.65	4.96	3.63	4.43	5.01	1.81	2.88	2.73	2.88
Probability of being in Kobe green quadrant	P(Green)	0.68	0.73	0.74	0.73	0.74	0.75	0.71	0.73	0.73	0.73
Probability of being in Kobe red quadrant	P(Red)	0.22	0.17	0.15	0.16	0.15	0.14	0.2	0.18	0.19	0.18
Probability of fishery shutdown	P(shutdown)	0	0	0	0	0	0	0	0	0	0
Probability that spawner biomass is above 20% SB[0]	P(SB > 0.20 x SB0)	0.9	0.91	0.92	0.91	0.91	0.92	0.9	0.91	0.91	0.91
Probability that spawner biomass is above SBlim	P(SB>SBlimit)	1	1	1	1	1	1	1	1	1	1

Table 21b. Candidate MP performance for standard IOTC performance measures for the year 2023-2032.

Performance metrics	**name**	**MP1**	**MP10**	**MP13**	**MP14**	**MP15**	**MP16**	**MP4**	**MP7**	**MP8**	**MP9**
Mean catch over years	mean(C)	28889.35	26250.9	26775.19	26902.81	26902.3	25761.25	26366.8	27028.76	26977.51	27029.57
Mean fishing mortality relative to FMSY	F/FMSY	1.05	0.79	0.73	0.79	0.77	0.7	0.86	0.84	0.86	0.84
Mean fishing mortality relative to target	F/Ftarget	1.05	0.79	0.73	0.79	0.77	0.7	0.86	0.84	0.86	0.84
Mean proportion of MSY	C/MSY	0.93	0.83	0.84	0.85	0.85	0.81	0.85	0.86	0.86	0.86
Mean spawner biomass relative to unfished	SB/SB0	0.35	0.36	0.36	0.36	0.36	0.37	0.36	0.36	0.36	0.36
Mean spawner biomass relative to SBMSY	SB/SBMSY	1.58	1.65	1.65	1.64	1.65	1.67	1.63	1.64	1.64	1.64
Minimum spawner biomass relative to unfished	min(SB/SB0)	0.3	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Percentage inter-annual change in catch	IAC(C)	2.35	2.07	3.68	2.7	3.39	3.73	1.07	2.28	2.14	2.28
Probability of being in Kobe green quadrant	P(Green)	0.66	0.74	0.75	0.72	0.74	0.77	0.71	0.73	0.72	0.73
Probability of being in Kobe red quadrant	P(Red)	0.25	0.17	0.14	0.17	0.15	0.12	0.22	0.18	0.19	0.18
Probability of fishery shutdown	P(shutdown)	0	0	0	0	0	0	0	0	0	0
Probability that spawner biomass is above 20% SB[0]	P(SB > 0.20 x SB0)	0.88	0.92	0.92	0.91	0.92	0.92	0.9	0.91	0.91	0.91
Probability that spawner biomass is above SBlim	P(SB>SBlimit)	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Table 2c. Candidate MP performance for standard IOTC performance measures for the year 2023-2042.

Performance metrics	name	MP1	MP10	MP13	MP14	MP15	MP16	MP4	MP7	MP8	MP9
Mean catch over years	mean(C)	28821.21	29061.02	30917.55	29999.6	30888.25	29304.96	26147.75	30417.81	29793.06	30419.28
Mean fishing mortality relative to FMSY	F/FMSY	1.72	1.04	0.92	1.12	1.07	0.84	1.24	1.16	1.24	1.17
Mean fishing mortality relative to target	F/Ftarget	1.72	1.04	0.92	1.12	1.07	0.84	1.24	1.16	1.24	1.17
Mean proportion of MSY	C/MSY	0.92	0.91	0.96	0.94	0.96	0.9	0.84	0.95	0.94	0.95
Mean spawner biomass relative to unfished	SB/SB0	0.34	0.37	0.36	0.36	0.36	0.38	0.37	0.36	0.36	0.36
Mean spawner biomass relative to SBMSY	SB/SBMSY	1.59	1.69	1.64	1.65	1.64	1.71	1.72	1.64	1.65	1.64
Minimum spawner biomass relative to unfished	min(SB/SB0)	0.27	0.3	0.28	0.28	0.28	0.3	0.3	0.29	0.29	0.29
Percentage inter-annual change in catch	IAC(C)	1.93	2.44	3.91	2.96	3.71	3.92	0.95	2.63	2.42	2.63
Probability of being in Kobe green quadrant	P(Green)	0.64	0.72	0.67	0.66	0.67	0.73	0.71	0.67	0.66	0.67
Probability of being in Kobe red quadrant	P(Red)	0.29	0.18	0.16	0.21	0.18	0.13	0.24	0.21	0.23	0.21
Probability of fishery shutdown	P(shutdown)	0.02	0.01	0	0.01	0.01	0	0.01	0.01	0.01	0.01
Probability that spawner biomass is above 20% SB[0]	P(SB > 0.20 x SB0)	0.82	0.91	0.91	0.89	0.91	0.93	0.88	0.9	0.89	0.9
Probability that spawner biomass is above SBlim	P(SB>SBlimit)	0.97	0.98	0.99	0.98	0.99	0.99	0.98	0.98	0.98	0.98