Long-term Performance of Pacific Bluefin Tuna harvest controls with a 25% Limit on Quota Change under a Low Recruitment Scenario

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Summary

Here we assess the impact of a 10-year long shift to a low recruitment phase on PBF spawning stock biomass (SSB), fishing intensity (F), and catch using a 48-years long PBF MSE simulation with no observation, assessment, or implementation error. We use the set of twelve harvest control rules (HCRs) with a constraint on changes in Total Allowable Catch (TAC) between consecutive management periods of no more than 25% proposed at the 8th 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. Preliminary results show that the drop in recruitment generates a decline in SSB and catch, triggering a management-driven reduction in F and associated further reductions in catch across all HCRs. All the HCRs are able to rebuild median SSB above their threshold reference point (ThRP) by the end of the simulation and to maintain the probability of breaching the limit reference point (LRP) associated with each HCR to less than 20%. A 10-year low recruitment period has been observed in the past for PBF and this work was useful to assess HCR behavior relative to stakeholder-derived performance metrics in such a case. A similar implementation of a decline in recruitment may be a robustness scenario to consider in the final PBF MSE simulation.

Introduction

The 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%$SSB_{F=0}$ (JWG 2022). As part of the MSE process, the JWG finalized a list of candidate HCRs and reference points to evaluate in the MSE and specified that these HCRs be tested with a limit that constrains changes in TAC between consecutive management periods of no more than 25% (WCPFC 2023a) to meet the stability management objective put forward by the JWG of limiting changes in overall catch limits between management periods to no more than 25%, unless the ISC has assessed that the stock is below the LRP (WCPFC 2023b).

Tommasi and Lee (2023) described how the PBF MSE code was modified to implement the 25% limit on TAC changes. They showed that limiting TAC changes to 25% of levels in the previous management period results in a more gradual increase in catch from the current, management imposed low catch levels, leading to a much slower build up to target fishing intensity (F_{target}) as compared to simulations with no limit on TAC changes. The lower F for much of the 24 years long simulation period leads to higher and more variable biomass than when no limit on TAC change is implemented, and SSB increases above target levels for every HCR. HCRs only reached the stationary phase, with median SSB and F at target levels, at the end of the simulation. Tommasi and Lee (2023) suggested that to fully assess the impact of the 25% limit on TAC changes, it would also be important to carry out a longer simulation with a multi-year drop in recruitment. This would allow an assessment of the impact of the limit on TAC change when biomass is decreasing, and the reduction in TAC may be less than that prescribed by an HCR with no limit. It is important to asses that the HCRs are still able to meet management objectives in this case, as multi-year periods of low recruitment have been observed for PBF in the past (ISC 2015).

Here, we assess HCR performance with the 25% TAC limit in the presence of a sustained drop in recruitment by carrying out the same simulation as Tommasi and Lee 2023 but for a 48 years simulation with a 10 years long low recruitment period.

Methods

The preliminary PBF MSE framework (Fig. 1) was outlined in Tommasi and Lee (2022), Tommasi et al. 2023a, Tommasi et al. 2023b, and is available at https://github.com/detommas/PBF_MSE. In this analysis, the MSE is run with no assessment model error (i.e. no estimation model) to reduce run times, and each simulation was run for 48 years and 100 different iterations to account for recruitment process uncertainty. There is also no implementation error. In years 30 to 39 of the forward simulation recruitment deviations are sampled at random with replacement from a set of 11 predefined low recruitment deviations from the historical period. These low recruitment deviations are taken from years 1980 to 1988 and 1991 and 1992 of the short assessment period. Years 1980-1989 were defined as the low recruitment period used to select recruitment for projections in the 2016 PBF assessment. Here we don't consider year 1989 as the recruitment deviation was positive and add 1991 and 1992 as they were the lowest recruitment deviations of the timeseries. The low recruitment period in this simulation was 10 years long since the historical period of low recruitment lasted approximately 10 years (ISC 2016). In the other years of the simulation, recruitment deviations are sampled from a normal distribution with mean 0 and standard deviation of 0.6, the σ_R used in the 2022 PBF stock assessment (ISC 2022). As described in Tommasi and Lee (2022), the PBF MSE uses a modified version of the short 2022 Stock Synthesis (SS) PBF stock assessment model (Fukuda et al. 2022) as the base case operating model (OM). The OM has been conditioned using historical data and is run with no estimation using parameters set in the .par file during the forward simulation. In the full MSE simulation, data from the OM would be sampled with error and fed into the estimation model (EM), i.e. the simulated stock assessment model. However, here we assume there is a perfect estimation with no observation or assessment error. Catches in the OM .dat file are updated every three years as set by the TAC determined by the HCR. Thus, in each 48-year long simulation a TAC is set 16 times. However, the catch for the first three years of the simulation is set to the CMM catch limits (see Tommasi and Lee 2022) and thus the HCRs starts being applied over the last 45 years of the simulation.

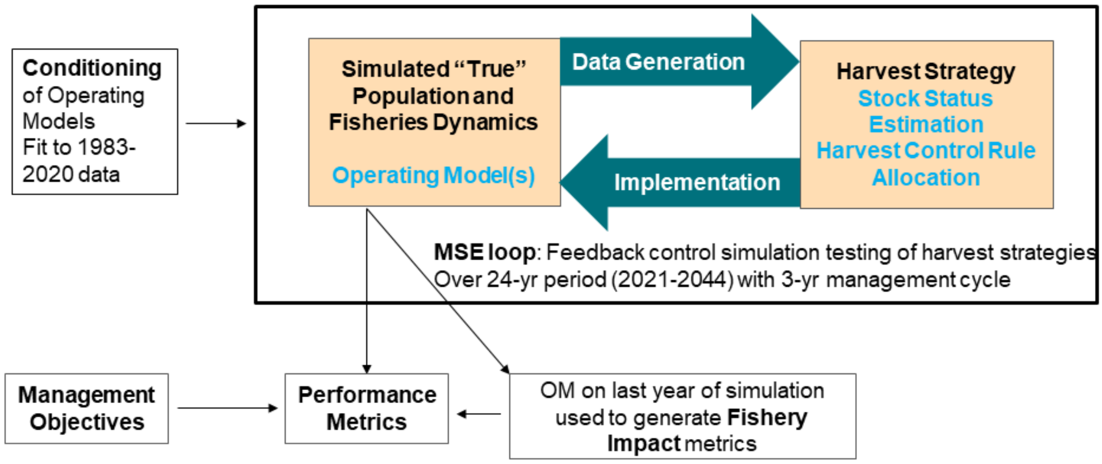

Figure 1. Overview of preliminary PBF MSE framework. Note that for this initial analysis the MSE loop was run assuming no error in data, assessment, or implementation.

We run the same HCRs with a 25% limit on the change in TAC between management periods examined by Tommasi and Lee 2023 and refer readers to that working paper for an overview of the HCRs and how they are implemented in the MSE framework. Note that following the stability management objective, the limit on the TAC change was only applied when the SSB was above the LRP associated with each HCR. Results from the current simulation are compared to those of a simulation for the same recruitment scenario and HCRs but with no limit on TAC change between management periods.

Results

As expected, implementation of the 10-year drop in recruitment deviations led to a lower median recruitment from years 2050 to 2059 (Fig. 2). Note that since that all the HCRs are forced by the same recruitment trends, hence the recruitment trends across all the HCRs in Fig. 2 are the same., Since PBF tuna are fully mature at age five, the decline in median SSB was only evident starting around year 2056 (Fig. 3). For HCRs 1, 2, 7, and

9, the recruitment decline led to the 5th quantile of SSB breaching their respective LRP (Fig. 3) and to a higher probability of SSB breaching the LRP during the simulation years with lower biomass as compared to other HCRs (Fig. 4). Nevertheless, the probability of biomass being below the LRP associated with each HCR remained below 20% in any year and therefore all HCRs still met the safety objective even with the recruitment drop (Fig. 4). By contrast, the risk of SSB falling below the second rebuilding target (20%$SSB_{F=0}$) became higher than 20% for all HCRs except HCRs 3, 4, and 5 due to their higher F_{target} of FSPR40% (Fig. 5).

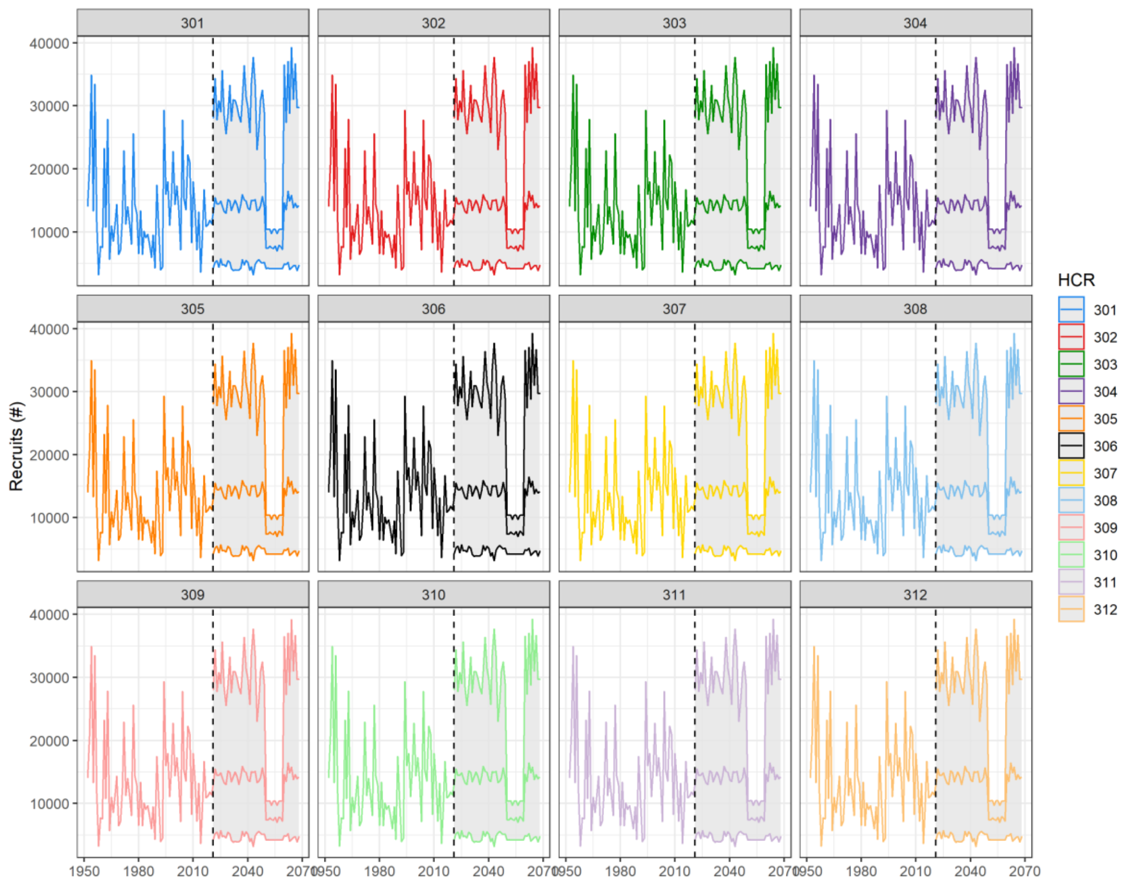

Figure 2. Historical trends in recruitment from the 2022 Pacific bluefin tuna (PBF) stock assessment (ISC 2022) and median recruitment (thick color line) across all iterations for each harvest control rule (HCR) from the PBF MSE with no limit on the change in TAC between management periods. The vertical dotted line marks the end of the historical estimates and start of the MSE simulation output. For the MSE output, the grey shading represents trends in the 5th to 95th quantiles of recruitment. Note that HCRs are labelled 301 to 312 to specify that they were run with a recruitment drop, but correspond to HCRs 1 to 12 proposed by the JWG.

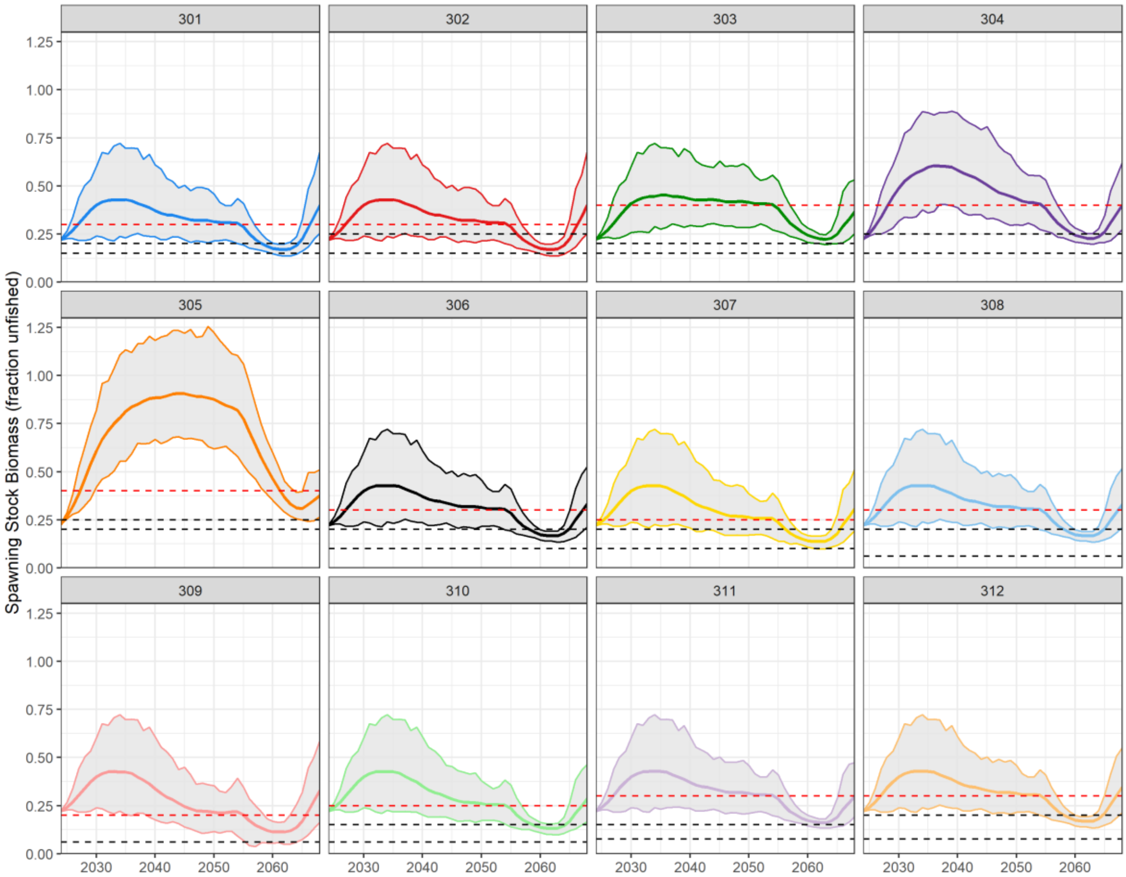

Figure 3. Median spawning stock biomass (SSB, thick color lines) across all iterations for each harvest control rule (HCR) from the PBF MSE simulation with a 25% limit on the change in TAC between management periods. The grey shading represents trends in the 5th to 95th quantiles of SSB. The threshold and limit reference points associated with each HCR are shown as black horizontal dotted lines, while SSB levels associated with the F_{target} are highlighted as red dotted lines. Note that HCRs are labelled 301 to 312 to specify that they were run with a recruitment drop, but correspond to HCRs 1 to 12 proposed by the JWG.

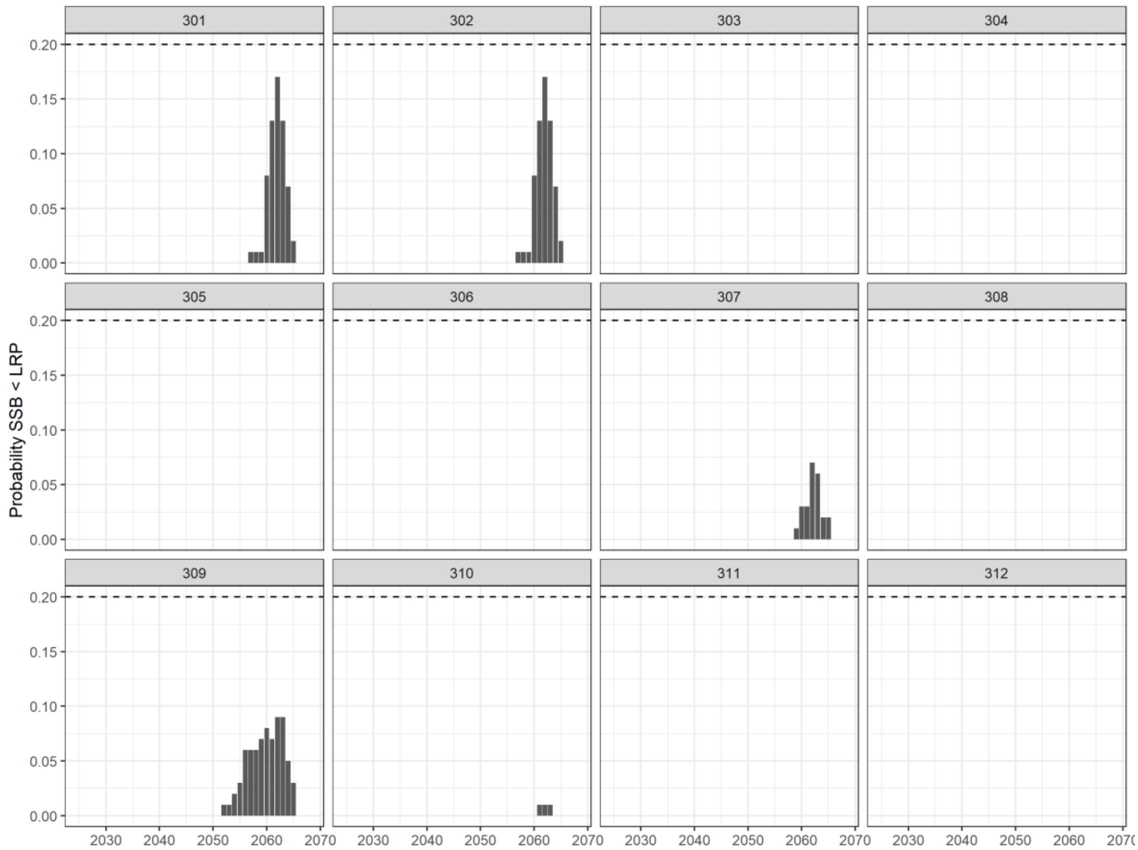

Figure 4. Probability of each HCR being below its limit reference point (LRP). The probability was calculated for each year of the simulation across 100 iterations as the fraction of iterations with SSB below the LRP. The dotted line represents a 20% probability. Note that HCRs are labelled 301 to 312 to specify that they were run with a recruitment drop, but correspond to HCRs 1 to 12 proposed by the JWG.

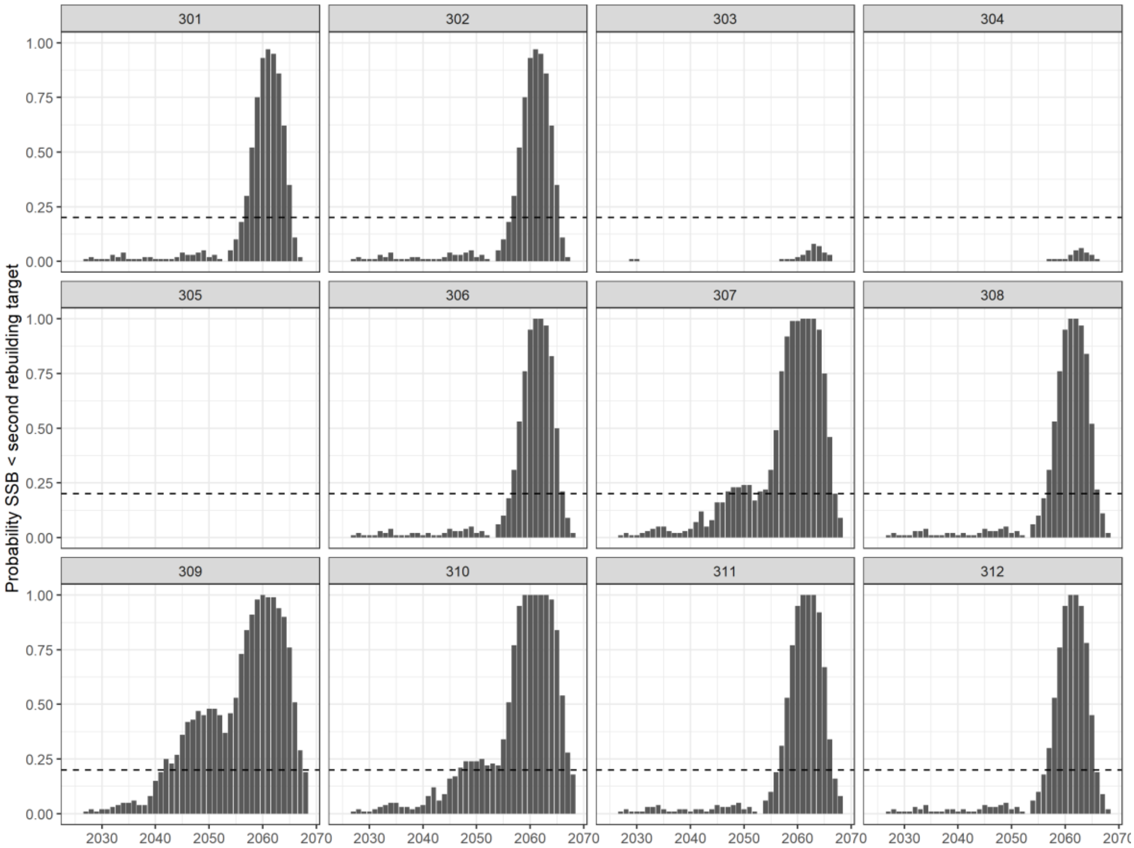

Figure 5. Probability of HCR being below the second rebuilding target of 20%$SSB_{F=0}$. The probability was calculated for each year of the simulation across 100 iterations as the fraction of iterations with SSB below 20%$SSB_{F=0}$. The dotted line represents a 20% probability. Note that HCRs are labelled 301 to 312 to specify that they were run with a

Even if constrained by the limit on TAC change, implementation of management actions (i.e. reduction in F with SSB decline according to each HCR), was able to bring SSB above the second rebuilding target in less than 10 years on average across iterations for most HCRs except HCRs 9 and 10 (Table 1). However, most HCRs had at least one iteration with a rebuilding time to the second rebuilding target longer than 10 years (Table 1). The effectiveness of the HCRs for rebuilding after the environmentally driven recruitment drop was assessed by calculating the probability of SSB being above the second rebuilding target 10 years after median SSB fell below 20%$SSB_{F=0}$. HCRs 7, 9, and 10 showed probabilities of SSB being above the second rebuilding target of 20%$SSB_{F=0}$ below 60% even after 10 years (Table 1). However, these rebuilding probabilities were for the current second rebuilding target level, not for the rebuilding levels implicitly built-in each HCR. While HCRs 7 and 9 have their threshold reference point (ThRP) set at the current second rebuilding target of 20%$SSB_{F=0}$, HCR 10 has a ThRP of 15%$SSB_{F=0}$. If we set this level as the rebuilding target for this HCR, the probability of the stock being rebuilt after 10 years was 98%.

Table 1. Rebuilding metrics of each HCR with a 25% limit on TAC change between management periods. Rebuilding is defined relative to the current second rebuilding target of 20%$SSB_{F=0}$. NA indicates the rebuilding metric is not applicable for the specific HCR.

HCR	Mean rebuilding time (number of consecutive years SSB<20%$SSB_{F=0}$) across iterations	Maximum rebuilding time (number of consecutive years SSB<20%$SSB_{F=0}$) across iterations	Probability SSB>20%$SSB_{F=0}$ 10 years after median SSB<20%$SSB_{F=0}$
1	7	13	1
2	7	13	1
3	0	4	NA
4	0	4	NA
5	0	0	NA
6	7	14	0.98
7	9	17	0.54
8	7	14	0.98
9	10	19	0.24
10	10	19	0.46
11	8	14	0.92
12	7	14	0.98

Following the decline in recruitment and biomass, there was a decline in median F away from the F_{target} for most HCRs (Fig. 6). The steepness of the decline in F is HCR-specific and depends on the status of SSB relative to the first control point of each HCR. Note that the decline is steepest for HCRs 1, 2, and 9 (Fig. 6) as their LRP is breached in some iterations, leading to drastic changes in F not constrained by the limit on TAC change.

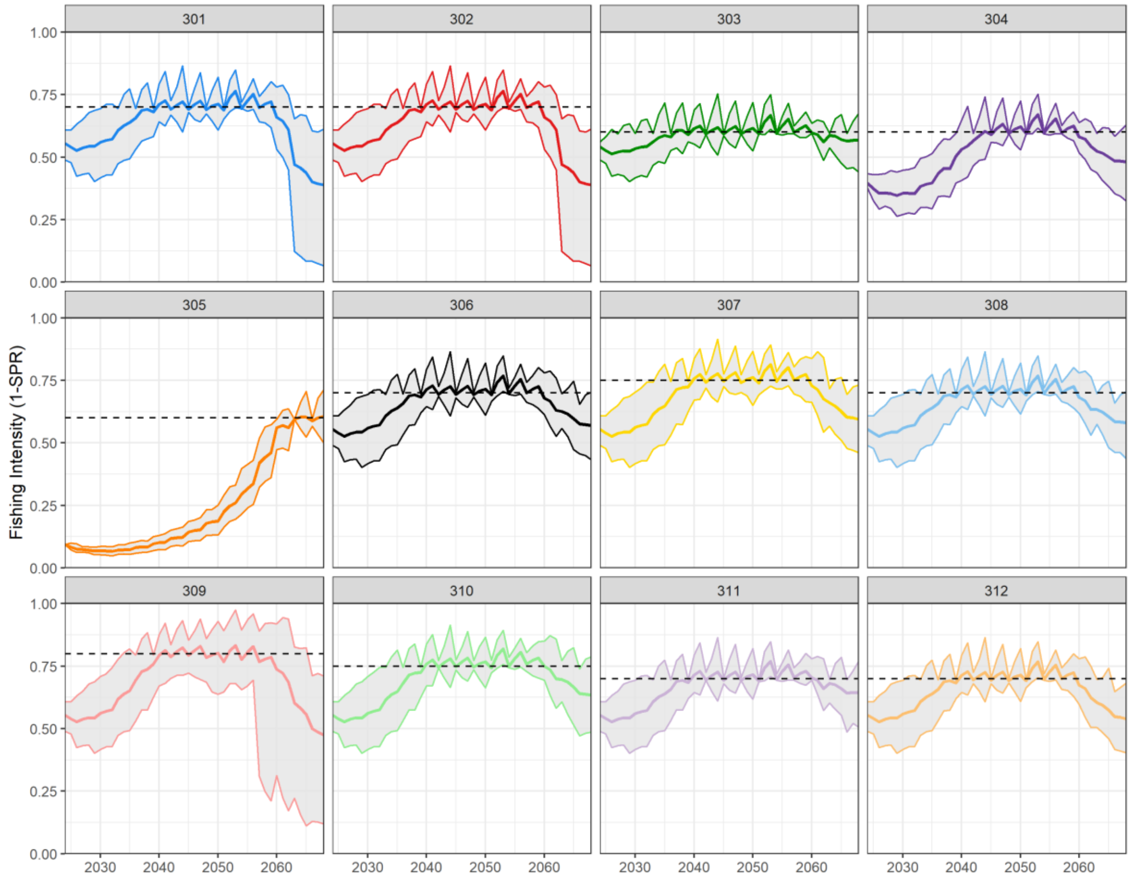

Figure 6. Median fishing intensity (F, 1-SPR, thick color lines) across all iterations for each harvest control rule (HCR) from the PBF MSE simulation with a 25% limit on the change in TAC between management periods. The grey shading represents trends in the 5th to 95th quantiles of SSB. The target reference point associated with each HCR is shown as black horizontal dotted lines. Note that HCRs are labelled 301 to 312 to specify that they were run with a recruitment drop, but correspond to HCRs 1 to 12 proposed by the JWG.

The decline in recruitment resulted in a decline in catch (Fig. 7). As some fleets capture juvenile PBF tuna the decline in catch started before that in SSB (compare Fig. 7 and Fig. 3). Catch then declines further as it becomes constrained by management-driven changes in F as the SSB controls points are breached (Fig. 7).

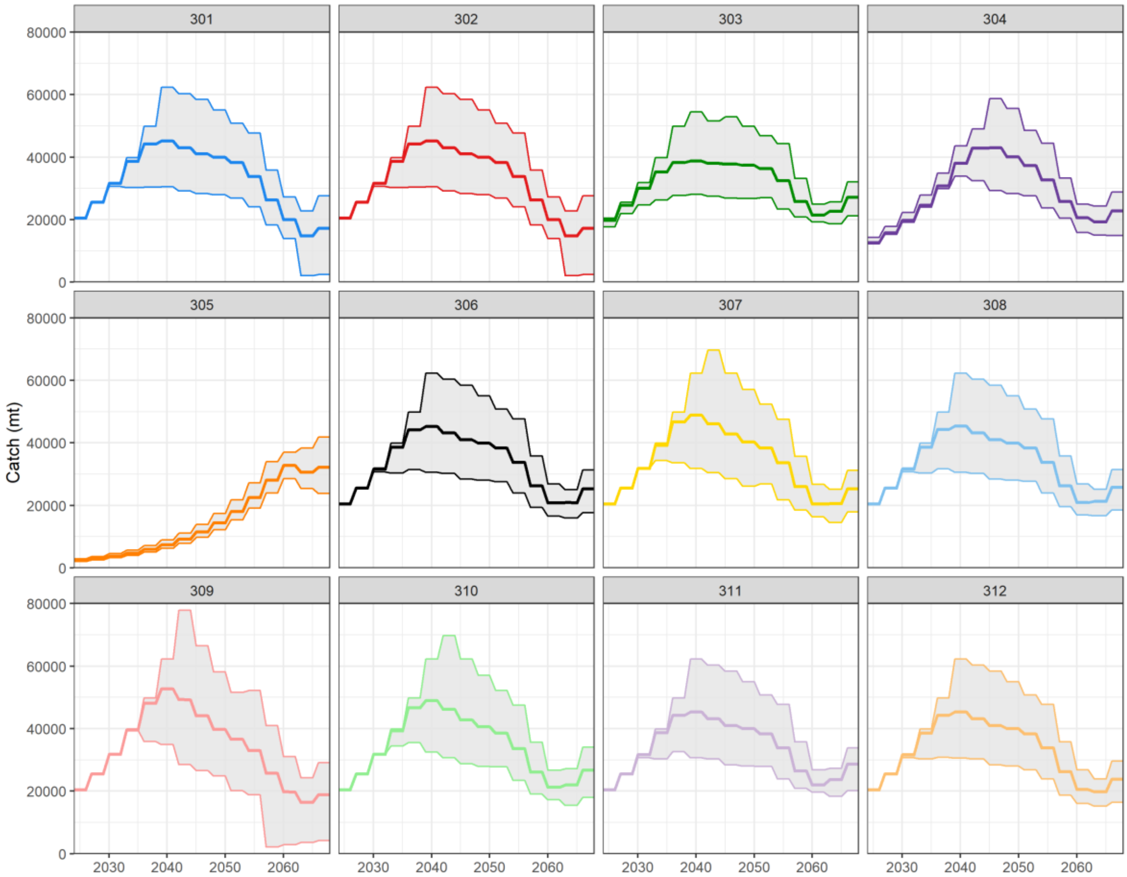

Figure 7. Median catch (mt, thick color lines) across all iterations for each harvest control rule (HCR) from the PBF MSE simulation with a 25% limit on the change in TAC between management periods. The grey shading represents trends in the 5th to 95th quantiles of SSB. Note that HCRs are labelled 301 to 312 to specify that they were run with a recruitment drop, but correspond to HCRs 1 to 12 proposed by the JWG.

When median catch is computed across the period starting with the first low recruitment year (2050) until the end of the simulation, it was lowest for HCRs 1, 2, and 9 (Fig. 8, right panel). HCRs 1 and 2 had a more stringent reduction in fishing intensity relative to other HCRs with an F_{target} of FSPR30% once the ThRP is crossed due to their higher LRP. This resulted in higher median SSB levels over the low biomass period than other FSPR30% HCRs, but lower catch (Fig. 8). SSB levels during the low biomass period were lowest for HCRs with the lowest F_{target}, as their decline started from a lower target level (Fig. 3 and Fig. 8). HCR 9 has the lowest F_{target} of FSPR20% and lowest biomass (Fig. 8), triggering significant declines in fishing intensity (Fig. 6) and resulting in low catch (Fig. 8).

For HCRs that only differed in their ThRP, like 3 and 4, and 11 and 12, there was an evident tradeoff between biomass and catch. The earlier management action associated with a higher ThRP (HCRs 4 and 12) maintained biomass at slightly higher levels during the decline, but this came at the cost of reduced catch (Fig. 8).

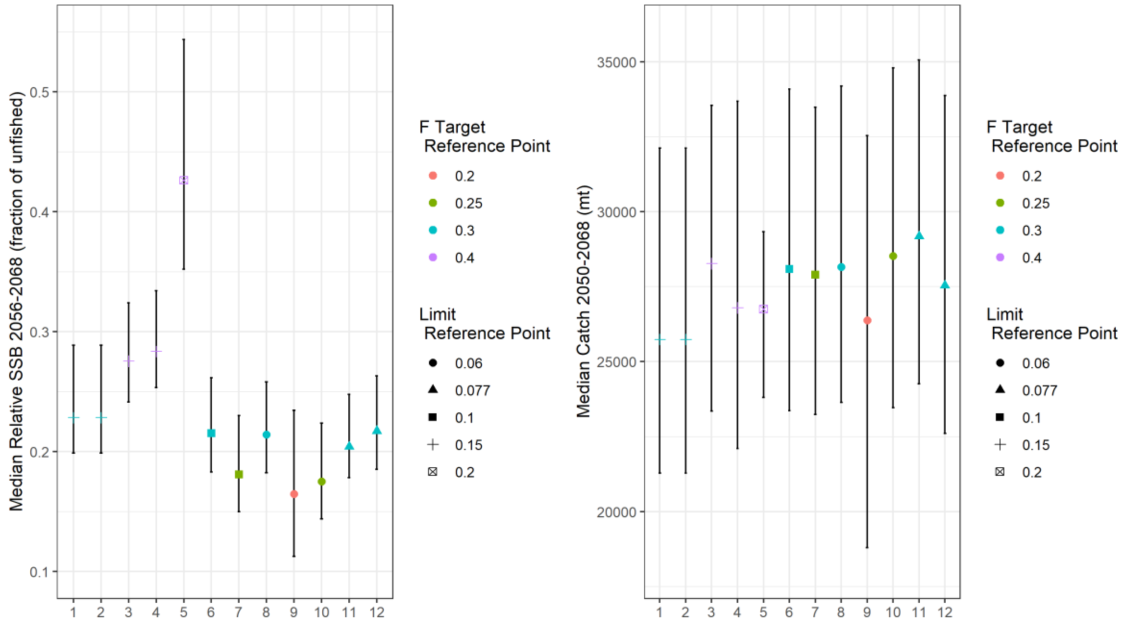

Figure 8. Median SSB as fraction of unfished (left panel) and catch (right panel) across all iterations and years following the start of the decline in SSB (2056-end of simulation) or catch (2050-end of simulation) for each harvest control rule (HCR) with a 25% limit on the change in TAC between management periods. The error bars represent the 5th to 95th quantiles of SSB or catch.

In the same simulation run without a limit on the change in TAC between management periods, as soon as SSB breaches the first control point of each HCR, F is allowed to be reduced by as much as is required by each HCR. This leads to a faster initial drop in fishing intensity and a faster recovery to the F_{target} (compare Fig. 9 to Fig. 6) and to SSB being less variable and not falling to as low a level (compare Fig. 10 to Fig. 3). In particular, the more stringent initial management action prevents median SSB from breaching the LRP for HCRs 1, 2, and 9. Therefore, the same drastic reduction in fishing intensity is not required, leading to a higher median catch for these HCRs than when a limit on TAC change is implemented (compare Fig. 11 and Fig. 8). Without a limit on TAC change, the tradeoff between biomass and catch is evident across HCRs with those with a higher target fishing intensity having a higher median SSB but a lower median catch (Fig. 11).

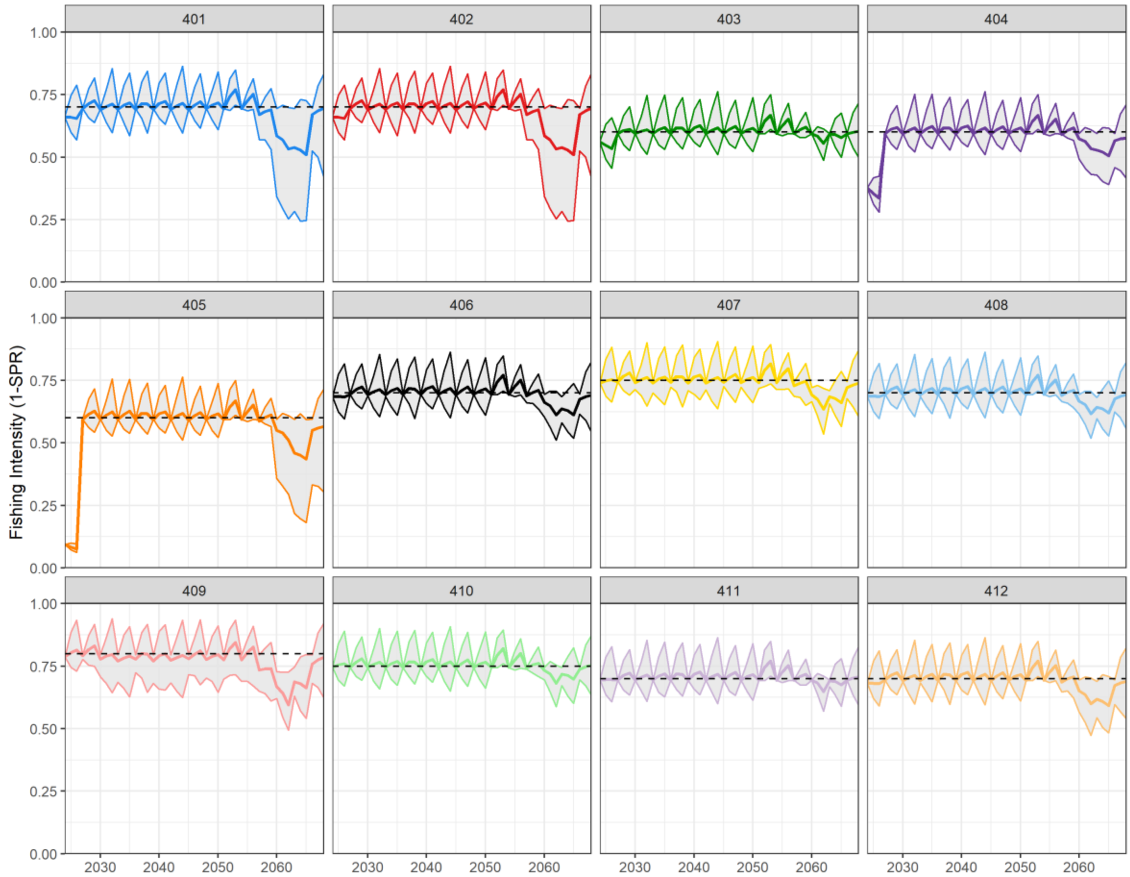

Figure 9. Median fishing intensity (F, 1-SPR, thick color lines) across all iterations for each harvest control rule (HCR) from the PBF MSE simulation with no limit on the change in TAC between management periods. The grey shading represents trends in the 5th to 95th quantiles of SSB. The target reference point associated with each HCR is shown as black horizontal dotted lines. Note that HCRs are labelled 401 to 412 to specify that they were run with a recruitment drop and no limit on TAC change, but correspond to HCRs 1 to 12 proposed by the JWG.

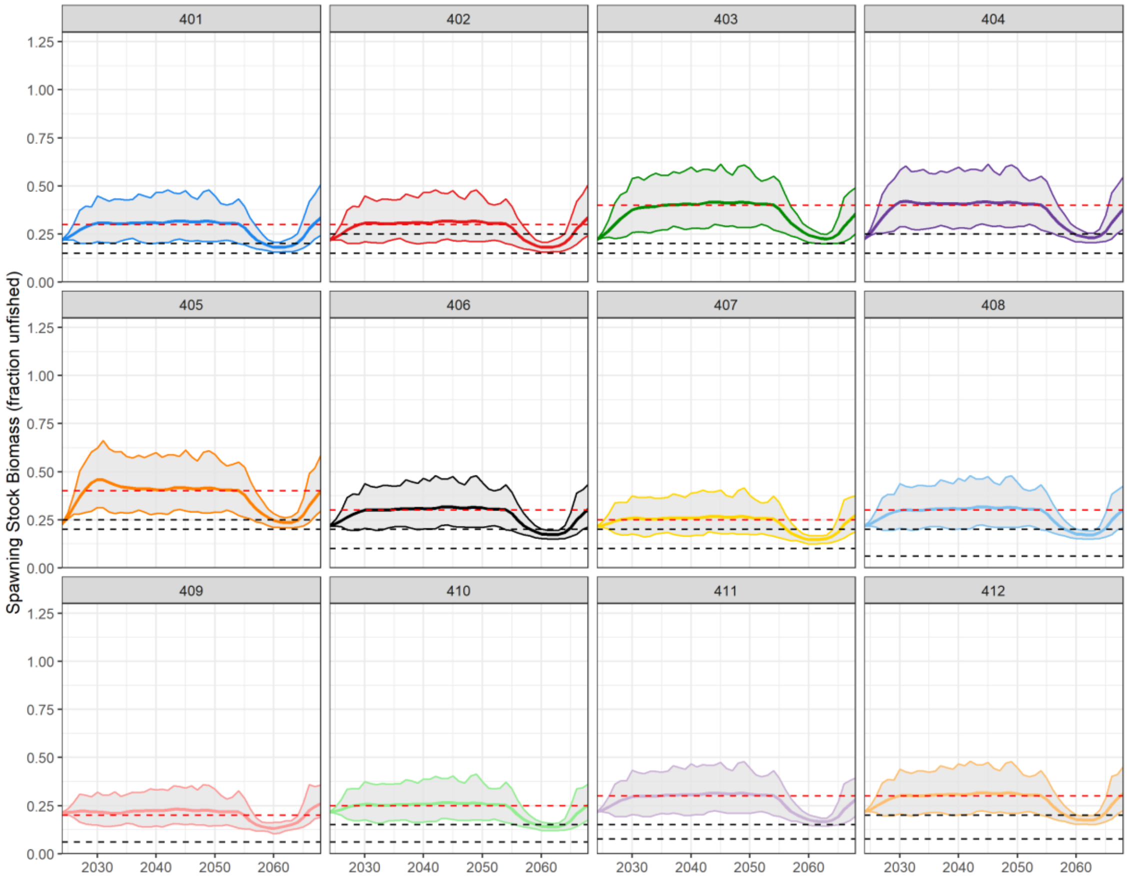

Figure 10. Median spawning stock biomass (SSB, thick color lines) across all iterations for each harvest control rule (HCR) with no limit on the change in TAC between management periods. The grey shading represents trends in the 5th to 95th quantiles of SSB. The threshold and limit reference points associated with each HCR are shown as black horizontal dotted lines, while SSB levels associated with the F_{target} are highlighted as red dotted lines. Note that HCRs are labelled 401 to 412 to specify that they were run with a recruitment drop and limit on the change in TAC, but correspond to HCRs 1 to 12 proposed by the JWG.

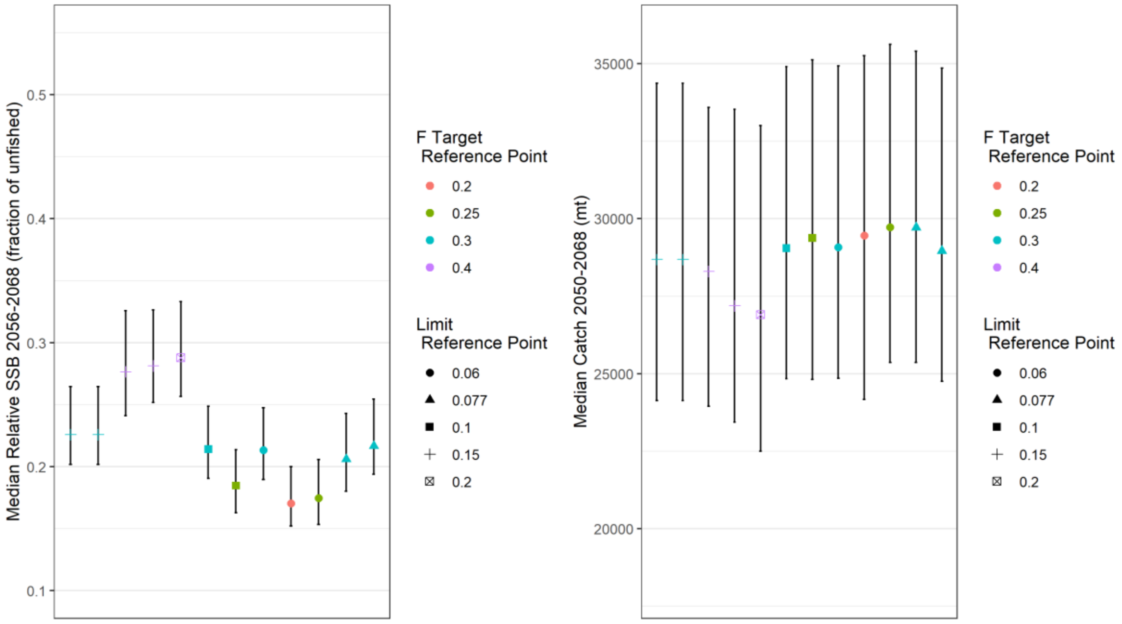

Figure 11. Median SSB as fraction of unfished (left panel) and catch (right panel) across all iterations and years following the start of the decline in SSB (2056-end of simulation) or catch (2050-end of simulation) for each harvest control rule (HCR) with a 25% limit on the change in TAC between management periods. The error bars represent the 5th to 95th quantiles of SSB or catch.

Discussion

We have implemented capabilities in the PBF MSE code to run a low recruitment phase scenario. This code may be useful to generate a robustness test for the final MSE simulation. Implementation of this scenario enabled an assessment of each HCRs' ability to maintain SSB above the LRP, timeframe needed to rebuild to a specified biomass level, and change in catch when there is an environmentally driven long-term (10-year) period of low recruitment. Even with the limit on TAC reduction, all the HCRs are able to rebuild median SSB to their TRP by the end of the simulation and to maintain the probability of breaching the limit reference point (LRP) associated with each HCR to less than 20%. However, the cost in terms of loss catch to maintain SSB above the LRP was different across HCRs.

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