Indian Ocean swordfish MSE: investigating an alternative Operating model[1]

Introduction

The reference operating model for the Indian Ocean swordfish stock was developed over the last two years and has been endorsed by the IOTC scientific committee. The OM was based on the 2019 WPB SS3 assessment, and covered the dynamics of the swordfish until the year 2018. This OM was updated to the year 2021, by projecting the stock forward based on the reported catches for 2019 and 2020.

Further developments to the swordfish MSE were made in 2022 and 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. Preliminary results were presented at the 2022 TCMP-05.

Examination of the first MSE runs showed that tunning objectives were achieved (mean p(Green) at 0.5, 0.6 or 0.7) but there was a large variability in p(Green) between simulation iterations (i.e. the 25th-75th quantile interval ranges from 0 to 1). This came from the fact that the choices made when assembling the reference OM (i.e. the grid of stock assessment assumptions used) resulted in a very wide range of stock dynamics and initial stock status.

In this document, we briefly present the results of these preliminary MSE runs to illustrate the implications of using a OM with a very wide range of initial stock status, show how this large variability in the starting conditions is a consequence of some of the choices made when constructing the structural uncertainty grid of the reference OM, and test a narrower range of assumptions to construct an OM in an attempt to develop a more suitable basis for conducting a MSE.

Reference OM and first MSE runs

OM construction

The structural uncertainty grid used to generate the reference OM (table 1) resulted in a total of 2592 combination of factors. Using factorial design optimization technics (implemented with the R library "AlgDesign"), the size of the grid was reduced to 108 combinations for which the stock assessment model was run. From these runs, a total of 67 were considered acceptable after removing runs with unrealistic virgin biomass estimates, poor convergence, or values of the hindcasting cross-validation MASE statistic greater than 1, the latest being indicative of poor prediction capability.

Figure 1 (left) shows the variability in the stock status at the start of the simulation. The 90% envelop of the SB/SB_{MSY} ranges from 0.69 to 2.29, with a median value of 1.18.

MSE runs

The reference OM was used as a basis to conduct MSE runs in which two types of MPs were implemented:

- a data-based MP, in which the recent slope in a CPUE index, and its distance to a target value are used to compute the proportion by which the TAC should be modified
- a model-based MP, in which a stock assessment (in the preliminary runs a perfect assessment was used) informs a "hockey-stick" harvest control rule.

The parameters in these MPs were obtained by tunning using the objectives defined by TCMP-04, these being p(Kobe Green) 2034-2039 = 50%, 60% or 70%.

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Figure 2 shows the selected performance indicators computed over the tunning period (2034-2039) for the 6 tunned MPs. Differences are observed in the indicators both between MP types, and depending on tunning objective. Tunning objectives are achieved, with the mean (across OM iterations) of p(Green) being indeed at the value aimed (50%, 60%, 70%), but there is a large variability in p(Green) between iterations (i.e. the 25th-75th quantile interval ranges from 0 to 1).
Closer examination of the results indicated that distribution of the iteration specific p(Green) values is almost binary, with the majority of the iterations having a p(Green) of either 0 or 1 (meaning they are always in the green part of the Kobe plot over the tunning period, or never), and few iterations having values in between (figure 3, corresponding to MP5).
Most of the iterations that start in the red (or green) quadrant of the Kobe plot, remain in the same quadrant throughout the simulation period, despite the implementation of a MP. Tunning is able to achieve its objective by finding a MP that modifies the proportion of the simulations that change quadrant on the Kobe plot (and thereby affects the mean p(Green)). However, most of the simulation iterations have a p(Green) of either 0 or 1, and only a small fraction have a p(Green) close to the tunning objective (0.6 in the example taken on figure 3).

Link between structural uncertainty grid design and the variability in OM starting conditions

A regression tree was used to see to what extend the variability in the reference OM (i.e. the differences in SB/SB_{MSY} in 2018 across iterations) could be related to the different levels of the factors used in the structural uncertainty grid. The results indicate that different sub-groups of iterations with substantially different starting stock status can be separated on the basis of a few factors (figure 4). The most influential factor is the steepness of the stock-recruitment model, with iterations corresponding to a steepness of 0.9 having a very high SB/SB_{MSY} in 2018 (average 1.8) compared to iterations with steepness 0.6 and 0.75 (1.1 on average). Some further ramification of the tree lead to much lager differences, with a mean SB/SB_{MSY} of 0.93 when combining steepness of 0.6 or 0.75 and a logistic fisheries selectivity, and a mean of SB/SB_{MSY} of 2 when combining steepness of 0.9 with natural mortality other than 0.2.

The performance indicator p(Green) for the MSE run for MP5 can be displayed for each of the 5 leaves of the regression tree (figure 5). For this specific MP, the tuning has to bring p(Green) from 0.7 in 2020 to 0.6 for the period 2034 to 2039. This requires that a small proportion of the iterations that are in the green in 2020 move to another part of the Kobe plot by 2034. This is mainly achieved by iterations belonging to the intermediary leaves (leaves 2 and 3) which are the ones for which the distribution of p(Green) changes the most.

Test of a more restricted structural uncertainty grid

OM construction

In an attempt to obtain an OM with less variable stock status, while still accounting for the main sources of structural uncertainty, a new list of assumptions was made (see table 2). The main differences with the reference OM are the values of steepness that were revised, with overall lower values and with a narrower range. Notably, the highest value of 0.9, which led to very high initial SB/SB_{MSY}, was replaced by a maximum value of 0.8. In order to reduce the size of the grid, some factors that had little impact on the initial stock status were no longer included in the grid (selectivity – 2 levels – and CPUE scaling scheme – 3 levels), and the configuration from the base case assessment was used instead.

The alternative grid resulted in 432 combinations, of which 150 were selected by factorial design optimization for running the stock assessment. Ultimately a total of 115 runs were considered acceptable and used as a basis for the alternative OM.

This alternative OM has a narrower range of starting stock status (figure 1), with a median SB/SB_{MSY} of 1.21 and a 90% envelop between 0.78 and 1.96.

Applying the regression tree showed that effective sample size and the choice of the CPUE series are now the main structuring factors for the initial SB/SB_{MSY}. However, the separation achieved with the regression tree now results in much smaller differences between the leaves (mean SB/SB_{MSY} vary from 1.1 to 1.5) and the variability within the leaves is now much larger than between the leaves (in contrast to what was observed for the reference OM).

MSE runs

Despite the reduction of the variability in the OM, there is still a large dispersion of the performance indicator used for tuning the MP, with the interquartile interval of p(Green) still spanning between 0 and 1 for most MP tuned (figure 7). Looking at the example of MP5, the distribution of p(Green) 2024:2039 remains nearly bimodal, as observed with the reference OM (figure 3).

Conclusion and perspective

There is a considerable variability in the swordfish reference OM that originates from the different assumptions made on the structural uncertainty grid. Even by reducing the number of factors included in the grid and making less extreme assumptions about the steepness of the recruitment model, the variability remains large.
This poses a challenge when tuning the MPs in the MSE. Although the tuning objectives are achieved in terms of mean p(Green), iteration specific values of p(Green) is for the majority of the iterations very different from the mean we are aiming at (most are either 0 or 1).

In addition to the variability in the OM, this issued by also be related to a combination of the factors :

- starting conditions p(Green) = 0.7 are not far from any of the tuning objectives (0.5, 0.6 or 0.7). This means that the MP does not need cause any major change in the stock status to achieve tuning objective.
- Indicator use for tuning is a probability calculated on a limited number of years. If interannual variability in the stock is low (this is a quite long-lived species), and if the MP does not result in any substantial trend, most iteration should remain in the same quadrant of the Kobe plot over the relatively short tuning period (2034 to 2039), resulting in a majority of 0 or 1 p(Green) values.

The initial concern that lead to testing a narrower OM grid does not appear to be really a problem, but a feature of the way the indicator is computed. But the smaller grid gives rise to an OM that does not differ greatly in its dynamics from the original one. The factors and levels that have been eliminated do not alter greatly the model dynamics. A smaller proportion of the runs fail the selection criteria, so the effective size of the grid is in fact larger. We would therefore propose adopting this new model grid for further analysis.

Table 1 : 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 2 : Proposal for a new OM structural uncertainty grid (difference highlighted in bold)

Variable	Values		
Selectivity	Double Normal		
Steepness	0.6	0.7	0.8
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			Biomass
CPUEs	JPN late + EU.PRT	JPN late	TWN + EU.PRT
Catchability increase	0%	1% / year	

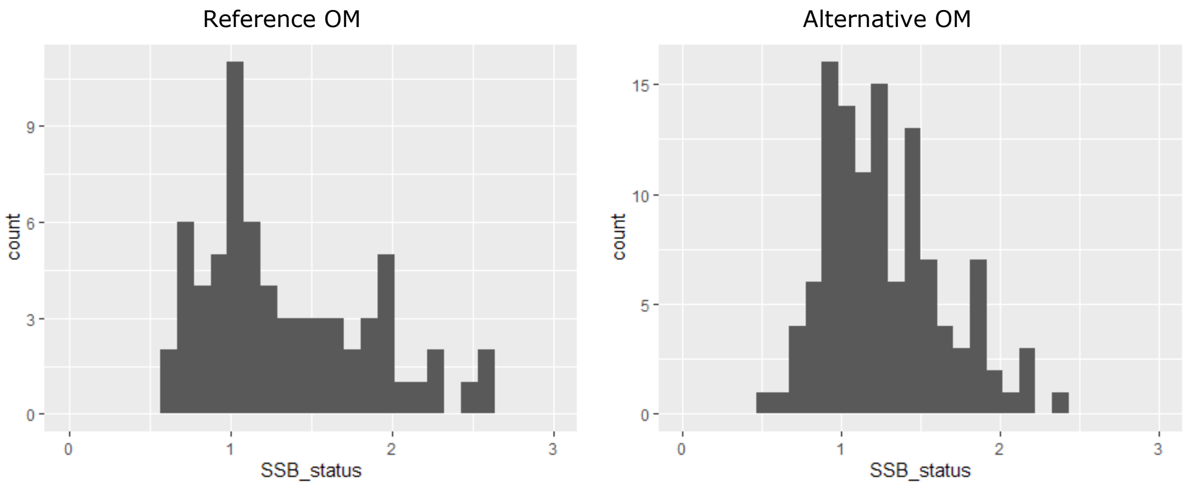

Figure 1 : distribution of the stock status (SB/SB_{MSY}) in the terminal assessment year (2018) for the reference and alternative OMs.

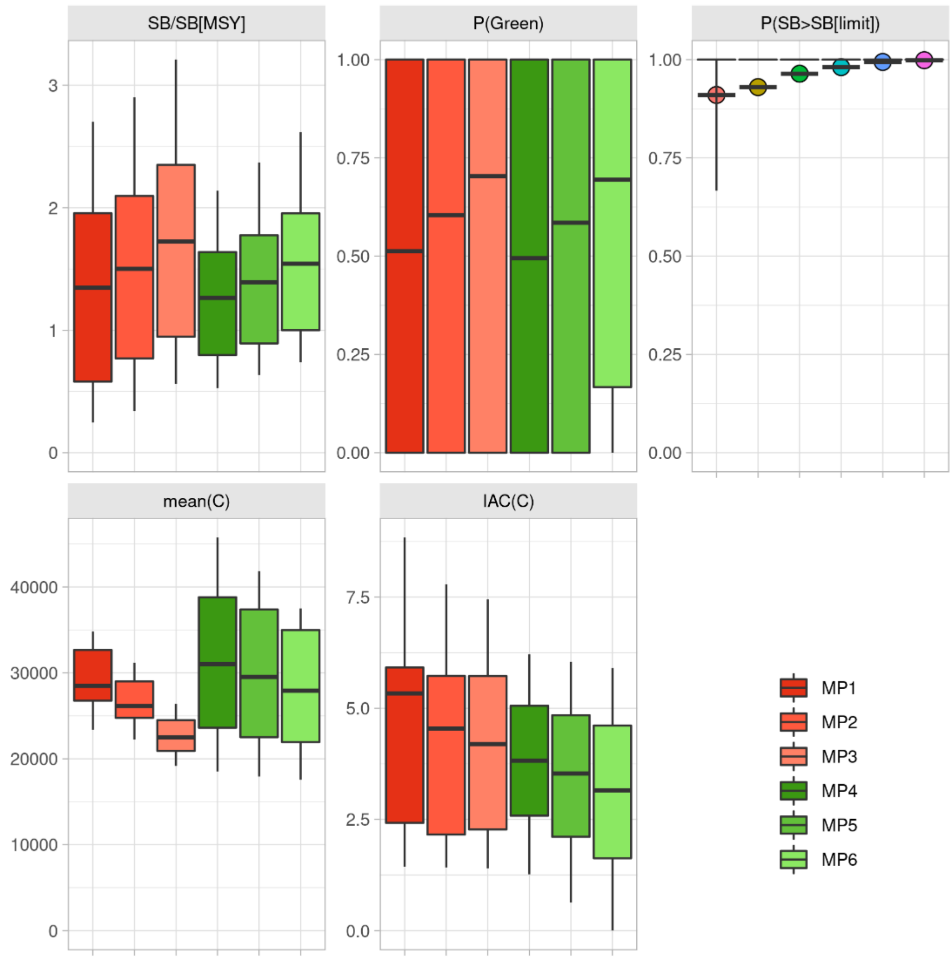

Figure 2. Boxplots comparing candidate MPs run with the reference OM with respect to key performance measures averaged over the period 2034-2039. Horizontal line is the mean, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. The data based MPs are depicted in red and model-based MPs are depicted in Green

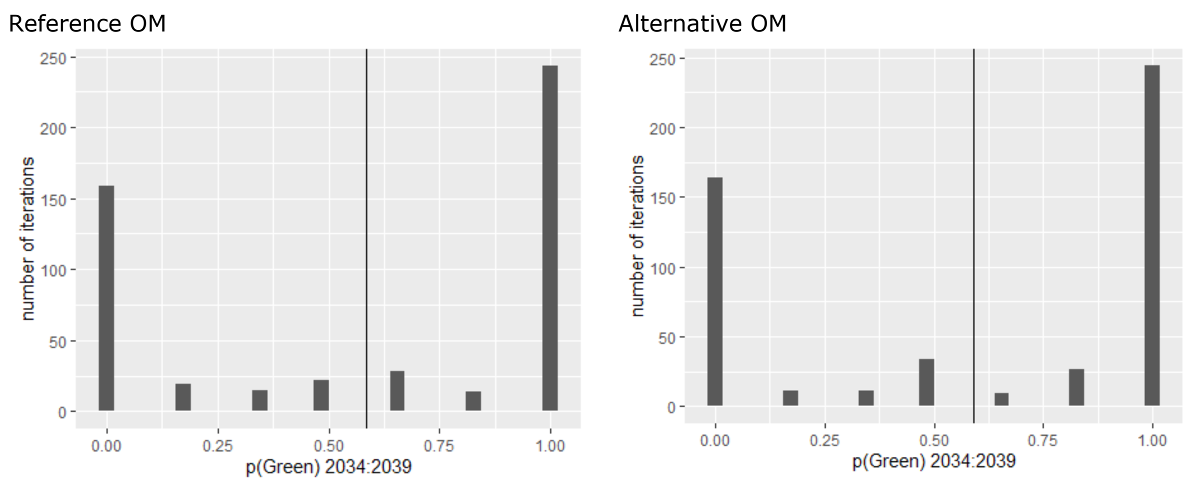

Figure 3 : distribution of the iteration specific p(Green) 2034:2039 values for the MP5 with the reference and alternative OM (vertical bar depicts the mean).

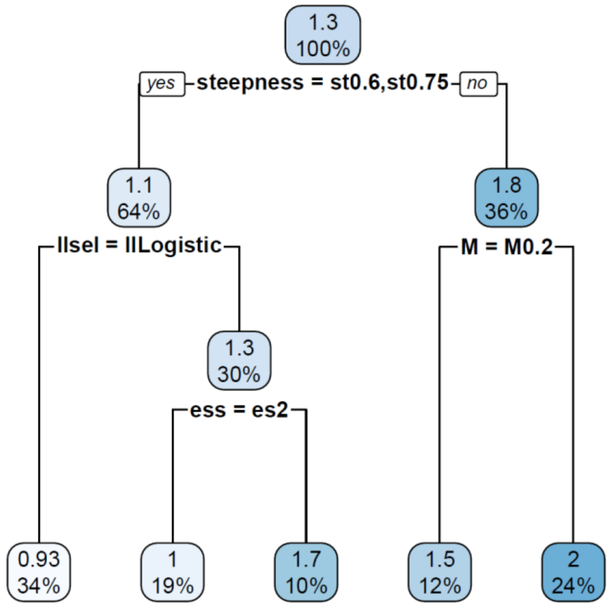

Figure 4 : regression tree for the stock status (SSB/SSBMSY) in the terminal assessment year as a function of the factors used to construct the structural uncertainty grid for the reference swordfish OM.

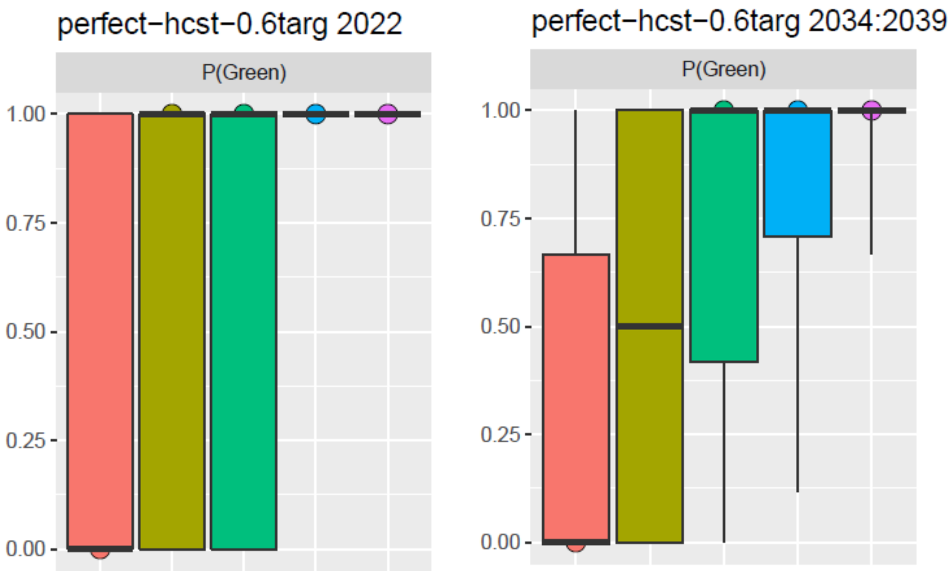

Figure 5: Boxplot of the probability of being in the green part of the Kobe plot at the start of the simulation (2022, left) and for the period used for tunning (2034 to 2039, right) for the model-based MP tunned for a 60% probability of being in the green part of the Kobe plot. The different colors correspond to the subparts of the OM resulting from the regression tree shown on figure 4.

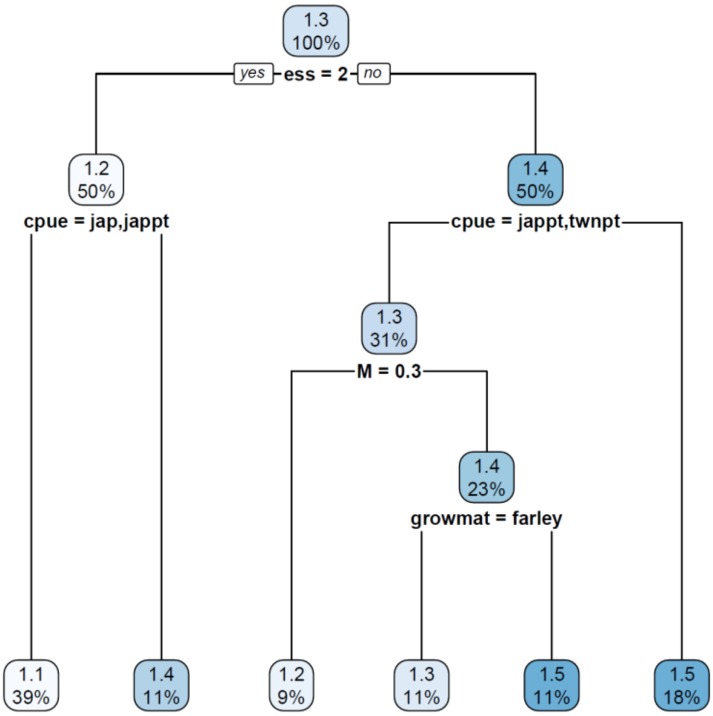

Figure 6 : regression tree for the stock status (SSB/SSBMSY) in the terminal assessment year as a function of the factors used to construct the structural uncertainty grid for the alternative swordfish OM.

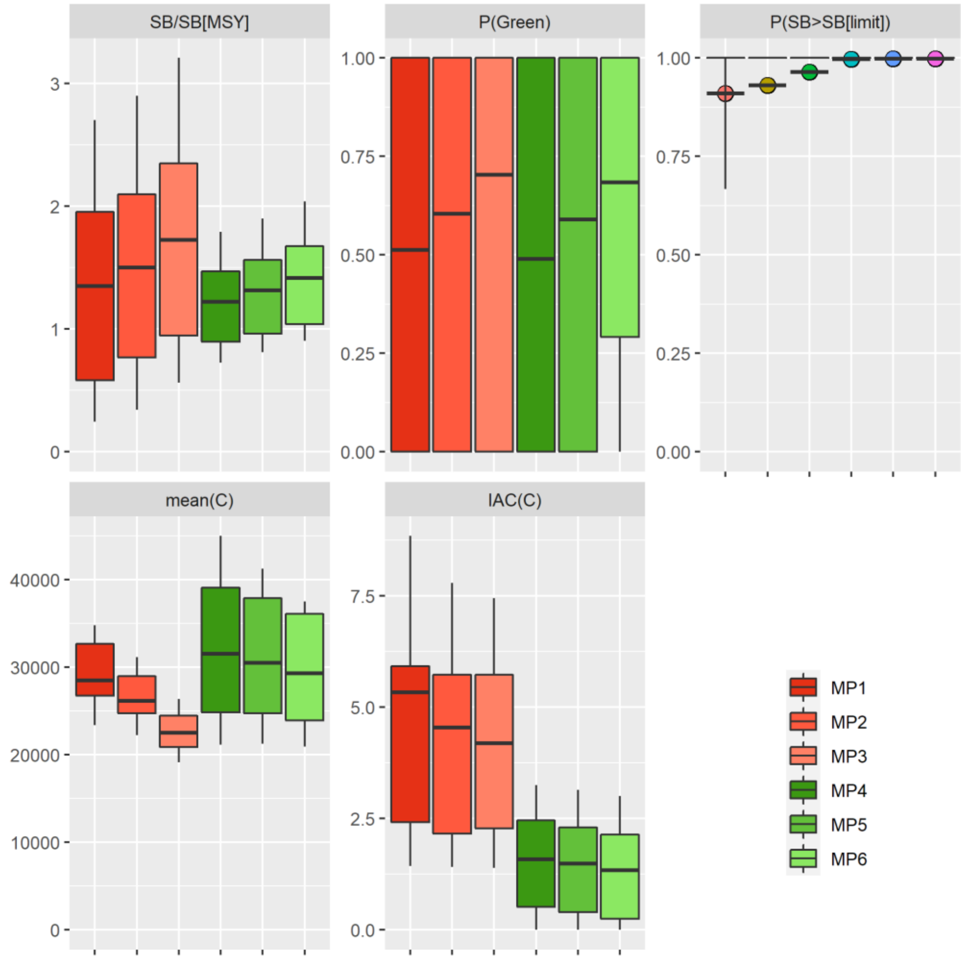

Figure 7. Boxplots comparing candidate MPs run with the alternative OM with respect to key performance measures averaged over the period 2034-2039. Horizontal line is the mean, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. The data based MPs are depicted in red and model-based MPs are depicted in Green