Technical development of Management Strategy Evaluation for Indian ocean albacore tuna: 2025 progress report and current status

Iago Mosqueira (WMR)*   Richard Hillary (CSIRO)†

December 2025

Abstract

Work carried out for the development and application of Management Strategy Evaluation (MSE) for Indian ocean albacore tuna (ALB) in 2025 is summarized in this report. This work has been carried out under an LoA between WMR and IOTC/FAO, andf with the collaboration of CSIRO, building upon the work carried out in 2023 and 2024. A new methodology for the conditioning of operating models, separated but still informed by the stock assessment has been developed. A formulation of the Approximate Bayesian Computation (ABC) algorithm is employed to condition on datas wehile recognize and incorporate the unxcertainty in the system and our knowledge of it. The report outlines the current status of the MSE framework, including the toolset developed for simulating the OMs and evaluating the MPs. Preliminary runs have been conducted for a number of candidate MPs. Future steps for the completion of the work are presented.

*Wageningen Marine Research, Haringkade 1, 1976CP, IJmuiden, The Netherlands. iago.mosqueira@wur.nl

†CSIRO Environment. Battery Point, Hobart 7000, Tasmania, Australia.

Contents

1 Introduction

This report summarizes the progress made in 2025 on the technical development of Management Strategy Evaluation (MSE) for Indian ocean albacore tuna (ALB). It builds upon the work carried out in 2023 and 2024, which focused on the conditioning of operating models (OMs) using the Approximate Bayesian Computation (ABC) algorithm, and the initial testing of candidate management procedures (MPs). The report also outlines the current status of the MSE framework, including the toolset developed for simulating the OMs and evaluating the MPs, as well as the performance statistics employed. This document complements the working documents presented at WPM and the WPM-MSE session and includes work carried out in the last section of the contract.

The results presented here and the code used to generate them is available at the public git repository used for development, https://github.com/iagomosqueira/albMSE. Please refer to this repository for further details on the implementation of the MSE framework and instructions for installation of the necessary software. Note the repository is constantly being updated as work progresses. Any question or problem please do not hesitate to use the repository's issue tracker to get in touch or contact directly the authors.

2 Conditioning and testing of operating Models

Following the recommendations of WPM (IOTC 2024), (IOTC 2025), the following operating models were selected from the initial set developed employing various options for the ABC algorithm.

The **base case** operating model, referred to as **OM5b**, uses the LL1 (NW) CPUE series as index of abundance,

Two other ABC operating models were selected to form a **robustness set** to be used in the MSE testing of candidate management procedures: one that employs the LL2 (SW) CPUE series as index of abundance (**OM5a**), and another that includes a 1% annual increase in LL fisheries catchability to account for increases in overall efficiency (**OM6b**).

A climate change robustness OM set has been also developed, including a version of the base case operating model with climate change effects on recruitment, maturity, growth and carrying capacity (**OM5b_cc**). The scenario covered by this OM considers faster growth and earlier maturity, but a decrease in maximum body size, due to higher temperatures. Carrying capacity is expected to decrease due to a displacement of the species' suitable habitat, limited in the North by the presence of land. In the case of recruitment, spawning areas may be affected by changes in oceanographic conditions, leading to lower larval survival and lower recruitment in the medium term. But higher juvenile survival and the establishment of new spawning areas may lead to an increase in productivity in the longer term. Potential scenarios have been assembled on available literature on climate change effects on Indian ocean albacore tuna (Dueri et al. 2017; Mondal et al. 2023, 2025; Erauskin-Extramiana et al. 2024). It would be beneficial to present them to the WPTmT and WPERB experts to obtain agreement on their formulation. The climate change effects are being implemented over a 50 year period, 2025–2075, and focus on the potential effects on the performance of a management procedure tuned to current stock conditions.

Additionally, a final robustness operating model was created to explore the effects of sudden reductions in recruitment, with 25 and 50% lower recruitment deviations compared to the base case model And ocurring over a 5 year period. This model is referred to as **OM5b_rec**.

Runs of candidate MPs on the robustness set have not yet been carried out, as work is ongoing on achieving satisfactory results of the MPs proposed so far on the base case OM.

2.1 Incorporating the updated catch dataset

The operating models were updated to reflect the new catch series available from the WPTmT 2025 stock assessment dataset, which includes data up to 2023. The updated catch series shows higher catches in the period 2010–2023 compared to the previous dataset used in the conditioning of the operating models, which only included data up to 2020. Figure 1 shows the two catch series together with the results obtained by the SS3 model runs both using the LL1 NW CPUE as index of abundance.

The updated total catch series was incorporated into the operating models by projecting them forward from their 2010 conditioned state for the new annual nominal catches, also including the reported value for 2024. The forecast used the recruitment deviances obtained from the 2022 conditioned OM up to 2020, and used lognormal sampled future deviances for 2021–2024.

The updated base case OM shows the effect of the higher catches between 2011 and 2016 with a higher harvest rate over that at MSY (HR/HR_{MSY}, Figure 2) and a lower decrease in SSB. Trends for the 2020–2024 period are merely

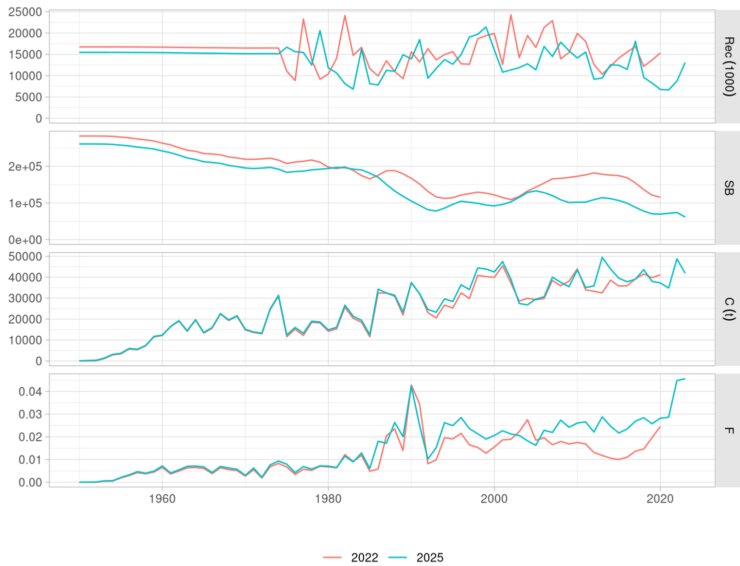


Figure 1: Comparison of the time series of recruitment, SSB, total catch and fishing mortality between the 2022 and 2023 stock assessment runs of SS3 with the LL1 NW CPUE.

driven by the new catch series, as the new indices of abundance could only be applied if a full reconditioning of the operating models was carried out.

The breakdown of HR by fishery in Figure 3 shows that the increase in total HR is driven by all fisheries, with the longline fisheries (LL1-NW and LL2-SW) showing the largest increases.

The indices of abundance were updated based on new 'observations' generated from the hindcasted operating models using the updated catch series, rather than from the new CPUE series. This was done to ensure the relationship between index and biomass, through the catchability constant, was maintained. The probability distribution of the predicted index is compared to the original observations in Figure 4. Observation error was then added to these predictions, lognormal with variance and autocorrelation computed from the OM conditioning runs. The resulting updated indices, plotted for a series of individual

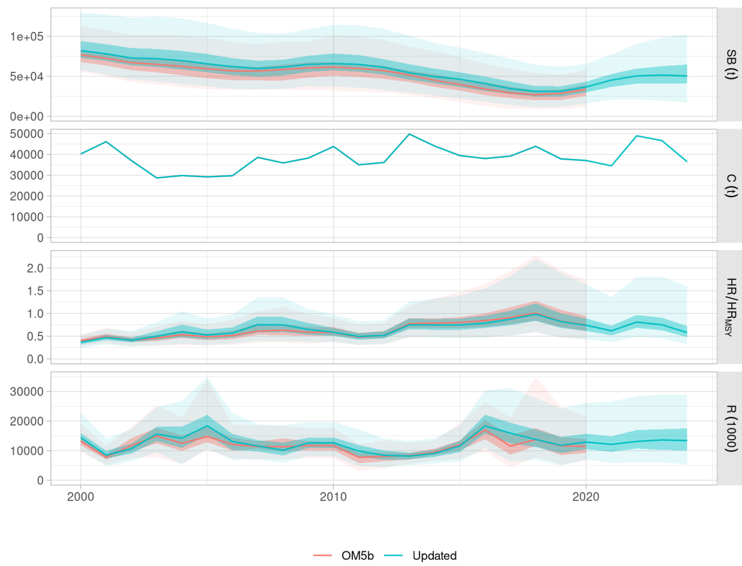


Figure 2: Time series of spawning biomass (SSB), catch, harvest rate over MSY (HRMSY) and recruitment for the base case OM (OM5b) and its update to the new 2010-2024 catch series. Coloured areas present the 50% and 90% probability intervals and the central line the median values.

iterations in Figure 5, show a range of differences, as the responses of different biomass to the same level of catch. The initial period of the MSE simulations is likely to be more affected by these discrepancies, which should have a limited impact in medium and long term results.

The differences above can be compared now with those for ther same index, LL1 NW, between the 2022 and the 2025 WPTmT datasets, as shown in Figure 6. A larger variability is apparent in the seasonal pattern for the years employed in the OM condition, starting in 2000. If this relates to differences in the standardization methodology, it would necessary to ensure the most recent one is then applied in the future. The OM would then be conditioned on indices that will be comparably generasted in the future.

At this point, the updating strategy appeared to be viable when considering the

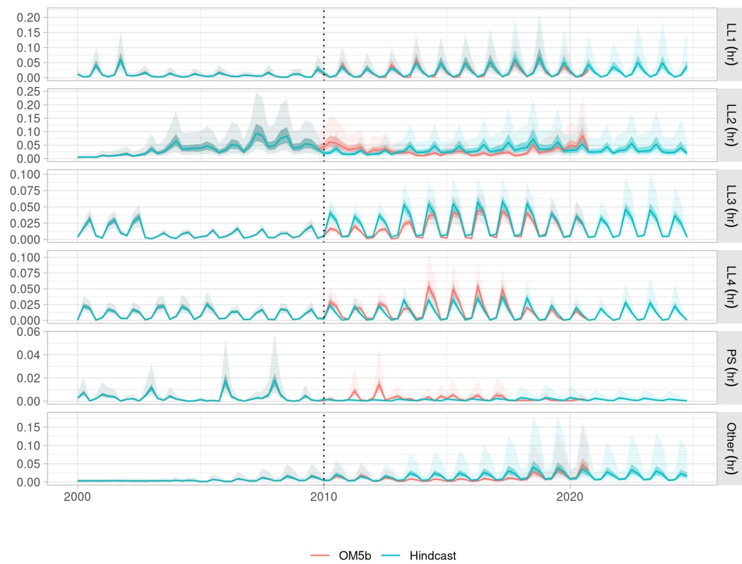


Figure 3: Time series of harvest over MSY (HR) for the base case OM (OM5b) and its update to the new 2010–2024 catch series, by fishery. Coloured areas present the 50% and 90% probability intervals and the central line the median values.

overlap between the distribution of stock abundances (Figure 2), but questions remained on the updated indices of abundance and their impact on the initial period of the MSE simulations. Model-free MPs that rely on trends in the indices of abundance might not be affected sop severely, but a model-based MP employing a surplus production model should be faced with the actual indices. The differences between the 2022 and 2025 indices 6 should also be considered. A full reconditioning of the operating models to the new catch series and indices appears now to be clearly preferable, and this should be attempted in the near future.

2.2 Observation Error Model

The Observation Error Model (OEM) component in the current toolset has not been modified and only considers a moderate level of observation error,

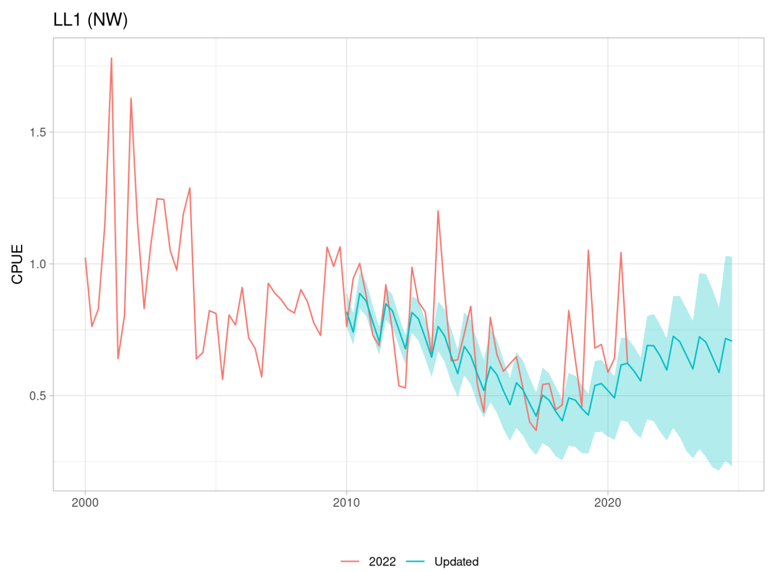


Figure 4: Comparison of the input CPUE LL1 (NW), in red, and the predictions obtained from the updated OM using the updated 2010-2024 catch series, in green. Coloured areas present the 50% and 90% probability intervals and the central line the median values.

with a CV of approximately 10%, on both total catch per fishery and indices of abundance. Potential scenarios that include known sources of error in the input data, such as misreporting of catch or bias in indices of abundance, were discussed with members of WPTmT. No proposal was made to modify the OEM but the issue could be further raised at future meetings of IOTC WPTmT or WPS. The test conducted so far have not incorporated these sources of error so as ton help in uncovering the behaviour of the candidate MPs under a more idealized setting.

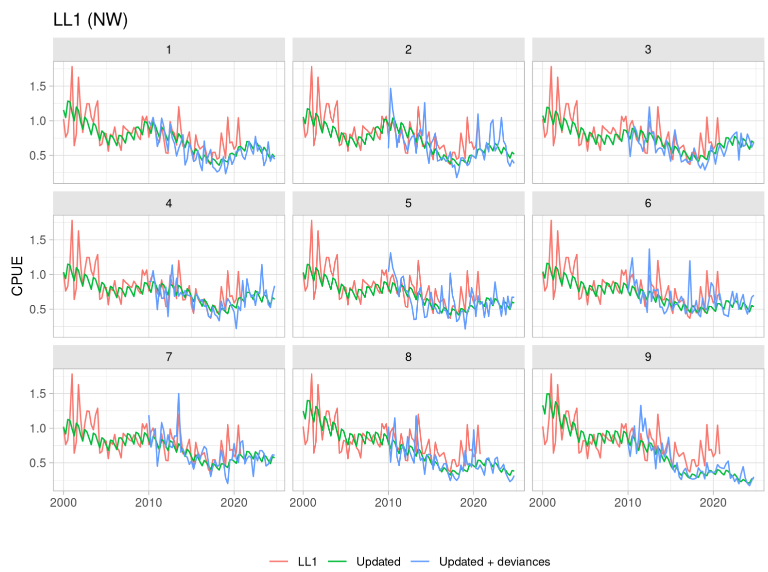


Figure 5: Comparison of individual iterations of the input CPUE LL1 (NW), in red, the predicitions obtained from the hindcasted OM using the updated 2010-2024 catch series, in green, am d those with added deviances computed using historical variance and autocorrelation, in blue. Coloured areas present the 50% and 90% probability intervals and the central line the median values.

3 Management Strategy Evaluation

3.1 Toolset for ABC OM

A significant amount of work has been devoted to the development of a toolset to carry out Management Strategy Evaluation (MSE) simulations using the ABC operating models. The structure and approach for modelling populations ands fisheries taken in the development of the ABC algorithm is tailored to the information contained by the data, and strikes a good balance between detail and robustness of estimation. It has also required extension and testing of the FLR toolset functions and methods. The seasonal, two-sex, multiple fishery structure, together with the adoption of harvest rates by fishery as measure of exploitation, all led to longer development times compared to simpler MSE

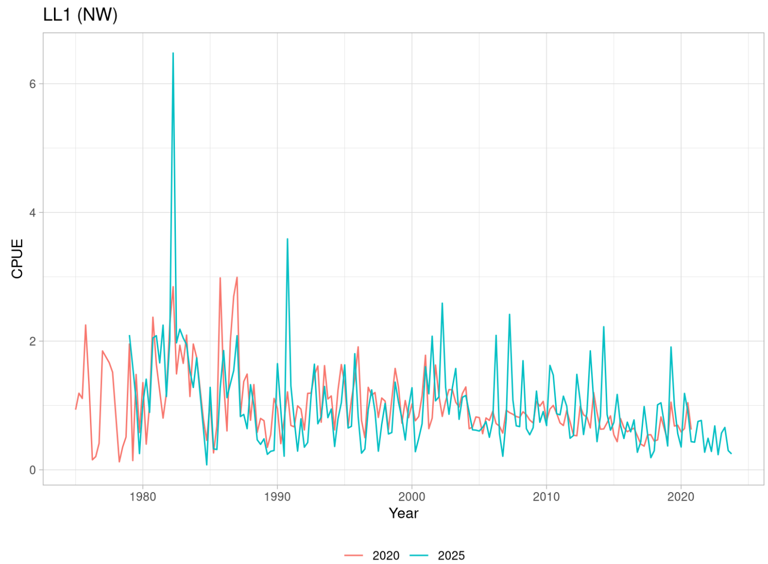


Figure 6: Comparison of the LL1 (NW) CPUE index between the 2022 and 2025 WPTmT series.

frameworks. However, the end result is a flexible and powerful toolset well suited for this type of operating models. The extended tools are now available in the FLR toolset.

3.2 Performance statistics

The performance statistics being employed in this study are those recommended by IOTC SC, with some changes and additions. First, no fishing mortality is being calculated in the OM, and instead harvest rates, the proportion of catch in weight to the biomass vulnerable to a fishery, is computed and employed to apply the seasonal catch levels to the population. To monitor the exploitation level, harvest rates by fishery, divided by the estimated level at MSY, are used. This statistic, aggregated over all six fisheries, is then used to, for example, compute the quadrant of the Kobe plot in which the stock falls. The new *HRMSY* statistics is thus defined as an annual relative harvest rate, computed as an seasonal average of the sum of the harvest rates by fishery over that at MSY, $\sum_{f=1}^{6} HR_f/HR_{MSY}$. Values of *HRMSY* over or below 1 are then used to classify the *Kobe* status. So, for example, the stock is deemed to be in the Kobe green quadrant when $SB > SB_{MSY} \wedge HRMSY < 1$.

Following work carried out in other stocks and regions, the toolset is now able to report back on the probability of catch being limited by the upper or lower limits to TAC change that are used in many MPs. This has been found out to be an useful statistic to understand how much of the MP stability and behaviour is affected by this constraint, as it was recently noted in the review of IOTC MSE work for bigeye tuna (Neubauer 2025).

4 Exploratory runs of candidate procedures

Preliminary runs of some candidate management procedures have been carried out on the base case operating model (OM5b). The results are shown here for demonstration purposes and do not reflect yet any MP with satisfactory performance.

4.0.1 Constant catch MP

A constant catch MP has been tuned to the 60% Kobe green management objective (Figure 7. This is an unrealistic run that gives an initial value for the catch levels that are necessary to bring the stock to the required exploitation and abundance levels. The tuned target catch value obtained, 40,625 t, is At the high end of the historical catches, and reflects the fact that the stock appears to the OM to be at the start of the simulations at a higher Kobe green probability level, 72%.

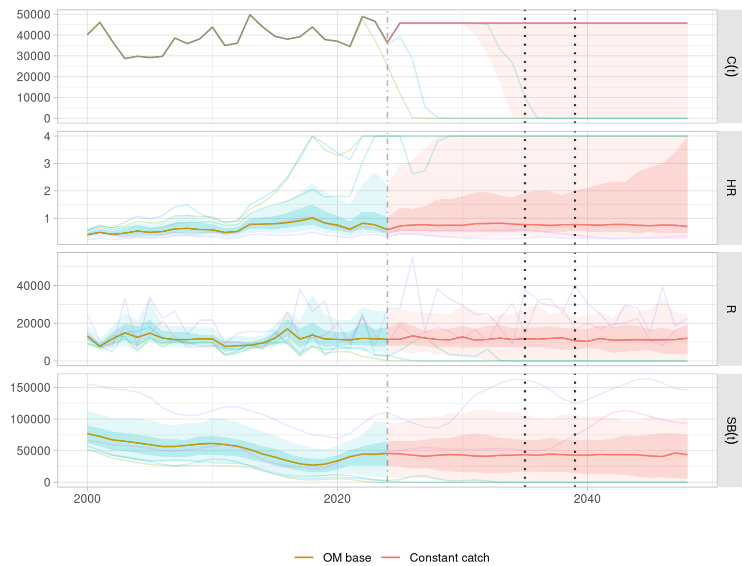


Figure 7: Time series of catch, harvest over MSY (HR), recruitment and spawning biomass (SSB) for the tuned fixed catch MP, run on thje base case OM. Coloured areas present the 50% and 90% probability intervals and the central line the median values.

4.1 CPUE average and buffer HCR MP

A first model-free MP has been tested, combining the average of recent values of the LL1 NW CPUE index of abundance as measure of changes in stock size, and a buffer catch-based HCR that sets a multiplier for the TAC from previous levels (Figure 8. Test runs have been carried out that tune this MP to a probability of 60% for the stock to fall on the Kobe green quadrant on average between 2034 and 2039. The upper buffer limit, from which catches are allowed to increase, was chosen as the tuning argument. Given the need for the stock to move into higher exploitation levels for the management objective to be achieved, it was considered that finding the point at which catch would increase was likely to be the best option for tuning this MP. A more complete exploration of tuning options will be carried out in the near future.

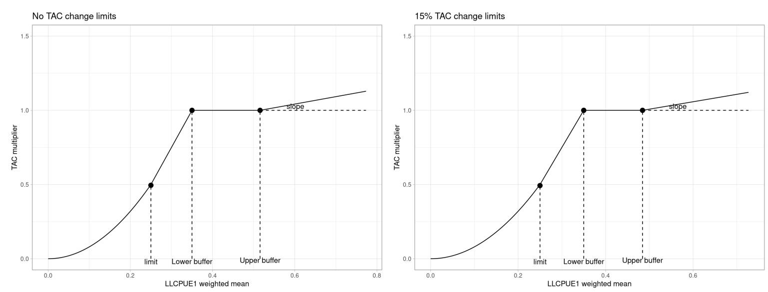


Figure 8: Harvest control rules obtained from tun in g to a 60% probability of stock falling in the Kobe green quadrant for the buffer HCR using the LL1 NW CPUE index of abundance, run on the base case OM. Left panel sets no limiots to TAC changes, while the right panel involved a 15% limit up and down ion each triannual management decision.

Two alternative runs of this MP, tuned to the same management objective, are presented here. One has no limit on the maximum annual change in TAC (Buffer 60%), while the other imposes a 15% limit on triannual TAC changes, both increases and decreases (Buffet 60% TAC). Differences between the two are not substantial, with both achieving the objectives at the expense of bringing biomass below the required levels after the tuning period (Figure 9. This can also be observed in the plot of the annual Kobe status (Figure 10. The run with no TAC change limits shows a slightly better performance, with higher probabilities of being in the Kobe green quadrant after 2030. However, both runs show similar patterns, with the stock decreasing slightly during the tuning period, and then falling to lower biomass levels due to overfishing. The current implementation uses a four-year weighted average of the CPUE series to quantify changes in abundance, which might not allow the MP to respond quickly enough to decreases in biomass. A proportion of iterations, up to 24%, lead to biomass falling below the limit level, set at 10% of the virgin value.

The simulated indices of abundance for both runs are compared with the set buffer limits in Figure 11. Both of them show similar patterns, with the index increasing over time as the stock rebuilds. The run with no TAC change

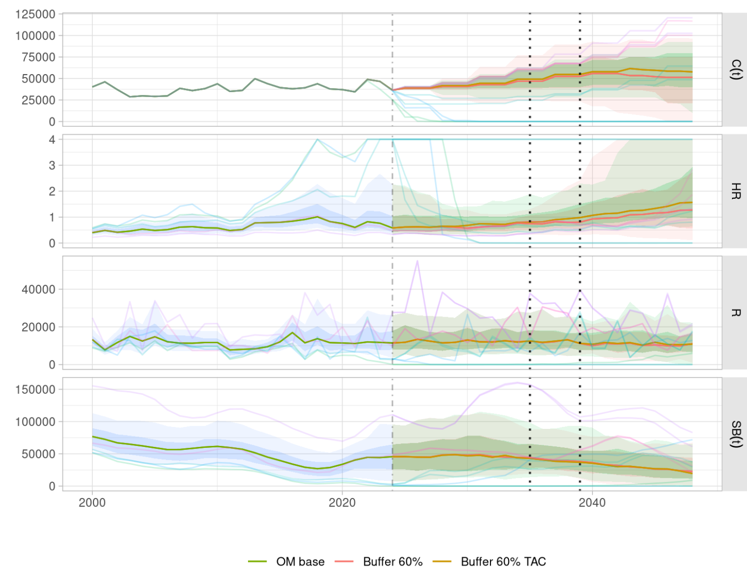


Figure 9: Time series of catch, harvest over MSY (HR), recruitment and spawning biomass (SSB) for the tuned buffer MPs applied to the LL1 NW CPUE, and run on the base case OM. Coloured areas present the 50% and 90% probability intervals and the central line the median values.

limits shows a more pronounced increase in the index, reflecting the higher catches allowed by the buffer HCR. Both indices fall towards the expected areas, between both buffers, but this still leads to overfishing after the tuning period.

4.2 Depletion catch multiplier HCR

The MP currently in place for Indian ocean bigeye tuna has been implemented and tested. MPs with some level of information on depletion are often found to perform better than purely model-free MPs, as they obtain some measure of scale in stock status. The MP is top be implemented using a surplus production model, but the present exploration has been carried out using a shortcut observation of depletion level from the OM. As such, it reacts to information that is more accurate than what would be available in real life, and its performance

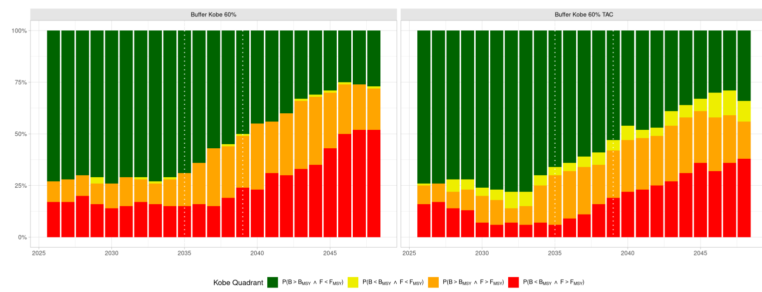


Figure 10: Trajectories of the annual probability of the stock falling in the Kobe *green* quadrant for the buffer MP using the LL1 NW CPUE index of abundance, run on the base case OM, and tuned to a 60% probability using two options for limits to annual TAC changes: no limits and 15% limits up and down. Shaded areas present the 50% and 90% probability intervals.

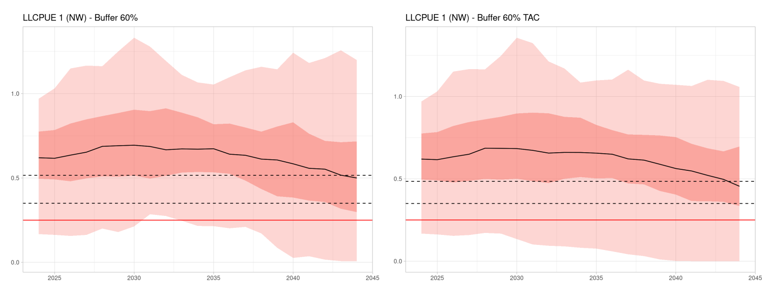
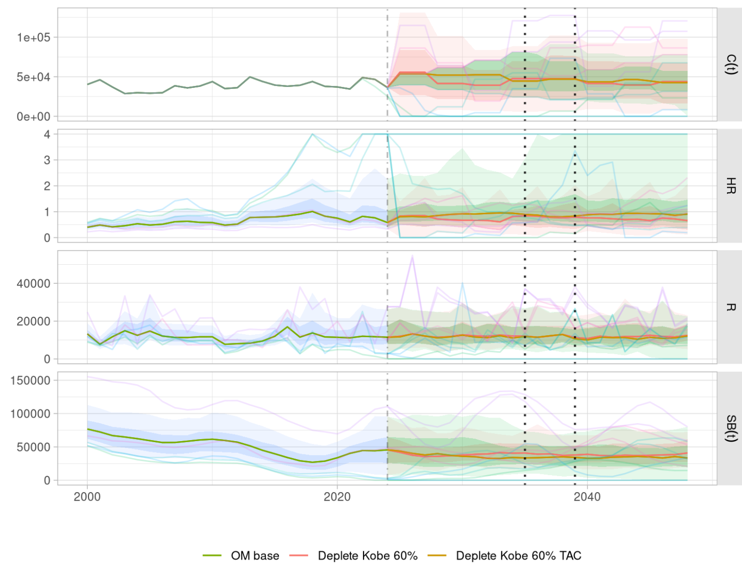


Figure 11: LL1 NW CPUE indices of abundance obtained from the tuned buffer MP without and with 15% TAC change limits.

should be considered as an upper bound for MPs of this type.

4.3 Tuning period vs. long-term performance

When tuning MPs for probabilities of being in the Kobe green quadrant, the choice of the tuning period can have a significant impact on the long-term performance of the MP. <MPs in IOTC have been generally tuned to a short period of between 11 and 15 years after the start of simulations. This often leads to sharp biomass trajectories that continue their trends after the tuning period, as the MP is optimized for that specific time frame. ons A test has been carried



out to explore the effects of tuning period length on the performance of the buffer HCR MP using the LL1 NW CPUE index of abundance. Two tuning periods were considered: the standard one, from 2035 to 2039, and a longer period, from 2035 to 2046. Both MPs were tuned to achieve a 60% probability of being in the Kobe green quadrant during their respective tuning periods. The trends differ specially at the end of the series with biomass not decreasing as markedly when tuning takes place over the longer period (Figure 12.

5 Summary and next steps

The development of the toolset for the analysis of candidate MPs for Indian ocean albacore based on the ABC operating models is now in a stage where MP evaluations can be started once the final set of OM has been built. Reconditioning runs of the OMs could be tested in a short while, and the necessary modifications of the OM conditioning code to include the new catch series and indices of abundance should be carried out quickly.

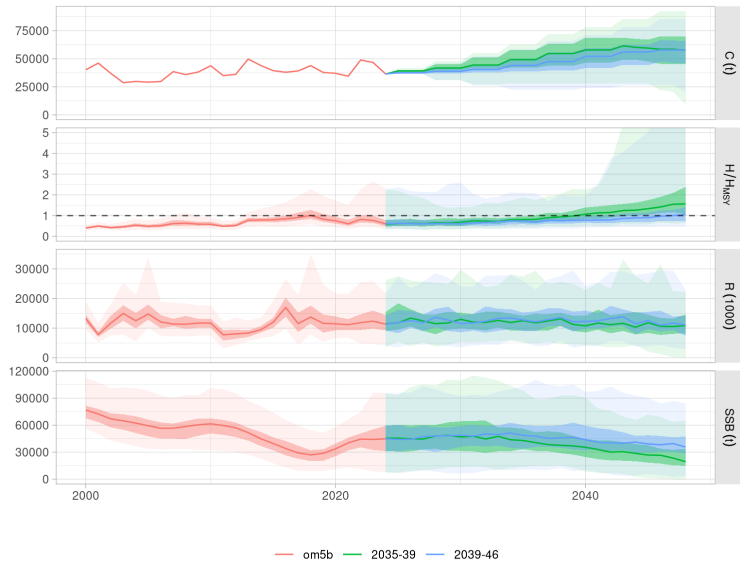


Figure 12: Time series of catch, harvest over MSY (HR), recruitment and spawning biomass (SSB) for the buffer MP applied to the LL1 NW CPUE, and run on the base case OM, and tuned over the 2035-2039 and 2035-2046 period. Coloured areas present the 50% and 90% probability intervals and the central line the median values.

5.1 OM

The necessary steps to complete the set of operating models are as follows:

- **Extension of ABC conditioning code to include new catch series and indices of abundance.** The current conditioning code needs to be modified to include the updated catch series and the new indices of abundance. This will ensure that the OMs are fully conditioned to the latest data available.
- **Correction of the harvest rate limit constraint in the ABC projection code.** Individual harvest rates per fishery are limited to 90% of the available biomass, as it is done win the conditioning algorithm. However, this can still lead to overall harvest rates for the whole population that are

unrealistic. An intermediate calculation of total HR should be included to avoid this problem.

- **Full reconditioning of the base case and robustness OMs**. Once the code has been updated and tested, the base case OM (OM5b) and the robustness OMs (OM5a and OM5b_rec) should be fully reconditioned to the new catch series and indices of abundance.
- **Discussion and agreement with relevant experts on the formulation of climate change robustness OMs**. The ideas formulated above come from a sucint exploration of the available literature, and could benefit greatly from the knowledge of experts in the field. A discussion with WPTmT and WPEB experts could help refine the scenarios and ensure they are realistic and relevant.

5.2 MP

- **Conduct a wide exploration of model-free and model-based MPs**. The candidate MPs presented here would be explored further over the new set of OMs, and alternative model-free options proposed. In particular, the range of potential values for the HCR arguments should be investigated further, as it was done for the swordfish harvest control rule. The effect of alternative tuning periods could also be explored further.
- **Finalize the implementation of model-based MPs**. Exploratory fits of two surplus production formulations, based on JABBA and SPICT, have already been carried out. The implementation of these MPs should be finalized, and their performance tested over the base case OM. The possibility of combining multiple indices of abundance should be explored as well. This could safeguard against further decreases in the activity on the longline fleets in the NW area, which could lead to the LL1 CPUE index becoming less informative.

- **Run the selected MPs over the full set of OMs**. Once the OMs are fully conditioned and the candidate MPs have been refined, the next step is to run the MPs over the full set of OMs, including the robustness scenarios.

5.3 MSE

- **Improve the performance of projection code**. At a technical level, the projection code would benefit from some optimization to improve its performance and reduce computation time.

References

Dueri, S. et al. 2017. "Impacts of Climate Change and Ocean Acidification on Tuna in the Indian Ocean." Paris, France: IDDRI.

Erauskin-Extramiana, M. et al. 2024. "Climate Change Effects on Albacore Tuna: Environmental Drivers, Habitat, and Stock Responses." In *Collective Volume of Scientific Papers*, 81:3077–3100. ICCAT.

IOTC. 2024. "Report of the 15th Session of the IOTC Working Party on Methods." IOTC–2024–WPM15–R[E]. Indian Ocean Tuna Commission.

———. 2025. "Report of the 16th Session of the IOTC Working Party on Methods." IOTC–2025–WPM16–R[E]. Indian Ocean Tuna Commission.

Mondal, S. et al. 2023. "Habitat Modeling of Mature Albacore (Thunnus alalunga) in the Indian Ocean." *Frontiers in Marine Science* 10: 1258535. https://doi.org/10.3389/fmars.2023.1258535.

——— et al. 2025. "Climate-Driven Shift of Immature Albacore in the Indian Ocean." *Fisheries Oceanography*. https://doi.org/10.1111/fog.xxxxx.

Neubauer, P. 2025. "Review of the IOTC Bigeye Tuna (BET) Base Operating Model." IOTC-2025-WPM16-14. Indian Ocean Tuna Commission (IOTC). https://iotc.org/sites/default/files/documents/2025/10/IOTC-2025-WPM16-14-BET_review.pdf.