Overview of the preliminary Pacific bluefin tuna management strategy evaluation framework

Desiree Tommasi[a,b] and Huihua Lee[a]

a: NOAA Fisheries, Southwest Fisheries Science Center,
La Jolla, CA, USA
b: Institute of Marine Sciences, University of California Santa Cruz,
Santa Cruz, CA, USA

November 2022

Working document submitted to the ISC Pacific bluefin tuna Working Group, International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC), from 1 to 8 November 2022, Webinar.

Introduction

Management strategy evaluation (MSE) is a process whereby the performance of a set of harvest strategies relative to some management objectives and performance metrics of interest to stakeholders is assessed under a range of uncertainties using a computer simulation (Punt et al. 2016). The two Regional Fisheries Management Organizations (RFMOs) tasked with managing the Pacific Bluefin tuna (PBF) stock, namely the Western and Central Pacific Fisheries Commission of the Northern Committee (WCPFC NC) and the Inter American Tropical Tuna Commission (IATTC) requested, via the Joint Working Group, 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). According to the JWG workplan the MSE results would be presented at JWG10 in 2025 (JWG 2022 – Annex G).

To capture the range of uncertainty in the system, an MSE simulation includes a set of operating models (OMs), which are mathematical representations of the true dynamics of the population and fisheries of interest. Having more than one OM allows an MSE to evaluate performance of harvest controls under different assumptions related to the biology of the stock, the fisheries, or the management system (Punt et al. 2016). For example, are the harvest strategies robust to changes in growth parameters or the shape of the stock-recruitment curve or a change in the data sampling frequency? An MSE also accounts for process uncertainty (e.g., in recruitment) by running many simulations with different recruitment trajectories. Once it is determined that the OMs can reasonably represent past trends in catch, catch per unit effort (CPUE), and size composition data, the OMs are used to simulate trends in the population under a range of different management procedures in a closed-loop forward simulation. Data are generated with error from the OM and, for a model-based management procedure (i.e. where stock status is determined via an assessment model), are input to the estimation model (EM, i.e. the assessment model). As running a full stock assessment during each assessment period in the forward simulation can be computationally expensive, to save running time, some MSEs approximate the assessment error by adding an auto-correlated log-normal error to the biomass output from that OM that informs the harvest control rule. If the harvest control rule is empirical (i.e. based on survey data without the assessment), data are generated with error from the OM and input directly into the HCR.

Here, we focus on describing the overall workflow of the MSE framework for PBF. Rather than discussing potential uncertainties and the range of OMs to consider, only the base-case OM is presented. The aim of this working paper is to provide an overview of the following MSE components: 1) base-case operating model, 2) data generation, 3) estimation model, 4) harvest control module, and 5) implementation error and feedback control of each HCR back into the OM. The paper also aims to serve as a user manual for running the current version of the PBF MSE framework. We note that the MSE framework is a work in progress and that the final version used to run the results to be presented to the JWG in 2025 might be different than what is presented here.

Methods

The code to run the PBF MSE is based on that used for the ISC ALBWG MSE (ISC 2021) and is available at https://github.com/detommas/PBF_MSE. It is written in R, and, since the OM and EM are based on the Stock Synthesis (SS3) software, allows SS3 to be run directly from R. The repository contains all the directories, files, and functions needed to run the MSE framework for scenario 1 (the base case OM), harvest strategy 1, and harvest control rule 1.

The PBF MSE directory structure has the following format:

PBF_MSE/harvest strategy/hcr/scenario/iteration/time step

Before running the main *PBF_MSE_itr1.R* code, the repository needs to be cloned from GitHub to ensure that all the required directories and files are on the user's computer. In this code the user specifies the harvest strategy, harvest control rule (hcr), and scenario being run. It also calls the main PBF_MSE function, *PBF_MSE_hs1.R*, which sets the harvest strategy. Note that for different harvest strategies, a different harvest strategy function would be called. A harvest strategy is the overall management procedure and specifies how data is collected, if a stock assessment is run, and the harvest control rule itself, including its shape and reference points. In the PBF MSE context, the harvest control rule specifies only the reference points to be used in the HCR. For instance, two HCRs that are identical except for their limit reference point would need to be considered as separate HCRs, thus requiring set up of a different hcr folder under the same harvest strategy directory. Note that while the limit and threshold reference points are set in the call to *PBF_MSE_hs1.R*, the F_{target} needs to be specified in the SS3 forecast file in the hcr folder as the algorithm requires SS3 to determine in the benchmark section the F multiplier associated with the F_{target}. Thus, there needs to be an SS3 forecast file under each hcr directory. The scenario refers to the uncertainty scenario and operating model being used. The code uses the scenario to select which operating model files in the Condition folder to use for the MSE forward simulation. The iteration reflect which random recruitment deviation time series is being run and the time step refers to the estimation time step (i.e. when an assessment would be run). The MSE simulation is run for 30 years with an assessment every two years, thus there are 15 time steps in total. According to the base case OM, the generation time for PBF is ~9 years, so the simulation time horizon corresponds to about 3 PBF generations. A code to run the PBF MSE for many iterations in parallel is also available on GitHub and is *PBF_MSE_prll.R*

Here we focus on providing an overview of the MSE forward simulation, and do not provide an overview of the conditioning process. In this example simulation the OM was projected forward from 2021 to 2050. The PBF MSE aims to simulate a realistic management process and has capabilities to generate data with error and estimate stock status given the observed data using a stock assessment. The PBF stock assessment is conducted every two years, hence in the MSE simulation data with error is generated from the OM and ingested into an estimation model (EM) every two years. Estimates of stock biomass and reference points are then supplied 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 two years. To account for the fact that in practice not the exact TAC will be implemented, there is a capability to add an implementation error to the catch before it is entered in the OM. We describe below in more detail each component of the forward closed loop simulation (Fig. 1).

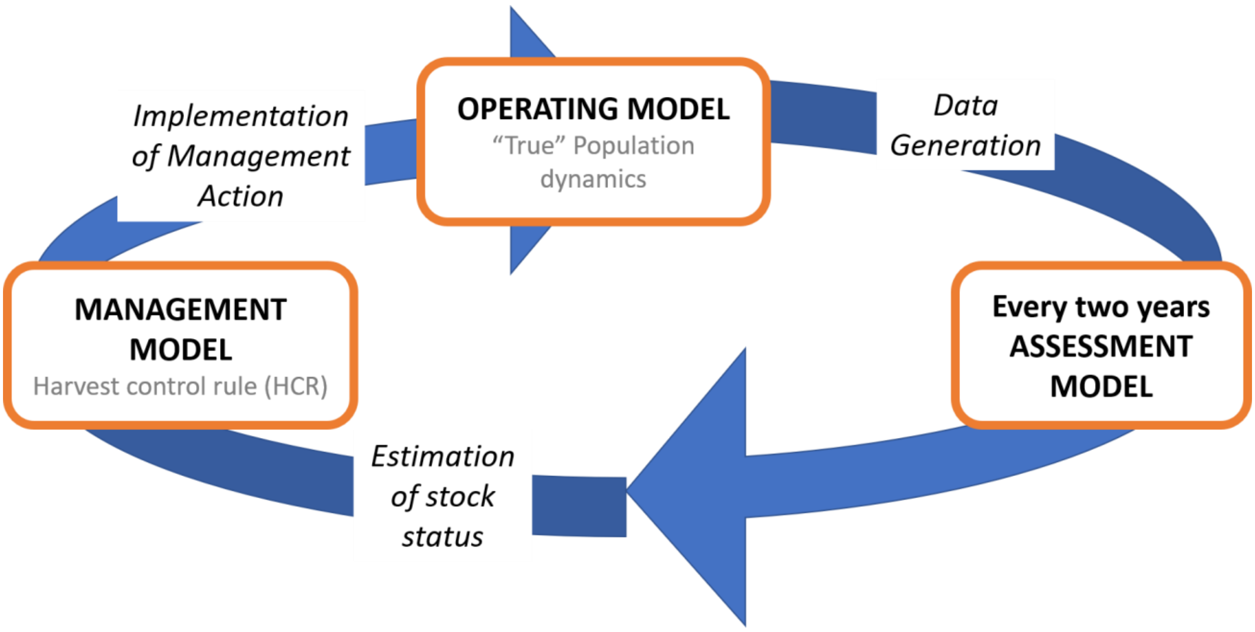


Figure 1. Overview of the Pacific Bluefin tuna management strategy evaluation framework. Details of each component of the MSE framework are described in the

Methods section.

Operating model

In the PBF_MSE framework, OMs consist of a population dynamics model of PBF with a fishery model component relating the modeled dynamics to catch, CPUE, and size composition data. Like the stock assessment, the OMs need to be developed using the Stock Synthesis modelling platform (Methot and Wetzel 2013). Furthermore, the PBF MSE framework assumes that the specified OM has been conditioned and that the fit to historical data has been evaluated and deemed sufficiently reasonable to consider the model as an OM. The PBF MSE can use different OMs, depending on which scenario is specified in the *PBF_MSE_prll.R* or *PBF_MSE_itr1.R* code. Here we use the base case OM to exemplify how the framework works. The base case OM is the short assessment model (start year 1983) used for sensitivity runs in the 2022 PBF stock assessment report. For information on model structure and parameters please refer to Fukuda et al. 2022. For the MSE, the short 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) The model was also simplified to not have any time varying parameters except for blocks as the forward simulation keeps all parameters constant. Note that for blocks, future selectivity values are kept at the values of the last year of the conditioning period.
3) The model was re-run with SS version V3.30.18.00 as the version used to run the short assessment had a bug in the bootstrap data generation routine that prevented r4ss reading bootstrap data output.
4) The relF years for the benchmark calculations in the forecast file were switched from 2002-2004 to 2017-2019, matching the selectivity years and reflecting the more current exploitation pattern.

During the simulation the OM is run with no estimation using values from the parameter file. The OM starter file is modified automatically within the code to use vales in the par file and the par file is updated automatically within the code with new recruitment deviations for each year of the simulation. Recruitment deviations are random and sampled from a distribution with mean 0 and a standard deviation (sigmaR) of 0.6 as specified in the base case OM control file. The iteration controls the seed for the random sample of deviations so simulations using the same iteration will have the same recruitment deviations across scenarios, HCRs, and harvest strategies. Note also that catch informing OM dynamics is updated during every assessment time step according to the catch specified by the management module.

Data Generation

Catch, CPUE, and size composition data is generated using the Stock Synthesis bootstrap data generation routine (Methot and Wetzel 2013). First, the new catch data given the TAC is added to the operating model data files and dummy data is put in for the two CPUE indices and the size composition data. The code also automatically specifies in the starter file to generate a parametric bootstrap file. The data generation routine then creates a new data set of random observations using the same variance properties (standard error of fleet specific catch, standard error of the CPUE indices, and effective sample size of the size composition data) and error structure (lognormal for catch and CPUE, multinomial for the size composition data) assumed during the conditioning phase. The new data with observation error are then input into the EM.

For the forward simulation, catch data was assigned a CV of 0.1. The indices of abundance were set to those from the Japanese Longline, Taiwanese Longline, and the Japanese Troll recruitment index. All were assigned a CV of 0.2 as for the conditioning period. Note that even if there is no data for the Japanese longline index for 2020 and for 2017-2020 for the Japanese troll recruitment index, the MSE assumed that they would be available in the forward simulation. Alternative data availability scenarios, for example where the Taiwanese Longline is the only index, can be examined in the MSE if deemed appropriate by the WG. The effective sample size for the size composition data was set to the average of the conditioning period as specified in Table 1. Note that now the MSE workflow uses the bootstrap procedure in SS without modification to generate data with error. We are working on implementing in the MSE the bootstrap bias corrections outlined in Lee et al. (2021).

Table 1. Fleet-specific effective sample sizes used to generate data with error from the operating model for input into the estimation model. Note that for some fleets, size composition data is available for more than one season.

Fleet #	Season	Effective Sample Size
1	11.5	10
2	2.5	9
2	11.5	14
3	8.5	14
4	2.5	11
5	11.5	10
6	5.5	12
6	8.5	7
6	11.5	4
12	11.5	11
14	8.5	9
15	5.5	6
15	11.5	6
17	11.5	3
18	5.5	10
20	11.5	16
21	8.5	3
21	11.5	10

During the first time step of the simulation, as an assessment to inform the management module has not yet been run, the initial catch data is set to the catch limits specified in the first harvesting scenario of the 2022 stock assessment projections based on the CMM: 4475 mt to WPO small fish, 7860 mt to WPO large fish, and 3995 mt to the EPO (ISC 2022). We refer to this catch limit as the CMM catch control. Thus, the HCR tested in the MSE starts being implemented from 2022 onwards. In the simulation, these initial catches need to be split among the different OM fleets. This was done using the average 2017-2019 catch ratios and the fleet designations listed in Table 2. Note that while the CMM specifies large and small fish catches for the WPO, some WPO fleets are mixed (catch both small and large fish). Their share of the total WPO catch is small (6%). It was assumed that 3% of the small fish WPO catch and 3% of the large fish catch would go to these fleets for a total of 370 mt to the mixed fleet, 4341 to the small, and 7624 to the large. For subsequent time steps the OM fleet-specific catch is set by the management module as described below.

Table 2. List of the fleets present in the base-case operating model of the Pacific Bluefin tuna MSE and the associated gear type, country, and fleet type. WPO is Western Pacific Ocean and EPO Eastern Pacific Ocean. WPO fleets are further separated based on the size of fish caught. WPO mix fleets catch both large and small fish.

SS Fleet #	Fleet name	Gear Type	Country	Fleet Type
1	F1JLL	Longline	Japan	WPO Large
2	F2JSPPS (S1, 3, 4)	Purse Seine	Japan	WPO Small
3	F3KOLPS	Trawl, Setnet, Troll	Korea	WPO Mix
4	F4TPSJS	Purse Seine	Japan/Taiwan	WPO Large
5	F5TPSPO	Purse Seine	Japan	WPO Large
6	F6JTroll (S2-4)	Troll	Japan	WPO Small
7	F7JPL	Pole-and-Line, driftnet	Japan/(for driftnet also Taiwan)	WPO Small
8	F8JSN(S1-3)	Set Net	Japan	WPO Small
9	F9JSN(S4)	Set Net	Japan	WPO Mix
10	F10JSN(HK_AM)	Set Net	Japan	WPO Mix
11	F11JOthers	Miscellaneous	Japan	WPO Mix
12	F12TWLLSouth	Longline	Taiwan	WPO Large
13	F13USCOMM (-2001)	Miscellaneous	United States	EPO
14	F14MEXCOMM (2002-)	Miscellaneous	Mexico	EPO
15	F15EPOSports	Recreational	United States	EPO
16	F16JTroll4Pen	Troll for Penning	Japan	WPO Small
17	F17TWLLNorth	Longline	Taiwan	WPO Large
18	F18JSPPS (S2)	Purse Seine	Japan	WPO Small
19	F19JTroll (S1)	Troll	Japan	WPO Small
20	F20JSPPS (Penning)	Purse Seine for	Japan	WPO Small

		Penning		
26	F21Disc_mt	Discard	Japan/Korea	WPO Mix
27	F22Jpn_Disc_Num	Discard	Japan	WPO Small
28	F23JLL (1993-S1-3)	Longline	Japan	WPO Large
29	F24EPOsports_early	Recreational	United States	EPO
30	F25EPOsports_Disc	Recreational	United States	EPO

Estimation Model

The estimation model has the same modeling structure of the base-case OM. Discrepancies between OM/EM output are driven by observation error and estimation issues since, unlike the OM, the EM actually estimates all the parameters as the short stock assessment starting from initial values in the control file. Estimates of terminal year SSB, terminal year numbers at age, and unfished SSB from the EM are input into the harvest control rule. The EM is also used to compute the F multiplier that will achieve, given the biology, selectivity, and relative intensity of fishing between fleets, the SPR-based F_{target} specified by the HCR. A 30-years run with the EM takes 1 day to run instead of 30 minutes without an EM. Thus, computation time can pose a limit to the amount of runs and uncertainty scenarios one can complete within the MSE timeline set in the JWG-07 workplan. We have thus developed the capability to run the MSE framework without an assessment model to be able to run quick simulations for debugging purposes. This capability can also be used to test and cull HCRs before running them into a simulation with an EM since strategies not performing well with perfect information are unlikely to perform better in the simulation considering observation and assessment error. The results here presented are run without the assessment.

Management Module

The management module specifies the harvest control rule being used. The current MSE framework has the capability to run the candidate HCR1a rule brought forward at NC15 (WCPFC 2019). Work is underway to code the remaining HCRs. The rule is defined in the function *HCR1a_pbf_byfleet_f.R*. However, the user specifies the fraction of unfished SSB used to calculate the biomass-based limit and threshold reference points and the fraction of the F_{target} used to calculate the minimum F in the call to the main harvest strategy function. Given the different possible combinations of reference points, there are 50 potential HCRs associated with HCR1a (Table 3). In this example we run HCR15 with a limit reference point of 7.7%$SSB_{F=0}$, a threshold reference point of 20%$SSB_{F=0}$, and a F_{target} of FSPR30% and compare it to a rule that uses a constant catch set to the CMM catch limit.

Table 3. List of harvest control rules (HCRs). The target reference point (F_{target}) is an indicator of fishing intensity based on SPR. SPR is the spawning stock biomass (SSB) per recruit that would result from the current year's pattern and intensity of fishing mortality relative to the unfished stock. An F_{target} of FSPR40% is associated with a fishing intensity that would leave 40% of the SSB per recruit as compared to the unfished state. An F_{target} of FSPR30% implies a higher fishing intensity (i.e., 1-SPR of 0.7) and would result in a SSB per recruit of 30% of the unfished SPR. The threshold and limit reference points are SSB-based and refer to the specified percentage of unfished SSB ($SSB_{F=0}$). The minimum F refers to the fraction of the F_{target} that the fishing intensity is set to when SSB is below the limit reference point. The HCR tested in this example is highlighted in yellow.

HCR	Limit Reference Point	Threshold Reference Point	Target Reference Point	Minimum F
1	5%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR15%	5%F_{target}
2	5%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR20%	5%F_{target}
3	5%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR30%	5%F_{target}
4	5%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR40%	5%F_{target}
5	5%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR20%	5%F_{target}
6	5%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR30%	5%F_{target}
7	5%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR40%	5%F_{target}
8	5%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR30%	5%F_{target}
9	5%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR40%	5%F_{target}
10	7.7%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR15%	5%F_{target}
11	7.7%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR20%	5%F_{target}
12	7.7%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR30%	5%F_{target}
13	7.7%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR40%	5%F_{target}
14	7.7%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR20%	5%F_{target}
15	7.7%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR30%	5%F_{target}
16	7.7%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR40%	5%F_{target}

17	7.7%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR30%	5%F_{target}
18	7.7%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR40%	5%F_{target}
19	15%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR20%	5%F_{target}
20	15%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR30%	5%F_{target}
21	15%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR40%	5%F_{target}
22	15%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR30%	5%F_{target}
23	15%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR40%	5%F_{target}
24	20%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR30%	5%F_{target}
25	20%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR40%	5%F_{target}
26	5%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR15%	10%F_{target}
27	5%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR20%	10%F_{target}
28	5%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR30%	10%F_{target}
29	5%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR40%	10%F_{target}
30	5%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR20%	10%F_{target}
31	5%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR30%	10%F_{target}
32	5%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR40%	10%F_{target}
33	5%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR30%	10%F_{target}
34	5%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR40%	10%F_{target}
35	7.7%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR15%	10%F_{target}
36	7.7%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR20%	10%F_{target}
37	7.7%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR30%	10%F_{target}
38	7.7%$SSB_{F=0}$	15%$SSB_{F=0}$	FSPR40%	10%F_{target}
39	7.7%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR20%	10%F_{target}
40	7.7%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR30%	10%F_{target}
41	7.7%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR40%	10%F_{target}
42	7.7%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR30%	10%F_{target}
43	7.7%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR40%	10%F_{target}
44	15%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR20%	10%F_{target}
45	15%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR30%	10%F_{target}
46	15%$SSB_{F=0}$	20%$SSB_{F=0}$	FSPR40%	10%F_{target}

47	15%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR30%	10%F_{target}
48	15%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR40%	10%F_{target}
49	20%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR30%	10%F_{target}
50	20%$SSB_{F=0}$	25%$SSB_{F=0}$	FSPR40%	10%F_{target}

In the management module, if there is 50% chance or grater that terminal year SSB is above the threshold reference points, the fishing intensity is set to the F_{target}, FSPR30% (Fig. 2). To obtain a catch per fleet and season to input into the OM given an F_{target}, first the F multiplier that achieves the F_{target} is multiplied by the relative F ($relF_{f,s}$ where f = fleet and s = season) for the period specified in the SS3 forecast file (in this case 2017-2019) to find the apical F for each fleet and season ($F'_{f,s}$). The relative F in SS3 is computed as $relF_{f,s}= F'_{t,f,s}$/(sum of $F'_{t,f,s}$ for all fleets and seasons) where t here is 2017-2019. Then the Barnov equation is used to calculate the catch per fleet and season given terminal year numbers at age. The fleet and season specific catches are summed to obtain an overall TAC as well as an EPO and WPO TAC. The fleet and season specific catches are then input into the operating model dat file for the next time step and kept constant for two years until the next assessment. If terminal year SSB is below the threshold reference points but above the limit reference point, the F multiplier is gradually diminished based on a proportional reduction of the F multiplier associated with F_{target} (Fig. 2). If terminal year SSB is below the limit reference point with a 50% or greater chance the F multiplier is set to 5% of the F multiplier that would achieve the F_{target} (Fig. 2).

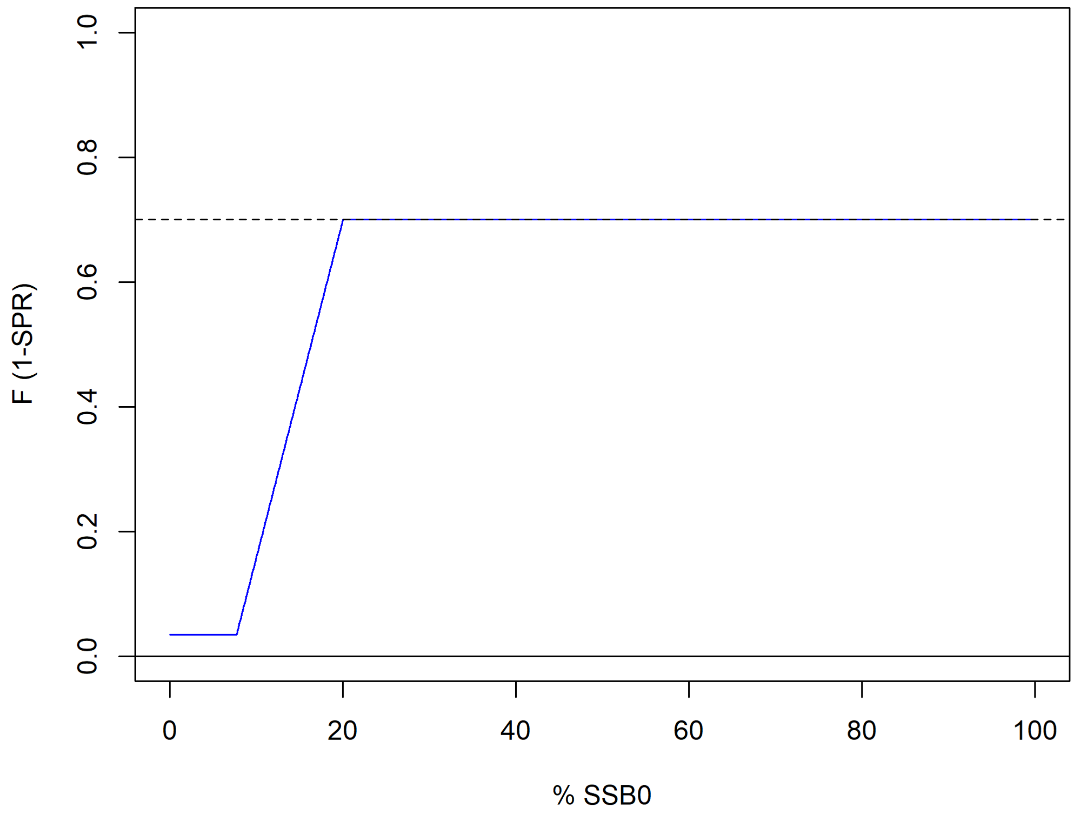


Figure 2. Harvest control rule tested. The horizontal dotted lines indicate the FSPR30% (1-SPR, 0.7) target reference point. The limit reference point is 7.7% of unfished SSB (SSB0) and the threshold reference points is 20% of SSB0.

Implementation Error

Before the catch determined by the HCR is introduced into the OM, an implementation error can be added to the fleet specific catches. This is done by specifying the *err* parameter in the *HCR1a_pbf_byfleet_f.R* function. For instance, specifying an *err* of 1.2 would increase the catches for each of the fleets by 20%. The implementation error accounts for errors in reporting, problems with compliance, or unforeseen changes in fisher behavior. In this example there is no implementation error and *err* is set to 1. The code to allow for a different implementation error per fleet is currently being developed.

Performance Evaluation

Output for each year of the MSE simulation from both the OM and EM is automatically saved in the file outlist.txt to be used to calculate performance metrics. Output from the

OM can be used to compute the performance metrics produced at JWG07 and outlined in Table 4. We have developed code to generate all the performance metrics except for the fishery impact.

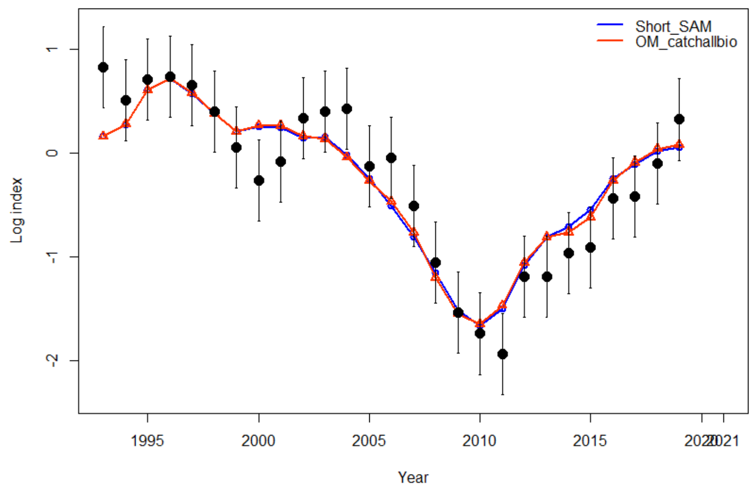
Table 4. List of operational management objectives and performance metrics for Pacific Bluefin tuna generated during JWG07 and to be revised at JWG08 (JWG07 Annex E). SSB refers to female spawning stock biomass, LRP to limit reference point. F is the fishing intensity (1-SPR) and F_{target} is the target reference point.

Category	Operational Management Objective	Performance Metric
Safety	There should be a less than [5-20%] probability of the stock falling below the LRP	Probability that SSB< LRP in any given year of the evaluation period
Status	To maintain fishing mortality at or below F_{target} with at least [50-75]% probability	Probability that $F \leq F_{target}$ in any given year of the evaluation period
Stability	To limit changes in overall catch limits between management periods to no more than [15%] downwards [unless the ISC has assessed that there is a greater than 50%chance the stock is below the LRP]	Percent change upwards in catches between management periods excluding periods when SSB<LRP Percent change downwards in catches between management periods excluding periods when SSB<LRP
Yield	[Maintain a proportional fishery impact between the WCPO and EPO [similar to the average proportional fishery impact from1971-1994]	Median fishery impact (in %) on SSB in any given year of the evaluation period by fishery and by WCPO fisheries and EPO fisheries The probability that the proportional EPO fishery impact is at least the1971-1994 average in any given year
	To maximize yield over the medium (5-10 years) and long	Expected annual yield over years5-10 of the evaluation period, by

	(10-30 years) terms, as well as average annual catch yield from the fishery.	fishery. Expected annual yield over years10-30 of the evaluation period, by fishery. Expected annual yield in any given year of the evaluation period, by fishery.
	[To increase average annual catch in all fisheries across WCPO and EPO]	Expected annual yield in any given year of the evaluation period

Results

The base case OM fit the indices of abundance just as well as the short assessment model (Figure 3). However, the removal of time varying age selectivity deviations resulted in a poorer fit to the size composition data with the size composition likelihood increasing from 1490.68 to 1588.26.



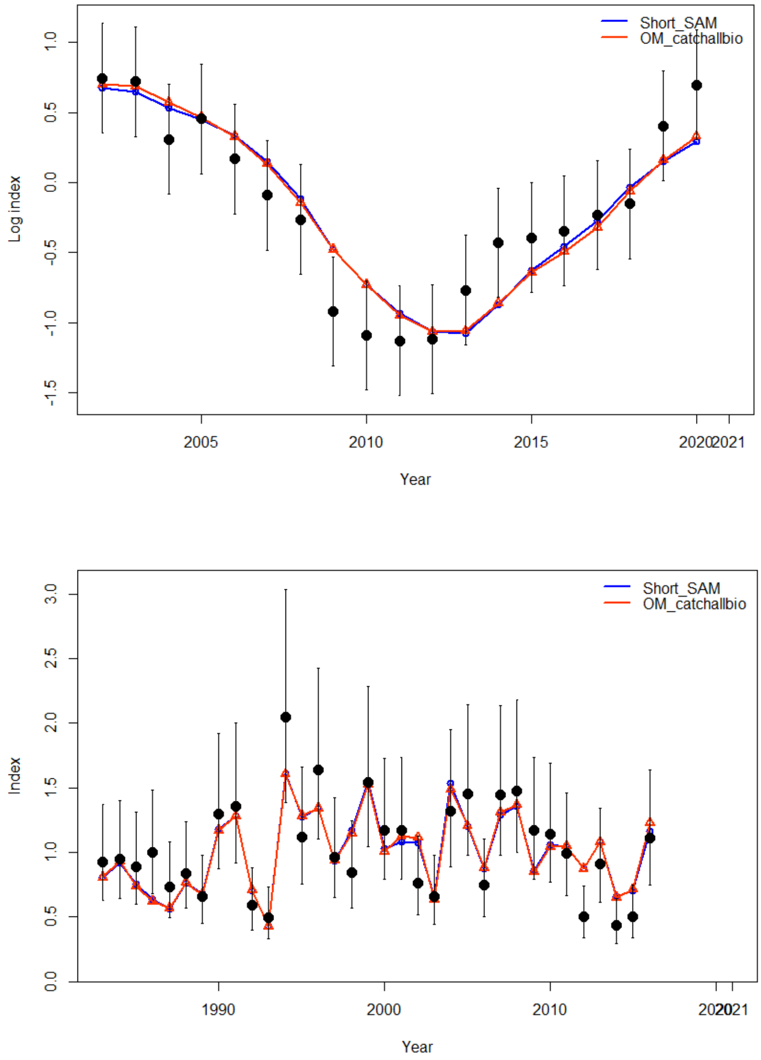


Figure 3. Comparisons of the Japanese longline index (top), Taiwanese longline index (middle), and Japanese troll index (bottom) predicted by the short stock assessment model (blue), and the base-case operating model (red). Black closed circles with error bars represent the observed abundance indices with 95% CI.

Nevertheless, trends in management relevant quantities such as estimated fishing intensity (1-SPR) and SSB relative to unfished SSB were comparable between models (Fig. 4).

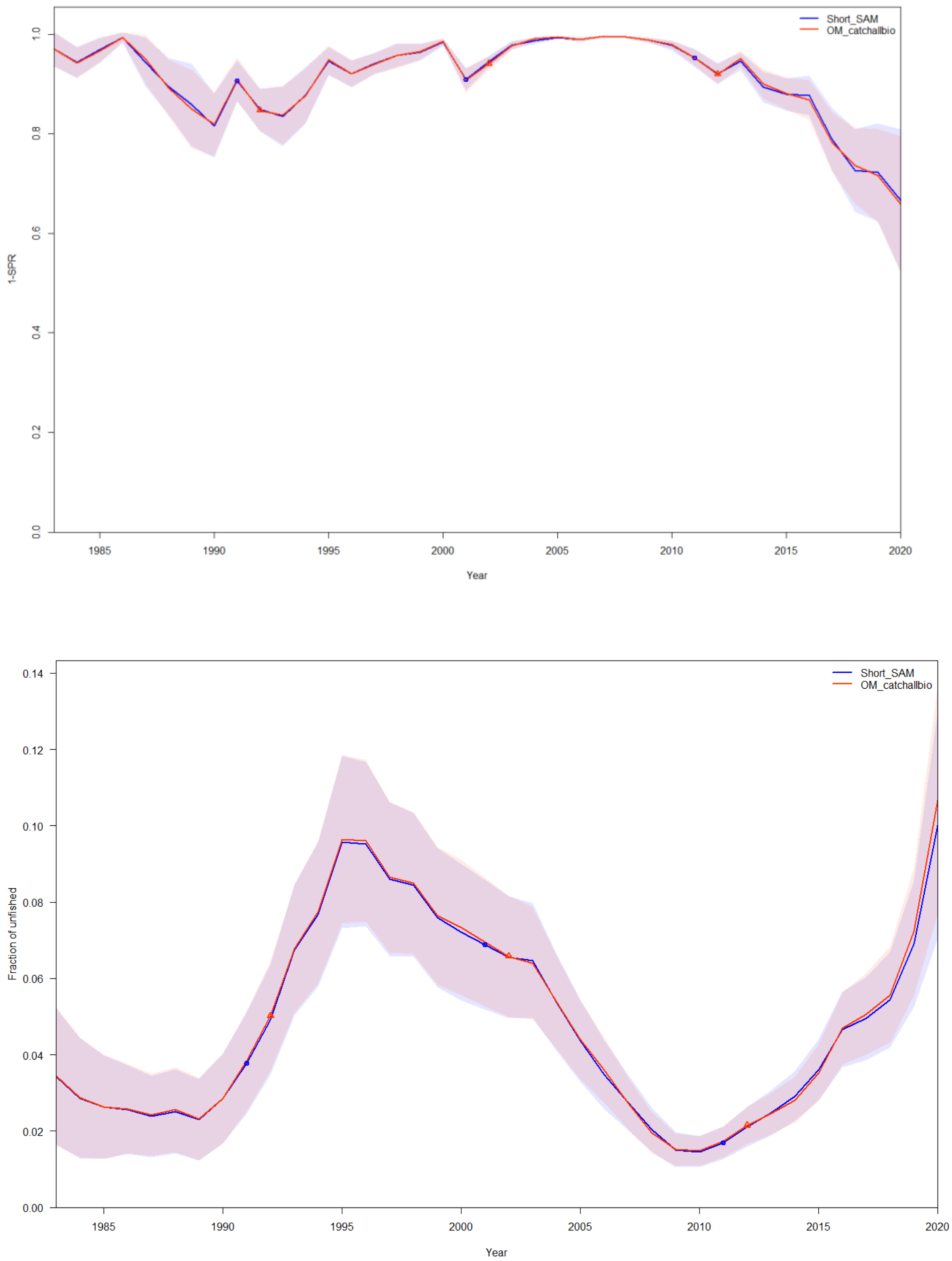


Figure 4. Comparisons of estimated timeseries of fishing intensity (1-SPR, top) and spawning stock biomass as fraction of unfished spawning stock biomass (bottom) estimated by the short stock assessment model and the base-case operating model.

To test an exemplify how the PBF MSE code works we run 25 iterations with both a constant catch set to the CMM catch limit and HCR 15 from Table 3. The two strategies had the same recruitment deviations , resulting in similar recruitment timeseries (Fig. 5).

However, since the constant catch strategy maintained a lower catch (Fig. 6), it resulted in a higher spawning stock biomass as compared to HCR15 (Fig. 7). However, both strategies maintain SSB above the limit reference point with high probability (Fig. 8).

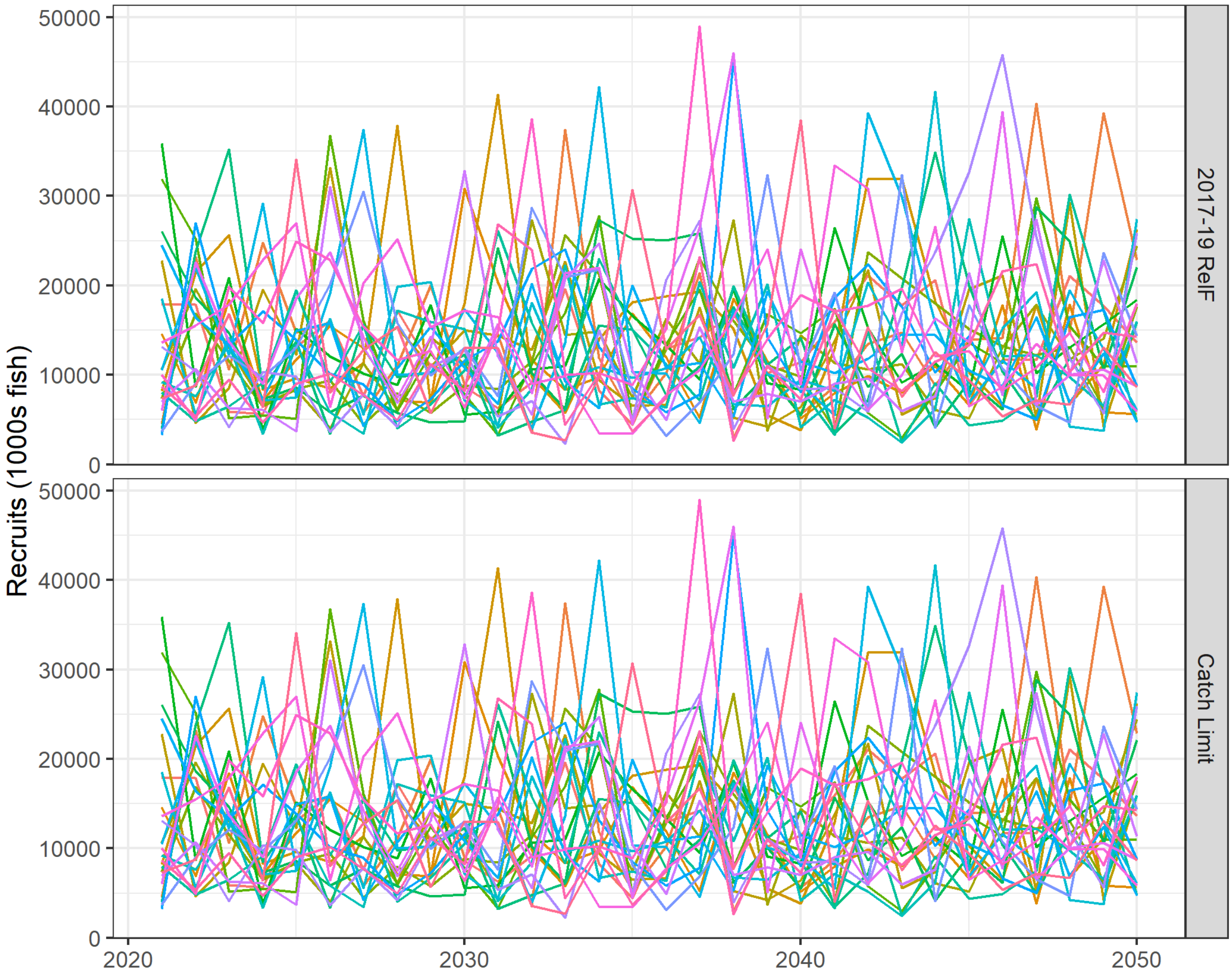


Figure 5. Worm plots of recruitment for individual runs for the CMM Catch Limit simulation and for harvest control rule 15 with the base case operating model. Each panel presents the results for the labeled HCR. Trajectories represent separate iterations differing in simulated random recruitment deviates.

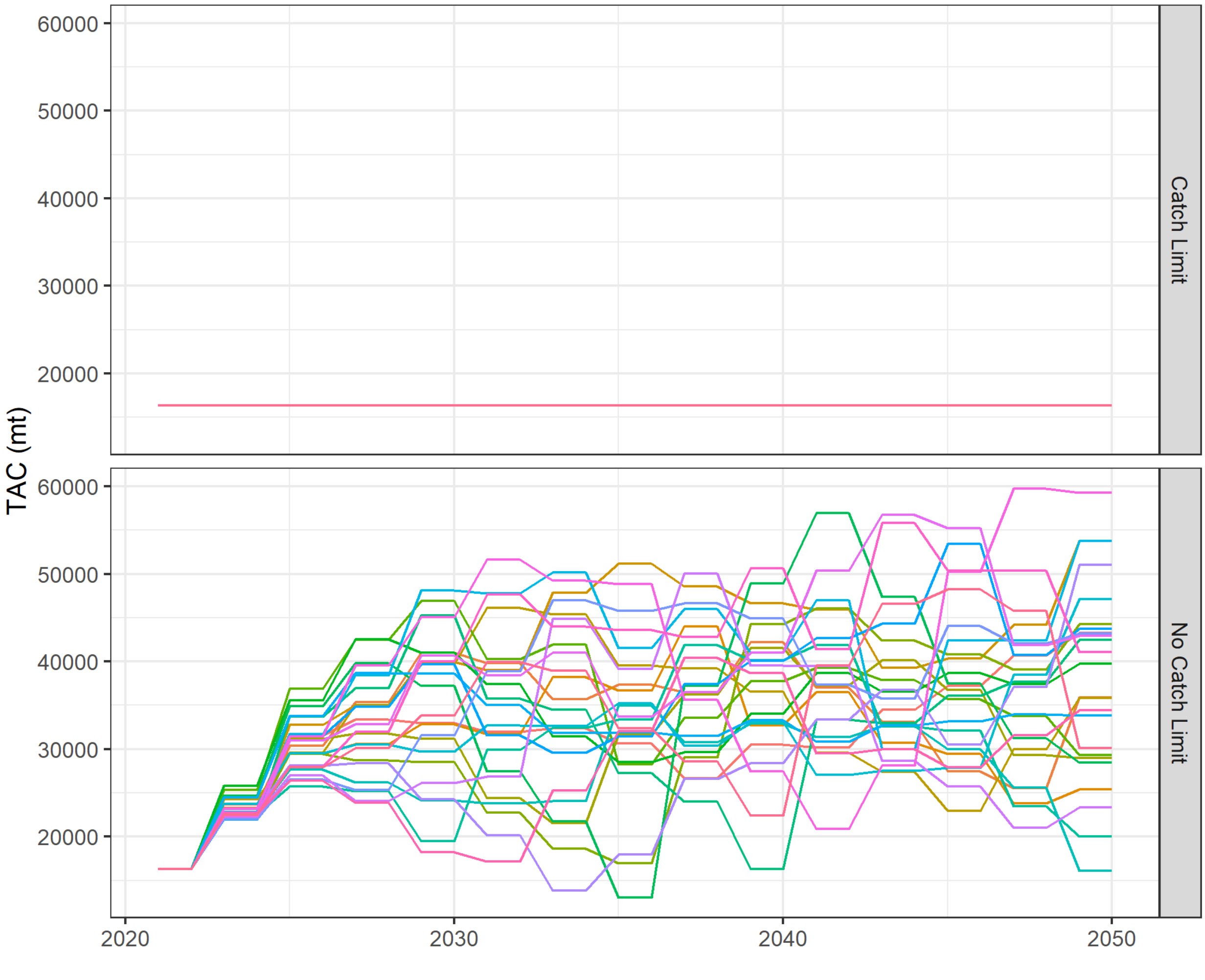


Figure 6. Worm plots of the Total Allowable Catch (TAC) for individual runs for the CMM Catch Limit simulation and for harvest control rule 15 with the base case operating model. Each panel presents the results for the labeled HCR. Trajectories represent separate iterations differing in simulated random recruitment deviates.

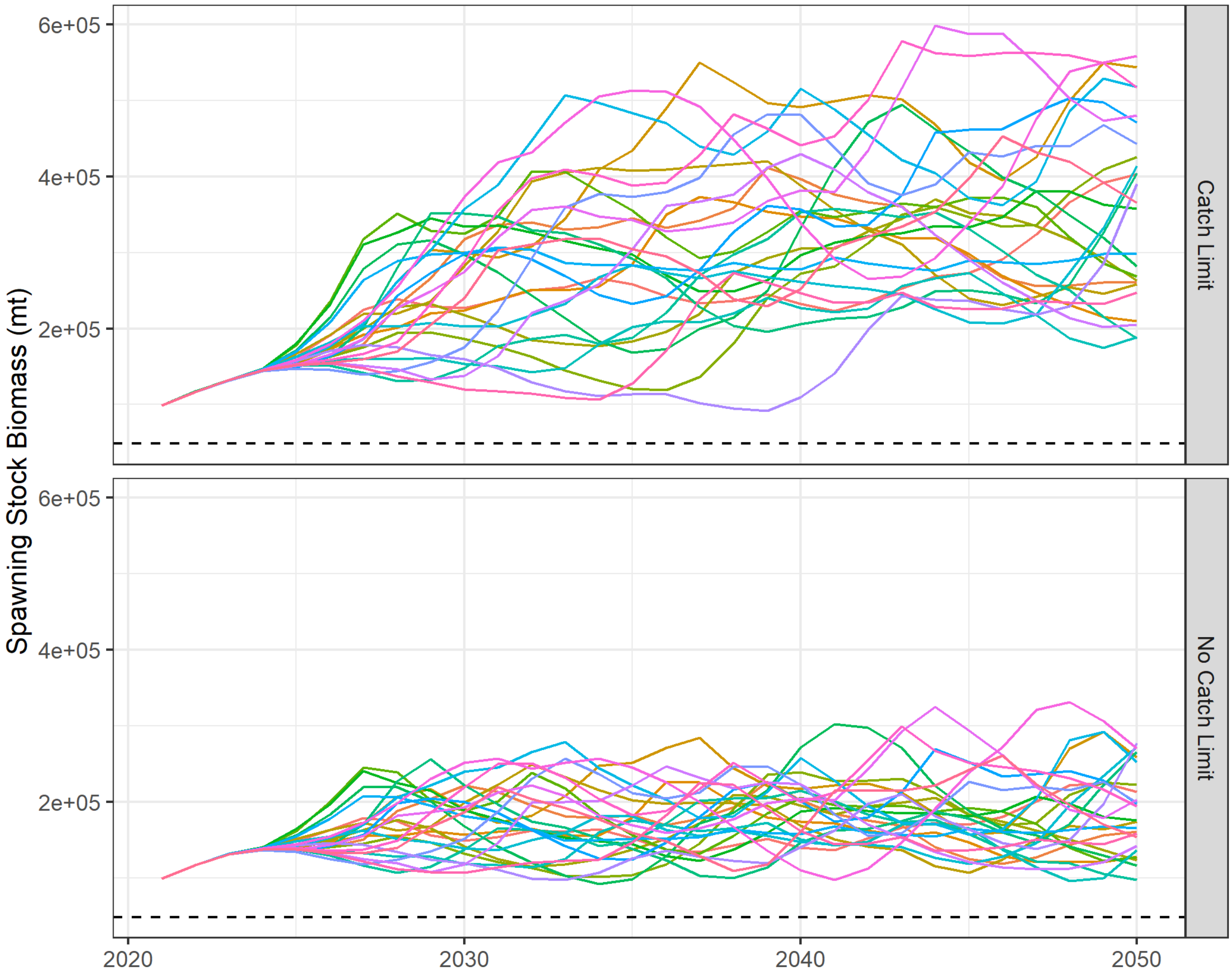


Figure 7. Worm plots of spawning stock biomass for individual runs for the CMM Catch Limit simulation and for harvest control rule 15 with the base case operating model. Each panel presents the results for the labeled HCR. Trajectories represent separate iterations differing in simulated random recruitment deviates. The dotted line represents the the 7.7%SSB0 limit reference point.

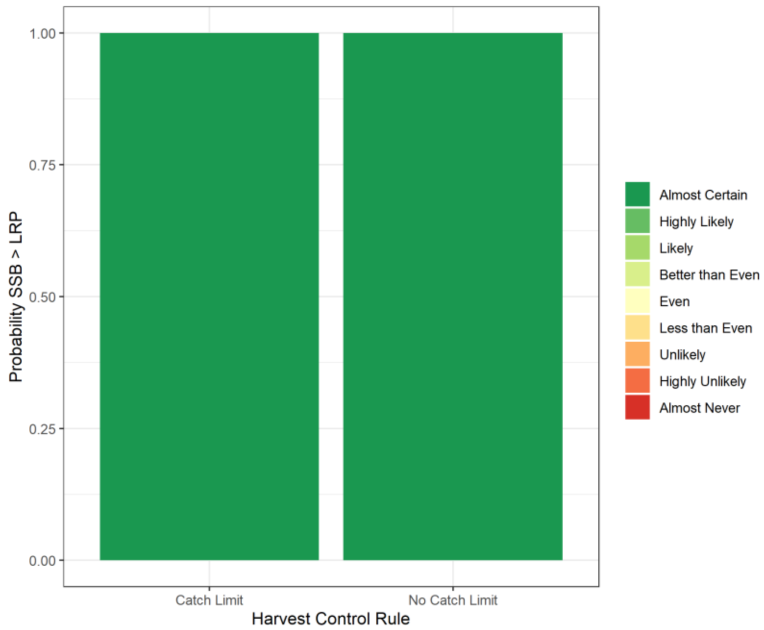


Figure 8. Plot of the probability of spawning stock biomass (SSB) being greater than the 7.7%SSB0 limit reference point (LRP for the CMM catch limit control rule and HCR 15 for the base case model. Note that these probabilities were computed using only 25 iterations and should not be considered as the finalized performance metrics for these harvest control rules.

Discussion

The PBF MSE code is now able to run candidate HCR1a with and without an estimation model and save output to compute most of the candidate performance metrics identified during JWG-07. Work is underway to update the PBF MSE framework to 1) correct the bias in generating bootstrap samples, 2) allow for a fleet-specific implementation error, 3) compute all the HCRs outlined in JWG, and 4) ensure all output required to compute fishery impact performance metrics is saved. Discussion with the working group to assess what is a reasonable level of implementation error, what the inputs required to calculate the fishery impact performance metric are, and what uncertainty scenarios are the most relevant to PBF (including productivity, recruitment, and data) will be helpful for further MSE development.

References

Punt, A.E., Butterworth, D.S., de Moor, C.L., De Oliveira, J.A.A. and Haddon, M. (2016) Management strategy evaluation: best practices. Fish and Fisheries 17, 303–334.

JWG 2022. Chairs' Summary of the 7th Joint IATTC and WCPFC-NC Working Group Meeting on the Management of Pacific Bluefin Tuna. Available at https://meetings.wcpfc.int/node/16046

ISC 2021. Report of the North Pacific Albacore Tuna Management Strategy Evaluation – ANNEX 11 21st Meeting of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean. Available at https://meetings.wcpfc.int/node/14095

ISC 2022. Stock Assessment of Pacific Bluefin Tuna in the Pacific Ocean in 2022. Annex 13 22nd Meeting of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean. Available at https://isc.fra.go.jp/pdf/ISC22/ISC22_ANNEX13_Stock_Assessment_for_Pacific_Bluefin_Tuna.pdf

Methot, R.D., and Wetzel, C.R. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142: 86–99. Elsevier B.V. doi:10.1016/j.fishres.2012.10.012.

Fukuda, H., Tsukahara, Y. and Nishikawa, K. 2022. Update of the PBF population dynamics model using short time series data (1983-) and the sensitivity runs for the robustness test. ISC/22/PBFWG-1/06.

Lee, H., Fukuda, H., Tsukahara, Y., Piner, K., Maunder, M., and Methot, R. 2021. The devil is in the details: Investigating sources of bootstrapped bias in the Pacific bluefin tuna assessment and the associated impact on the future projections. ISC/21/PBFWG-1/07. Available at: https://isc.fra.go.jp/pdf/PBF/ISC21_PBF_1/ISC_21_PBFWG_1_07_H_Lee.pdf

WCPFC 2019. Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean. Northern Committee Fifteenth Regular Session Annex F Candidate Reference Points and Harvest Control Rules for Pacific Bluefin Tuna. Available at https://meetings.wcpfc.int/meetings/nc15