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Bigeye Tuna Management Procedure for adoption

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Contents

Acknowledgments..ii

1 Executive summary 1

2 Introduction 2

3 MSE Summary 2

3.1 Management objectives 2

3.2 Candidate Management Procedures...3

3.3 Operating Models...3

3.4 Results...4

4 Actions for the Commission...5

Appendix A: Candidate Management Procedures 6

Appendix B: Reference and robustness sets of operating models...7

Appendix C: Final Results 8

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The WPM MSE Scientists and Chair, for review and feedback.

1 Executive summary

This document provides background information to inform the Commission's decision on the adoption of a Bigeye Tuna Management Procedure (MP), as outlined in the Commission workplan.

The final two candidate Management Procedures (MP1_Harvest and MP2_Target) have very similar performance and are likely to meet the Commission's objectives with a high probability.

The advantages of MP1_Harvest are slightly higher average catches and slightly better initial performance in the years after a poor recruitment period (in robustness tests).

The advantages of MP2_Target are a lower probability of an initial catch reduction below recent average levels, a smaller initial catch decrease, lower catch variability, and lower probability of going over or under MSY at the end of the projection period. MP2_Target also showed a lower probability of SSB falling below the biomass limit reference point (50%SBMSY) and lower probability of exceeding the fishing mortality limit reference point (130%FMSY) (in robustness tests).

Both MPs show slowly increasing TACs after the first two TAC decisions.

The decisions to be made by the Commission are:

1. Selection of the level of performance that the Commission wishes to achieve in the future: either 60%, or 70%, probability of being in the Kobe green zone (i.e. not overfished and not subject to overfishing) by 2034-2038.
2. Selection and adoption of one of the two candidate Bigeye Management Procedures.

Adoption of a Management Procedure will help improve the standard for Bigeye Tuna fishery management globally. It is the culmination of the Commission's work, since adoption of Resolutions 12/01, 15/10 and 16/09, to develop a robust Management Procedure to guide management advice.

2 Introduction

The IOTC, at its 15th Session in 2011, endorsed the development of a management strategy evaluation (MSE) process and the Scientific Committee endorsed a roadmap for its development later that year. In addition, a meeting of all tuna RFMOs (i.e., Kobe III) in 2011 recognised that an MSE process needs to be widely implemented in the tuna RFMOs in line with implementing a precautionary approach for tuna fisheries management. In 2016, the IOTC established the Technical Committee on Management Procedures (TCMP) specifically to "enhance the decision-making response of the Commission in relation to management procedures".

The MSE process and development of a Management Procedure (MP) for Bigeye Tuna has been in progress since 2014.

This document describes the structure and core concepts of the Bigeye Tuna MSE and summarises the results from the evaluation of the final two candidate MPs. The intention is to provide sufficient knowledge to facilitate the decision-making processes of the Commission in relation to the adoption of a Bigeye Tuna MP in the IOTC.

3 MSE Summary

The purpose of MSE is to evaluate candidate MPs against a range of possible conditions of the population and fishery dynamics, to find the best performing MP that meets the management objectives of the Commission and is robust to a range of uncertainties.

3.1 Management objectives

The overall objective of the Commission is the conservation and optimum utilisation of tuna stocks in the IOTC area of competence. Specific management objectives outlined in Resolution 15/10 for key target species, including Bigeye Tuna, are to maintain the biomass at or above levels required to produce MSY and maintain the fishing mortality rate at or below FMSY.

Consistent with these objectives, the Commission is considering one of two tuning objectives that guide the required performance of the Management Procedure:

1. Exactly **60%** probability of fishing mortality being less than F_{MSY} (not overfishing) and biomass being greater than B_{MSY} (not overfished) (i.e., being in the Kobe green zone) by 2034-2038[1].
2. Exactly **70%** probability of fishing mortality being less than F_{MSY} (not overfishing) and biomass being greater than B_{MSY} (not overfished) (i.e., being in the Kobe green zone) by 2034-2038[1].

The Commission needs to select which one of these two tuning objectives it wishes to use.

[1] The TCMP NOTED in 2021 that delays in the MSE developments have resulted in reference years for tuning objective being too close to the current terminal year of the OMs. The TCMP REQUESTED that the reference years of 2030-2034 for tuning are replaced with relative placeholders (11-15 years from model terminal year).

3.2 Candidate Management Procedures

As agreed by the SC in 2021 (IOTC–2021–SC24, paragraph 123), there are two final candidate MPs for the Commission to select from (see Appendix A for more details):

1. MP1_Harvest: a model-based MP, which fits a simple population model, then prescribes the TAC as a hockey stick-shaped Harvest Control Rule based on the estimated stock depletion
2. MP2_Target: a model-based MP, which fits a simple population model, then uses internal projections to solve for the TAC to attain a pre-defined biomass depletion target (i.e. the tunning objective) in 2034-2038.

Both MPs:

- assume a 3-year management cycle and calculate a total allowable catch (TAC) for the entire IOTC management area.
- use a simple model, with only catch and CPUE as input data, to calculate the TAC for the next 3-year cycle.
- have a limit on the maximum change to the TAC of 15%.

To enable comparison between the MPs, they are "tuned" to achieve a common objective on stock status. By standardising for this performance measure, performance against other management objectives can be compared. Once tuned, this fully defines the parameters in the MP.

3.3 Operating Models

The operating models (OMs) are the simulation models within which MPs are tested. The Bigeye Tuna OMs, endorsed by the IOTC SC at its 2021 meeting (IOTC–2021–SC24, paragraph 122), are described in more detail in Appendix B.

There are a range of uncertainties relating to aspects of stock biology and fishery dynamics that are accounted for in the OMs. The Bigeye Tuna MSE includes 72 alternative operating models (i.e., the "reference set or grid of OMs") that cover these sources of uncertainty (Appendix B). Each operating model in the MSE represents a plausible scenario for the dynamics of the stock and the fishery.

There are an additional 5 "robustness" tests to evaluate less likely scenarios (Appendix B), similar to more extreme "sensitivity runs" included in a stock assessment (Hillary et al 2022).

3.4 Results

Final results (Appendix C) show key trade-offs in performance for the two "tuning" management objectives.

The performance of the two MPs (Table 1) can be summarised as:

- Both MPs were able to be tuned to the 60% and 70% probability of being in the Kobe green quadrant by 2034-2038 tuning objectives.
- The performance of both MPs differs in a similar manner between the tuning objectives (i.e. either 60% or 70% probability of being in the Kobe green zone during 2034-2038). The 60% tuning objective results in slightly higher catches (and lower relative biomass) than the 70% tuning objective, for both MPs.
- The advantages of MP1_Harvest are slightly higher average catches and slightly better initial performance in the years after a poor recruitment period (in robustness tests).
- The advantages of MP2_Target are a lower probability of an initial TAC decrease, a smaller initial TAC decrease, lower catch variability, and lower probability of going over or under MSY at the end of the projection period. MP2_Target also showed slightly better performance on the probability of SSB falling below the biomass limit reference point and lower probability of exceeding the fishing mortality limit reference point (in robustness tests).
- Both MPs show slowly increasing TACs after the first two TAC cycles.
- The performance of the two MPs differed in only two of the robustness tests (i.e. recruitment shock and increasing trend in longline CPUE).

Table 1 Performance statistics summary. The performance advantage is in bold.

Performance Metric	MP1_Harvest	MP2_Target
Average catches	**Higher**	Lower
Probability of initial catch decrease	Higher	**Lower**
Catch variability	Higher	**Lower**
Range of Biomass and Fishing mortality at the end of projection period	Wider	**Narrower**
Probability $B>B_{LIM}$ over the projection period (in robustness test)	Lower	**Higher**
Probability $F<F_{MSY}$ over the projection period (in robustness test)	Lower	**Higher**
Recovery from a poor recruitment period (in robustness test)	**Faster**	Slower

4 Actions for the Commission

1. Selection of the management objective that the MP will be tuned to, either:
    a) **60%** probability of being not overfished and not subject to overfishing (in the Kobe green zone) by 2034-2038, or
    b) **70%** probability of being not overfished and not subject to overfishing (in the Kobe green zone) by 2034-2038.
2. Selection and adoption of one of the two Bigeye Management Procedures, as outlined in the Commission's workplan, either:
    a) MP1_Harvest, or
    b) MP2_Target.

Related documents

A schedule for the implementation of an MP for Bigeye Tuna is outlined in Preece et al. (2022).

The process for evaluating exceptional circumstances adopted by the IOTC SC is described in Appendix 6a of the 2021 IOTC SC report (Anon, 2021).

References

Anon. 2021. Report of the 24th Session of the IOTC Scientific Committee. IOTC–2021–SC24–R[E], Appendix 6A.

Hillary, RM, A. Williams, A. Preece, and P. Jumppanen. 2022. Update of Indian Ocean Bigeye Tuna MSE. IOTC-2022-WPM13(MSE)-05

Preece AL, Williams A and Hillary RM. 2022. MP Implementation – schedule of activities: meta-rules. IOTC-2022-TCMP05-##

Appendix A: Candidate Management Procedures

Table A.1: Description of candidate management procedures

MP	Brief description and formulae for calculating TACs	References
MP1_Harvest	$HCR_{\text{mult}} = 1 \quad \text{if} \quad B_y/K >= 0.4$ $HCR_{\text{mult}} = \frac{B_y/K - 0.1}{0.3} \quad \text{if} \quad 0.1 < B_y/K < 0.4$ $HCR_{\text{mult}} = 0.0001 \quad \text{if} \quad B_y/K <= 0.1$ $TAC_{\text{new}} = B_y\left(1 - \exp(-F_{\text{mult}} * HCR_{\text{mult}} * F_{\text{MSY}})\right)$ The candidate MP uses a hockey-stick HCR that constructs a harvest rate based on biomass depletion from a simple biomass dynamic model fitted to overall catch and spatially aggregated longline CPUE. The pivot points are at 0.4 and 0.1 with a linear decrease from 1 to almost zero in the HCR multiplier between those pivot points. The main suite of equations that define the HCR are above, and a symmetric 15% maximum TAC change is enforced.	Kolody and Jumppanen (2021) IOTC Bigeye Tuna Management Procedure Evaluation Update. March 2021. *IOTC-2021-TCMP04-08*
MP2_Target	The candidate MP uses the same simple biomass dynamic model described above. In the HCR the TAC is calculated via a projection required to meet a future biomass depletion target. As above, a symmetric 15% maximum TAC change is enforced.	Kolody and Jumppanen (2021) IOTC Bigeye Tuna Management Procedure Evaluation Update. March 2021. *IOTC-2021-TCMP04-08*

Data specification

The input data for both MPs are:

- **Total catches of bigeye tuna** in the IOTC Area of Competence. These are collated by the IOTC Secretariat and prepared annually for the IOTC Working Party on Tropical Tuna
- **Standardised and spatially aggregated longline catch per unit effort (CPUE)**. These are derived from the joint standardisation analysis approach described by Hoyle et al (2019) applied to the most recent catch and effort data available.

References

Hoyle, S., Chang, S.T, Fu, D., Kim, D.N., Lee, S.I., Matsumoto, T., Chassot, E., Yeh, Y.M. 2019. Collaborative study of bigeye and yellowfin tuna CPUE from multiple Indian Ocean longline fleets in 2019, with consideration of discarding. IOTC–2019–WPM10–16.

Kolody, D. and Jumppanen, P. (2021) IOTC Bigeye Tuna Management Procedure Evaluation Update. March 2021. IOTC-2021-TCMP04-08.

Appendix B: Reference and robustness sets of operating models

For Bigeye Tuna, the operating model implements:

- an historical period from 1952 through to 2018,
- 2023 as the first TAC implementation year, and
- a projection period that extends to the year 2040, although the target period for achieving the tuning objectives on average is 2034-2038.

The reference set of 72 operating models capture uncertainty through combinations of different levels of the following:

1. Recruitment: the number of age 1 fish; reflects stock productivity over time (3 levels)
2. Natural mortality: the percent of individuals who die of natural causes at a given age (3 levels)
3. Tag recapture: different weightings on the reliability of the tagging data (3 levels)
4. Assumed longline catchability trend: whether or not catchability has increased in the longline fishery (2 levels)
5. Regional scaling of longline CPUE (2 levels)
6. Longline fishery selectivity (2 levels)
7. Effective Sample Size (ESS) which determines how informative the size composition data is (2 levels)

A robustness set of 5 operating models is used to test the candidate MPs against more extreme, but plausible, scenarios (Table B.1).

Table B.1: Set of scenarios used to evaluate the robustness of the 2 candidate MPs

Robustness test	Description
1. ICV30	The information content of the projected longline CPUE is reduced (spatially-aggregated annual σ_I = 0.30, auto-correlation = 0.5)
2. 10% ROC	Every fishery has a 10% overcatch implementation error, with accurate catch reporting
3. 10% UCC	Every fishery has a 10% overcatch implementation error, that is not reported
4. 3% qTrend	There is an annual increasing 3% longline CPUE catchability trend starting in the projections
5. Rec Shock	mean recruitment is reduced to 55% of the historical level (similar to estimates for yellowfin tuna in the early 2000s) for 8 consecutive quarters following the implementation of the MP

Appendix C: Final Results

Figure C.1 plots the general summary of MP performance time-averaged over the 20-year projection period for the reference set for each tuning objective. Key findings include::

- Spawning stock biomass (SSB) performance is very similar, with both MPs showing negligible risk of breaching the limit reference point
- Average catches are slightly higher for MP1_Harvest relative to MP2_Target but so is catch variability and MP1_Harvest also has a lower tail in the catch distribution (lowest catches are lowest for MP1_Harvest).

Tables C.1 and C.2 detail the high level and more detailed time-averaged (20 years) performance statistics for the reference set, respectively. Figures C.2 and C.3 summarise the Kobe probability characteristics of the MPs. In the time varying case (Figure C.2), both are very similar up to about 2030, but afterwards the probability of re-entering the orange and red zones begins to rise rapidly for the MP1_Harvest given it begins to increase catches more in this period, relative to MP2_Target. Overall Kobe performance is very similar between MPs (Figure C.3), with the tuning objective making far more difference than the MP structure.

Figure C.4 shows time series plots of catch, biomass ratio and fishing mortality ratio:

- Catch: Due to higher catches in the middle of the projection period MP1_Harvest appears to be going to undershoot/overshoot the biomass/fishing mortality MSY targets, whereas MP2_Target appears to be approaching stochastic equilibrium more monotonically.
- Catch: short term catch performance (i.e. first two TAC periods) differs most for the tuning objective of 70% probability of being in the green zone of the Kobe plot. MP1_Harvest shows a tendency for median catches to be below the recent three-year 85.6 kt average (2018-2020) for the first two TAC decision periods; for MP2_Target the median TAC for the first period is slightly lower than the recent average, and for the second TAC period it is basically the same. For both MPs and tuning criteria, median TACs are above the recent three-year average by 2030 and stay above this level afterwards, reaching a plateau at around 110-120 kt.
- Biomass ratio (SSB/SSB_{MSY}): SSB relative to MSY dynamics are very similar between MPs for the same tuning criteria.
- Fishing mortality ratio (F/F_{MSY}): Fishing mortality relative to MSY is also very similar between MPs for the same tuning, but by the last decade of the projections the probability of being both above F_{MSY} target and limit levels is increasingly higher for MP1_Harvest, relative to MP2_Target.

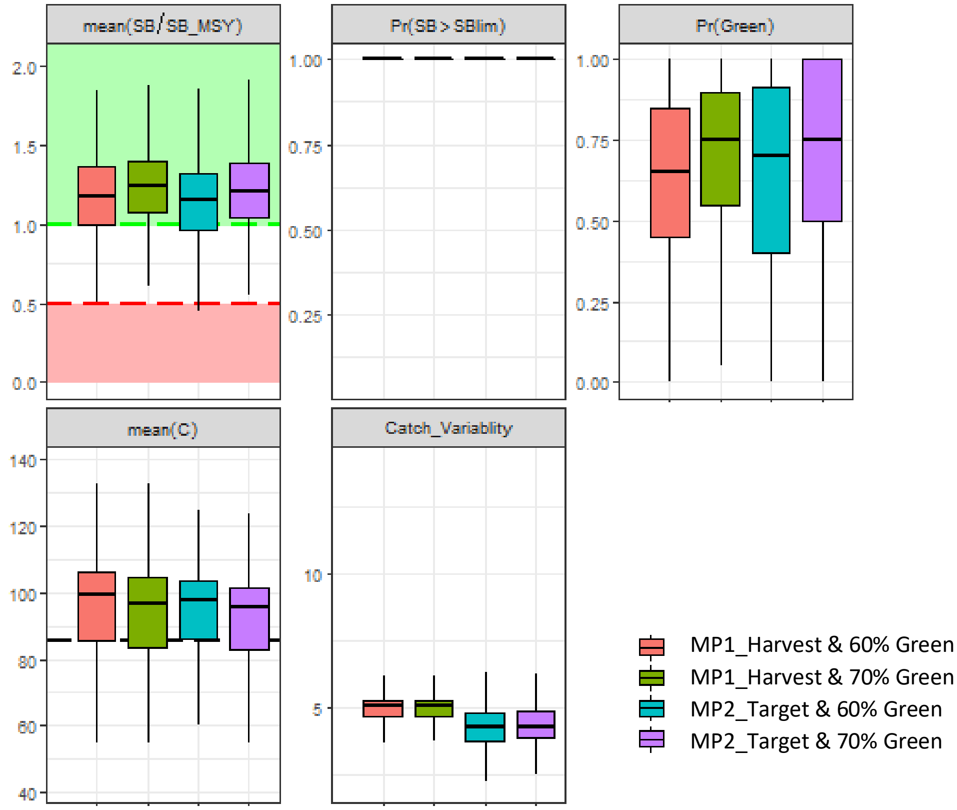

Figure C.1: Boxplots comparing candidate MPs (tuned to 60% or 70% probability of being in the green zone during 2034-2038) with respect to key performance measures averaged over 20 years, for the reference set. Horizontal line is the median, boxes represent 25th - 75th percentiles, thin lines represent 10th - 90th percentiles. Red and green horizontal lines (in mean SB/SB_MSY plot) represent the interim limit and target reference points for the mean SB/SB_{MSY} performance measure. The horizontal dashed black line (in mean(C) plot) is the 2018-2020 average catch.

Table C.1: High level summary table with respect to key performance measures for MP1_Harvest and MP2_Target tuned to the 60% and 70% probability of being in the green zone of the Kobe plot during 2034-2038. A 20-year averaging period was used to create these statistics, from the reference set. The darker shading indicates best relative performance for individual performance measures. The values in parentheses for SB/SB_{MSY} and mean catch represent 80% confidence intervals.

	Performance Measure				
MP	SB/SB_{MSY}	Prob(Green)	Prob(SB>limit)	Mean Catch (t)	Catch Variability (%)
MP1_Harvest 60% Green	1.18 (1.00-1.36)	0.63	0.97	99.3 (85.6-106.1)	5.06
MP2_Target 60% Green	1.15 (0.96-1.32)	0.63	0.97	97.7 (86.0-103.6)	4.23
MP1_Harvest 70% Green	1.24 (1.07-1.40)	0.69	0.98	96.6 (83.7-104.6)	5.08
MP2_Target 70% Green	1.21 (1.04-1.39)	0.69	0.98	95.8 (82.8-101.6)	4.28

Table C.2: Detailed table of results for MP1_Harvest and MP2_Target tuned to the 60% and 70% probability of being in the green zone of the Kobe plot during 2034-3028, for the reference set. A 20-year averaging period was used to create these statistics. Shading indicates best relative performance in each performance measure.

Performance measure		**20-year average**			
		MP1_Harvest 60% Green	MP2_Target 60% Green	MP1_Harvest 70% Green	MP2_Target 70% Green
Status: maximise stock status					
Mean spawner biomass relative to pristine	SB/SB_0	0.32	0.30	0.34	0.33
Minimum spawner biomass relative to pristine	SB/SB_0	0.21	0.22	0.22	0.23
Mean spawner biomass relative to SB_{MSY}	SB/SB_{MSY}	1.18	1.15	1.24	1.21
Mean fishing mortality relative to F_{MSY}	F/F_{MSY}	0.82	0.82	0.78	0.76
Probability of being in Kobe green quadrant	SB,F	0.63	0.63	0.69	0.69
Probability of being in Kobe red quadrant	SB,F	0.21	0.22	0.16	0.16
Safety : maximise the probability of remaining above low stock status (i.e. minimise risk)					
Probability of spawner biomass being above 20% of SB_0	SB	0.87	0.87	0.90	0.91
Probability of spawner biomass being above B_{Lim}	SB	0.97	0.97	0.98	0.98
Yield : maximise catches across regions and gears					
Mean catch (1000 t)	C	99.35	97.69	96.57	95.81
Mean relative CPUE (aggregate)	C	0.83	0.82	0.81	0.79
Mean catch relative to MSY	C/MSY	1.10	1.07	1.15	1.14
Stability: maximise stability in catches to reduce commercial uncertainty					
Mean absolute proportional change in catch	C	5.06	4.23	5.08	4.28
% Catch coefficient of variation	C	0.20	0.16	0.22	0.17
Probability of shutdown	C	0.00	0.00	0.00	0.00

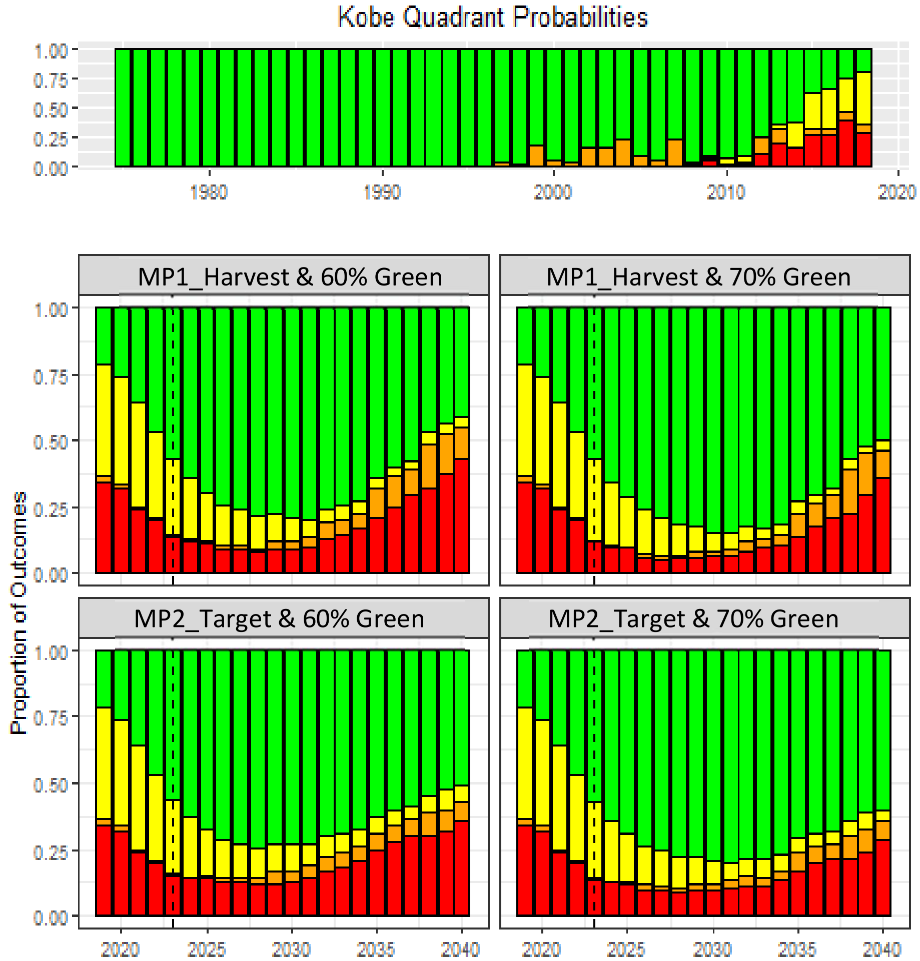

Figure C.2: Proportion of simulations in each of the Kobe quadrants over time for each of the candidate MPs tuned to the 60% and 70% probability of being in the green zone of the Kobe plot during 2034-2038. Historical estimates are included in the top panel. The lower panels are projections, for the reference set, with the first MP application indicated by the broken vertical line (2023).

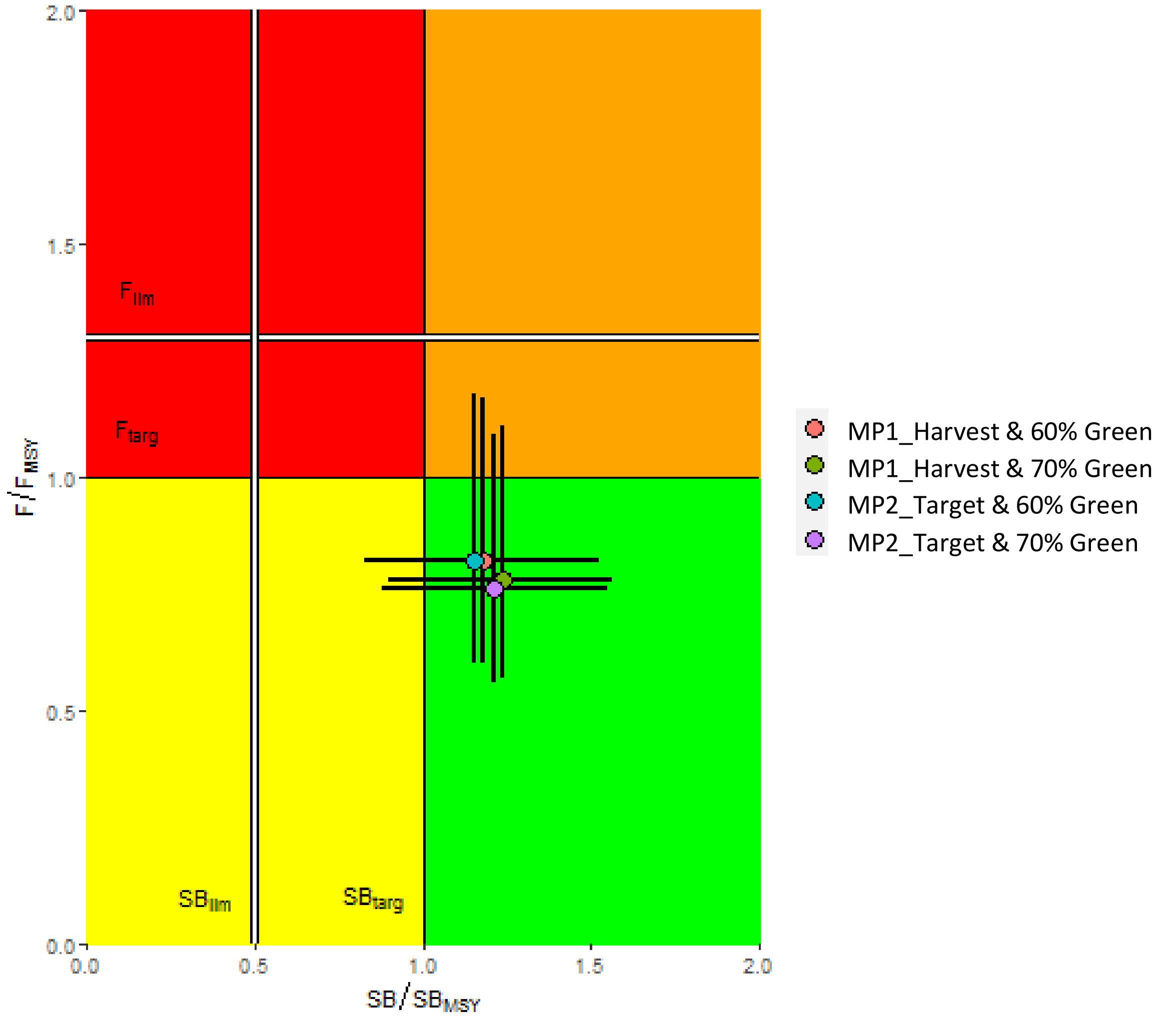

Figure C.3: Time-averaged Kobe plot for the two candidate MPs tuned to the 60% and 70% probability of being in the green zone of the Kobe plot during 2034-2038 and averaged over the first 20 years of the projection period, for the reference set. Error bars show the 80% confidence intervals.

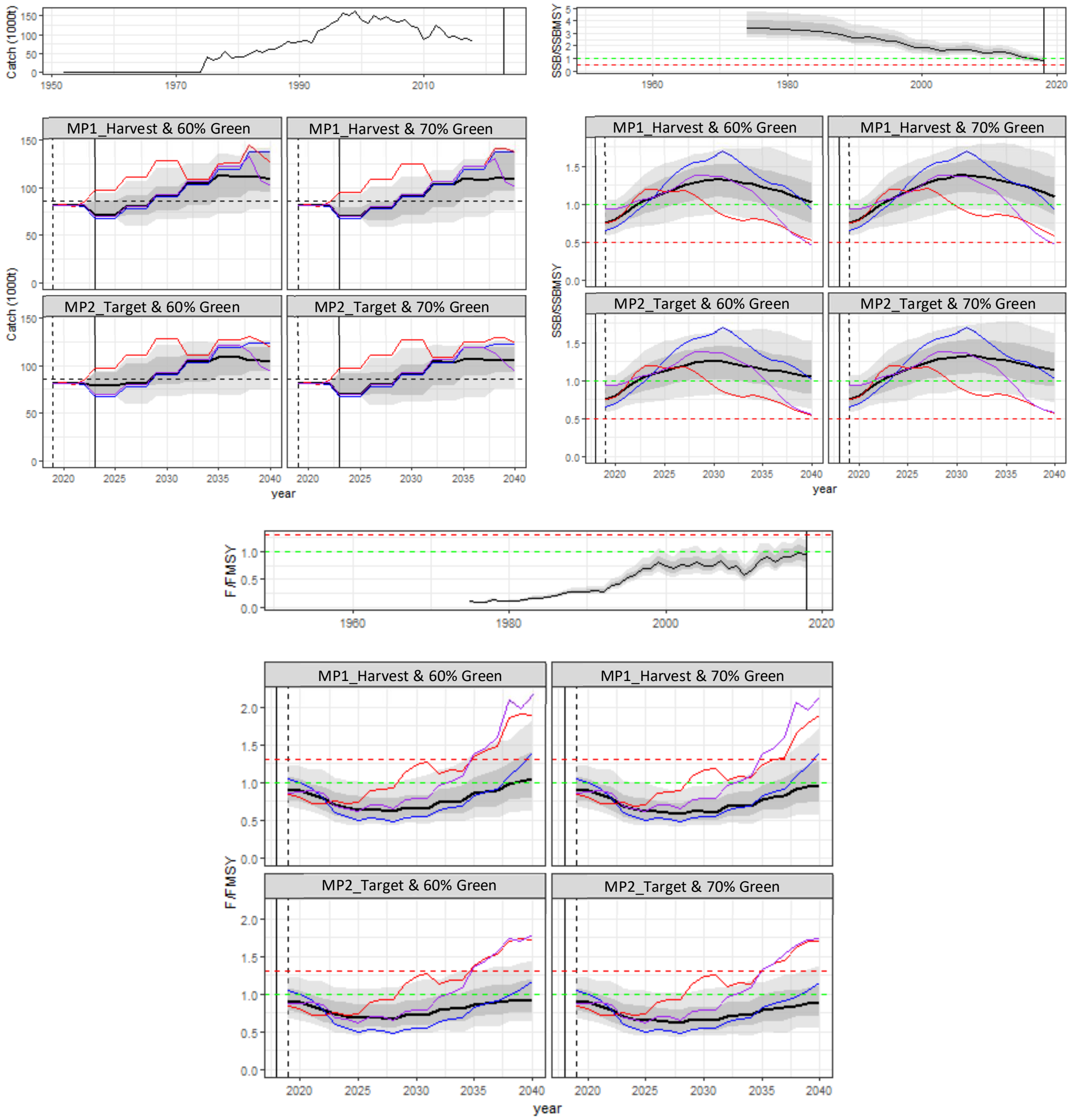

Figure C.4: Time series of Catch (top left), SSB_{MSY} ratio (top right) and F_{MSY} ratios (bottom) for the two candidate MPs tuned to the 60% and 70% probability of being in the green zone of the Kobe plot during 2034-2038. The top panel represents the historical estimates from the reference set of operating models, 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 current catch (average 2018-2020, black), 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.

Robustness tests

The only significant differences from the MPs tuned to the reference set of OMs was for the recruitment shock and increasing longline catchability robustness tests. Figure C.5 compares the time-dependent Kobe probabilities for MP1_Harvest and MP2_Target for one tuning objective (60% in the Kobe green zone) for the recruitment shock robustness test. In terms of limiting the short-term impact of the recruitment shock, MP1_Harvest slightly outperforms MP2_Target (due to more ability to reduce catch via higher TAC variability) but over the medium to longer term this reverses and MP2_Target is able to continue to reduce the impact of the recruitment shock all the way through to the end of the projection period.

For the increasing longline catchability robustness test, Figure C.6 details the time-dependent probabilities for MP1_Harvest and MP2_Target for one tuning objective (60% in the Kobe green zone). Both MPs display a clear response to this robustness trial: the increasing bias trend in the abundance index causes catches to increase and an increase in both the orange and red Kobe probabilities after 2030. The main observable difference between the two is that MP2_Target does a slightly better job of limiting the rise in the orange and red Kobe probabilities, relative to MP1_Harvest.

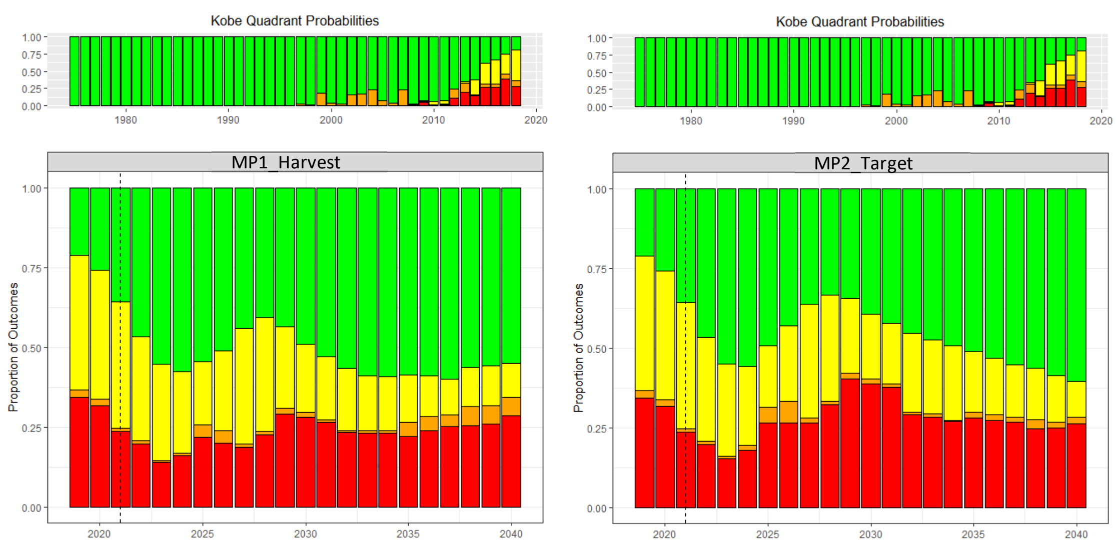

Figure C.5: Time-dependent Kobe probabilities for MP1_Harvest (left) and MP2_Target (right) for the recruitment shock robustness test.

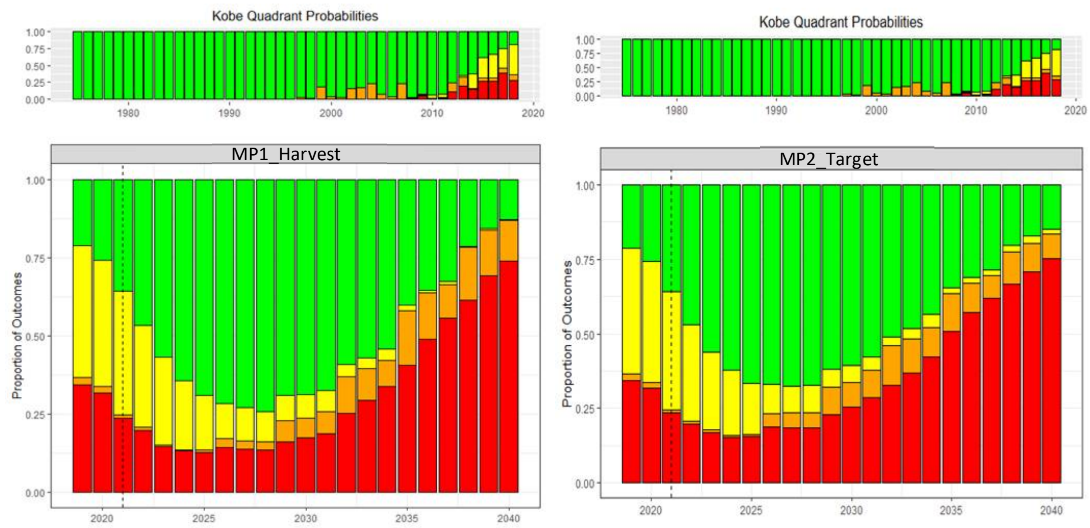

Figure C.6: Time-dependent Kobe probabilities for MP1_Harvest (left) and MP2_Target (right) for the increasing longline catchability robustness test.

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