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Management Strategy Evaluation for Indian Ocean yellowfin tuna: Operating Model and Candidate Management Procedures

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Abstract

This document outlines the initial steps in evaluating management strategies for Indian Ocean yellowfin tuna using Management Strategy Evaluation (MSE). The focus is the development of a reference Operating Model (OM) conditioned from the latest stock assessment, along with exploratory evaluations of three types of Candidate Management Procedures (CMP). Details of the OM and an early review of both model-based and empirical CMPs are provided. This document is intended as a foundation for discussion at the 17th IOTC Working Party on Methods (MSE Task Force) meeting. The goal is to further refine and agree on reference OMs and explore various CMP options.

Introduction

MSE is recognized as the appropriate methodology for evaluating uncertainty in fisheries management. MSE can be used to quantify the effects of uncertainty in the management of fisheries and to identify attainable performance based on available data and the uncertainties that are inherent to natural systems. MSE steps include among others: (a) identifying relevant uncertainties in biology, environment, fisheries, and management; (b) building models (operating models, OM) that represent plausible system dynamics; and (c) fitting OMs and assessing the impact of uncertainties.

In this paper we describe a first reference OM conditioned from the stock assessment developed for Indian Ocean yellowfin tuna in 2024 and 2025. The proposed OM is composed of a factorial grid of 12 models that characterize uncertainty using alternative values of steepness (3), assumptions on longline selectivity (2) and effort creep (2). We compare the trends and reference points of the OM and the stock assessment, develop tests to ensure the OM can be used for forward projections and develop a first exploratory evaluation of three CMP as an example.

The final section covers the suggested performance metrics for CMP evaluation and outlines the upcoming steps of this MSE.

Operating Model

The OM proposed here as a reference of the Indian Ocean yellowfin tuna MSE is conditioned from the most recent stock assessment for this stock (Urtizberea et al., 2024; Correa et al., 2025). The key features of the stock assessment are:

- Developed in Stock Synthesis (Methot and Wetzel, 2013).
- Age structured spatially-explicit (4 areas).
- Fitted to catch, catch per unit of effort (CPUE), length compositions, tagging data and conditional age-at-length.
- Assessment period: 1950-2023 with quarterly time steps.
- Assumes that the Indian Ocean yellowfin tuna constitute a single spawning stock, modelled as spatially disaggregated in four regions, with twenty-one fisheries (Urtizberea et al., 2024).
- Revised growth (Farley et al, 2023; Fraile et al., 2024), natural mortality (Arrate-Artetxe et al., 2024; Hamel and Cope, 2022) and maturity (Zudaire et al., 2022).
- CPUE from main longline fleets as the only relative abundance index (Matsumoto et al., 2024) revised in 2025 by Kitakado et al.

The stock assessment was conditioned into a single area age-structured population model using FLBEIA (García et al., 2017) and libraries of the Fisheries Library in R (Kell et al., 2007), specifically the library *ss3om* (Mosqueira, 2026). FLBEIA is a simulation model developed to conduct the evaluation of fisheries management strategies using MSE and FLR is a collection of tools for quantitative fisheries science, developed in the R language, that facilitates the construction of bio-economic simulation models of fisheries systems as well as the application of a wide range of quantitative analyses.

The source code for the conditioning is publicly available in a Github repository (IOTC_MSE_YFT). All participants in the WPM should be able to replicate the conditioning process.

Table 1. Factors used to develop the reference OM for Indian Ocean yellowfin from the latest stock assessment.

Description	
LL CPUE was divided into two periods?	
NoSplit	No divided
SplitCPUE	Divided: before and after 2000
Effort creep of 0.5% per year was included for LL CPUE?	
EC0	No
EC1	Yes
Steepness (h)	
h0.7	h = 0.7
h0.8	h = 0.8
h0.9	h = 0.9

The factors described in Table 1 are the basis for the 12 models used in the stock assessment developed in 2024 and 2025. Figure 1 shows the estimated reference points (unfished spawning stock biomass (SSB0), spawning biomass at the maximum sustainable yield (SSBMSY), the fishing mortality at MSY and the productivity of the stock (MSY) for each one of the 12 model runs.

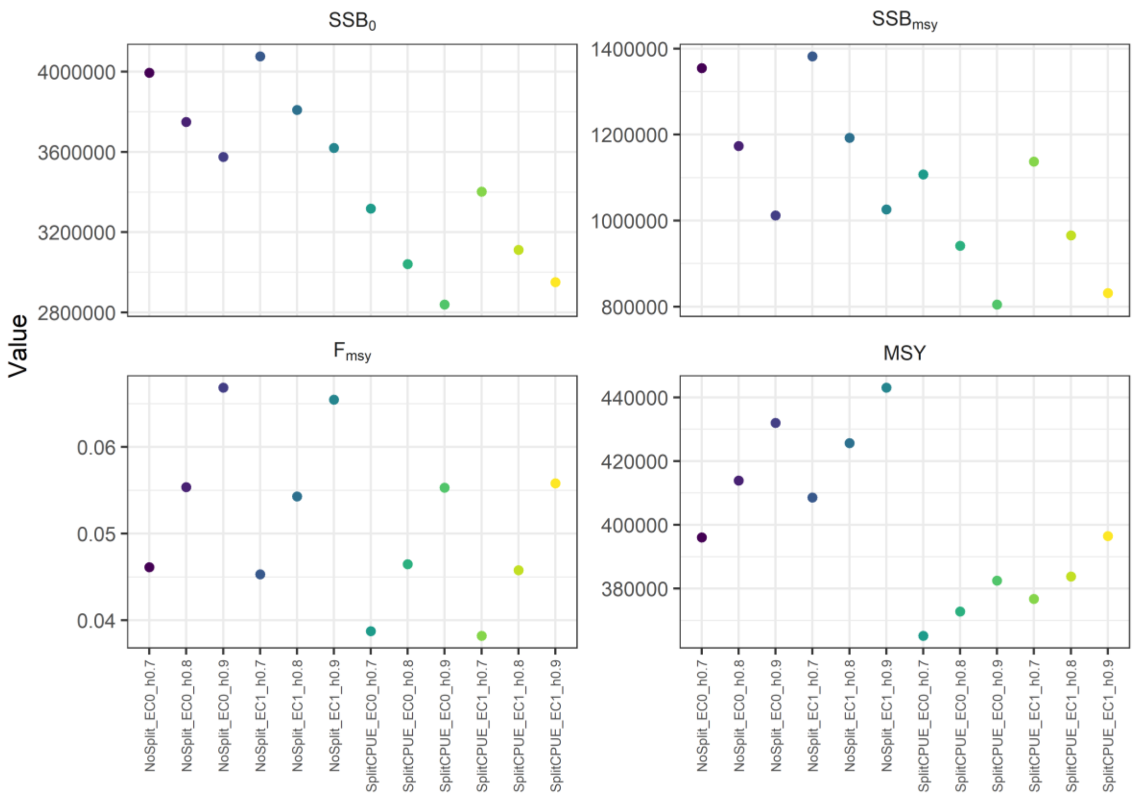

Figure 1. Estimated reference points for the 12 models of the proposed OM.

Figures 2 and 3 display the estimated historical trajectories of SSB and fishing mortality (F) across 12 OM models. Most models show similar trends, with notable scaling differences between those using a split abundance index and those that do not.

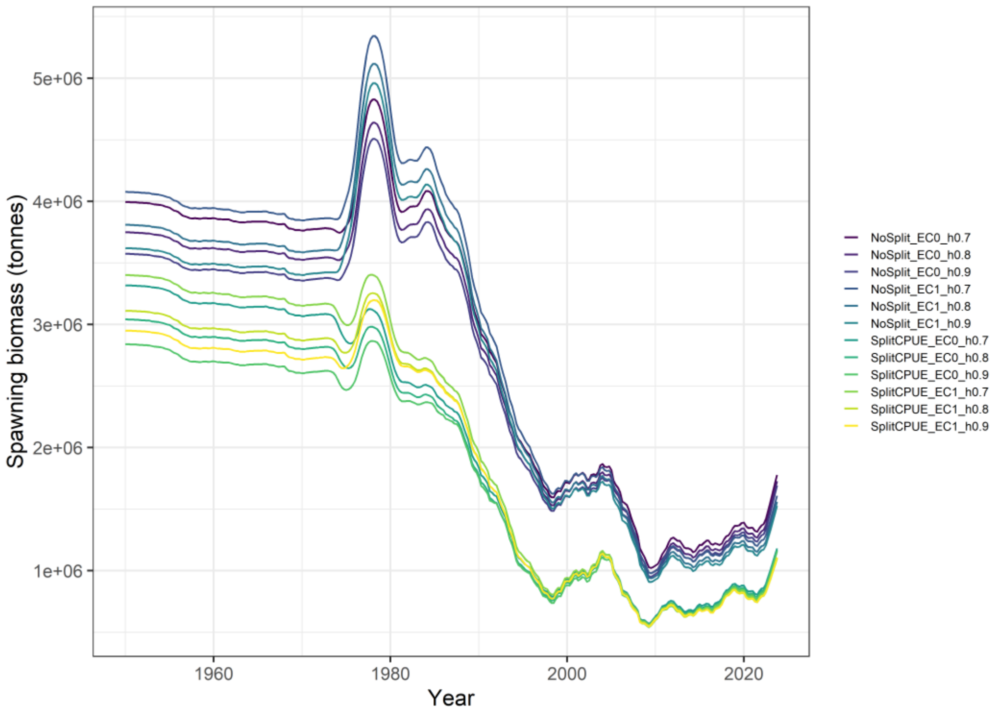

Figure 2. Estimated SSB for the estimation period for the 12 models of the reference OM.

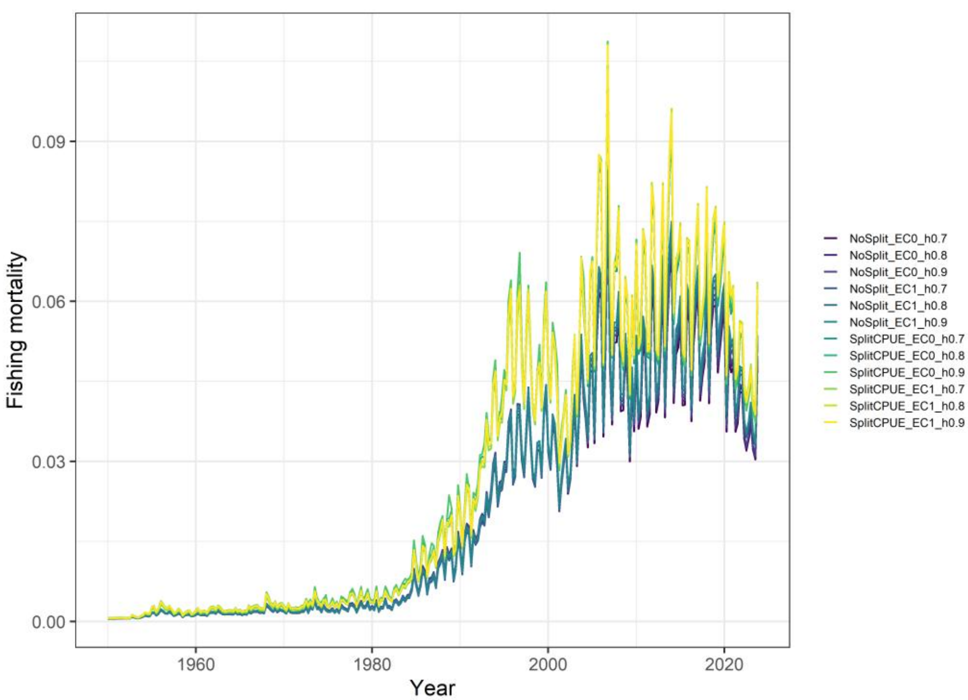

Figure 3. Estimated SSB for the estimation period for the 12 models of the reference OM.

Figures 4 and 5 display the trajectory of the status of the stock (SSB and F relative to MSY) across the 12 models. Overall, the relative trajectories don't display the differences between the models with and without the split abundance index seen in Figure 2.

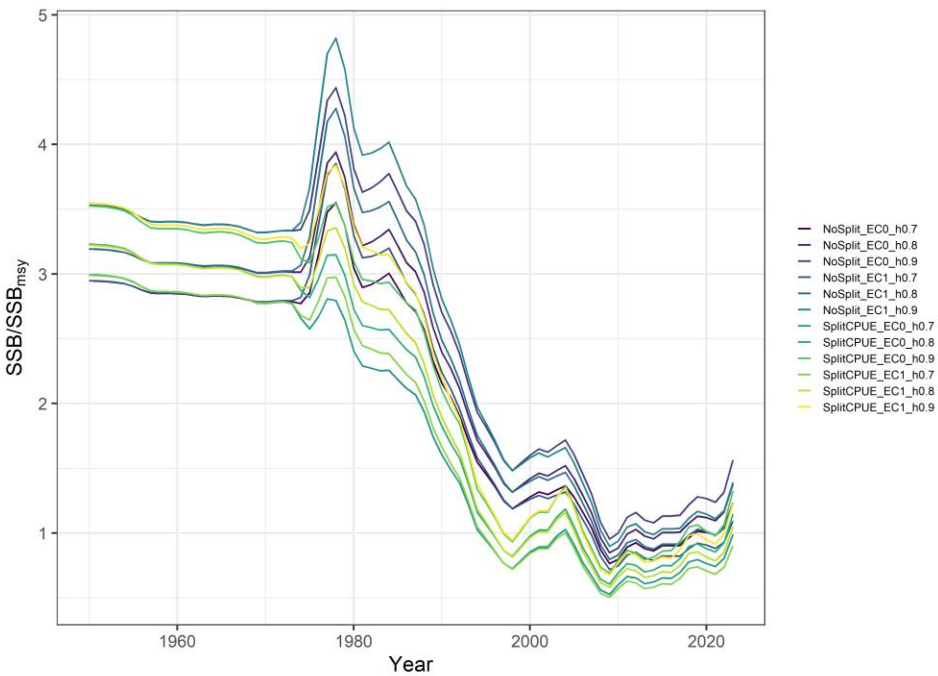

Figure 4. Estimated SSB/SSB$_{MSY}$ for the estimation period for the 12 models of the reference OM.

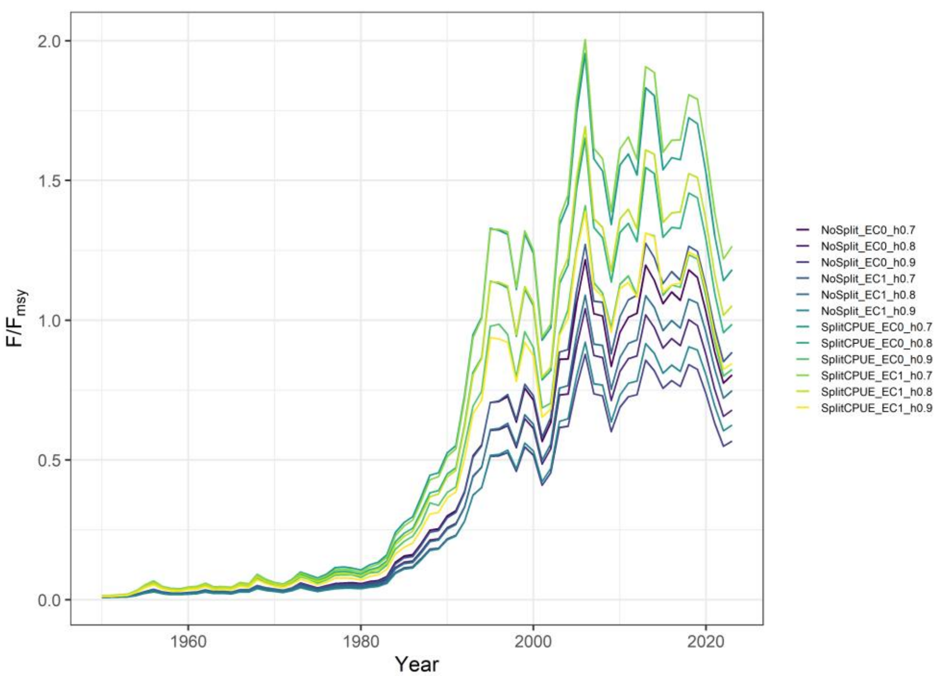

Figure 5. Estimated F/FMSY for the estimation period for the 12 models of the reference OM.

Characterization of uncertainty

Figure 6 shows the uncertainty associated with the OM. The OM depicts a stock that is probably not overfished or experiencing overfishing, but there remains a notable chance that it could be both overfished and undergoing overfishing. With regards to the productivity of the stock, the OM covers a wide range of MSY values, from 350 to 450 thousand tons (mean 399 th tons and sd=25,040 tons).

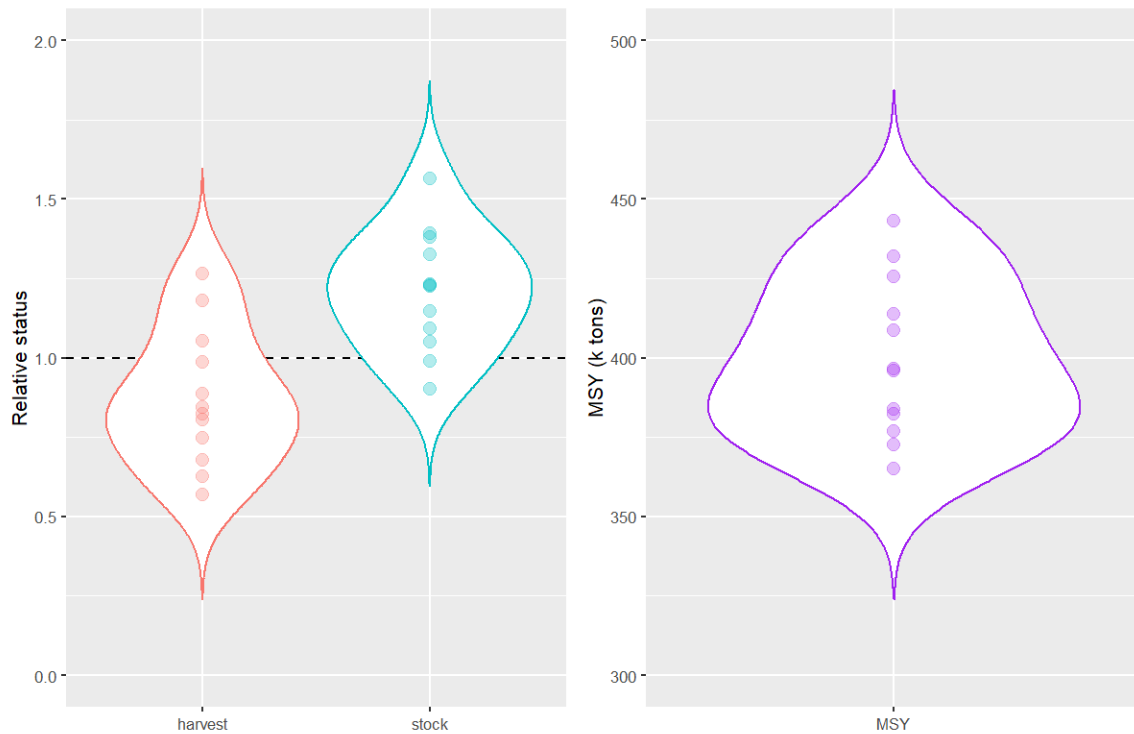

Figure 6. Violin plots that illustrate the range of uncertainty on Indian Ocean yellowfin status and productivity characterized with the OM.

Candidate Management Procedures

We propose three types of CMP for this stock:

1) *Model based:* This MP consists of a stochastic surplus production model in continuous time (SPiCT) as the stock estimator. SPiCT is a full state-space model, where biomass and fishing dynamics are modelled as states, which are observed indirectly through biomass indices and commercial catches sampled with error (Pedersen and Berg, 2017). SPiCT calculates maximum sustainable yield (MSY) reference points and, absolute and relative biomass and fishing mortality.

The results of the estimator (biomass and relative biomass (B/B_{MSY}), reference points ($B_{MS}Y$ and F_{MSY})) are used in combination with a harvest control rule (HCR, Figure 7) to set the fishing mortality and multiply the estimated absolute biomass and determine a Total Allowable Catch (TAC) for a three year management period. The control parameters of the HCR are the target fishing mortality (Ftgt), the threshold or trigger biomass (Bthr), the minimum fishing mortality (Fmin) and the level of biomass at which the fishing mortality will be reduced to the Fmin (Blim). Additionally, this MP can include a maximum % of change of TAC between management periods and a maximum TAC.

This CMP is comparable with the recently adopted MPs for Indian Ocean bigeye (Resolution 22-03) and Indian Ocean swordfish (Resolution 24-06).

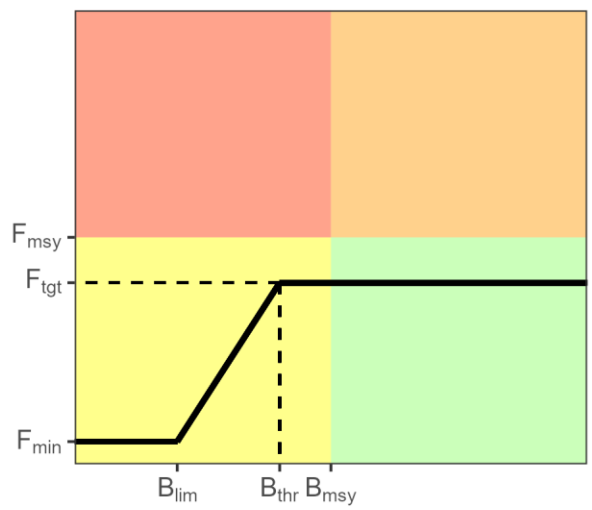

Figure 7. Example of HCR within the model-based MP proposed for Indian Ocean yellowfin.

2) *Index-based*: This MP consists of modulating TAC as a response to deviations of the Joint Longline CPUE from a target level ($CPUE_{target}$). With this index, the TAC will equal to the previous management period if the CPUE (averaged for the last three years) is within a range of $CPUE_{target}$ x ($1 \pm \alpha$); for α defining the range of acceptable deviation from the $CPUE_{target}$ and β the management response in the form of change in TAC (%) from the TAC in the previous management period (Equation 1). For this CMP, a maximum TAC can also be implemented.

Equation 1; $$TAC_{t:t+3} = \begin{cases} if(\frac{\text{CPUE(3yrs)}}{\text{CPUEtarget}} > \text{CPUEtarget x } (1+\alpha) \longrightarrow TAC_{t-1} \times (1+\beta); \\ if(\text{CPUEtarget x } (1-\alpha) \leq \frac{\text{CPUE(3yrs)}}{\text{CPUEtarget}} \leq \text{CPUEtarget x } (1+\alpha) \longrightarrow TAC_{t-1} \\ if(\frac{\text{CPUE(3yrs)}}{\text{CPUEtarget}} < \text{CPUEtarget x } (1+\alpha) \longrightarrow \ TAC_{t-1} \times (1-\beta) \end{cases} ;$$

3) *Pseudo-constant catch:* This MP consist of a constant TAC (TAC_{ct}) unless the Joint LL CPUE falls within a reference value (CPUEref). When the Joint LL CPUE (3 year average) is lower than CPUEref, the TAC will be reduced proportionately towards the total closure of the fishery (TAC=0) (Figure 8 and Equation 2). This CMP can include a maximum change in TAC (%) between management periods. This CMP is comparable with the MP adopted for Indian Ocean skipjack (Resolution 24-07).

Equation 2;
$$TAC_{t:t+3} = \left\{ \begin{array}{c} if\ (CPUE(3yrs) \geq CPUEref\ \rightarrow TACct \\ if\ (CPUE(3yrs) < CPUEref\ \rightarrow TACct\ x\ \frac{CPUE(3yrs)}{CPUEref} \end{array} \right| ; \right\} \ ;$$

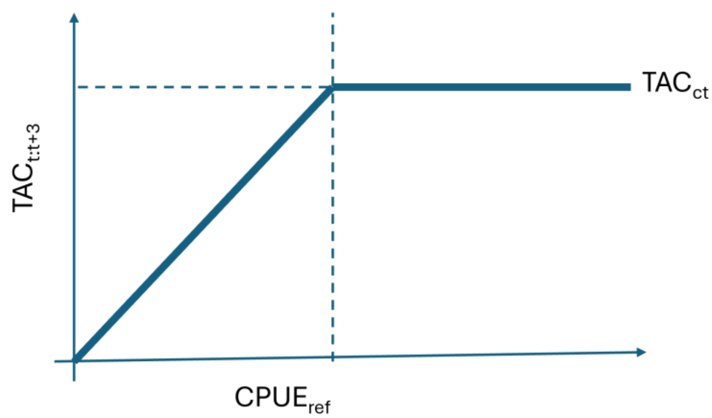

Figure 8. Visual representation of the pseudo-constant catch MP.

Results

This section includes a sanity check with one of the models included in the OM and exploratory evaluations of one example of the three CMPs. The starting point for the projections is 2025 in all cases.

First, we projected one of the models of the OM (*NoSplitCPUE_EC08_h80*) with fishing effort = 0 and with the fishing mortality of the terminal year of the assessment period ($Ef_{current}$). Figure 9 shows the estimated trajectory of catch, recruitment (rec), fishing mortality (f) and spawning stock biomass (ssb). As expected, when fishing is halted, the stock recovers to the levels at the onset of the fishery and likewise the recruitment. Note that for these simulations, we do not include the recruitment adjustment for the projections as recommended in Merino et al (2025). This is why, the unfished equilibrium is identical at the early years of the assessment and at the end of the projection.

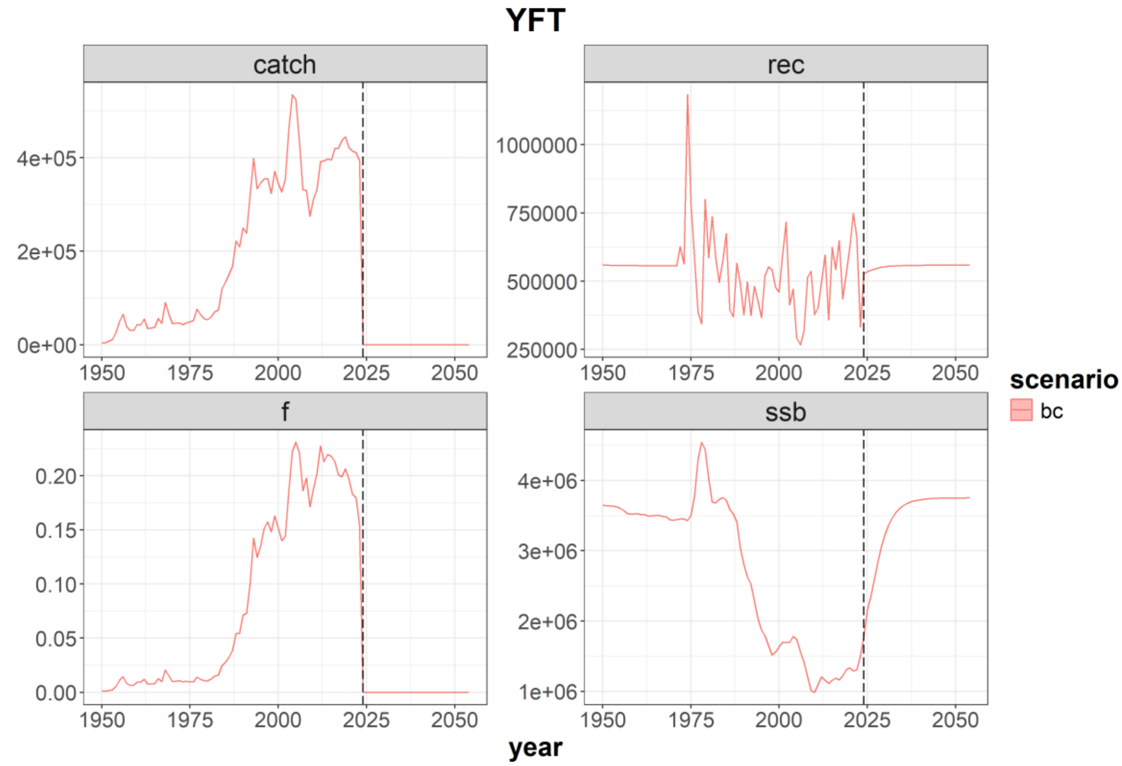

Figure 9. Projections with the OM (*NoSplitCPUE_EC08_h80*) with fishing mortality set at zero.

We also projected the same model with the fishing mortality of the terminal year of the assessment. Figure 10 shows that at the fixed fishing mortality, catch would converge approximately at 400 th tons, the recruitment would be maintained at levels only slightly below the equilibrium recruitment for the unfished stock (R0). The SSB would consolidate the recovery estimated for the last years of the assessment and would stabilize at the level estimated for the end of the 1990s decade. This projection helps identify a new equilibrium for the fishery when the estimated recruitment variability throughout the projection period is omitted.

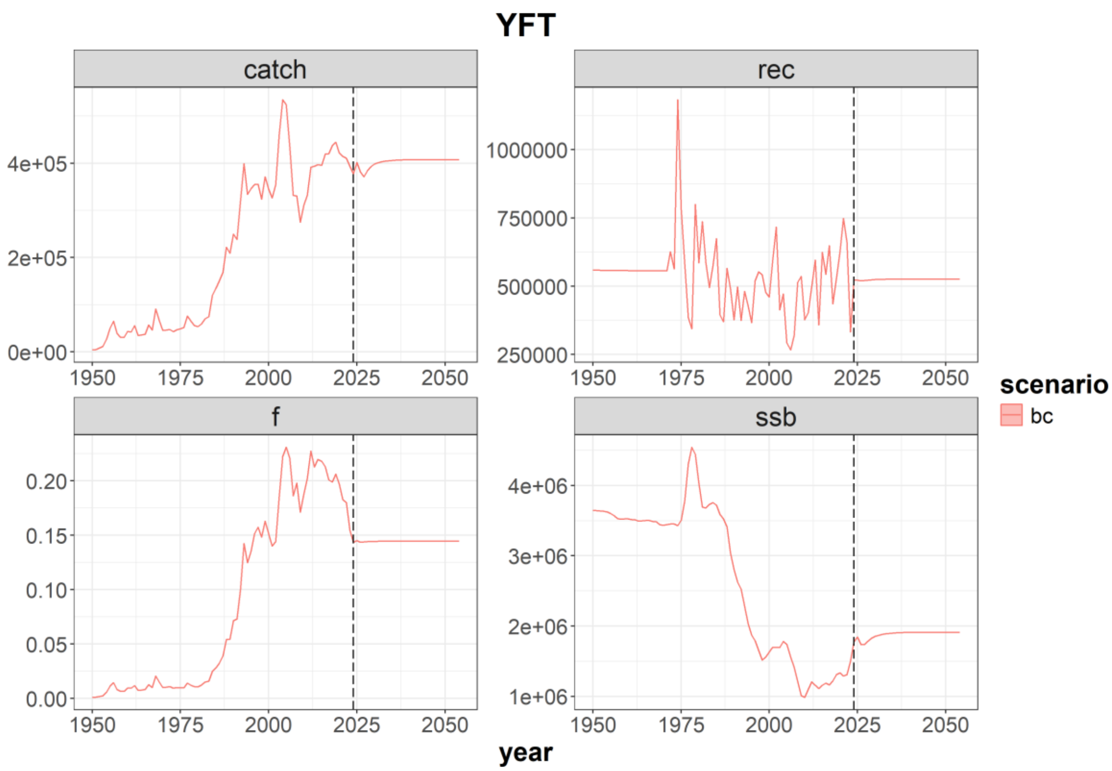

Figure 10. Projections with the OM (NoSplitCPUE_EC08_h80) with fishing mortality set at the levels of the terminal year of the assessment.

The MSE framework is used for a preliminary evaluation of three CMP shown as examples. The CMPs evaluated here are:

1) *Model-based MP (MB):* With the following specifications of the decision rule or HCR:
    - Ftgt=0.8xFmsy
    - Bthr=Bmsy
    - Blim=0.4xBmsy
    - Fmin=0.1xFmsy
    - Maximum TAC change = 15%.
    - Maximum TAC = 450,000 tons.

2) *Index-based MP (IB):* With the following specifications:
    - CPUEtarget=0.7 x of the normalized historical Joint LL CPUE.
    - α = 0.1 (10%), this means that the range for maintaining TAC constant is when the CPUE(3yr) is within 10% up or down the CPUE target.
    - β = 0.1. This means that TAC will increase or decrease 10% as a response when the CPUE(3yr) is not within the range of 10% up or down the CPUE target.
    - Maximum TAC = 450,000 tons.

3) *Pseudo-constant catch MP (PCC):* With the following specifications:

- CPUEref=0.7 x of the normalized historical Joint LL CPUE.
- TACct = 421,000 tons.
- Maximum TAC change = 15%.

The projections of the 3 CMPs are shown in Figure 11. Overall, the three CMPs should maintain the stock above the adopted biological target reference point (B_{MSY}). However, the three CMPs display differences in the stability of catch and fishing mortality:

The model-based MP (green line) increases TAC to the maximum of 450,000 tons following the favourable status and total biomass estimated in the initial years of the simulation. However, this TAC is reduced as biomass approaches the B_{MSY} threshold to approximately 450,000 tons first and to approximately 375,000 tons later. This reduction is estimated to allow for the stock recovery and therefore, the TAC is again increased to 430,000 tons approximately. With this MP, biomass is not predicted to decrease below the SSB_{MSY} benchmark anytime in the simulation. The MP seems to detect the trend in biomass and adjusts the TAC accordingly to each management period.

The index-based MP (red line) seems to detect that the abundance index is well above the target at the start of the simulation and increases TAC to its maximum of 450,000 tons. However, this catch is not reduced fast enough when biomass decreases as a response and the TAC is maintained at those levels in the second management period as well, bringing the fishing mortality to levels above the F_{MSY} reference. The stock continues to decline and then catch is reduced to approximately 325,000 tons to recover the abundance index towards the target. Overall, this MP is the one that seems less stable, at least with the control parameters used as an example.

The PCC (blue line) maintains catch at 421 th tons for the first 3 assessment cycles. After that, the abundance index is predicted to fall below the reference value and catch is slightly reduced accordingly to approximately 400 th tons. In the following management period the abundance index seems to increase and catch does so as well.

Note that these preliminary MSE projections have been carried out under a perfect knowledge assumption. In other words, the simulated CPUE reflects perfectly the trends in the exploitable biomass of the population.

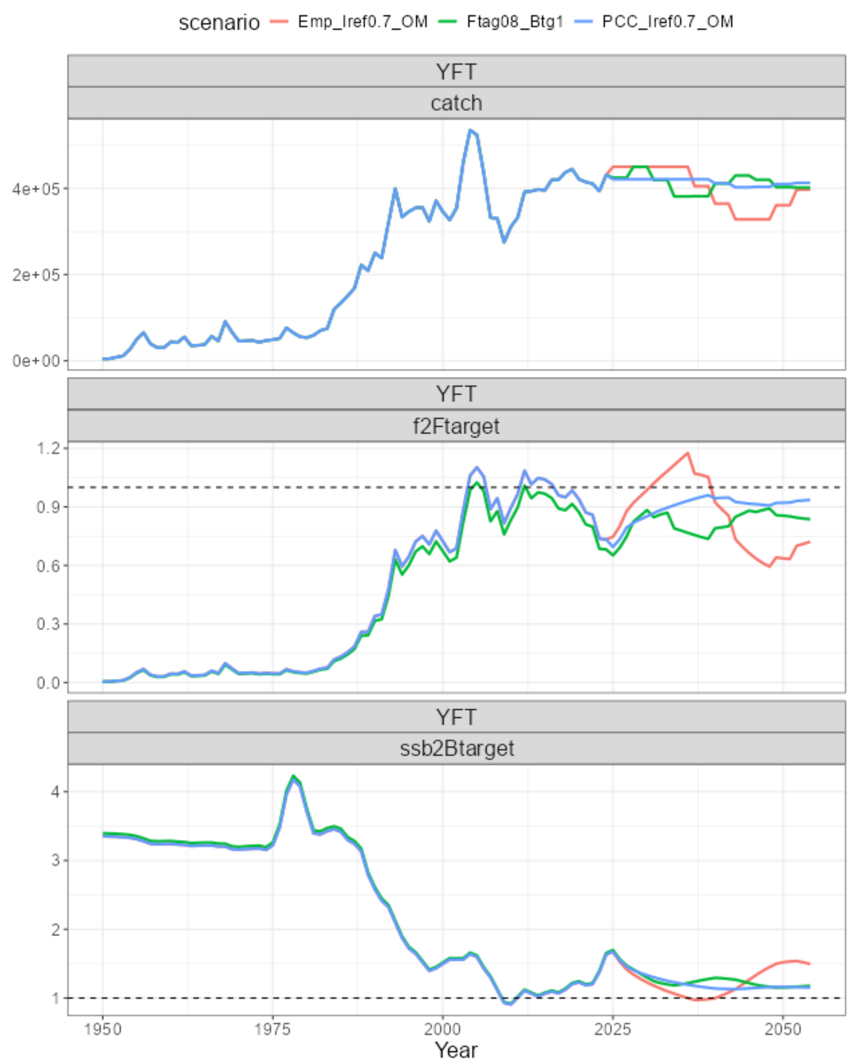

Figure 11. Projection of the Indian Ocean yellowfin stock with three examples of CMP.

Discussion and next steps

This document is a first step towards the development of an MSE framework for Indian Ocean yellowfin tuna and is intended to trigger discussions within the WPM and to expand the evaluation of CMPs.

Operating Models

Overall, the proposed OM covers a relatively wide range of stock status and productivity. Additional hypotheses of biological or fishery parameters could be used to expand this initial grid.

Candidate Management Procedures

We propose expanding the CMPs including alternative options for the alternative control parameters for each one:

1) *Model based MP:* We propose an initial expansion of the CMP using options for the target fishing mortality (e.g. 0.8, 0.9, 1.0), the stability clause (10%, 15%, 20%) and considering the inclusion or not of the maximum TAC parameter.
2) *Index based MP:* Alternative values of the target CPUE can be proposed based on the values observed in the stock assessment period. The 0.7 value used here represents the value of the CPUE that corresponds approximately with the SSB_{MSY}. Also, the range of deviation from the CPUE target (α) may be reduced from the current 10% to increase the reactivity of the CMP. The change in TAC (β=10%) can also be increased or reduced. Here as well, the maximum TAC can be included, changed or discarded.
3) *Pseudo*-constant MP: The alternatives may include different TACct and reference $CPUE_{ref}$ or the % of change between management periods.

The control parameters can be proposed based on preferences for the fishery (e.g. keeping fishing mortality below FMSY, therefore Ftgt < 1). Also, managers and stakeholders may show preference for using CPUE values that correspond to other levels of SSB as a reference and target. Once some alternatives are agreed for the control parameters, the MSE framework can be used to evaluate if they would achieve minimum standards of conservation (e.g. probability of maintaining the stock in the green quadrant of the Kobe plot or of falling below the adopted Limit Reference Point).

Another option could be to tune the control parameters of the HCR to exactly meet management objectives expressed as probabilities (e.g. 50%, 60% or 70% of maintaining the stock in the green quadrant of the Kobe plot). This has been the practice in the MSEs developed for IOTC fisheries (bigeye, skipjack and swordfish).

Observation Error Model

As said, the simulations shown here have developed under the assumption of perfect knowledge of the biomass trends of the OMs. One of the next steps of this MSE is to develop an Observation Error Model (OEM) from the statistical properties of the Joint Longline CPUE and the OM fits to them. This will include an analysis of residuals, autocorrelation etc. that will be used to generate simulation indices throughout the MSE simulations.

The final evaluation of CMPs will be made with the OEM.

Performance metrics

The CMPs will be evaluated against the agreed performance metrics used in the MSE processes in the IOTC.

Conclusions

This document is a discussion paper for the 2026 MSE Task Force of the WPM. We expect to discuss the reference OM, the options for CMP, the OEM, performance metrics, timeline for technical developments and for presentation of results to the Technical Committee on Management Procedures.

During the MSE Task Force we will also show the visualization tools developed for this MSE.

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