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Updates to the Management Strategy Evaluation Framework for Pacific Bluefin Tuna

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Summary

Here we summarize updates made to the Pacific Bluefin tuna (PBF) Management Strategy Evaluation code following input from the March 2024 ISC PBF Working group (WG) and the 9th Meeting of the Inter American Tropical Tuna Commission (IATTC) and Western and Central Pacific Fisheries Commission of the Northern Committee (WCPFC NC) Joint Working Group (JWG) on PBF management. Main changes include the adoption of a new base case operating model (OM) based on the latest 2024 PBF stock assessment, implementation of the real-world lag between the availability of data for the simulated assessment and the simulated implementation of the catch advice, and generation of a separate total allowable catch (TAC) by size category for fleets operating in the Western and Central Pacific Ocean (WCPO) and Eastern Pacific Ocean (EPO).

Introduction

The two Regional Fisheries Management Organizations (RFMOs) tasked with managing the PBF stock, WCPFC NC and IATTC, requested, via the JWG, that the ISC PBF working group develop an MSE to help inform development of a long-term management strategy for PBF once the stock is rebuilt to the second rebuilding target of 20%SSB0 (JWG 2022). As part of the MSE process the JWG at their 9th meeting agreed that a 2015-2022 small:large fish allocation baseline be used in the MSE and that the management strategies tested should produce a TAC by region and size category (i.e. EPO, WCPO small, and WCPO large) (JWG 2024).

Furthermore, at their March 2024 meeting, the PBFWG requested a 1.75-year lag between the end of the assessment and the implementation of a resulting management action be implemented in the MSE as this is the lag duration in the real world (ISC 2024a). For example, the 2024 assessment, which informed a management action for January 2025, used data up to and ended in the second quarter of 2023. The PBFWG also suggested that in the final MSE runs, the first simulated stock assessment should include data up to fishing year (FY) 2023 (June 2024) to inform management advice in calendar year 2026, and that this would require using available observed catches for FY2023 and FY2024 for the MSE if such data were made available by the member countries or the existing catch limits. The PBFWG also agreed at their March 2024 meeting to ensure the MSE framework is updated to work with operating models (OMs) based on the newly developed 2024 PBF stock assessment (ISC 2024a, ISC 2024b).

The aim of this paper is to detail how the preliminary PBF MSE framework outlined in Tommasi and Lee (2022) and Tommasi et al. 2023 has been modified to reflect these requests.

Methods

The PBF MSE framework was modified from that outlined in Tommasi and Lee (2022) and Tommasi et al. 2023 and is available at https://github.com/detommas/PBF_MSE. It was updated to use the 2024 stock assessment (ISC 2024b) instead of the short 2022 Stock Synthesis (SS) PBF stock assessment model (ISC 2022) as the base case operating model (OM). The OM was conditioned using historical (1983-2022) data and, during the forward MSE simulation, is run with no estimation using parameters set in the .par file.

The OM represents the true dynamics of the PBF stock and fisheries and since there is uncertainty about what the true dynamics are, the MSE considers 21 equally plausible versions of the true dynamics (i.e. 21 OMs, see Lee and Tommasi 2024). The PBF MSE aims to simulate a realistic management process and generates data with error from the OM, feeding it into a simulated stock assessment (i.e. the estimation model, EM), which estimates stock status given the observed data. The simulated stock assessment is conducted every three years. Hence, data with error is generated from the OM and ingested into the EM every three years.

Estimates of stock status are then supplied from the EM to a management model, which is comprised of a harvest control rule (HCR) with specific reference points. A total allowable catch (TAC) is set by the HCR and this determines the catch in the OM for the following three years. To account for the fact that there are additional discards catches on top of the TAC, the MSE framework applies additional discard catches using three discard fleets (see details below). The closed loop simulation is run from July 2023 to June 2044 for a total of 22 years and eight simulated stock assessments. Many iterations are run to account for process uncertainty in recruitment, with recruitment deviations in the OM being sampled from a normal distribution with mean 0 and standard deviation of 0.6, the σ_R used in the 2024 PBF stock assessment (ISC 2024b). Fig. 1 provides an overview of the MSE framework.

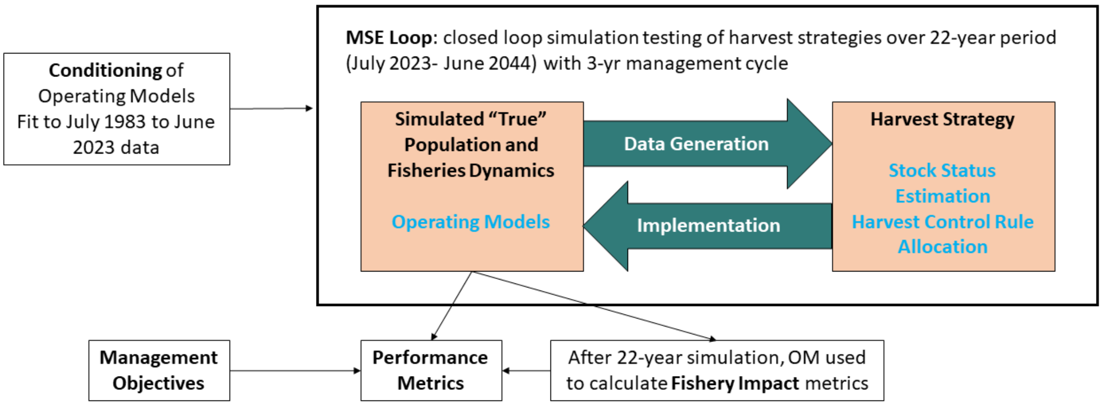

Figure 1. Overview of the PBF MSE framework.

To develop the base case OM for the MSE, the 2024 stock assessment model had to be modified to:

1) Set catches of all fleets in the .dat file to biomass and not numbers. This makes it more straightforward to feed a catch in mt from the management model back into the OM .dat file at each simulated assessment time step.

2) Not have any time varying parameters. For those fleets with time varying selectivity implemented using blocks, future selectivity values are kept at the values of the last block of the conditioning period, which was updated to reflect average 2015-2022 selectivity. For those fleets with time varying selectivity implemented as deviations, deviations in the forward simulated were kept constant at the 2015-2022 average.

3) The relative F years for the benchmark and forecast calculations in the forecast file were switched to 2015-2022, matching the selectivity years and reflecting the allocation baseline agreed upon by the JWG (JWG 2024).

4) Recruitment deviations were estimated also for the terminal year in the conditioning period (in the assessment they were estimated only until 2021).

5) Catchability of the abundance index from Chinese Taipei, the only index used in the MSE forward simulation, was fixed in the OM rather than floating so that consistent expected data was generated by the SS bootstrap routine when new catches were added.

In addition to the operating model in Stock Synthesis, the MSE code in R was modified to:

- Work with the most Stock Synthesis V3.30.22.1 and the r4ss package version 1.50.0
- Have the data generation routine work with the new fleet numbering in the 2024 assessment

- Have the capability to specify the average selectivity and relative F for calculation of benchmark quantities and forecast in the MSE wrapper function (set to 2015-2022)
- Read in as a text file the initial catches based on the CMMs and latest available catches (see below for details)
- Ensure the F multiplier value is also saved as output
- Output and save catch at age by fleet
- Output a TAC is by region and size category (i.e. EPO, WCPO small, WPO large). Note discards are not included in the TAC, but the EPO recreational fleet is, as desired by the JWG (JWG 2024).
- Apply the TAC by calendar rather than fishing year
- Apply the 25% TAC limit by fleet segment (i.e. EPO, WCPO small, WPO large) rather than for the overall TAC and without including discards
- Use discard fleets (Fleets 24, 25, and 26) to represent implementation error due to WCPO non-penning discards, discards from the Japanese troll fleet for penning, and EPO recreational discards. These were set, respectively, to: 1) 5% of the WCPO total TAC except for Fleet 14 (Japanese troll for penning), 2) 100% of the Fleet 14 TAC, and 3) 1.2% of the total EPO recreational catches.
- Modify the lag between the terminal year of the simulated assessment and application of the TAC based on that assessment to reflect the realistic timeline (see details below).

The first simulated assessment in the MSE (i.e. the EM) is run with data available up to FY2023 (up to June 2024 in calendar year) and sets the TAC for calendar year 2026. The 2024 assessment had catch data until FY2022 (ISC 2024), so the MSE simulation needed catches for FY2023 (July 2023-June 2024 calendar year) and FY2024 (July 2024-June 2025 calendar year), and the first semester of FY2025 (July 2025 to December 2025) since the first HCR-established TAC only sets catches starting in January 2026. Member countries provided catch data for FY2023 for the MSE. Catches for FY2024 semester 1 (July 2024 to December 2024) were based on the agreed upon catch limits for calendar year 2024 (CMM 2023-02 and C-21-05) while catches for FY2024 semester 2 and FY2025 semester 1 were based on the agreed upon catch limits for calendar year 2024 (NC20 Summary Report | WCPFC Meetings). These catch limits are by country and, for WCPO countries, also size category (smaller or larger than 30 kg). However, fleets in the MSE operating model are at a finer level than country and size category to account for variable selectivity at age by season and region of operation. Thus, to generate catches for FY2024 and the first semester of FY2025 for the MSE, country and size category catch limit were split between the fleets for a specific country and size category using the same catch ratios as in the last year of the 2024 stock assessment. Note that catch limits for the US and Mexico were combined as, like the stock assessment, the OM has a combined EPO commercial fleet. Since recreational catches in the EPO were not part of the catch limit, EPO recreational catches for FY2024 and the first semester of FY2025 in the MSE were set to be the same as in the last year of the 2024 stock assessment. Discards are also not included in the catch limits, so discards for Fleet 24 (discards from Japanese fisheries and Korean purse seine fisheries) were set to 5% of the WCPO total catches in each FY except Fleet 14 (Japanese troll for penning), discards for Fleet 25 (discards from Japanese fisheries for penning) were set to 100% of the total catches for Fleet 14, and discards for the EPO recreational fleet were set to 1.2% of the total EPO recreational catches.

Test runs were produced with this updated framework for all the 21 OM scenarios and all the HCRs requested by the JWG using the 2015-2022 average selectivity and relative F and no estimation error. See Tommasi et al. 2023 for an overview of the HCRs and how they are implemented in the MSE. There was no estimation error, but there was implementation error We run 100 iterations for each scenario and HCR combination for a total of 25,200 runs.

Results and Discussion

After all the 21 OMs were conditioned, we compared the 2015-2022 average selectivity at age by fleet as this can affect the resulting fishery impact by region. The different OMs have different productivity parametrizations by design (see Lee and Tommasi 2024), and this led to their estimated selectivity also being differed. All the selectivity plots by fleet, season and scenario are available at https://drive.google.com/drive/folders/1PxcAUFoRQd9zp71FkSXCokG9-zYSczFP?usp=drive_link. Here we highlight results for those that differed the most across scenarios.

Selectivity for age 6-9 differed between OMs for Fleet 5, the Japanese tuna purse fleet operating in the Pacific Ocean (Fig. 2). Only in OMs 3 to 8, and 11 to 13, Fleet 5 was estimated to not fully select age 6 fish and to have very low selectivity for age 8 fish (Fig. 2). OMs 3 to 8 are those with a lower natural mortality for age 2 and older (M_2^+) of 0.193 (Lee and Tommasi 2024). OMs 11 to 13 are the only ones with both a M_2^+ of 0.25 and a steepness of 0.99 (Lee and Tommasi 2024).

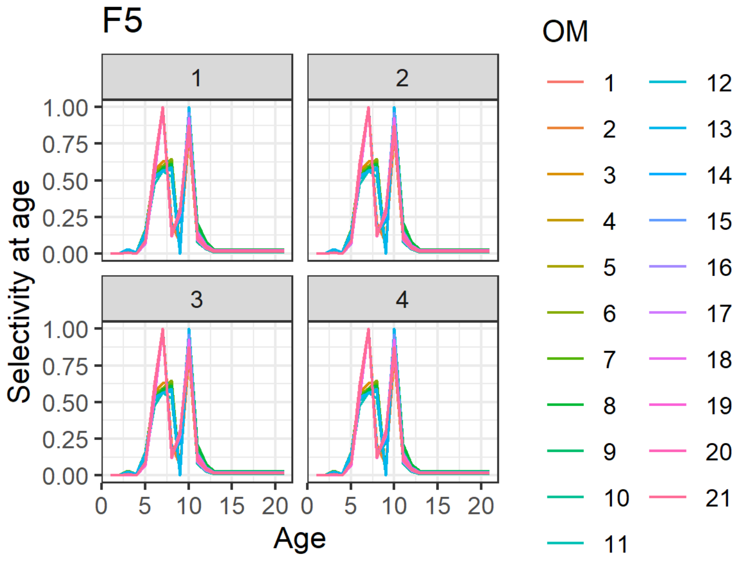

Figure 2. Selectivity at age by season for Fleet 5 for the different operating models. Note that age in the figure is from 1-21 and this corresponds to age 0-20 in the models.

Selectivity at age also differed markedly for those same OMs for the EPO commercial fleet, Fleet 21. OMs 3 to 8 and 11 to 13 estimated lower selectivity for age 4 and older, particularly ages 4 to 7 (Fig. 3).

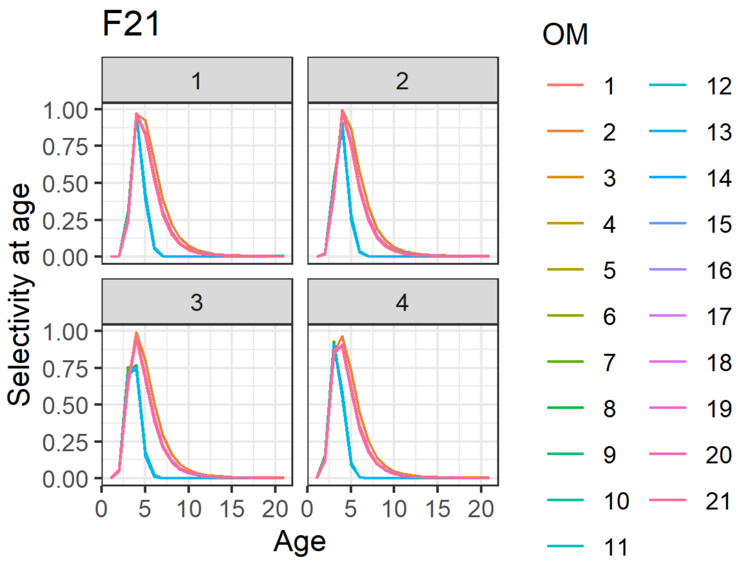

Figure 3. Selectivity at age by season for Fleet 21 for the different operating models. Note that age in the figure is from 1-21 and this corresponds to age 0-20 in the models.

Selectivity for the EPO recreational fleet also differed markedly across OMs (Fig. 4). OMs 4 to 7, 11 to 13, and 19 had the lowest selectivity for ages 1 to 4. These are all

OMs with a steepness of the stock-recruitment relationship of 0.99 or higher (Lee and Tommasi 2024). OM3, the one with the lowest spawning stock biomass relative to unfished (Lee and Tommasi 2024), had an intermediate selectivity for age 2 and then a consistent selectivity of approximately 0.26 from ages 3 to 10 (Fig. 4). OM2 had a consistent selectivity around 0.37 for ages 4 to 10, while OM8 had a steep decline in selectivity from age 2 to 5 and estimated the lowest selectivity for ages 5 to 10 (Fig. 4).

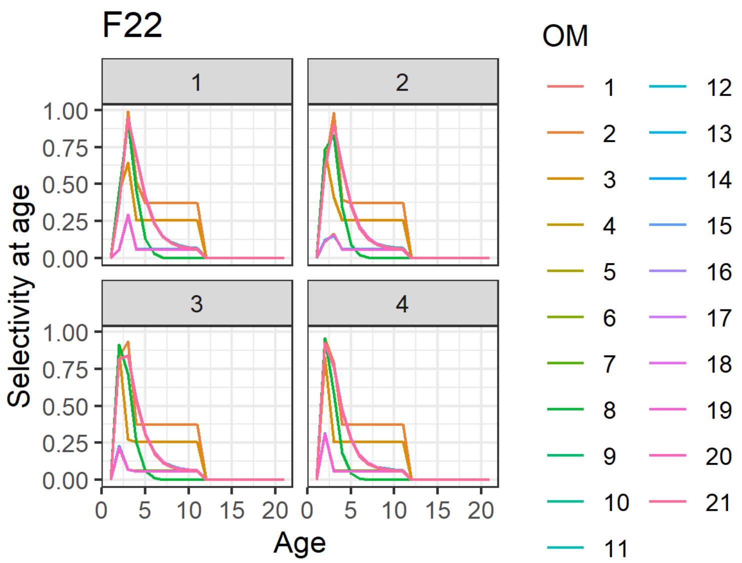

Figure 4. Selectivity at age by season for Fleet 22 for the different operating models. Note that age in the figure is from 1-21 and this corresponds to age 0-20 in the models.

We also plotted time series of the median and 5th and 95th quantiles of quantities of interest across the 100 iterations for each HCR and OM to assess if reasonable dynamics were generated. Given the different productivity parametrization, OMs have different starting levels of spawning stock biomass and spawning stock biomass relative to unfished (Lee and Tommasi 2024). The base case OM, which has the same M_2^+, length at age 3, and steepness as the 2024 stock assessment, had the highest spawning stock biomass relative to unfished, while OM3 had the lowest. We use these two OMs as representative examples of potential stock and catch patterns under the different HCRs tested, but time series plots for all the OMs and HCRs combinations are available at https://drive.google.com/drive/folders/1Ke17Er9NQnmke_A3l46OrDwquazjO6vx?usp=drive_link. Under OM1 initial biomass in FY2023 is higher than the second rebuilding target of 20% $SSB_{F=0}$ and the threshold and limit reference points of all the HCRs (Fig. 5), so all HCRs results in an increase in TAC relative to FY2023, but given the 25% limit on the increase in TAC, the catch increase happens slowly (Fig. 6) and the median fishing intensity only reaches the target fishing intensity for each HCR from 2035 onwards (Fig. 7).

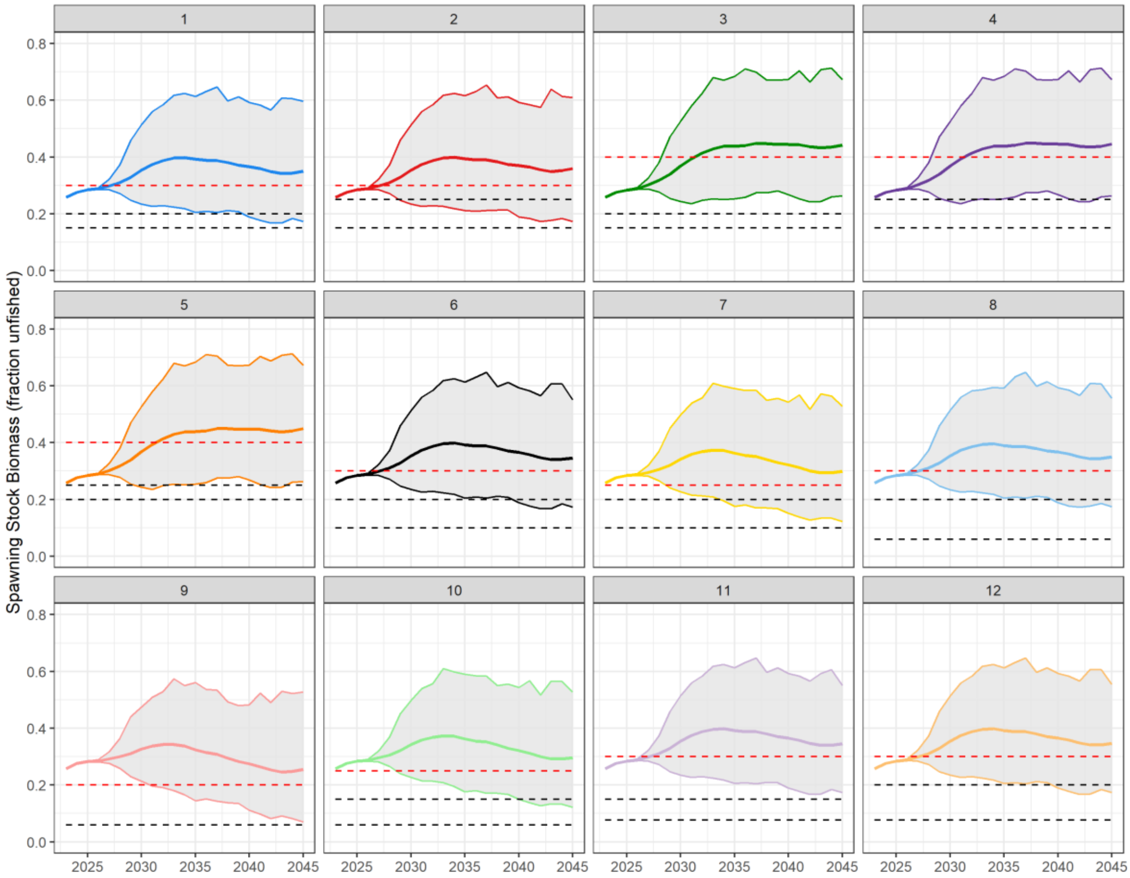

Figure 5. Median (solid line) and 5th to 95th quantiles (grey shading) of SSB relative to unfished across all iterations for each HCR for OM 1. The threshold and limit reference points associated with each HCR are shown as horizontal black dotted lines, while the relative SSB corresponding to the F-based target is represented by the red dotted line. Note that for HCR9 the threshold is the same as the target reference point.

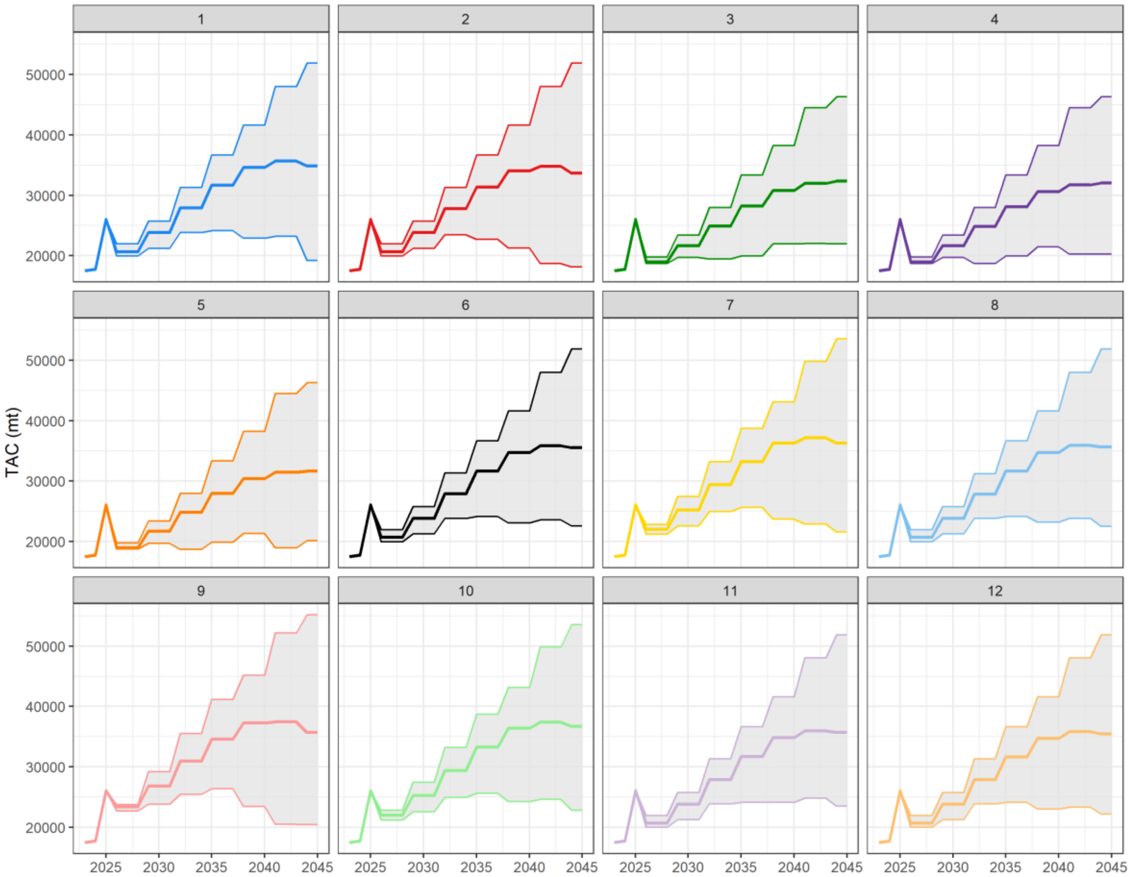

Figure 6. Median (solid line) and 5th to 95th quantiles (grey shading) of the TAC across all iterations for each HCR for OM 1.

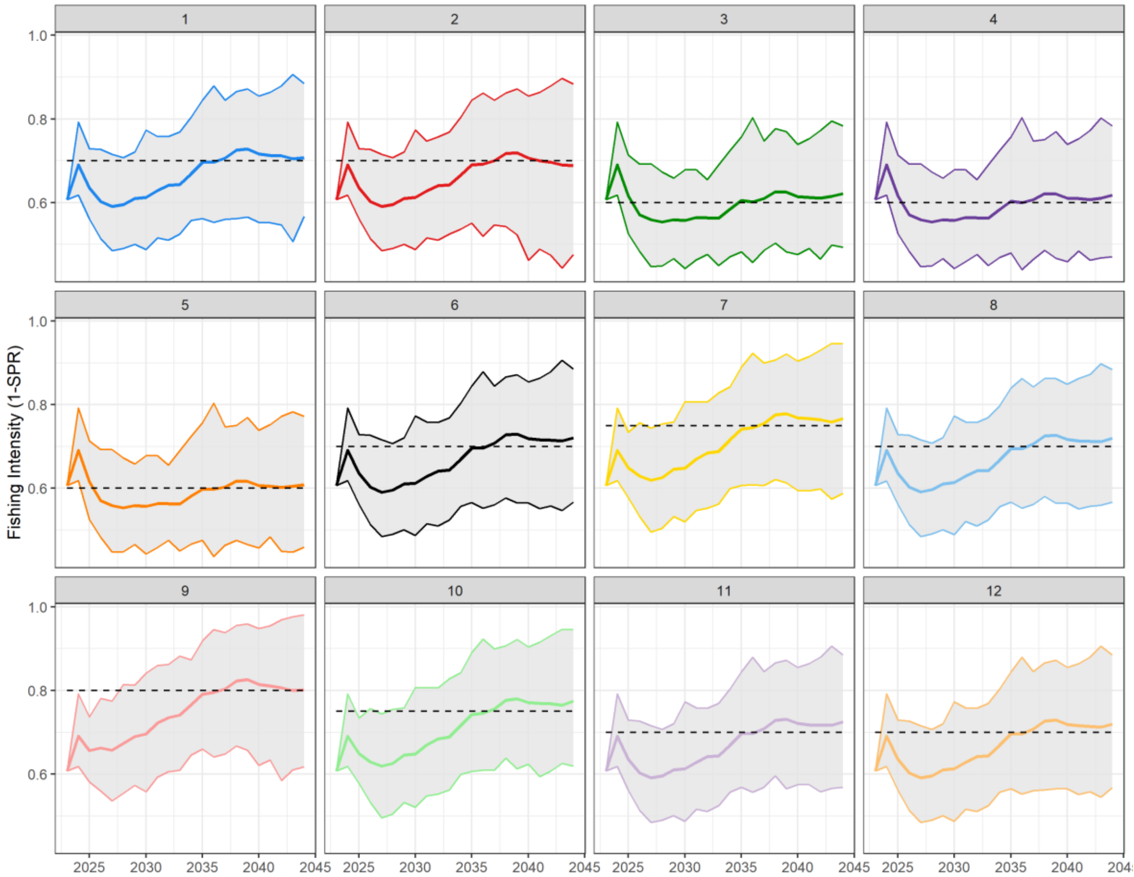

Figure 7. Median (solid line) and 5th to 95th quantiles (grey shading) of fishing intensity (1-SPR) across all iterations for each HCR for OM 1. The target reference point associated with each HCR is shown as a horizontal black dotted line.

While median total and WCPO large fish TAC are higher than FY2023 at the end of the simulation (Fig. 6 and 8), the EPO and WCPO small fish TAC are lower (Fig. 9 and 10), reflecting the 2015-2022 baseline allocation, which is based on the 2015-2022 relative apical fishing intensity. Patterns in fishing intensity, relative SSB, and catch are similar to those in OM1 for most HCRs for OMs 9 to 15 as these OMs have an initial relative SSB higher or at the second rebuilding target and the SSB-based threshold and reference points of most HCRs. Exceptions are OM11 for HCRs 2, 4, and 5 and OM12 and OM13 for HCRs 1 to 5. These are OMs with the lowest relative SSB of the OMs mentioned above and thus for those HCRs with the highest SSB-based reference points, an initial decrease in TAC is triggered, making the increase in F to target levels even slower as it is starting from an even lower TAC.

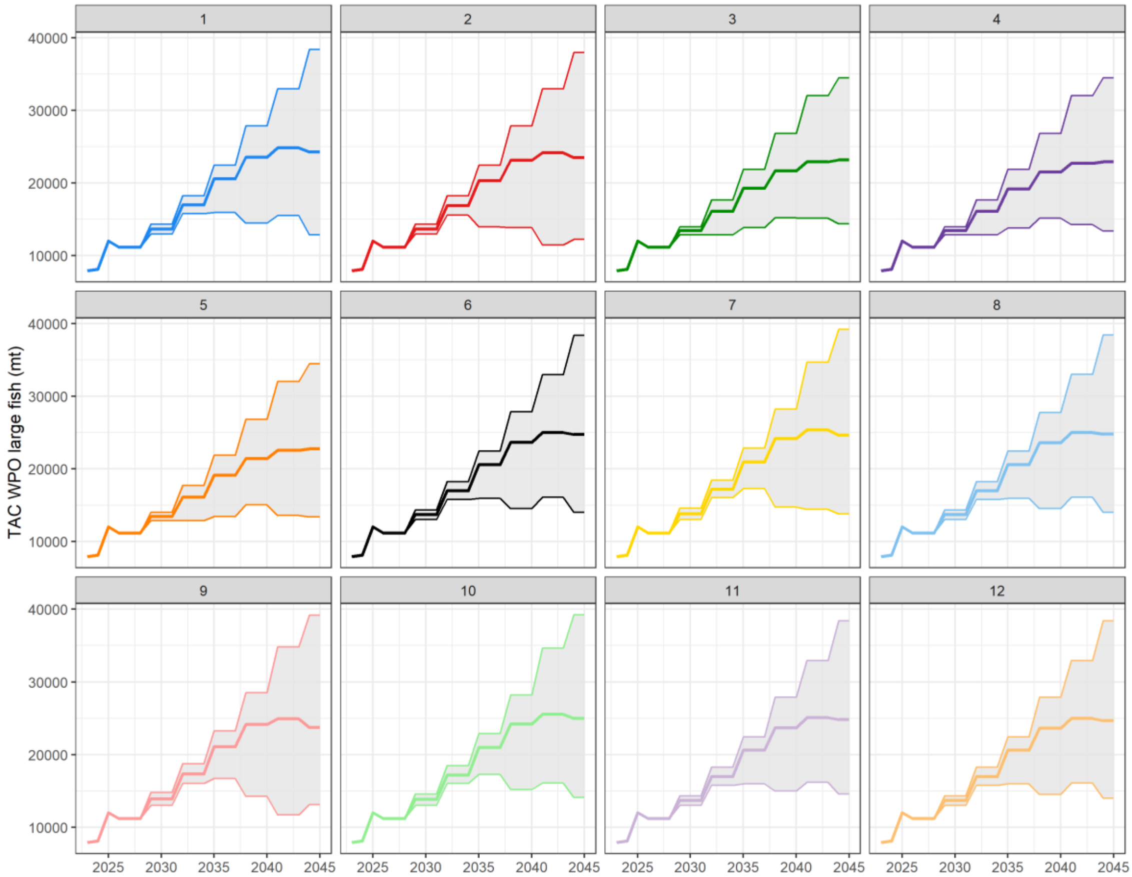

Figure 8. Median (solid line) and 5th to 95th quantiles (grey shading) of the WCPO large fish TAC across all iterations for each HCR for OM 1.

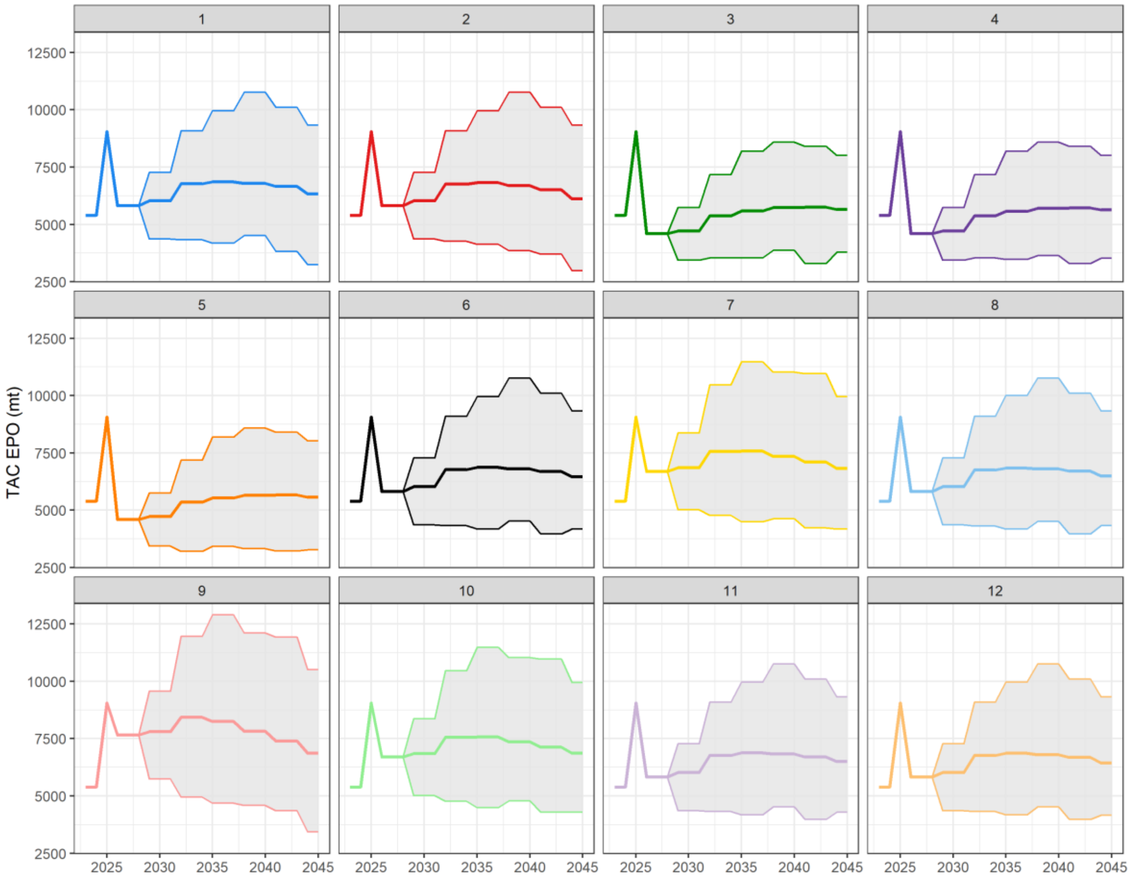

Figure 9. Median (solid line) and 5th to 95th quantiles (grey shading) of the EPO fish TAC across all iterations for each HCR for OM 1.

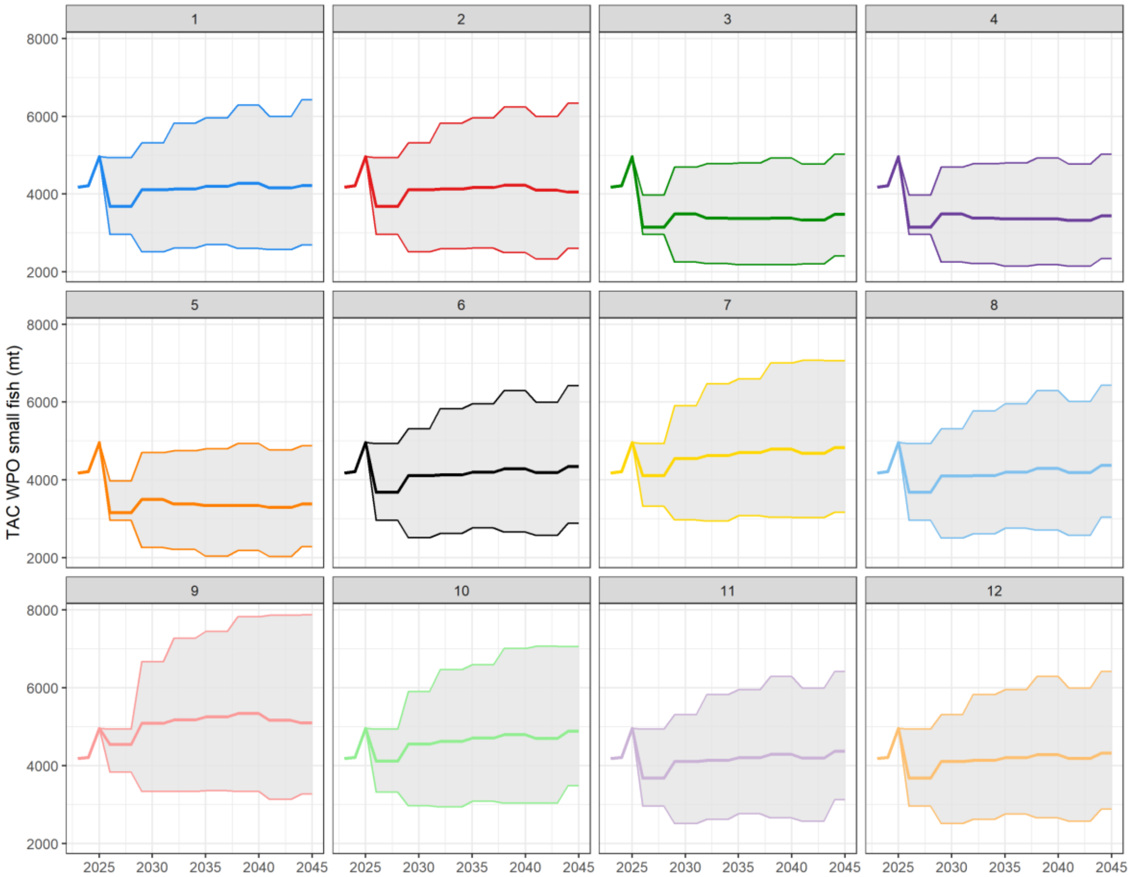

Figure 10. Median (solid line) and 5th to 95th quantiles (grey shading) of the WCPO small fish TAC across all iterations for each HCR for OM 1.

The pattern of an initial decrease in TAC and slow increase from those low levels is apparent for all HCRs in the OMs with an FY2023 relative SSB less than 20% $SSB_{F=0}$, OMs 2-8, and 16 to 21. We use OM3 to exemplify those patterns. Relative SSB in FY2023 is lower than the threshold reference point for all HCRs and in some cases also lower than the limit reference point (Fig. 11). This leads to the HCR implementing a decrease in F, which is particularly steep when SSB is less than the limit reference point as it is not bound by the 25% TAC change limit (Fig. 12). This results in a low TAC and a low increase from that low level due to the 25% TAC change limit (Fig. 13), even if the SSB increases quickly above the target reference point (Fig. 11).

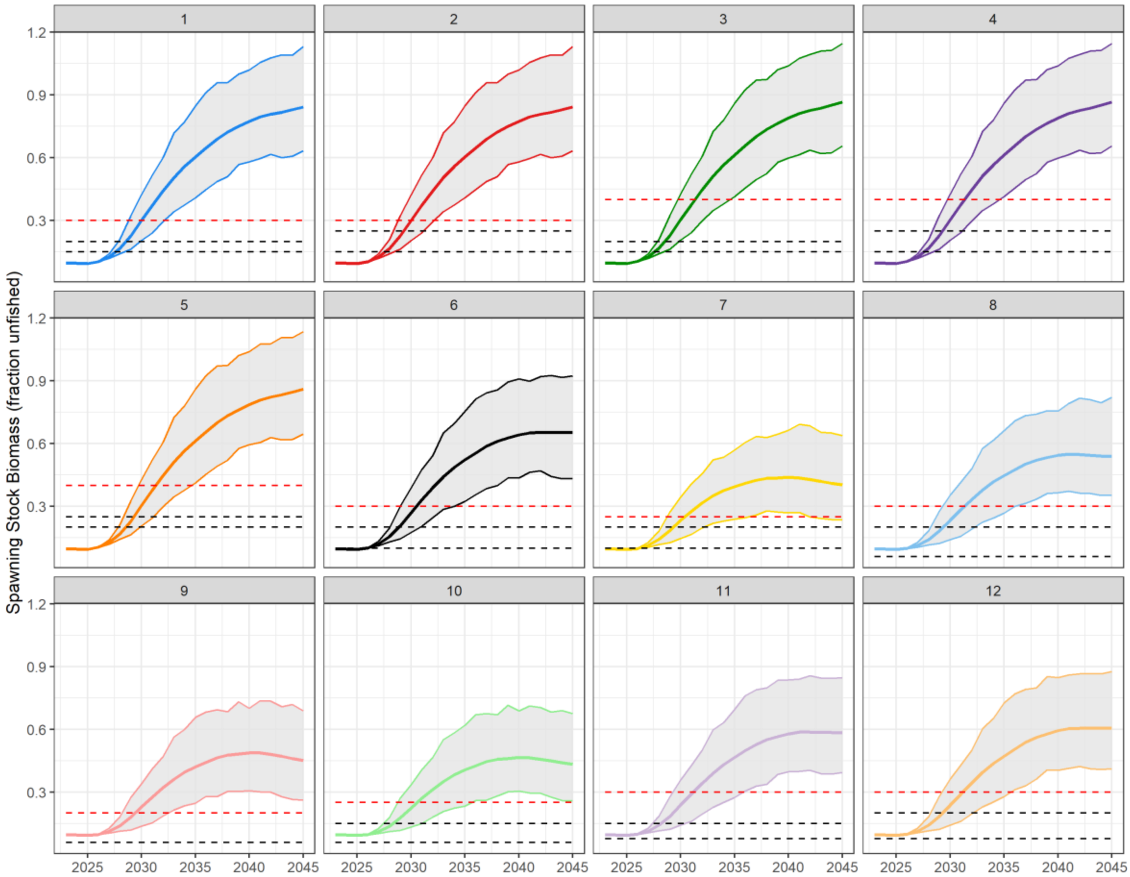

Figure 11. Median (solid line) and 5th to 95th quantiles (grey shading) of SSB relative to unfished across all iterations for each HCR for OM 3. The threshold and limit reference points associated with each HCR are shown as horizontal black dotted lines, while the relative SSB corresponding to the F-based target is represented by the red dotted line. Note that for HCR9 the threshold is the same as the target reference point.

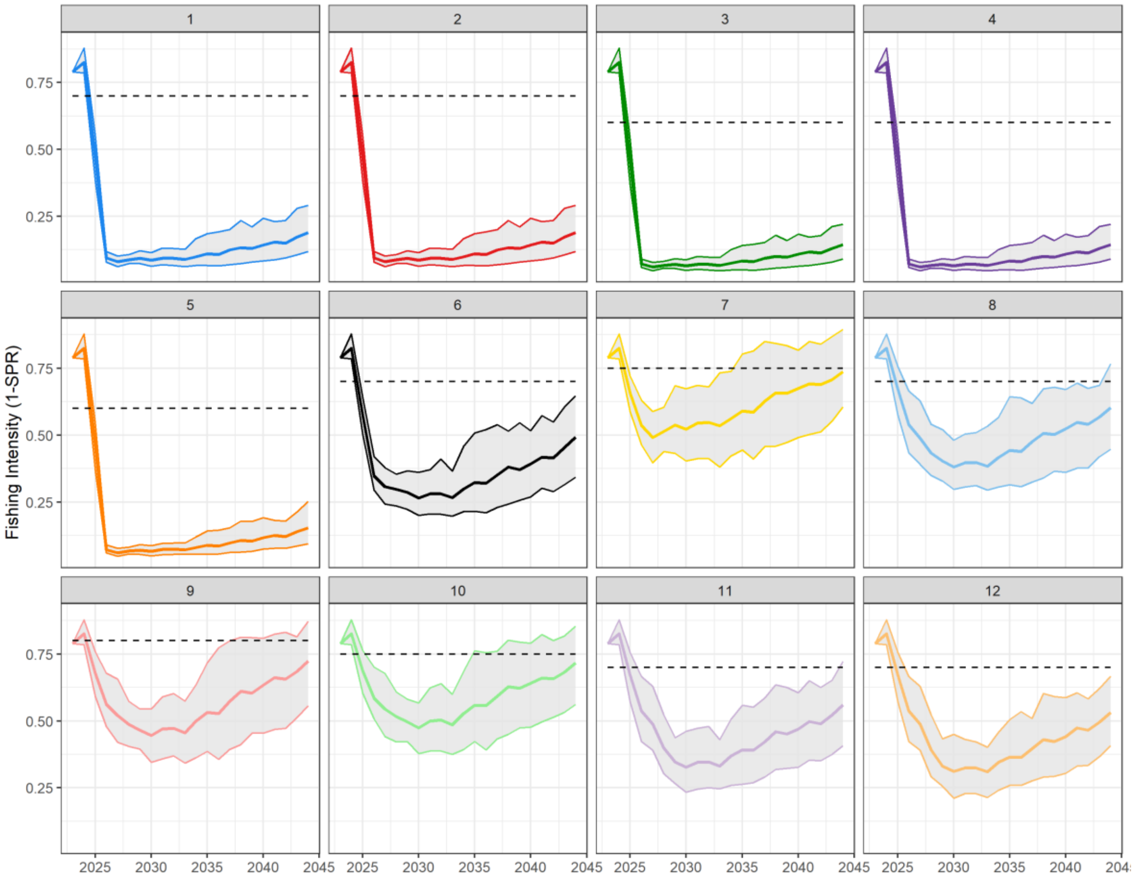

Figure 12. Median (solid line) and 5th to 95th quantiles (grey shading) of fishing intensity (1-SPR) across all iterations for each HCR for OM 3. The target reference point associated with each HCR is shown as a horizontal black dotted line.

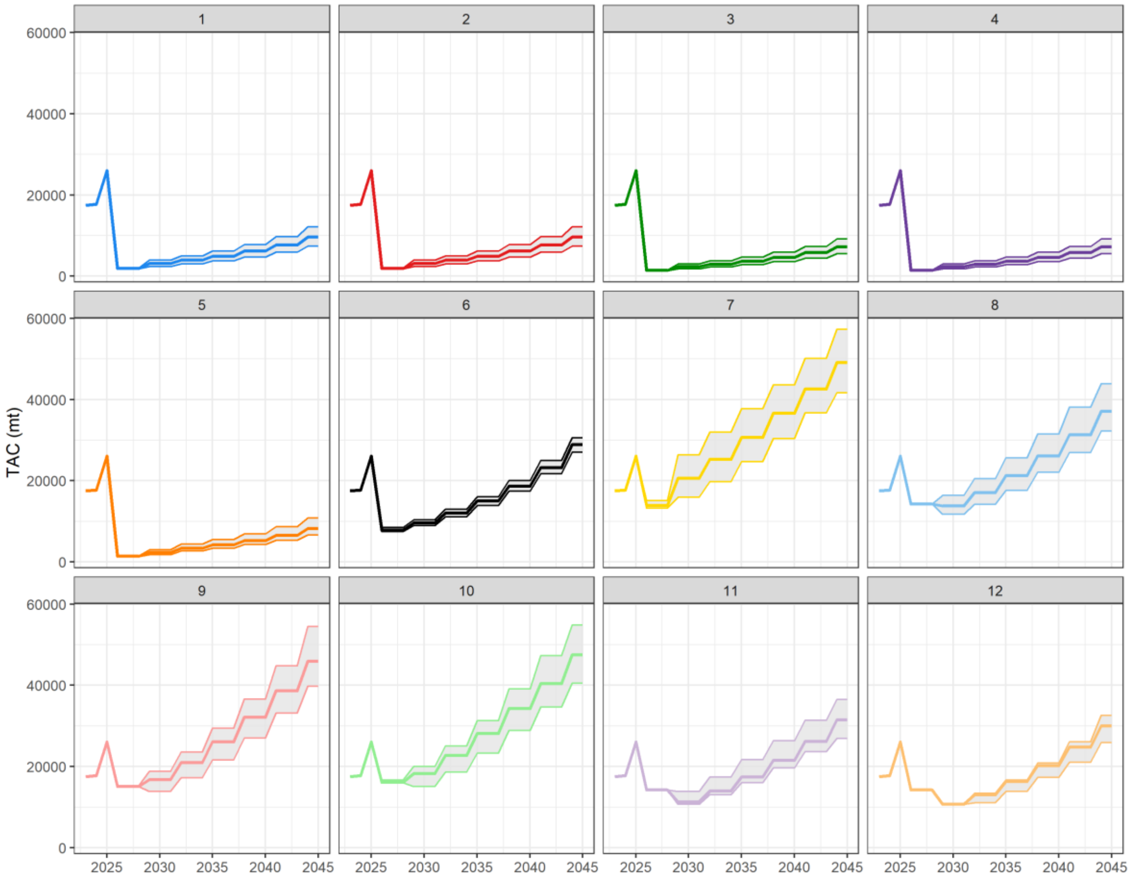

Figure 13. Median (solid line) and 5th to 95th quantiles (grey shading) of the total TAC across all iterations for each HCR for OM 1.

In plotting the results, we observed unusual low relative biomass (less than 1) for OM8. It was identified that this was due to problems with the data generation for that OM, so it will need to be re-run. All the other OMs and HCRs produced reasonable patterns and could be used to generate performance metrics and show preliminary results at the JWG meeting planned for February 2025. However note that these are results under a perfect assessment and would differ when the MSE is run with an estimation model, particularly under those OMs different from the base case on which the EM is based.

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