(Working paper prepared for the Indian Ocean Tuna Commission Working Party on Methods 2019)

IOTC Bigeye and Yellowfin Tuna Management Procedure (MP) Evaluation Update Oct 2019

Dale Kolody (dale.kolody@csiro.au)

Paavo Jumppanen

(CSIRO, Australia)

Food and Agriculture Organization of the United Nations

Acknowledgments

This work was jointly funded by the Global Environment Facility – Common Oceans - Areas Beyond National Jurisdiction Project (administered through FAO) and CSIRO, Australia. Technical oversight and advice was provided by various IOTC Working Groups, and notably the participants of the IOTC MSE Task Force, including Iago Mosqueira, Toshihide Kitakado, Gerald Scott, Gorka Merino, Hilario Murua, Dan Fu and M. Shiham Adam. Operating model conditioning built upon the stock assessment work of Dan Fu, Adam Langley and others at the IOTC, with useful Stock Synthesis advice from Ian Taylor. The original R-based MSE code from phase 1 was adapted from the Atlantic Bluefin MSE work developed by Tom Carruthers (funded by the ICCAT GBYP project). Summary result graphics were adopted from the Fisheries Library in R (FLR) code provided by Iago Mosqueira.

Contents

Summary

This document presents an update of Management Procedure (MP) evaluation results for bigeye and yellowfin tunas since the 2019 IOTC Technical Committee on Management Procedures (TCMP) and Commission meetings, from which we highlight the following points:

- The reference set Operating Models (OMs) have evolved since the 2019 TCMP, with some minor corrections, and more thorough investigation of the yellowfin OM in particular. However, the changes do not substantially change the MP evaluation results reported to the 2019 TCMP.
- Substantial effort was spent developing the model-based MP algorithms, including i) improving the reliability of surplus production model fitting, and ii) developing a new class of MP (model-rebuilding class) which includes an internal projection algorithm that may improve rebuilding behaviour.
- Funding has been identified to continue the yellowfin and bigeye MSE work through 2020.
- **Bigeye MP evaluation results:**
    - The 2019 TCMP requested results from 2 tuning objectives:
        - B18.2: Pr(Kobe Green 2030-34) = 0.6 (stock status in the Kobe green quadrant over the period 2030-2034 exactly 60% of the time, averaged over all simulations)
        - B18.3: Pr(Kobe Green 2030-34) = 0.7 (stock status in the Kobe green quadrant over the period 2030-2034 exactly 70% of the time, averaged over all simulations)
    - Performance evaluations for contrasting MP classes are presented for the reference set OM and a suite of robustness tests.
    - The MP results were largely unchanged from the 2019 TCMP.
    - The generally optimistic stock status for bigeye results in the tendency for MPs to recommend catch increases which may not be consistent with recent industry objectives (i.e. otherwise current catches would be higher). If catches have to be greatly increased to hit the tuning objective, this can result in subsequent biomass declines to below target levels, but this is not a big problem with the current tuning levels.
    - While no obvious problems were identified with the bigeye reference set OM, it will need to be compared with the results and insights from the 2019 stock assessment.
    - The species-specific summaries in the text identify development feedback priorities required from the 2019 WPTT and WPM.
- **Yellowfin MP evaluation Results**
    - The 2019 TCMP requested results from 2 tuning objectives:
        - Y18.2: Pr(B(2029) > B(MSY)) = 0.5
        - Y18.3: Pr(B(2034) > B(MSY)) = 0.6
    - Results of contrasting MP classes are presented for the reference set OM and a suite of robustness tests. As per the 2019 TCMP request, key MP results are presented in additional formats that only summarize performance up to the tuning rebuilding targets. This request was motivated by the fact that the MPs available at the time had a tendency to overshoot the biomass rebuilding objective.
    - The revised MPs largely resolve the biomass overshoot problem, and demonstrate the value of i) developing situation-specific MPs, rather than relying on generic MPs, and ii) having competing MP developers that explore different approaches and share

experiences. However, the MP results are still very pessimistic in that large catch reductions from current levels are likely required to hit the rebuilding targets.

- The MPs that achieved successful tuning all required the TAC change constraints to be larger than the targeted 15% (>50%). As per the TCMP request to explicitly explore how change constraints relate to rebuilding possibilities, the earliest possibly recovery dates (i.e. based on continuous quota drops rather than feedback-based MPs) were determined for a range of options (with quotas effective starting 2021) including:
  - 2042 with a 15% change constraint
  - 2031 with a 25% change constraint
  - 2029 with a 35% change constraint
  - 2022 with a fishing moratorium

- There are substantial concerns about the most recent yellowfin stock assessment, and the corresponding operating models upon which the MP evaluations are undertaken. Accordingly, the OMs will need to be revisited in relation to the results and insights that may arise from the ongoing assessment review process.

Introduction

This document describes recent MP evaluation results for bigeye and yellowfin tunas, using the reference set Operating Models (OMs) described in the attachments of Kolody and Jumppanen (2019f, g), which were endorsed by the IOTC MSE Task Force in 2019 (WPM 2019), and used to generate the TCMP 2019 MP results (Kolody and Jumppanen 2019d, e). These OMs have not yet been reviewed by the formal IOTC technical working parties, but we have attempted to address the requests of the WPTT/WPM 2018. However, we note that there is a broad collaborative review process underway which might have substantial implications for the yellowfin assessment and OMs. The bigeye reference set OM is believed to be more stable, but the stock assessment around which it is structured is 3 years old (and will also need to be compared with the 2019 bigeye assessment to see if it remains appropriate).

Key developments since the 2019 TCMP include:

- Minor corrections to OM specifications (see Kolody and Jumppanen 2019f,g)
- MP development, particularly to improve yellowfin biomass rebuilding behaviour
- New requests from the TCMP and Commission (detailed in subsequent sections)
- MP Performance evaluated against Robustness OMs

The results are presented with the reduced set of tuning levels requested by the TCMP-03 (2019), as detailed in the species-specific sections.

Discussion points for the technical working parties to consider are included in the species-specific sections.

Management Procedure Development

In earlier iterations of the MSE process, all of the MPs that we presented conformed to the basic structures shown in Figure 1 and Figure 2. The proposed tuning objectives were originally based on aggregate performance over a large time period, and the main driver of MP performance was the selected tuning objective. However, the tuning objectives have since been applied to narrower time windows, and desirable performance characteristics have been more precisely defined. By simply tinkering with the combinations of control parameters from the MPs shown in Figure 1 and Figure 2, we were not able to substantially improve the tendency for the yellowfin biomass to greatly overshoot the rebuilding target in time for TCMP 2019.

A new “Model-based Rebuilding” (Mr) class of MP was developed (Figure 3) to resolve the yellowfin biomass overshoot problem. The Mr-class MP is also a Pella-Tomlinson model (with a fixed “shape” parameter), but uses a Harvest Control Rule (HCR) that prescribes catch in relation to projected dynamics that (ideally) approach the biomass target asymptotically. Inspired by the lessons learned in the Mr-class development, additional efforts were taken to improve the performance of the original M class MPs, with considerable success. Key changes to one or both of the Pella-Tomlison-based production models included:

- Further efforts to make the observation error PT model minimization more robust, including:
    - An adaptive grid search of r and K parameters when minimization was doubtful.
    - Reparameterizing the model in terms of K and MSY (rather than r)
    - Higher weighting on the first few and last few CPUE observations
    - Redefining the catch observations in stock collapse situations

    - Adding an empirical step in which there is no attempt to fit the model if the recent CPUE is less than a small fraction of the initial CPUE
- Internal projections to estimate where the population is likely to be when the TAC is applied, rather than when the last data were observed. In the Mr class there is further projection to estimate the TAC required to hit an interim biomass target.
- Partitioning the biomass into a longline vulnerable component and a juvenile component, in a proportion that is a function of depletion (independent of time)
- Further relaxing TAC change constraints

It is not clear which of these features or what combinations were required to obtain the improved performance shown in the yellowfin section. Relaxing the TAC change constraint was required, but probably not sufficient. The Mr-class model has some other distinguishing performance features that are discussed in the yellowfin section. The exercise illustrates the potential value of customizing MPs to achieve specific management objectives, rather than expecting generic MPs to be appropriate for all situations.

The MP names in this document, sometimes use the full name, while in other cases abbreviations are sufficient:

- M = model-based MP (PT41*)
- Mr = Model-based Rebuilding (PTproj*)
- D = data-based (empirical) MP (IT5*)
- Y2 = yellowfin tuning objective 2, B3 = bigeye tuning level 3, etc.

There are an infinite number of MPs within each class, defined by a number of control parameters that are adjusted to achieve the desired management performance. The control parameters for a tuned MP will usually not correspond to the conceptual expectations (e.g. for conventional Harvest Control Rules as shown in Figure 1), because i) MP performance can often be counter-intuitive, and ii) simple models are biased relative to the complex OMs, and MPs must strike a compromise among a diverse range of uncertainties represented in the OMs. The specific control parameters are not reported here (but may be obtained along with the precise MP implementation details for any individual MSE result from the github).

Additional MP development requests from TCMP (2019) and IOTC (2019) are discussed in the following two sections. The requests were made in the context of yellowfin, but are relevant for both species.

"M" class (model-based) MPs

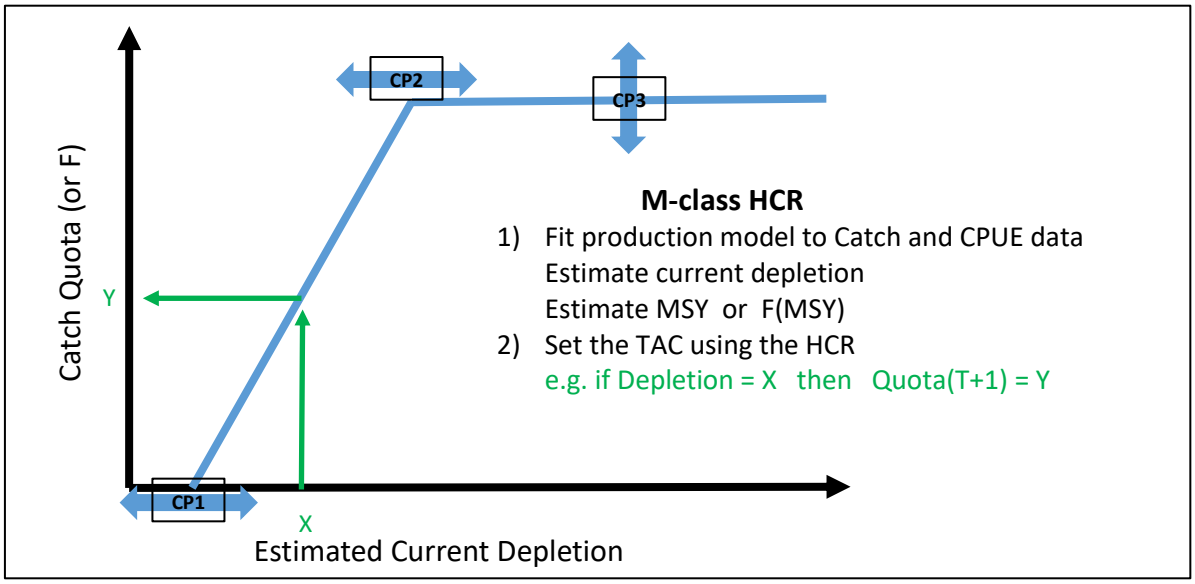

Figure 1. The model-based (M-class) MPs involve two steps: 1) fitting a simple surplus production model, and 2) applying a Harvest Control Rule (HCR) to the model estimates. The individual M-class MPs differ in terms of the Control Parameters (CP1-CP3) that define the shape of the HCR. In the examples presented here, CP1 and CP2 were constant (at a range of different levels in different candidate MPs), while numerical optimization was used to find the value of CP3 that achieves the precise tuning objective. An additional control parameter was added to allow the connection between CP1 and CP2 to be non-linear.

"D" class (data-based or empirical) MPs

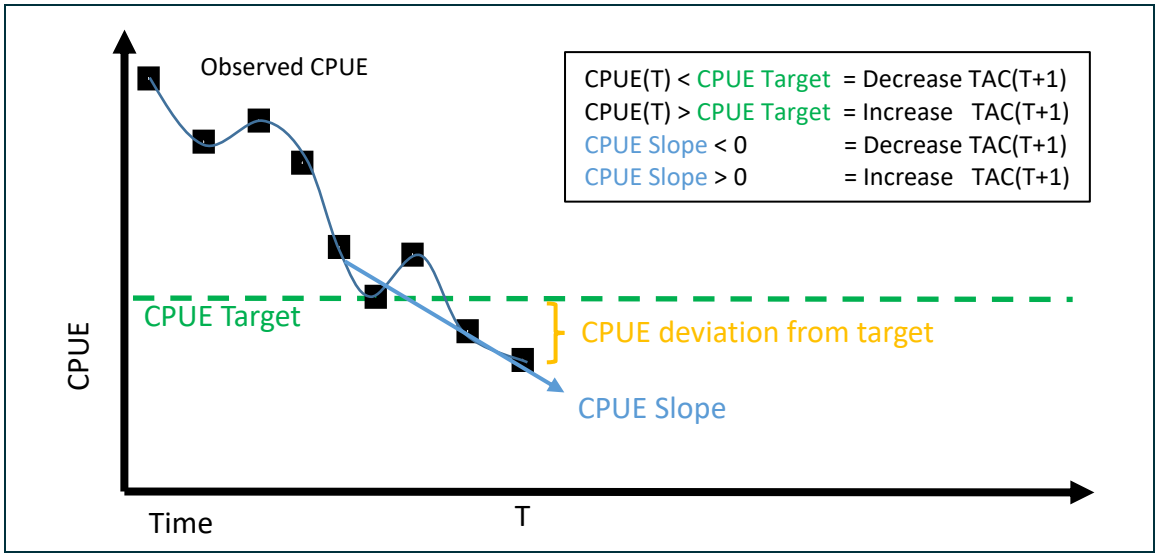

Figure 2. The data-based (D-class) MPs attempt to manage the fishery to achieve a target value of (standardized longline) CPUE. The next TAC is increased relative to the current TAC if current CPUE is above the target CPUE and the CPUE trend is increasing. Conversely, the next TAC is decreased relative 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. Control parameters include: 1) the number of years in the CPUE slope calculation, 2) responsiveness to CPUE target deviation, 3) responsiveness to CPUE slope and 4) the CPUE target (the tuning parameter in this case).

"Mr" class (model-based) MPs

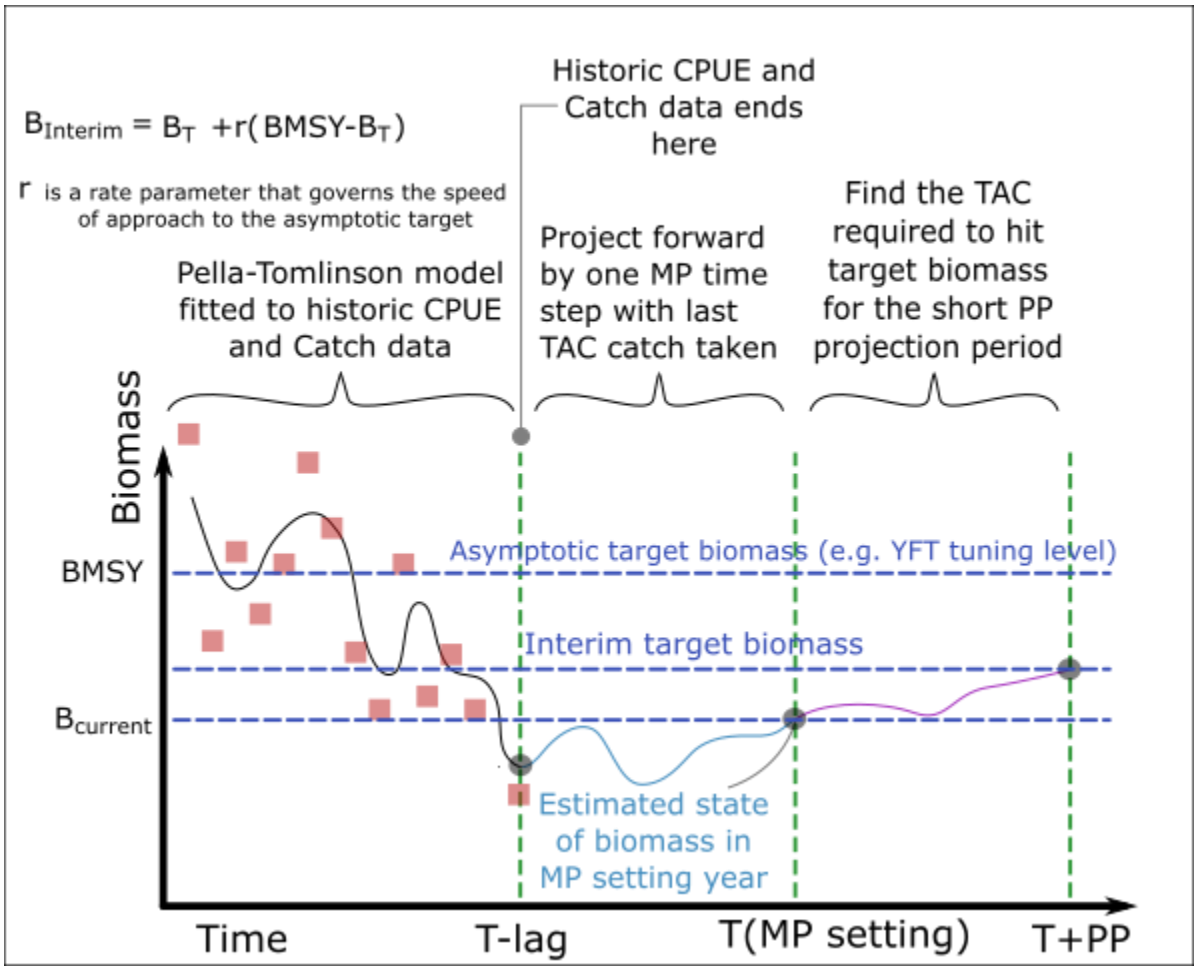

*Figure 3. The model-based (Mr-class) MPs involve three steps: 1) fitting a simple surplus production model, 2) using the fitted model to project one MP time step forward to give an estimate of the current state of the biomass (remember that the MP data lags the current fishery state) and 3) estimate the TAC required to result in the Biomass reaching the next MP time step target. This approach asymptotically approaches the ultimate target of BMSY with the speed of that approach governed by **r**, the rate parameter*

TCMP proposal for future Management Procedure Reporting

TCMP (2019) provided the following feedback for the next iteration of MP development:

> ***7.3 YELLOWFIN TUNA***
>
> *…*
>
> ***40.*** *The TCMP **NOTED** that the desired Management Procedure (MP) would be one that recovers the stock and keeps it around the target. Most of the MPs tested to date tend to overshoot the target. This may be because the MPs are too simple or the data not sufficiently informative. Additional complexity could be added to the MP design but it is difficult to design a single MP that will achieve the desired MP behaviour with certainty. Another option would be to develop one MP for rebuilding and another one for the time that stock is recovered. The TCMP **AGREED** to develop an MP for the rebuilding period, which will be updated once recovery is achieved, but the TCMP also **REQUESTED** that performance statistics are shown for the two periods: tuning objective recovery period, and the 20 years projected period when tuning to the recovery target…*
>
> ***44.*** *The TCMP **NOTED** that is seems that the model-based MPs work better, probably because they include insights on the productivity and dynamics of the stock. The model-based component of the Management Procedures under development are centred on the biomass production model; the TCMP **SUGGESTED** that the possibilit[y] of using non-equilibrium production models instead of stationary ones are discussed within the MSE technical group...*
>
> ***46.*** *The TCMP **REQUESTED** that the first rebuilding time period (5 years) is not used as a tuning objective and instead, 10 and 15 year recovery objectives are used for tuning (Y2 and Y3).*
>
> ***47.*** *The TCMP also **REQUESTED** results that demonstrate how long rebuilding will take if TAC change constraints are limited to 15% (and alternative options of TAC change constraints such as 10% and 20% with some flexibility on the values for the technical developing team).*

We have addressed the points in paragraph 40, 46 and 47 in the yellowfin section of this report and offer the following comments in relation to paragraph 44 ("*the TCMP **SUGGESTED** that the possibilit[y] of using non-equilibrium production models instead of stationary ones are discussed within the MSE technical group")*:

- We are not entirely sure what was meant by this request and consider 3 possibilities:
    - The models that are used in the current MPs are not equilibrium models in the historical sense of the term (i.e. equilibrium methods evolved before computers were commonly used in fisheries science, and assume that if a fishery evolves slowly enough, it will always be near a state of equilibrium). The current MP models are dynamic and attempt to explicitly describe changes in the population from the 1950s to the present.
    - The statement might be requesting non-stationary production models, which we are not very familiar with (though the empirical MPs that we use do not make inferences about production dynamics). One possible interpretation might be the sort of statistical model used in the CCSBT MP, which does not include any density dependent term and on its own could not provide any advice with respect to the

usual (e.g. MSY-related) reference points. As such, it is true that the model has non-stationary production, but it might be more appropriately described as a population smoother, that has more in common with empirical MPs. Furthermore, it relies on data that are specific to southern bluefin (CPUE as an index of adult biomass and a fisheries-independent recruitment index).

    - The statement might be referring to production models that include both process and observation error (instead of observation error only, as currently implemented). We are not certain that this would improve the convergence characteristics over an observation error only model. This approach was also attempted by CCSBT MP developers, but they found that their implementation was not numerically stable (Rich Hillary, CSIRO, pers. comm.), and opted for the smoother discussed in the previous point.

- Given that the current IOTC assessment and management paradigm is based on stationary production dynamics (SPD) assumptions (e.g. MSY-based reference points), it seems odd to consider an MP that is designed for non-SPD situations. We would expect this to be a natural consideration if the OMs include non-SPD, as it would likely be a handicap for the non-SPD MP if it was competing against other MPs that have *a priori* knowledge that the fishery OM is actually an SPD system.
- This raises the question of whether the IOTC should be considering non-SPD OMs. To date, this issue has been side-stepped with the expectation that gradual shifts in productivity can probably be addressed through periodic MP reviews, while rapid regime shifts would be expected to invoke "exceptional circumstances" meta-rules to suspend the MP. Recruitment failure robustness scenarios are tested, though they are defined as anomalies within an SPD system. Embracing these additional complexities would also undermine the interim (MSY-based) reference points which assume stationary dynamics. e.g. instead of B/B_{MSY}, the appropriate depletion estimator might be B/B_{NF}, where B_{NF} is the biomass that would have been observed in the absence of fishing (sometimes referred to as dynamic B_0).
- Irrespective of the above points, if there is reason to expect that a non-SPD MP will outperform the alternatives (and if it is fast enough to run in the MSE software), then it could be tested. We would encourage the proponents to provide an appropriate implementation, and preferably, engage in MP testing with the MSE software. It can be very time consuming to come up with a sophisticated customized MP that is numerically robust and performs as desired. We note that the CCSBT MP development process was thought to have benefitted from having competing MP developers. And this was found to be the case here within a small team of two developers aiming to improve the yellowfin rebuilding performance. An additional analyst motivated by confidence in an MP and dedicated to its development would be a welcome addition to the process.

2019 Commission request for additional MP information

IOTC (2019) notes the following request (in the context of yellowfin MPs):

> "*The Commission **AGREED** that more information on the options to reduce catches was required and **REQUESTED** the Scientific Committee and the TCMP to investigate the possibility of including an additional parameter, namely the reduction of juvenile catch, in future tunings of the management procedure in order to determine plausible ranges of juvenile catch reduction. If*

this parameter proves to be difficult to be included as a tuning criteria, it should be presented as a summary performance statistic."

To date, the OMs have assumed that future catches will be allocated among existing fisheries proportional to the average catches over the last two years as reported in the stock assessment data. Technically, it is not difficult to change the catch allocations among fisheries in the MP evaluations, and the software is prepared for this as an expected input resulting from allocation negotiations. It should be noted however, that given that the fisheries are aggregated within gear types, the secretariat's assistance would be required to partition fishery definitions by CPC.

However, it is not clear what is meant by "*tunings…to determine plausible ranges of juvenile catch reduction*". The intent of the term "tuning" in this case is unclear, and may imply a level of sophistication that is not possible (or practical). Changing allocations is a political process for the Commission, to be negotiated among CPCs, and not a decision for scientists. Furthermore, unless this process is used to directly inform allocation negotiations, it is not clear what the exercise is intended to achieve.

Bigeye Tuna MP evaluation update for WPM 2019

Management Procedure Evaluation Status

- Management Procedure (MP) evaluation is being pursued in the strict sense (i.e. as in the International Whaling Commission and Commission for the Conservation of Southern Bluefin Tuna), in which the data to be input to the MP, the analysis, and the Harvest Control Rule (HCR) are all defined in advance and simulation-tested together.
- The bigeye reference set Operating Model (currently OMrefB19.6) has been iteratively developed in line with IOTC technical working party requests (WPTT and WPM) and the IOTC MSE Task Force (Kolody and Jumppanen 2019f).
    - The MP evaluations described were run with 500 realizations, and a tuning precision of +/- 1%.
- A small set of generic MPs have been evaluated for each of the tuning objectives (see below) requested by the TCMP (2019).
- Results from 4 robustness set OMs are presented for bigeye:
    - *OMrobB19.6.ICV30* - What happens if the (annualized aggregate) longline CPUE observation error CV is increased to 30% (auto-correlation 0.5) in projections?
    - *OMrobB19.6.10overRep* - What happens if there is a consistent 10% future over-catch (accurately reported), equally distributed among fleets?
    - *OMrobB19.6.10overIUU* – What happens if there is a 10% future over-catch (unreported) equally distributed among fleets ?
    - *OMrobB19.6.qTrend3* - What happens if the longline CPUE catchability trend is 3% per year going forward (but remains as in the reference scenario for conditioning)?

Bigeye MP Development Guidance from TCMP03 (2019)

The tuning objective refers to a key management objective that the MPs can achieve precisely (e.g. achieving $SB \geq SB_{MSY}$ with a 50% probability by 2024). The tuning objective normally relates to a desirable biomass (in terms of the risk of exceeding reference points and/or a rebuilding timeframe), and has a very strong influence on the obtainable yield (because biomass risk and attainable catch are closely related). Tuning ensures that candidate MPs are identical with respect to this high priority objective, making it easier to select among MPs on the basis of performance with respect to secondary management objectives (e.g. yield and catch stability). Ideally the Commission will have narrowed down the tuning objectives to 1 or 2 before MP selection. This will allow MP developers to focus MP development on improving secondary performance characteristics.

TCMP (2019) decided that 2 interim tuning objectives were sufficient for the next bigeye iteration:

B18.2: Pr(Kobe green zone 2030:2034) = 0.6. The stock status is in the Kobe green quadrant over the period 2030-2034 exactly 60% of the time (averaged over all simulations).

B18.3: Pr(Kobe green zone 2030:2034) = 0.7. The stock status is in the Kobe green quadrant over the period 2030-2034 exactly 70% of the time (averaged over all simulations).

TCMP03 (2019) recognized the desirability of other MP constraints used in preliminary testing:

- TAC to be set every 3 years (and remain constant between settings)
- A maximum change of 15% to the TAC (increase and decrease) relative to the previous TAC

Summary of Bigeye Candidate MP Performance against the reference set OM

MP evaluation results from the reference set OM (OMrefB19.6) are summarized in the standard format in Figure 4 - Figure 10, and Table 1 - Table 2, from which we note the following:

- All MPs and both of the retained tuning levels tend to predict substantial increases in catch relative to current, with modest declines in biomass levels required to bring the stock in line with the tuning objectives.
- The performance among both tuning objectives and MPs is fairly similar, but we note some MP-specific points:
    - The M-class MPs tends to have the lowest catch variability, followed by the D-class. The Mr-class MPs have the highest catch variability and the one without TAC change constraints also has the highest biomass risk. The Mr-class MP was adopted with the same structure as developed for yellowfin (but re-tuned for bigeye). While this MP has very good yellowfin performance it is not appropriate for bigeye. This illustrates the point that there is value in custom-designing MPs, and it may not be prudent to simply assume that a generic form of MP will be appropriate. We did not attempt to restructure the Mr-class MP for bigeye (except to add the 15% TAC change constraint in one version), but expect that it could have performed better.
- Biomass risk is generally low over the next 20 years (including the 2030-34 tuning period). There is considerable variability in the projected outcomes, but even the lower 10th percentile biomass trajectories appear to be above the biomass limits for the next 10-15 years for most MPs
- The contrasting 0 and 1% CPUE catchability trend assumptions represent a stock status uncertainty that increases with time, e.g. if two identical populations are assessed, the abundance estimates will diverge by 10% in 10 years and 35% in 30 years (this is on top of the divergence that arises from the conditioning uncertainty). If there is no way for an MP to identify a catchability trend, this divergence will lead to progressively larger uncertainty, and presumably requires a more conservative approach when evaluating over longer time periods.

Summary of Bigeye Candidate MP Performance against the robustness tests

OMrobB19.6.ICV30 – (longline CPUE observation error CV 30% in projections, lag(1 year) auto-correaltion = 0.5) – The MP performance is difficult to distinguish from the reference set (Figure 11-Figure 17).

OMrobB19.6.10overRep – (10% future over-catch, accurately reported) – MP performance is more pessimistic than the reference set performance, but the change is incremental, similar among MPs and without drastic consequences (Figure 18-Figure 24). This might be optimistically interpreted as a reasonable safety buffer to quota implementation errors.

OMrobB19.6.10overIUU – (10% future over-catch, unreported) – MP performance is very similar to *OMrobB19.6.10overRep (*Figure 25-Figure 31), but the biomass risk is elevated in the latter part of the time series. We would expect MP performance to degrade further as unreported catches increase, but IUU trends are presumably more risky than consistent biases.

OMrobB19.6.qTrend3 – (catchability trend 3% per year going forward) - if there is an unrecognized increase in longline catchability of this magnitude, this will substantially increase the overfishing risk,

with all MPs and tuning levels resulting in greater than 50% chance of exceeding biomass limits before 2040 (Figure 32-Figure 38). The effect of the catchability trend would be greater if it was assumed to be occurring during the conditioning period as well. MPs have limited power to compensate for fundamentally misleading data. If these sorts of CPUE biases are considered likely, there are two options i) more conservative quotas (with potentially lost economic opportunities), or ii) collection of improved monitoring data.

Bigeye discussion Points for the 2018 WPM and WPTT

- Assuming that any changes proposed for the reference set OMs do not substantially change the central tendencies of the MP performance:
    - Should we add additional tuning levels to the TCMP requests, either to i) expand the range of results shown, or ii) suggest that tuning might be pursued in an alternative currency that is easier to interpret and compare among species and from the standard output graphics (e.g. SB/SBMSY)?
- Are the robustness scenarios tested worth showing to the TCMP and should others be considered? Should the robustness tests be presented differently from the reference set?
- Further MP development:
    - If we can obtain more feedback on desirable MP performance characteristics, it may be possible to further customize MP behaviour. However, it is not obvious which MP performance characteristics are most in need of improvement at this time.
- The technical working parties have requested simulating a 2 year lag between available data and TAC implementation. The draft yellowfin MP resolution proposes a 3 year lag. This discrepancy should be resolved for future MSE work.

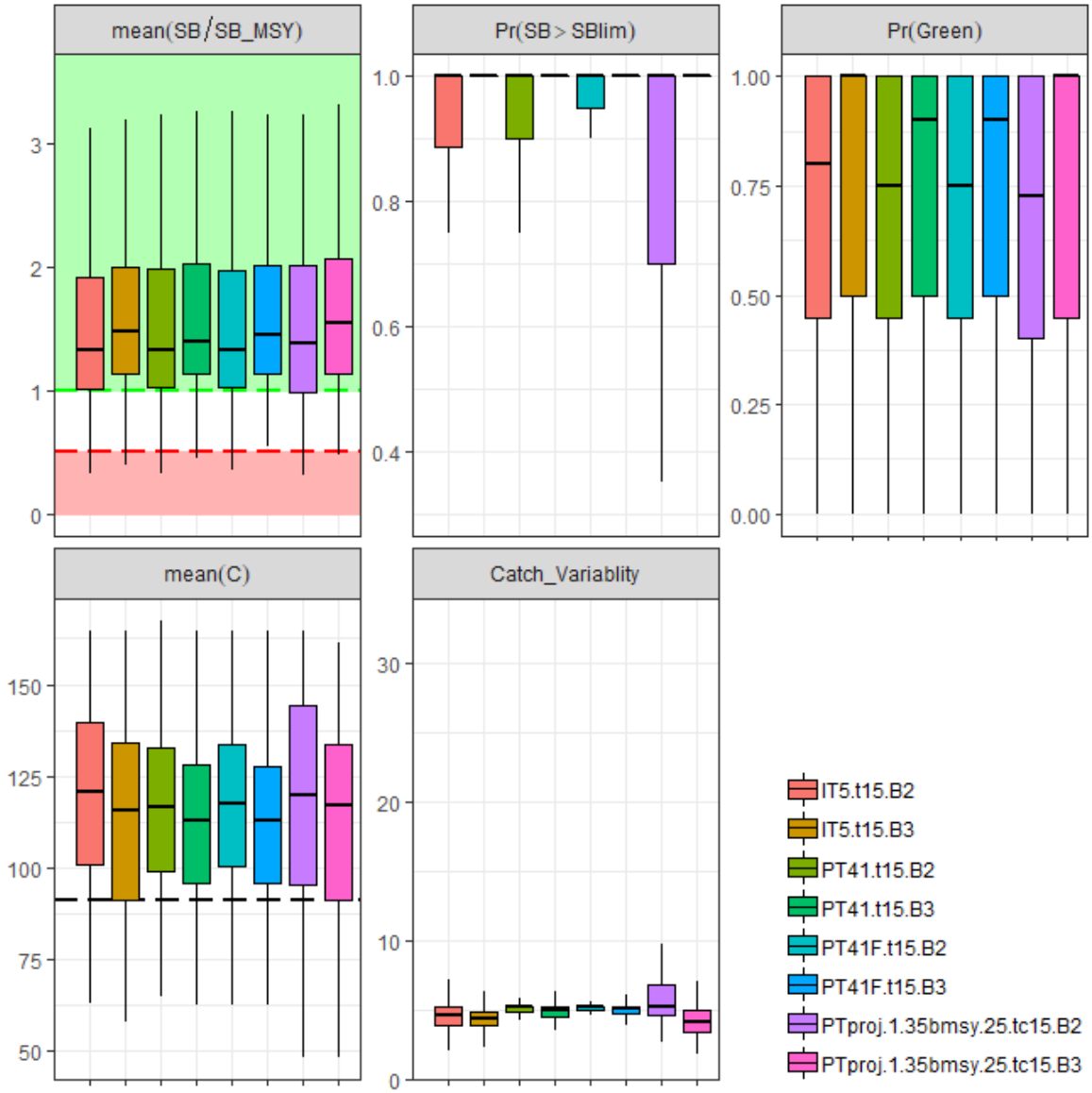

Figure 4. Bigeye reference set (OMrefB19.6) - Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2019 - 2038. Horizontal line is the median, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB_{MSY} performance measure. The horizontal dashed black line is 2016 catch.

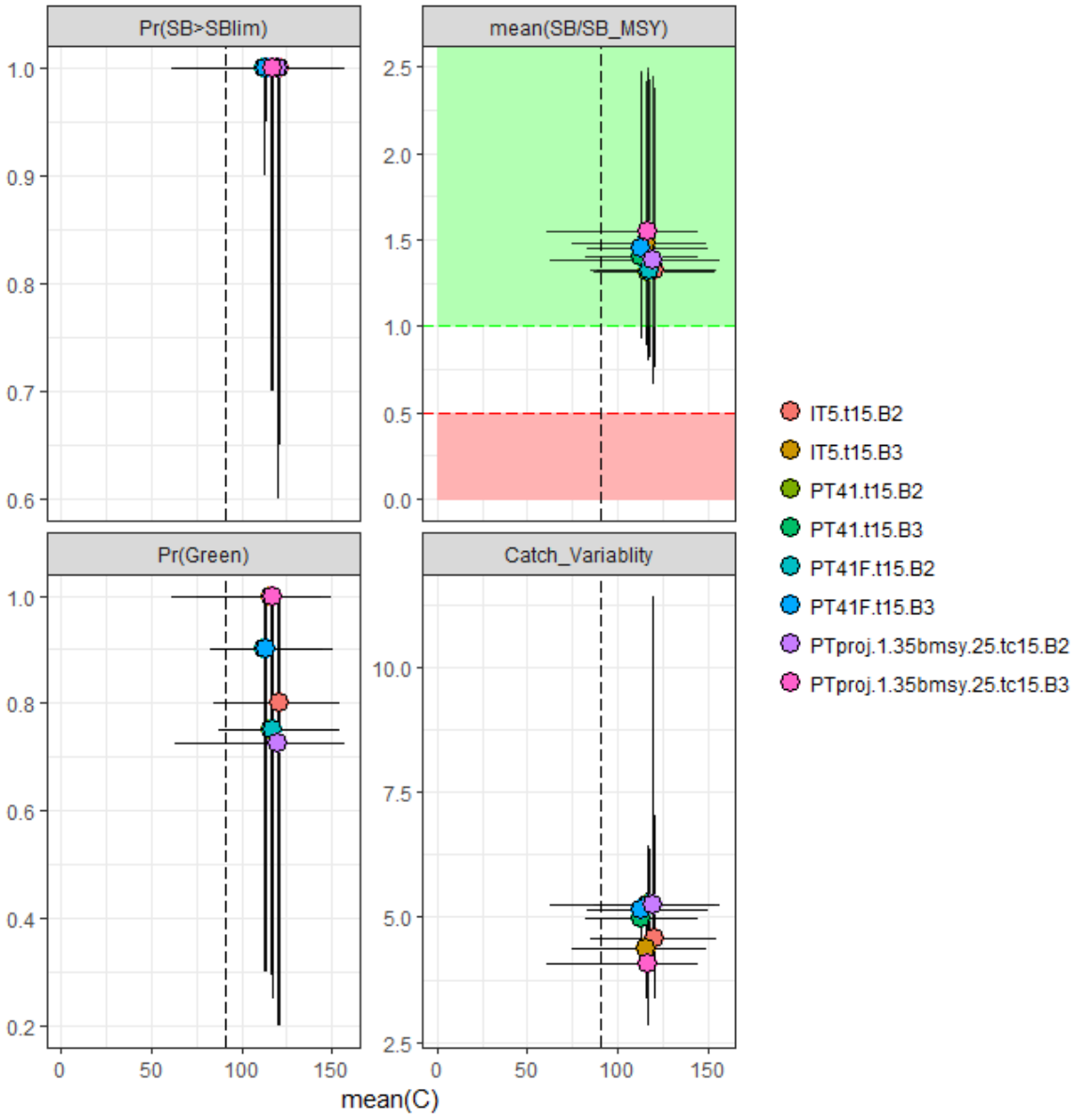

Figure 5. Bigeye reference set (OMrefB18.5) - Trade-off plots comparing candidate MPs with respect to catch on the X-axis, and 4 other key performance measures on the Y-axis, each averaged over the period 2019 - 2038. Circle is the median, lines represent 10th-90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB_{MSY} performance measure. The dashed vertical black line is 2016 catch.

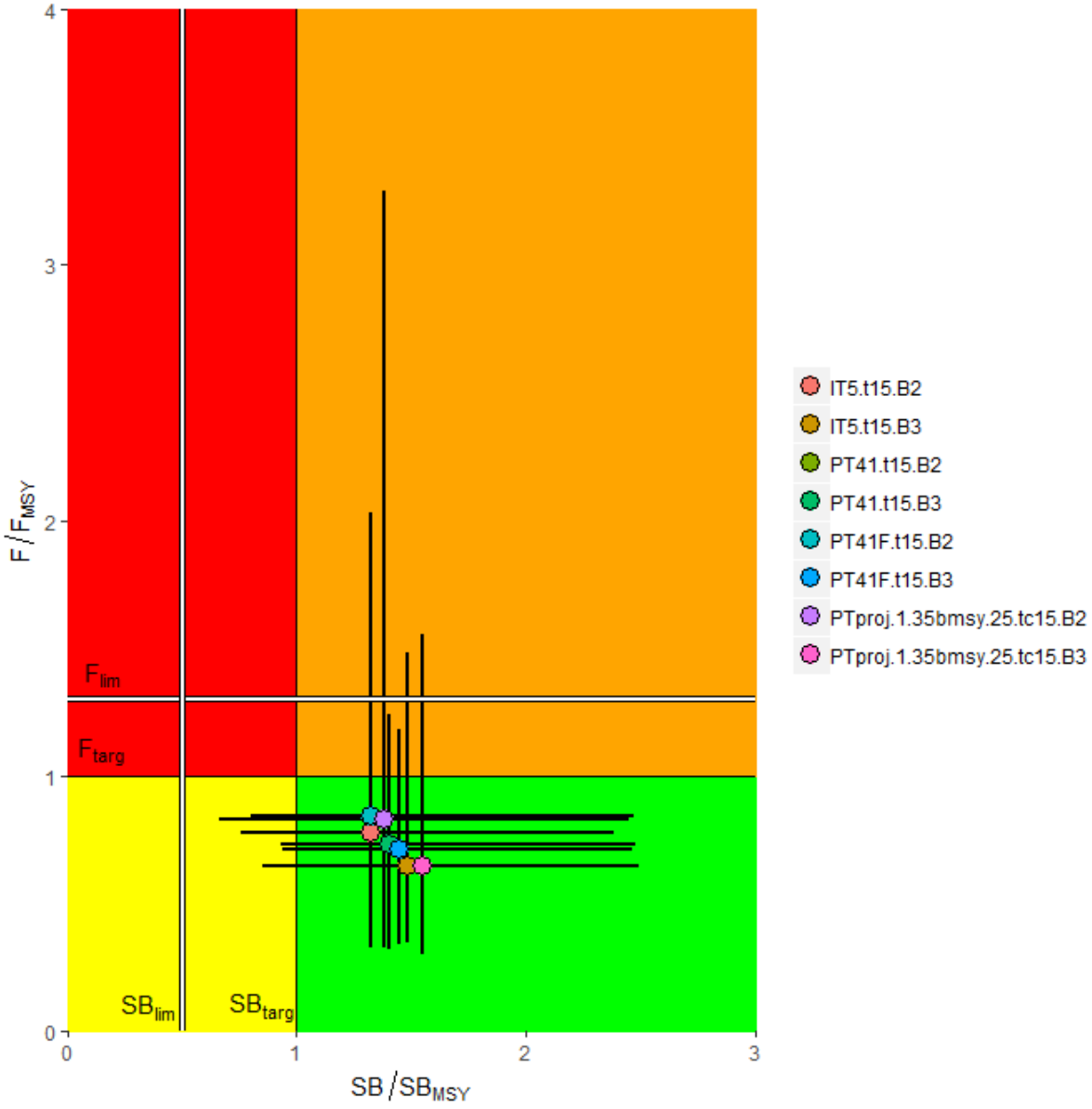

Figure 6. Bigeye reference set (OMrefB18.5) - Kobe plot comparing candidate MPs on the basis of the expected 20 year average (2019-2038) performance. Circle is the median, lines represent 10th-90th percentiles.

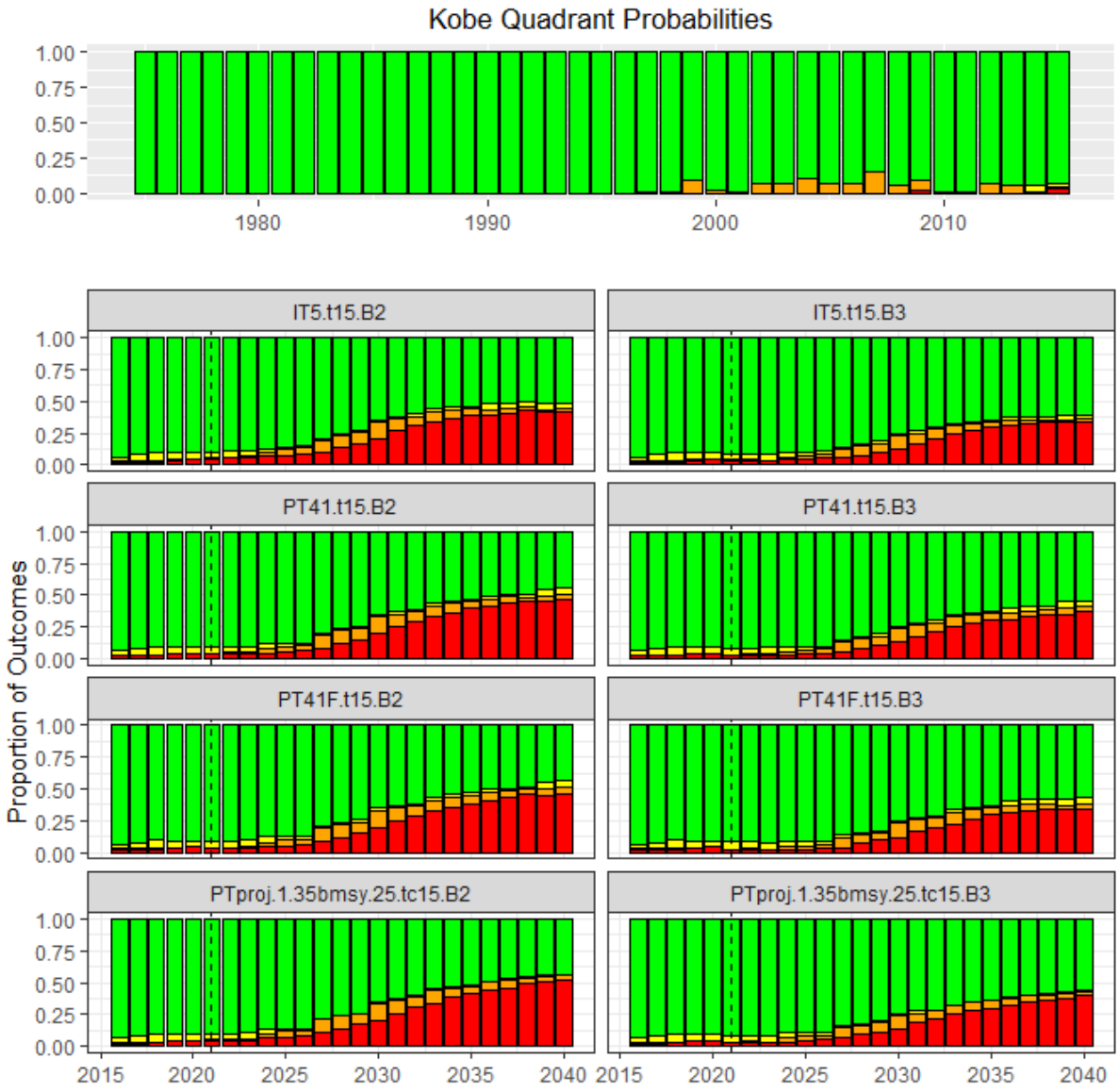

Figure 7. Bigeye reference set (OMrefB19.6) - Proportion of simulations in each of the Kobe quadrants over time for each of the candidate MPs. Historical estimates are included in the top panel. The lower panels are projections, with the first MP application indicated by the broken vertical line (2021).

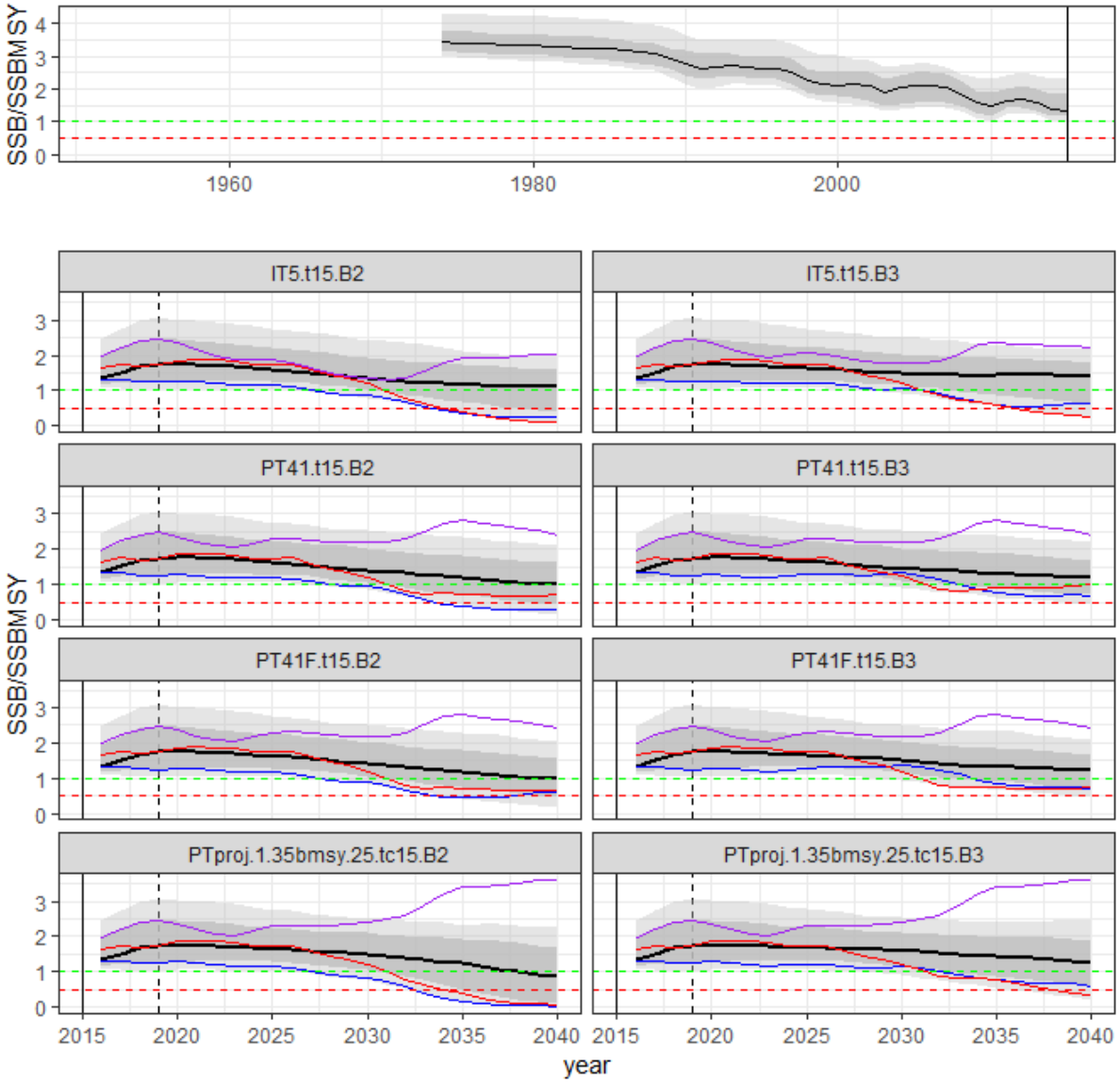

Figure 8. Bigeye reference set (OMrefB19.6) - Time series of spawning stock size for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.

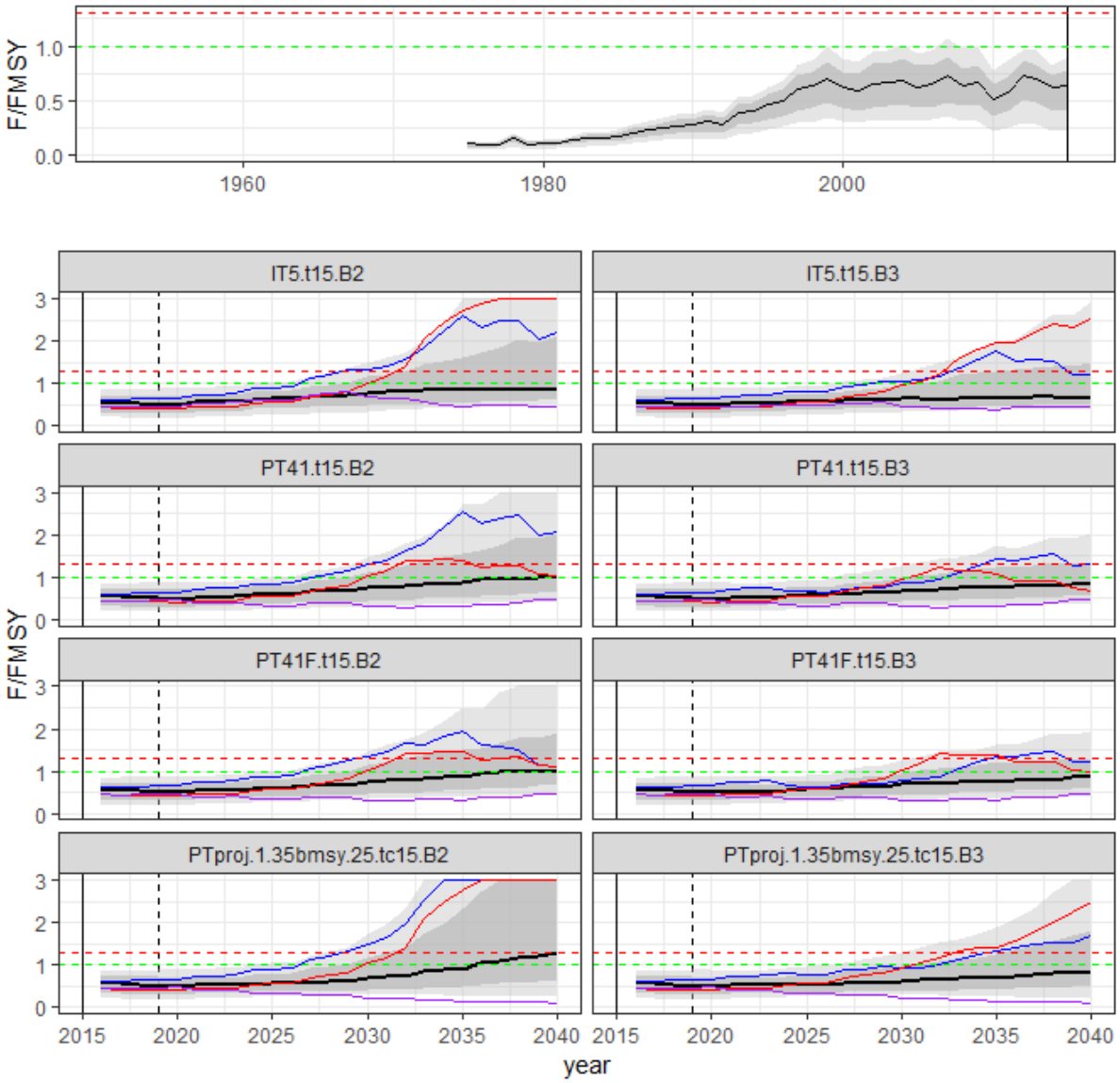

Figure 9. Bigeye reference set (OMrefB19.6) - Time series of fishing intensity (Upper bound truncated at F = 3) for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.

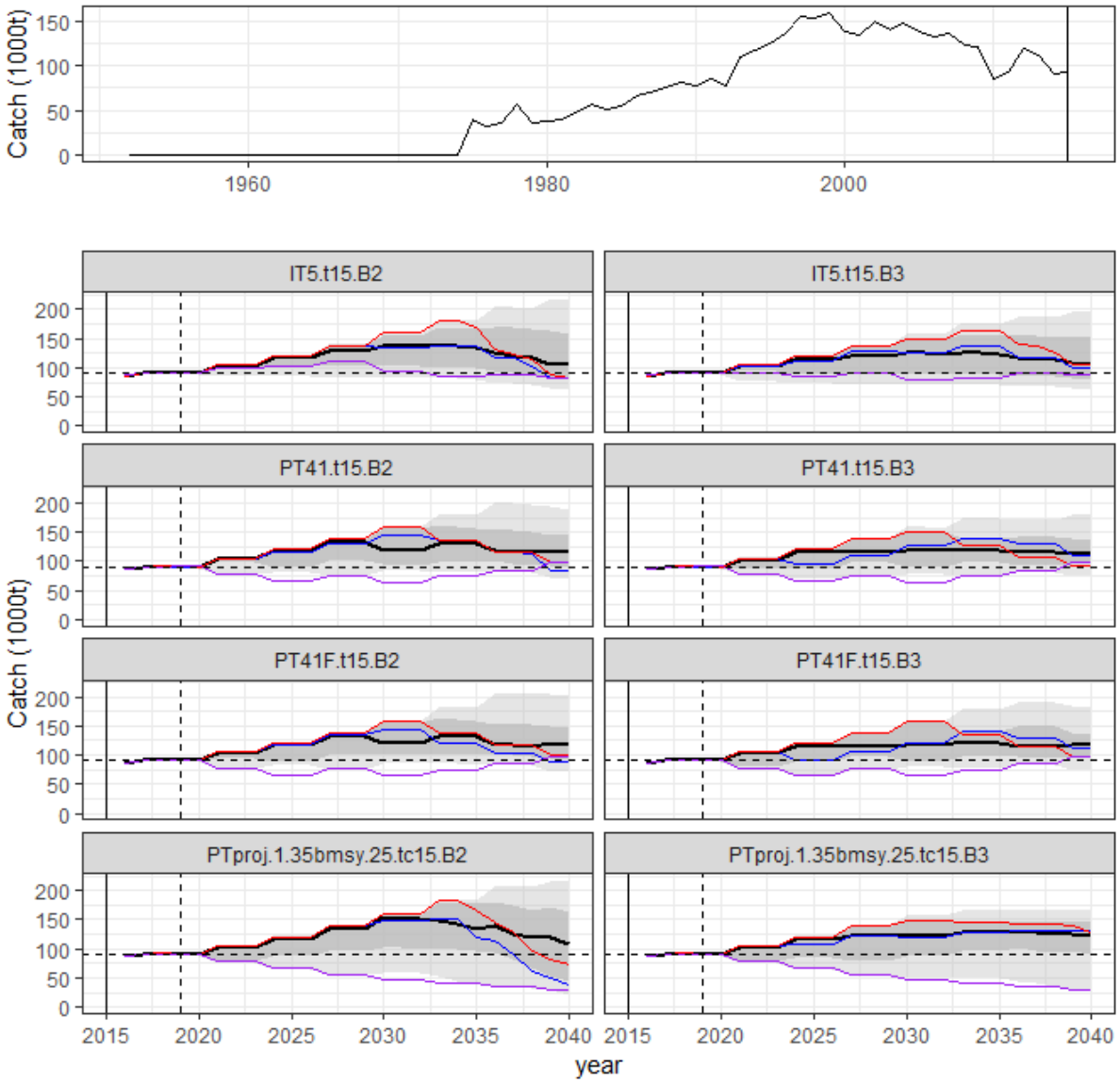

Figure 10. Bigeye reference set (OMrefB19.6) - Time series of catch for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. The broken black horizontal line represents recent (2016) catch. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.

Table 1. Bigeye reference set (OMrefB19.6) - Performance of candidate MPs with respect to key performance measures (averaged over the period 2021-2040). Shading indicates the relative performance (darker = better).

	Performance Measure				
Management Procedure	SB/SB_{MSY}	Prob(Green)	Prob(SB>limit)	Mean Catch	Catch Variability
MB2	1.32 (1.03-1.98)	0.68	0.92	116.4 (99.1-132.7)	5.25
MB3	1.40 (1.13-2.02)	0.75	0.97	112.9 (96.0-128.0)	4.97
MrcB2	1.38 (0.98-2.01)	0.67	0.87	119.6 (95.3-144.1)	5.25
MrcB3	1.55 (1.14-2.07)	0.75	0.95	117.1 (91.1-133.7)	4.08
DB2	1.33 (1.01-1.91)	0.69	0.92	120.7 (100.7-139.8)	4.56
DB3	1.48 (1.14-2.00)	0.76	0.95	115.8 (91.3-134.2)	4.36
MfB2	1.33 (1.03-1.96)	0.68	0.93	117.6 (100.2-133.8)	5.25
MfB3	1.45 (1.14-2.01)	0.76	0.97	113.0 (95.9-127.7)	5.14

Table 2a. Bigeye reference set (OMrefB19.6) - Candidate MP performance for standard IOTC performance measures for the year 2021.

Status : maximise stock status		**1 year average**							
		MB2	**MB3**	**MrcB2**	**MrcB3**	**DB2**	**DB3**	**MfB2**	**MfB3**
Mean spawner biomass relative to pristine	SB/SB_0	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
Minimum spawner biomass relative to pristine	SB/SB_0	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
Mean spawner biomass relative to SBMSY	SB/SB_{MSY}	1.75	1.76	1.75	1.76	1.75	1.75	1.75	1.76
Mean fishing mortality relative to FMSY	F/F_{tar}	0.54	0.53	0.52	0.51	0.56	0.54	0.53	0.52
Mean fishing mortality relative to target	F/F_{MSY}	0.54	0.53	0.52	0.51	0.56	0.54	0.53	0.52
Probability of being in Kobe green quadrant	SB,F	0.92	0.93	0.91	0.92	0.91	0.92	0.92	0.93
Probability of being in Kobe red quadrant	SB,F	0.04	0.03	0.04	0.03	0.05	0.04	0.03	0.02
Safety : maximise the probability of remaining above low stock status (i.e. minimise risk)									
Probability of spawner biomass being above 20% of SB0	SB	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Probability of spawner biomass being above BLim	SB	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Yield : maximise catches across regions and gears									
Mean catch (1000 t)	C	103.06	102.76	102.91	102.34	103.03	102.52	103.04	102.30
Mean relative CPUE (aggregate)	C	0.82	0.80	0.80	0.79	0.85	0.82	0.82	0.79
Mean catch relative to MSY	C/MSY	0.99	0.99	0.99	1.00	0.99	0.99	0.99	1.00
Stability: maximise stability in catches to reduce commercial uncertainty									
Mean absolute proportional change in catch	C	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
% Catch coefficient of variation	C	NA	NA	NA	NA	NA	NA	NA	NA
Probability of shutdown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table2c. Bigeye reference set (OMrefB19.6) - Candidate MP performance for standard IOTC performance measures for the 5 year period 2021-2025.

Status : maximise stock status		**5 year average**							
		MB2	**MB3**	**MrcB2**	**MrcB3**	**DB2**	**DB3**	**MfB2**	**MfB3**
Mean spawner biomass relative to pristine	SB/SB_0	0.44	0.45	0.45	0.45	0.44	0.45	0.45	0.45
Minimum spawner biomass relative to pristine	SB/SB_0	0.41	0.41	0.42	0.42	0.41	0.41	0.41	0.42
Mean spawner biomass relative to SBMSY	SB/SB_{MSY}	1.69	1.70	1.71	1.72	1.69	1.71	1.70	1.71
Mean fishing mortality relative to FMSY	F/F_{tar}	0.56	0.55	0.54	0.52	0.59	0.56	0.56	0.54
Mean fishing mortality relative to target	F/F_{MSY}	0.56	0.55	0.54	0.52	0.59	0.56	0.56	0.54
Probability of being in Kobe green quadrant	SB,F	0.90	0.92	0.89	0.91	0.89	0.91	0.90	0.92
Probability of being in Kobe red quadrant	SB,F	0.04	0.03	0.05	0.03	0.06	0.04	0.04	0.02
Safety : maximise the probability of remaining above low stock status (i.e. minimise risk)									
Probability of spawner biomass being above 20% of SB0	SB	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Probability of spawner biomass being above BLim	SB	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Yield : maximise catches across regions and gears									
Mean catch (1000 t)	C	108.60	107.77	108.81	107.55	108.40	106.84	108.56	107.16
Mean relative CPUE (aggregate)	C	0.84	0.83	0.82	0.79	0.88	0.84	0.84	0.80
Mean catch relative to MSY	C/MSY	0.96	0.97	0.96	0.98	0.96	0.96	0.97	0.98
Stability: maximise stability in catches to reduce commercial uncertainty									
Mean absolute proportional change in catch	C	6.00	6.00	6.00	6.00	6.00	5.96	6.00	6.00
% Catch coefficient of variation	C	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Probability of shutdown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2d. Bigeye reference set (OMrefB19.6) - Candidate MP performance for standard IOTC performance measures for the 10 year period 2021-2030.

Status : maximise stock status		**10 year average**							
		MB2	**MB3**	**MrcB2**	**MrcB3**	**DB2**	**DB3**	**MfB2**	**MfB3**
Mean spawner biomass relative to pristine	SB/SB_0	0.42	0.43	0.44	0.45	0.41	0.43	0.42	0.43
Minimum spawner biomass relative to pristine	SB/SB_0	0.35	0.36	0.35	0.37	0.34	0.36	0.35	0.36
Mean spawner biomass relative to SBMSY	SB/SB_{MSY}	1.59	1.60	1.62	1.66	1.57	1.61	1.58	1.62
Mean fishing mortality relative to FMSY	F/F_{tar}	0.64	0.60	0.58	0.54	0.67	0.60	0.64	0.58
Mean fishing mortality relative to target	F/F_{MSY}	0.64	0.60	0.58	0.54	0.67	0.60	0.64	0.58
Probability of being in Kobe green quadrant	SB,F	0.84	0.87	0.83	0.87	0.83	0.87	0.84	0.88
Probability of being in Kobe red quadrant	SB,F	0.08	0.05	0.10	0.06	0.10	0.06	0.08	0.05
Safety : maximise the probability of remaining above low stock status (i.e. minimise risk)									
Probability of spawner biomass being above 20% of SB0	SB	0.99	0.99	0.98	0.99	0.99	0.99	0.99	1.00
Probability of spawner biomass being above BLim	SB	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Yield : maximise catches across regions and gears									
Mean catch (1000 t)	C	118.65	110.74	121.47	115.03	118.31	112.07	119.08	109.84
Mean relative CPUE (aggregate)	C	0.90	0.87	0.86	0.83	0.93	0.86	0.89	0.86
Mean catch relative to MSY	C/MSY	0.95	0.97	0.94	0.97	0.93	0.96	0.95	0.99
Stability: maximise stability in catches to reduce commercial uncertainty									
Mean absolute proportional change in catch	C	6.00	6.00	6.00	5.60	5.13	5.08	6.00	6.00
% Catch coefficient of variation	C	0.14	0.12	0.15	0.13	0.12	0.11	0.15	0.13
Probability of shutdown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2e. Bigeye reference set (OMrefB19.6) - Candidate MP performance for standard IOTC performance measures for the 20 year period 2021-2040.

Status : maximise stock status		**20 year average**							
		MB2	**MB3**	**MrcB2**	**MrcB3**	**DB2**	**DB3**	**MfB2**	**MfB3**
Mean spawner biomass relative to pristine	SB/SB_0	0.36	0.38	0.38	0.42	0.36	0.40	0.36	0.38
Minimum spawner biomass relative to pristine	SB/SB_0	0.24	0.28	0.23	0.31	0.26	0.31	0.24	0.28
Mean spawner biomass relative to SBMSY	SB/SB_{MSY}	1.32	1.40	1.38	1.55	1.33	1.48	1.33	1.45
Mean fishing mortality relative to FMSY	F/F_{tar}	0.84	0.73	0.83	0.65	0.78	0.65	0.84	0.71
Mean fishing mortality relative to target	F/F_{MSY}	0.84	0.73	0.83	0.65	0.78	0.65	0.84	0.71
Probability of being in Kobe green quadrant	SB,F	0.68	0.75	0.67	0.75	0.69	0.76	0.68	0.76
Probability of being in Kobe red quadrant	SB,F	0.23	0.17	0.26	0.18	0.24	0.17	0.23	0.16
Safety : maximise the probability of remaining above low stock status (i.e. minimise risk)									
Probability of spawner biomass being above 20% of SB0	SB	0.86	0.92	0.83	0.90	0.85	0.90	0.87	0.93
Probability of spawner biomass being above BLim	SB	0.92	0.97	0.87	0.95	0.92	0.95	0.93	0.97
Yield : maximise catches across regions and gears									
Mean catch (1000 t)	C	116.43	112.89	119.61	117.09	120.69	115.82	117.58	112.97
Mean relative CPUE (aggregate)	C	0.97	0.92	0.95	0.90	0.95	0.88	0.97	0.92
Mean catch relative to MSY	C/MSY	0.82	0.87	0.81	0.89	0.79	0.87	0.82	0.89
Stability: maximise stability in catches to reduce commercial uncertainty									
Mean absolute proportional change in catch	C	5.25	4.97	5.25	4.08	4.56	4.36	5.25	5.14
% Catch coefficient of variation	C	0.18	0.16	0.24	0.16	0.18	0.16	0.18	0.17
Probability of shutdown	C	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00

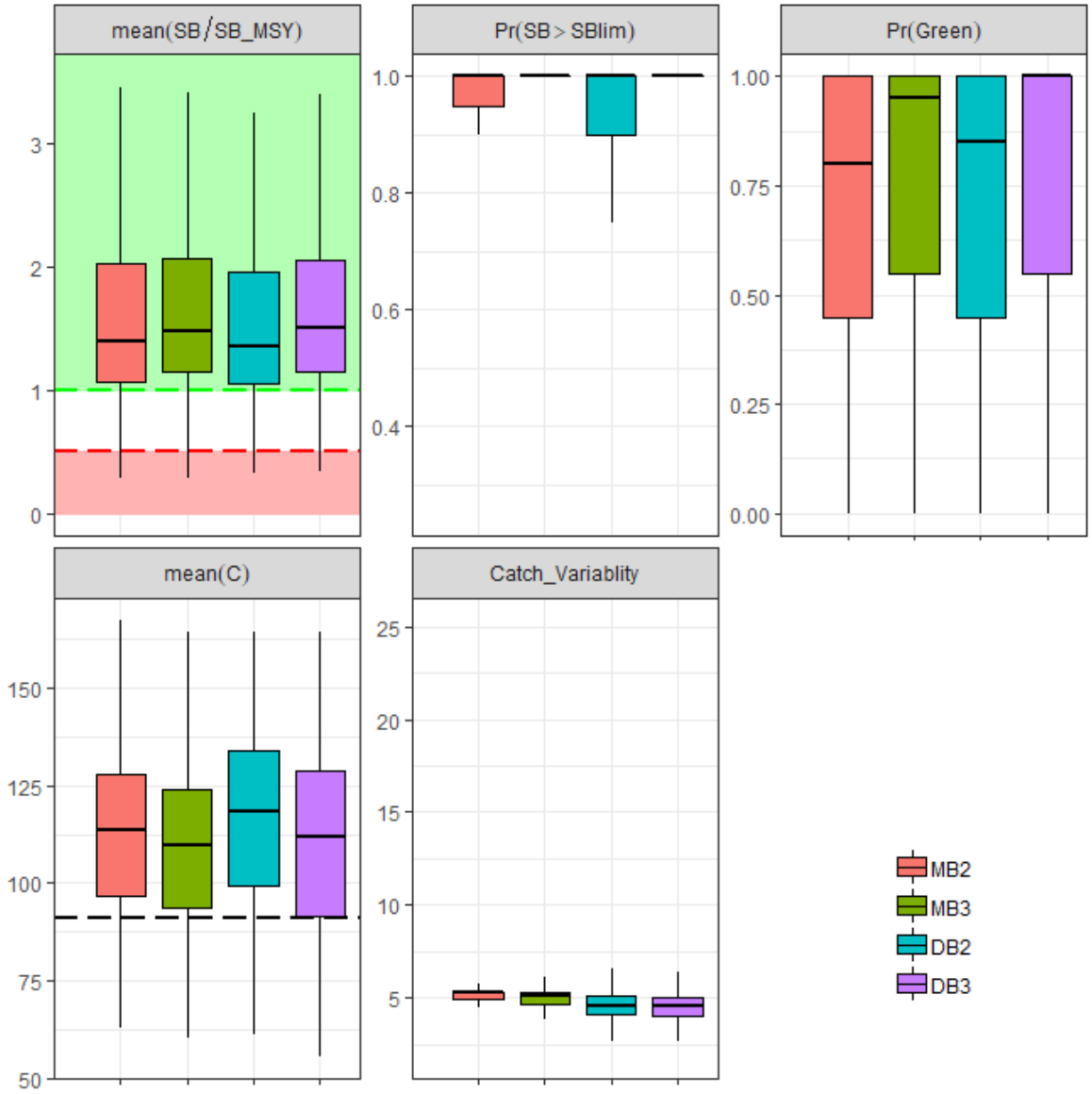

*Figure 11. Bigeye robustness test (*OMrobB19.6.ICV30 *– CPUE observation error CV = 30%) - Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2021 - 2040. Horizontal line is the median, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB$_{MSY}$ performance measure. The horizontal dashed black line is 2017 catch.*

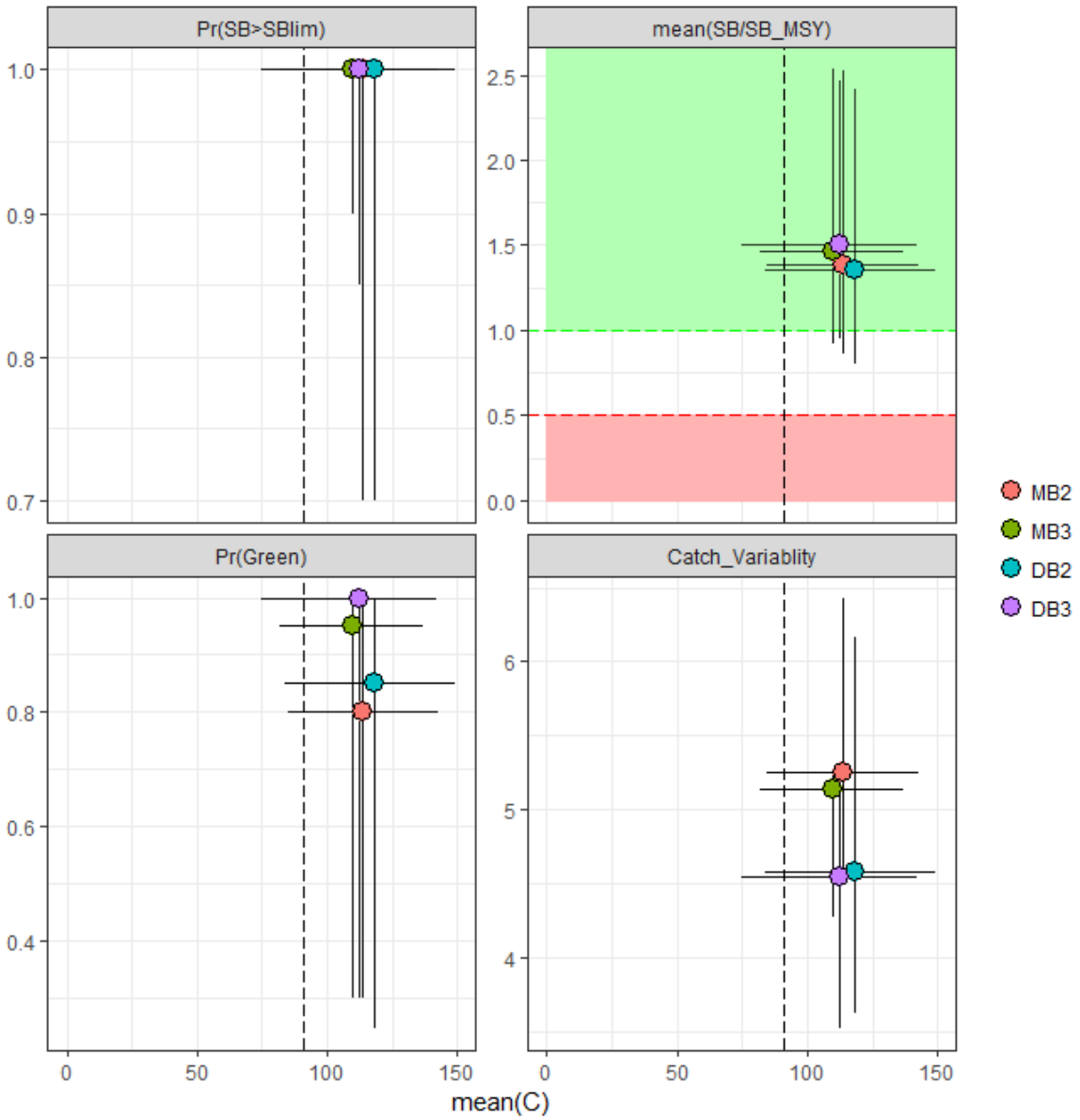

*Figure 12. Bigeye robustness set (*OMrobB19.6.ICV30 *– CPUE observation error CV = 30%) - Trade-off plots comparing candidate MPs with respect to catch on the X-axis, and 4 other key performance measures on the Y-axis, each averaged over the period 2021 - 2040. Circle is the median, lines represent 10th-90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB_{MSY} performance measure. The dashed vertical black line is 2017 catch.*

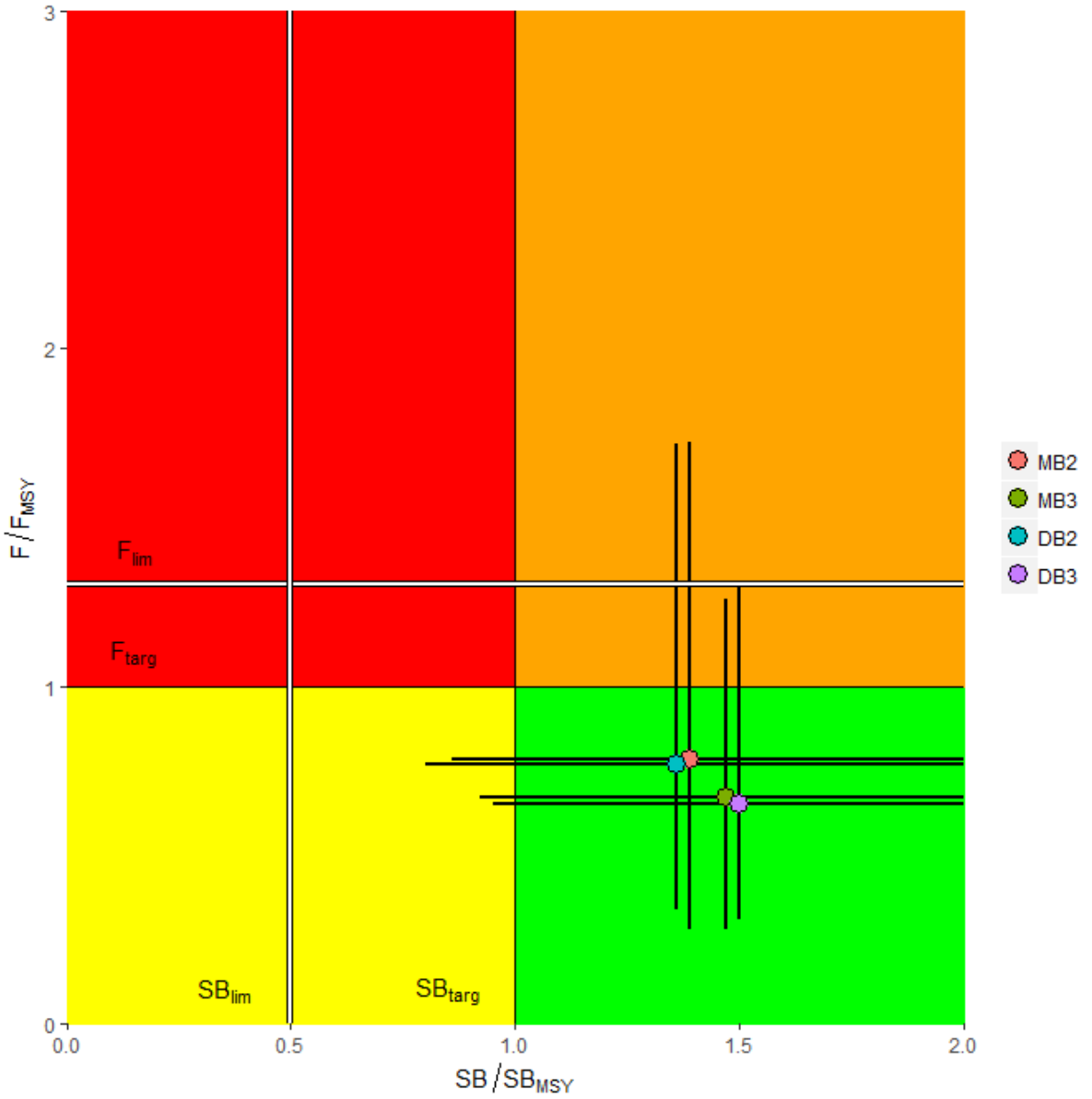

*Figure 13. Bigeye robustness set (*OMrobB19.6.ICV30 *– CPUE observation error CV = 30%) - Kobe plot comparing candidate MPs on the basis of the expected 20 year average (2021-2040) performance. Circle is the median, lines represent 10th-90th percentiles.*

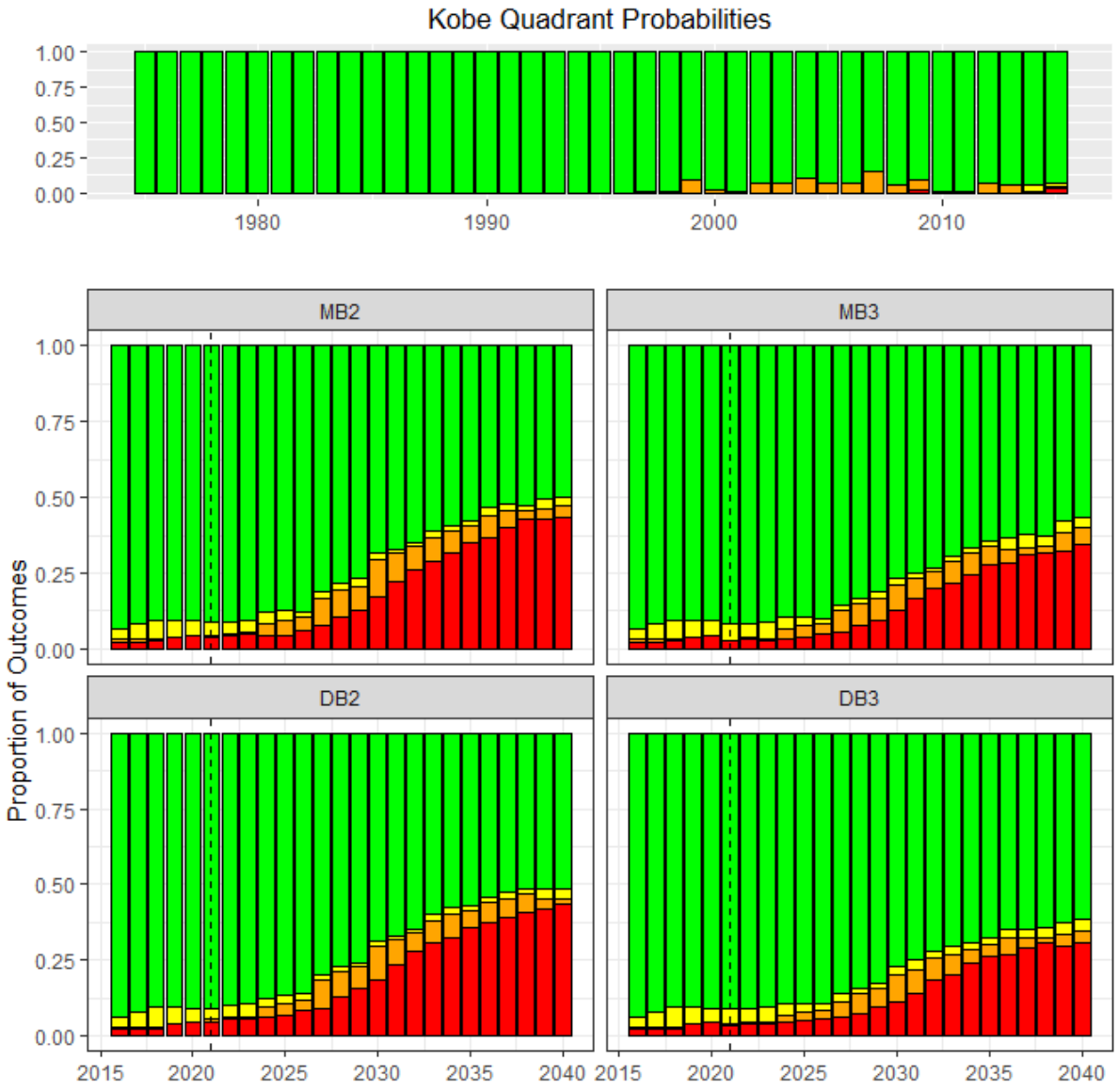

*Figure 14. Bigeye robustness set (*OMrobB19.6.ICV30 *– CPUE observation error CV = 30%) - Proportion of simulations in each of the Kobe quadrants over time for each of the candidate MPs. Historical estimates are included in the top panel. The lower panels are projections, with the first MP application indicated by the broken vertical line (2019).*

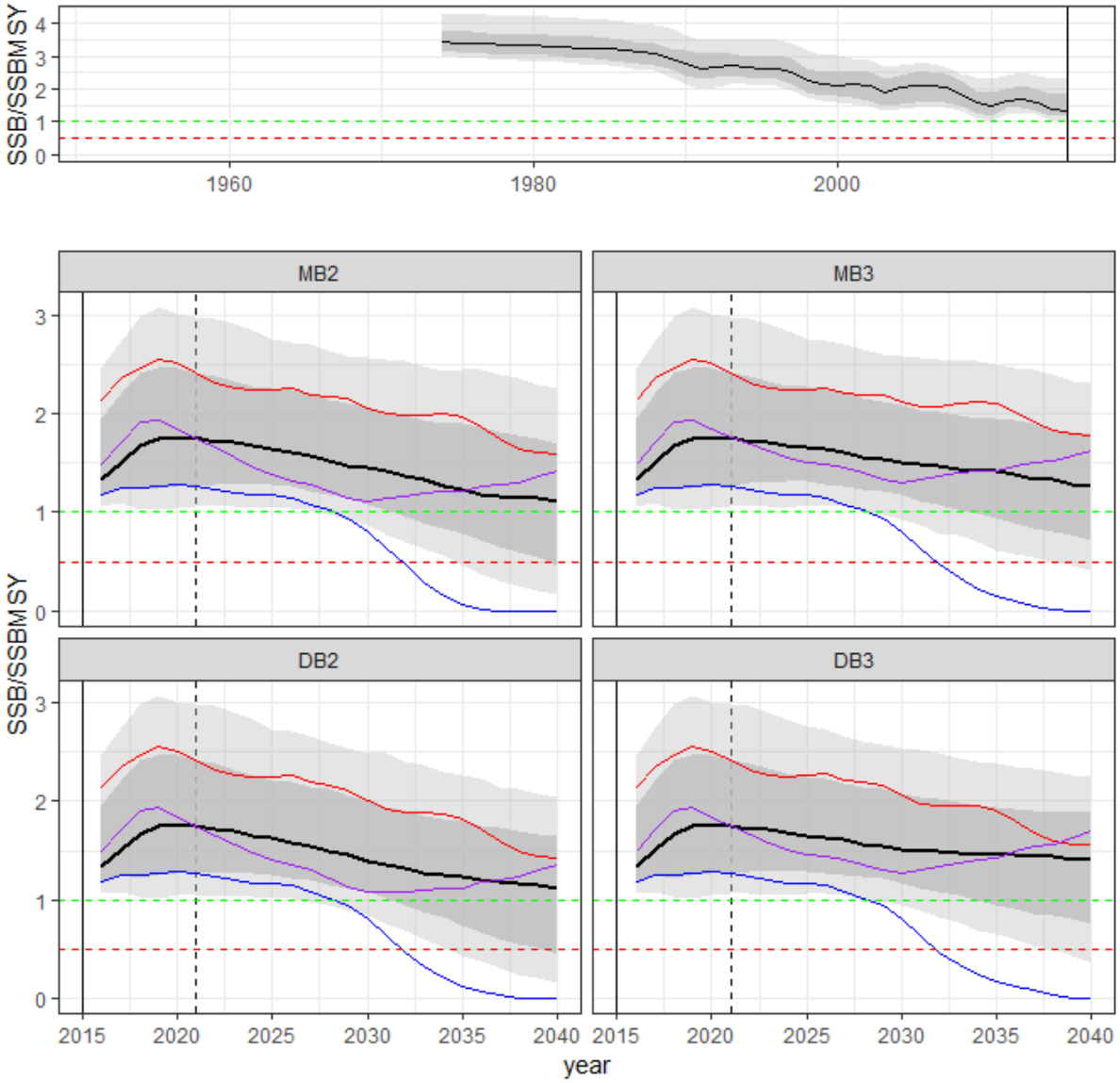

*Figure 15. Bigeye robustness set (*OMrobB19.6.ICV30 *– CPUE observation error CV = 30%) - Time series of spawning stock size for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

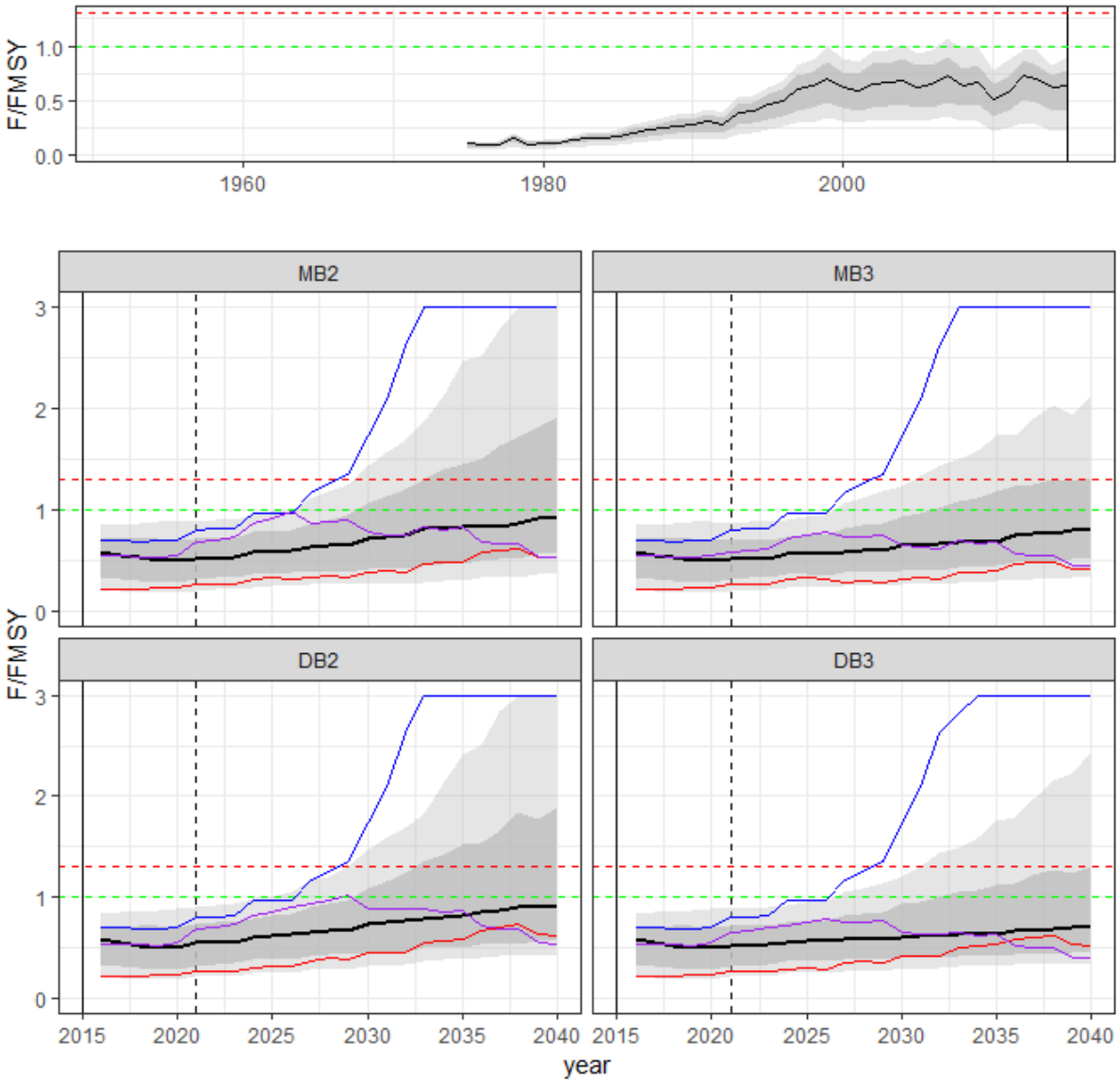

*Figure 16. Bigeye robustness set (*OMrobB19.6.ICV30 *– CPUE observation error CV = 30%) - Time series of fishing intensity (Upper bound truncated at F = 3) for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

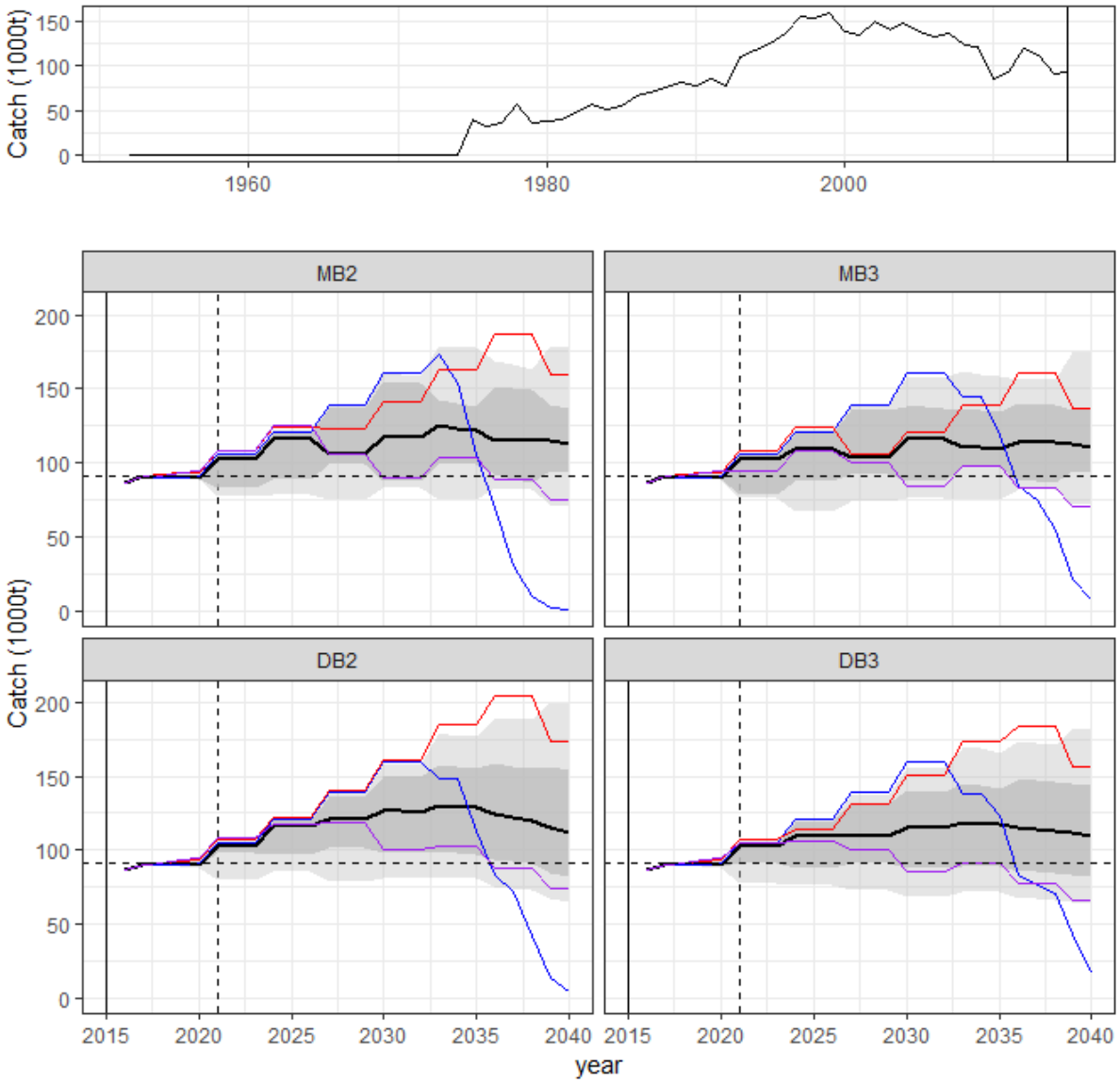

*Figure 17. Bigeye robustness set (*OMrobB19.6.ICV30 *– CPUE observation error CV = 30%) - Time series of catch for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. The broken black horizontal line represents recent (2016) catch. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

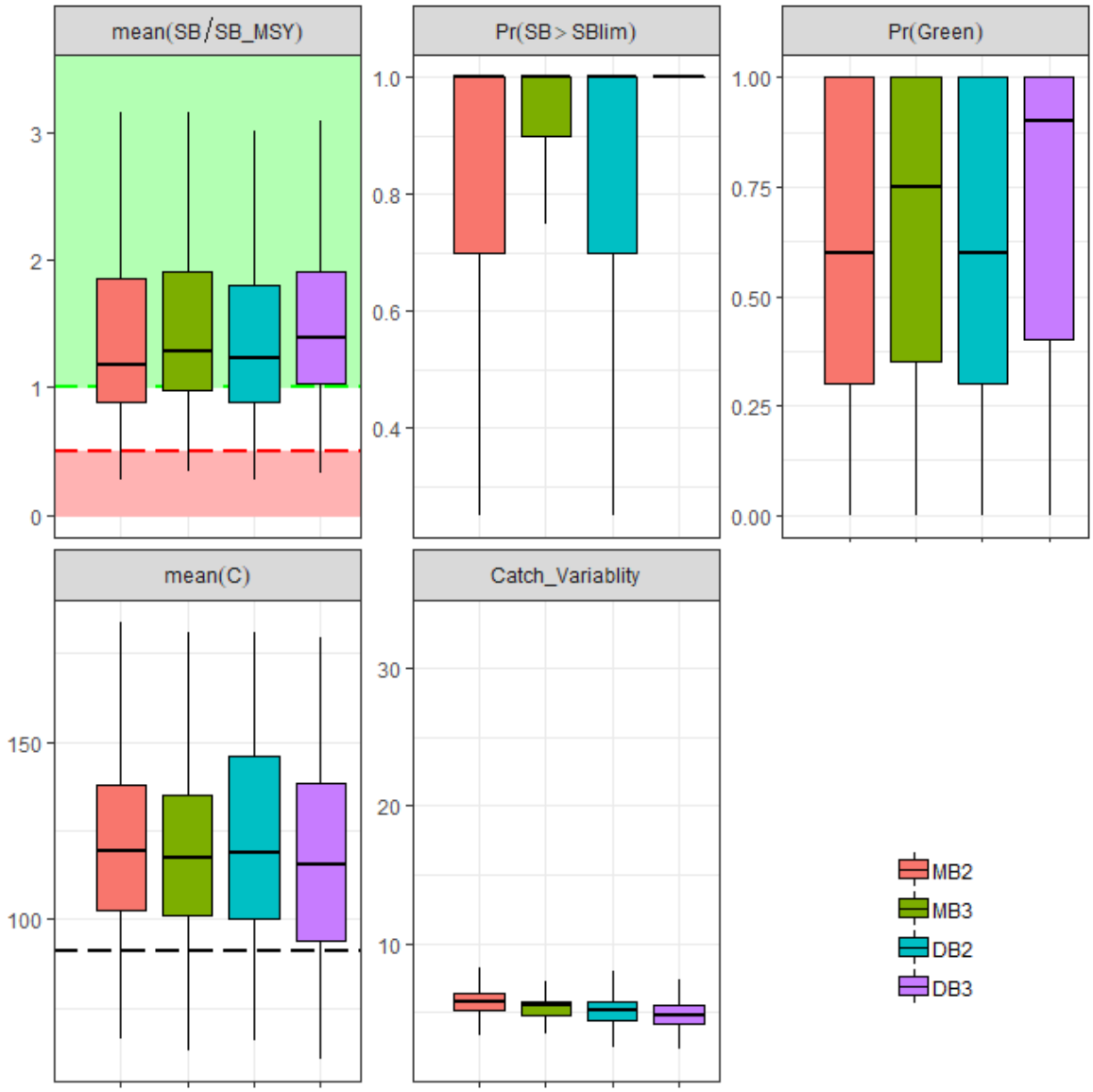

*Figure 18. Bigeye robustness test (*OMrobB19.6.10overRep *– projected 10% reported over-catch) - Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2021 - 2040. Horizontal line is the median, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB_{MSY} performance measure. The horizontal dashed black line is 2017 catch.*

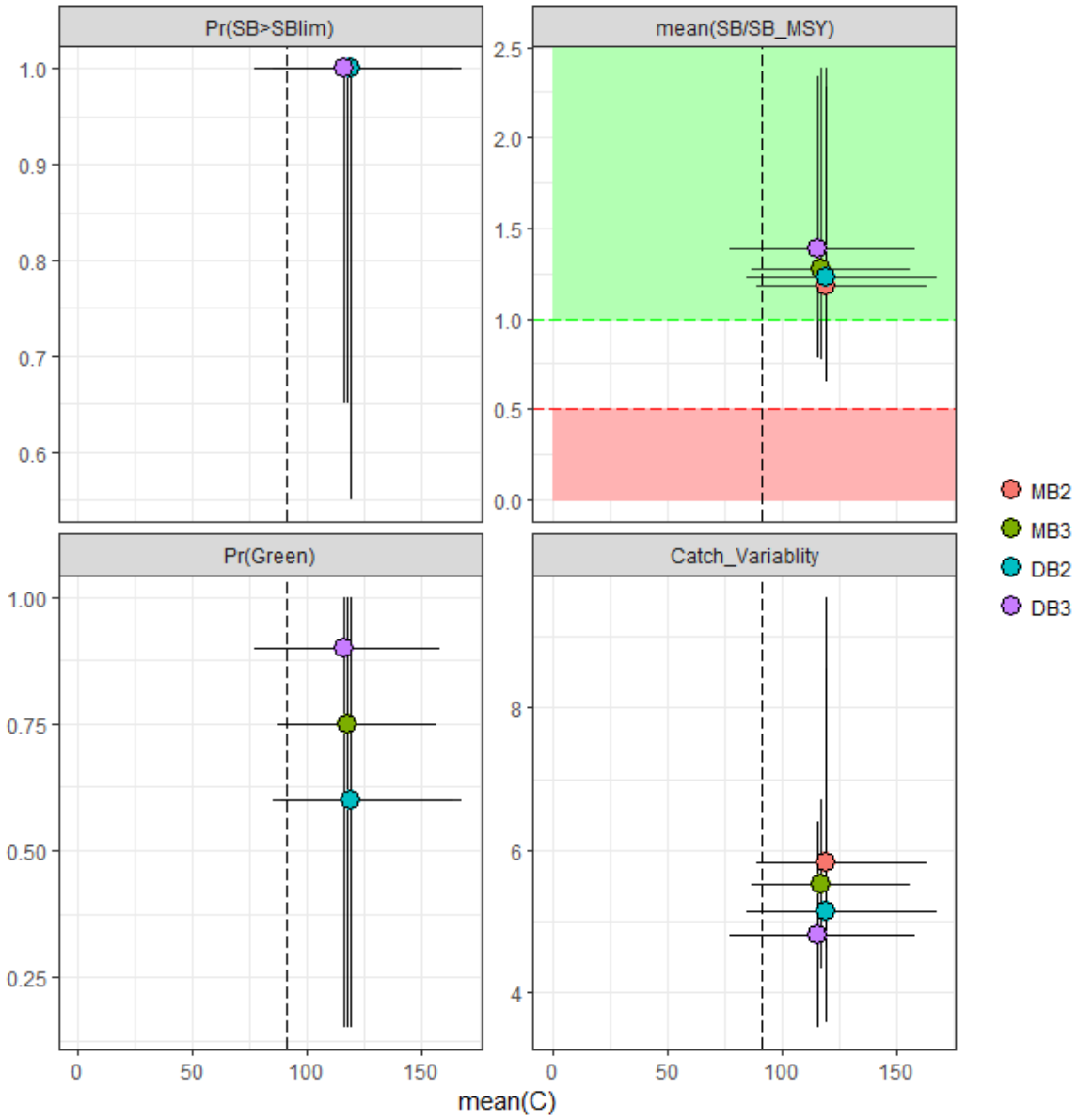

*Figure 19. Bigeye robustness set (*OMrobB19.6.10overRep *– projected 10% reported over-catch) - Trade-off plots comparing candidate MPs with respect to catch on the X-axis, and 4 other key performance measures on the Y-axis, each averaged over the period 2021 - 2040. Circle is the median, lines represent 10th-90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB_{MSY} performance measure. The dashed vertical black line is 2017 catch.*

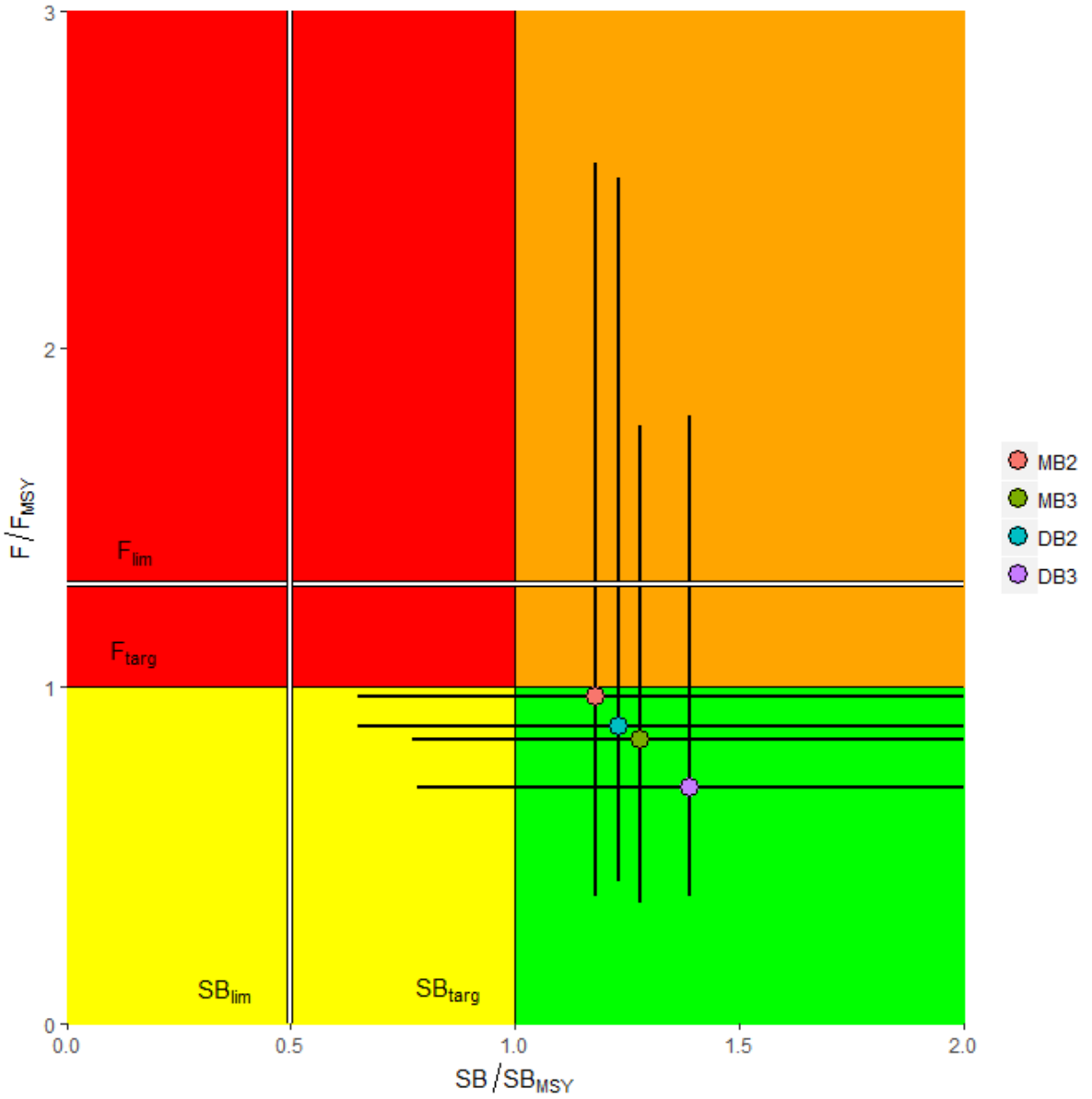

*Figure 20. Bigeye robustness set (*OMrobB19.6.10overRep *– projected 10% reported over-catch) - Kobe plot comparing candidate MPs on the basis of the expected 20 year average (2021-2040) performance. Circle is the median, lines represent 10th-90th percentiles.*

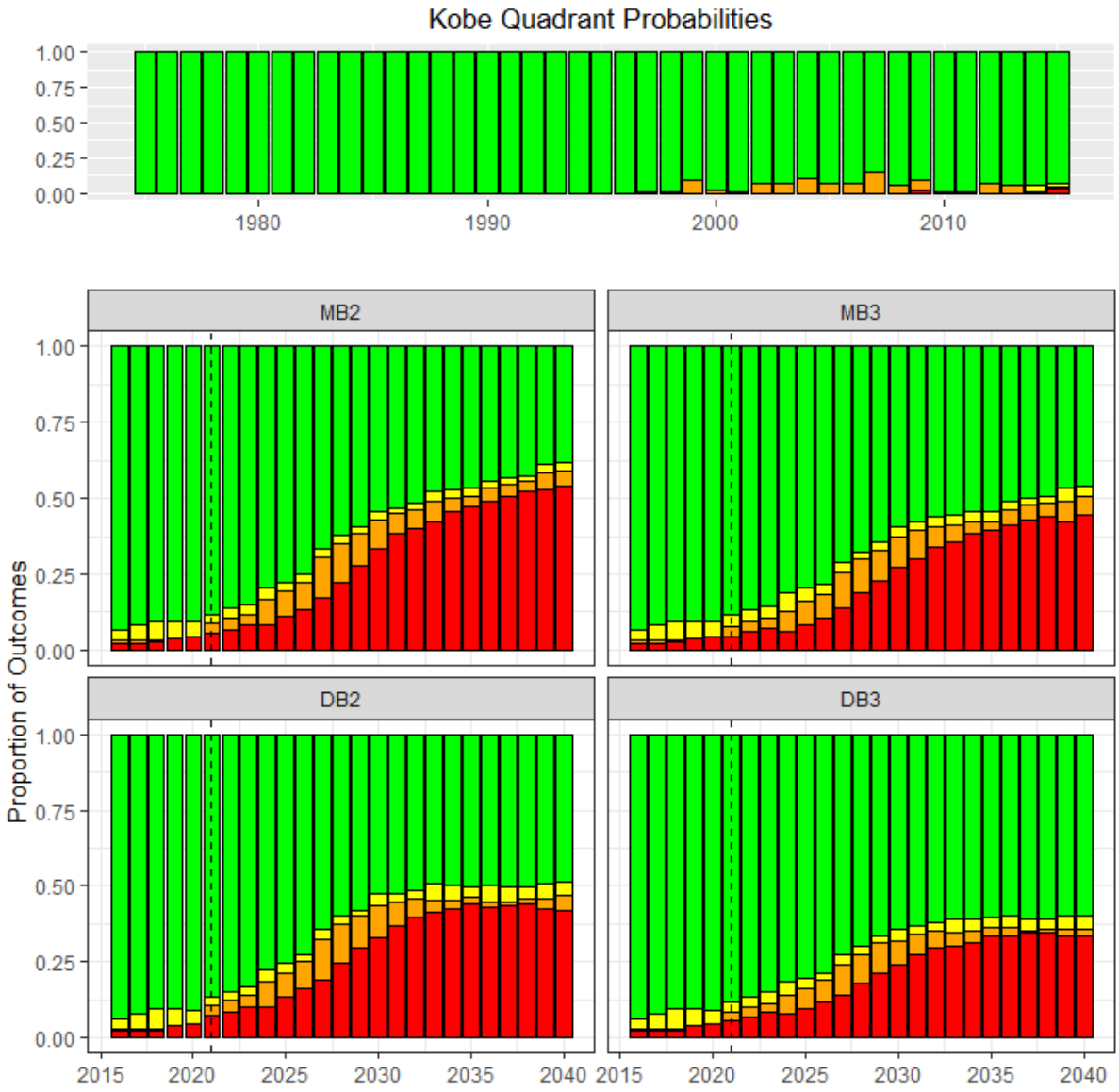

*Figure 21. Bigeye robustness set (*OMrobB19.6.10overRep *– projected 10% reported over-catch) - Proportion of simulations in each of the Kobe quadrants over time for each of the candidate MPs. Historical estimates are included in the top panel. The lower panels are projections, with the first MP application indicated by the broken vertical line (2019).*

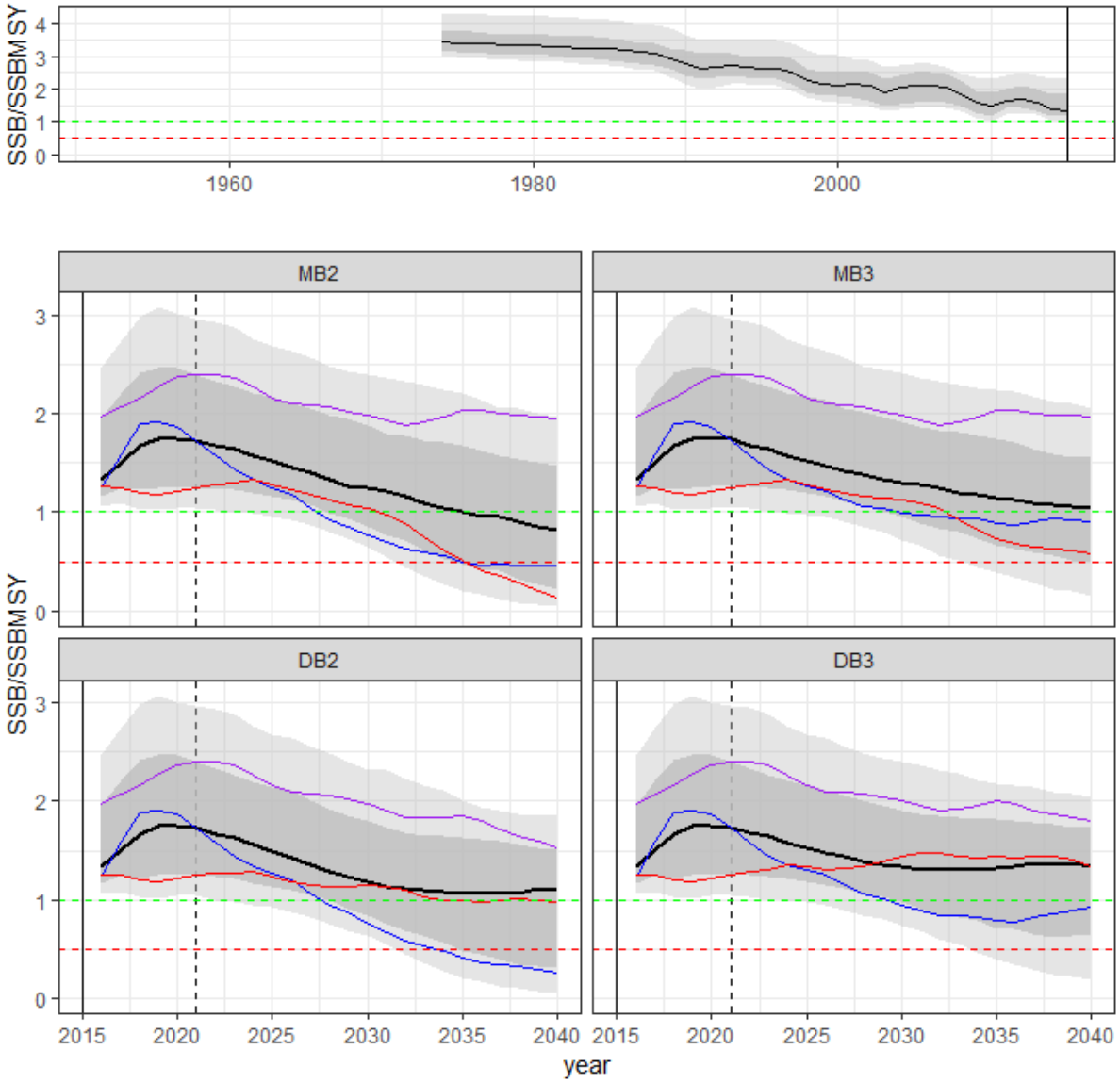

*Figure 22. Bigeye robustness set (*OMrobB19.6.10overRep *– projected 10% reported over-catch) - Time series of spawning stock size for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

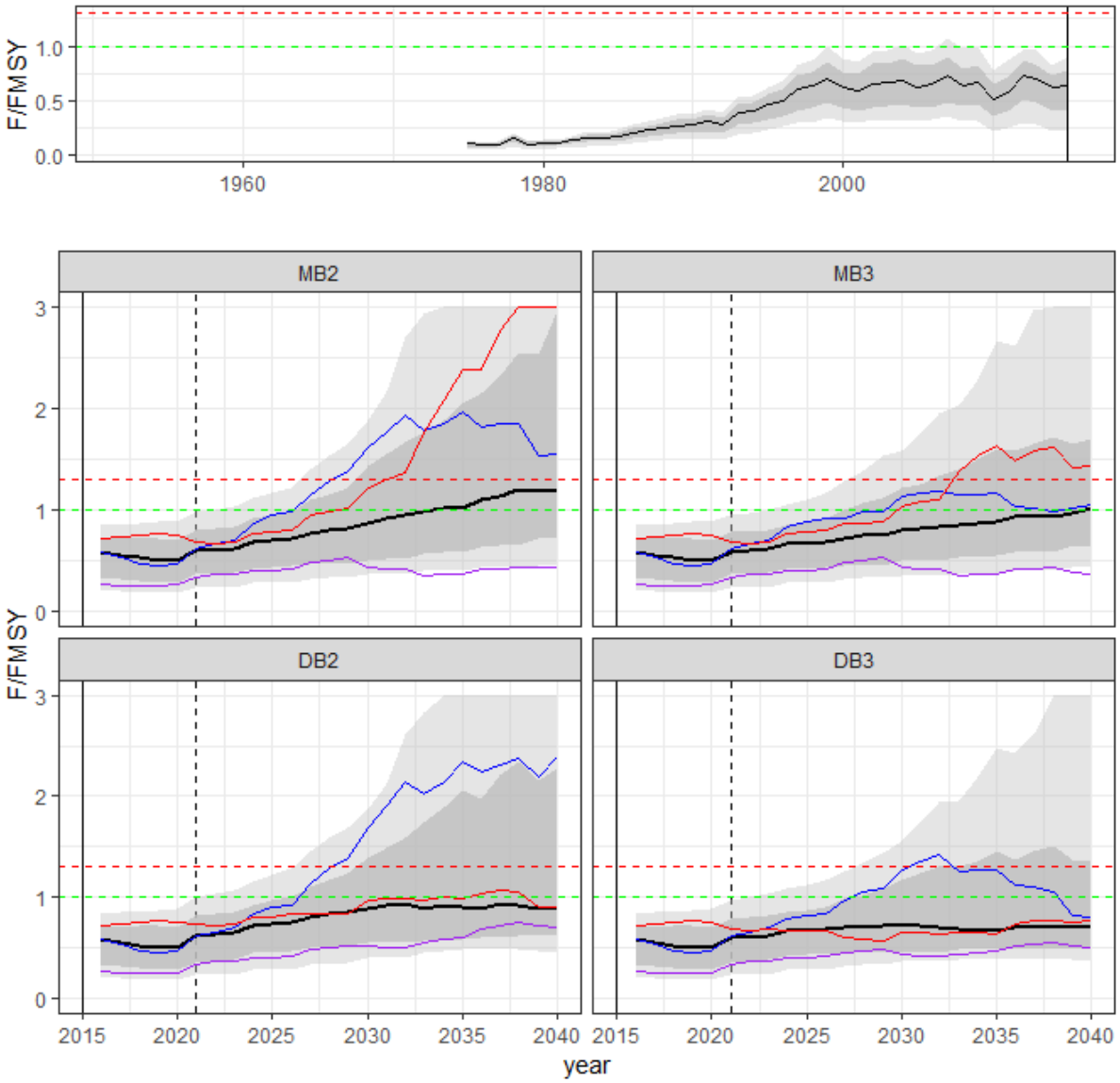

*Figure 23. Bigeye robustness set (*OMrobB19.6.10overRep *– projected 10% reported over-catch) - Time series of fishing intensity (Upper bound truncated at F = 3) for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

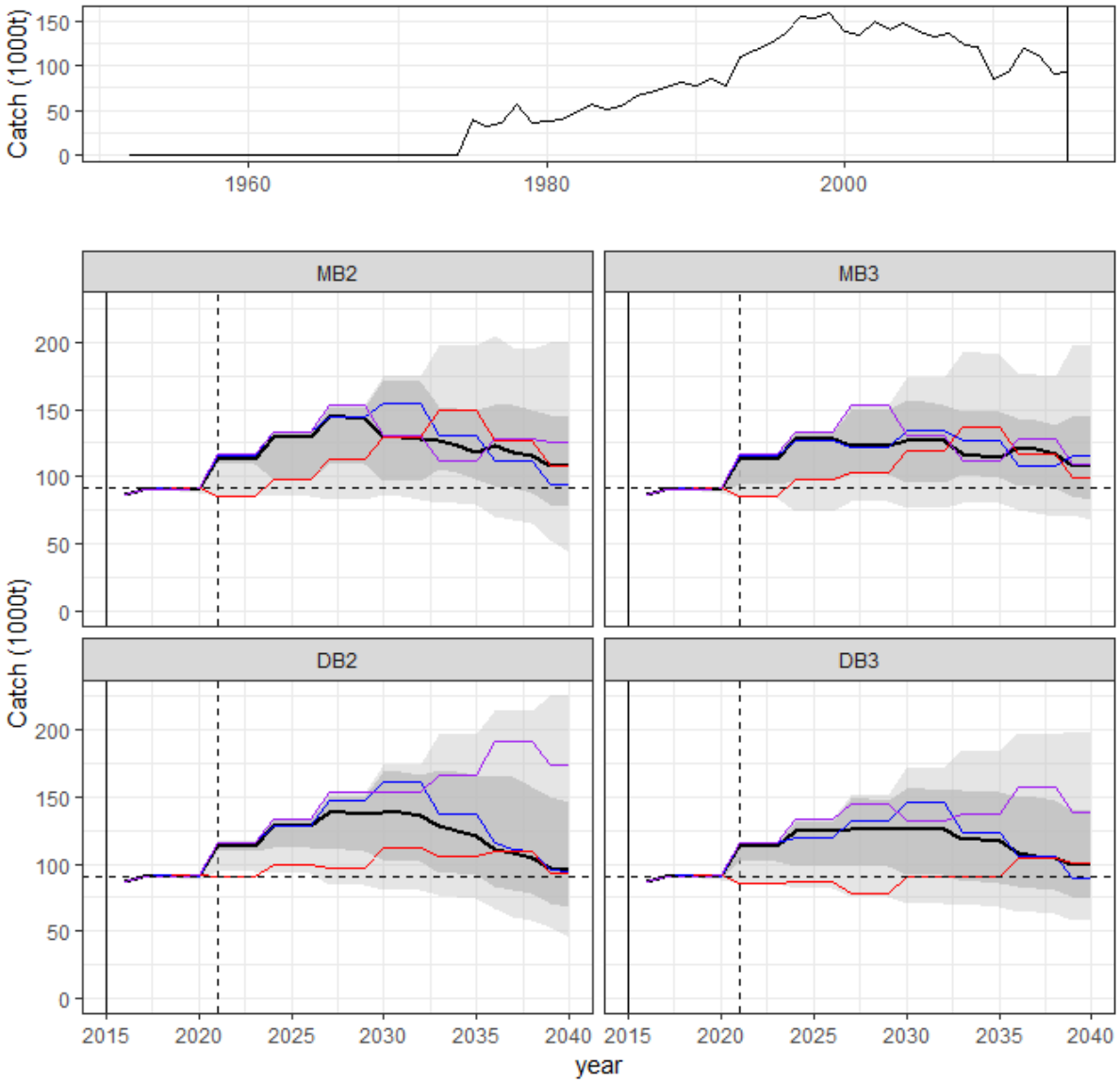

*Figure 24. Bigeye robustness set (*OMrobB19.6.10overRep *– projected 10% reported over-catch) - Time series of catch for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. The broken black horizontal line represents recent (2016) catch. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

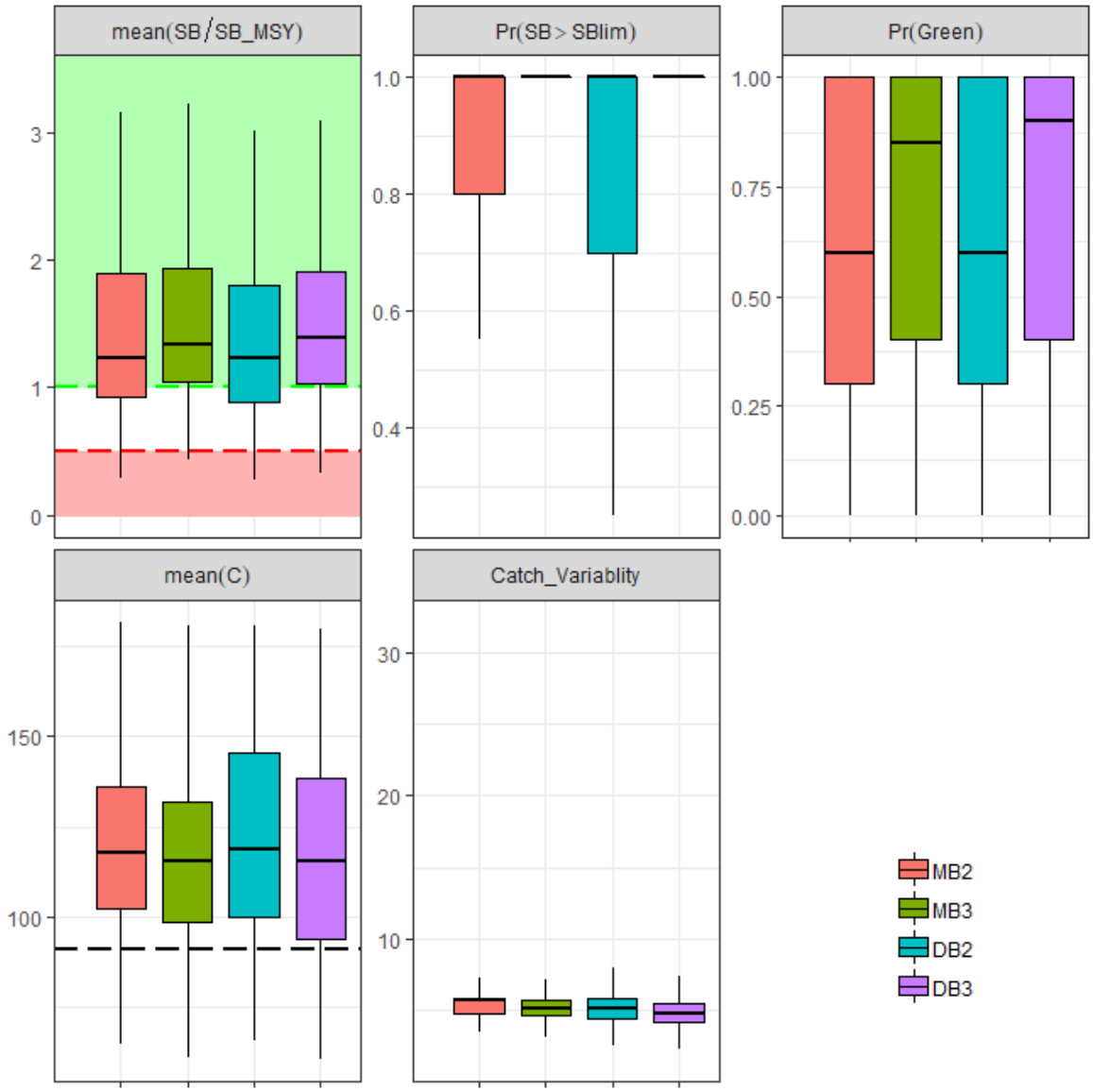

*Figure 25. Bigeye robustness test (*OMrobB19.6.10overIUU *– projected 10% unreported over-catch) - Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2021 - 2040. Horizontal line is the median, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB_{MSY} performance measure. The horizontal dashed black line is 2017 catch.*

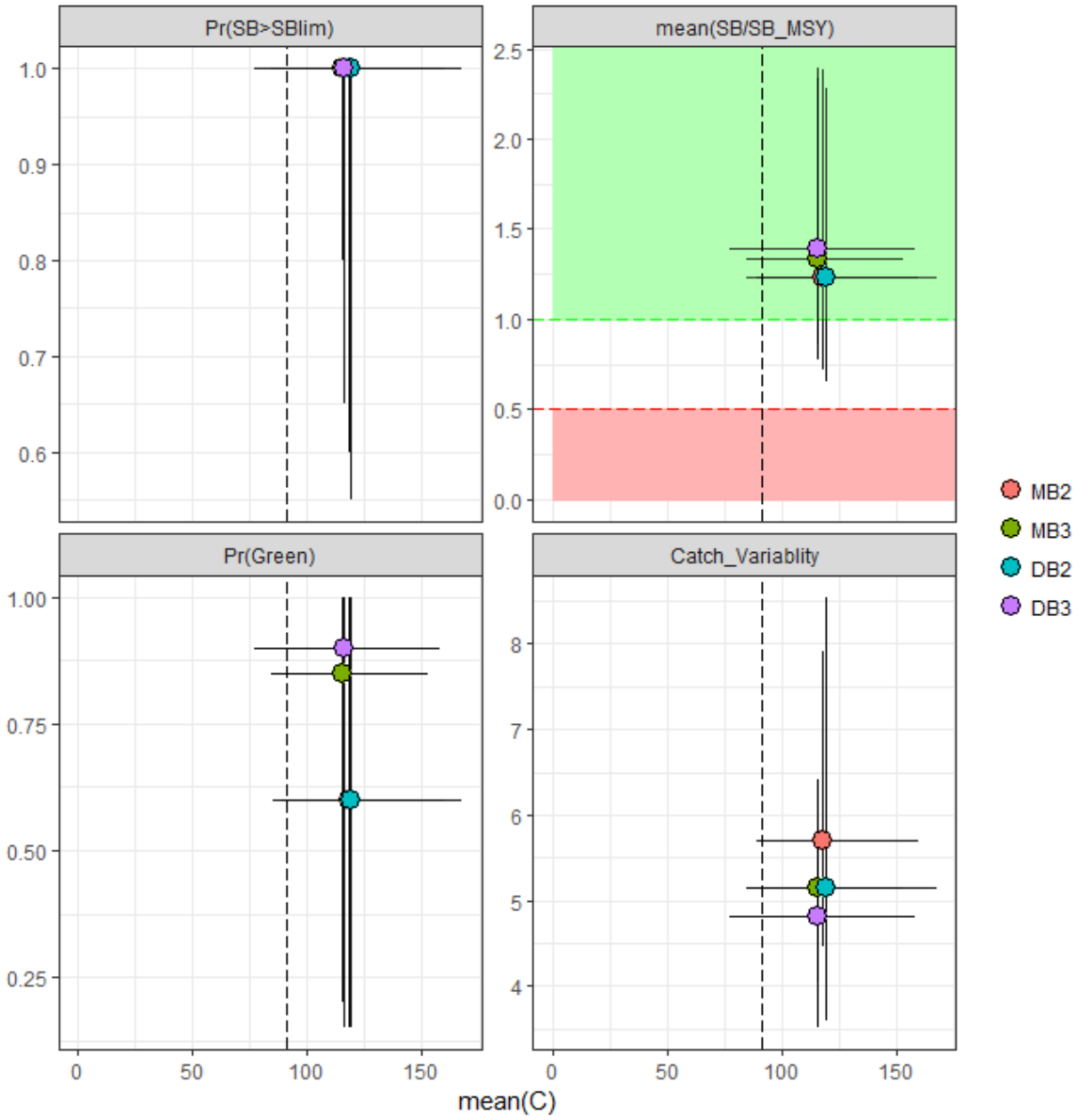

*Figure 26. Bigeye robustness set (*OMrobB19.6.10overIUU *– projected 10% unreported over-catch) - Trade-off plots comparing candidate MPs with respect to catch on the X-axis, and 4 other key performance measures on the Y-axis, each averaged over the period 2021 - 2040. Circle is the median, lines represent 10th-90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB_{MSY} performance measure. The dashed vertical black line is 2017 catch.*

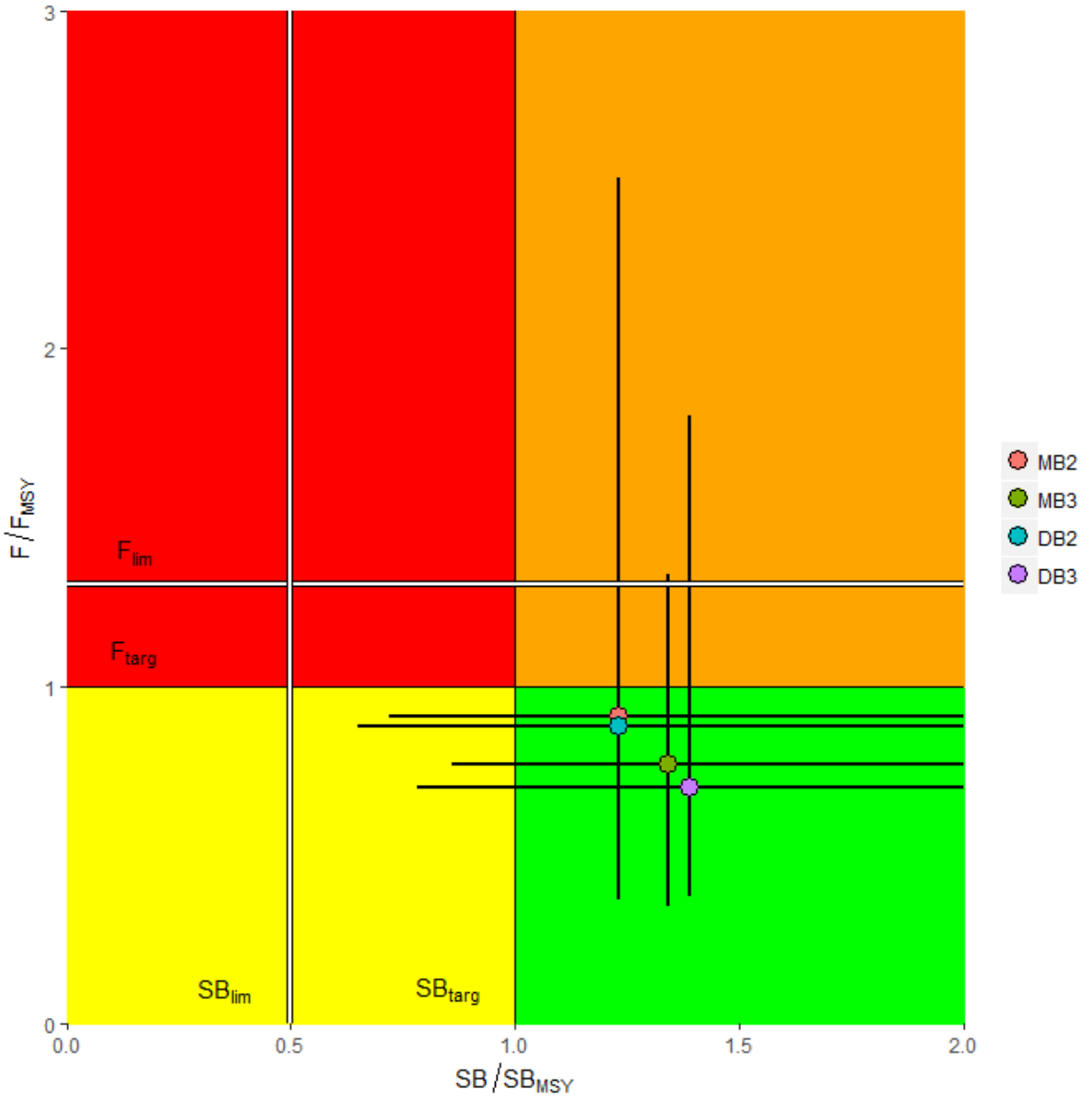

*Figure 27. Bigeye robustness set (*OMrobB19.6.10overIUU *– projected 10% unreported over-catch) - Kobe plot comparing candidate MPs on the basis of the expected 20 year average (2021-2040) performance. Circle is the median, lines represent 10th-90th percentiles.*

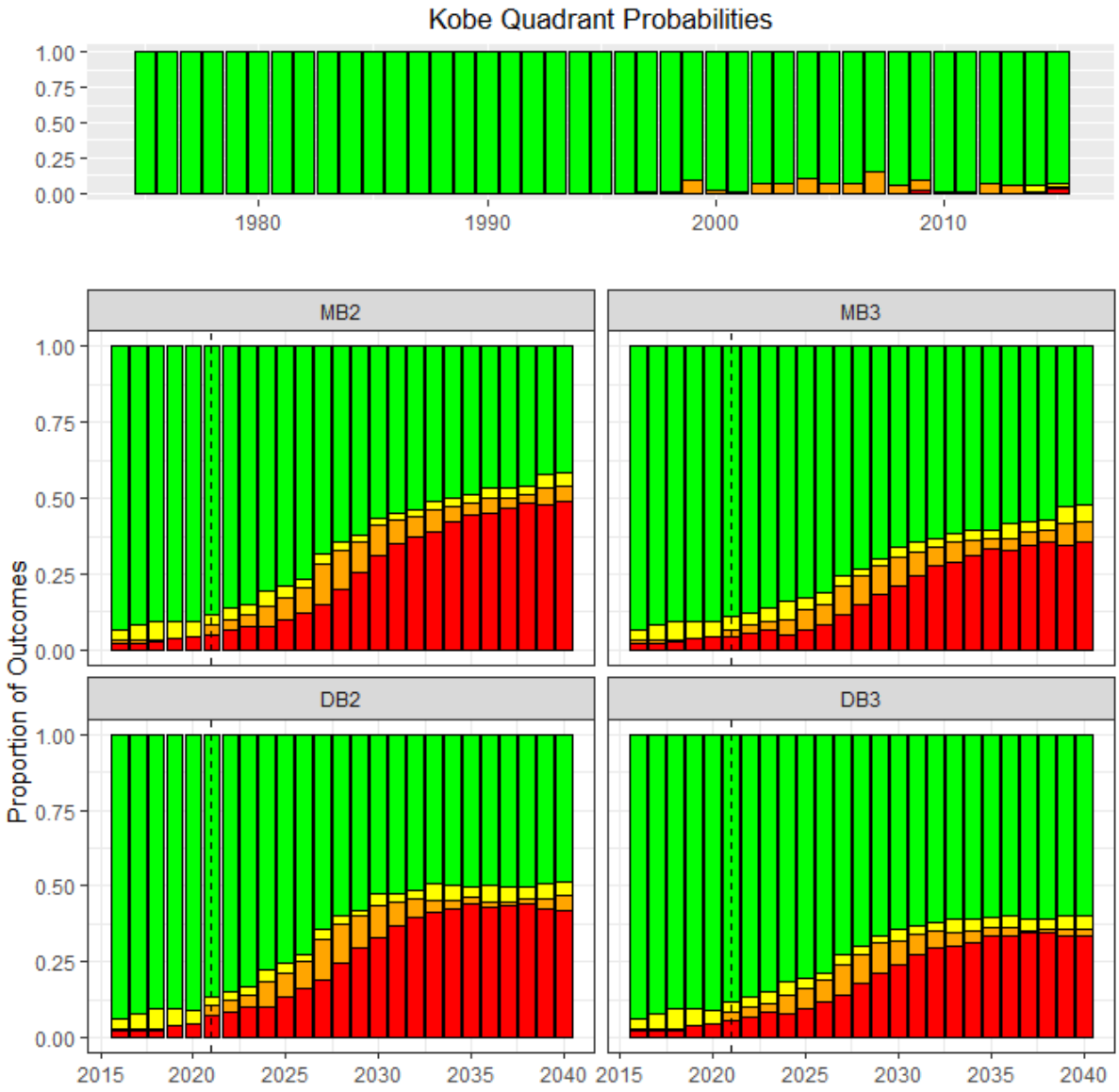

*Figure 28. Bigeye robustness set (*OMrobB19.6.10overIUU *– projected 10% unreported over-catch) - Proportion of simulations in each of the Kobe quadrants over time for each of the candidate MPs. Historical estimates are included in the top panel. The lower panels are projections, with the first MP application indicated by the broken vertical line (2019).*

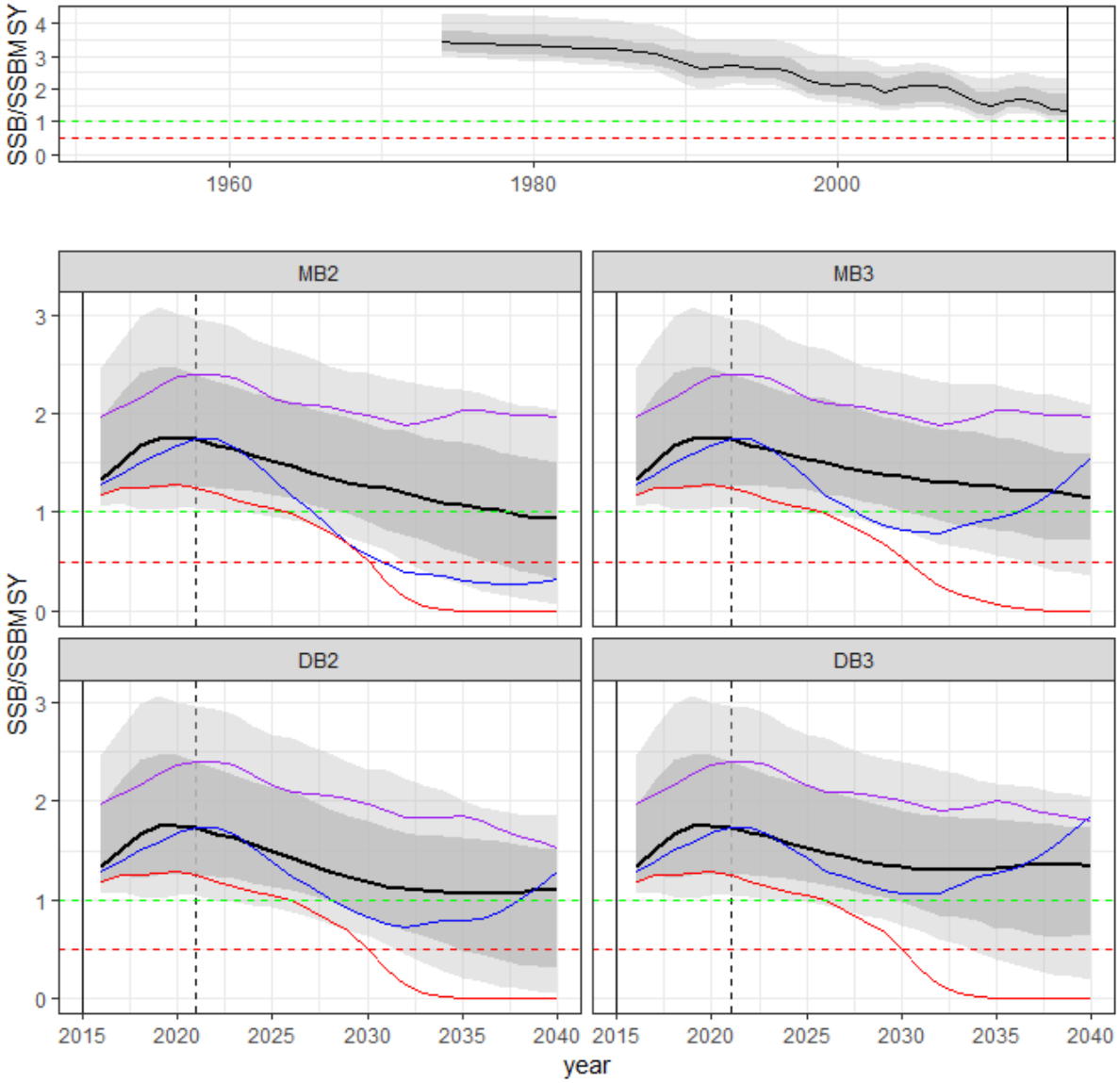

*Figure 29. Bigeye robustness set (*OMrobB19.6.10overIUU *– projected 10% unreported over-catch) - Time series of spawning stock size for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

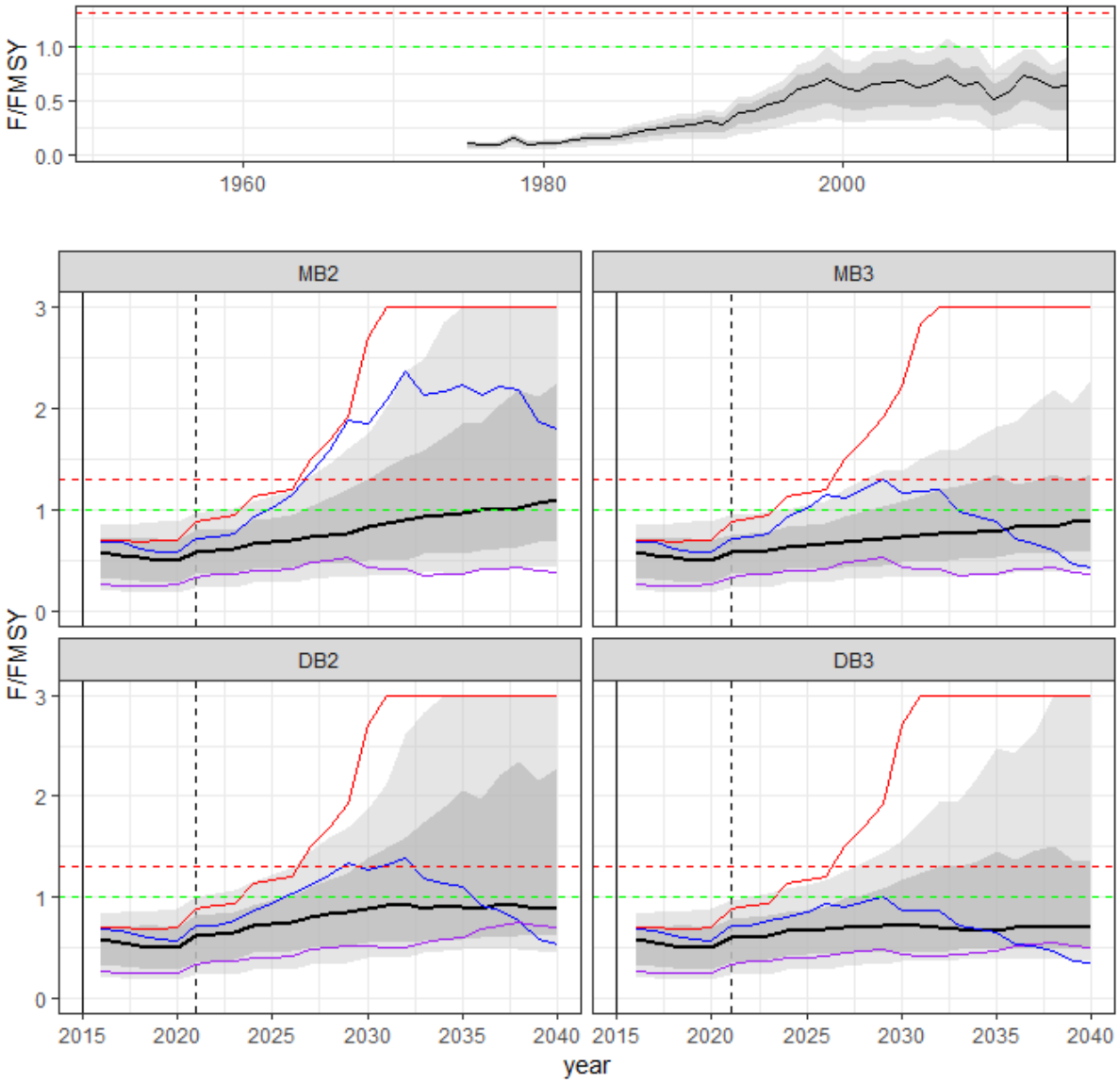

*Figure 30. Bigeye robustness set (*OMrobB19.6.10overIUU *– projected 10% unreported over-catch) - Time series of fishing intensity (Upper bound truncated at F = 3) for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

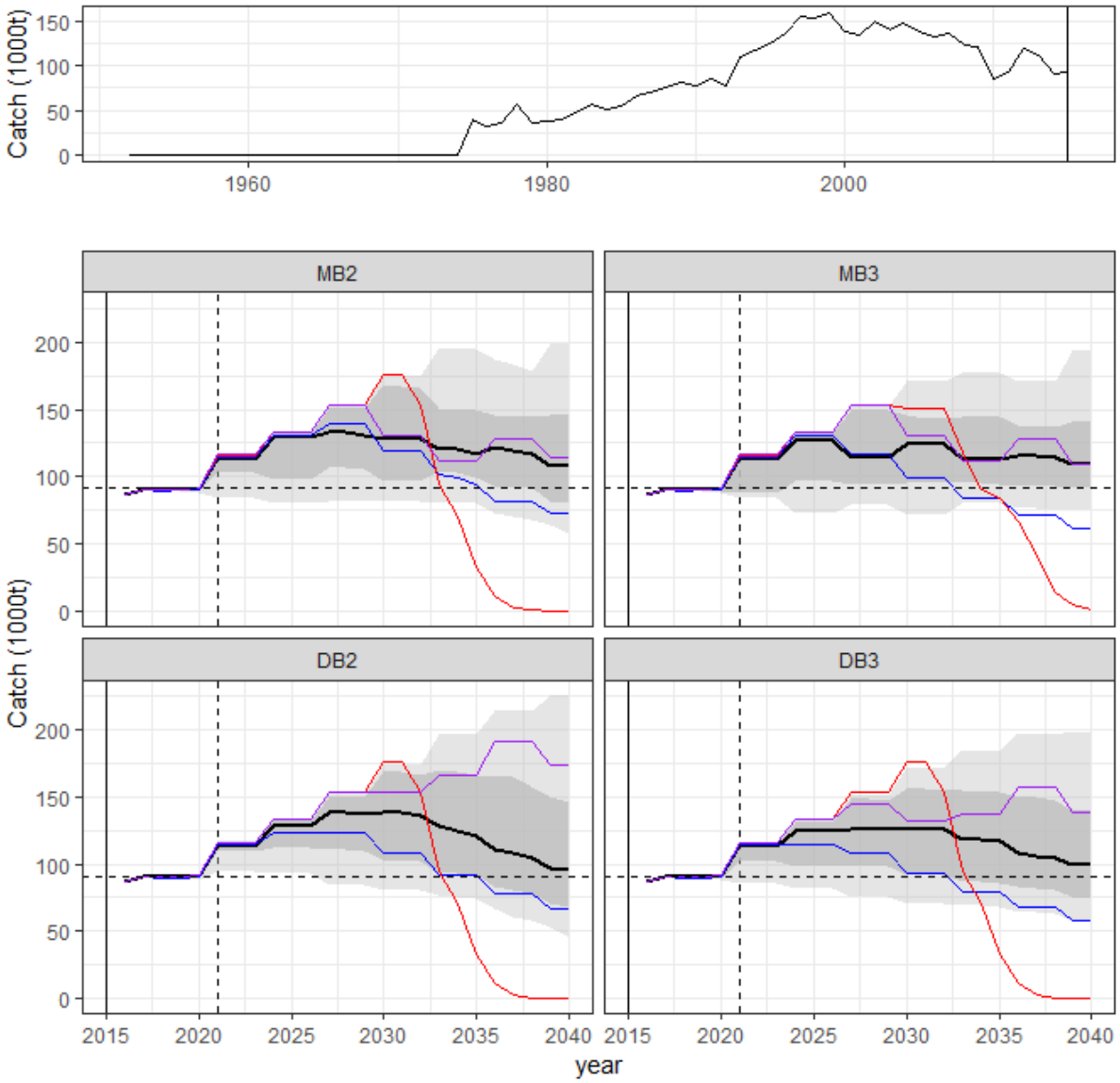

*Figure 31. Bigeye robustness set (*OMrobB19.6.10overIUU *– projected 10% unreported over-catch) - Time series of catch for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. The broken black horizontal line represents recent (2016) catch. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

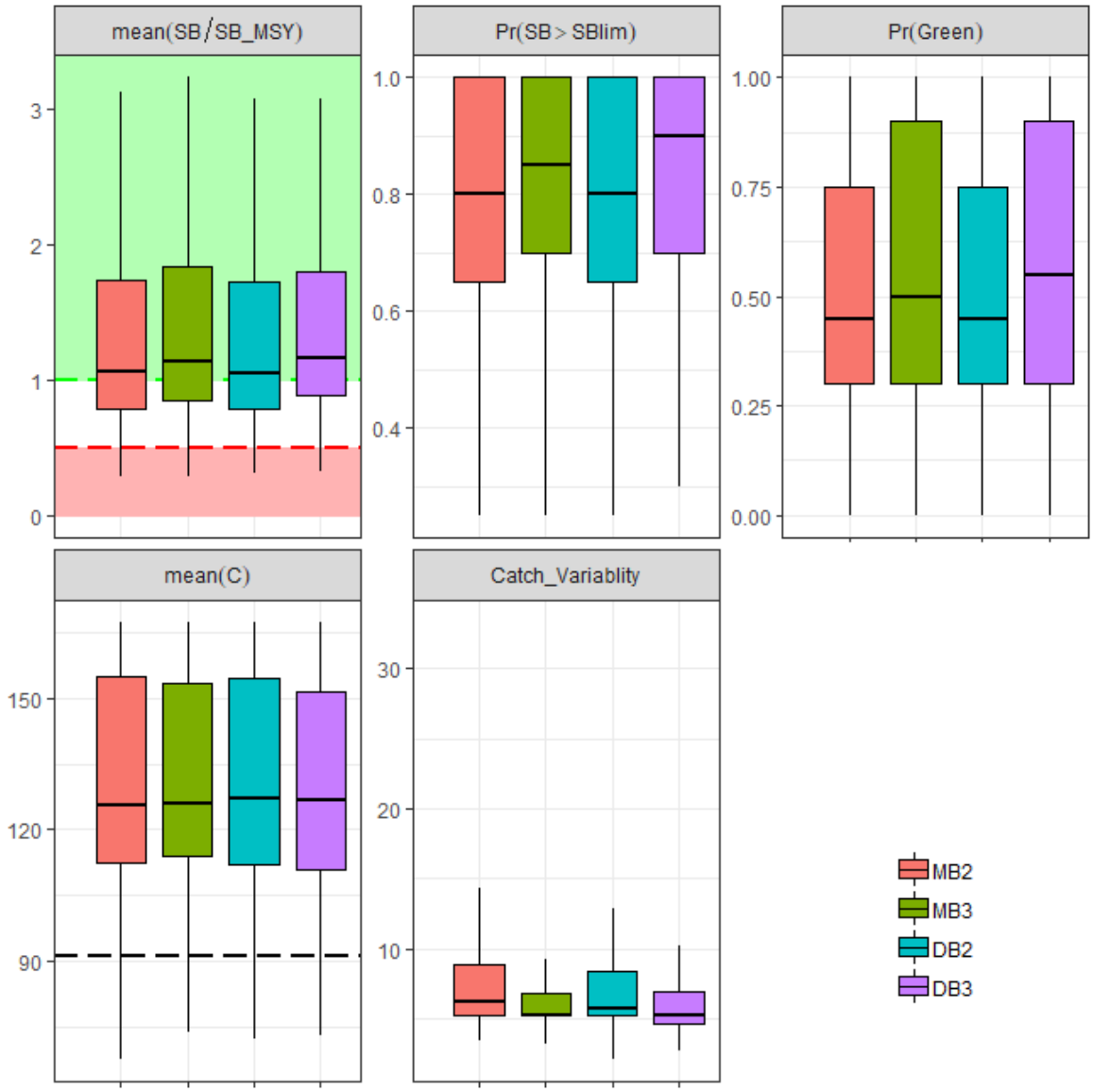

*Figure 32. Bigeye robustness test (*OMrobB19.6.qTrend3 *– projected 3% per year LL catchability increase) - Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2021 - 2040. Horizontal line is the median, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB_{MSY} performance measure. The horizontal dashed black line is 2017 catch.*

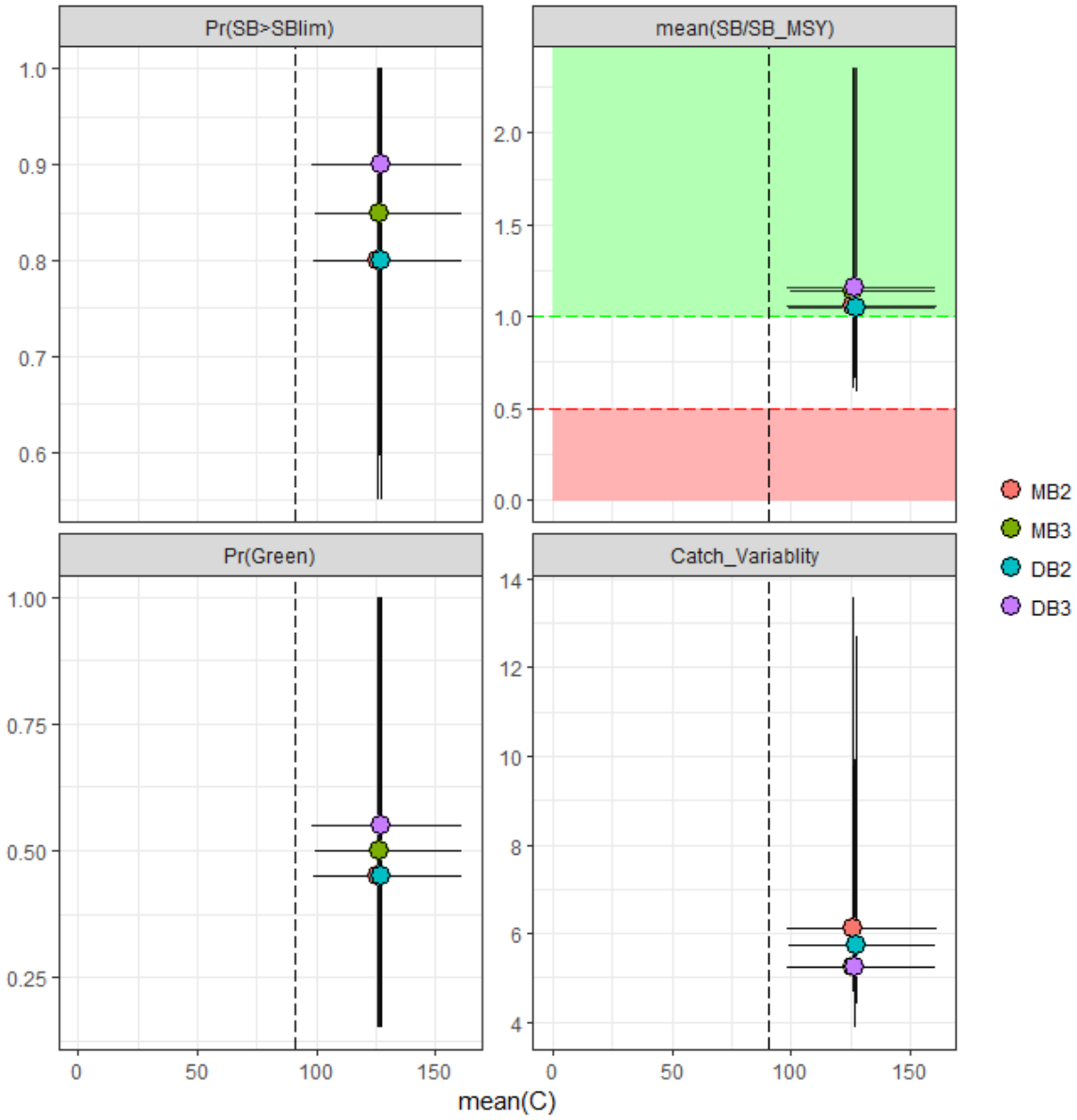

*Figure 33. Bigeye robustness set (*OMrobB19.6.qTrend3 *– projected 3% per year LL catchability increase) - Trade-off plots comparing candidate MPs with respect to catch on the X-axis, and 4 other key performance measures on the Y-axis, each averaged over the period 2021 - 2040. Circle is the median, lines represent 10th-90th percentiles. Red and green horizontal lines represent the interim limit and target reference points for the mean SB/SB$_{MSY}$ performance measure. The dashed vertical black line is 2017 catch.*

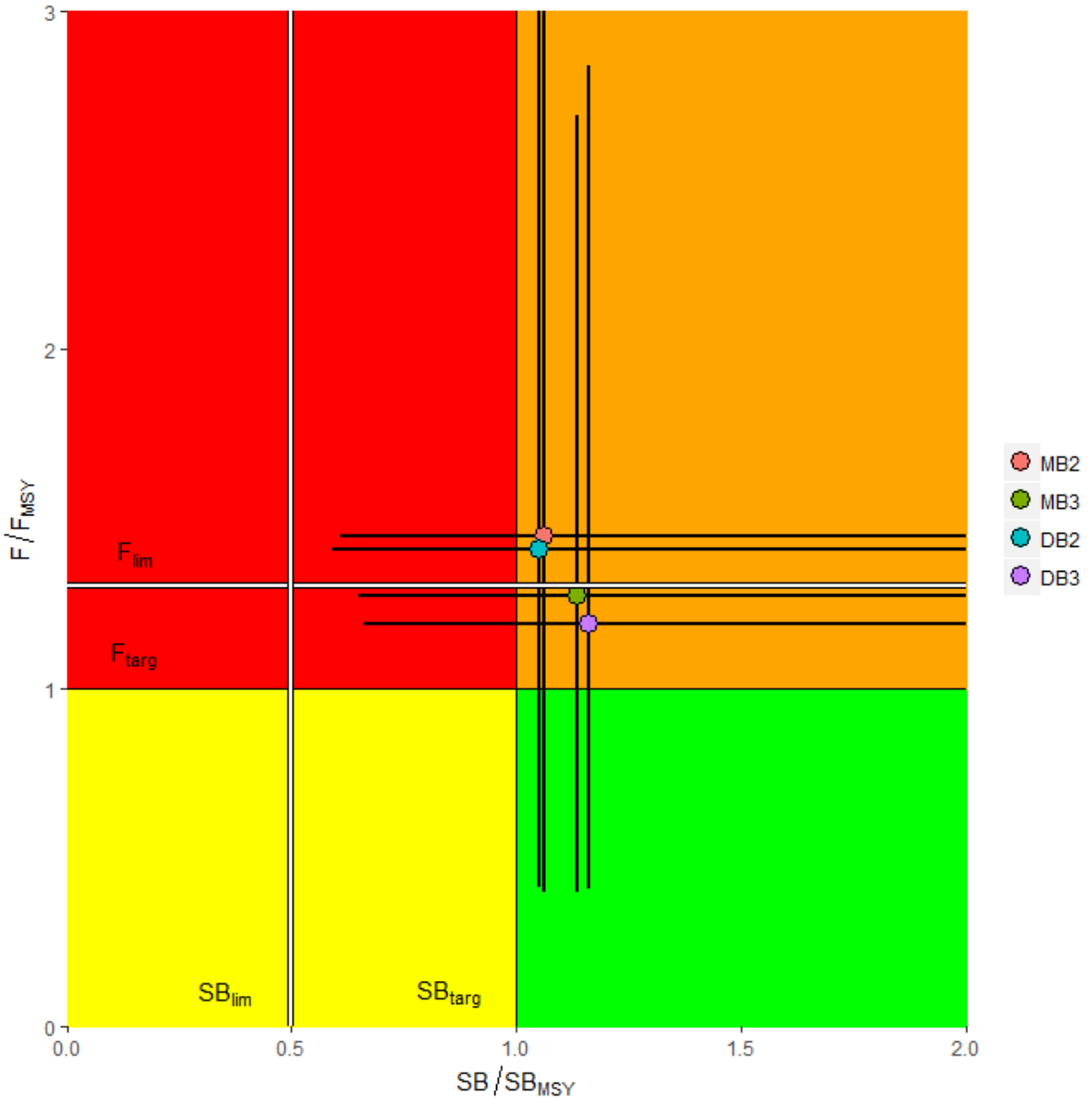

*Figure 34. Bigeye robustness set (*OMrobB19.6.qTrend3 *– projected 3% per year LL catchability increase) - Kobe plot comparing candidate MPs on the basis of the expected 20 year average (2021-2040) performance. Circle is the median, lines represent 10th-90th percentiles.*

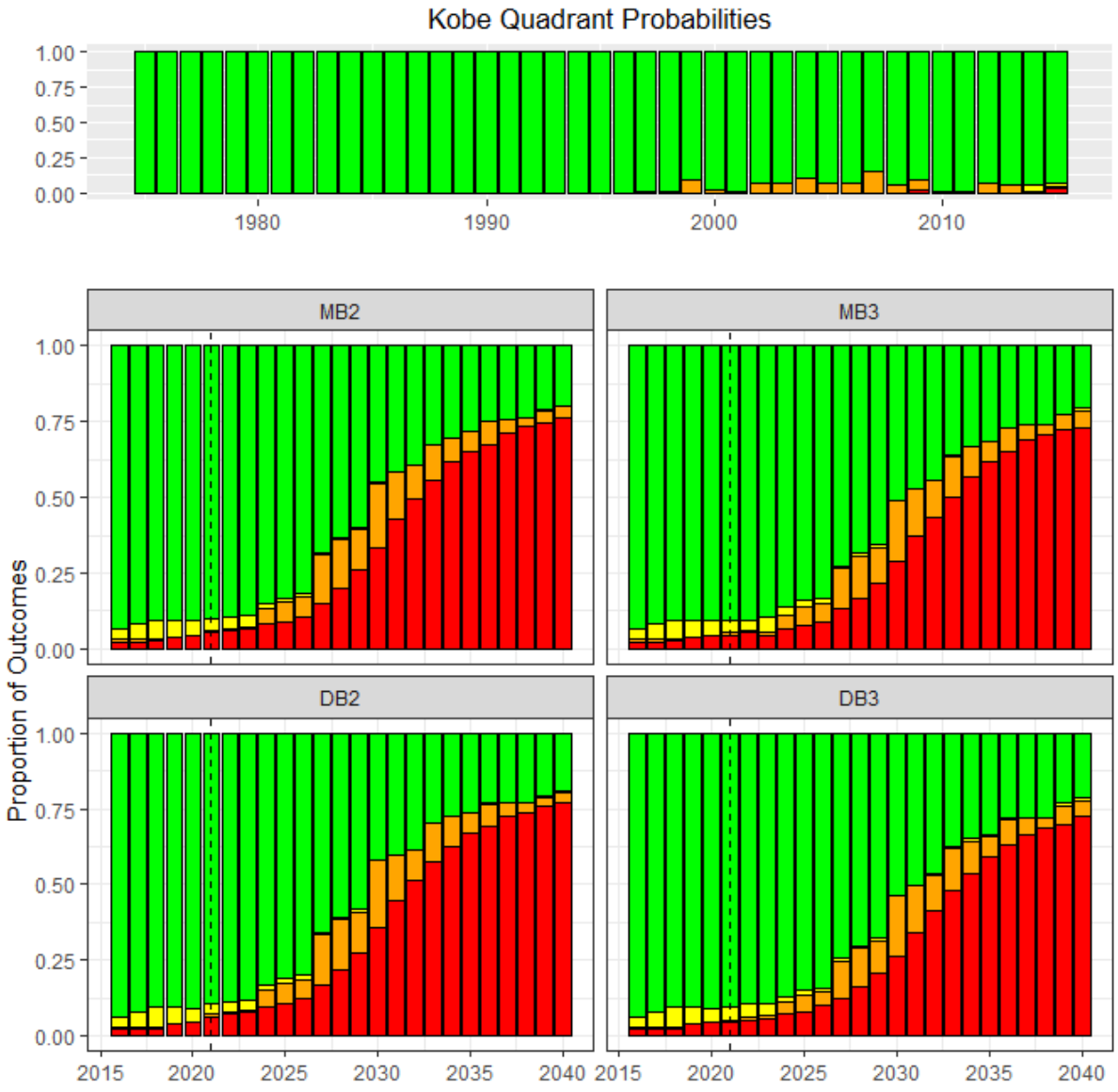

*Figure 35. Bigeye robustness set (*OMrobB19.6.qTrend3 *– projected 3% per year LL catchability increase) - Proportion of simulations in each of the Kobe quadrants over time for each of the candidate MPs. Historical estimates are included in the top panel. The lower panels are projections, with the first MP application indicated by the broken vertical line (2019).*

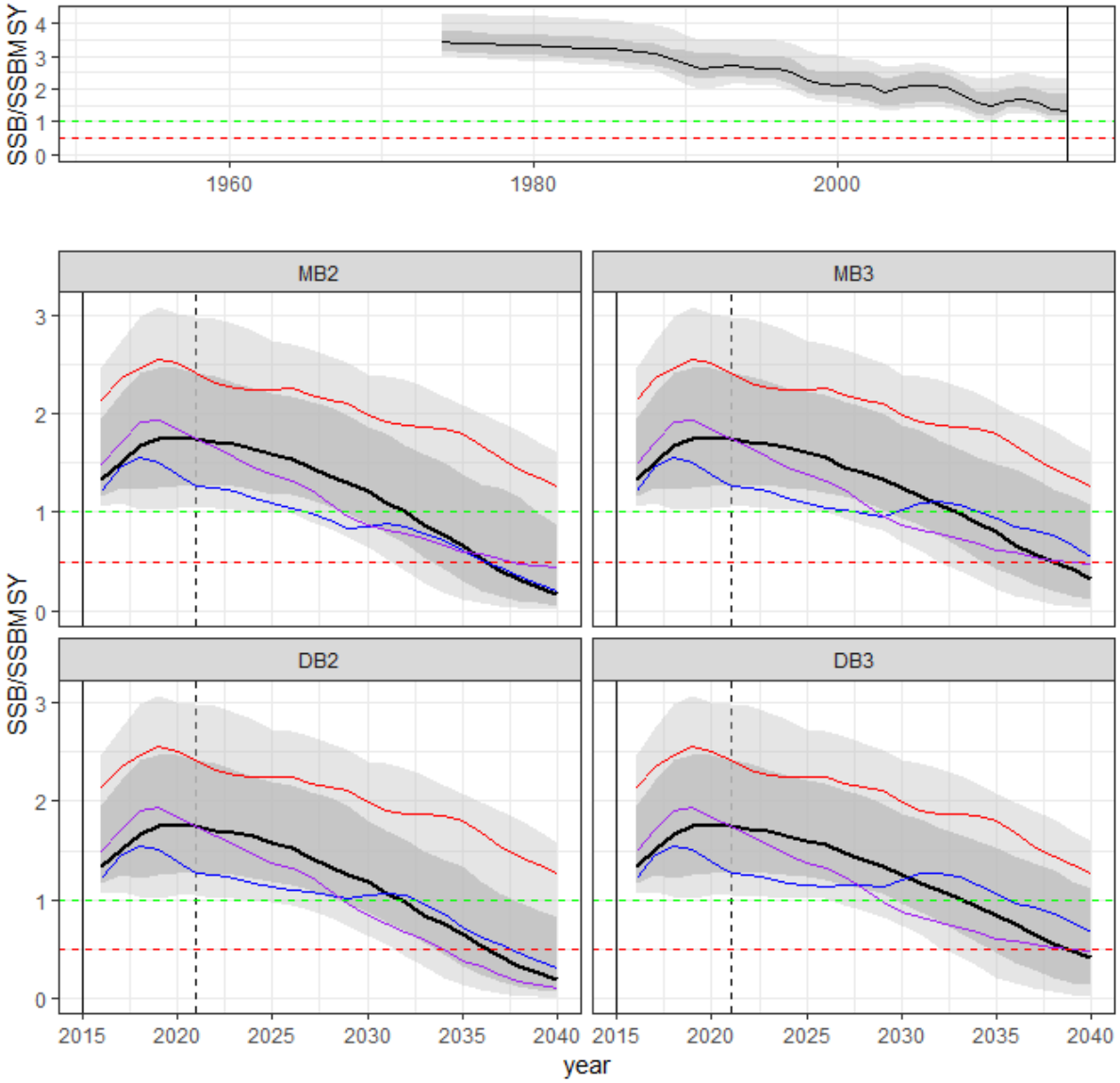

*Figure 36. Bigeye robustness set (*OMrobB19.6.qTrend3 *– projected 3% per year LL catchability increase) - Time series of spawning stock size for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

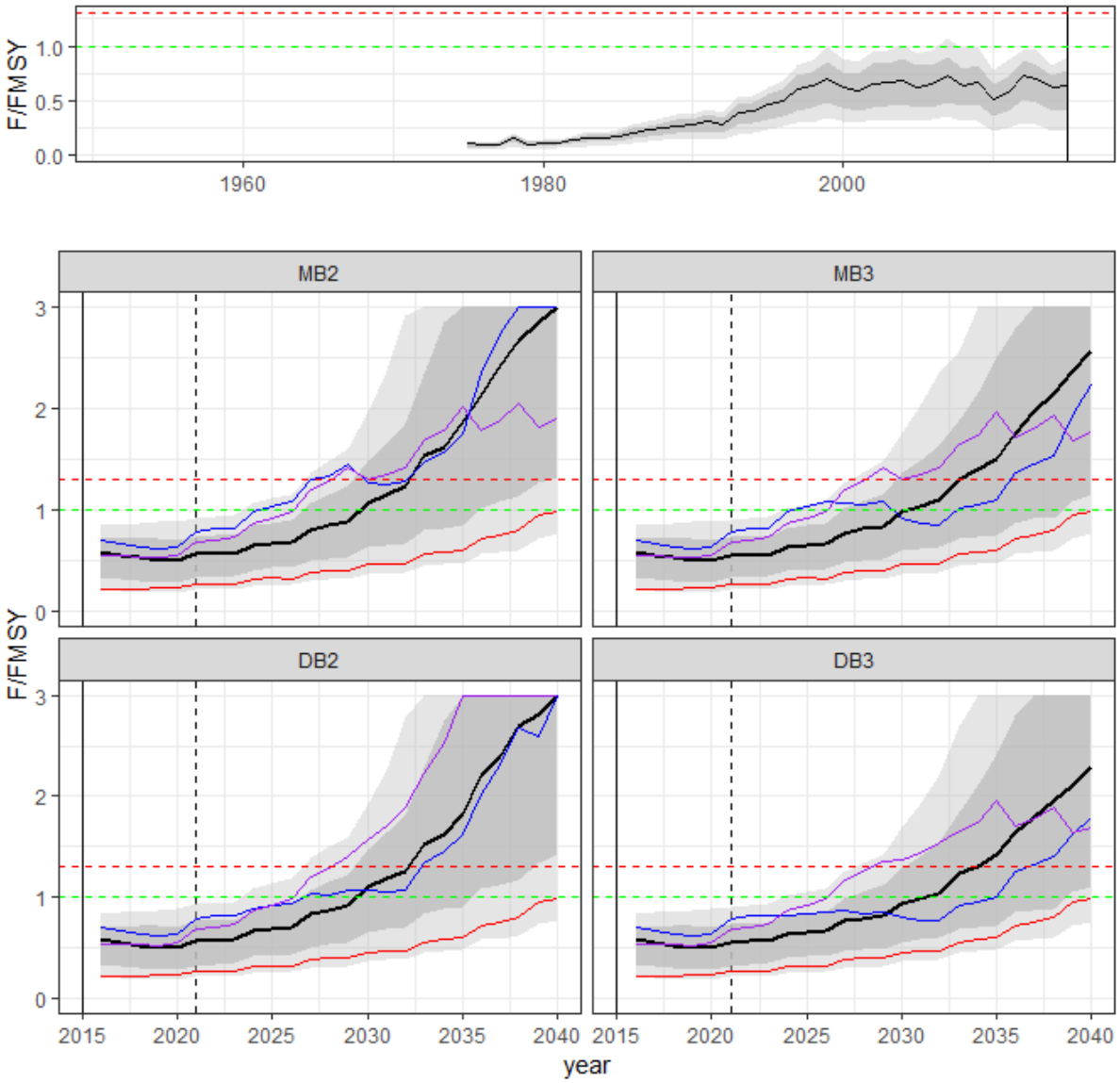

*Figure 37. Bigeye robustness set (*OMrobB19.6.qTrend3 *– projected 3% per year LL catchability increase) - Time series of fishing intensity (Upper bound truncated at F = 3) for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

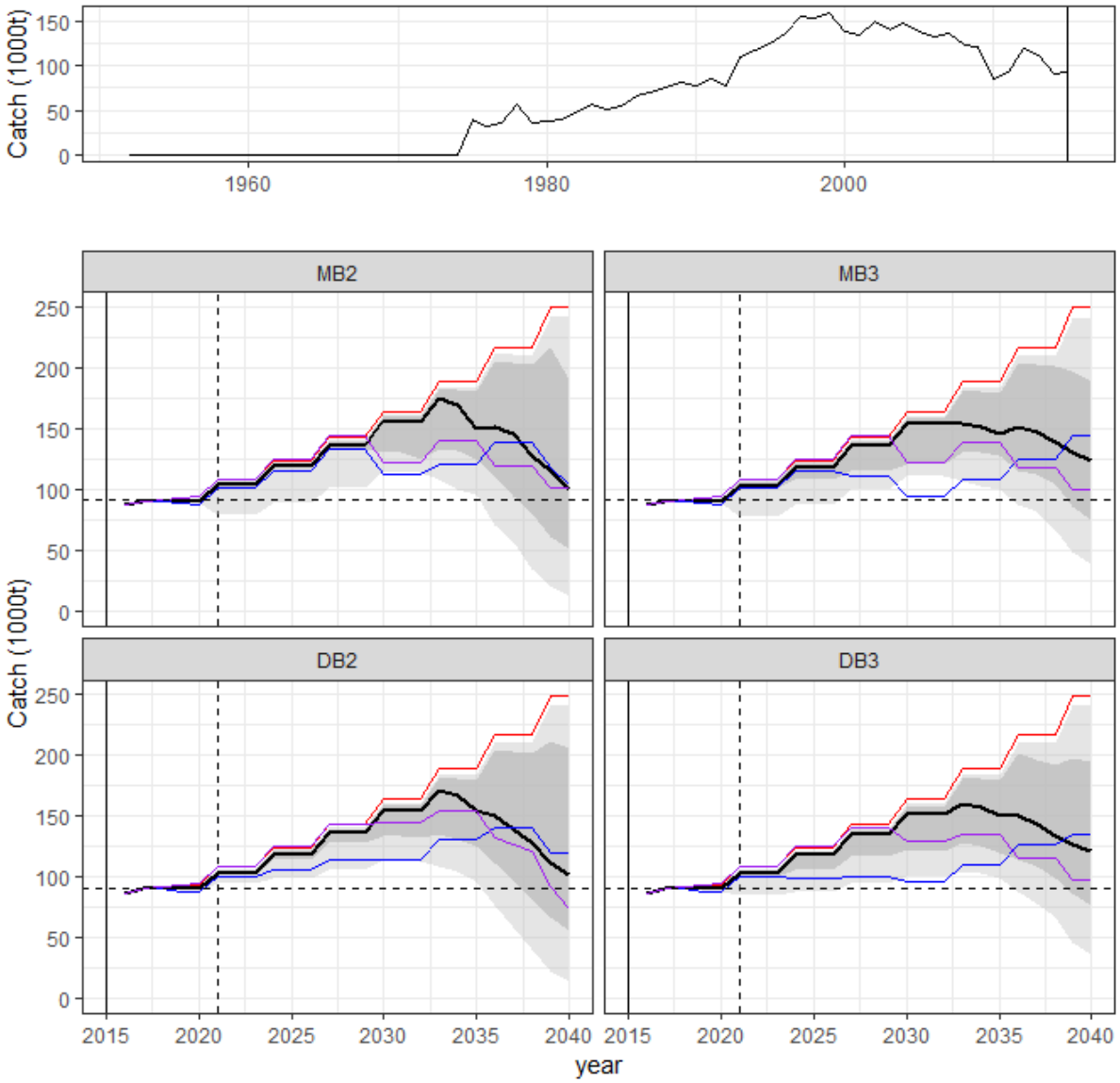

*Figure 38. Bigeye robustness set (*OMrobB19.6.qTrend3 *– projected 3% per year LL catchability increase) - Time series of catch for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. The broken black horizontal line represents recent (2016) catch. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.*

Yellowfin Tuna MP evaluation update for WPM 2019

Yellowfin Management Procedure Evaluation Status

- Management Procedure (MP) evaluation is being pursued in the strict sense (i.e. as in the International Whaling Commission and Commission for the Conservation of Southern Bluefin Tuna), in which the data to be input to the MP, the analysis, and the Harvest Control Rule (HCR) are all defined in advance and simulation-tested together.
- The yellowfin reference set Operating Model (simulator) is being iteratively developed in line with IOTC technical working party requests (described in Kolody and Jumppanen 2019g). The assessment upon which the OM is based is currently under review, which may have implications for the next MSE iteration.
- A small set of generic MPs has been evaluated for each of the tuning objectives requested by the TCMP (2019) below.
- Results from 5 robustness set OMs are presented for yellowfin:
    - *OMrobY19.4.ICV30* - What happens if the (annualized aggregate) longline CPUE observation error CV is increased to 30% (auto-correlation 0.5) in projections?
    - *OMrobY19.4.10overRep* - What happens if there is a consistent 10% future over-catch (accurately reported), equally distributed among fleets?
    - *OMrobY19.4.10overIUU* – What happens if there is a 10% future over-catch (unreported) equally distributed among fleets ?
    - *OMrobY19.4.qTrend2* - What happens if the longline CPUE catchability trend is 2% per year going forward (but remains as in the reference scenario for conditioning)?
    - *OMrobY19.4.recShock* - What happens if there are two years of poor (55% of expected) recruitment starting in 2021?

Yellowfin MP Development Guidance from TCMP-02 (2018)

Tuning objectives refer to a key management objective that the MPs can achieve precisely (e.g. achieving SB ≥ SB_{MSY} with a 50% probability by 2024). The tuning objective normally relates to a desirable biomass (in terms of the risk of exceeding reference points and/or a rebuilding timeframe), and has a very strong influence on the obtainable yield (because biomass risk and attainable catch are closely related). Tuning ensures that candidate MPs are identical with respect to this high priority objective, making it easier to select among MPs on the basis of performance with respect to secondary management objectives (e.g. yield and catch stability). Ideally the Commission will have narrowed down the tuning objectives to 1 or 2 before MP selection. This will allow MP developers to focus on targeted MP development rather than relying on generic MPs. TCMP-02 (2018) defined 3 interim yellowfin tuning objectives. The first one did not appear to be attainable in 2019 (i.e. because of the extremely large catch reductions required), so TCMP-03 (2019), requested reporting on only the following:

TY18.2: Pr(SB(2029)>=SB(MSY)) = 0.5. Average SB in 2029 exceeds SB_{MSY} in exactly 50% of the simulations.

TY18.3: Pr(SB(2034)>=SB(MSY)) = 0.5. Average SB in 2034 exceeds SB_{MSY} in exactly 50% of the simulations.

TCMP (2019) endorsed Total Allowable Catch (TAC) setting every 3 years (held constant between settings), and recommended further exploration of alternative TAC change constraints around the 15% level (the difference between the new TAC and the previous TAC). Figure 39 illustrates the fastest achievable rebuilding to target levels with a range of 6 different TAC constraints including:

- 2042 with a 15% change constraint
- 2031 with a 25% change constraint
- 2029 with a 35% change constraint

- 2022 with no change constraint

These are the absolute minimum rebuilding times possible because they involve continuously dropping catches at the maximum rate and are only useful as a reference. A useful feedback-based MP would not likely recommend these decreases in catch.

MP evaluation results are presented at both the original 20-year projection summary timeframe, and only up to the 2029 and 2034 rebuilding time-frames. These new reporting periods were requested because the MPs available for the 2019 TCMP had a tendency to overshoot rebuilding targets at the expense of lost economic opportunity. It was recognized that it might be worth scheduling an MP review in relation to successful rebuilding, and hence worth avoiding selecting an MP based on post-rebuilding performance (though we note below that the biomass overshoot problem can be greatly reduced).

Summary of Yellowfin MP Performance evaluated with the reference set OM

MP results from the reference set OM (OMrefY19.4) are summarized in the standard format in Figure 40 - Figure 46, and Table 3 - Table 4, from which we note:

- The results are considerably more pessimistic than observed in 2018.
- All of the MPs and tuning levels examined suggest that sizable average catch reductions (to around 200Kt) will be required over the 20 year summary period, with a >75% chance that the average catch will need to drop below recent levels (413Kt). The M- and D-class MPs had >90% probability of dropping catch below recent levels. The largest catch reductions are mostly required in the first quota setting.
- The revised M-class MPs and the new Mr-class MPs have largely resolved the biomass overshoot problem, with median biomass stabilizing near the target rebuilding level (Figure 44). The D-class MPs exhibit the same rebuilding overshoot observed at the 2019 TCMP.
- The Mr-class MPs have a higher probability of maintaining higher catches and are more stable in terms of catch variability than the M-class MPs, but this is achieved at the expense of greater risk of violating biomass limits.

Summary of Yellowfin Candidate MP Performance against the robustness tests

OMrobY19.4.ICV30 – (longline CPUE observation error CV 30% in projections) – The MP performance is difficult to distinguish from the reference set (Figure 47, Figure 48).

OMrobY19.4.10overRep – (10% future over-catch, accurately reported) – MP performance is more pessimistic than the reference set performance, but the change is incremental, similar among MPs and without drastic consequences (Figure 49). This might be optimistically interpreted as a reasonable safety buffer to quota implementation errors.

OMrobY19.4.10overIUU – (10% future over-catch, unreported) – MP performance is very similar to *OMrobB19.6.10overRep (*Figure 50), but we would expect MP performance to degrade further as unreported catches increase.

OMrobY19.4.qTrend2 – (catchability trend 2% per year going forward) - if there is an unrecognized increase in longline catchability of this magnitude, this elevates the overfishing risk, and the Mr-based MP undershoots the tuning target (Figure 51). However, we question the plausibility of this particular robustness test. i.e. It is not clear why the catchability trend would start in the projection period rather than operating continuously throughout the conditioning period. MPs have limited power to compensate for fundamentally misleading data. If these sorts of CPUE biases are considered likely, then there are two options i) more conservative quotas (with potentially lost economic opportunities), or ii) collection of improved monitoring data.

OMrobY19.4.recShock - as would be expected, a recruitment failure of the magnitude estimated for yellowfin in the 2000s increases the biomass risk over the 20 year summary period (Figure 52), and particularly in the first 5 years of MP application. This delays the rebuilding process, but it subsequently occurs much like in the reference set.

Yellowfin discussion points for the 2018 WPM and WPTT

- The highest priority issue facing the yellowfin MSE will be consideration of the results of the ongoing yellowfin stock assessment review process. The review may recommend fundamental changes to the assessment which may require similar changes to the OM. It is expected that the full yellowfin assessment will not be delivered until 2020. In this case, we may need advice on how to present results to the 2020 TCMP, based on either the current OM (which might have fallen out of favour), or an updated OM that might be very different and has not been reviewed/endorsed by the WPTT/WPM.
- If the current yellowfin OM is deemed satisfactory, we seek general feedback on all aspects of reference set and robustness set OM formulation.
- We also seek advice on MP performance characteristics that will enable us to further improve MP performance with current or alternative MPs.
- The 2019 TCMP made a request to consider MPs for “non-equilibrium” situations. This was deferred to the technical working groups for further consideration. We seek clarification from the WPM on this request, noting several points in the main text. This might be a good opportunity to further engage other IOTC scientists in the MP development process. i.e. noting that a competitive MP development process often leads to new ideas and improved MP performance.
- The Commission requested information about alternative catch allocation possibilities and implied a role for “tuning” that is not consistent with what has been done to date. We seek clarification from the WPM on how to interpret this request, noting that it is technically easy to change the allocations among fisheries in the MP evaluations (this will be necessary if/when allocation agreements can be adopted (to replace the recent catch distribution assumptions that are currently used). However, allocations are a political decision not a scientific decision. Unless the CPCs are planning to negotiate allocations on the basis of MP results, the value of conducting these evaluations is not clear.
- The technical working parties have requested simulating a 2 year lag between available data and TAC implementation. The draft yellowfin MP resolution proposes a 3 year lag. This discrepancy should be resolved for future MSE work.

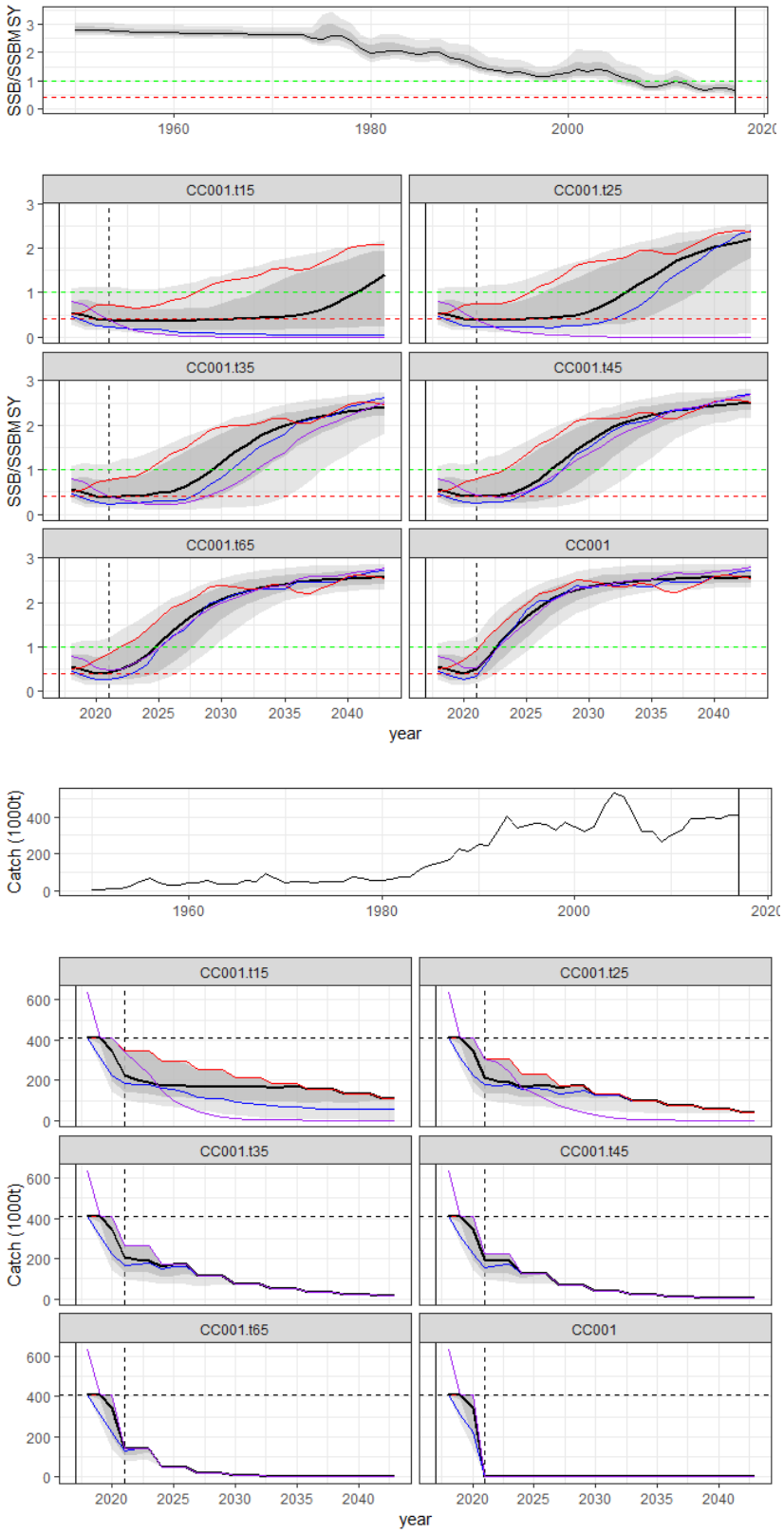

Figure 39. Minimum spawning biomass recovery trajectories (top) associated with TAC change constraints of 15, 25, 35, 45, 65 and 100% per triennial TAC application, and associated catch (bottom).

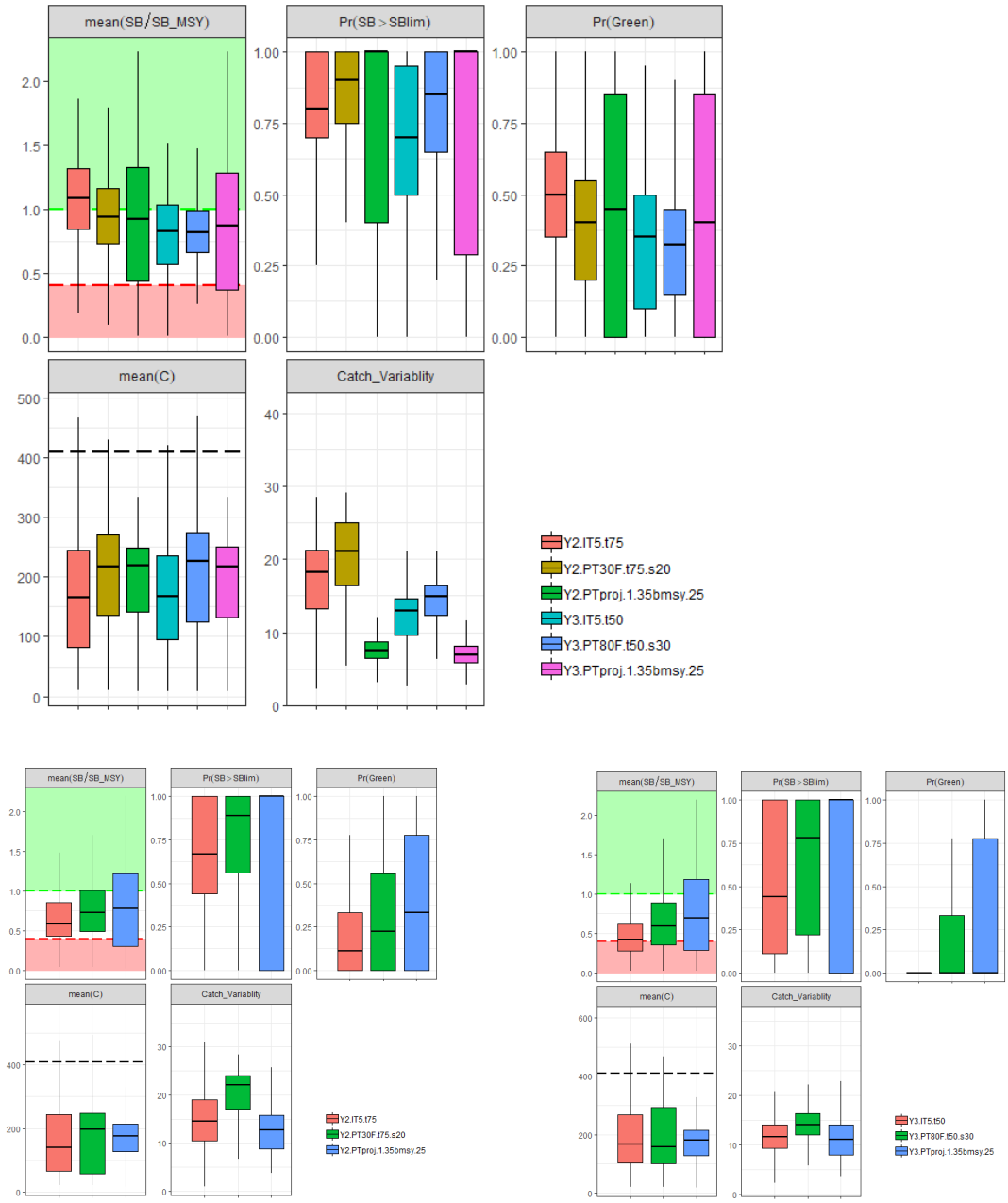

Figure 40. YFT reference set (OMrefY19.4.500) - Boxplots comparing candidate MPs with respect to key performance measures averaged over the period 2021 – 2040 (top), 2021-2029 (bottom left) and 2021-2034 (bottom right). Horizontal line is the median, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. Red and green horizontal lines represent the interim limit and target reference points. The horizontal dashed black line is 2017 catch.

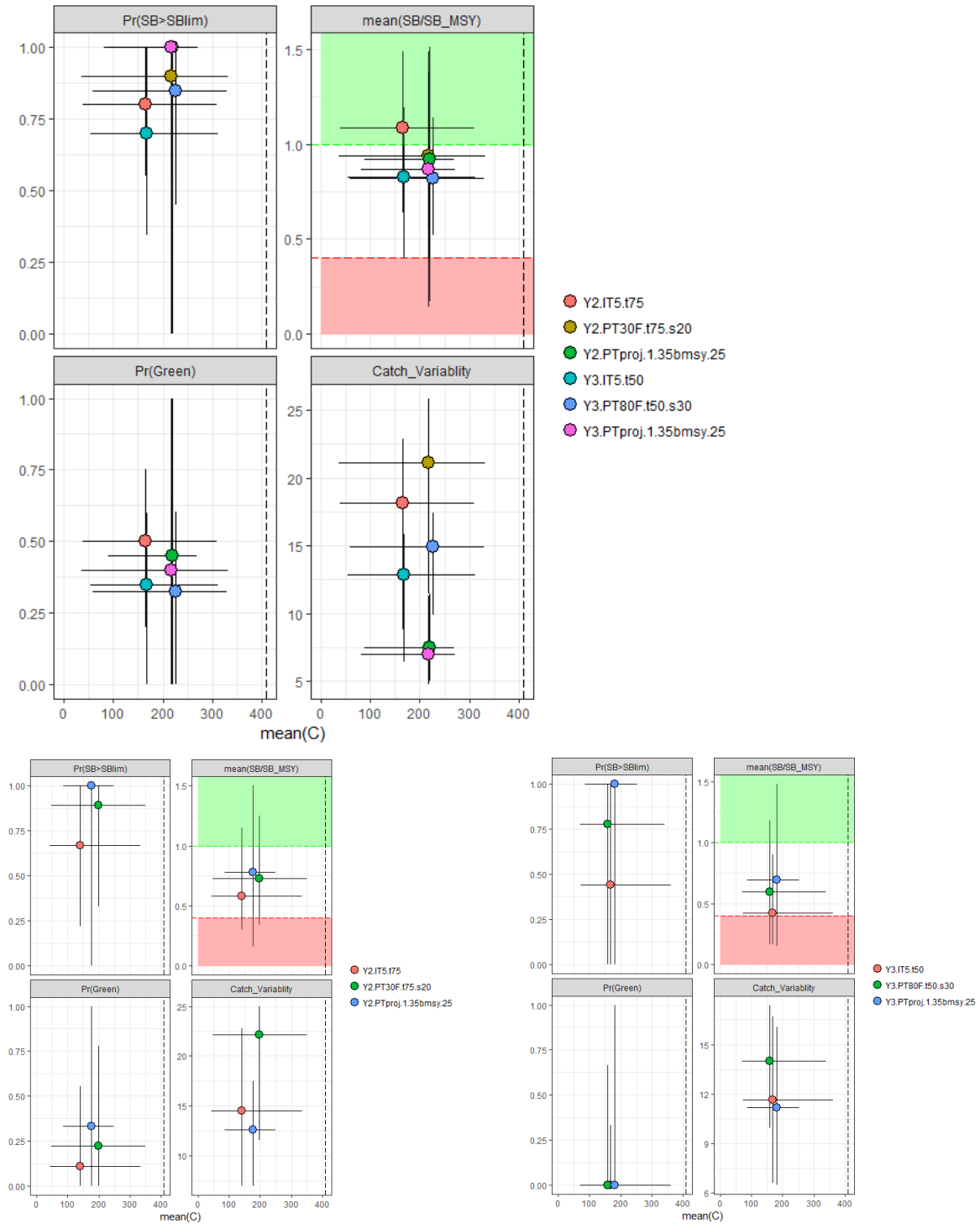

Figure 41. YFT reference set (OMrefY19.4.500) - Trade-off plots comparing candidate MPs with respect to catch on the X-axis, and 4 other key performance measures on the Y-axis, each averaged over the period 2021 – 2040 (top), 2021-2029 (bottom left) and 2021-2034 (bottom right). Circle is the median, lines represent 10th-90th percentiles. Red and green horizontal lines represent the interim limit and target reference points. The dashed vertical black line is 2017 catch.

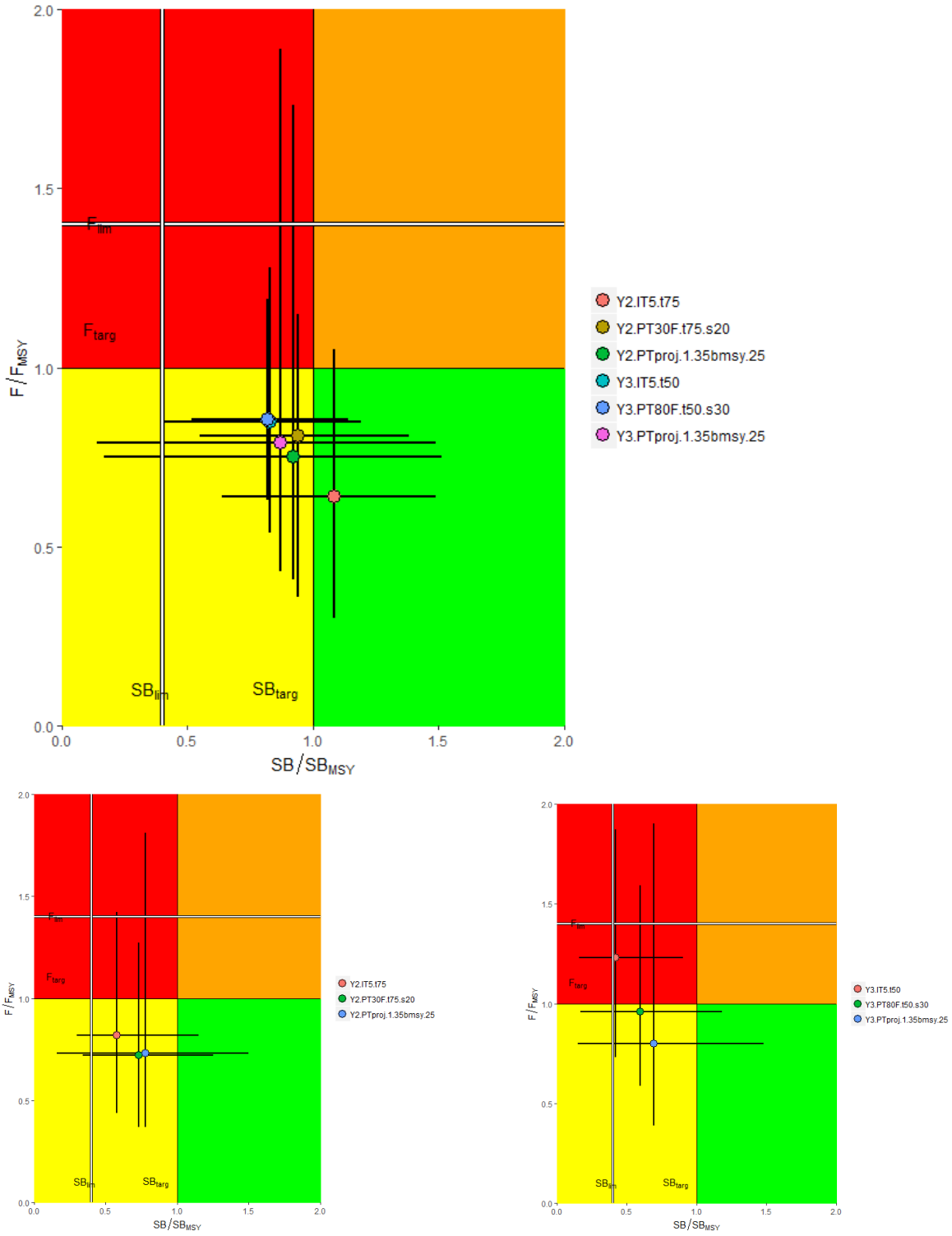

Figure 42. YFT reference set (OMrefY19.4.500) - Kobe plot comparing candidate MPs on the basis of the expected average over the periods 2021 – 2040 (top), 2021-2029 (bottom left) and 2021-2034 (bottom right) performance. Circle is the median, lines represent 10th-90th percentiles.

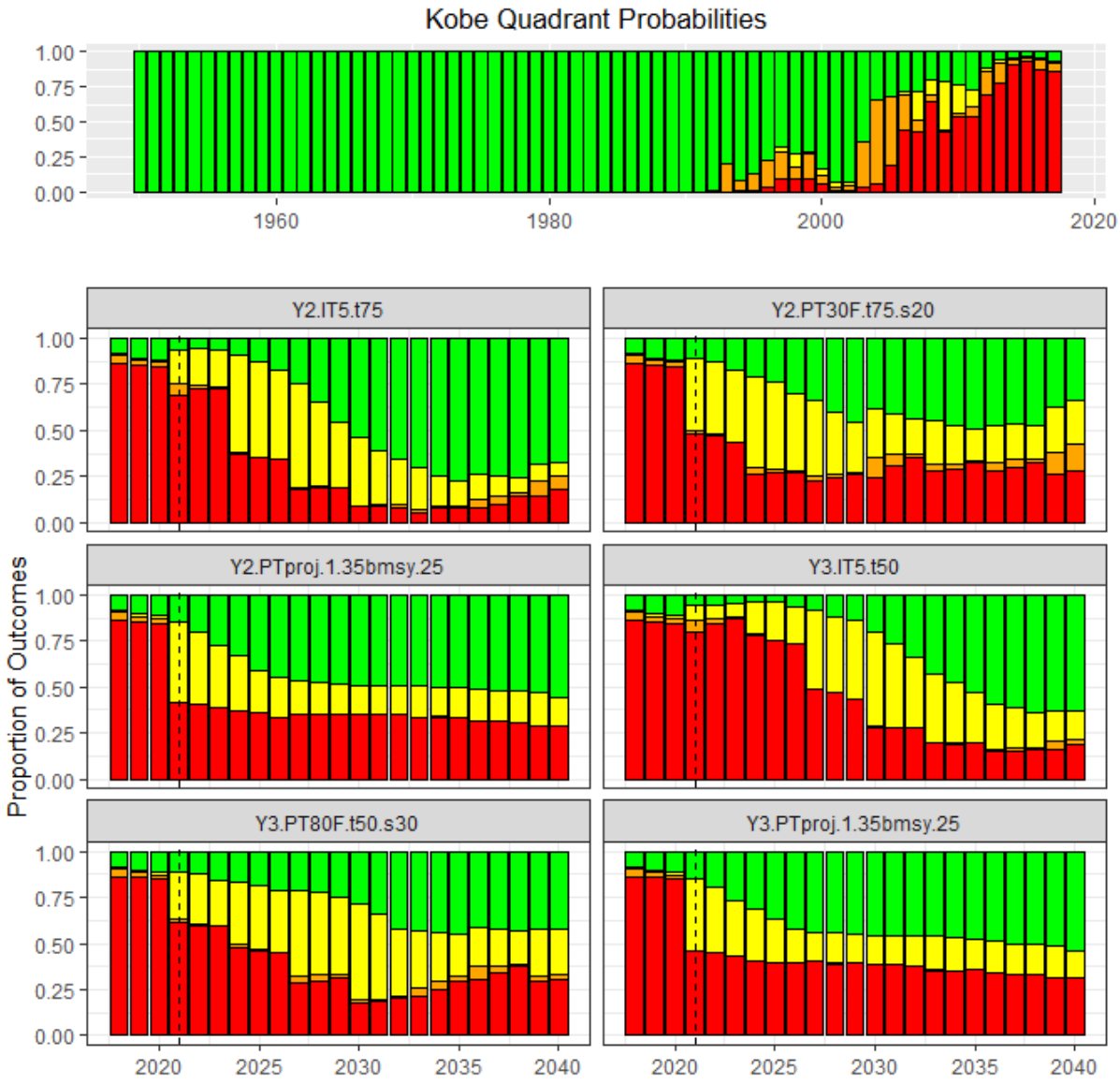

Figure 43. YFT reference set (OMrefY19.4.500) - Proportion of simulations in each of the Kobe quadrants over time for each of the candidate MPs. Historical estimates are included in the top panel.

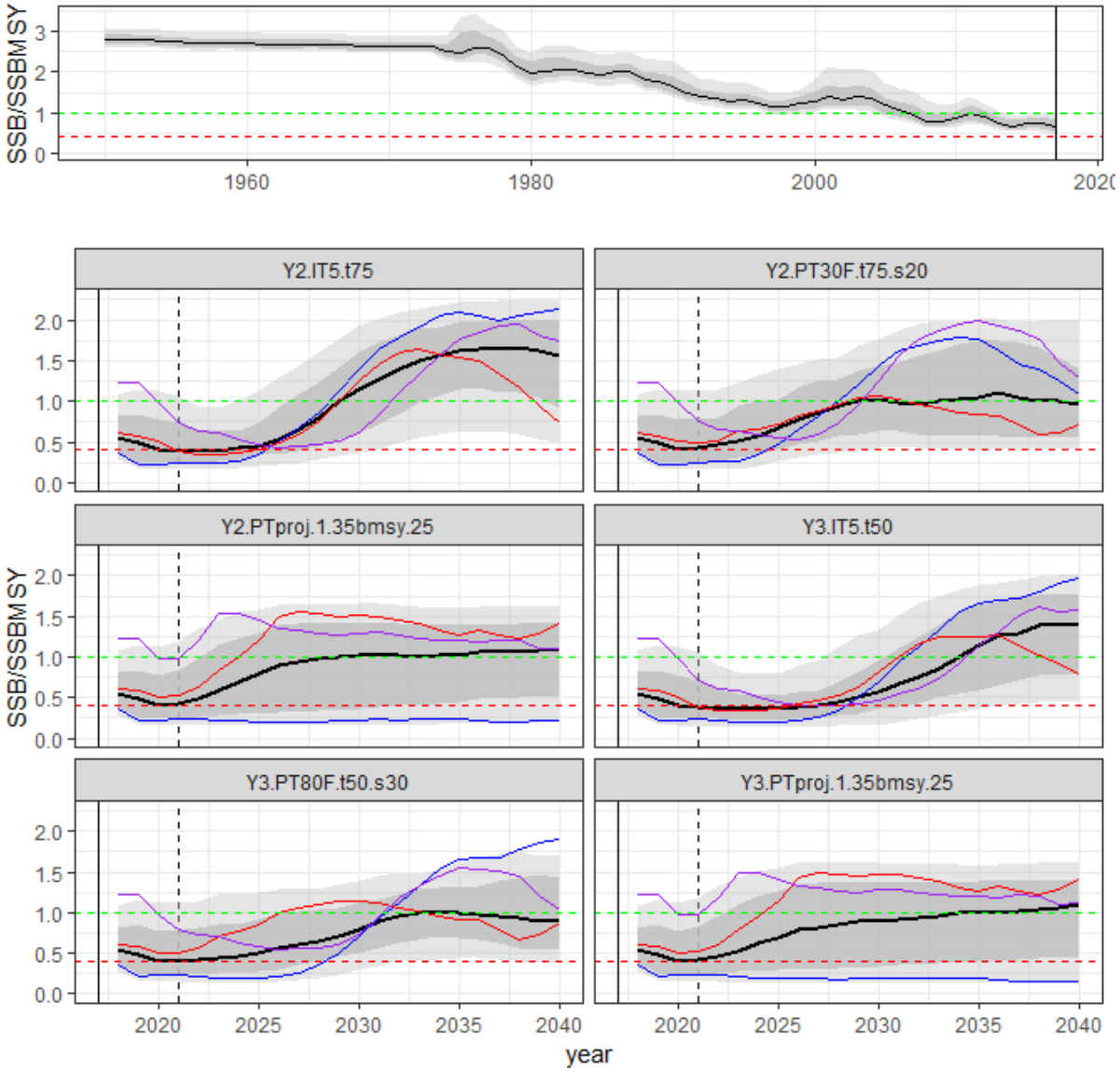

Figure 44. YFT reference set (OMrefY19.4.500) - Time series of spawning stock size for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.

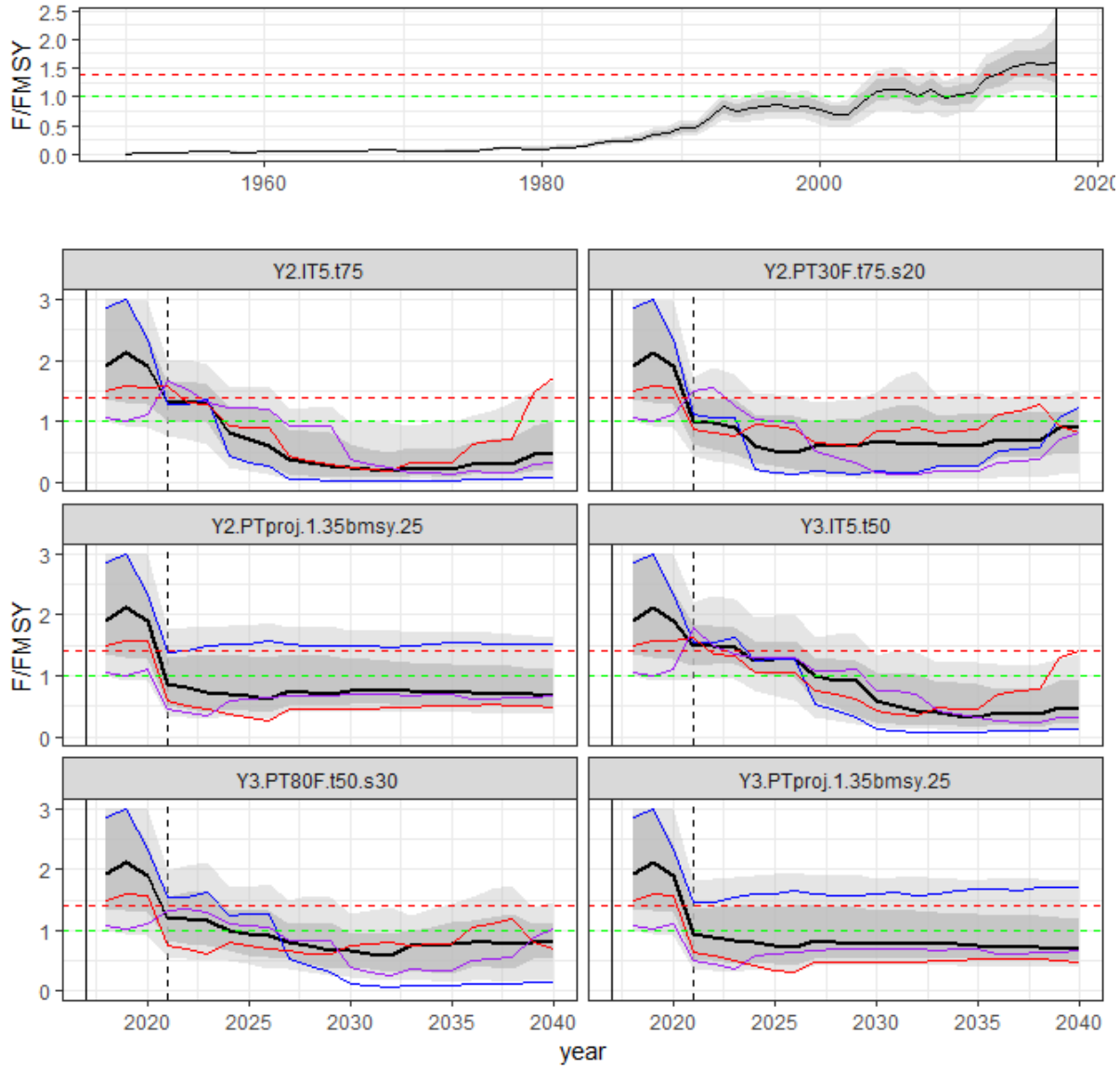

Figure 45. YFT reference set (OMrefY19.4.500) - Time series of fishing intensity (Upper bound truncated at F = 3) for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. Thick broken lines represent the interim target (green) and limit (red) reference points. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.

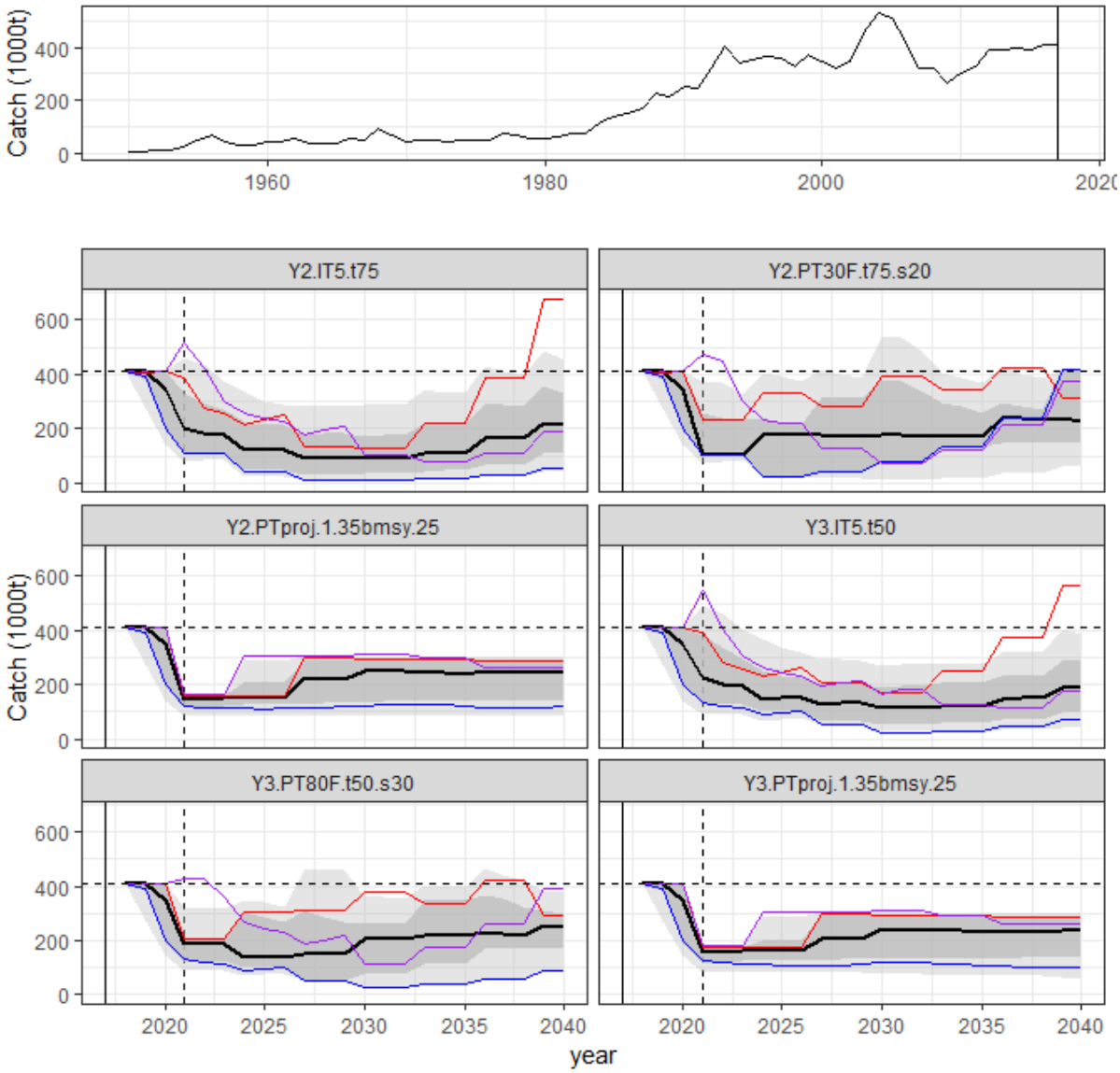

Figure 46. YFT reference set (OMrefY19.4.500) - Time series of catch for the candidate MPs. The top panel represents the historical estimates from the reference set operating model, and lower plots represent the projection period. The solid vertical line represents the last year used in the historical conditioning. The broken vertical line represents the first year that the MP is applied. The median is represented by the bold black line, the dark shaded ribbon represents the 25th-75th percentiles, the light shaded ribbon represents the 10th-90th percentiles. The broken black horizontal line represents recent (2017) catch. The 3 thin coloured lines represent examples of individual realizations (the same OM scenarios across MPs and performance measures), to illustrate that individual variability greatly exceeds the median.

Table 3. YFT reference set (OMrefY19.4.500) - Performance of candidate MPs with respect to key performance measures (averaged over the indicated period). Shading indicates the relative performance (darker = better). Note that 2016 catch was 413 000 t, and the mean catch from 1992-2016 was 374 000 t.

	Performance Measure (2021-2040)				
Management Procedure	SB/SB_{MSY}	Prob(Green)	Prob(SB>limit)	Mean Catch	Catch Variability
D.Y2	1.08 (0.85-1.32)	0.48	0.81	164.5 (82.9-244.4)	18.18
Mr.Y2	0.92 (0.44-1.33)	0.46	0.72	219.2 (140.5-247.8)	7.51
M.Y2	0.94 (0.73-1.16)	0.38	0.84	217.2 (135.6-270.3)	21.13
D.Y3	0.83 (0.57-1.03)	0.32	0.69	166.9 (95.6-234.9)	12.89
Mr.Y3	0.87 (0.37-1.28)	0.44	0.69	217.0 (132.4-250.5)	6.98
M.Y3	0.82 (0.66-0.99)	0.33	0.78	226.6 (124.0-274.0)	14.97

	Performance Measure (2021-2029)				
Management Procedure	SB/SB_{MSY}	Prob(Green)	Prob(SB>limit)	Mean Catch	Catch Variability
D.Y2	0.58 (0.43-0.85)	0.20	0.63	140.5 (67.2-243.9)	14.50
Mr.Y2	0.78 (0.30-1.22)	0.38	0.65	176.6 (126.3-213.1)	12.64
M.Y2	0.73 (0.49-1.01)	0.29	0.74	197.7 (57.5-247.4)	22.13
D.Y3	0.42 (0.28-0.62)	0.08	0.48	167.4 (102.6-267.5)	11.65
Mr.Y3	0.69 (0.29-1.18)	0.36	0.62	180.3 (126.9-215.5)	11.17
M.Y3	0.59 (0.35-0.89)	0.20	0.63	158.1 (100.2-293.5)	14.02

	Performance Measure (2021-2034)				
Management Procedure	SB/SB_{MSY}	Prob(Green)	Prob(SB>limit)	Mean Catch	Catch Variability
D.Y2	0.88 (0.63-1.14)	0.37	0.74	134.8 (66.7-227.1)	16.89
Mr.Y2	0.89 (0.34-1.29)	0.43	0.68	204.3 (130.1-235.6)	9.73
M.Y2	0.88 (0.67-1.09)	0.35	0.80	208.2 (73.2-279.7)	23.07
D.Y3	0.58 (0.41-0.80)	0.18	0.59	155.7 (89.5-236.8)	12.31
Mr.Y3	0.80 (0.32-1.26)	0.40	0.66	204.5 (128.8-239.9)	8.84
M.Y3	0.71 (0.53-0.95)	0.28	0.72	191.3 (97.2-285.1)	15.44

Table 4a. YFT reference set (OMrefY19.4.500) (OMrefY19.4.500) - Candidate MP performance for standard IOTC performance measures for the year 2021.

Status : maximise stock status		**1 year average**					
		D.Y2	**Mr.Y2**	**M.Y2**	**D.Y3**	**Mr.Y3**	**M.Y3**
Mean spawner biomass relative to pristine	SB/SB_0	0.14	0.15	0.16	0.14	0.15	0.15
Minimum spawner biomass relative to pristine	SB/SB_0	0.14	0.15	0.16	0.14	0.15	0.15
Mean spawner biomass relative to SBMSY	SB/SB_{MSY}	0.40	0.43	0.44	0.38	0.42	0.40
Mean fishing mortality relative to FMSY	F/F_{tar}	1.31	0.86	0.99	1.48	0.93	1.18
Mean fishing mortality relative to target	F/F_{MSY}	1.31	0.86	0.99	1.48	0.93	1.18
Probability of being in Kobe green quadrant	SB,F	0.07	0.17	0.12	0.07	0.17	0.12
Probability of being in Kobe red quadrant	SB,F	0.70	0.41	0.48	0.81	0.46	0.61
Safety : maximise the probability of remaining above low stock status (i.e. minimise risk)							
Probability of spawner biomass being above 20% of SB0	SB	0.32	0.39	0.37	0.31	0.39	0.36
Probability of spawner biomass being above BLim	SB	0.50	0.53	0.54	0.48	0.53	0.50
Yield : maximise catches across regions and gears							
Mean catch (1000 t)	C	200.66	146.71	102.47	226.37	158.94	186.36
Mean relative CPUE (aggregate)	C	0.55	0.38	0.34	0.61	0.41	0.48
Mean catch relative to MSY	C/MSY	0.50	0.53	0.52	0.49	0.52	0.51
Stability: maximise stability in catches to reduce commercial uncertainty							
Mean absolute proportional change in catch	C	37.78	55.12	48.22	30.16	52.51	39.28
% Catch coefficient of variation	C	NA	NA	NA	NA	NA	NA
Probability of shutdown	C	0.00	0.01	0.00	0.00	0.01	0.00

Table 4b. YFT reference set (OMrefY19.4.500) - Candidate MP performance for standard IOTC performance measures averaged over the years 2021-2025.

Status : maximise stock status		**5 year average**					
		D.Y2	**Mr.Y2**	**M.Y2**	**D.Y3**	**Mr.Y3**	**M.Y3**
Mean spawner biomass relative to pristine	SB/SB_0	0.16	0.22	0.20	0.13	0.20	0.16
Minimum spawner biomass relative to pristine	SB/SB_0	0.12	0.15	0.14	0.12	0.15	0.14
Mean spawner biomass relative to SBMSY	SB/SB_{MSY}	0.44	0.61	0.54	0.38	0.56	0.46
Mean fishing mortality relative to FMSY	F/F_{tar}	1.11	0.73	0.85	1.41	0.83	1.06
Mean fishing mortality relative to target	F/F_{MSY}	1.11	0.73	0.85	1.41	0.83	1.06
Probability of being in Kobe green quadrant	SB,F	0.09	0.30	0.20	0.05	0.29	0.17
Probability of being in Kobe red quadrant	SB,F	0.58	0.39	0.39	0.81	0.43	0.55
Safety : maximise the probability of remaining above low stock status (i.e. minimise risk)							
Probability of spawner biomass being above 20% of SB0	SB	0.32	0.50	0.47	0.25	0.47	0.40
Probability of spawner biomass being above BLim	SB	0.53	0.60	0.64	0.44	0.58	0.56
Yield : maximise catches across regions and gears							
Mean catch (1000 t)	C	165.28	150.36	132.95	186.25	161.81	165.77
Mean relative CPUE (aggregate)	C	0.48	0.42	0.40	0.52	0.44	0.47
Mean catch relative to MSY	C/MSY	0.56	0.74	0.69	0.48	0.70	0.57
Stability: maximise stability in catches to reduce commercial uncertainty							
Mean absolute proportional change in catch	C	18.74	13.66	25.12	14.64	13.01	16.33
% Catch coefficient of variation	C	0.30	0.08	0.32	0.16	0.07	0.19
Probability of shutdown	C	0.04	0.01	0.10	0.00	0.01	0.00

Table 4c. YFT reference set (OMrefY19.4.500) - Candidate MP performance for standard IOTC performance measures averaged over the years 2021-2029.

Status : maximise stock status		**10 year average**					
		D.Y2	**Mr.Y2**	**M.Y2**	**D.Y3**	**Mr.Y3**	**M.Y3**
Mean spawner biomass relative to pristine	SB/SB_0	0.22	0.29	0.27	0.16	0.25	0.22
Minimum spawner biomass relative to pristine	SB/SB_0	0.11	0.15	0.13	0.10	0.15	0.13
Mean spawner biomass relative to SBMSY	SB/SB_{MSY}	0.64	0.81	0.78	0.45	0.72	0.62
Mean fishing mortality relative to FMSY	F/F_{tar}	0.76	0.74	0.72	1.18	0.80	0.94
Mean fishing mortality relative to target	F/F_{MSY}	0.76	0.74	0.72	1.18	0.80	0.94
Probability of being in Kobe green quadrant	SB,F	0.24	0.39	0.30	0.09	0.37	0.21
Probability of being in Kobe red quadrant	SB,F	0.39	0.37	0.32	0.65	0.41	0.43
Safety : maximise the probability of remaining above low stock status (i.e. minimise risk)							
Probability of spawner biomass being above 20% of SB0	SB	0.48	0.57	0.60	0.30	0.54	0.50
Probability of spawner biomass being above BLim	SB	0.66	0.65	0.76	0.50	0.63	0.66
Yield : maximise catches across regions and gears							
Mean catch (1000 t)	C	139.73	184.18	206.77	161.39	187.55	161.33
Mean relative CPUE (aggregate)	C	0.39	0.50	0.55	0.46	0.51	0.48
Mean catch relative to MSY	C/MSY	0.82	0.99	0.93	0.58	0.91	0.79
Stability: maximise stability in catches to reduce commercial uncertainty							
Mean absolute proportional change in catch	C	17.32	12.74	25.49	13.54	11.28	16.97
% Catch coefficient of variation	C	0.44	0.23	0.52	0.30	0.19	0.29
Probability of shutdown	C	0.13	0.02	0.13	0.02	0.02	0.02

Table 4d. YFT reference set (OMrefY19.4.500) - Candidate MP performance for standard IOTC performance measures averaged over the years 2021-2040.

Status : maximise stock status		**20 year average**					
		D.Y2	**Mr.Y2**	**M.Y2**	**D.Y3**	**Mr.Y3**	**M.Y3**
Mean spawner biomass relative to pristine	SB/SB_0	0.38	0.33	0.33	0.30	0.31	0.29
Minimum spawner biomass relative to pristine	SB/SB_0	0.11	0.15	0.12	0.10	0.15	0.13
Mean spawner biomass relative to SBMSY	SB/SB_{MSY}	1.08	0.92	0.94	0.83	0.87	0.82
Mean fishing mortality relative to FMSY	F/F_{tar}	0.64	0.75	0.81	0.85	0.79	0.85
Mean fishing mortality relative to target	F/F_{MSY}	0.64	0.75	0.81	0.85	0.79	0.85
Probability of being in Kobe green quadrant	SB,F	0.48	0.46	0.38	0.32	0.44	0.33
Probability of being in Kobe red quadrant	SB,F	0.25	0.34	0.31	0.42	0.38	0.35
Safety : maximise the probability of remaining above low stock status (i.e. minimise risk)							
Probability of spawner biomass being above 20% of SB0	SB	0.69	0.64	0.68	0.52	0.60	0.64
Probability of spawner biomass being above BLim	SB	0.81	0.72	0.84	0.69	0.69	0.78
Yield : maximise catches across regions and gears							
Mean catch (1000 t)	C	164.48	219.15	217.16	166.86	217.02	226.62
Mean relative CPUE (aggregate)	C	0.47	0.59	0.61	0.48	0.58	0.64
Mean catch relative to MSY	C/MSY	1.34	1.13	1.09	0.97	1.08	1.00
Stability: maximise stability in catches to reduce commercial uncertainty							
Mean absolute proportional change in catch	C	18.18	7.51	21.13	12.89	6.98	14.97
% Catch coefficient of variation	C	0.62	0.21	0.56	0.41	0.19	0.42
Probability of shutdown	C	0.14	0.03	0.11	0.06	0.04	0.05

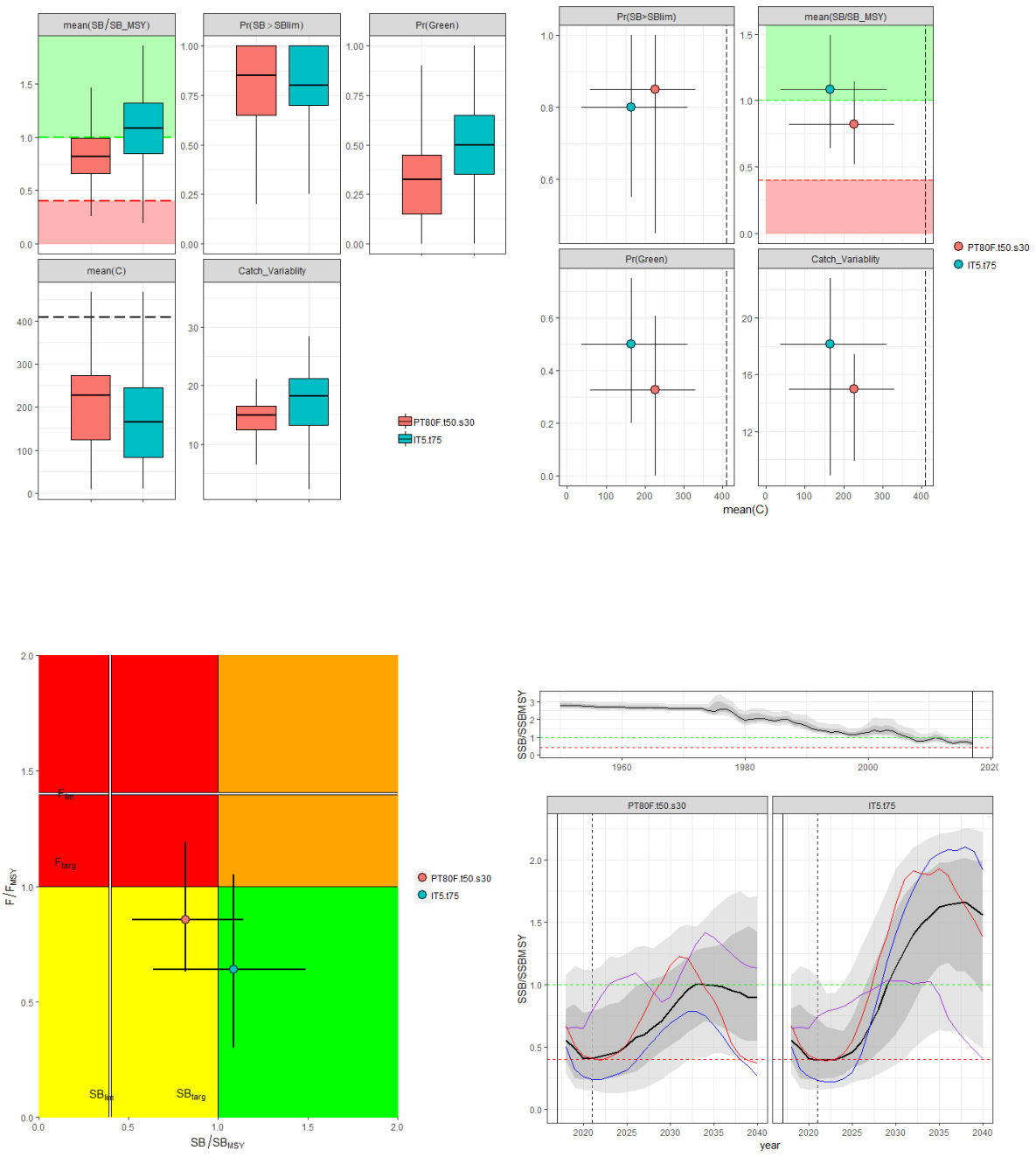

Figure 47. YFT reference set OM (OMrefbY19.4.500) - with two contrasting MPs and a subset of standard result plots to facilitate comparison with robustness tests in the following figures..

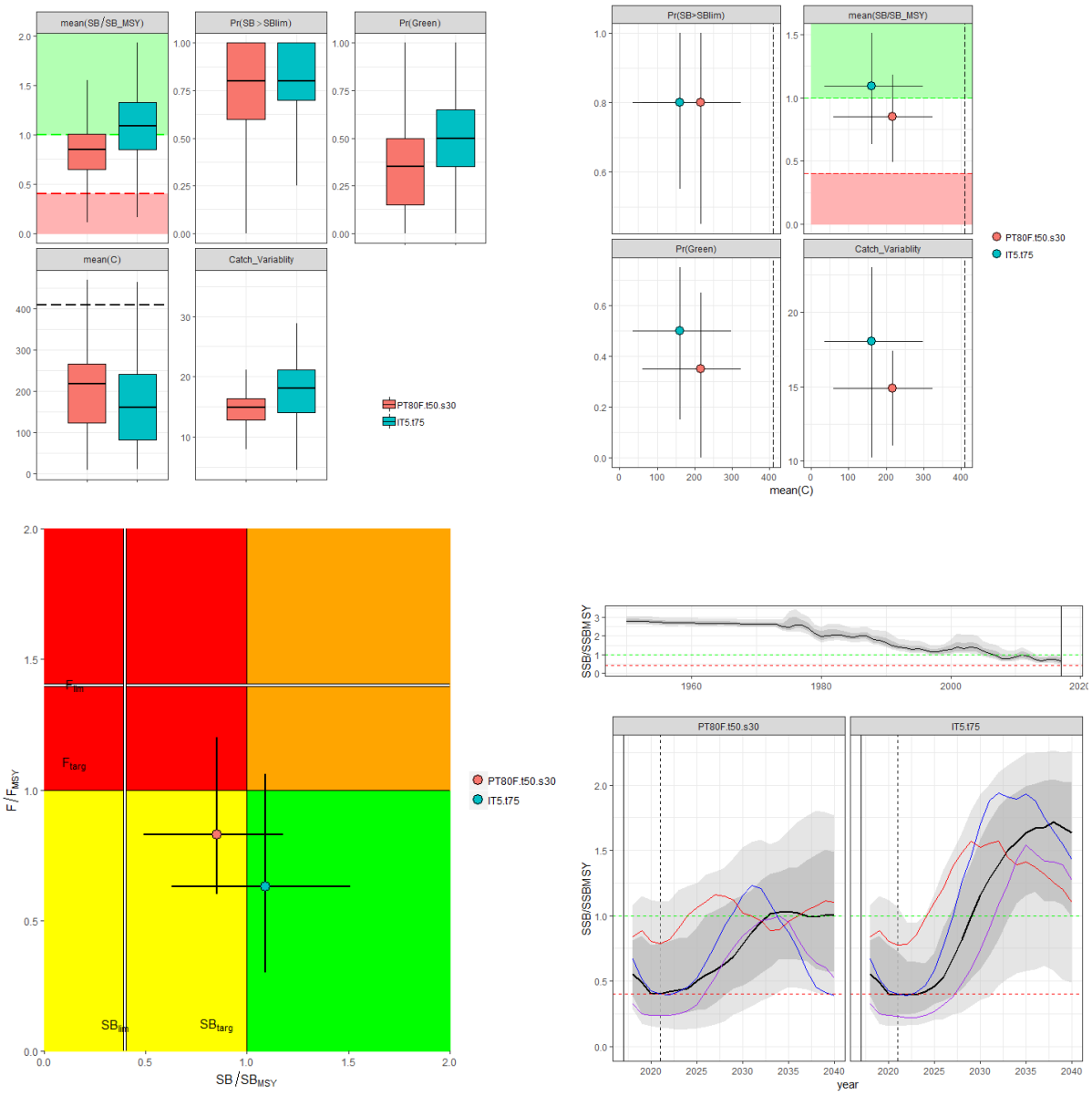

Figure 48. YFT robustness test (OMrobY19.4.ICV30 - high CPUE observation error) – Subset of the standard MP performance plots.

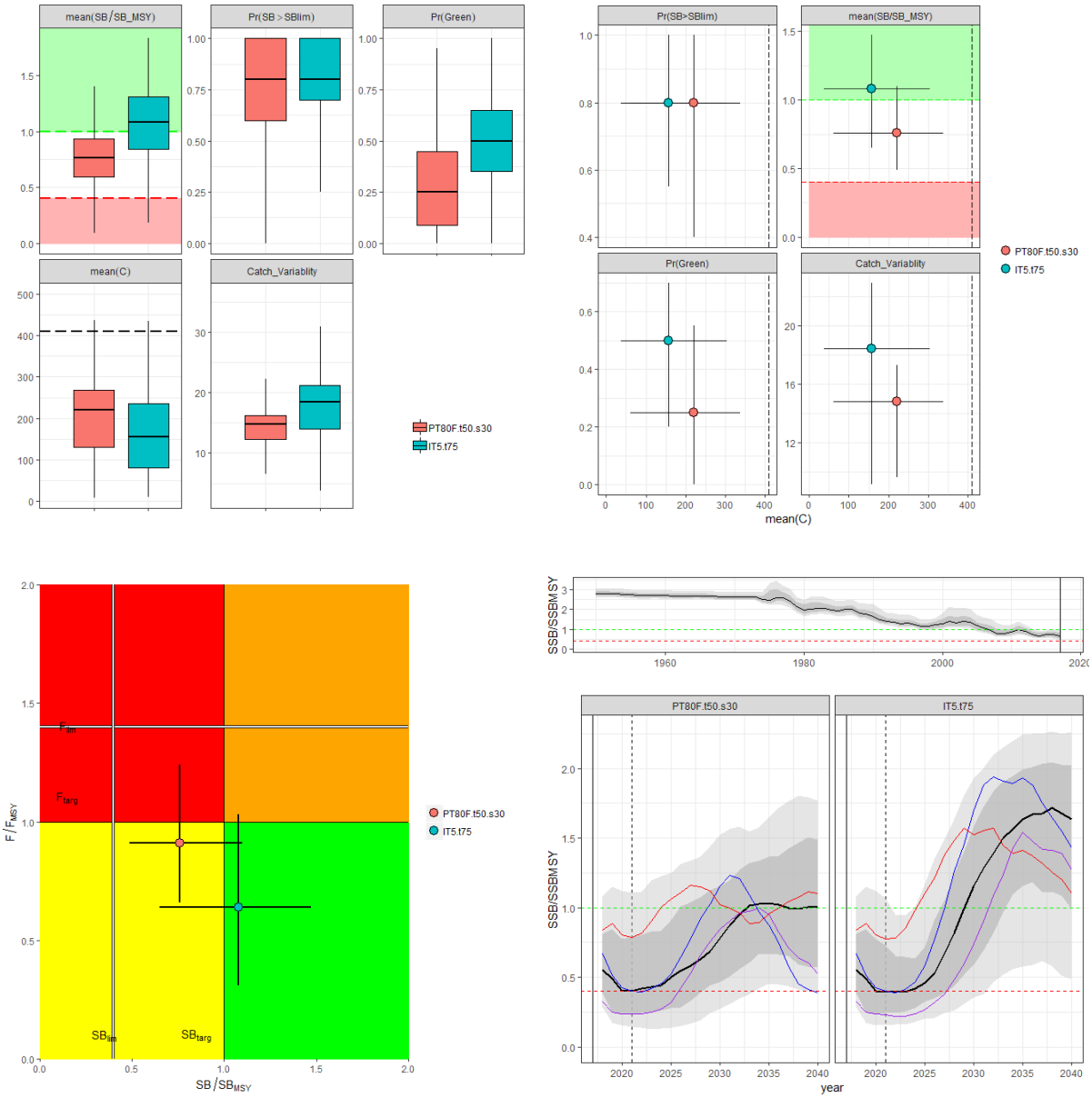

Figure 49. YFT robustness test (OMrobY19.4.10overRep – 10% reported over-catch in projections) – Subset of the standard MP performance plots.

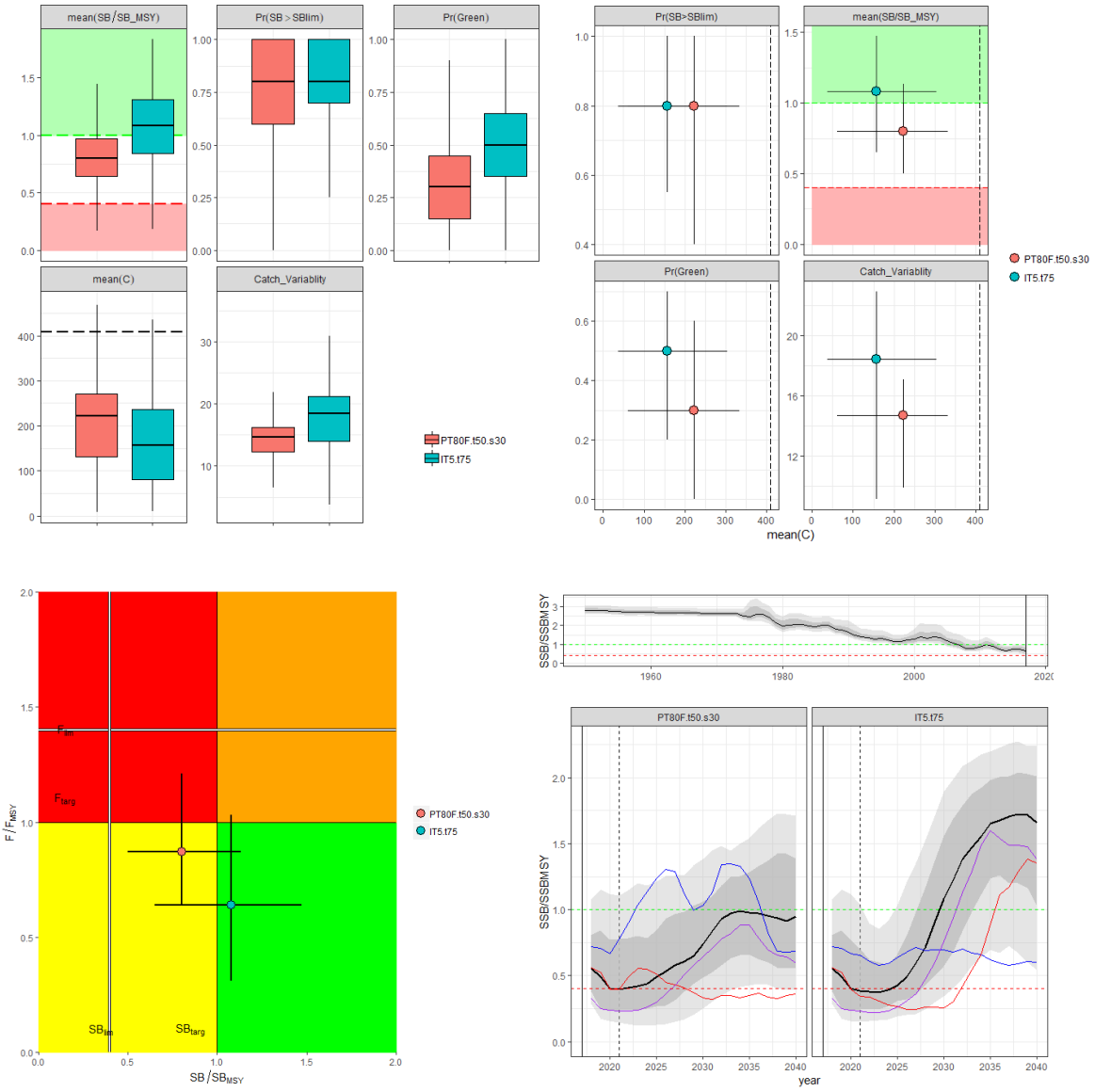

Figure 50. YFT robustness test (OMrobY19.4.10overIUU – 10% IUU over-catch in projections) – Subset of the standard MP performance plots.

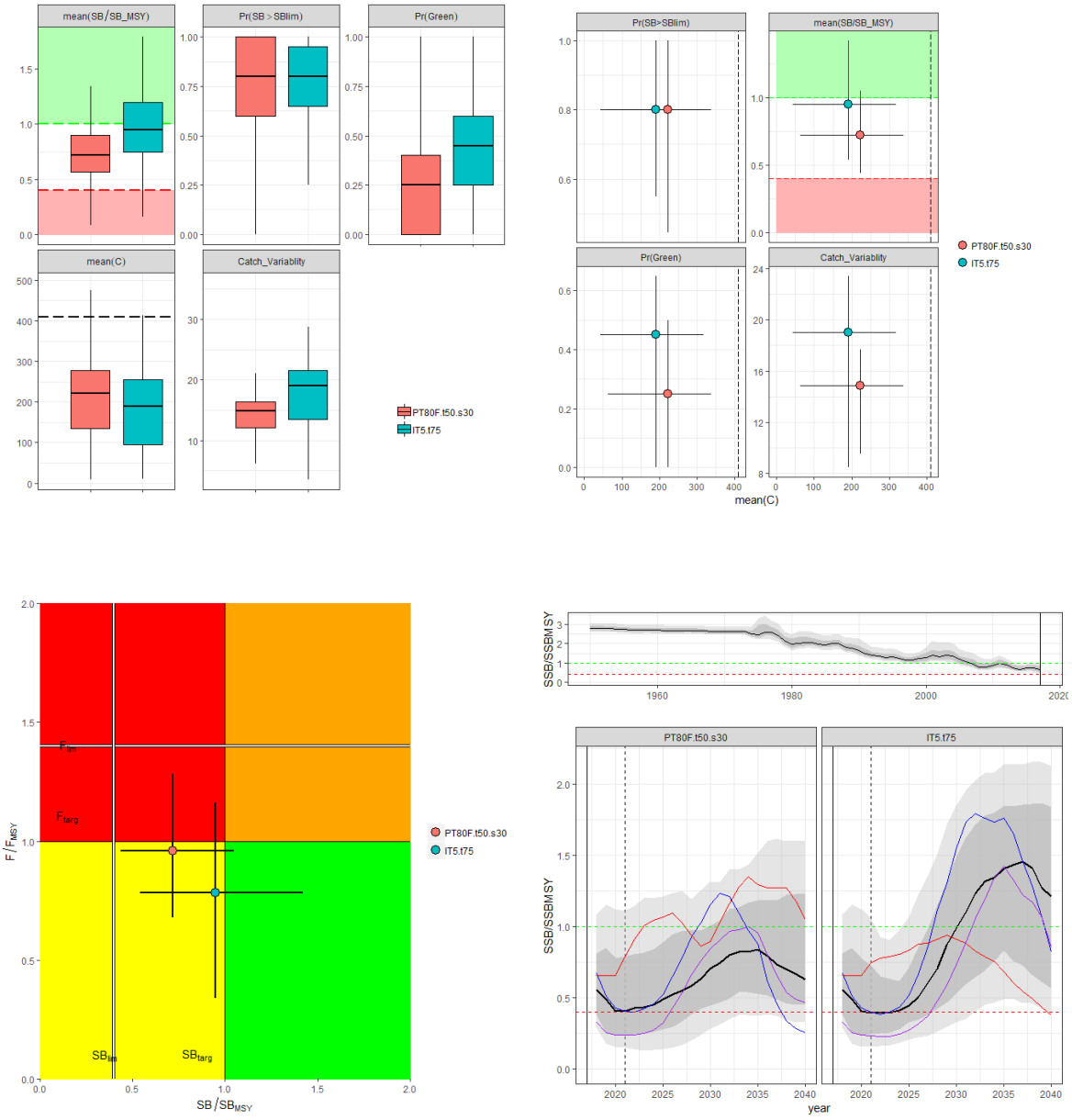

Figure 51. YFT robustness test (OMrobY19.4.qTrend2 – projected 2% per year LL catchability trend) – Subset of the standard MP performance plots.

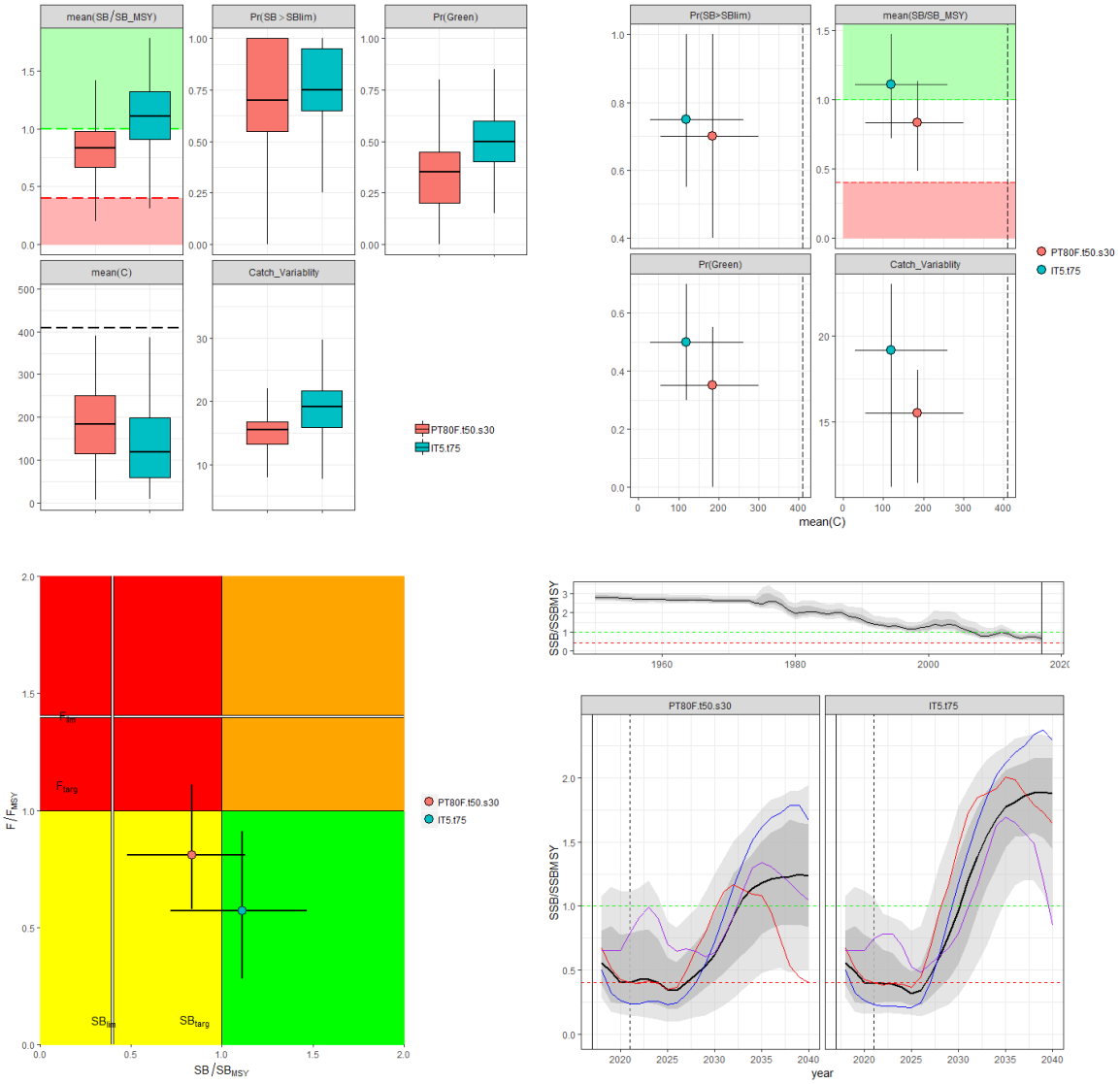

Figure 52. YFT robustness test (OMrobY19.4.recShock – 8 quarters of 55% expected recruitment) – Subset of the standard MP performance plots.

References

IOTC. 2019. Report for the 23rd session of the Indian Ocean Tuna Commission. IOTC-2019-S23-RE

Kolody, D, Jumppanen, P. 2019d. IOTC bigeye Management Procedure evaluation update June 2019. IOTC-2019-TCMP03-10.

Kolody, D, Jumppanen, P. 2019e. IOTC yellowfin Management Procedure evaluation update June 2019. IOTC-2019-TCMP03-11.

Kolody, D, Jumppanen, P. 2019f. Update on IOTC bigeye tuna MSE Operating Model Development October 2019. IOTC-2019-WPM10-08.

Kolody, D, Jumppanen, P. 2019g. Update on IOTC yellowfin tuna MSE Operating Model Development October 2019. IOTC-2019-WPM10-09.

TCMP. 2019. Report of the 2nd IOTC Technical Committee on Management Procedures. IOTC–2019–TCMP03–R[E].

WPM. 2019. Report of the 8th Workshop on Management Strategy Evaluation in Working Party on Methods of Indian Ocean Tuna Commission. IOTC–2019–WPM10-INF01.