

# IOTC Swordfish

## Management Strategy Evaluation Update

### 14th Working Party on Methods Meeting (WPM14)

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### Status of the MSE work

- The reference operating model for the Indian Ocean swordfish stock was 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 current 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.
- The choices made in 2020 for the construction of the OM by the previous researcher have been revisited, following the feedback received during the 2022 working party on billfish (WBP20). The structural uncertainty grid (different options for the stock assessment model parameters) was simplified by removing those parameters that were found to have little impact on the assessment (e.g. choice of the scaling method for the CPUE indices). This change in the grid resulted in a reduced number of combinations to consider, but in the end in a higher number of valid stock assessment models that can serve as the basis for the OM.
- 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) for a range of management objectives over the next 11 to 15 years.
- An in-depth analysis of the impact of the choices of the parameters for the CPUE MP was conducted in order to make an informed choice of the value of those parameters that are not obtained by tuning. On the basis of this investigation, a configuration of the CPUE MP with low reactivity to the changes and values in the CPUE index used for management was proposed.

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- Robustness test were also carried out. The robustness of the model based MP to a recruitment failure and to a systematic overshoot of the TAC by 20% appeared to be quite poor.

## Operating model

### Latest developments

The status of the current swordfish OM was presented at the 2022 WPB. A document presented 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. Two factors in the grid were eliminated: the choice of selectivity function shape for the CPUE fleets (previously set as double normal or logistic) and the scaling factor applied to the biomass by area estimates (previously based on surface area, biomass or catch). A change in the range of steepness values was also suggested, to 0.6-0.8 from the previous 0.6-0.9 but it was not endorsed by WPB, that noted that values between 0.6 and 0.9 were used for swordfish in other oceans (e.g. at ICCAT). The original structural uncertainty grid and the updated grid after WPB 2022 are given in table 1a and 1b of annex 1 respectively.

The decisions made at WPB were implemented, which resulted in a new grid containing 648 combinations, of which 175 were selected by factorial design optimization (vs 2592 and 108 respectively for the original 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, credibility of B0 estimates) and used as a basis for the OM (vs 67 for the original OM).

The SS3 runs based on the latest available stock assessment data for the Indian ocean swordfish cover 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 nominal catch estimates for the years 2019 to 2021, and assuming a status quo fishing mortality for 2022 ( $F_{2022}=F_{2021}$ ).

The updated OM presents a slightly different distribution of stock status at the end of the assessment period from the previous OM (figure 1), with a broader distribution of values, and, overall, slightly higher values. The updated OM gives the perception of a stock that was unfishied at the start of the assessment period, and for which exploitation started in the 1990s, which caused stock size to decrease until the mid-2000s after which it stabilized (figure 2). This is similar to the previous OM.

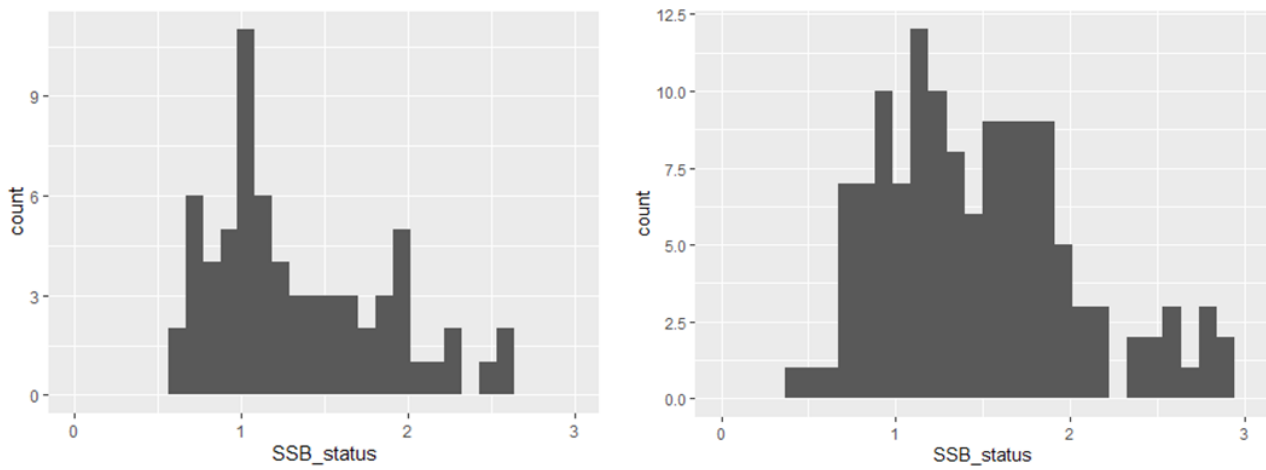


Figure 1 : Distribution of the estimated stock status in 2018 ( $SB/SB_{MSV}$ ) on the previous OM grid (left) and new one (right).

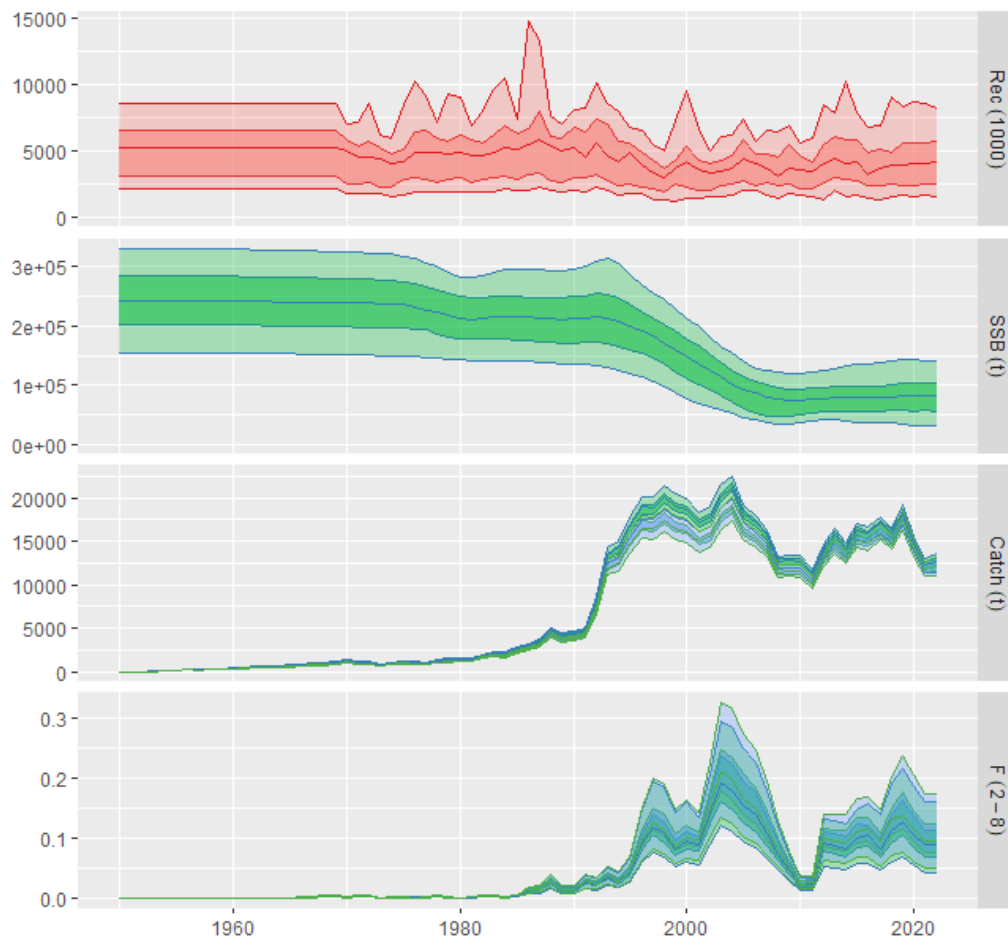


Figure 2: historical stock development in the updated swordfish OM

## Comparison of the swordfish OM with the 2023 WPB swordfish assessment

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 3). Likewise, the historical stock status from the 2023 assessment is comprised within the envelop of the OM (figure 4). 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 construction, 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.

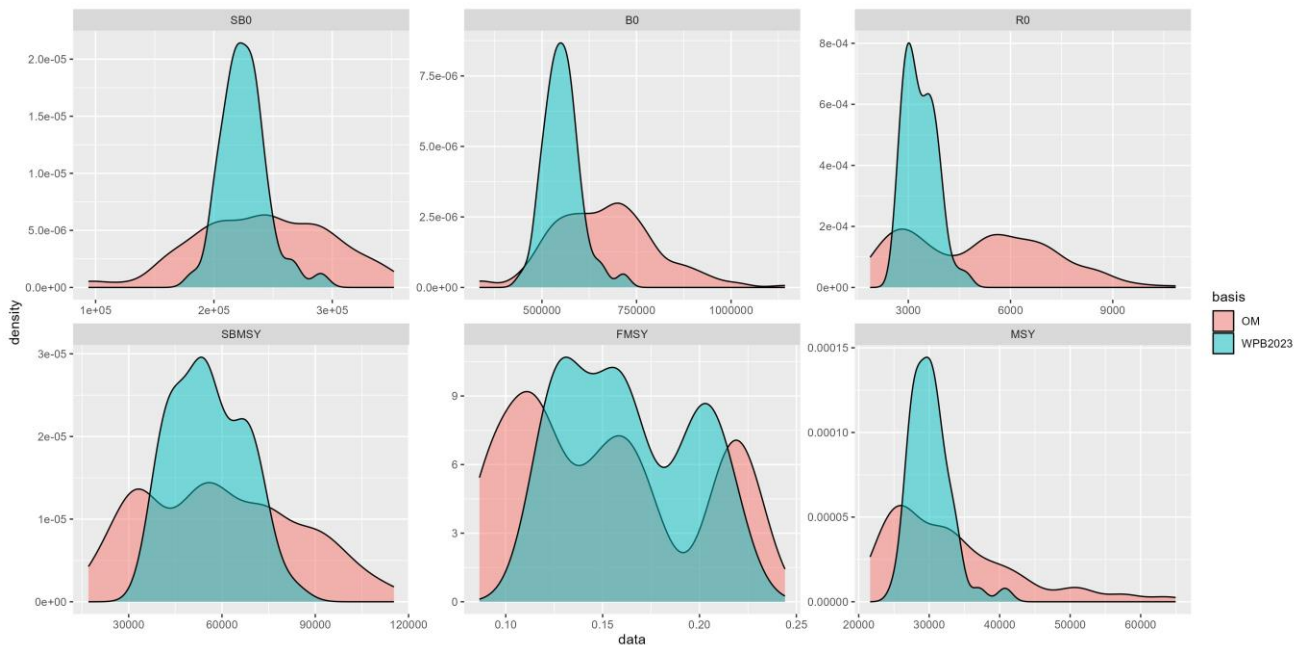


Figure 3 : Comparison of the population dynamics parameters from the WPB 2023 swordfish assessment, and from the Operating Model developed for the MSE analysis from the previous assessment.

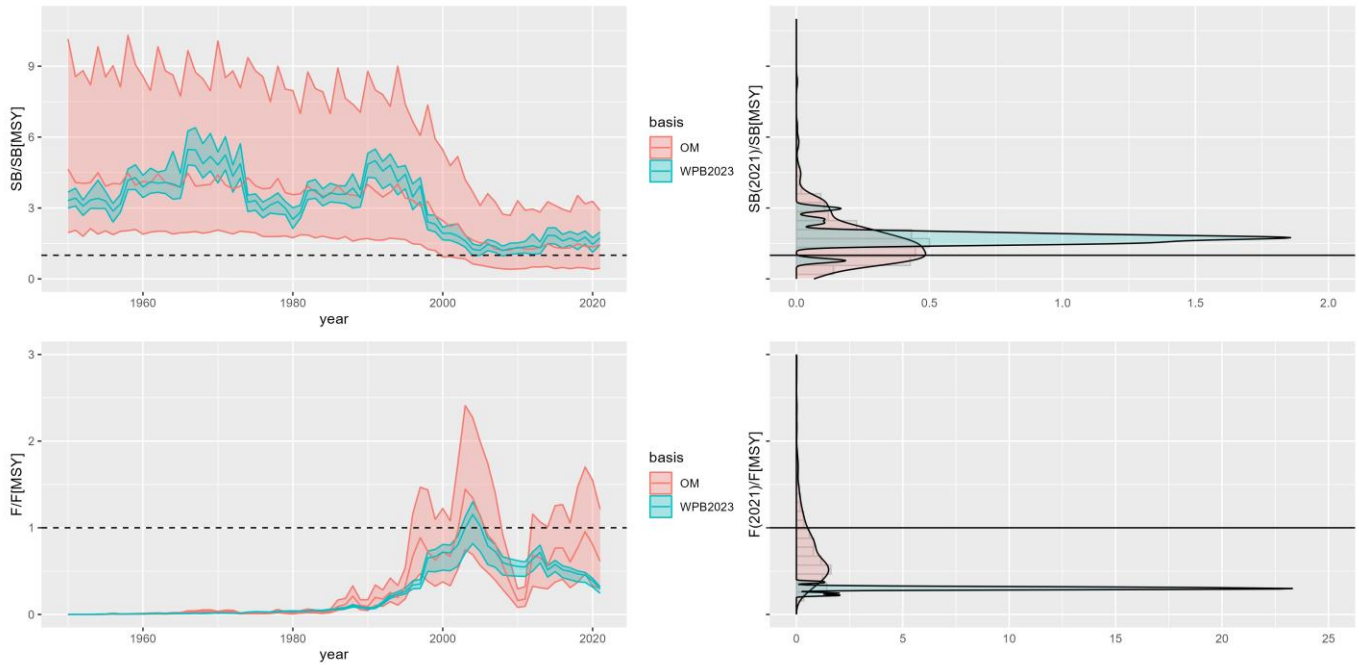


Figure 4 : Comparison of the historical development and current stock status from the WPB 2023 swordfish assessment, and from the Operating Model developed for the MSE.

## Candidate Management Procedures

The swordfish MSE analyses focussed on two types of MPs:

- A model-based one, in which the surplus-production model JABBA provides an estimate of stock status, in terms of current biomass depletion ( $B/B_0$ ), which is then used in a hockey-stick-shaped harvest control rule to determine the advised catch.
- A data-based one in which the advised catch changes from the previous level based on both the value and recent (5 year) trend in a CPUE index.

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

- with a 3 year advice cycle (TAC set for a period of 3 years)
- with an inter-annual TAC variation limit (or TAC stabilizer) of 15 %, whereby when the implementation of the MP leads to a change in TAC larger (in absolute values) than 15%, the TAC applied is that corresponding to the max 15% change (increase or decrease).
- 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 and 1 year management 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 and provided estimates of the depletion rate, as  $SB/SB_0$  ( $SB_0$  =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  $SB=SB_{lim}$ ) 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. In agreement with the decision made by the TCMP-03 (2018), the MP was tuned for three tuning objectives corresponding to a probability of being in the green quadrant of the Kobe plot ( $p(\text{Kobe}=\text{green})$ ) over the period 2034:2038 of exactly 50%, 60% and 70% (average over all stock replicates and years) respectively.

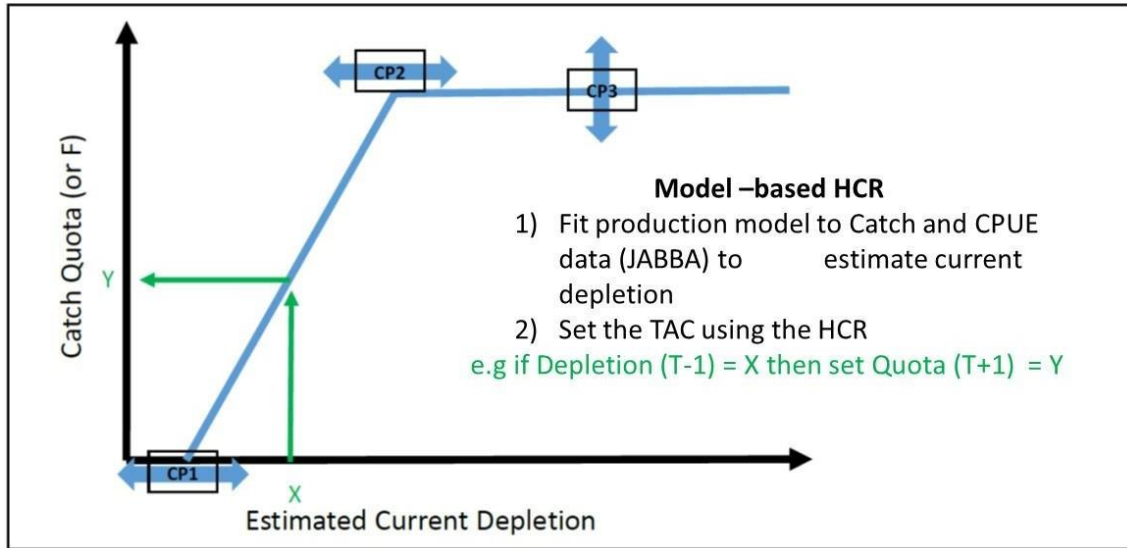


Figure 3. Harvest control rules used in the model-based MP.

## 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

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

and

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

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 ( $k_1$  and  $k_2$ ), CP3) responsiveness to CPUE target deviation ( $k_3$  and  $k_4$ ) and CP4) the CPUE target value.

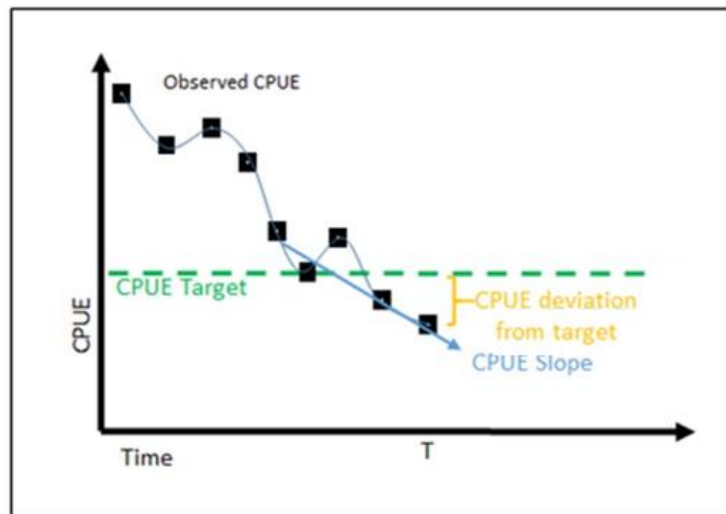


Figure 4 : The CPUE rule is based on the recent slope in the CPUE index and the distance to the target index value.

### 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 (see section below for a justification of the  $k$  values chosen). The MP was tuned to estimate the target CPUE value for the same three management objectives as for the model-based MPs.



## Performance of the candidate Swordfish MPs

MP rankings against key performance indicators are presented in Table 1 and Figures 5 and 6 illustrate their performance characteristics.

The two types of MP led to similar levels of spawning biomass (for a given tuning objective) except for  $P(\text{Kobe} = \text{green}) = 50\%$ , for which spawning biomass was markedly lower with the model-based MP. The model-based MP also led to a wider distribution of values across simulation iterations.

For all tuned MPs, the probability that the stock remains above  $SB_{\text{lim}}$  for the tuning period was very high (average values above 99%).

The data-based MPs (MP1-3) led to larger average catches than the model-based ones, but a wider distribution of values across simulation iterations. For the model-based MPs, the average catch is consistent across iterations, reflecting the fact that it is most of the time equal to the plateau of the hockey stick harvest control rule. This also results in a low interannual change in the catch although a little less so when the MP is tuned for  $P(\text{Kobe} = \text{green}) = 50\%$ , as the stock is more often at  $SB/SB_0$  below 40%, where catches are decreased from  $C_{\text{max}}$ . For the data-based MPs, interannual change in catches is higher, although it remains at low values (likely due to the implementation of a maximum interannual TAC variation limit of 15%).

Tuning objectives are achieved (mean  $P(\text{Kobe}=\text{green})$  at 0.5, 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  $SB_{\text{msy}}$ . 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  $p(\text{Kobe}=\text{green})=73\%$ , 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.

*Table 1: Performance of candidate MPs with respect to key performance measures (averaged over the period 2034-2038).*

MP	prob( $SB > SB_{\text{limit}}$ )	Catch Variability	prob(Green)	Mean Catch	SB/SB <sub>MSY</sub>
MP1	>0.99	6.2	0.5	37149.6 (26571.2-46601)	1.6
MP2	>0.99	5.7	0.62	34421.4 (24348.0-44429)	1.7
MP3	>0.99	5.2	0.7	32498.0 (22853.7-43024)	1.7

MP4	>0.99	5.3	0.49	35031.2 (24245.3-35031)	1.4
MP5	>0.99	3.4	0.6	30652.3 (25633.8-30652)	1.6
MP6	>0.99	2.3	0.71	26820.8 (26249.4-26821)	1.8

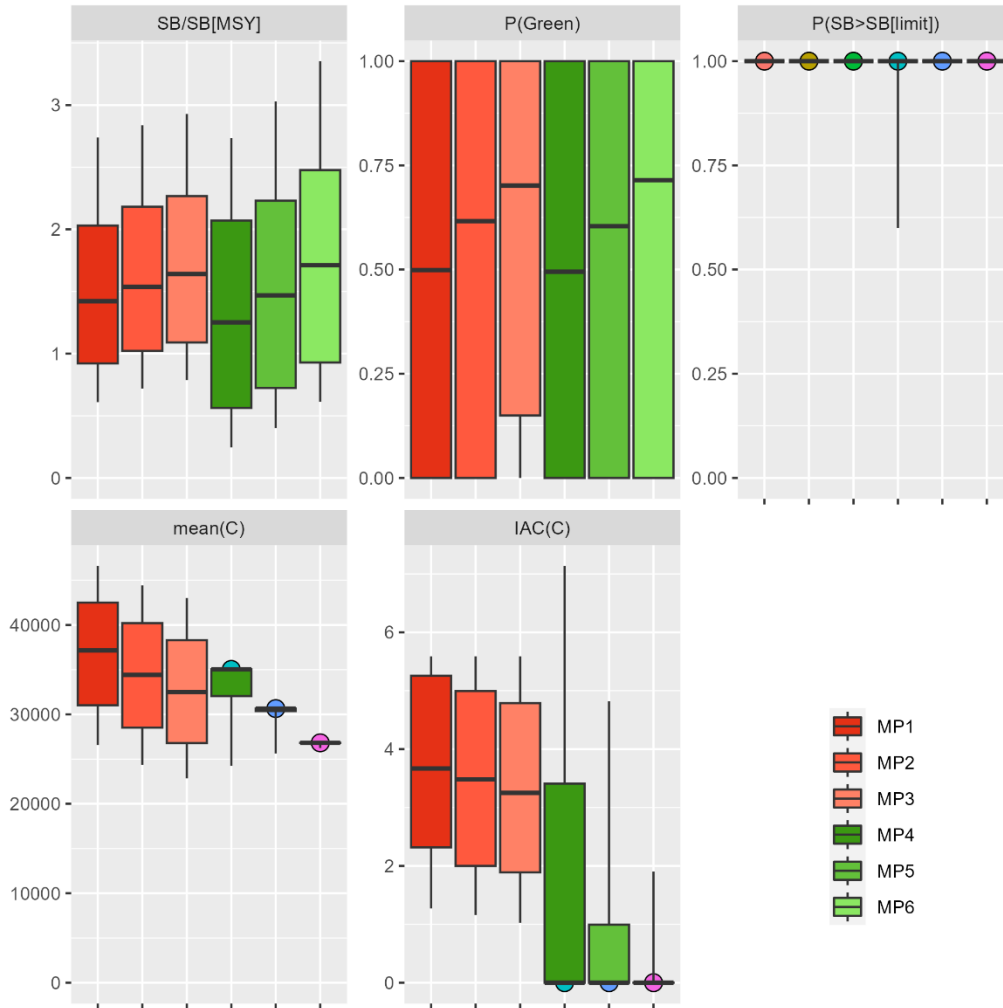


Figure 5. Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2034-2038. Horizontal line is the median (mean for P(Green)), while boxes represent 25th - 75th percentiles, and thin lines represent 10th - 90th percentiles. The data-based MPs are depicted in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

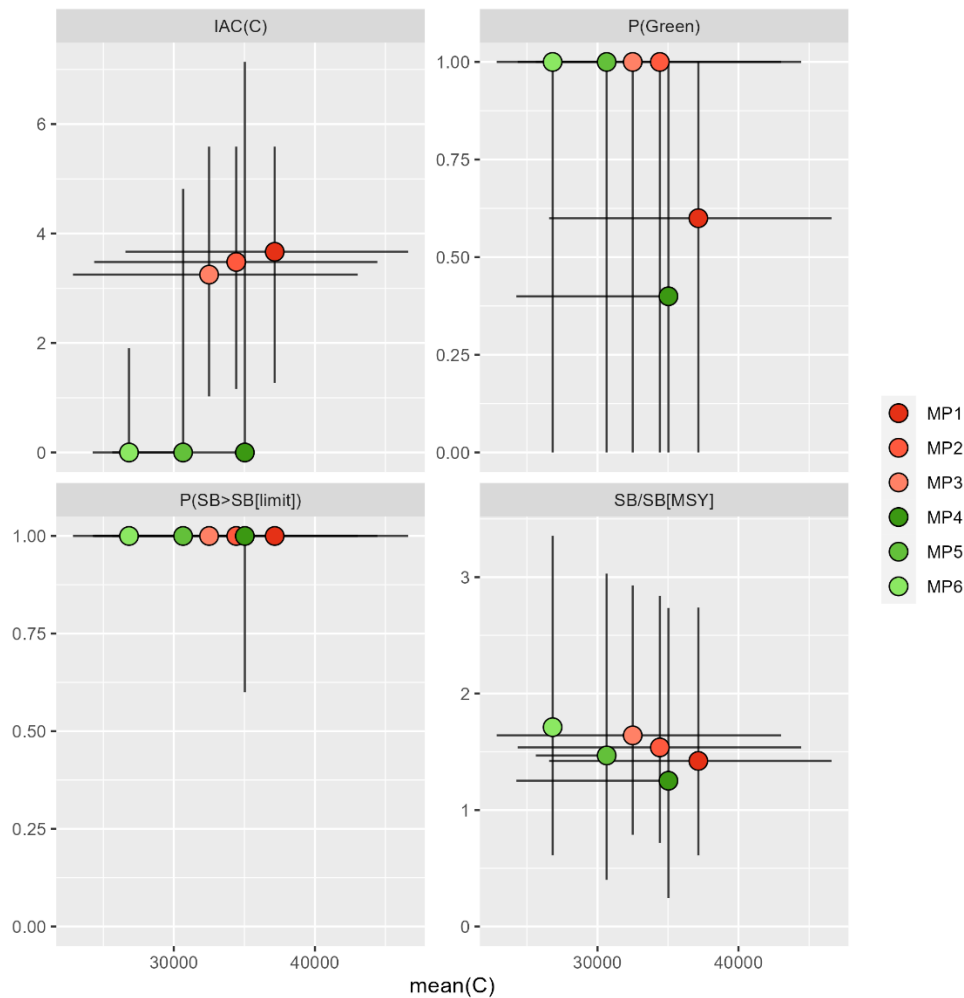


Figure 6. Trade-off plots comparing candidate MPs with respect to catch on the X-axis, and 4 other key performance measures on the Y-axis, each averaged over the period 2034-38. Circle is the median, lines represent 10<sup>th</sup>-90<sup>th</sup> percentiles.

## Investigation of different parameterization options for the CPUE MP

### MP reactivity to changes in the CPUE index and to the distance to the target value

The CPUE MP has multiple control parameters, and it is not straightforward to decide which parameters should have values chosen a priori and which parameters should have values obtained by tuning. In order to examine the impact of the different parameters on the MP performance, simulations were run for a grid of parameter values and key performance indicators were calculated over the period for which tuning should be done (2034-2038). The grid used was the following :

- $k_1=k_2$  varying between 0.1 and 3 and
- $k_3=k_4$  varying between 0.1 and 1.2
- target = mean of historical CPUE index values (1.00)

The MP performance indicators were slightly more influenced by the responsiveness to the distance to the target CPUE ( $k_3$  and  $k_4$ , figure 7) rather than to the slope ( $k_1$  and  $k_2$ ). The mean catch is rather stable along the isolines for  $p(\text{Kobe}=\text{green})$ , showing that these two performance metrics are linked to a large extent. Along the  $p(\text{Kobe green})$  isolines, management strategies that are more reactive to the CPUE index (higher values of  $k$  parameters) lead to higher interannual catch variability. For all options on the grid the risk of  $SB < SB_{lim}$  was null.

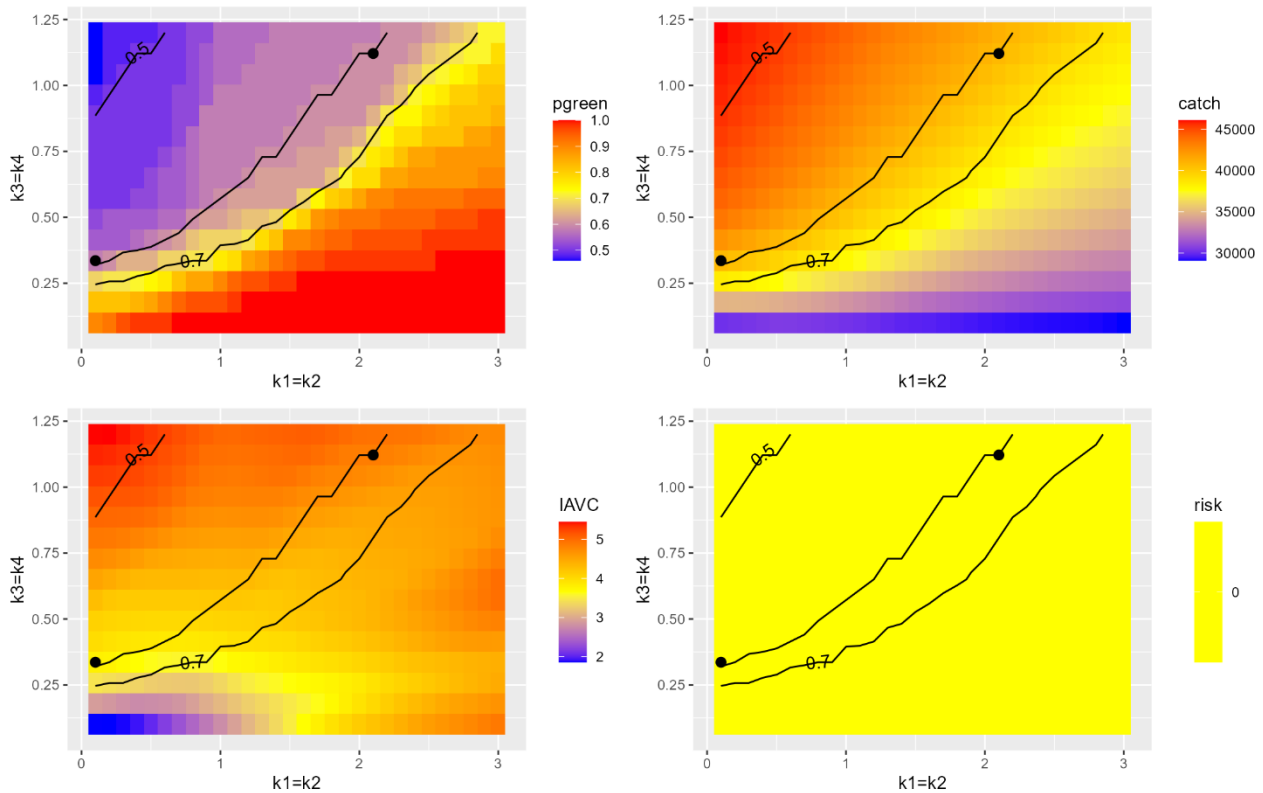


Figure 7 : values of 4 MP performance indicators ( $p_{\text{green}}$  :  $P(\text{Kobe green})$ , catch : mean catch, IAVC: interannual catch variability and risk3 :  $p(SB < SB_{lim})$  computed over the period 2034-2038 for a grid of  $k$  responsiveness parameters with symmetric response for positive and negative CPUE slope and distance to target (isolines show the 50, 60 and 70% probability of being in the green zone of the Kobe plot).

### Impact of the implementation of the TAC variation limit

In order to investigate the impact on the MP performance of the implementation of a 15% TAC interannual variation limit, the CPUE MP was tuned again, with the same  $k$  parameter values as above, but without the TAC variation limit.

For each tuning objective, the CPUE MP tuned without TAC variation limit consistently had a slightly higher value of the CPUE index target value, meaning that the MP had to be a little more precautionary to achieve the tuning objective than the MPs with the TAC variation limit. Comparison of the performance of the MP with and without TAC variation limit shows that there is overall little difference, the effect of the tuning criteria being overall larger than the effect of implement the TAC variation limit.

## Robustness tests

### Recruitment failure

The exploration of the performance of the CPUE MP for different types of configurations presented above suggests that configuration with low reactivity, combined to a TAC variation limit led, for the swordfish stock, to slightly better performance than alternative configurations. However, such a MP, with slow reactivity to changes in stock size and limited possibilities to change the TAC, might not be capable of protecting the stock in case of unfavourable events.

Likewise, the model-based MP contains a biomass safeguard mechanism (reduction of the catch when  $SB < 40\% SBO$ ) which is supposed to prevent the stock from declining to low levels and ensure its return to levels above 40% SBO. However, whether this mechanism can successfully protect the stock when adverse circumstances occur remains to be tested for the three tuned model-based MPs.

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, in multiplicative scale, from the stock-recruitment model to 0.1 for the period 2022 to 2025. This purely fictitious 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. Simulations were run for the three tuned data-based MPs and the three tuned model-based MPs.

The occurrence of the recruitment failure between 2022 and 2025 leads to a decrease in the swordfish SB which reaches a minimum around 2032 (Figure 8). After this year, the recovery of the stock depends on the MP implemented. The data-based (cpue) MP tuned for  $p(\text{green})=50\%$  leads to a slow recovery. A non-negligible proportion of the iterations do not recover and collapse. Technical problems were encountered when running the test for the model-based (jabba+hcst) MP tuned for  $p(\text{green})=50\%$  due to issues with running Jabba in the MP with very low biomasses. Trials done on a subset of the OM (10 iterations) showed that the rate of stock collapse was large (at least 50% of the iterations). MPs tuned for  $p(\text{green})=70\%$  led to a recovery of the stock, to higher levels at the end of the simulation period in the case of the model-based MP compared to the data-based MP.

The performance of the MPs for the tuning period (2034 to 2038) is affected by the recruitment failure (figure 9). The probability of being in the green part of the Kobe plot is much lower than the values used for tuning (around 0.1 lower for all MPs, except for the model-based MP tuned for  $P(\text{green})=70\%$  for which the tuning object is still achieved). Catches are much lower (between 5000 and 12000 t lower). The median of the probability of  $SB > SBlim$  is still of 1, but there is a proportion of the iterations for which  $P(SB > SBlim)$  falls to very low values (between 10 and 20% of the iterations, depending on MPs, have a  $P(SB > SBlim)$  lower than 10%).

This test, based on a purely fictional recruitment scenario, shows that biological risk for the stock (probability of falling below  $SBlim$ ) is considerably increased for the MPs tuned for  $p(\text{green})=50\%$ , especially the model-based one (even if based on a partial set of runs). This MP has a maximum catch (CP3 on figure 3) of around 35 000 t which is the level of catch required to bring the stock from the current

status down to 50% probability of being in the green part of the Kobe plot in the tuning period. However, such a high maximum catch, in combination with a recruitment failure, is not sustainable, and leads to stock collapse as the MP is unable to reduced efficiently the catches. MPs tuned for a higher  $P(\text{green})$  lead to lower risk for the stock in case of a recruitment failure, especially the model-based MP tuned for  $p(\text{green})=70\%$  which is the most robust one.



*Figure 8: Time series of spawning stock size for the candidate MPs in the event of a recruitment failure occurring from 2022 to 2025. 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. NB : there were technical issues running the robustness test for the data based MP tuned for 50%  $p(\text{green})$  and this run is not presented here.*

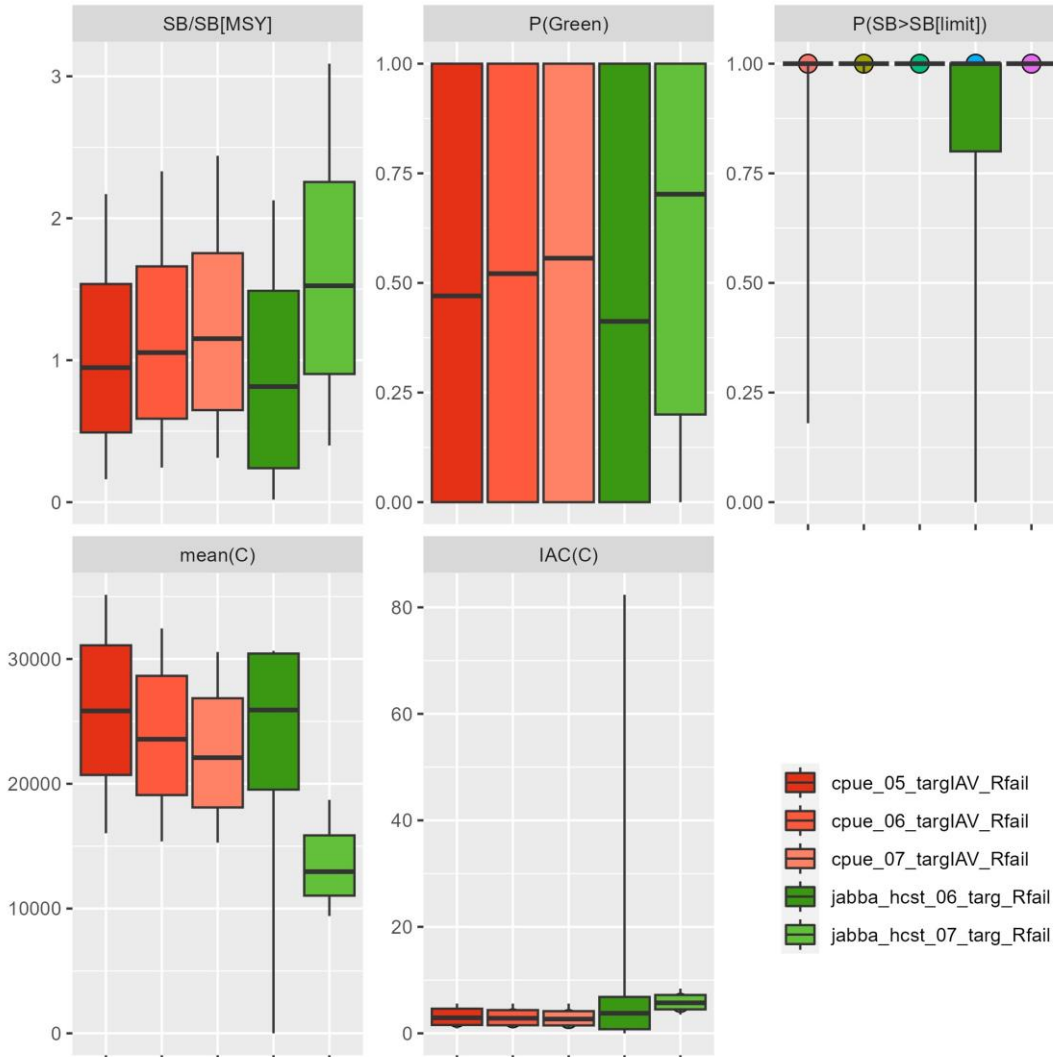


Figure 9. Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2034-2038 for the test of robustness to the occurrence of a recruitment failure.

### Systematic TAC overshoot (implementation error)

The robustness of the 6 candidate MPs to implementation error was also tested, by applying a systematic 20% overshoot of the TAC (with catches fully reported). The performance of all MPs is severely altered (Figure 10). The probability of being in the green part of the Kobe plot is much lower than the tuning objectives the MPs were setup for. Stock biomass in the tuning period is much lower than without implementation error (figure 5), especially for the model-based MP tuned for  $P(\text{green})=50\%$ . Catches are higher (due to the overshoot), but for the model based MP catches can decrease to very low values, as a



result of the strong decrease in stock size for some iterations. Biological risk becomes very high for the 3 model- based MPs

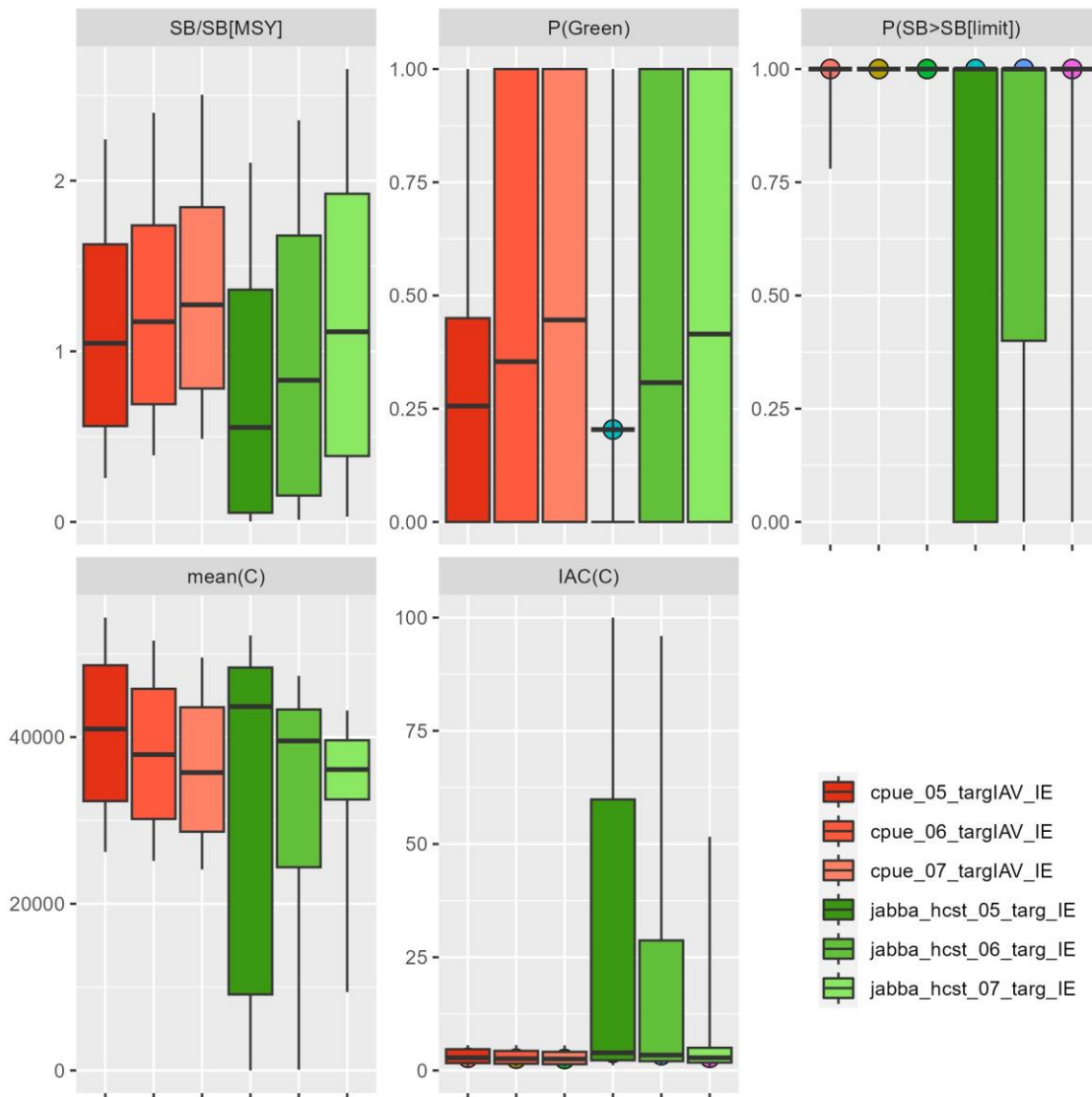


Figure 10. Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2034-2038 for the test of robustness to a systematic overshoot of the TAC by 20%

## Appendix 1. Changes in the structural uncertainty grid used to generate the swordfish OM

**Table 1a : Reference OM structural uncertainty grid**

Variable	Values		
Selectivity	Double Normal	Logistic	
Steepness	0.6	0.75	0.9
Growth + Maturity	Slow growth, late maturity (Wang et al.,2010)	Fast growth, early maturity (Farley et al., 2016, otoliths)	
M	Low = 0.2	High = 0.3	Sex-specific Lorenzen M (Farley et al. (2016), otoliths)
Sigma R	0.2	0.6	
ESS	2	20	
CPUE scaling schemes	Area effect x Surface	Catch	Biomass
CPUEs	JPN late + EU.PRT	JPN late	TWN + EU.PRT
Catchability increase	0%	1% / year	

**Table 1b : Proposal for a new OM structural uncertainty grid (additions and removals highlighted respectively in bold and with a cross )**

Variable	Values		
Selectivity	Double Normal		
Steepness	0.6	0.75	0.90
Growth + Maturity	Slow growth, late maturity (Wang et al.,2010)	Fast growth, early maturity (Farley et al., 2016, otoliths)	
M	Low = 0.2	High = 0.3	Sex-specific Lorenzen M (Farley et al. (2016), otoliths)
Sigma R	0.2	<b>0.4</b>	0.6
ESS	2	20	
CPUE scaling schemes			Biomass
CPUEs	JPN late + EU.PRT	JPN late	TWN + EU.PRT
Catchability increase	0%	1% / year	