



PRELIMINARY RESULTS OF THE INDIAN OCEAN ALBACORE MSE

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Feedback (to collect input and suggestions)

- Feedback is required on the overall structure of the MSE, particularly the operating models and the potential need for reconditioning (Section 2.1), the assumptions for the forward projections (Section 2.2), and the performance metrics used to evaluate the candidate management procedures (Section 2.3)

Decisions (to request formal approval of actions)

- Decisions are required regarding reconditioning of operating models (Section 2.1 and Section 4), and the tuning specifications and other settings of the candidate management procedures (Section 2.4)



Abstract

This paper describes the continuing work on the Indian Ocean albacore management strategy evaluation (MSE). Earlier phases of this work were focused on conditioning of the operating models (OMs) and some initial exploration of the performance of candidate management procedures (CMPs). This paper describes the continuing work on this MSE, including the development of a flexible MSE framework for this fishery, tuning of a set of candidate management procedures (CMPs) to alternative management objectives, and the evaluation of their performance using closed-loop simulation testing. The aims of this paper are to (i) provide an updated set of CMPs and tuning results for discussion by the Working Party on Methods (WPM), (ii) illustrate the trade-offs between catch and the risk to the stock under alternative management objectives, and (iii) identify the work needed before the CMPs can be compared for adoption. The results demonstrate that both model-based and model-free CMPs can be achieve the management objectives for this fishery. However, the also highlight that the choice of the management objectives that are used in the tuning of the CMPs is more important than the structure and design of the CMPs themselves. Additionally, because more recent data are now available, which differ significantly from those data used to condition the OMs, it may be necessary to recondition the OMs before the MSE can be finalized. Feedback is required on the overall structure and design of the MSE framework, and specific decisions need to be made regarding OM reconditioning and the tuning specifications for the CMPs.

1. Introduction

The IOTC has been developing a management procedure (MP) for Indian Ocean albacore through management strategy evaluation (MSE). In earlier phases of this work, operating models (OMs) were conditioned using an Approximate Bayesian Computation (ABC) approach (Hillary & Mosqueira, 2024), and a set of preliminary MPs were tested (Mosqueira & Hillary, 2025a, 2025b, 2026).

This paper describes the continuing work on this MSE, including the implementation of the albacore OMs in the openMSE framework (Hordyk et al., 2025), the tuning of a set of candidate management procedures (CMPs) to alternative management objectives, and their performance for the Base Case OM. The aims of this paper are to (i) provide an updated set of CMPs and tuning results for discussion by the Working Party on Methods (WPM), (ii) illustrate the trade-offs between catch and the risk to the stock under alternative management objectives, and (iii) identify the work needed before the CMPs can be compared for adoption.

This paper summarises the main methods and results, and highlights the primary areas for discussion. The full technical specifications are given in the Trial Specifications Document (TSD; <https://iotcalb.bluematterscience.com/tsd>), and readers are referred to that document for further details on the methodology described in this paper. The preliminary MSE results can be explored in Slick (<https://shiny.bluematterscience.com/app/slick>), an online application designed to interactively explore MSE results (Hordyk et al., 2026).

2. Methods

2.1 Operating Model

The operating models (OMs) were conditioned with an Approximate Bayesian Computation (ABC) developed for IOTC tuna species (Hillary & Mosqueira, 2024). The conditioning model outputs were downloaded from the [albMSE GitHub repository](#) and imported into the MSE framework.

The ABC approach generates a distribution of plausible historical stock dynamics that is consistent with available data and a set of prior beliefs about current and historical stock status. In general, the population model underlying the ABC conditioning is sex-structured with quarterly time steps, and is conditioned on catch, LL1 (NW) CPUE, and length-composition data for 2000 – 2020. The output of the ABC conditioning model was imported into the MSE framework, with 500 samples from the ABC posterior representing individual simulations within the OM.

Table 1 summarises the MSY reference points and the estimated stock status in the terminal year of the conditioning period (2020) and Figure 1 the historical time series for the Base Case OM. The MSY values vary widely over the 500 simulations, reflecting the high variability in the estimated magnitude of the stock. SB_{MSY} is a small fraction of the unfished spawning biomass (median 18% of SB_0), so a limit reference point (LRP) of $0.4 SB_{MSY}$ corresponds to about 7.3% of SB_0 . The median estimated spawning biomass was about 40% of the equilibrium unfished level, and almost two times SB_{MSY} . None of the 500 simulations estimated $SB < SB_{MSY}$ in the terminal year.

The previous work described the development of several additional robustness operating models, namely OM5a, a model that was conditioned on the LL2 (SW) CPUE series, OM6b, a model that included a 1% annual increase in the longline catchability, OM5b_cc, a model that considered the impacts of climate change, and OM5b_rec, a model that explored the consequences of sudden reductions in recruitment (Mosqueira & Hillary, 2025b). The latter two OMs (OM5b_cc and OM5b_rec) were not available in the albMSE GitHub repository and therefore were not included in this analysis. Versions of the first two robustness models (OM5a and OM6b) were available in the repository, however further inspection revealed that those models were not conditioned as they were described, and were essentially identical to the Base Case OM. Therefore, only the Base Case OM was used in this paper.

Table 1. MSY reference points and stock status in 2020 in the Base Case OM: median (5th–95th percentile) over simulations. SB is the female spawning biomass and SB_0 the equilibrium unfished female spawning biomass.

Metric	Quantity	Median (5th–95th percentile)
MSY Reference Points	MSY (t)	51,055 (32,220–90,814)
	F_{MSY}	0.48 (0.36–0.66)
	SB_{MSY} (t)	24,913 (15,791–44,957)
Relative to unfished	SB_{MSY}/SB_0	0.183 (0.154–0.209)
	$0.4 SB_{MSY}/SB_0$	0.073 (0.062–0.084)
Stock status in 2020	SB/SB_0	0.41 (0.23–0.51)
	SB/SB_{MSY}	1.96 (1.00–2.77)
	F/F_{MSY}	0.49 (0.24–1.33)

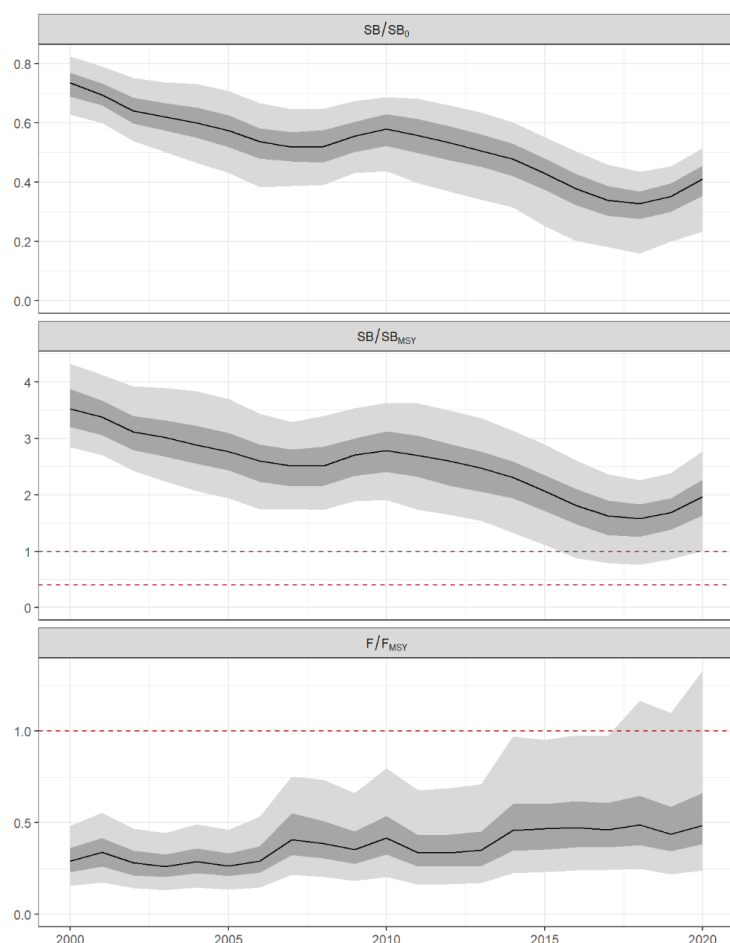


Figure 1. Historical female spawning biomass relative to the equilibrium unfished spawning biomass (top) and to SB_{MSY} (middle), and fishing mortality relative to F_{MSY} (bottom), in the Base Case OM. The line is the median and the shaded areas the 25th–75th and 5th–95th percentiles over simulations. The dashed lines show the limit reference point ($0.4 SB_{MSY}$), SB_{MSY} , and F_{MSY} .

While the OMs are conditioned on the data assembled for the 2022 stock assessment (IOTC, 2022), with data up to 2020, catch and CPUE data up to 2023 are now available from the 2025 stock assessment. These updated data included

a revision of the historical catches and CPUE indices standardised with a revised methodology, and, for the 2000 – 2020 period, the updated dataset were different than those used to condition the OMs (Figure 2, Figure 3, Figure 4).

The current OMs have not been reconditioned to these data. However, the updated data were used in the MSE by providing these data to the CMPs rather than the historical data that the OMs were conditioned on. The Base Case OM was conditioned on the LL1 index, which shows a steeply declining trend in the last decade (Figure 2). A decline of this magnitude is not predicted in most of the simulations in the Base Case OM. There were considerable differences in the fleet-specific catches as well (Figure 3). Because of these differences, it is recommended that the OMs are reconditioned with the updated data, and the results presented here should be considered preliminary at this stage.

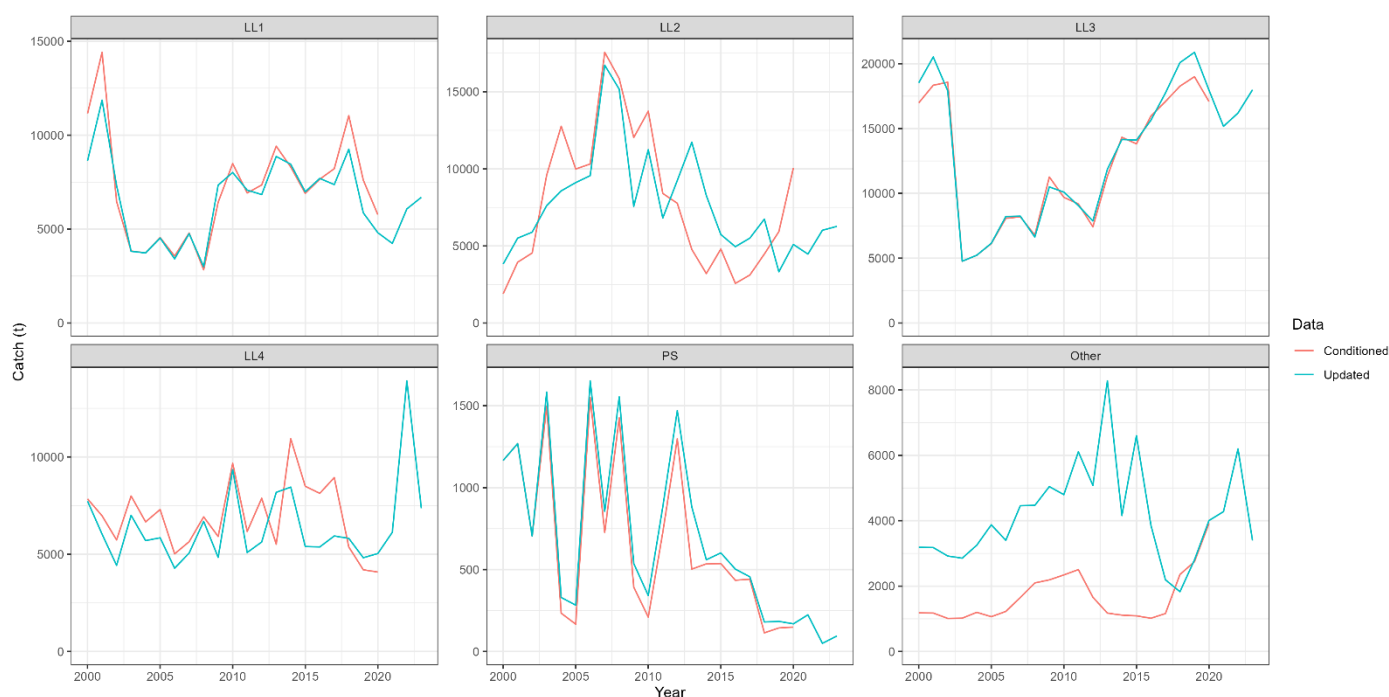


Figure 2. Annual catch by fleet in the data used to condition the OMs (2000–2020) and in the updated data from the 2025 stock assessment (2000–2023).



Figure 3. Annual overall catch data used to condition the OMs (2000–2020) and in the updated data from the 2025 stock assessment (2000–2023).

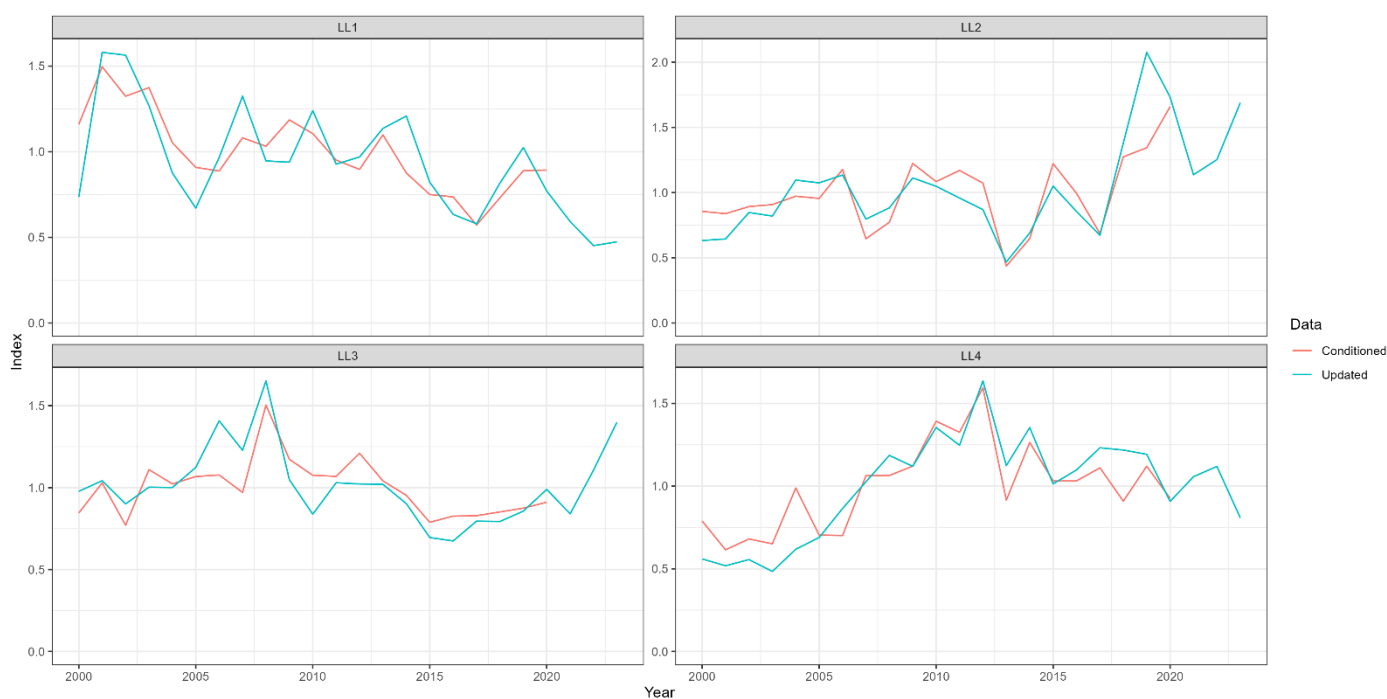


Figure 4. Annual mean of the longline CPUE indices (standardised to a mean of 1 over 2000–2020) in the data used to condition the OMs and in the updated data from the 2025 stock assessment.

2.2 Assumptions for Forward Projections

The projection period runs from 2021 to 2058, with the first TAC set by the CMPs set in 2029, a 3-year management cycle and a 2-year data lag (Figure 5). This means that the TAC for 2029 is calculated in 2028 using data up to 2026, and the TAC is then updated every 3 years after that.

Implementation Year	Calculation Year	Management Year?	TAC decision	DataYear used
2029	2028	Yes	Calculated in 2028, implemented 2029	2026
2030	2029	No	Carries forward 2029's TAC	—
2031	2030	No	Carries forward 2029's TAC	—
2032	2031	Yes	Calculated in 2031, implemented 2032	2029
2033	2032	No	Carries forward 2032's TAC	—
2034	2033	No	Carries forward 2032's TAC	—
2035	2034	Yes	Calculated in 2034, implemented 2035	2032

Figure 5. The management interval and data lag used in the Indian Ocean albacore MSE.

Because the first TAC set by the CMPs is applied in 2029, the first 8 years of the projection period (2021–2028) are an extension of the historical period rather than years managed by the CMPs. Where catch and CPUE data are available (2021 – 2023), these data were used directly in the MSE. For 2024 – 2028, the CPUE indices were simulated and the catches were assumed to be log-normally distributed with a mean of the annual catch from 2021 – 2023 and an assumed CV of 5% (Figure 6).

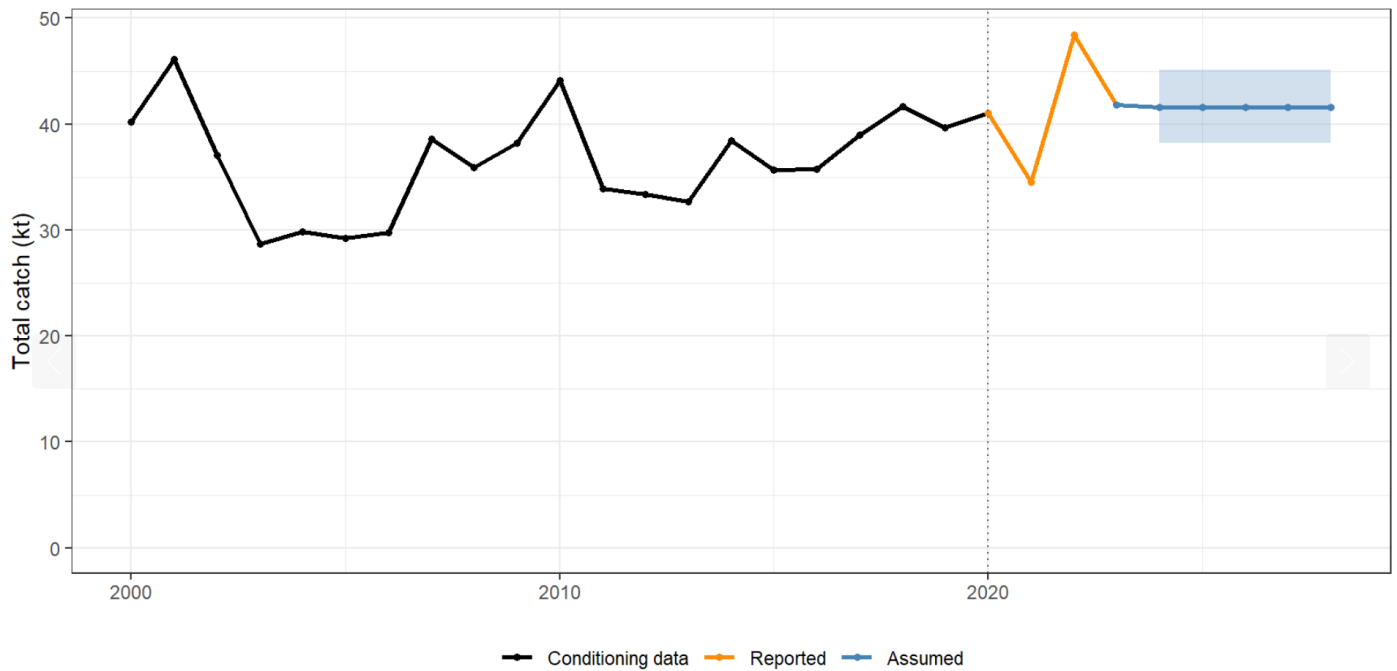


Figure 6. Total annual catch (all fleets) in the Base Case OM up to 2028: the catches used in the conditioning (2000–2020), the reported catches (2021–2023), and the assumed catches (2024–2028; mean and 90% interval). The dotted line shows the end of the historical period.

In 15 of the 500 simulations of the Base Case OM (3%), the stock collapses ($SB < 0.1 SB_{MSY}$) before the first TAC is set in 2029 (Figure 7). Compared to the other simulations, these cases represented low productivity cases with estimates of a smaller magnitude in stock size (SB_0 and MSY), a lower estimate of stock status, and generally a poor fit to the CPUE (Figure 8). The consequence of this is these simulations result in poor outcomes for all CMPs simply because the stocks was at such a low level before the TAC advice was implemented. Options to resolve these issues include retaining them as part of the uncertainty (the approach taken in this paper), to exclude or down-weight simulations with a poor fit to the CPUE, or to resolve the issue by reconditioning the OMs to the updated data.

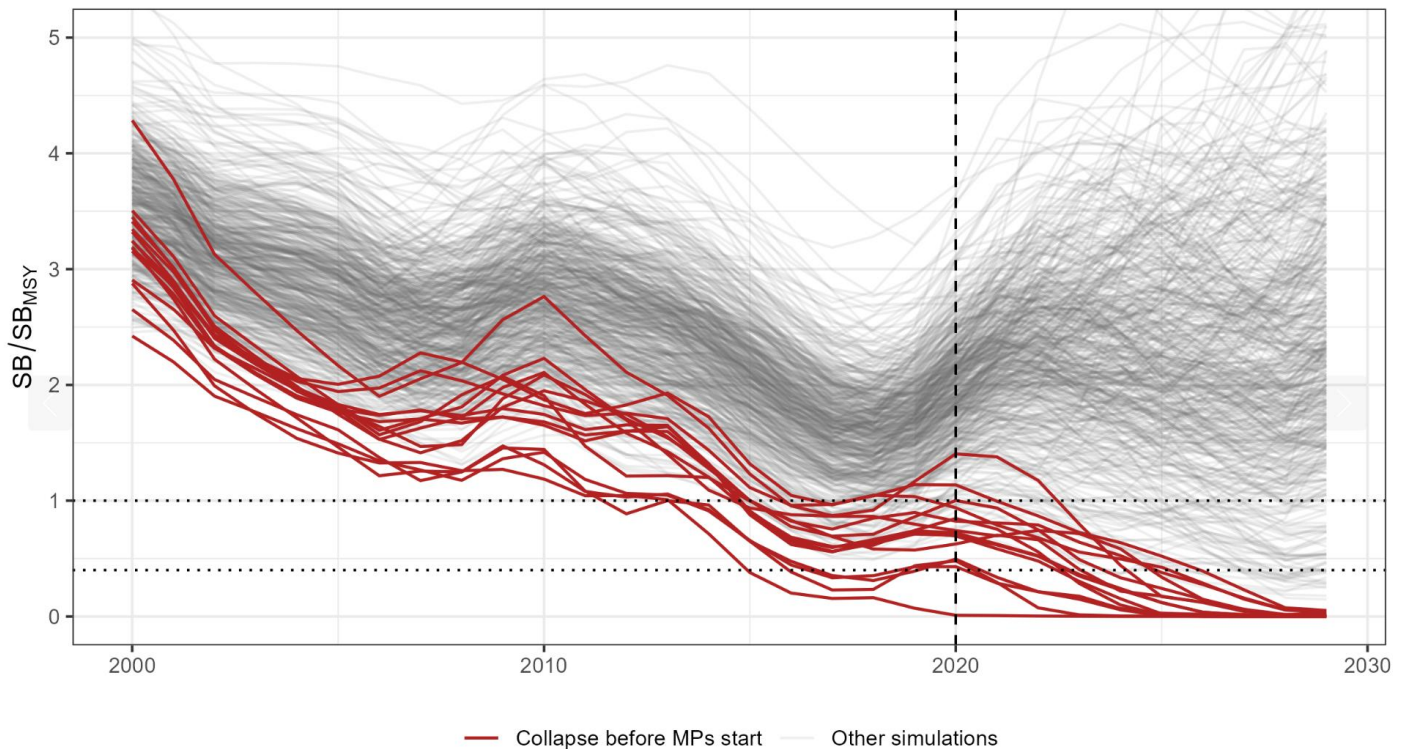


Figure 7. Female spawning biomass relative to SB_{MSY} in the Base Case OM up to 2029, with the reported and assumed catches in the initial projection years (vertical dashed line: end of the historical period). The red lines show the simulations where $SB < 0.1 SB_{MSY}$ in 2029. The dotted lines show the LRP ($0.4 SB_{MSY}$) and SB_{MSY} .

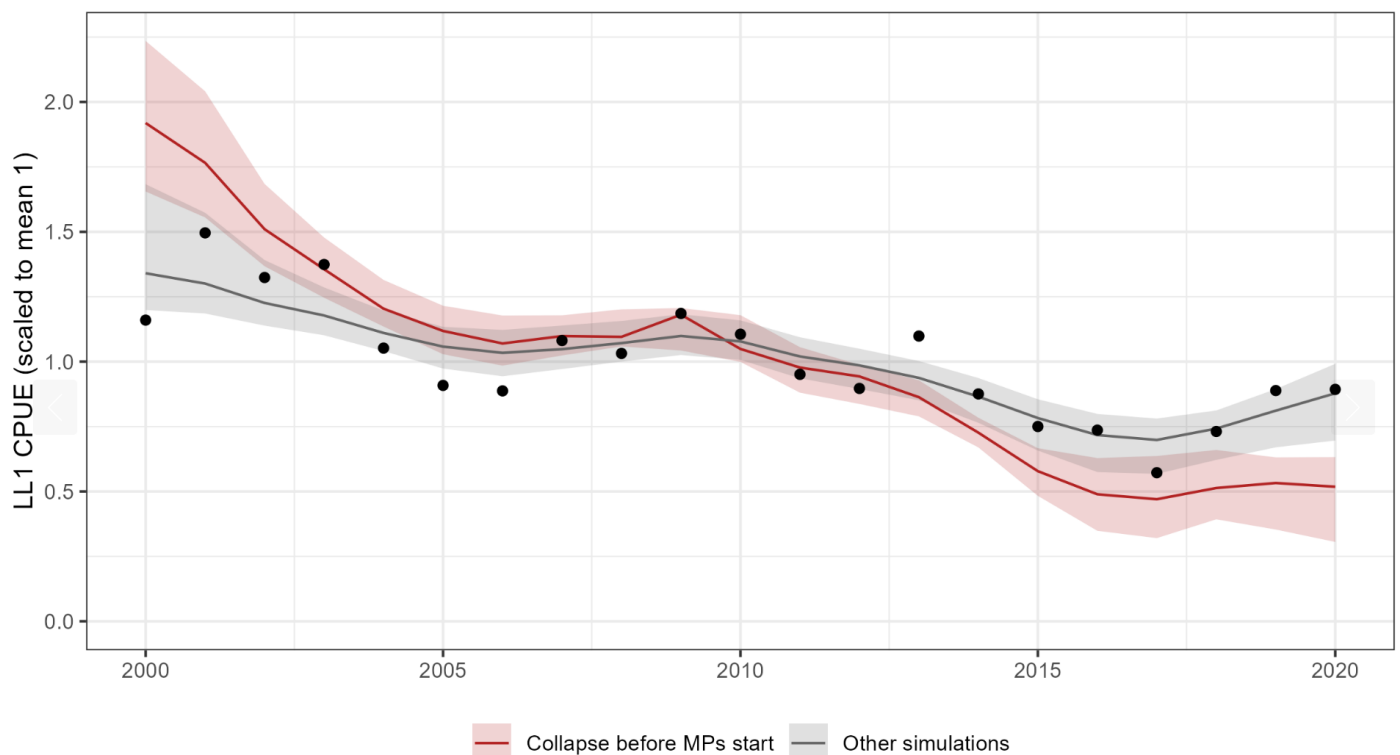


Figure 8. Fit of the ABC conditioning model to the LL1 CPUE (annual mean, scaled to a mean of 1; points) for the simulations where the stock collapses before the CMPs start (red) and the other simulations (grey). The lines show the median and the shaded areas the 5th–95th percentiles of the predicted index.

2.3 Management Objectives and Performance Metrics

The CMPs are evaluated against the following candidate management objectives:

1. **Status:** Maintain the stock in the green quadrant of the Kobe plot ($SB > SB_{MSY}$ and $F < F_{MSY}$) with at least 60% probability;
2. **Safety:** Spawning biomass should not fall below the limit reference point, with at least 90% probability, and fishing mortality should be below the limit reference point with a high probability;
3. **Yield:** Maximise catches;
4. **Stability:** Changes in the TAC between management periods should be relatively gradual.

The IOTC has adopted interim target and limit reference points for albacore: targets of SB_{MSY} and F_{MSY} , and limits of $0.4 SB_{MSY}$ and $1.4 F_{MSY}$ (IOTC, 2015).

The CMPs are tuned for the Base Case OM to maximise the mean annual catch over the years the CMPs are active (2029–2058), at two tuning levels (see below for more details):

1. T1: a probability of at least 0.6 of being in the Kobe green quadrant over the last 15 years of the projection period (2044–2058);
2. T2: the T1 constraint plus a requirement of a probability of at least 0.9 that spawning biomass stays above the LRP ($0.4 SB_{MSY}$) in every year over 2034–2058.

Table 2 shows a summary of the management objectives and the performance metrics related to each objective. Additional performance metrics, such as the mean and minimum SB/SB_{MSY} , mean F/F_{MSY} , and the probability that the change in TAC between management cycles was restricted by the TAC change limit were also calculated. See the Trial Specifications Document for more information on the performance metrics used in the MSE.

Table 2. The management objectives and the corresponding performance metrics.

Management Objective	Performance Metric
Status	
Maintain the stock in the Kobe green quadrant with at least 60% probability	Probability that $SB > SB_{MSY}$ and $F < F_{MSY}$ over 2044–2058 (tuning constraint, T1 and T2), over 2029–2058, and in each time window
	Probability that $SB < SB_{MSY}$ and $F > F_{MSY}$ (Kobe red quadrant)
	Mean SB/SB_{MSY} and mean F/F_{MSY}
	Minimum SB/SB_{MSY}
Safety	
SB should not fall below the LRP, with at least 90% probability, and F should be below the limit with high probability	Probability that $SB > 0.4 SB_{MSY}$ in every year over 2034–2058 (tuning constraint, T2)
	Probability that $SB > 0.4 SB_{MSY}$ (proportion of simulations and years)
	Probability that $F < 1.4 F_{MSY}$
Yield	
Maximise catches	Mean annual catch over 2029–2058 (maximised in tuning)
	Mean annual catch in each time window
Stability	
Change in TAC between management periods should be relatively gradual	Mean absolute proportional change in the TAC between management periods
	Probability that the TAC change limit is binding

2.4 Candidate Management Procedures

Four types of CMP were evaluated (Table 3). Following the choice made when conditioning the OMs, all CMPs used the LL1 (NW) CPUE index. Each CMP is named by its type and tuning level; e.g., *IR_T2* is the Index Rate CMP tuned to T2. Additional details on the CMPs are provided in the Trial Specifications Document.

The CMPs were tuned in the Base Case OM, using a stratified sample of 80 simulations, to maximise the mean annual catch over 2029–2058, at the two tuning levels (T1 and T2) described above. The safety objective of T2 excluded the first five years that the CMPs were active, so that the stock could recover from the catches of the initial projection years, which the CMPs do not control.

Under the T1 tuning, the TAC changes were limited to 15%, while for the T2 tunings the TAC increases were limited to 15% while the decreases were limited to 30%. The larger limit on TAC decreases in T2 was required because, with a 15% limit, the TAC could not be reduced quickly enough in the simulations depleted by the initial catches, and no CMP could meet the Safety objective.

Table 3. Overview of the candidate management procedures (CMPs).

CMP	Description	Type
Index Rate (IR)	TAC = catch/index rate × current index, with the rateModel-free reduced linearly from SB_{MSY} to zero at the LRP (index relative to its level at SB_{MSY}).	Model-free
Index Target with a buffer HCR (ITB)	TAC = reference catch × buffer HCR: the reference catch while the index is within the buffers, reduced below the lower buffer and increased slowly above the upper buffer.	Model-free
Buffer MP (BUF)	Replica of the CPUE + buffer HCR MP of the earlier work: the previous TAC is multiplied by the buffer HCR, so the TAC is held within the buffers and adjusted in every cycle outside them.	Model-free
Surplus Production (SP)	A Schaefer surplus production model is fitted to the catch and LL1 index; F = tuning parameter × estimated F_{MSY} , reduced below the HCR threshold.	Model-based

3. Results

All four CMP types could be tuned to T1, however only three of the four could be tuned to T2. The Buffer MP could be tuned to meet the T2 safety objective and was therefore not included in the analysis.

Table 4 summarises the performance of the tuned CMPs over the 500 simulations of the Base Case OM. Under the T1 CMPs, the median SB/SB_{MSY} declined from around 2.2 at the start of the MPs to around 1.2–1.5 by 2058 (Figure 9), and the probability of being in the Kobe red quadrant was 0.22–0.29 (Figure 10).

Under the T2 CMPs, the median SB/SB_{MSY} was stable at around 2, the probability of being in the Kobe red quadrant was lower (0.07–0.10), and the probability of being in the Kobe green quadrant over 2044–2058 was 0.84–0.91.

The average catch was generally higher for the T1 versions of the CMPs compared to those with the T2 tunings (Table 4). However, the T1 catches were more variable, with catches dropping close to zero in at least 10% of the simulations as a result of the decline in biomass for those simulations (Figure 11). In contrast, the T2 versions of the CMPs had lower average catch but also were considerably more stable and did not have the large declines that were evident in the T1 CMPs (Figure 11).

The main trade-off in the performance of the CMPs was between catch and the risk to the stock (Figure 12). Meeting the safety objective of T2 reduced the mean catch by 8% for the Index Rate CMP, 17% for the Index Target CMP, and 24% for the Surplus Production CMP, compared with T1. The Index Rate CMP had the highest catch at T2 (40.5 kt), close to the recent catches, but it also had the most variable TACs (mean change of 16%). The Index Target CMP had the most stable TACs, and the Surplus Production CMP the lowest catches in the first management cycles (Table 4).

Table 4. Performance of the tuned CMPs in the Base Case OM (mean over 500 simulations): probability of being in the Kobe green quadrant (2044–2058) and red quadrant (2029–2058), probability that SB stays above the LRP in every year (2034–2058), probability that $F < 1.4 F_{MSY}$, mean annual catch (2029–2058 and 2029–2038), and mean change in the TAC between management cycles.

CMP	P(Kobe green)	P(Kobe red)	P(SB > LRP every year)	P($F < 1.4 F_{MSY}$)	Mean catch (t)	Mean catch 2029–38 (t)	TAC change
IR_T1	0.61	0.26	0.70	0.79	43,980	47,230	13%
ITB_T1	0.60	0.29	0.68	0.76	41,080	45,190	7%
BUF_T1	0.58	0.27	0.63	0.77	42,140	41,670	4%
SP_T1	0.59	0.22	0.67	0.81	44,850	41,030	11%
IR_T2	0.84	0.10	0.89	0.92	40,470	42,580	16%
ITB_T2	0.87	0.10	0.89	0.92	33,910	34,380	5%
SP_T2	0.91	0.07	0.92	0.94	34,190	31,110	10%

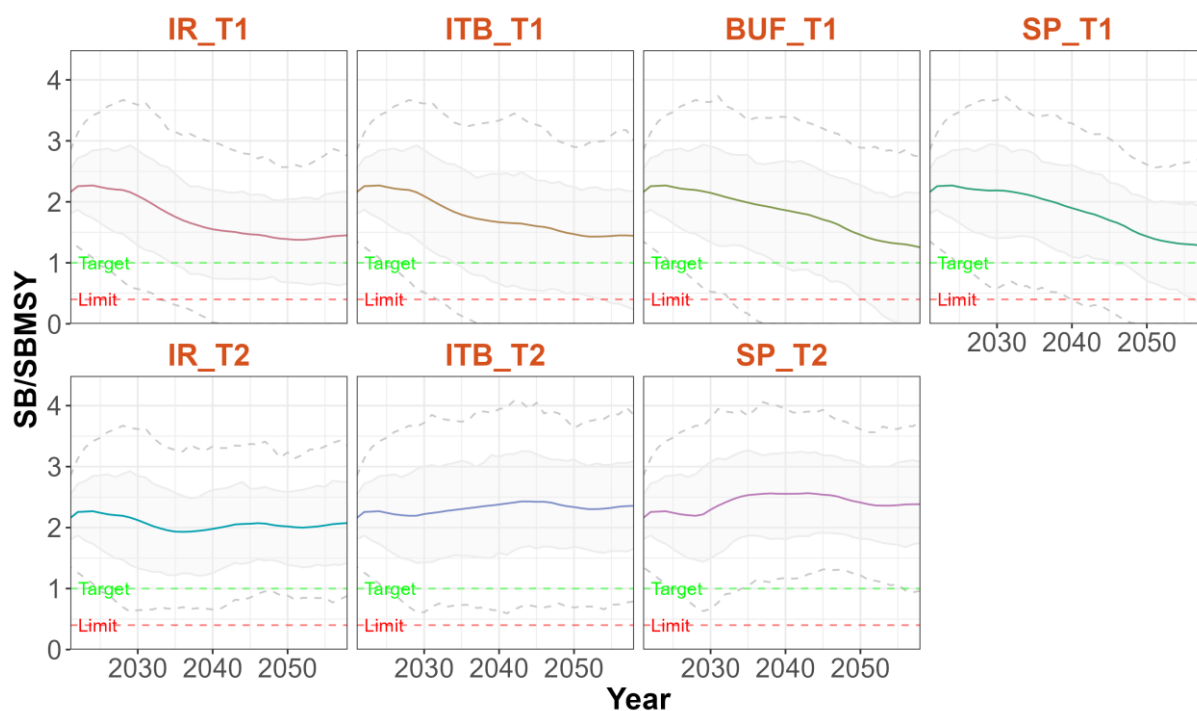


Figure 9. Projected female spawning biomass relative to SB_{MSY} for each CMP in the Base Case OM. The line shows the median, the shaded area the 25th–75th percentiles, and the dashed lines the 10th and 90th percentiles over simulations.

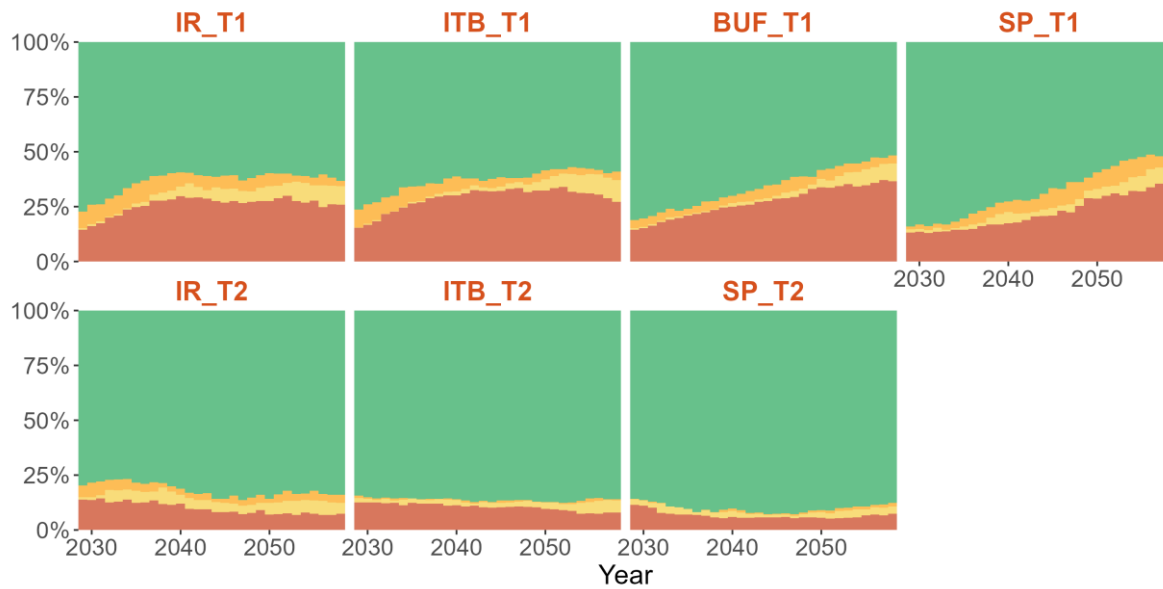


Figure 10. Proportion of simulations in each quadrant of the Kobe plot in each year for each CMP in the Base Case OM (green: $SB > SB_{MSY}$ and $F < F_{MSY}$; red: $SB < SB_{MSY}$ and $F > F_{MSY}$; yellow and orange: the other quadrants).

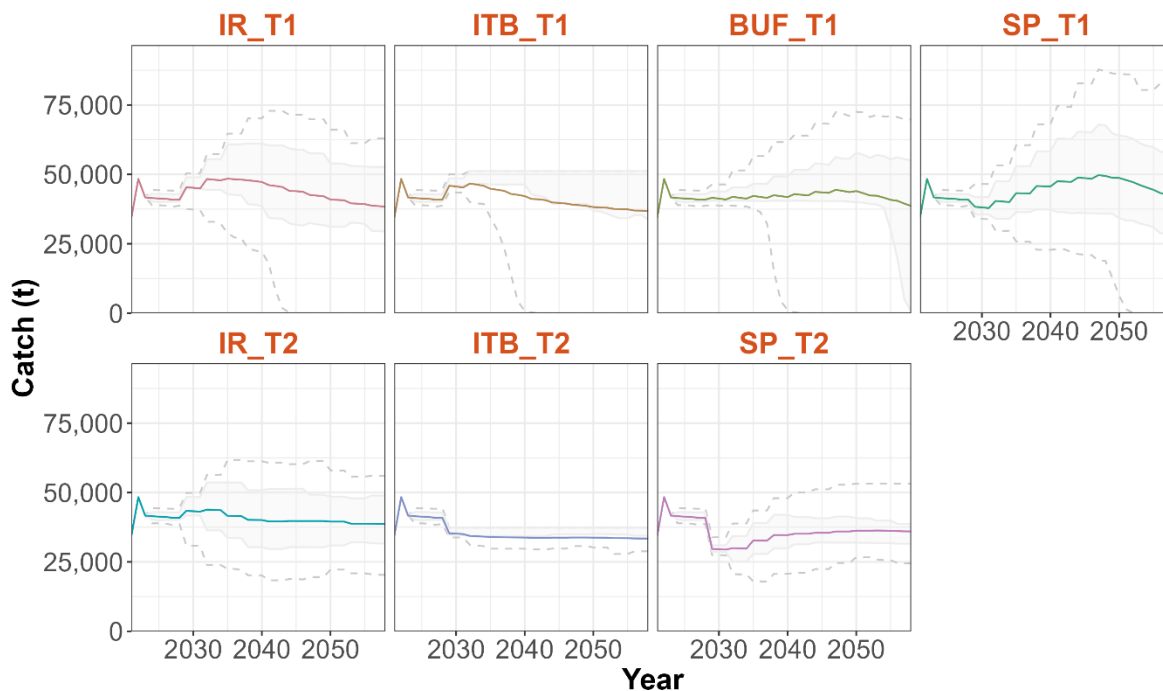


Figure 11. Projected catch (t) for each CMP in the Base Case OM. The line shows the median, the shaded area the 25th–75th percentiles, and the dashed lines the 10th and 90th percentiles over simulations.

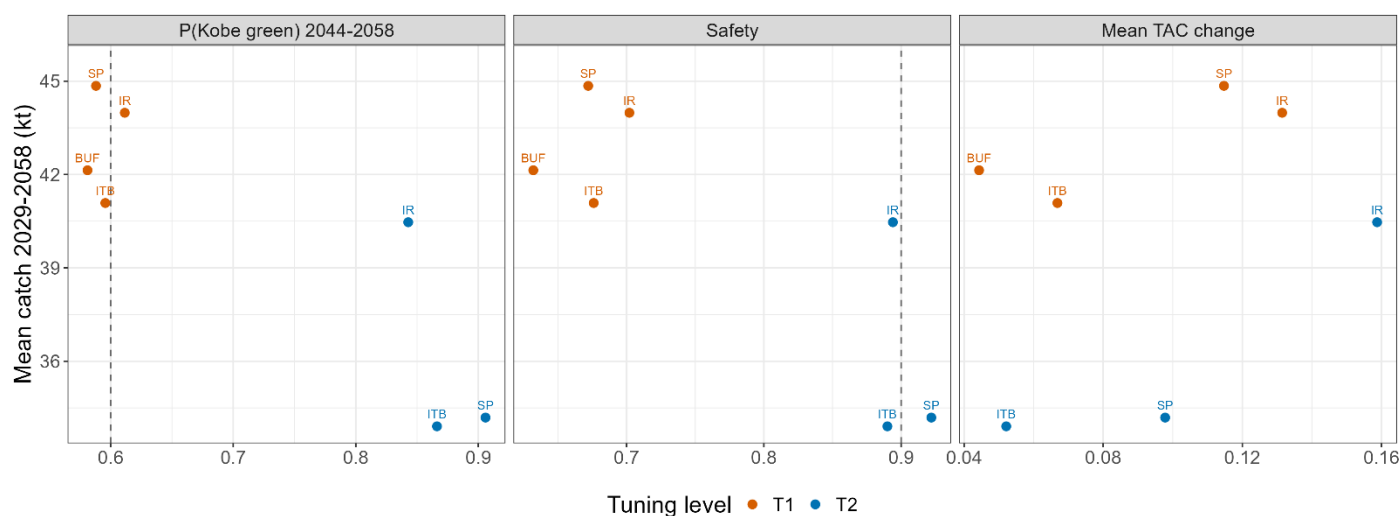


Figure 12. Trade-offs between the mean annual catch (2029–2058) and the probability of being in the Kobe green quadrant (2044–2058), the probability that SB stays above the LRP in every year (2034–2058), and the mean change in the TAC, for each CMP in the Base Case OM. The dashed lines show the tuning objectives.

4. Discussion

The preliminary results of this MSE demonstrate the significance of the management objectives used for tuning the CMPs, and reveal that this choice is more important than the type of CMP. Tuning to a probability of being in the Kobe green quadrant alone (T1) allowed a gradual decline of the stock and a high risk of falling below the LRP in the low-productivity simulations, because the average probability can be met by keeping the stock well above SB_{MSY} in most simulations while the others are depleted. A safety objective, defined as the probability that the stock never falls below the LRP, protects these simulations at a moderate cost in catch. The probability and the definition of the safety objective, and the years over which it is evaluated, as well as any other performance metrics that are to be used in the CMP tuning are decisions that must be made before the MSE results can be finalized.

The results also demonstrate that both model-based and model-free methods were able to meet the management objectives for the Base Case OM. The surplus production model CMPs converged in all management cycles, but its estimates of stock status were only weakly correlated with the stock status in the OM, and its performance was not markedly different than the model-free methods. This result suggests that Members of the Working Party should consider the trade-offs between the higher complexity of model-based CMPs against the more transparent model-free methods.

An additional issue for the group to consider is how much the change in TAC between management cycles should be constrained. For example, with symmetric 15% limits, the TAC could not be reduced quickly enough in the simulations depleted by the catches of the initial projection years. Asymmetric limits (slow increases, faster decreases) made the safety objective achievable, but will also result in more variable TAC advice for the fishery. Therefore, the design of the TAC change limits is an important part of the MP that should be considered.

As noted in the Methods section, the conditioning was based on data up to 2020 and more recent data is now available. Those data differ significantly from the data used to condition the OMs, particularly in the declining trend in the recent years that is not captured by the OMs. Additionally, several potential technical issues were identified in the conditioning process, which should be discussed with the model developers and resolved if necessary. Therefore, it is recommended that the group consider reconditioning the OMs before finalizing the MSE results. At the same time, a decision should be made regarding how to handle the individual simulations that result in extreme dynamics such as a crash in the population by 2029. This issue may be resolved during the reconditioning process. However, if the same

pattern occurs in the reconditioned models, the treatment of these simulations needs to be considered as they impact the calculation of the performance metrics and the tuning of the CMPs that rely on these metrics.

The analysis described in this paper was focused on the Base Case OM that was conditioned with the ABC conditioning model. Robustness models have been discussed in previous iterations of this work, but these models were not available to be included in this analysis. Developing the specified robustness models could happen at the same time as the OM reconditioning. Including robustness OMs is an important part of the MSE process, where the aim is to identify the CMP that is most robust to uncertainty.

A final point to discuss is the input data that will be used by the MP to set management advice in the future. It is important that the CMPs evaluated in the MSE are based on data that are expected to continue to be available in the future years. Equally important is that future data updates do not significantly change the historical data that was used to condition the OMs and used by the CMPs within the MSE to set the management advice. In the MSE, each CMP is applied in every management cycle to the historical catch and CPUE data, plus the observations added since the previous cycle. Once a data value has been observed, it does not change in later management cycles. The performance of the CMPs, and the tuning of their catch level, therefore assume that the MP will be applied in the same way, that is new data are added to the existing series, but the existing values are not revised.

This is important because the CMPs are calibrated to the historical data. For example, the index level at SB_{MSY} (I_{MSY}), which sets the position of the HCR control points of the index-based CMPs, is calculated from the historical LL1 index. If the historical index were revised after an MP is adopted, for example by a new standardisation of the CPUE, the same stock status would give a different index relative to I_{MSY} , and therefore a different TAC. This would mean that the MP applied in practice would then no longer be the MP that was tested in the MSE. The revision of the historical LL1 index between the 2022 and 2025 stock assessments shows that revisions of this size can occur, and this issue should be discussed by the group before a CMP is adopted.

Acknowledgements

We thank Richard Hillary for support in importing the conditioned operating models into this MSE framework, and the IOTC Secretariat for providing the updated data. Funding for this work is gratefully acknowledged from The Ocean Foundation, FCF Co., Ltd, and Thai Union Group PCL.

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