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POTENTIAL MANAGEMENT PROCEDURES FOR NORTH ATLANTIC SWORDFISH

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SUMMARY

This document summarises alternative management strategies that can be simulation tested using Management Strategy Evaluation (MSE), and potentially be used for the management of North Atlantic Swordfish. Alternative management strategies are specified in the form of an MP, which are the combination of pre-defined data, together with an algorithm to which such data are input to provide a value for a TAC or effort control measure. The intention is to demonstrate, through simulation trials, to show robust performance in the presence of uncertainties.

RÉSUMÉ

Le présent document récapitule des stratégies de gestion alternatives qui peuvent être testées par simulation à l'aide d'une évaluation de la stratégie de gestion (MSE) et potentiellement utilisées pour la gestion de l'espadon de l'Atlantique Nord. Des stratégies de gestion alternatives sont spécifiées sous la forme d'une procédure de gestion (MP), c.-à-d. la combinaison de données prédéfinies conjointement avec un algorithme auquel les données sont saisies pour fournir une valeur pour un TAC ou une mesure du contrôle de l'effort. Le but consiste à montrer, par le biais d'essais de simulation, des performances robustes en présence d'incertitudes.

RESUMEN

Este documento resume estrategias de ordenación alternativas que pueden probarse por simulación utilizando la evaluación de estrategias de ordenación (MSE) y ser potencialmente utilizadas para la ordenación del pez espada del Atlántico norte. Se especifican estrategias de ordenación alternativas en forma de MP, que son la combinación de datos predefinidos, con un algoritmo al que se asignan los datos para proporcionar un valor para un TAC o una medida de control del esfuerzo. La intención es demostrar, mediante pruebas de simulación, el funcionamiento robusto en presencia de incertidumbres.

KEYWORDS

Atlantic, Swordfish, MSE, Management Procedures

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Relevant Sections of the Agreed Work Plan

Del 3. Summary of alternative Management Procedures; including alternative stock estimation procedures with coding requirements and appropriate code, libraries and packages. For example, there are a variety of stock assessment methods already tested as management procedure, North Atlantic albacore (Kell, *et al.,* 2017), swordfish (Kell *et al.*, 2012), and bluefin (Kell *et al.*, 2015). These may need modification to be used within a common MSE framework or adapted to use North Atlantic swordfish data and stock assessment assumptions.

Deliverable 3 is related to all 6 Milestones in the work plan: and it is proposed by:

- Sept 1 – propose a set of MPs for discussion, this document.

- *Sept 14* – add initial code to github and update the SCRS paper on MP following response from the Swordfish Working Group.

- *26-27 September* – present report on progress regarding evaluation of alternative MPs to the Swordfish WG.

Introduction

This document summarises alternative Management Procedures (MPs) that will be simulation tested using Management Strategy Evaluation (MSE), that potentially could be used for the management of North Atlantic Swordfish (SWON). Initially, focus will be on evaluating MPs that have been tested by the tuna RFMOs (see Bentley *et al*., 2015, Hillary *et al*., 2015, Kell, *et al.,* 2012, 2015a, and 2017).

Alternative management strategies are specified in the form of an MP, which are the combination of pre-defined data, together with an algorithm to which such data are input to provide a value for a TAC or effort control measure. The intention is to demonstrate, through simulation trials, to show robust performance in the presence of uncertainties (Rademeyer, 2017).

There is a general requirement of MSE in that it is necessary to simplify MPs in order to evaluate them quantitatively, for instance the simulated stock assessment method that forms part of the management procedure is much less complex than the real-world stock assessment upon which the operating model is commonly based. There are two main types of MP, namely:

> ***Empirical:*** An MP where resource-monitoring data (such as survey estimates of abundance) are input directly into a formula that generates a control measure such as a TAC without an intermediate (typically population-model based) estimator; and
>
> ***Model-based:*** An MP where the process used to generate a control measure such as a TAC.

There are multiple examples of both types in management strategies adopted in various fisheries worldwide. It has been suggested (see Punt 2018) that there is little difference between model-based and empirical MPs in terms of performance. Model-based ones are attractive because they may be linked to the stock assessment results and generally have a greater capacity to "learn" about stock productivity. In most cases the model used as part of the HCR is a much simpler version of the one used for actual assessments or it might be a very different type model for stock assessment altogether. Alternatively, HRCs may be based on empirical indicators that are thought to follow trends in stock status (or other variables of interest) reliably, and which may have an advantage of being more easily understood by managers and stakeholders, while using the more complex model-based MPs does not necessarily ensure a more robust management (ISSF, 2003).

Material and Methods

To build on the experience gained under the Kobe Process, and to facilitate collaboration across the MSEs being developed within ICCAT and the other tRFMOs, the first trials will involve variants of MPs that have already been tested by the tRFMOs, namely:

1. ***North Atlantic albacore:*** a model based MP based on a biomass dynamic stock assessment with a hockey stick HCR[2].

2. ***CCSBT:*** a MP comprising two empirical HCRs which were then "averaged" together to set the TAC, one used an adult CPUE series and trends in the index and the other used both adult and juvenile indices and compared current status to status in a reference period[3].

3. ***IOTC skipjack:*** an empirical MP[4].

Code with documentation will be placed on the Github repository by September 14th with initial results by the end of September.

Model based MPs

The first model based MP to be evaluated by ICCAT (Kell *et al*., 2012) was based on a biomass dynamic model (Kell *et al*., 2017a) and a hockey stick harvest control rule (Kell *et al.*, 2017b). The first example was applied to North Atlantic swordfish as an example of an MP while the second was evaluated at the request of the Commission. In both case the biomass dynamic model had previously been used by the SCRS to perform the stock assessment and provides estimates of stock status relative to Maximum Sustainable Yield (MSY) based reference points.

The HCR was used limit and target reference points to set a total allowable catch (TAC) based on Commission recommendation (Rec-15-04) namely:

- If the average spawning stock biomass (SSB) level is less than SSB_{lim} ($SSB<SSB_{lim}$), the Commission shall adopt severe management actions immediately to reduce the fishing mortality rate, including measures that suspend the fishery and initiate a scientific monitoring quota to be able to evaluate stock status. This scientific monitoring quota shall be set at the lowest possible level to be effective. The Commission shall not consider reopening the fishery until the average SSB level exceeds SSB_{lim} with a high probability. Further, before reopening the fishery, the Commission shall develop a rebuilding program in order to ensure that the stock returns to the green zone of the Kobe plot. The green zone is where fishing mortality below the exploitation level that leads to long-term maximum sustainable yield (MSY) and spawning stock biomass is above SSB at MSY.
- If the average SSB level is equal to or less than $SSB_{threshold}$ and equal to or above SSB_{lim} ($SSB_{lim} \leq SSB \leq SSB_{threshold}$) and F is above the level specified in the HCR, the Commission shall take steps to reduce F as specified in the HCR to ensure F is at a level that will rebuild SSB to SSB_{MSY} or above that level.
- If the average SSB is above $SSB_{threshold}$ but F exceeds F_{target} ($SSB>SSB_{threshold}$ and $F>F_{target}$), the Commission shall immediately take steps to reduce F to F_{target}
- Once the average SSB level reaches or exceeds $SSB_{threshold}$ and F is less or equal than F_{target} ($SSB> SSB_{threshold}$ and $F\leq F_{target}$), the Commission shall assure that applied management measures will maintain F at or below F_{target}.

The task of the SCRS is to translate the estimates of stock status and reference points from the stock assessment into limits thresholds and targets, then to use these to set a TAC that allow the objectives of the Commission to be met. The point of using MSE is that it allows the impact of uncertainty on scientific framework to be evaluated and for robust values for the limits thresholds to be made.

For the model based MP, the MP developed for North Atlantic albacore will be used, as this has already been through an SCRS review process, has been accepted by the Commission and is currently undergoing external peer review.

[2] Details in SCRS/2016/025 and SCRS/2016/026.
[3] For further information, consult https://onlinelibrary.wiley.com/doi/abs/10.1111/faf.12121 ;
and https://www.iccat.int/Documents/CVSP/CV071_2015/n_6/CV071062790.pdf for an example.
[4] Documented on https://github.com/iotcwpm/SKJ/blob/master/reports/procedures/stencil.cila and reports are at https://github.com/iotcwpm/SKJ/blob/master/README.md

The default ICCAT HCR is a hockey stick (**Figure 1**) where for any biomass a corresponding fishing mortality is given, which is then used to derive a TAC. The hockey stick is defined by two points, the target fishing mortality (F_{target}) and a threshold ($B_{threshold}$) that cause management action to be triggered if it is breached. Above $B_{threshold}$ F_{target} defines a target level of fishing mortality that management seeks to achieve, below $B_{threshold}$ F declines linearly to the limit biomass B_{lim}.

The reference points and stock status will be estimated by the biomass dynamic stock assessment. Conducting an assessment requires choices to be made for parameters that are difficult to estimate form fisheries dependent data alone, for example in an age based assessment natural mortality and the steepness of the stock recruitment relationship. The importance of these parameters are that they determine the productivity of the stock as they dictate the level of productivity, the shape of the production function, and reference points such as F_{MSY}5, B_{MSY}6, and FCrash7.

In a biomass dynamic stock assessment model the production function is modelled explicitly, e.g. in the case of the Pella-Tomlinson (Pella and Tomlinson, 1969) production function which is a function with three parameters i.e.

$$\frac{r}{p}(B(1-(\frac{B}{K})^{p})$$

Where B is the current biomass and r is population growth rate at small population sizes, K the carrying capacity or virgin biomass and the shape parameter (p).

The dynamics i.e. productivity, the response of the stock to perturbations, and reference points are determined largely by r and the shape of the production function; if p=1 then MSY is found halfway between 0 and K, as p decreases then B_{MSY} shifts to the left and consequently the value of B_{lim} where productivity compromised is reduced.

The choice of these parameters is critical, for if they are misspecified then the productivity of the stock and the target and limit reference points will be biased. Even in a simple model such as one based on biomass dynamics there is often sufficient information in the data to estimate the parameters of the production function and so values have to be fixed or priors used to help estimate them. In a stock assessment most of the effort of a WG is to spent on finding plausible choices for parameters such as r, K and p (e.g. Arrizabalaga, et al., 2018), and then exploring goodness of fit diagnostics (SEDAR, 2015). In MSE it is not possible to replicate this process, therefore we will conduct a cross test (Deroba, *et al*., 2014) where the OM will be used to simulate data for the assessment model and the robustness of choices for the different stock assessment model choices evaluated.

Empirical MPs

Empirical MPs follow trends or changes in indices of abundance and translate these into TACs. There are two main ways to do this, namely use the rate of change in an idex (i.e. D the derivative) or the difference between the current index value and a reference point or reference period (i.e. P the proportional difference), see Pomarede *et al*., 2010 and Rivera *et al*., (1986).

CCSBT

The first MP to be adopted was that of CCSBT. Initially the intention of the CCSBT scientific committee was to run a competition to compare two alternative empirical MPs using MSE and then to select the best performing one. However, the MP actually implemented combined the two MPs and sets a TAC that is the average of the values obtained from each.

The first MP used a single index for relative stock abundance and then increased or decreased the TAC if the index was increasing or decreasing respectively. The second MP was based on indices of adult biomass and recruits which were compared to reference levels.

See supplementary material for the specification of the MPs.

[5] The fishing mortality or harvest rate that would support the maximum sustainable yield
[6] The biomass or SSB that would support the maximum sustainable yield
[7] A reference point corresponding to the level of fishing mortality that would drive the stock to extinction, estimated from where the SSB per recruit vs. F curve crosses the x-axis on the righthand side.

The MP that was adopted was tuned, i.e. to find the values of the hyperparameter that best met management objectives. A hyperparameter is a configuration that is external to a model and whose value cannot be estimated from data, instead it needs to be specified and then tuned for a given problem (Bergstra and Bengio, 2012).

It is not possible to run an MP straight out of the box as tuning needs to be done. Tuning is a potentially complex procedure and requires many choices about the resource and its management to be made. The intention therefore is not to run the CCSBT MP but to compare the properties of the two types of MPs, i.e. that based on trends and value relative to a reference value.

iRate

The iRate[8] MP used by IOTC is another version of an empirical MP and has been simulation tested for albacore and skipjack. In this procedure, TACs are determined by trends in an index of relative abundance to reference values set from a period in the past (Bentley and Adam 2015). It is therefore similar to the 1st of the two CCSBT MPs. In addition, it includes smoothing of the index may be advantageous in that it reduces the influence of annual random variation in CPUE due catchability or operational variations. However, smoothing also reduces adds a lag to the index. iRate will therefore allow the benefit of smoothing to be evaluated.

Candidate Management Procedures

The candidate MPs will be coded up and illustrative examples run to allow a comparison of their performance and to obtain feedback from stakeholders.

For the empirical MPs (iRate, and the two MPs based on CCSBT) the default hyperparameters (i.e. tunable parameters) will be used.

The input time series of abundance will be an unbiased index of relative abundance, this is because it is easier to check the procedures and algorithms and understand the behaviour of of such complex models when setting them up in this way. Once model misspecifications are included it is difficult if not impossible to validate them. See OM paper for specification of the OM and OEM.

Implementation

The MPs are implemented in R and can be installed from https://github.com/ICCAT/swonmse, whereas examples are provided at
https://github.com/iccat/swonmse/wiki/Management-Procedures.

The examples will be posted on the github in the form of reproducible documents developed in Rmarkdown.

Results

Some example results are presented for three MPs, namely for M: the biomass dynamic MP with Hockey Stick HCR, P: empirical HCR based on trend in CPUE, and D: Empirical HCR based on relative difference in CPUE.

Figure 2 and **Figure 3** compare the estimates of biomass and fishing mortality from the MP to the OM for absolute values and relative to MSY based reference points for data from 1980 and a biomass index. Similar comparisons are made in **Figures 4** and **5** and **Figures 6** and **7** and **Figures 8** and **9** for exploited biomass, mature biomass and juvenile biomass index. The results are then summarised in the form of a Kobe phase plot in **Figure 10**.

The Time Series of SSB, F and Yield relative to MSY reference points are summarised in **Figure 11** to show the relative impact of the OM scenario and choice of random number stream for recruitment and index deviates. The colours correspond to OM scenario, solid lines shows two OM scenarios with the same random stream and the dashed line a simulation with a different random number stream.

Next the results from the biomass dynamic MP with Hockey Stick HCR (M), empirical HCR based on trend in CPUE (P), and Empirical HCR based on relative difference in CPUE (D) are presented.

[8] See https://github.com/iotcwpm/ALB/blob/master/documents/reports/WPM07_2016-SEZ/IOTC-2016-WPM07-08.pdf

In the biomass dynamic MP with Hockey Stick HCR (M), columns correspond to the F_{target} multiplier; **Figure 12** shows SSB relative to B_{MSY} , **Figure 13** Fishing mortality relative to F_{MSY} , **Figure 14** Yield relative to MSY, **Figure 15** Recruitment relative to virgin level

For the empirical HCR based on trend in CPUE (P), rows correspond to gain term for increasing and columns to decreasing trends. **Figure 16** SSB relative to B_{MSY} , showing median, interquartiles and 95% Cis, **Figure 17** Fishing mortality relative to F_{MSY} , showing median, interquartiles and 95% Cis, **Figure 18** Yield relative to MSY , showing median, interquartiles and 95% CI, and **Figure 19** Recruitment relative to virgin level, showing median, interquartiles and 95% CIs.

Finally results for the empirical HCR based on relative difference in CPUE (D) are presented, rows correspond to gain term for increase and columns to decrease CPUE relative to reference level. **Figure 20** SSB relative to B_{MSY} , **Figure 21** Fishing mortality relative to F_{MSY} , **Figure 22** Yield relative to MSY , and **Figure 23** the expected recruitment relative to virgin level

Performance Measures are summarised in **Figure 24,** using the 4 types agreed by the tRFMO MSE WG, i.e. saftey, status, yield and variability. For the 3 MPs and the hyperpameters, i.e. the different tuning options for the MPs.

There are actually 6 stats, as some need 2 ways to summarise them,

- safety; the distribution minimum value of predicted recruitment (i.e. for current biomass) relative to virgin biomass
- kobe_year; the distribution of the 1st year when $B>B_{MSY}$ and $F<F_{MSY}$
- kobe_p; once the stock is $B>B_{MSY}$ and $F<F_{MSY}$ what is the P() of it staying there
- yield; mean yield/MSY
- Yield_discounted; mean yield/MSY with a discount rate of 5%
- Yield_aav; average annual variabilty in yield

Discussion and Conclusions

The intention of the paper is to present examples of the type of summary statistics that can be used to compare MPs and so we do not wish to over interpret them.

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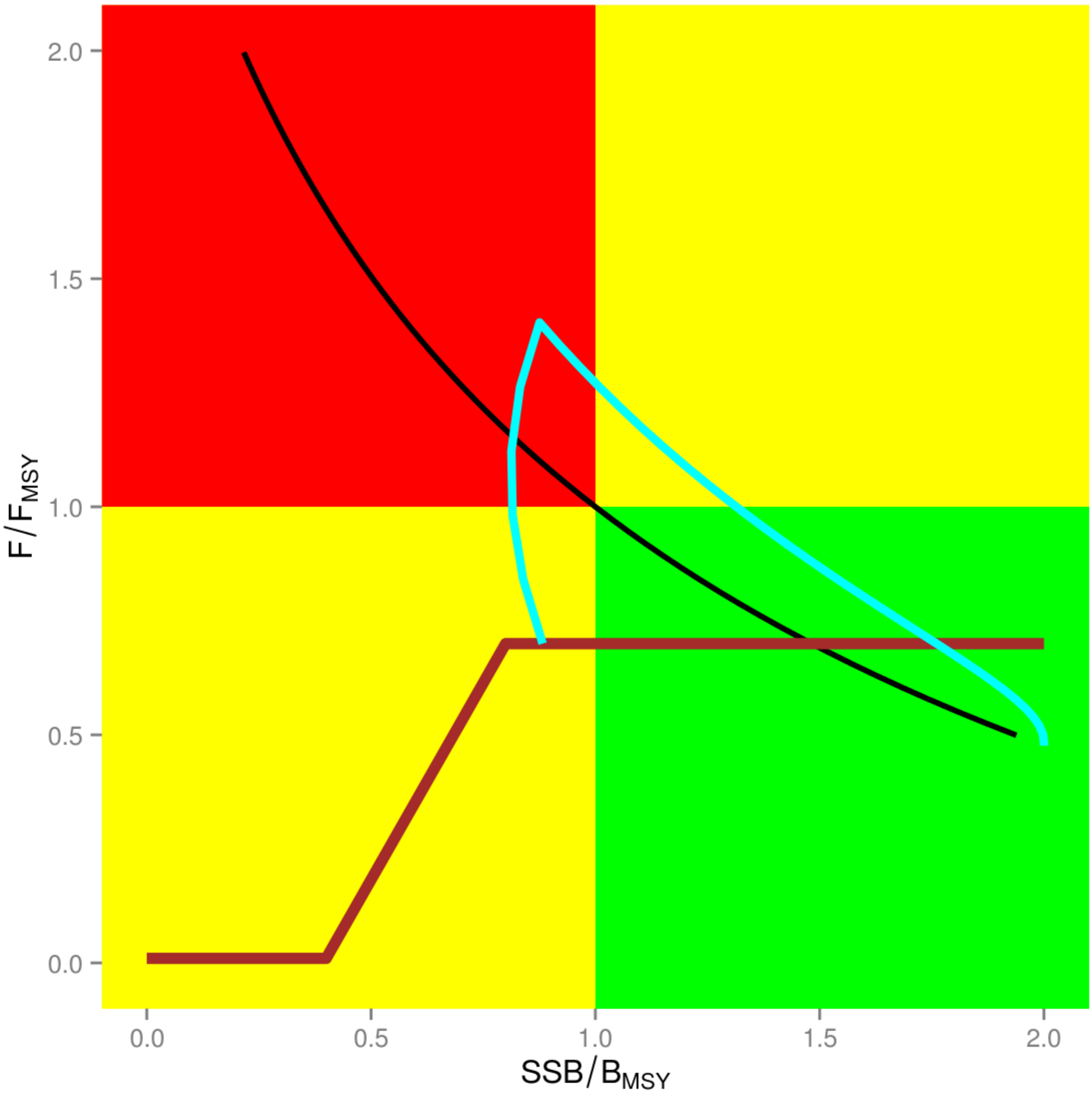

Figure 1. Harvest Control Rule (brown) plotted on a phase plot of harvest rate relative to F_{MSY} and stock biomass relative to B_{MSY}; the light line is the simulated stock and the black line is the replacement line.

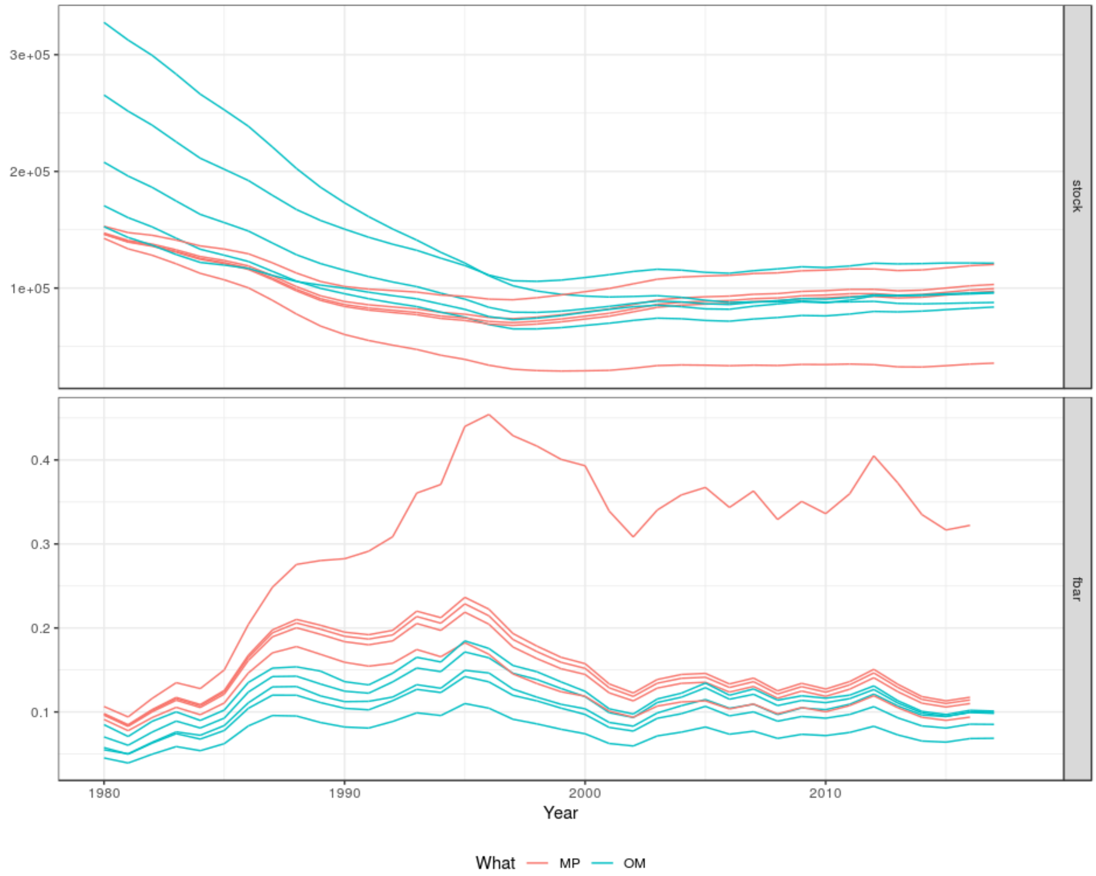

Figure 2. Absolute MP estimates compared to OM using data from 1980 and biomass index.

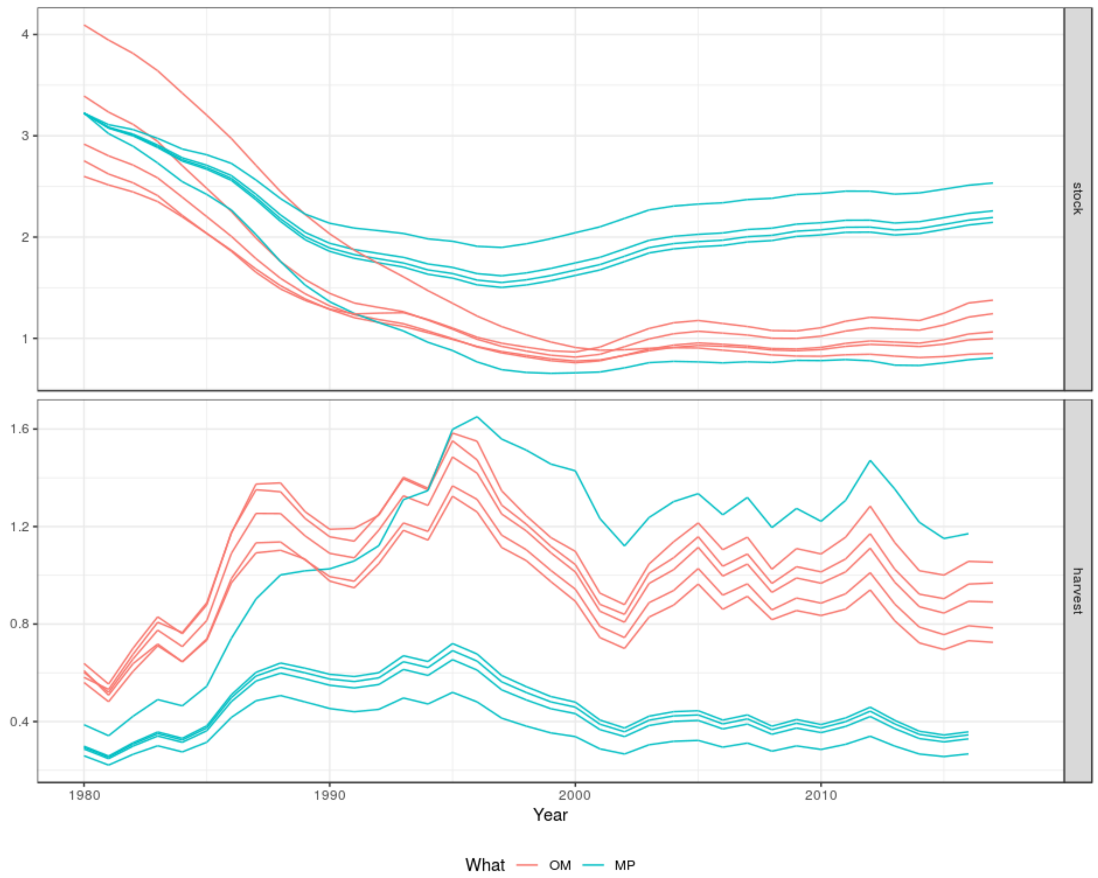

Figure 3. MP estimates relative to MSY based reference points compared to OM using data from 1980 and biomass index.

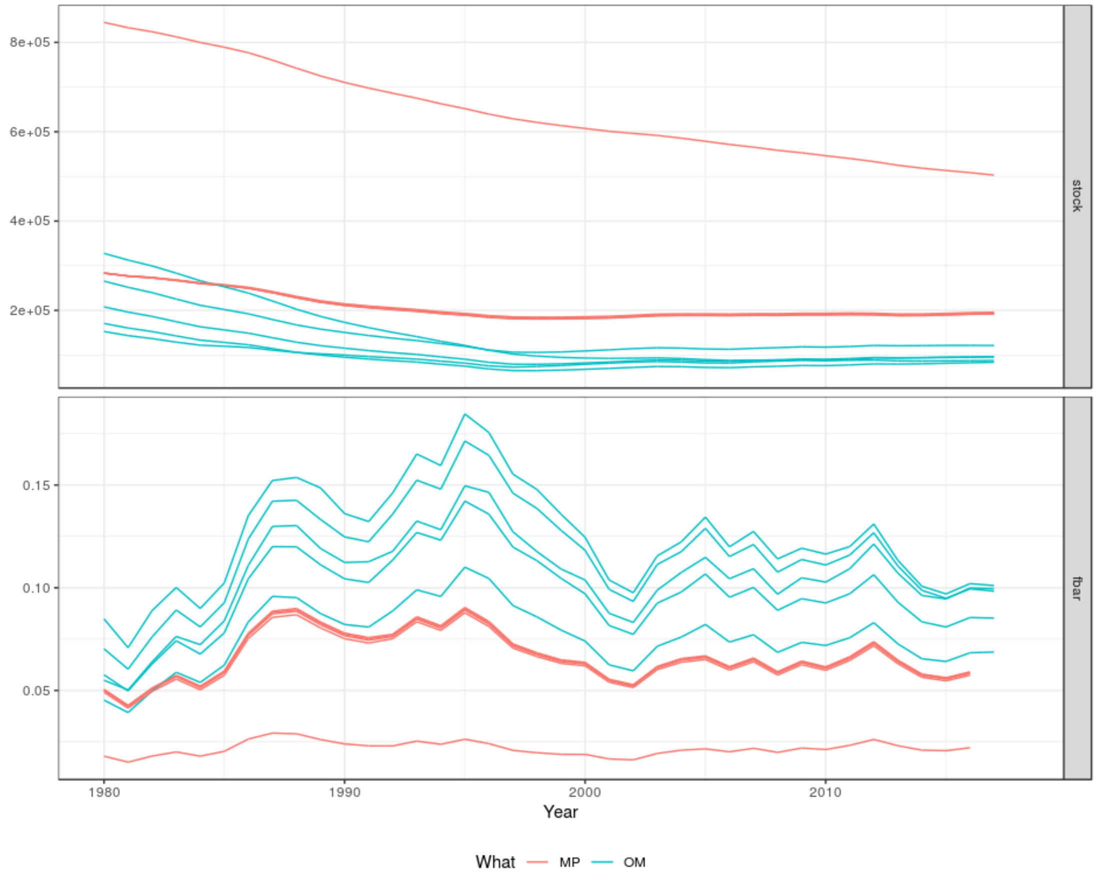

Figure 4. Absolute MP estimates compared to OM using data from 1980 and exploited biomass index.

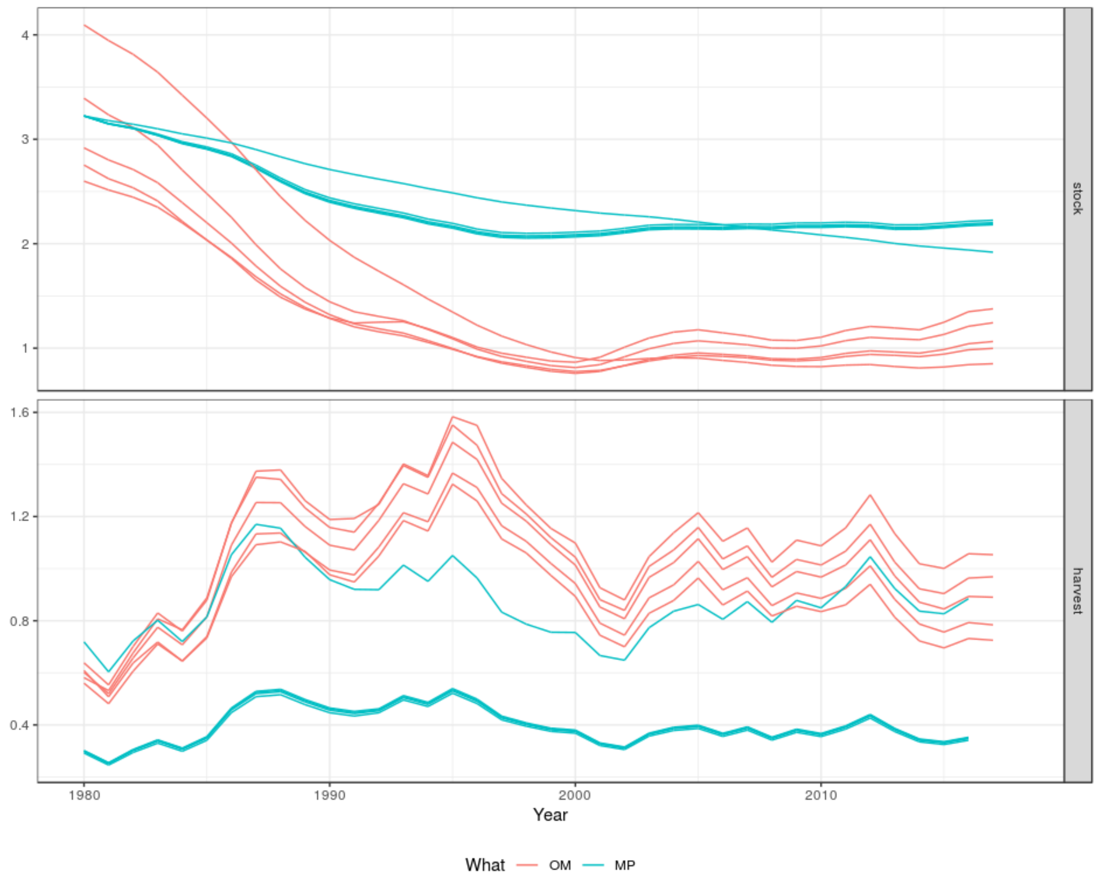

Figure 5. MP estimates relative to MSY reference pointscompared to OM using data from 1980 and exploited biomass index.

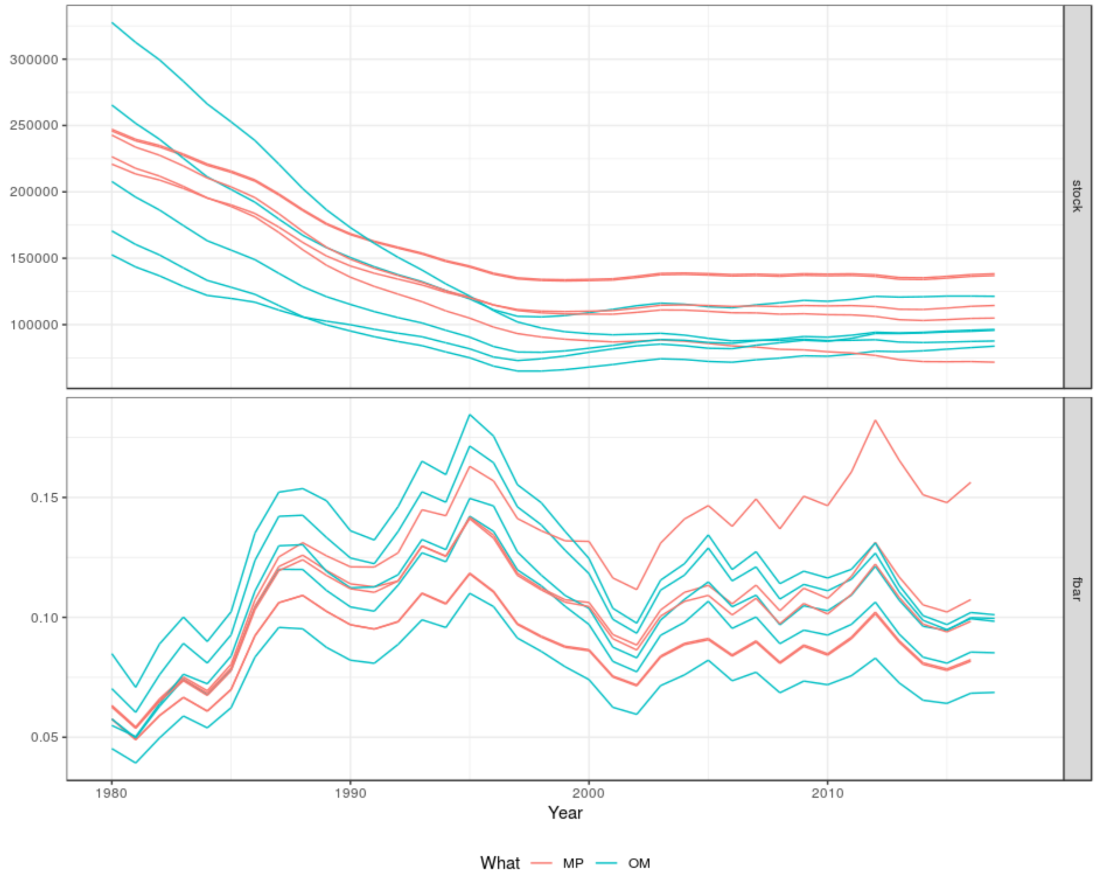

Figure 6. Absolute MP estimates compared to OM using data from 1980 and mature biomass index.

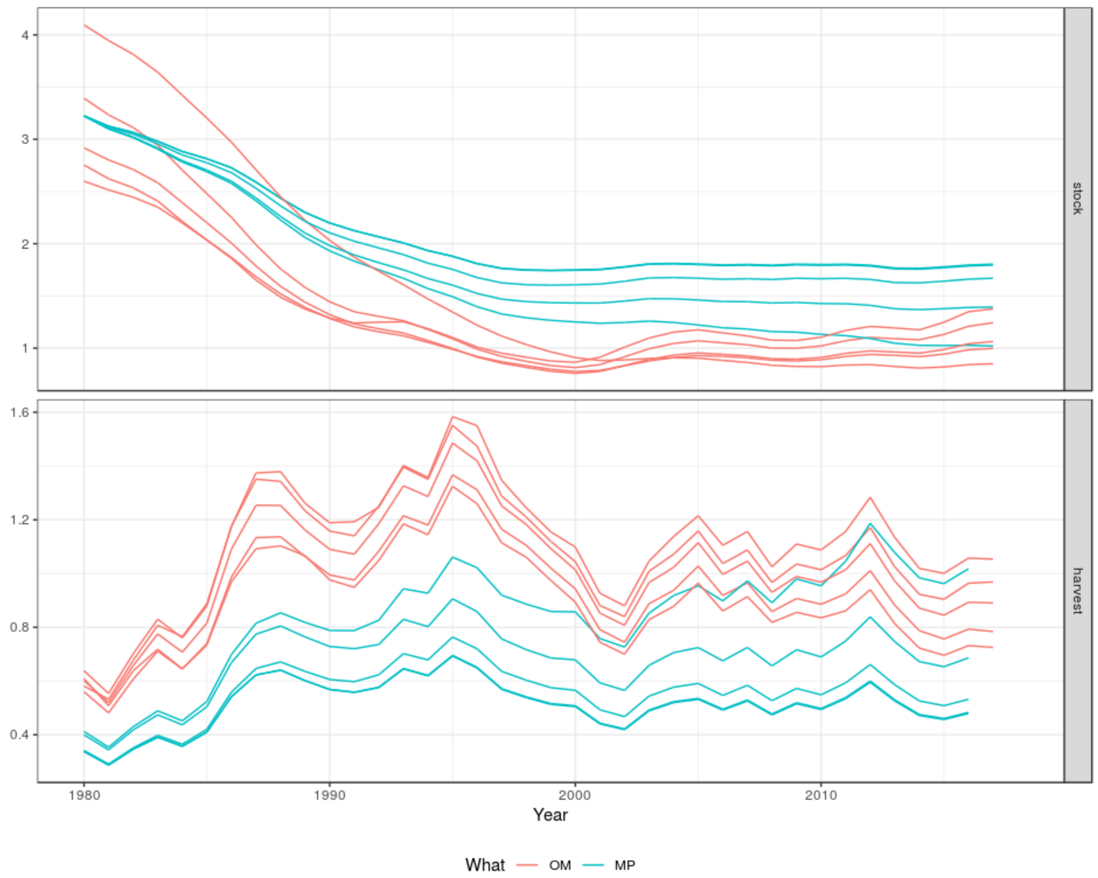

Figure 7. MP estimates relative to MSY based reference points compared to OM using data from 1980 and mature biomass index.

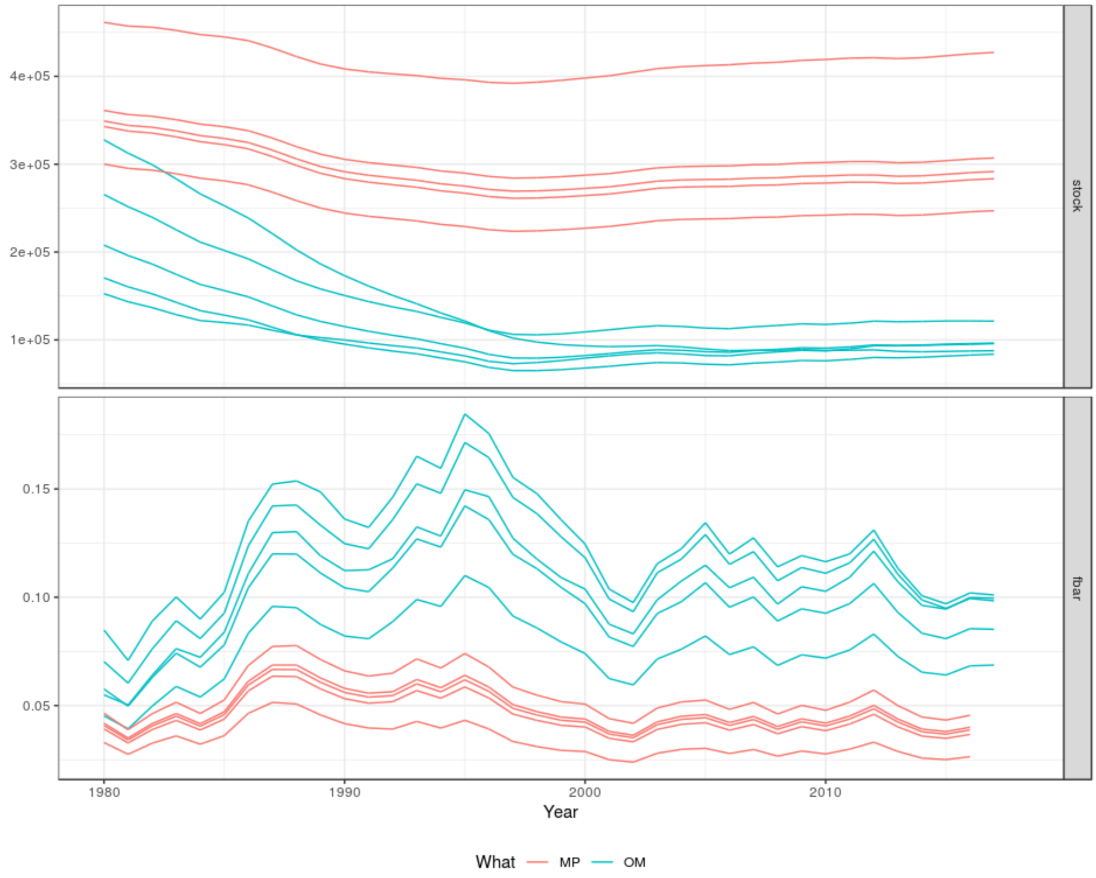

Figure 8. Absolute MP estimates compared to OM using data from 1980 and juvenile biomass index.

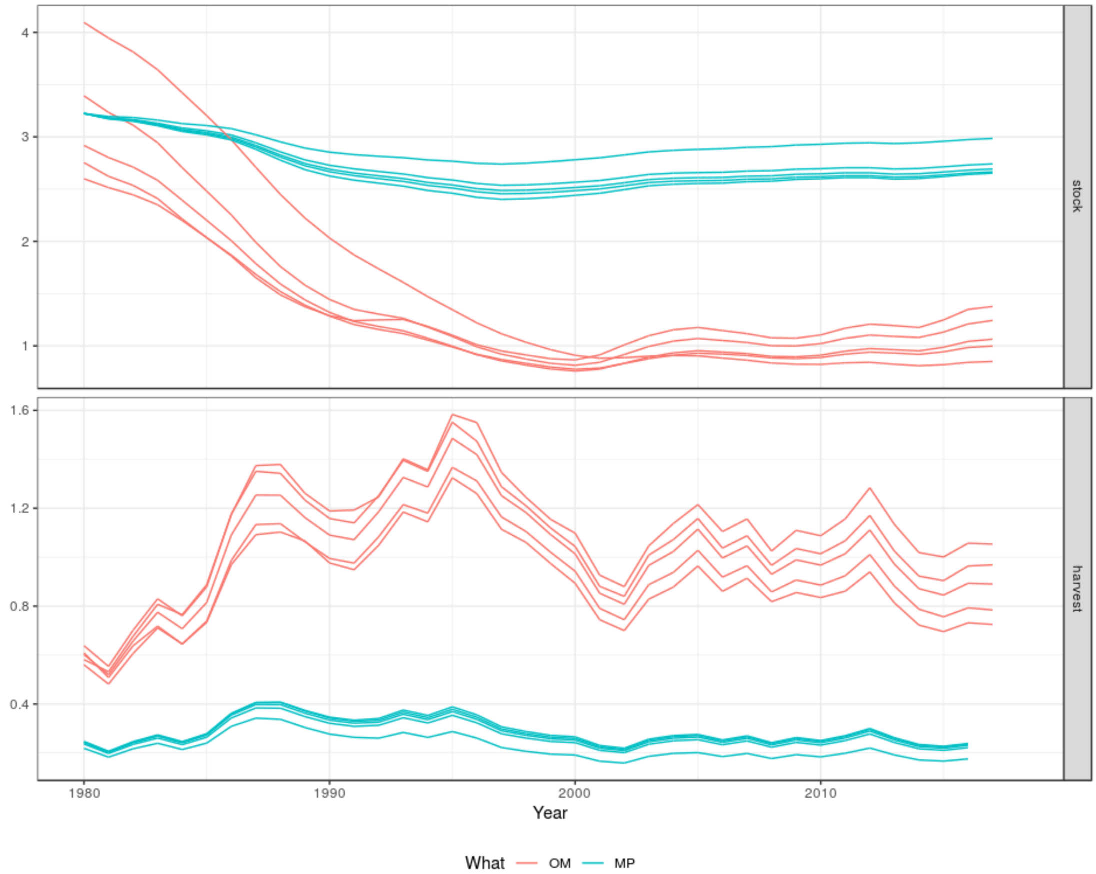

Figure 9. MP estimates relative to MSY based reference points compared to OM using data from 1980 and juvenile biomass index.

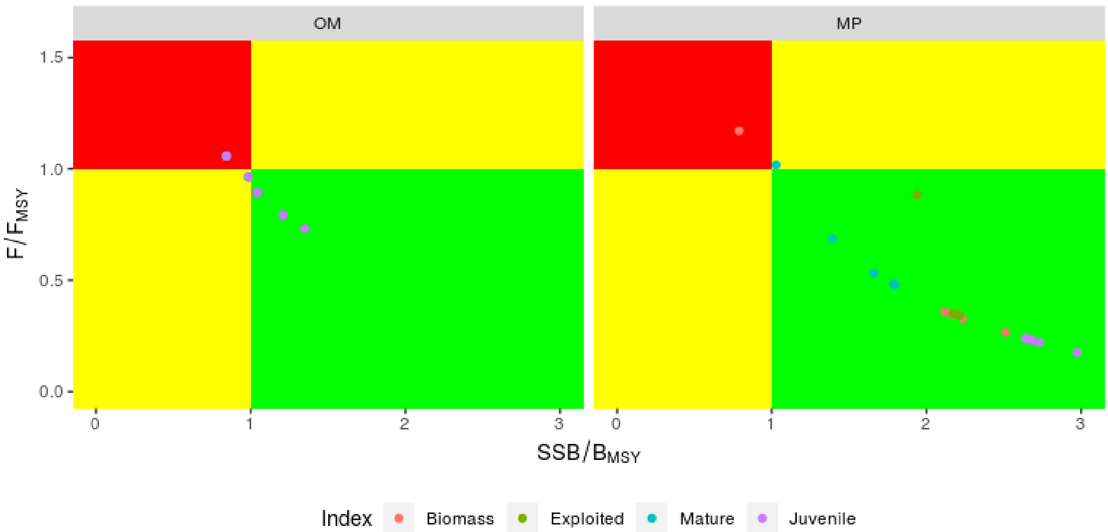

Figure 10. Kobe phase plot.

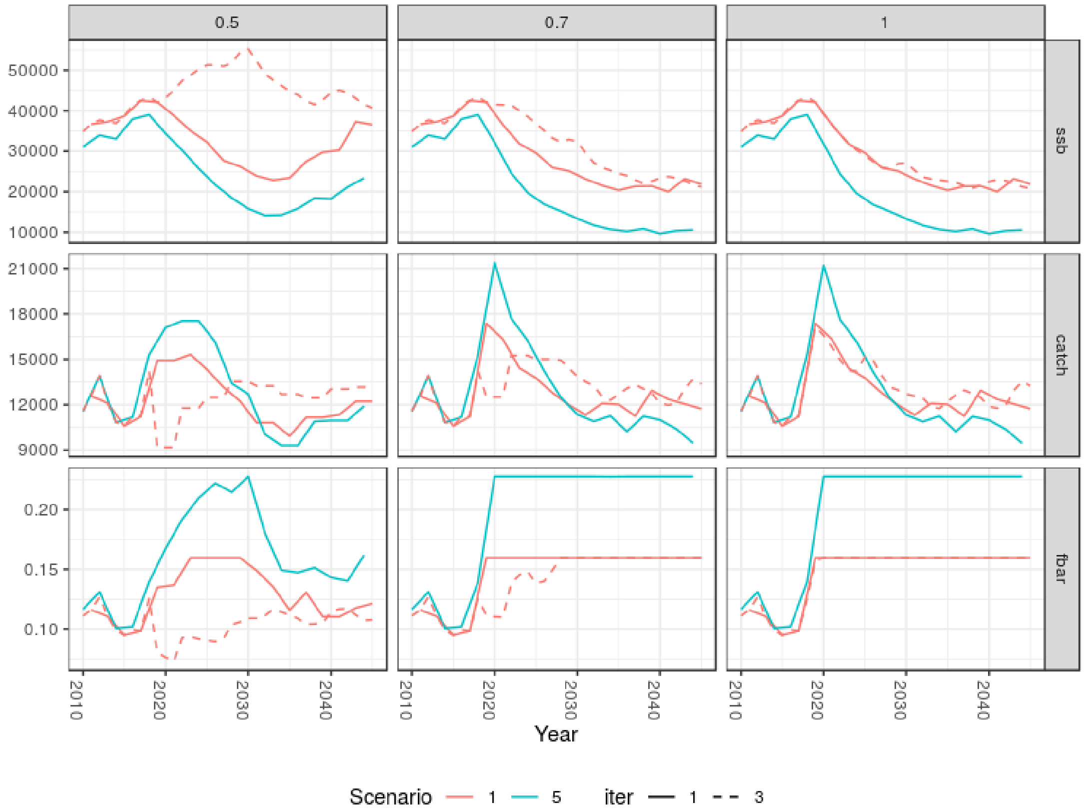

Figure 11. OM or random number stream? Colours correspond to OM scenario, solid lines shows two OM scenarios with the same random stream and the hashed line a simulation with a different random number stream.

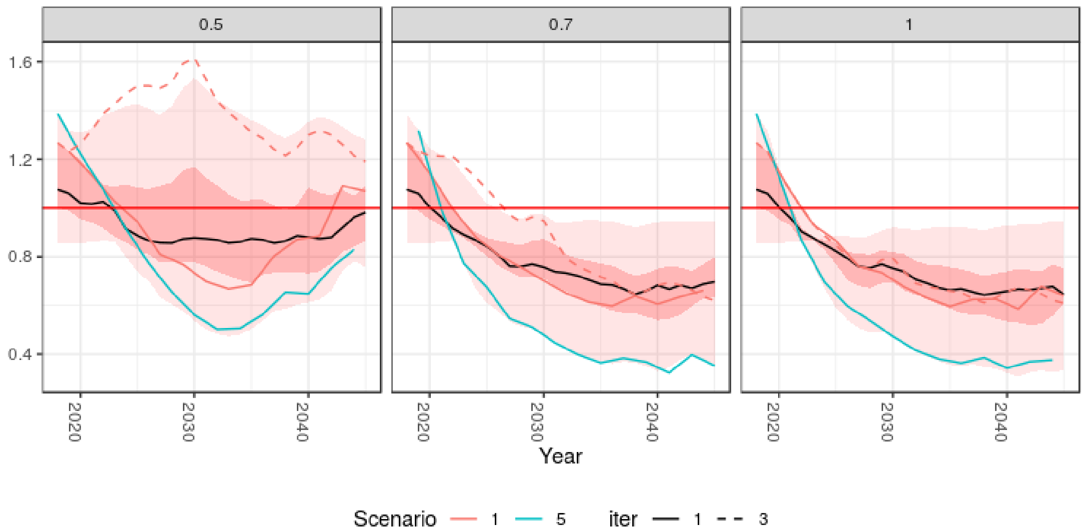

Figure 12. SSB relative to B_{MSY}, showing median, interquartiles and 95% Cis, columns correspond to Ftarget.

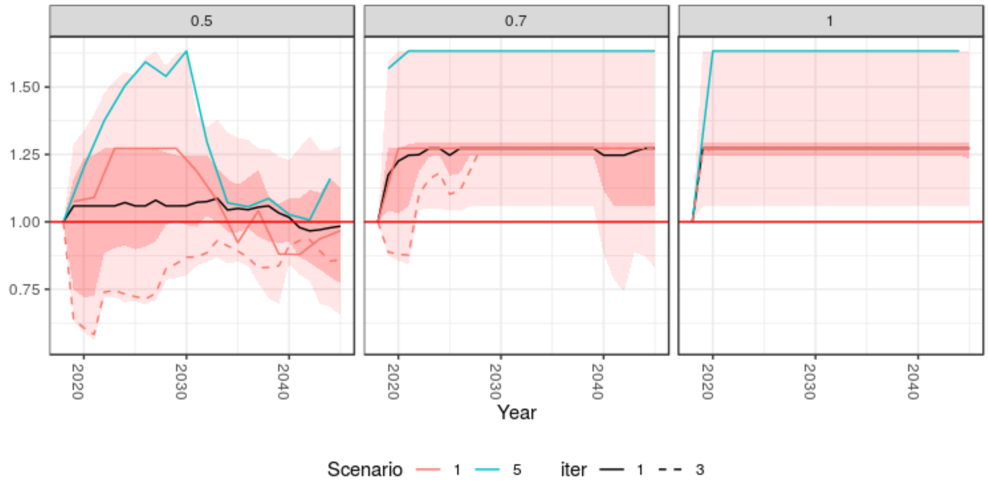

Figure 13. Fishing mortality relative to F_{MSY}, showing median, interquartiles and 95% CIs.

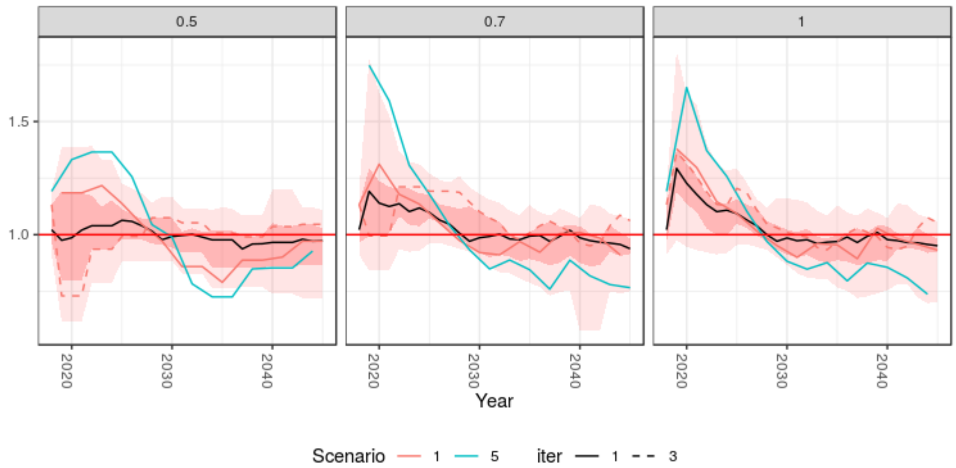

Figure 14. Yield relative to MSY, showing median, interquartiles and 95% CIs.

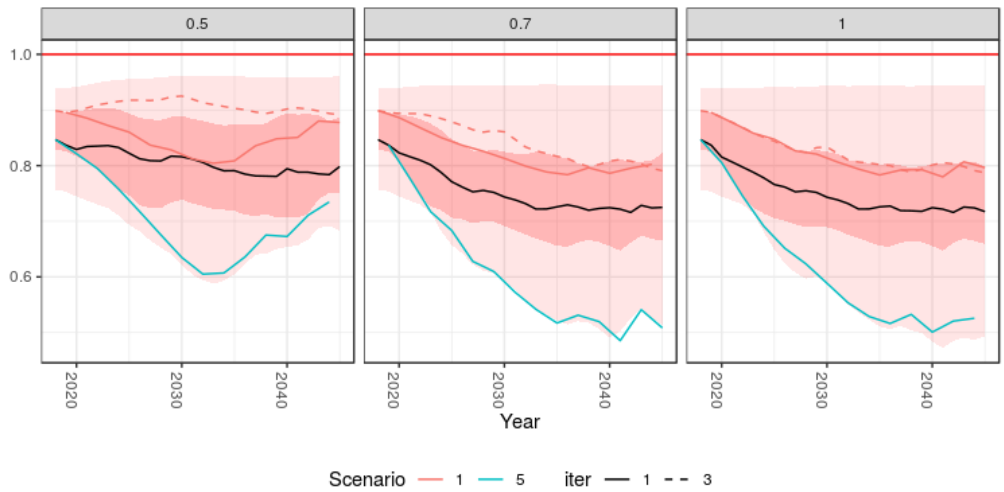

Figure 15. Recruitment relative to virgin level, showing median, interquartiles and 95% CIs.

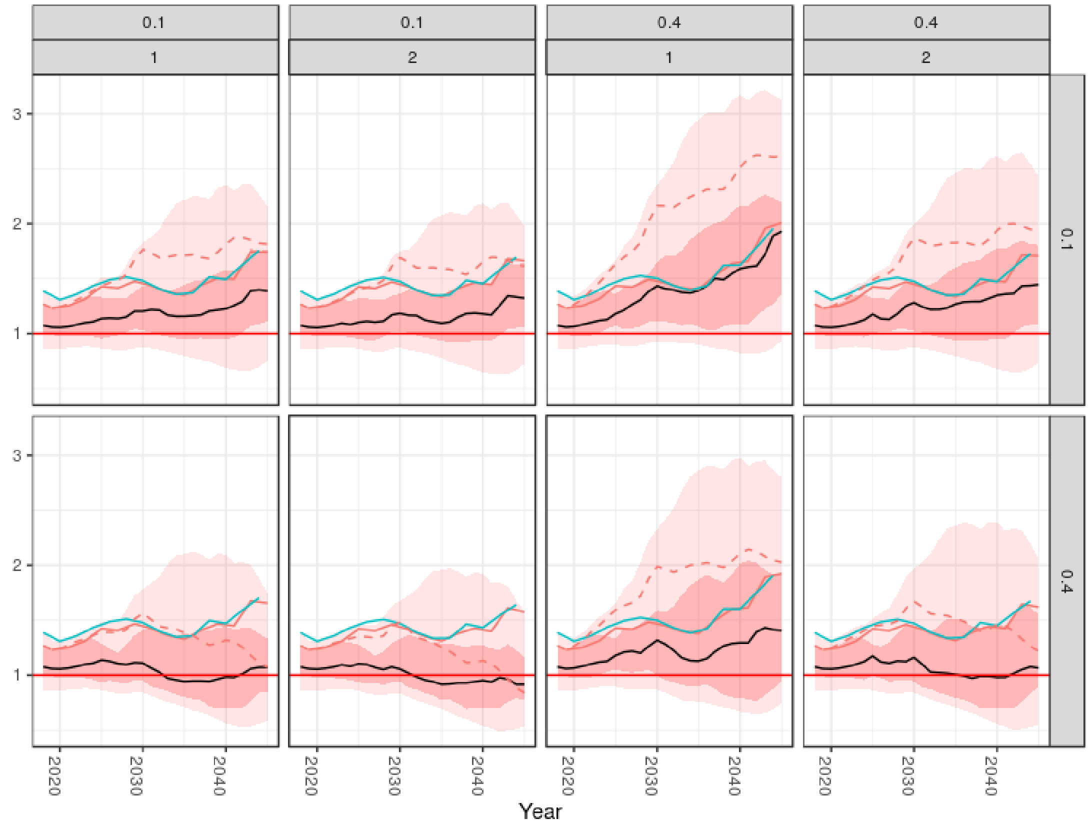

Figure 16. SSB relative to B_{MSY}, showing median, interquartiles and 95% Cis,Rows correspond to gain term for increasing and columns to decreasing trends.

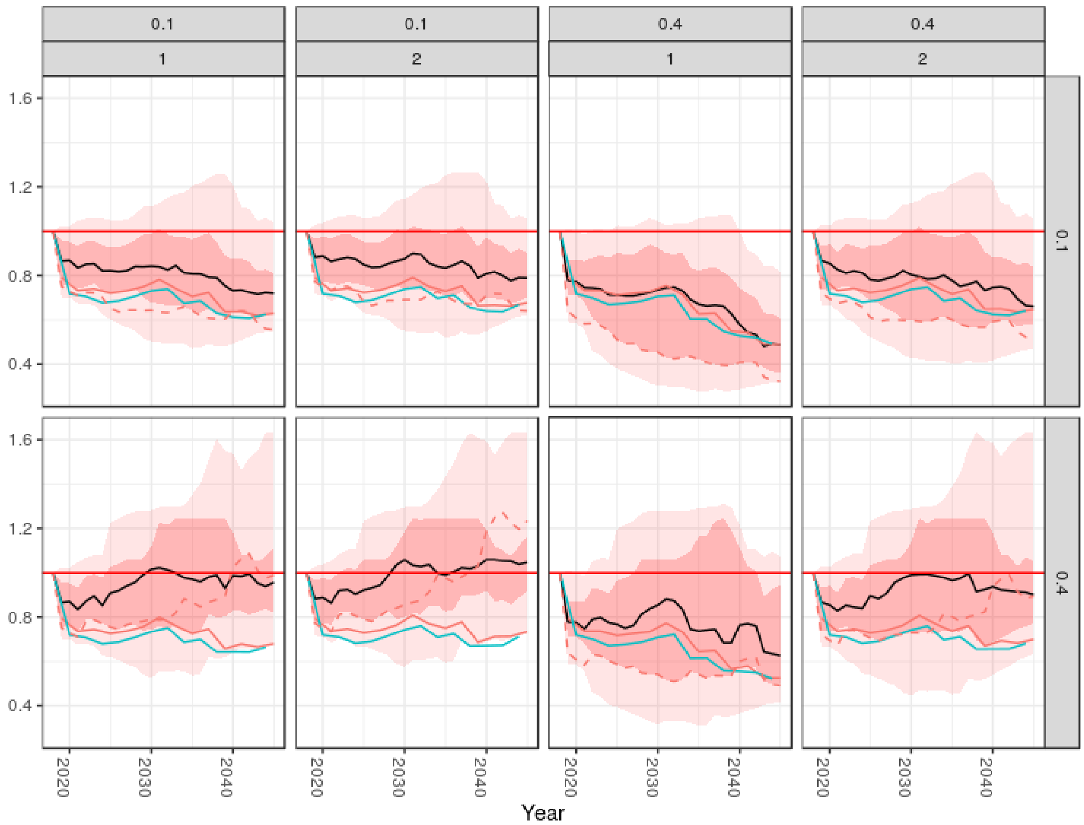

Figure 17. Fishing mortality relative to F_{MSY}, showing median, interquartiles and 95% CIs.

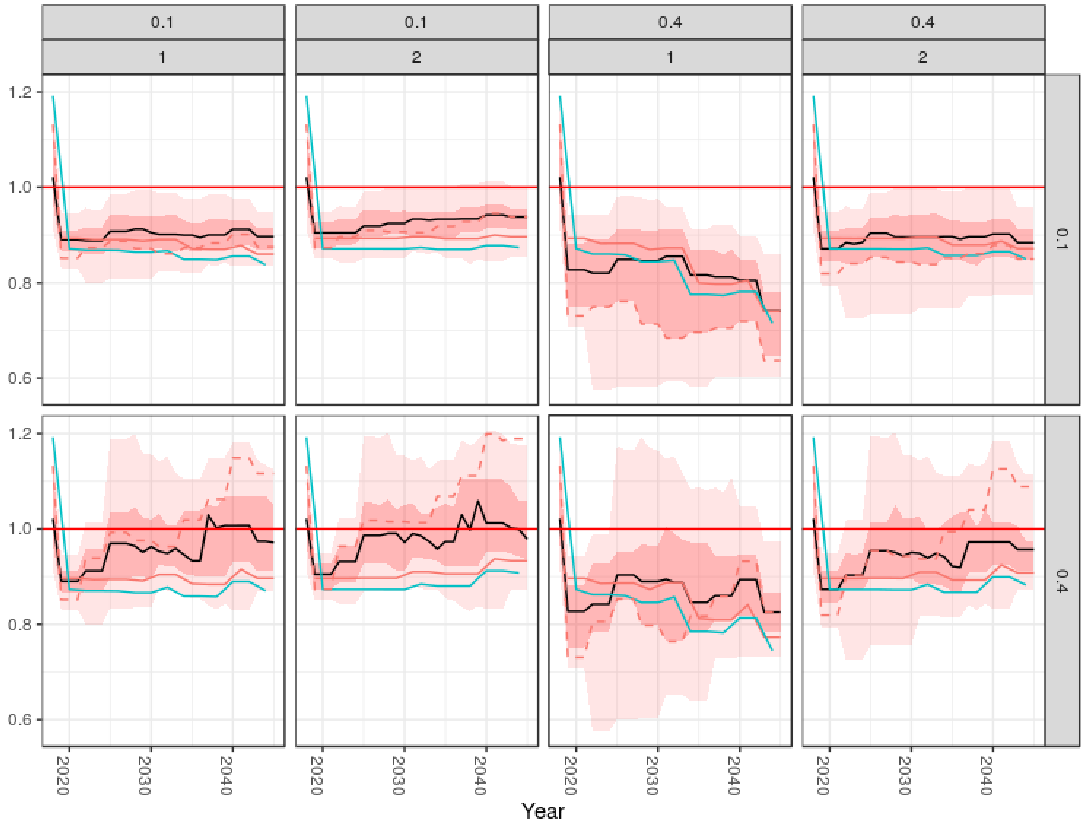

Figure 18. Yield relative to *MSY*, showing median, interquartiles and 95% CIs.

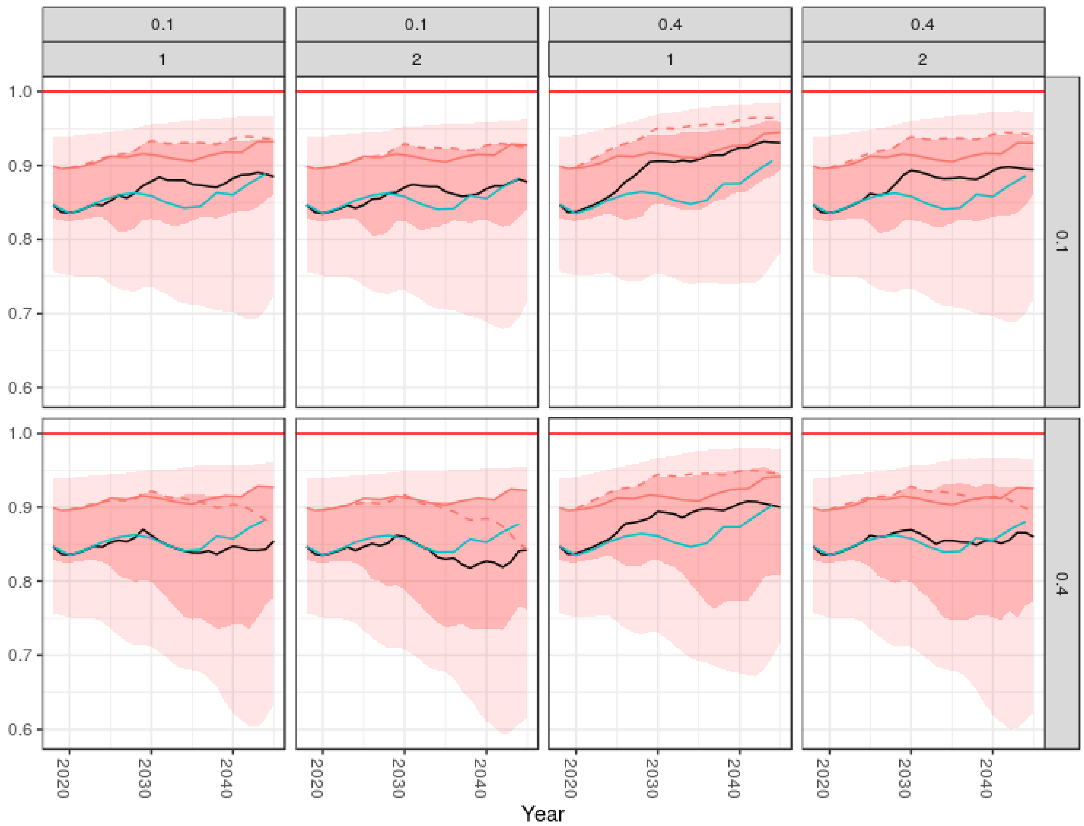

Figure 19. Recruitment relative to virgin level, showing median, interquartiles and 95% CIs.

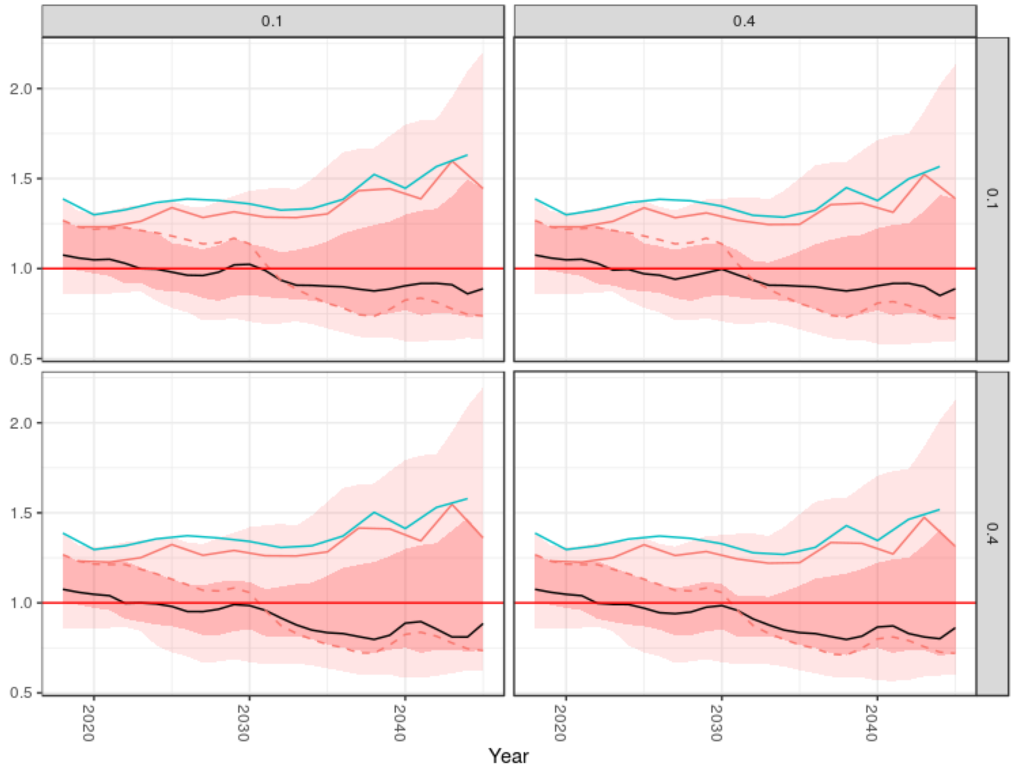

Figure 20. SSB relative to B_{MSY}, showing median, interquartiles and 95% Cis, Rows correspond to gain term for increase and columns to decrease CPUE relative to reference level.

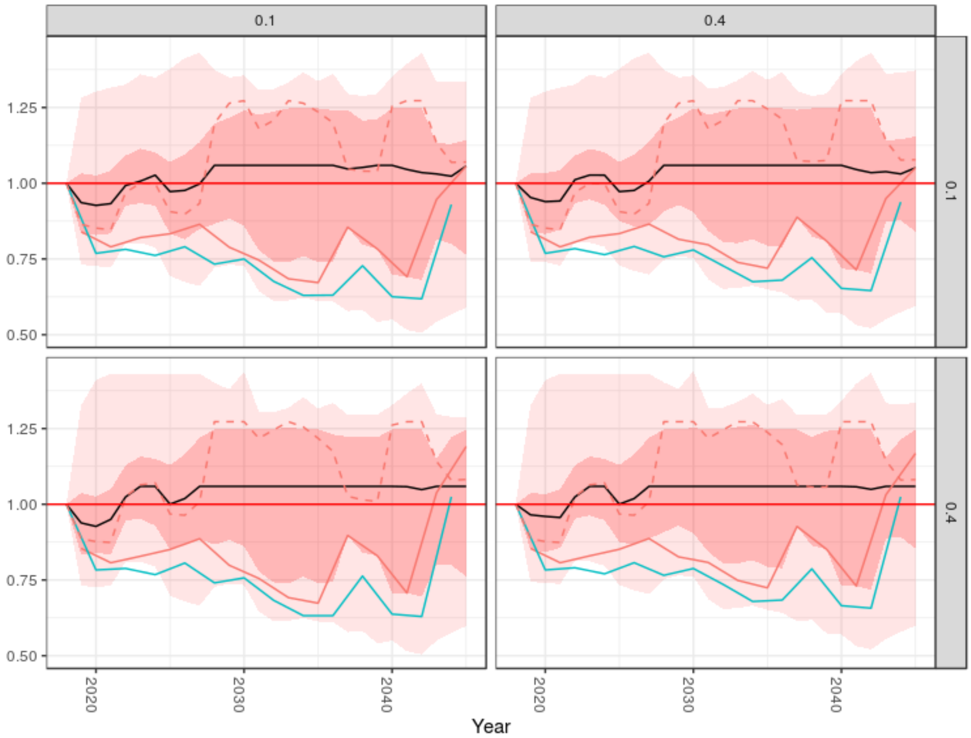

Figure 21. Fishing mortality relative to F_{MSY}, showing median, interquartiles and 95% Cis, Rows correspond to gain term for increase and columns to decrease CPUE relative to reference level.

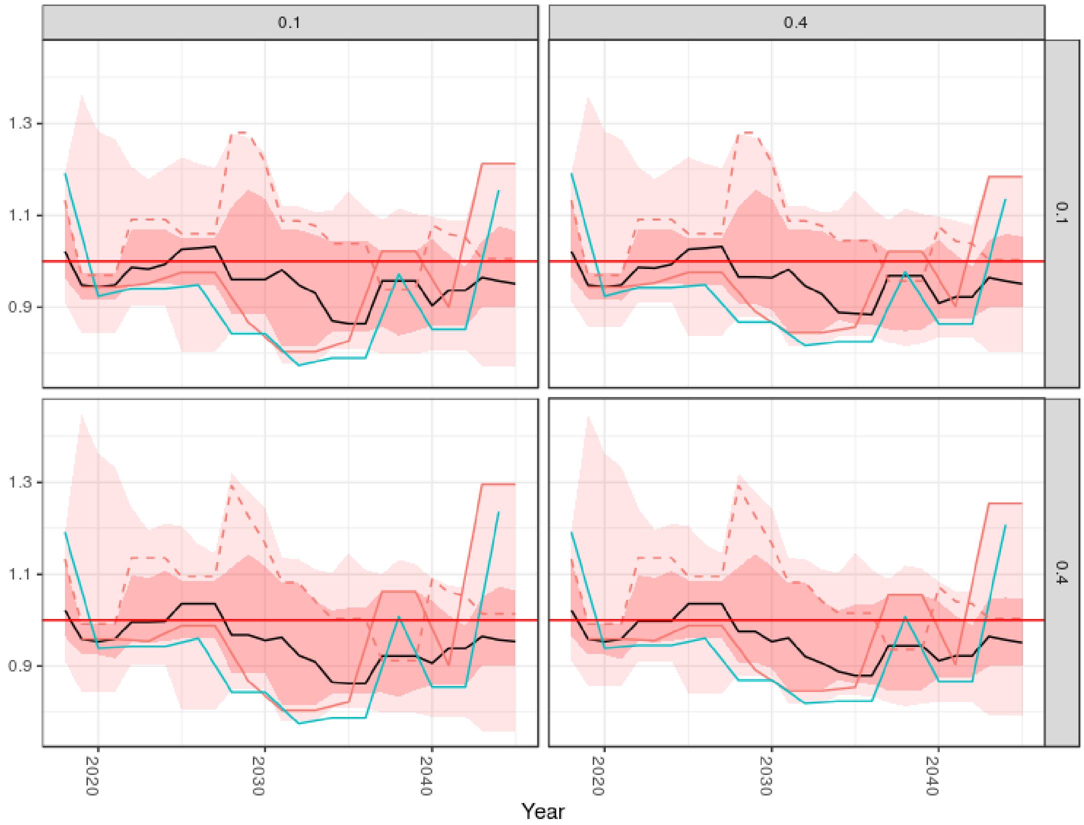

Figure 22. Yield relative to MSY, showing median, interquartiles and 95% CIs.

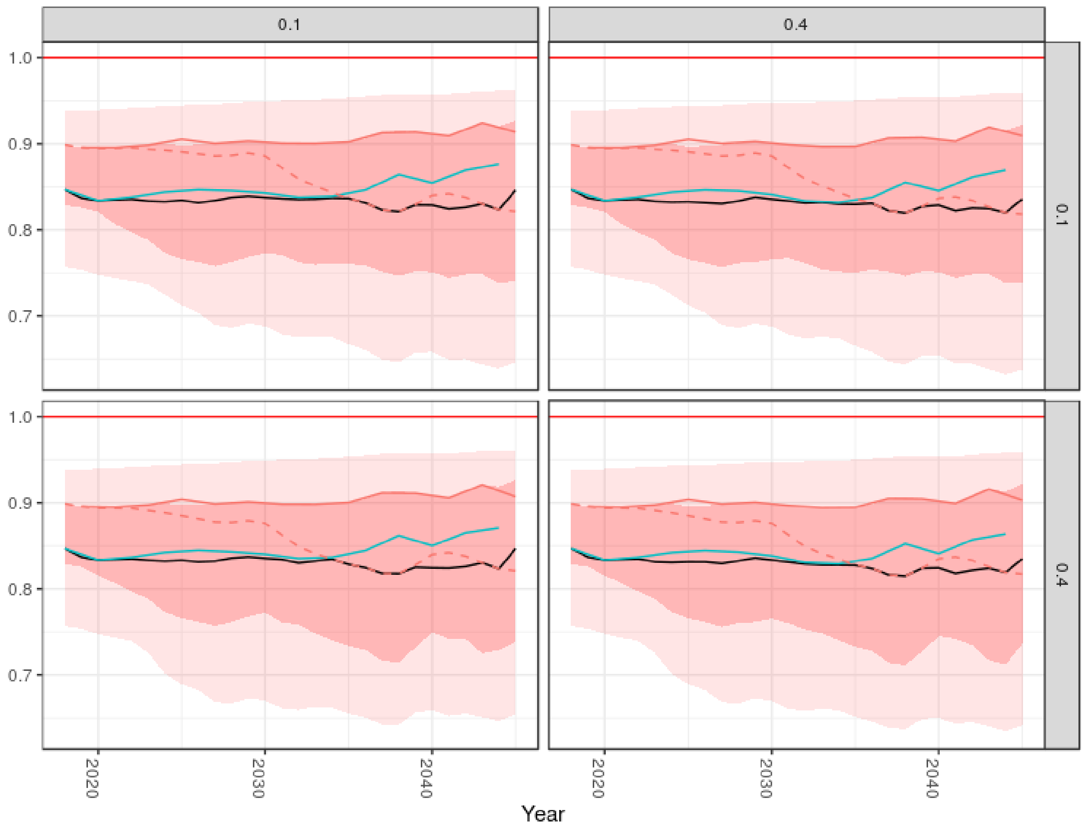

Figure 23. Recruitment relative to virgin level, showing median, interquartiles and 95% CIs.

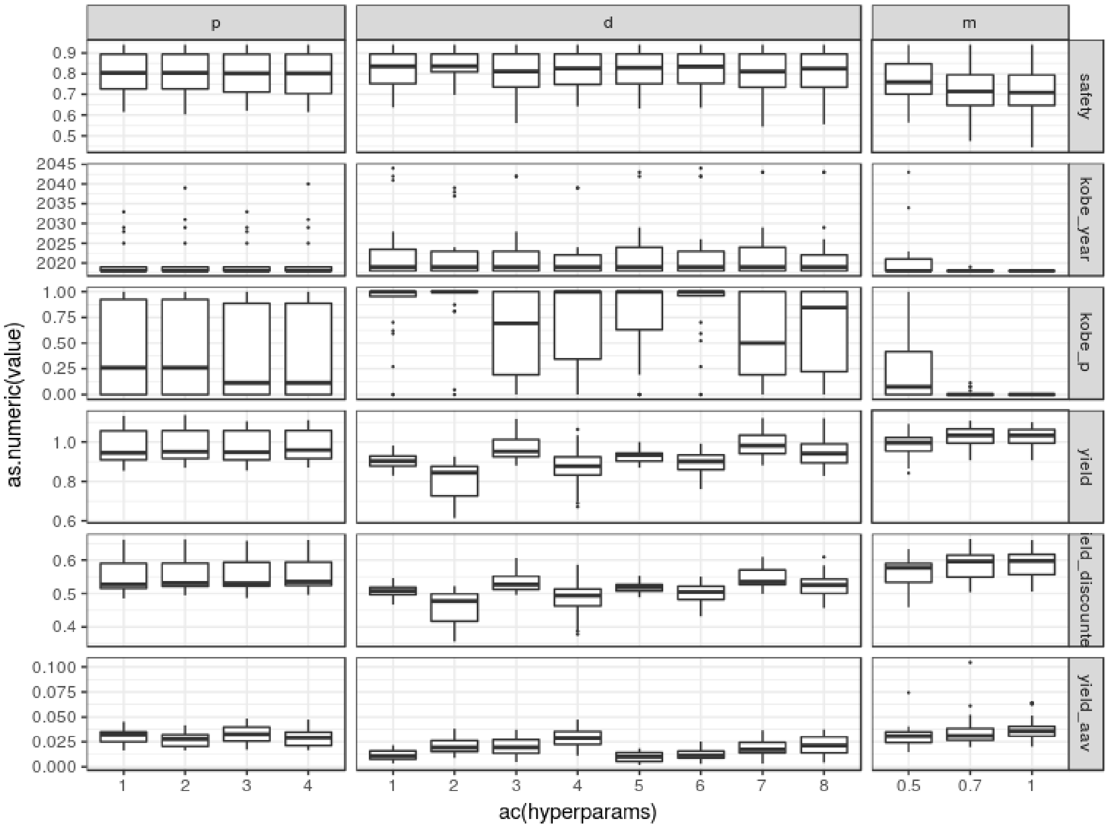

Figure 24. Plot of MPs by hyperparameter settings for performance measures.