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ISC18 – ANNEX 13
REPORT OF THE ALBACORE WORKING GROUP WORKSHOP
Attachment 4
Progress report on Management Strategy Evaluation (MSE) for North Pacific Albacore

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ISC[1]

[1] International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

FINAL

ISC/18/ANNEX/13

ANNEX 13

18th Meeting of the
International Scientific Committee for Tuna
and Tuna-Like Species in the North Pacific Ocean
Yeosu, Republic of Korea
July 11-16, 2018

REPORT OF THE ALBACORE WORKING GROUP WORKSHOP

30 April – 5 May 2018
La Jolla, CA, USA

July 2018

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Annex 13

REPORT OF THE ALBACORE WORKING GROUP WORKSHOP

International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

30 April – 5 May 2018

SWFSC/NOAA, La Jolla, CA, USA

1. OPENING AND INTRODUCTION

1.1 Welcome and introduction

An intersessional workshop of the Albacore Working Group (ALBWG or WG) of the International Science Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) was convened at the Southwest Fisheries Science Center (NOAA/SWFSC), La Jolla, CA, 30 April – 5 May 2018.

Kevin Hill, lead of the Fish Population Dynamics and Modeling Group of the Fisheries Resource Division, welcomed 14 participants (**Attachment 1**) to the Southwest Fisheries Science Center (SWFSC) and Inter-American Tropical Tuna Commission (IATTC), and wished them a productive meeting. Scientists from Canada, Chinese-Taipei, Japan, the United States of America (USA), the IATTC, and the Secretariat of the Pacific Community (SPC) attended the workshop.

The ALBWG Chair briefly described the objectives of the meeting and the expected outcomes. The objectives of this workshop are to: (1) Review the outcomes of the 3rd workshop on Management Strategy Evaluation (MSE) of North Pacific albacore tuna (NPALB) and a workshop of the ALBWG in Vancouver, Canada during October 2017; (2) Review MSE model development and conditioning; (3) Review preliminary MSE results and (4) Prepare draft executive summary of the MSE progress for the ISC18 plenary.

1.2 Meeting protocol

The ALBWG Chair noted that the efforts of the WG at this meeting would be collegial and follow the scientific method with an emphasis on empirical testing, open debate, documentation and reproducibility, reporting uncertainty, peer review, and constructive feedback to authors and presenters.

1.3 Review and adoption of agenda

The draft agenda was circulated prior to the meeting, reviewed and adopted at the workshop (**Attachment 2**).

1.4 Assignment of rapporteurs

Rapporteuring duties were assigned to Steven Teo, Hirotaka Ijima, Rob Scott, and Carolina Minte-Vera.

1.5 Distribution of documents and working paper availability

Two working papers were submitted and assigned numbers for the workshop (**Attachment 3**). All of the working papers will be publicly available through the ISC website (http://isc.fra.go.jp/) and author contact details will be provided for the other related materials.

2. OUTCOMES OF OCTOBER 2017 WORKSHOPS

A 2.5 day MSE workshop (3rd ISC MSE Workshop) with fishery managers, stakeholders, and scientists, was convened in Vancouver, Canada, October 17-19, to review and update management objectives, performance indicators and harvest control rules (HCRs) to be tested by the ALBWG. Subsequently, an intersessional workshop of the ALBWG was convened at the same location during 19-20 October 2017 (**Report of the Albacore Working Group Workshop, 19-20 October 2017**).

D. Tommasi and S. Teo provided a review of the 3rd MSE WS and ALBWG WS held in Vancouver, Canada in October 2017. The presenters reminded the WG that three candidate harvest strategies were proposed during the MSE WS, which were to be evaluated against the six management objectives previously identified. Within each harvest strategy, numerous candidate reference points (RPs) and harvest control rules (HCRs) were to be evaluated as well. The WG also prioritized developments to the operating model (OM) to capture specific uncertainties. This prioritization reflected an assessment of the uncertainties that were most consequential and the need to provide an initial set of results.

The WG thanked the presenters for the review and noted the large amount of work that was proposed at the October 2017 workshops.

3. MSE MODEL DEVELOPMENT AND CONDITIONING

The WG reviewed the progress of model development and conditioning for the NPALB MSE, and updates of the projection software used for NPALB stock assessments.

3.1 Progress on model development and conditioning for the NPALB MSE. Oral presentation by D. Tommasi.

Summary: Development and conditioning of the OMs and scenarios listed as high priority (recruitment, natural mortality, and growth) by the WG has been completed. Several of the OMs did not converge during the conditioning phase, and were not used further in the MSE. Other OMs produced unrealistic estimates of population size and were excluded. Eight OMs were selected as the final set of uncertainty scenarios to be considered. One problem highlighted was that the time needed to perform a single run of the MSE model loop for 30 years (2016-2045) is taking much longer than expected. The slow performance is mostly due to the use of a fully integrated assessment model as the estimation model (EM) in the MSE model loop. A single EM run can take over an hour, and the EM is run once every 3 years. Therefore, only a portion of the model runs have been completed, and the preliminary results presented later are considered incomplete. Priority was given to model runs of Harvest Strategy 1: the base case uncertainty scenario and two additional scenarios that bounded the range of estimated population size of the eight scenarios.

Discussion: The WG asked when all the model runs would be expected to be completed, if the same EM was used for all the runs. It was difficult to provide an accurate estimate, but if everything went smoothly, the expected time needed to complete all the runs, given current resources, would be in excess of a year. The WG agreed that the original work plan was overly ambitious and the MSE model runs would not be completed in time for the ISC Plenary in July 2018. **Therefore, the WG decided to provide a progress report on the MSE work instead of a full MSE report**. A progress report with an overview and detailed description of the MSE development is provided (**Attachment 4**).

Table X of Attachment 4 outlines the candidate Harvest Strategies and HCRs under consideration. The WG noted that the HCRs for Harvest Strategy 2 was meant to represent the HCRs used for tropical tunas by the IATTC. However, as it was set up, the HCRs did not include controls on F to maintain F at F_{MSY}. **Therefore, the WG recommended that Harvest Strategy 2 be modified to include HCRs to maintain F at or below F_{MSY} if $F>F_{MSY}$**.

The EM was considered to be the primary bottleneck for the MSE model loop. The essential issue was that the required time to run one iteration on one CPU was approximately 10 hours. In total, 246 combinations of high priority scenarios and basic HCRs (i.e., excluding options for rebuilding plans, management options if the LRP is breached, and whether HCRs applies to both targeting and non-targeting fleets) for Harvest Strategy 1 and 3 were proposed by the 3rd MSE WS but have not yet been completed. These runs are expected to be completed in about 3.5 months. It was also pointed out that Harvest Strategy 2 was not yet completed and several of the other HCR options were likely high priority for the managers and stakeholders, and including these options would expand the time needed in an exponential manner. Therefore, the WG discussed if the EM could be simplified in order to speed up the model loop. The following suggestions were made:

1. Apply a simple error distribution to the OM projections of stock status, if the error distributions between the EM estimates and the OM are consistent across management scenarios, a simple error distribution could be applied to the OM instead of running a fully integrated assessment model. This would dramatically reduce the run time. After reviewing the error distributions for various OMs and management scenarios, the WG decided this approach could not be used because the error distributions between the EM estimates and the OMs, varied considerably for different management scenarios.
2. Applying a simplified EM like the ASPM (Age Structured Production Model) instead of a fully integrated assessment model would also reduce run time substantially. There were some discussions on whether recruitment deviations should be estimated. Although the WG noted that this issue should be further explored and the error distributions between the ASPM estimates and OM be compared, the WG agreed that the ASPM is a reasonable option to reduce run time. **The WG recommended that the use of an ASPM as the EM be explored and if the error distributions are comparable to the fully integrated assessment model, would be a reasonable EM to use.**

3. Reducing the number of combinations to examine would also obviously reduce the time needed to complete the model runs. **The WG recommended that a reduced set of scenarios, HCRs and RPs be prepared and provided in the progress report (Attachment 4).** It was noted that feedback from the managers and stakeholders should be sought on this reduced set, if possible.
4. More computing resources could also be used to reduce the overall run time for all the models. However, it was noted that time may be needed to obtain the budget and for procurement and equipment installation.
5. The WG noted that an empirical harvest rule based on, for example, trends in CPUE could also be used within the management procedure. This approach would not require the use of an integrated stock assessment model and would likely be a substantially less computationally intensive and faster procedure and could lead to significantly reduced run times. The WG considered that this was an option to be considered later in the MSE development process and that methods based on an analytical estimate of stock status should be prioritized at this stage.

The WG recommended that options 2 - 4 be explored as possible solutions to reduce the time needed to complete the MSE model runs in order to complete NPALB MSE development on schedule.

3.2 Update future projection program for Stock Synthesis 3. Hirotaka Ijima. ISC/18/ALBWG/02.

Summary: The future projection program that was used by the ISC albacore working group was upgraded. The major update points are: 1) The updated program responds to stock synthesis 3 ver3.30. 2) Population dynamics were changed to the quarterly base. 3) Using F at age for each fleet, this new program calculates F based reference point (Fmsy or F%SPR). 4) the SS3 result of MCMC with recruitment uncertainty is available.

Discussion: The WG agreed that the upgrade would be useful for the NPALB stock assessment scheduled for 2020. In addition, the WG wondered if the future projection software could be used for the MSE model loop when rebuilding plan is triggered. For some candidate HCRs, a probabilistic rebuilding plan is triggered when the LRP is breached, and it is required to calculate the F that allows the SSB to reach the TRP with >50% probability and with a <10% probability of breaching the LRP within 30 years. Currently, the MSE model loop does not do that but instead uses F=0. The WG discussed the possibility of using this future projection software to do this. However, the author noted that part of the current software still uses R and is therefore too slow for this use but he will try to change the code to using only C++ in the near future. In addition, the WG noted that the rebuilding plan was only triggered infrequently and the time taken to perform projections may not be critical. The WG also discussed the possibility of using equilibrium-based calculations to calculate the F for the rebuilding plan. The WG agreed that using equilibrium-based calculations was reasonable for calculating the F that allows the SSB to reach the TRP with >50% probability because the NPALB population dynamics is expected to be close to reaching equilibrium after a large change in F within 30 years. However, it was less clear about using equilibrium-based calculations for calculating if the F will have a <10% probability of breaching the LRP. The WG did not have time to fully explore the options for simulating the rebuilding plan. Therefore, **the WG recommended that reasonable options for simulating the rebuilding plan be explored if there is time but did not make specific recommendations. However, if there are severe time constraints, the WG recommended that simulating the rebuilding plan be lowered in priority and the difference between the rebuilding plan in the simulations and the candidate HCRs be highlighted to managers and stakeholders.**

4. PRELIMINARY MSE RESULTS

The WG reviewed and discussed the preliminary MSE results (**Attachment 4**). In addition, the WG explored how other MSE projects have communicated their results.

4.1 Overview of initial MSE results. Oral presentation by D. Tommasi.

Summary: A selection of preliminary MSE results were presented to highlight the major trends in the preliminary results and to illustrate the issues of communicating complex results without overwhelming the audience. It was highlighted that these preliminary results are currently incomplete and should not be used to make any management decisions. Cobweb plots of performance indicators were used to illustrate the tradeoffs between the 6 management objectives for several candidate RPs and HCRs. As an example, one important tradeoff was between catch, biomass, and probability of breaching candidate LRPs. In addition, a variety of different plots and tables were used to provide details of the performance of specific candidate RPs and HCRs.

Discussion: The WG agreed that these preliminary results are currently incomplete and should not be used for management. Therefore, **the WG strongly recommended that these preliminary results should not be used to make any management decisions**. The WG agreed that a selection of results should be provided in the progress report (**Attachment 4**) for illustrative purposes and may help with getting feedback on the effectiveness of specific performance indicators and communication methods (i.e., plot types and tables). The WG noted the difficulties in condensing the large amount of complex information from even only a portion of the MSE model runs into easily digestible forms.

4.2 Recent work on MSE by the SPC. Oral presentation by R. Scott.

Summary: A brief presentation was provided of recent work undertaken to develop the MSE framework for the WCPFC skipjack/topical purse seine fishery focussing on initial work to condition operating models, using the 2016 skipjack tuna assessment uncertainty model grid as a basis. No agreement has yet been made on suite of operating models that will be used for the analyses and what will be basis of the reference set and robustness set of OMs. The presentation included an overview of recent developments to the MULTIFAN-CL assessment model software to enable pseudo-data generation for catch, effort, size composition and tag recapture data from those operating models. Ideas on the OMs for the reference and robustness model sets were briefly covered and areas of ongoing work both in terms of OM conditioning and pseudo data generation highlighted.

In addition a brief overview was provided on the results and plots produced for previous analyses to test harvest control rules for the WCPFC skipjack stock. The utility of the various plots was discussed in terms of their ability to convey appropriate information to either a scientific or management focussed audience. The plots used to illustrate temporal stability in catch or effort might be considered for similar application in the case of north Pacific albacore.

Discussion: The WG thanked the presenter for providing an overview of SPCs' MSE work, and sharing experiences, ideas, and viewpoints. The presenter noted that there was an upcoming MSE workshop for tuna RFMOs in Seattle during the coming June, and there are several papers in an upcoming special issue of the Canadian Journal of Fisheries and Aquatic Science on MSEs and communicating MSE results. D. Tommasi confirmed that she was attending the MSE workshop in June. The WG agreed with the presenter that the plots used to illustrate temporal stability in catch or effort might be useful for the NPALB MSE as well.

5. WORK PLAN

5.1 Time and place of next meeting

There will be a half-day session to review the presentation of MSE progress in advance of the ISC18 Plenary on July 8, 2018 in Yeosu, Korea.

5.2 MSE and stock assessment workplan

The WG developed a work plan for the completion of the first round of the NPALB MSE and the stock assessment scheduled for 2020 (**Attachment 5**). Most importantly, the Chair proposed to hold the 4th MSE WS for managers and stakeholders in March 2019 to provide information on the results of the first round MSE. However, it was noted that the ISC Plenary would need to approve of the plan and inform the Northern Committee (NC) of the WCPFC. The location of the 4th MSE WS will be in Japan, likely Yokohama, and the exact dates for the workshop will be determined in the future based on the availability of participants. An ALBWG meeting will be held in conjunction with the 4th MSE WS, either immediately before or after the MSE WS. **The WG agreed with the proposed work plan.**

6. OTHER MATTERS

One working paper and one presentation were provided to the working group on the influence of the environment on NPALB populations.

6.1 Correlations between climatic indices (NPGO and PDO) and abundance of albacore tuna in waters off Northwest coast of North America. Zane Zhang. ISC/18/ALBWG/01.

Summary: The Canadian troll fishery on juvenile albacore tuna primarily takes place in the Canadian and U.S. exclusive economic zones (EEZs), and adjacent high seas waters, in July-Sept. Annual abundances of these albacore tuna appear to be rather variable, as suggested by variations in Catch-per-unit-effort (CPUE) (Fig. 1). The objective of this working paper is to examine if the two climatic indices, the North Pacific Gyre Oscillation (NPGO) and the Pacific Decadal Oscillation (PDO), may have any impacts on the variations in these juvenile albacore abundances. The NPGO and the PDO were chosen, as they appear to combine to control low frequency upwelling and alongshore transport dynamics in the North Pacific sector (Di Lorenzo et al. 2013). In addition, the role of water temperature as measured by Canadian albacore fishing vessels was also investigated.

Discussion: The WG noted that the US albacore catch off the west coast are primarily made up of 3 age classes: age-2, 3, and 4. The WG discussed the potential impacts of oceanography on the low catches in 2017. The WG found it interesting that the US and Canadian surface albacore fisheries had relatively low catches in 2017, and coincided with low catches in the Japanese pole-and-line fisheries as well. However, it is still unclear if the low catches in 2017 are due to low recruitment several years ago or due to changes in movement patterns and behavior, and if and how environmental changes are related to that.

6.2 Influence of oceanographic environment on recruitment, productivity and distribution of albacore in the eastern North Pacific and California Current. Oral presentation by B. Muhling.

Summary: Previous studies have suggested that the oceanographic environment can influence the recruitment, productivity and distribution of albacore in the eastern North Pacific and California Current. Here we explore these relationships using outputs from the latest stock assessment. Temperature effects on annual recruitment were weak, and relied primarily on the 1976-7 regime shift. In addition, years of strong recruitment were not reflected in CPUE indices for the California Current region several years later, although the multiple year classes represented by the indices may have confounded these analyses. Distribution and migration of albacore in the eastern North Pacific were strongly related to temperature, with a warmer transition zone associated with a more northern and inshore distribution of catches in the U.S. surface fishery. In the future, seasonal forecasts of arrival times and locations of albacore in the California Current may be possible, based on temperature. Once in the California Current, finer-scale distributions of albacore, and thus their availability to fishers, may also be influenced by oceanographic conditions, including temperature, primary productivity, and meso-scale ocean features.

Discussion: The WG noted that there was a strong interest from US fishermen on the potential causes of the low catches in 2017, and enquired whether any of the research hinted at potential environmental causes. Unfortunately, the research is still in its early stages and nothing regarding this has been found yet. Although the research is currently of limited direct utility to the MSE models, it may be of more use in the future, if environmental drivers of variability in recruitment, movement, and/or other important parameters are found.

7. CLEARING OF THE REPORT

The WG Chair prepared a draft of the report, which was reviewed by the WG prior to adjournment of the workshop. After the workshop, the WG Chair evaluated and incorporated suggested revisions, made final decisions on content and style and distributed a second draft via email for approval by WG members. The final report will be forwarded to the Office of the ISC Chair for review and approval by the ISC18 Plenary.

8. ADJOURNMENT

The ALBWG meeting was adjourned at 12:40 on 4 May 2018. The WG Chair thanked the hosts (Drs. S. Teo and G. DiNardo, SWFSC; Drs. C. Minte-Vera and G. Compean, IATTC) for their hospitality and overall arrangements for a productive workshop. He expressed his appreciation to Dr. D. Tommasi (primary MSE modeler) for her enormous efforts to develop the MSE framework for North Pacific albacore. He also thanked the scientists participating in the workshop for their attendance and contributions on albacore matters.

Attachment 1

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Attachment 2

ALBACORE WORKING GROUP (ALBWG)

INTERNATIONAL SCIENTIFIC COMMITTEE FOR TUNA AND TUNA-LIKE SPECIES IN THE NORTH PACIFIC OCEAN

INTERSESSIONAL DATA PREPARATION WORKSHOP

30 April – 5 May 2018

SWFSC/NOAA, La Jolla, CA, USA

Agenda

1. Opening of the Workshop
   i. Welcoming Remarks
   ii. Chair's Remarks (context, objectives, outputs)
   iii. Meeting Arrangements
   iv. Introductions
2. Meeting Logistics
   i. Meeting Protocol
   ii. Review and Adoption of the Agenda
   iii. Distribution of documents and Working Paper Availability
   iv. Assignment of Rapporteurs
   v. Group Photo
3. Review MSE WS and ALBWG WS in October 2017
4. Review OM development and conditioning
5. Review preliminary MSE results
6. Draft executive summary of the MSE progress for the ISC18 plenary
7. Other matters
8. Clearing of Report
9. Adjournment

Attachment 3
List of Working Papers and Presentations

Number	Title and Authors	Availability
ISC/18/ALBWG-01/01	Correlations between Climatic indices (NPGO and PDO) and Abundance of Albacore Tuna in Waters off Northwest Coast of North America. Zane Zhang	Available from the ISC website
ISC/18/ALBWG-01/02	Update of future projection program for stock synthesis 3 Hirotaka Ijima	Available from the ISC website
Presentation	Overview of OM Conditioning and MSE Framework Desiree Tommasi	Contact the author

Attachment 4
Progress report on Management Strategy Evaluation (MSE) for North Pacific Albacore (NPALB)

Contents

The two Regional Fisheries Management Organizations (RFMOs) tasked with managing the NPALB stock, namely the Western and Central Pacific Fisheries Commission of the Northern Committee (WCPFC NC) and the Inter American Tropical Tuna Commission (IATTC), agreed for the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) Albacore Working Group (ALBWG) to start developing an MSE framework for NPALB. The aim of this MSE process is to examine the performance of candidate alternative management strategies and reference points for NPALB given uncertainty.

The purpose of this report is to present the progress up to date in the development of the MSE framework and some examples of results illustrating potential output from the MSE. It should be noted that the MSE for NPALB is still under development and that any materials shown in this report are highly preliminary and do not represent conclusive results.

1. Development of MSE framework for NPALB

MSE is a process whereby the robustness to uncertainty of a set of harvest control rules (HCRs) are assessed using a computer simulation given a set of management objectives and performance metrics of interest to managers and stakeholders. To capture the range of uncertainty in the system, the MSE simulation includes a set of operating models (OMs), which are mathematical representations of the true dynamics of the population of interest. To determine if these OMs are realistic representation of the stock, these models are "conditioned" on historical data. Section 1.1 provides a description of the operating models considered for the NPALB MSE and of the "conditioning" process. 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 models (i.e. different harvest strategies and harvest control rules). This closed-loop forward simulation is described in section 1.2.

1.2 "Conditioning" process

The uncertainties to be considered in this first round of NPALB MSE were agreed upon and prioritized at the 3rd ISC MSE WS in October 2017 in Vancouver, Canada (Table 1). Given the long run time to complete a single MSE simulation, this first set of OMs were developed to consider uncertainties in the factors agreed to be highest priority by the ISC NPALB WG:

1) Recruitment – autocorrelation and various values of steepness parameter
2) Natural mortality – various values of natural mortality parameters
3) Growth – various values of growth parameters

and in juvenile movement (via time varying age selectivity), which was a medium priority (Table 1).

Here we first describe the OM base case model and then the structure of the additional OMs developed to capture the range of uncertainties described above. All the OMs consist of a population dynamics model of NPALB with a fishery model component relating the modeled dynamics to catch, CPUE, and size composition data. Like the stock assessment, the OMs are developed using the Stock Synthesis modelling platform (Methot and Wetzel 2013).

1.1.1 Base Case Model Structure

The base case OM structure was similar to the latest stock assessment model (SAM) for NPALB (ISC 2017). One difference consisted of the addition of a new CPUE based juvenile index. This was made available by Dr. D. Ochi in February 2018 and was based on the Japanese long line fishery that operates in Areas 1 and 3 in quarter 1 targeting juvenile albacore. Before inclusion in the OM the consistency of the new index with the original assessment was evaluated by comparing the fit to the adult CPUE index, size composition data, and catch of a model with and without the new juvenile CPUE index.

As for the SAM, growth in the base case OM follows the von Bertalanffy growth function and growth curves are sex-specific. However, the specific growth parameters differed between the base case OM and the 2017 SAM. The SAM fixed the growth parameters to values obtained by Xu et al. (2014). Xu et al. (2014) collated age at length data from the Chen at al. 2012 and Wells et al. 2013 studies, and growth parameter estimates were computed by assuming that each length observation was a random sample for a given age. However, given gear selectivity and fish movement, this may not have been the case. Hence, for the OM, growth parameters were first estimated within the stock assessment model by fitting to age-length data in addition to length composition data from the catch. Note that while the model estimates growth parameters for females, the model estimates exponential offset parameters for males. For instance, the asymptotic length, L_{inf}, for males is calculated as: female L_{inf}*exp(L_{inf} offset parameter). During estimation of the growth parameters, a range of different likelihood weights for the age-length data were tested, and a 0.6 weight was chosen as the best trade-off between a good fit to the CPUE index, as compared to the SAM, and information from the age-length data.

Fitting to age-at length data not only informs growth parameter estimates but also stock status estimates. Therefore, the final base case OM had the growth parameters fixed at those estimated when fitting to the age at length data, and it was not fit to the age at length data. To summarize, growth parameters were estimated following these steps:

1. Estimate growth data given the age at length data with a weight of 0.6
2. Run the OM model with no age at length data and with the growth parameters fixed at what was estimated in step 1.

Unlike the SAM, recruitment deviations in the OM were autocorrelated. To select the amount of autocorrelation, the autocorrelation of recruitment deviates from both the base SAM model starting in 1993 and the sensitivity run starting in 1966 from the latest stock assessment were examined. Recruitment estimates from 1993 were not significantly autocorrelated at any lag. By contrast, estimates of recruitment deviations from 1966 showed a significant autocorrelation of 0.42 at lag 1. The autocorrelation of recruitment deviations in the OM was set to 0.42 (Table 2).

Albacore movement and, in particular, juvenile migration rates to the eastern Pacific Ocean (EPO) vary between years. To represent uncertainties in juvenile migration rates over time, the OM has a time varying selectivity for the EPO surface fleet, which targets juveniles. As in the stock assessment, age selectivity for the three juvenile targeting surface fisheries F16, F17, and F27 was set as a free parameter from ages 1-5. In addition, the age-selectivity of the EPO fleet was made time varying in the OM using additive random walk deviations for ages 1-4 (Table 2).

The following model structural features are in common to both the 2016 NPALB SAM, the base case OM, and the alternative OMs:

- One area model
- 29 fisheries

- Dome-shaped size selectivity
- Surface fisheries (Japan pole and line and US EPO) have age selectivity for ages 1 to 5 as free parameters
- Adult CPUE index from fishery F9, the Japanese longline fishery in area 2 quarter 1, from 1996 to 2015
- Model start year is 1993
- Quarterly length composition data compiled into 2-cm bins ranging from 26 to 142 cm for the Japanese longline area 1 and 3 fisheries, the Japanese longline Area 2 fisheries, the Japanese longline area 4 fisheries, the Japanese longline area 5 fishery, the Japanese pole and line fisheries, the US longline fishery, the Taiwanese longline fishery, and the EPO surface fishery.
- Length composition data from the Japanese longline Area 2 fisheries, the Japanese longline area 4 fisheries, and the US longline fishery are downweighted by multiplying the likelihood of these data by 0.1.

Specifications for the growth, recruitment, natural mortality and time varying selectivity parameters for the base case OM are outlined in Table 2.

1.1.2 Structure of Alternative Operating Models

Alternative OM structures were developed to consider uncertainties in natural mortality, steepness, and growth. As the base case OM, alternative OMs have autocorrelated recruitment deviations and time varying age selectivity for the EPO fishery. Values of natural mortality, steepness, and growth differ from the base case. We provide a description below of how these alternative parameter values were selected.

1.1.2.1 Natural Mortality of Alternative Operating Models

Following the stock assessment and best-available biological knowledge for this stock, the OMs have an age-specific natural mortality (M) for ages 0 to 2, and a sex-specific, constant M for ages 3+. The SAM and base case OM set M to the median of the M distribution derived from the meta-analyses of empirical relationships between adult M and life history parameters described in Teo (2017) and Kinney and Teo (2016). To capture the uncertainty in M the 25th percentile and 75th percentile of that same distribution were taken as alternative values of age 3+ M: 0.29 and 0.53 for males, and 0.36 to 0.66 for females. Following Teo (2017) and Kinney and Teo (2016), the 25th and 75th percentiles for M for ages 0 to 2 were calculated by assuming M for younger ages to be size dependent and using the Lorenzen method to calculate age-specifc M for ages 0 to 2 from the 25th or 75th percentiles of the male age 3+ M distribution.

1.1.2.2 Steepness of Alternative Operating Models

The current stock assessment has a steepness of 0.90. Alternative values of steepness were derived from Brodziak et al. (2011), which used Mangel's simulation method (Mangel et al. 2010) to estimate probable values of steepness given information on growth, maturity, weight at age, natural mortality, and reproductive ecology. Alternative values of steepness that were considered were the 5th percentile of the lowest Brodziak et al. (2011) estimate of mean steepness, 0.70, and the 95th of the highest estimate, 0.97.

1.1.2.3 Growth of Alternative Operating Models

The combination of three different steepness values and three different sets of M parameters, produces nine potential OMs, including the base case model. As for the base case, growth parameters for each of these alternative OMs were estimated using age at length data.

The asymptotic length, L_{inf}, was considered the most uncertain growth parameter by the ISC ALB WG. Therefore, to consider uncertainty in growth, 18 additional OMs were developed that used the 5th or 95th percentiles of the female L_{inf} parameter estimated for each of the nine potential OMs (Table 3 and 4). In these additional 18 OMs, the other growth parameters were estimated while keeping the female L_{inf} parameter fixed at the 5th or 95th percentiles values. The modelling work flow to estimate the growth parameters is outlined in more detail below:

1. Estimate growth data given the age at length data with a weight of 0.6 for each steepness and mortality combination
2. Run the model with no age at length data and with the growth parameters fixed at what was estimated in step 1. These are the g1 cases.
3. Compute the 5th or 95th percentile of the female L_{inf} given the standard deviation of the L_{inf} parameter estimated in step 1
4. Run the model again with the female L_{inf} fixed at the value in step 3 to estimate the other growth parameters using the age at length data
5. Run the model with no age at length data and with the growth parameters fixed at what was estimated in step 4. These are the g2 (5th percentile) or g3 (95th percentile) cases.

The 27 OMs (Table 3 and 4), like the assessment model, were conditioned on 1993-2015 observations by fitting the simulated historical data to observed catch, CPUE, and length composition data using maximum likelihood. Nine out of the 27 OMs failed to converge (Table 3) and were therefore not considered further. OMs with the high natural mortality parametrization produced unrealistic spawning biomass (SSB) estimates unless growth option 3 (large L_{inf}) was used concurrently (Fig. 1). These OMs were also excluded from the final set of OMs. OM no. 4 (Table 3) produced an extremely low SSB estimate (Fig. 1) and was put in a robustness set to be tested at a later date. The robustness set is meant to encompass those OM scenarios that are less likely but still plausible. Finally, the set of OMs was refined further by discarding OMs that produced similar trends in spawning potential ratio (SPR), SSB, and depletion, leaving a final set of 8 OMs (Fig. 2 and Table 3). For this preliminary set of MSE results, only the base case and the OMs with the highest (OM no. 27 in Table 3, Fig. 2) and lowest (OM no. 26 in Table 3, Fig. 2) productivity scenarios were used.

1.2 "Future" process (including management model)

Once the "conditioning" process is completed, the OMs can be projected forward in time in a closed loop simulation. Here, each of three OMs (base case, low, and high productivity) was projected forward from 2016 to 2045, a period of 30 years, which corresponds to 2 generations of NPALB. An MSE aims to simulate a realistic management process, which includes data collection, an estimation of stock status given the observed data using a stock assessment, and a management decision given the stock status estimate. The NPALB stock assessment is conducted every three years, hence in the MSE simulation data with error is generated from the OM and ingested into an estimation model (EM) every three years. Estimates of stock status and reference points are then supplied to a management model, which is comprised of a harvest control rule (HCR) with specific limit and target reference points. A total allowable catch (TAC) or total allowable effort (TAE) is set following the HCR and this determines the catch in the OM for the following three years. To account for the fact that in practice not the exact TAE or TAC will be implemented, an implementation error is added 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. 3).

1.2.1 Data Generation

Catch, CPUE, and size composition data is generated using the Stock Synthesis data generation routine (Methot and Wetzel 2013). First, the new catch data given the TAC or TAE 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 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), error structure (lognormal for catch and CPUE, multinomial for the size composition data) assumed during the conditioning phase and the expected value for each datum. The new data with observation error is then inputted into the EM, while data without error is added to the OM data file.

1.2.2 Estimation Model

The estimation model has the same modeling structure of the current SAM; it does not assume recruitment deviations are autocorrelated and does not employ time varying age selectivity for the EPO fishery. However, as the base case OM, it employs the new juvenile abundance index and the growth parameters are the same as the base case OM. Estimates of terminal year female SSB (SSB_{LATEST}), terminal year fishing intensity (F_{LATEST}) and reference points are produced by the EM and used by the management model to set a TAC or TAE. In this MSE, biomass-based reference points specify a fraction of the unfished female SSB, while F-based reference points refer to the exploitation rate (biomass at the beginning of the year/total catch per year) that produces the target SPR level.

1.2.3 Management Model

The management model specifies the harvest strategy (HS) and harvest control rule (HCR) to be implemented. During the 3rd ISC MSE WS, three candidate HS were selected for testing during the first NAPLB MSE (Table 5).

For HS1, if SSB_{LATEST} is at or above the $SSB_{THRESHOLD}$ reference point, the TAC or TAE are set to maintain a fishing impact around F_{TARGET} and a SSB around SSB_{TARGET} (Fig. 4). In the simulation this is done by setting the $F = F_{TARGET}$. If SSB_{LATEST} is below $SSB_{THRESHOLD}$ with a given probability (see Table 5 for the range of probabilities to be tested), but above SSB_{LIMIT}, F is gradually diminished based on a proportional reduction from F_{TARGET} using the fraction $SSB_{LATEST}/SSB_{THRESHOLD}$, so that $F = F_{TARGET^*}$ $SSB_{LATEST}/SSB_{THRESHOLD}$ (Fig. 4). If SSB_{LATEST} is below SSB_{LIMIT} with a given probability a range of alternative management actions can be considered (from initiating a rebuilding plan to setting a very low constant minimum F, F_{MIN}). Potential management actions put forward at the 3rd ISC MSE WS are outlined in Table 5. For this first set of preliminary results, the first rebuilding option of setting $F_{MIN} = 0$ was used. Also, for these initial runs, both the probability of SSB_{LATEST} being below $SSB_{THRESHOLD}$ and the probability of SSB_{LATEST} being below SSB_{LIMIT} was set at the 50% level. A set of different limit, target, and thresholds reference points were put forward to be tested at the 3rd ISC MSE WS, with combinations of different reference points leading to 16 potential HCRs for HS1 (Table 6).

HS3 is the same as HS1 except that the proportional reduction in F when SSB_{LATEST} is below $SSB_{THRESHOLD}$ but above SSB_{LIMIT} occurs at a faster rate, decreasing linearly until F_{MIN} when SSB_{LATEST} is below SSB_{LIMIT} (Fig. 4, Table 5). Like HS1, there are 16 candidate HCRs for HS3, given the same potential combinations of reference points.

HS2 is based on the IATTC-Resolution C-16-02, IATTC's HCR for tropical tunas. In this HS there is no $SSB_{THRESHOLD}$ (i.e. a biomass-based control point). Management actions occur if F_{LATEST} is above F_{TARGET}, whereby F is set to F_{TARGET}, which for this HS is F_{MSY}. For NPALB, F_{MSY} corresponds to a fishing intensity the produce an SPR level of approximately 14%. Management measures are also established if the probability that F_{LATEST} will exceed F_{LIMIT} is greater than 10% or if the probability that SSB_{LATEST} is below SSB_{LIMIT} is greater than 10%. For HS2, SSB_{LIMIT} is $SSB_{0.5r0}$ and F_{LIMIT} is $F_{0.5r0}$. This is the SSB or fishing intensity corresponding to a biomass that leads to a 50% reduction in the unfished recruitment level given a steepness value of 0.75. For NPALB this correspond to an SSB that is approximately 7.7% of the unfished biomass. Hence, we refer to these limit reference points as $F_{7.7\%}$ and $7.7\%SSB_{CURRENT,F=0}$. As for HS1 and HS3, the rebuilding option used for these preliminary results if F_{LATEST} or SSB_{LATEST} falls below the limit reference point is to set a constant F_{MIN} of 0.

For each HS, the F that is set by the HCR is then multiplied by the current total biomass to obtain a catch. The catch is then split into a fishery-specific catch using catch ratios for each fleet (fractions of total catch) that correspond to average historical catch ratios. At the 3rd ISC MSE WS, it was agreed that the historical period to determine catch ratios would be 1999 to 2015. For a TAC based rule, the same TAC is kept constant for the following three years of simulation. For a TAE-based rule, the F is kept constant for the following three years of simulation, but the actual catch varies depending on fluctuations in total biomass.

1.2.4 Implementation Error

Before the catch determined by the HCR is introduced into the OM, each fishery-specific F is modified by an implementation error. We assume that the actual F always exceeds the amount set by the HCR and the F is multiplied by a random implementation error ranging from 5% to 20% and set to 1.05 + abs(N(0, σ =0.05)).

1.2.5 Future Effort Scenarios

In addition to the uncertainties described in the "conditioning" section, two potential future fishing effort scenarios prioritized during the 3rd MSE Workshop were developed:

1) Shift of south Pacific fishing effort to the north Pacific – new entrant to fishery but catch is known to the assessment and under HCR – ramp in catch
2) Shift of south Pacific fishing effort to the north Pacific – new entrant to fishery but catch is known to the assessment and under HCR – step change in catch

To implement these scenarios the South Pacific albacore (SPALB) catch by country based on WCPFC Year book 2016 was examined. Since 2001 nine countries, namely Japan, Chinese Taipei, China, French Polynesia, Fiji, Korea, New Zealand, United States, and Vanuatu have fished SPALB. Average catch from 2001 to 2016 was approximately 72,000 mt. For future effort scenario 1, the total SPALB catch is divided by 30 years and the NPALB catch is gradually increased every year by 2400 mt. For future effort scenario 2, the total SPALB catch is introduced as a step change during the first time step of the simulation. For both fishing effort scenarios, the new catch is associated with a new longline fishery operating in area 4, whose selectivity is mirrored to that of the Area 4 Japanese longline fleet.

1.2.6 Current and Future Progress

The run time for one 30-year simulation is approximately 10 hrs. The long run time is because a full stock assessment is run every three years in each simulation, and each stock assessment can take 1 hr or more to complete, particularly in the latter time steps. The MSE is run in parallel on a computer with 36 cores with 72 threads and 320 GB of RAM. We can simultaneously perform 35 iterations for each HCR differing in their random process errors (for recruitment, time varying selectivity, and implementation error). Ideally, one would run at least 70 iterations for each HCR, increasing the run time to 20 hrs. Given the long run time, at the time of the ISC ALBWG meeting in May 2018, only simulations for portions of HS2 and HS1 using the TAC option were completed. For example, only 1 HCR option (HCR1) for HS1have been run with all uncertainty scenarios at this point in time. Otherwise, all HCR options (1-16) for HS2 and most HCR options (2-16) for HS1 were only run for the base case, the low and high productivity OM scenarios, as well as a robustness scenario. For this robustness scenario, a step change in catch equivalent to three times the historical catch was introduced during the first time step to assess how the model and management scenarios would react once the population was driven below the limit reference point. 35 iterations were completed for all the HCRs tested.

Completing all the HSs with all the potential options proposed at the 3rd ISC ALB MSE WS and outlined in Table 5 using the current MSE framework and computing resources, would take approximately 5 years. Hence, the ISC ALB WG recommended that a reduced set of scenarios, HCRs, and reference points that can be completed before the 4th ISC MSE workshop in spring 2019 be proposed. Here we present this reduced set and explain the rationale for the choices of proposed scenarios, HCRs, and reference points. We propose the number of OMs reflecting uncertainty scenarios be reduced from 8 to 5 by excluding OMs No. 10 and 19, which have similar trends in SSB, SPR, and depletion to OM No. 1 (Fig. 2), and OM No. 2, which has similar trends to OM No. 26 (Fig. 2). For HS1 and HS3, we propose to reduce the number of HCRs from 16 to 8. The selected HCR (Table 6) include all the proposed target reference points, and limit reference points. This final set represents the HCRs showing the most contrast in performance metrics following the initial MSE analysis. Initial results show that the choice of $SSB_{THRESHOLD}$ reference point has less of an effect on performance metrics than the limit or target reference points (see Section 2 below). The ISC NPALB WG also proposes to reduce the HCR options outlined in Table 5 to those outlined in Table 7. Briefly, the probability of SSB_{LATEST} being below $SSB_{THRESHOLD}$ and the probability of SSB_{LATEST} being below SSB_{LIMIT} will be set to only the 50% level, and only the $F_{MIN} = 0$ management action when SSB_{LATEST} is below SSB_{LIMIT} will be tested.

As another potential option to reduce run time, the ISC ALB WG recommended that the use of an Age Structured Production Model (ASPM) as an alternative EM be explored. An ASPM is a simplified version of the fully integrated stock assessment model the current EM is based on. It does not estimate selectivity parameters nor recruitment deviations and does not make use of the size composition data. As such it reduces the overall run time to one fifth of the time it takes to run the MSE with the current EM. The ISC ALB WG suggested that if error distributions between the EM estimates and the OM using the ASPM were comparable to the fully integrated model, the ASPM would be a reasonable EM to use.

Here we compare the errors (computed as OM – EM estimate) for dynamic unfished spawning biomass ($SSB_{CURRENT, F=0}$) and the exploitation rate that leads to F_{TARGET}. For the base case, taking HCR1 as an example, the ASPM produced less precise estimates of $SSB_{CURRENT, F=0}$ and, although errors were small, more biased estimated of F_{TARGET} (Fig. 5). As expected, bias was higher for the low productivity scenario, but estimates were comparably biased in the ASPM and the fully integrated EM for both $SSB_{CURRENT, F=0}$ and F_{TARGET} (Fig. 6). As in the base case, the $SSB_{CURRENT, F=0}$ ASPM estimate was less precise than that from the fully integrated EM (Fig. 6).

When examining the error distribution in the fully integrated model, it became apparent that there was feedback between the HCR, EM stock status estimates, and OM so that the bias and precision of F_{TARGET} varied across HCRs, even for the same uncertainty scenario (Fig. 7). In particular, HCRs with a higher F_{TARGET} had less precise, but less biased estimates (HCRs 13 to 15 in Fig. 7). It was important for such trends in error distribution across HCRs to be maintained in the ASPM. We compared HCRS 4, 10, and

13, which differ in their F_{TARGET}, for the low productivity scenario in both the ASPM and fully integrated model. The pattern of less biased F_{TARGET} estimates for the HCRs with higher F_{TARGET} was also apparent in the ASPM, albeit they were not as imprecise as in the fully integrated model (compare Fig. 7, 8, and 9).

For the ASPM to be used as an EM, resulting patterns in the OM quantities used to produce performance indicators have to be comparable. Trends in such quantities between an ASPM-MSE and the fully integrated EM-MSE were comparable (e.g. Figs. 10, 11, and 12), except for the catch and TAC metrics, which were less variable across iterations for the ASPM-MSE (Fig. 13). The ASPM stock status estimates are much less variable than for the integrated model, as the ASPM does not consider variability in recruitment or time varying selectivity, which is largely what drives differences between iterations. For example, estimates of $SSB_{CURRENT, F=0}$ from the ASPM EM are not as variable as the ones from the fully integrated EM (Fig. 14). They are also not as variable as the $SSB_{CURRENT, F=0}$ from the OM of either the ASPM-MSE or the fully integrated EM-MSE. This difference leads to less variable TACs and catches and is what drives the higher imprecision of the ASPM $SSB_{CURRENT, F=0}$ estimates. This is also leads to less drastic management actions (e.g. fishery closures) in the ASPM than the fully integrated model as the EM is less able to correctly assess if the SSB is below the LRP. Currently, no decision has been made with regards to the use of an ASPM as the EM. The decision will likely be based on the results of the ASPM exploration shown here, as well as the time required to complete the reduced set of model runs described above and the computing resources available in the near future.

2. Example of representation of performance indicators

Results from an MSE are typically very voluminous and complex, and some summarization is required to convey the important points of the MSE. Here we present some preliminary results to illustrate how MSE output can be described and to receive feedback on clarity of presentation for reporting of final MSE results in 2019. It is reiterated here that the MSE for NPALB is still under development and that any results described here are highly preliminary, do not represent conclusive results, and are for illustrative purposes only.

The output of each simulation is summarized into a set of performance indicators. These performance indicators or metrics are a quantitative representation of pre-determined management objectives and are used to evaluate the performance of each different HS and HCR. Management objectives and performance indicators of interest to stakeholders were finalized at the 3rd ISC ALB MSE WS (Table 7). Owing to the design of the NPALB MSE framework, whereby the TAC/TAE is allocated to different fisheries using historical catch ratios, the preliminary results indicated that there was no contrast between different HCRs in terms of management objective No.3, “Maintain harvest ratios by fishery at historical average”. Therefore, for this report, management objective No. 3 is not included in the examples of MSE output. Table 8 outlines potential examples of performance metrics that could be used to describe the specified management objectives.

Cobweb plots are a useful way to visualize the impact of different HCRs on multiple management objectives simultaneously. Hence, they can be employed to highlight tradeoffs among management objectives. Fig. 15 is an example of a cobweb plot depicting the outcome of each of the five performance indicators for 3 HCRs of HS1 differing only in their target reference point as well as HS2, the IATTC harvest strategy, for a simulation using the base case OM. Lines on the center web have a value of 0, while lines on the outer web of 1. Performance indicators are configured so that values closer to 1 mean better performance and values closer to 0 mean poorer performance. Clearly, there is a tradeoff between management objective 2 (probability of depletion being greater than minimum historical depletion) and management objective 3 (probability of catch being above average historical catch). For instance, the HCR with an F_{TARGET} of 50% has the highest probability of depletion being greater than minimum historical depletion, but the lowest probability of catch being above average historical catch (Fig. 15). By contrast, for the HCR with an F_{TARGET} of 30%, it is unlikely that depletion will be above minimum historical depletion, but it is almost certain that catch will be above the historical average. The HCR with an F_{TARGET} of 40% has an even probability of depletion being above the minimum historical level but also an almost certain probability that catch will be above the historical average.

It is also informative to look at the actual level of a performance metric for each management objective rather than the probability of it being above or below a desired level. For instance, Fig. 16 and 17 depict actual depletion or catch levels for HCRs 1-15 of HS1 for the base case OM scenario. It is evident that the choice of F_{TARGET} has a much stronger impact on performance metrics than the level of $SSB_{THRESHOLD}$ or SSB_{LIMIT}. This is because the NPALB population is in good condition, being at 46% of unfished SSB at the start of the simulation in the base case OM, and SSB never falls below SSB_{LIMIT}. Drastic management actions are never required even with an F_{TARGET} of 30%. However, when using the low productivity uncertainty scenario (OM No. 26 in Table 3, Fig. 2) which has an initial SSB of 21% of unfished levels, the risk of requiring a drastic management action increases with an F_{TARGET} of 30% (Fig. 18). Note, however, that this performance metric is also highly dependent on the level of the LRP, with higher SSB_{LIMIT} having a higher probability of being breached.

3. Workplan

Date	Task/Event
May 2018	9th SAC of IATTC: review of preliminary MSE results
July 2018	ISC18 Plenary: review of progress report and preliminary MSE results
August 2018	SC14: report preliminary MSE results
September 2018	NC14: present preliminary MSE results to managers
March 2019	4th ISC MSE workshop (tentative)
	ALBWG meeting: discuss MSE framework and first round of MSE

	results
May 2019	10th SAC of IATTC: review of first round of MSE results
July 2019	ISC18 Plenary: review of first round of MSE results
August 2019	SC14: report first round of MSE results
September 2019	NC14: present first round of MSE results

4. Glossary (Terminology for MSE)

Spawning potential ratio (SPR) – the ratio of female spawning stock biomass per recruit under fishing to female spawning stock biomass per recruit under unfished conditions.

Operating Model (OM) – Mathematical representation of plausible versions of the true dynamics of the system under consideration. These are conditioned on historical data. Generally, multiple OMs are required to represent the range of uncertainty in different factors. OMs can range in complexity (e.g. from single species to ecosystems models) depending on the management objectives and management strategies being evaluated.

Estimation Model (EM) – An analytical model that takes data generated with error by the operating model (e.g. catch, abundance index) and produces an estimate of stock status. This often mirrors a stock assessment model.

Harvest control rule (HCR) - Pre-agreed upon set of rules that specify a management action (e.g. setting the total allowable catch or location/timing of closures) based on a comparison of the status of the system to specific reference points.

Limit reference point (LRP) – A benchmark current stock status is compared to and that should not be exceeded with a high probability. It can be biomass-based (e.g. SSB_{LIMIT}) or fishing intensity-based (e.g. F_{LIMIT}).

Target reference point (TRP) - A benchmark current stock status is compared to. It represents a desired state management wants to achieve. It can be biomass-based (e.g. SSB_{TARGET}) or fishing intensity-based (e.g. F_{TARGET}).

$SSB_{THRESHOLD}$ – A spawning stock biomass in between a target and limit reference point. It is a biomass-based reference point representing a control point below which a management action is undertaken to bring the stock back to a target state.

Management Strategy Evaluation (MSE) – a simulation-based analytical framework that evaluates trade-offs achieved by alternative management strategies and assesses the consequences of uncertainty in achieving management objectives

Management Objectives – High-level goals of a management plan (e.g. prevent overfishing or promote profitability of the fishery).

Performance metrics - Quantitative indicators that are used to evaluate each HCR and serve as a quantitative representation of the management objectives.

5. References

Brodziak, J., Lee, H.H., and Mangel, M. 2011. Probable values of stock-recruitment steepness for north Pacific albacore tuna. ISC/11/ALBWG/11. Work. Pap. Submitt. to ISC Albacore Work. Gr. Stock Assess. Work. 4-11 June 2011, Natl. Res. Inst. Far Sea Seas Fish. Shimizu, Japan.

ISC. 2017. Stock assessment of albacore tuna in the North Pacific Ocean in 2017. Available from http://isc.fra.go.jp/pdf/ISC17/ISC17_Annex12-Stock_Assessment_of_Albacore_Tuna_in_the_North_Pacific_Ocean_in_2017.pdf

Kinney, M.J., and Teo, S.L.H. 2016. Meta-analysis of north Pacific albacore tuna natural mortality. ISC/16/ALBWG-02/07. Nanaimo, British Columbia, Canada.

Mangel, M., Brodziak, J., and DiNardo, G. 2010. Reproductive ecology and scientific inference of steepness: A fundamental metric of population dynamics and strategic fisheries management. doi:10.1111/j.1467-2979.2009.00345.x.

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.

Teo, S.L.H. 2017. Meta-analysis of north Pacific albacore tuna natural mortality: an update. ISC/17/ALBWG/07. Work. Doc. Submitt. to ISC Albacore Work. Gr. Meet. 11-19 April 2017, Southwest Fish. Sci. Center, La Jolla, California, USA.

Xu, Y., Sippel, T., Teo, S.L.H., Piner, K., Chen, K., and Wells, R.J. 2014. A comparison study of North Pacific albacore (*Thunnus alalunga*) age and growth among various sources 1. (April 2014).

6. Tables

Table 1. Uncertainties for OM conditioning and its progress.

		Progress
High Priority		
Recruitment	autocorrelation and various values of steepness	Done
Natural Mortality	various values of M	Done
Growth	Various values of growth parameters	Done
Medium Priority		
Age selectivity	time-varying age selectivity	Done
Recruitment	linked to environmental indices	in progress
Natural mortality	Sex-specificity	in progress
Catchability	time varying implementation error	in progress
Low Priority		
Growth	time-varying growth	in progress
Catchability	time varying catchability of indices	in progress
Size selectivity	time varying selectivity	in progress

Table 2. Specifications for the base case OM growth, recruitment, time varying selectivity, and natural mortality parameters.

Parameter	
Female asymptotic length (L_{inf})	108.91 cm
Female growth rate (k)	0.2836 y^{-1}
Female length at age-1 (L_1)	45.06 cm
Male L_{inf} Offset	0.1187
Male L_1 Offset	0.0393
Male k Offset	-0.4179
Autocorrelation in recruitment deviations	0.42
Steepness (h)	0.90
Standard deviation of age 1 age selectivity deviations	0.60
Standard deviation of age 2 age selectivity deviations	0.90
Standard deviation of age 3 age selectivity deviations	0.90
Standard deviation of age 4 age selectivity deviations	0.80
Natural mortality age-0 (M0)	1.36 y^{-1}
Natural mortality age-1 (M1)	0.56 y^{-1}
Natural mortality age-2 (M2)	0.45 y^{-1}
Female natural mortality age-3+ (Mf3+)	0.48 y^{-1}
Male natural mortality age-3+ (Mm3+)	0.39 y^{-1}

Table 3. List of the 27 operating models (OMs) representing different uncertainty scenarios and their parameter specifications. H refers to steepness, G to growth, and M to natural mortality. A value of 1 for a parameter means a base case value, a value of 2 a lower value than base, and a value of 3 a higher value than base. See Table 4 for a detailed list of actual steepness, growth, and natural mortality values for each operating model. Eight out of the 27 models were selected to test after thorough reviewing during the WS and those are denoted by an asterisk.

OM No.	h	G	M	Age selectivity	Recruitment autocorrelation	Convergence
Base*	1	1	1	Time varying	0.42	
2*	1	1	2	Base	Base	
3	1	1	3	Base	Base	No
4	1	2	1	Base	Base	
5	1	2	2	Base	Base	No
6	1	2	3	Base	Base	
7	1	3	1	Base	Base	No
8	1	3	2	Base	Base	
9	1	3	3	Base	Base	No
10*	2	1	1	Base	Base	
11	2	1	2	Base	Base	No
12	2	1	3	Base	Base	
13	2	2	1	Base	Base	
14	2	2	2	Base	Base	No
15	2	2	3	Base	Base	
16	2	3	1	Base	Base	No
17	2	3	2	Base	Base	No
18	2	3	3	Base	Base	
19*	3	1	1	Base	Base	
20	3	1	2	Base	Base	
21	3	1	3	Base	Base	
22*	3	2	1	Base	Base	
23	3	2	2	Base	Base	No
24	3	2	3	Base	Base	
25*	3	3	1	Base	Base	
26*	3	3	2	Base	Base	
27*	3	3	3	Base	Base	

Table 4. Steepness, growth and natural mortality parameter specifications for alternative operating models (OMs). See table 2 for definitions of parameter symbols.

OM No.	h	L_{inf}	k	L_1	L_{inf} offset	k offset	L_1 offset	M0	M1	M2	Mf 3+	Mm 3+
Base	0.90	108.91	0.2836	45.06	0.1187	-0.4179	0.0393	1.36	0.56	0.45	0.48	0.39
2	0.90	110.72	0.2641	45.75	0.1018	-0.3465	0.0310	1.01	0.42	0.33	0.36	0.29
3	0.90	108.28	0.2904	44.55	0.1309	-0.4727	0.0373	1.84	0.76	0.61	0.66	0.53
4	0.90	100.38	0.3803	42.90	0.2106	-0.7657	0.0896	1.36	0.56	0.45	0.48	0.39
5	0.90	101.31	0.3721	43.60	0.1944	-0.7065	0.0812	1.01	0.42	0.33	0.36	0.29
6	0.90	99.32	0.3977	42.36	0.2109	-0.7685	0.0853	1.84	0.76	0.61	0.66	0.53
7	0.90	117.44	0.2204	46.54	0.0455	-0.1516	0.0162	1.36	0.56	0.45	0.48	0.39
8	0.90	120.14	0.2110	45.92	0.0524	-0.1762	0.0120	1.01	0.42	0.33	0.36	0.29
9	0.90	117.25	0.2157	45.96	0.0657	-0.2400	0.0151	1.84	0.76	0.61	0.66	0.53
10	0.70	108.86	0.2842	45.02	0.1193	-0.4202	0.0395	1.36	0.56	0.45	0.48	0.39
11	0.70	109.54	0.2755	45.53	0.1124	-0.3871	0.0356	1.01	0.42	0.33	0.36	0.29
12	0.70	108.34	0.2898	44.56	0.1305	-0.4705	0.0367	1.84	0.76	0.61	0.66	0.53
13	0.70	100.43	0.3748	43.38	0.1681	-0.6481	0.0784	1.36	0.56	0.45	0.48	0.39
14	0.70	101.42	0.3721	43.55	0.1893	-0.6872	0.0793	1.01	0.42	0.33	0.36	0.29
15	0.70	99.36	0.3961	42.35	0.2143	-0.7811	0.0863	1.84	0.76	0.61	0.66	0.53
16	0.70	117.29	0.2248	45.63	0.0721	-0.2547	0.0139	1.36	0.56	0.45	0.48	0.39
17	0.70	117.65	0.2216	46.63	0.0479	-0.1461	0.0141	1.01	0.42	0.33	0.36	0.29
18	0.70	117.33	0.2155	45.92	0.0621	-0.2280	0.0152	1.84	0.76	0.61	0.66	0.53
19	0.97	108.88	0.2841	45.07	0.1190	-0.4191	0.0394	1.36	0.56	0.45	0.48	0.39
20	0.97	110.38	0.2677	45.70	0.1051	-0.3605	0.0329	1.01	0.42	0.33	0.36	0.29
21	0.97	108.28	0.2904	44.55	0.1309	-0.4729	0.0374	1.84	0.76	0.61	0.66	0.53
22	0.97	100.38	0.3826	43.03	0.2013	-0.7283	0.0848	1.36	0.56	0.45	0.48	0.39
23	0.97	101.24	0.3638	44.02	0.1642	-0.6217	0.0714	1.01	0.42	0.33	0.36	0.29
24	0.97	99.32	0.3978	45.96	0.2113	-0.7700	0.0859	1.84	0.76	0.61	0.66	0.53
25	0.97	117.38	0.2238	45.67	0.0691	-0.2458	0.0137	1.36	0.56	0.45	0.48	0.39
26	0.97	119.53	0.2055	47.10	0.0220	-0.0670	0.0110	1.01	0.42	0.33	0.36	0.29
27	0.97	117.24	0.2158	45.96	0.0657	-0.2400	0.0151	1.84	0.76	0.61	0.66	0.53

Table 5. Candidate harvest strategies, along with corresponding lists of candidate reference points and harvest control rules proposed at the 3rd ISC ALB MSE WS. $SSB_{CURRENT, F=0}$ refers to dynamic virgin (unfished) spawning stock biomass and fluctuates depending on changes in recruitment. $SSB_{0.5r0}$ is the spawning biomass that leads to a 50% reduction in the virgin recruitment level given a steepness value of 0.75. $F_{0.5r0}$ is the fishing intensity corresponding to $SSB_{0.5r0}$. F-based reference points in this table are not based on instantaneous fishing mortality. Instead, the Fs are indicators of fishing intensity based on SPR and calculated as 1-SPR so that the Fs reflect changes in fishing mortality. SPR is the SSB per recruit that would result from the current year's pattern and intensity of fishing mortality relative to the unfished stock. A fishing intensity of $F_{50\%}$ would result in 50% of the SSB per recruit relative to the unfished state. A fishing intensity of $F_{30\%}$ implies a higher fishing intensity, and would result in 30% of the SSB per recruit relative to the unfished state. $E_{2002-2004}$ refers to the average level of effort from 2002-2004. $E(F_{TARGET})$ refers to the level of effort required to fish at F_{TARGET}.

	Harvest Strategy 1	Harvest Strategy 2	Harvest Strategy 3
Reference Points			
B_{TARGET}	$50\%SSB_{CURRENT, F=0}$ $40\%SSB_{CURRENT, F=0}$ $30\%SSB_{CURRENT, F=0}$	$14\%SSB_{CURRENT, F=0}$	$50\%SSB_{CURRENT, F=0}$ $40\%SSB_{CURRENT, F=0}$ $30\%SSB_{CURRENT, F=0}$
$B_{THRESHOLD}$	$30\%SSB_{CURRENT, F=0}$ $20\%SSB_{CURRENT, F=0}$ $14\%SSB_{CURRENT, F=0}$		$30\%SSB_{CURRENT, F=0}$ $20\%SSB_{CURRENT, F=0}$ $14\%SSB_{CURRENT, F=0}$
B_{LIMIT}	$20\%SSB_{CURRENT, F=0}$ $14\%SSB_{CURRENT, F=0}$ $SSB_{0.5r0}$	$SSB_{0.5r0}$	$20\%SSB_{CURRENT, F=0}$ $14\%SSB_{CURRENT, F=0}$ $SSB_{0.5r0}$
F_{TARGET}	$F_{50\%}$ $F_{40\%}$ $F_{30\%}$ $0.75F_{14\%}$	$F_{14\%}$	$F_{50\%}$ $F_{40\%}$ $F_{30\%}$ $0.75F_{14\%}$
F_{LIMIT}		$F_{0.5r0}$	
Harvest Control Rules 1			
$SSB \geq SSB_{TARGET}$	$TAE = E_{2002-2004}$ $TAE = E(F_{TARGET})$		$TAE = E_{2002-2004}$ $TAE = E(F_{TARGET})$

	Harvest Strategy 1	Harvest Strategy 2	Harvest Strategy 3
	$TAC = B_{LATEST} * F_{TARGET}$		$TAC = B_{LATEST} * F_{TARGET}$
$SSB \geq SSB_{THRESHOLD}$	$TAE = E_{2002-2004}$ $TAE = E(F_{TARGET})$ $TAC = B_{LATEST} * F_{TARGET}$		$TAE = E_{2002-2004}$ $TAE = E(F_{TARGET})$ $TAC = B_{LATEST} * F_{TARGET}$
$SSB < SSB_{THRESHOLD}$, > SSB_{LIMIT}	$TAE = E(F_{TARGET}) * SSB / SSB_{THRESHOLD}$ $TAC = B_{LATEST} * F_{TARGET} * SSB / SSB_{THRESHOLD}$		$TAE = TAE_{MIN} + [E(F_{TARGET}) - TAE_{MIN}] * (SSB - SSB_{LIMIT}) / (SSB_{THRESHOLD} - SSB_{LIMIT})$, or TAE_{MIN}, whichever is greater $TAC = TAC_{MIN} + [(B_{LATEST} * F_{TARGET}) - TAC_{MIN}] * (SSB - SSB_{LIMIT}) / (SSB_{THRESHOLD} - SSB_{LIMIT})$, or TAC_{MIN}, whichever is greater TAE_{MIN} and TAC_{MIN} are the TAEs and TACs when $SSB \leq SSB_{LIMIT}$, without the rebuilding plan (see below)
$SSB \leq SSB_{LIMIT}$	Trigger rebuilding plan $TAE = 0$ $TAE = 0.25 * E_{SSBLIM}$ $TAE = 0.5 * E_{SSBLIM}$ $TAE = E(F_{TARGET}) * SSB / SSB_{THRESHOLD}$ $TAC = 0$ $TAC = 0.25 * C_{SSBLIM}$ $TAC = 0.5 * C_{SSBLIM}$ $TAC= B_{LATEST} * F_{TARGET} * SSB / SSB_{THRESHOLD}$ $E_{SSBLIM} = E(F_{TARGET}) * SSB_{LIMIT} / SSB_{THRESHOLD}$ $C_{SSBLIM} = B_{LATEST} * F_{TARGET} * SSB_{LIMIT} / SSB_{THRESHOLD}$	Trigger rebuilding plan	Trigger rebuilding plan $TAE = 0$ $TAE = 0.25 * E_{SSBLIM}$ $TAE = 0.5 * E_{SSBLIM}$ $TAC = 0$ $TAC = 0.25 * C_{SSBLIM}$ $TAC = 0.5 * C_{SSBLIM}$ E_{SSBLIM} and C_{SSBLIM} for this harvest strategy are the same as the E_{SSBLIM} and C_{SSBLIM} for harvest strategy 1 $E_{SSBLIM} = E(F_{TARGET}) * SSB_{LIMIT} / SSB_{THRESHOLD}$ $C_{SSBLIM} = B_{LATEST} * F_{TARGET} * SSB_{LIMIT}$ /

	Harvest Strategy 1	Harvest Strategy 2	Harvest Strategy 3
			$SSB_{THRESHOLD}$
$F > F_{LIMIT}$		TAE = E(F(Prob. ($F < F_{TARGET}$) > 50%) & Prob. ($F > F_{LIMIT}$) < 10%))	
F > Ftarget		TAE = E(F_{TARGET})	
Harvest Control Rules 2			
Prob($SSB > SSB_{LIMIT}$)	90%, 75%, 50%	90%	90%, 75%, 50%
Prob($SSB > SSB_{THRESHOLD}$)	75%, 50%		75%, 50%
Prob($F < F_{LIMIT}$)		90%	
Rebuilding plan	TAE = E(F(Prob. ($SSB > SSB_{TARGET}$) > 50%)) in 2 generations TAC = B * F(Prob. ($SSB > SSB_{TARGET}$) > 50%) in 2 generations	TAE = E(F(Prob. ($SSB > SSB_{TARGET}$) > 50%) & Prob. ($SSB < SSB_{LIMIT}$) < 10%))) in 2 generations TAC = B * F(Prob. ($SSB > SSB_{TARGET}$) > 50%) & Prob. ($SSB < SSB_{LIMIT}$) < 10%)) in 2 generations	TAE = E(F(Prob. ($SSB > SSB_{TARGET}$) > 50%)) in 2 generations TAC = B * F(Prob. ($SSB > SSB_{TARGET}$) > 50%) in 2 generations
Additional Assumptions			
Allocation	Average of 1999-2015	Average of 1999-2015	Average of 1999-2015
HCRs controls on albacore targeting and/or non-targeting	Both targeting and non-targeting Targeting only	Both targeting and non-targeting Targeting only	Both targeting and non-targeting Targeting only
Assessment	Once every 3 years	Once every 3 years	Once every 3 years

	Harvest Strategy 1	Harvest Strategy 2	Harvest Strategy 3
periodicity			

Table 6. List of harvest control rules for harvest strategies 1. F_{TARGET} is an indicator of fishing intensity based on SPR. SPR is the SSB per recruit that would result from the current year's pattern and intensity of fishing mortality relative to the unfished stock. A fishing intensity at an F_{TARGET} of 50 would result in 50% of the SSB per recruit relative to the unfished state. A fishing intensity at an F_{TARGET} of 30 implies a higher fishing intensity, and would result in 30% of the SSB per recruit relative to the unfished state. SSB-based reference points refer to the specified percentage of dynamic virgin (unfished) SSB. Dynamic virgin SSB fluctuates depending on changes in recruitment. Shaded rows represent the HCRs to be included in the reduced set (see Section 1.2.6)

HCR	F_{TARGET}	SSB_{TARGET}	$SSB_{THRESHOLD}$	SSB_{LIMIT}
1	50	50	30	20
2	50	50	30	14
3	50	50	30	7.7
4	50	50	20	14
5	50	50	20	7.7
6	50	50	14	7.7
7	40	40	30	20
8	40	40	30	14
9	40	40	30	7.7
10	40	40	20	14
11	40	40	20	7.7
12	40	40	14	7.7
13	30	30	20	14
14	30	30	20	7.7
15	30	30	14	7.7
16	14*0.75	14*0.75	14*0.75	7.7

Table 7. Candidate harvest strategies, along with corresponding reduced lists of candidate reference points and harvest control rules options to be evaluated in the initial MSE. $SSB_{CURRENT, F=0}$ refers to dynamic virgin (unfished) spawning stock biomass and fluctuates depending on changes in recruitment. $SSB_{0.5r0}$ is the spawning biomass that leads to a 50% reduction in the virgin recruitment level given a steepness value of 0.75. $F_{0.5r0}$ is the fishing intensity corresponding to $SSB_{0.5r0}$. F-based reference points in this table are not based on instantaneous fishing mortality. Instead, the Fs are indicators of fishing intensity based on SPR and calculated as 1-SPR so that the Fs reflect changes in fishing mortality. SPR is the SSB per recruit that would result from the current year's pattern and intensity of fishing mortality relative to the unfished stock. A fishing intensity of $F_{50\%}$ would result in 50% of the SSB per recruit relative to the unfished state. A fishing intensity of $F_{30\%}$ implies a higher fishing intensity, and would result in 30% of the SSB per recruit relative to the unfished state. $E_{2002-2004}$ refers to the average level of effort from 2002-2004. $E(F_{TARGET})$ refers to the level of effort required to fish at F_{TARGET}.

	Harvest Strategy 1	**Harvest Strategy 2**	**Harvest Strategy 3**
		Reference Points	
B_{TARGET}	$50\%SSB_{CURRENT, F=0}$ $40\%SSB_{CURRENT, F=0}$ $30\%SSB_{CURRENT, F=0}$	$14\%SSB_{CURRENT, F=0}$	$50\%SSB_{CURRENT, F=0}$ $40\%SSB_{CURRENT, F=0}$ $30\%SSB_{CURRENT, F=0}$
$B_{THRESHOLD}$	$30\%SSB_{CURRENT, F=0}$ $20\%SSB_{CURRENT, F=0}$ $14\%SSB_{CURRENT, F=0}$		$30\%SSB_{CURRENT, F=0}$ $20\%SSB_{CURRENT, F=0}$ $14\%SSB_{CURRENT, F=0}$
B_{LIMIT}	$20\%SSB_{CURRENT, F=0}$ $14\%SSB_{CURRENT, F=0}$ $SSB_{0.5r0}$	$SSB_{0.5r0}$	$20\%SSB_{CURRENT, F=0}$ $14\%SSB_{CURRENT, F=0}$ $SSB_{0.5r0}$
F_{TARGET}	$F_{50\%}$ $F_{40\%}$ $F_{30\%}$	$F_{14\%}$	$F_{50\%}$ $F_{40\%}$ $F_{30\%}$
F_{LIMIT}		$F_{0.5r0}$	
	Harvest Control Rules 1		
$SSB \geq SSB_{TARGET}$	$TAE = E_{2002-2004}$		$TAE = E_{2002-2004}$

	Harvest Strategy 1	**Harvest Strategy 2**	**Harvest Strategy 3**
	$TAE = E(F_{TARGET})$ $TAC = B_{LATEST} * F_{TARGET}$		$TAE = E(F_{TARGET})$ $TAC = B_{LATEST} * F_{TARGET}$
$SSB \geq SSB_{THRESHOLD}$	$TAE = E_{2002\text{-}2004}$ $TAE = E(F_{TARGET})$ $TAC = B_{LATEST} * F_{TARGET}$		$TAE = E_{2002\text{-}2004}$ $TAE = E(F_{TARGET})$ $TAC = B_{LATEST} * F_{TARGET}$
$SSB < SSB_{THRESHOLD}$, $> SSB_{LIMIT}$	$TAE = E(F_{TARGET}) * SSB / SSB_{THRESHOLD}$ $TAC = B_{LATEST} * F_{TARGET} * SSB / SSB_{THRESHOLD}$		$TAE = TAE_{MIN} + [E(F_{TARGET}) - TAE_{MIN}] * (SSB - SSB_{LIMIT}) / (SSB_{THRESHOLD} - SSB_{LIMIT})$, or TAE_{MIN}, whichever is greater $TAC = TAC_{MIN} + [(B_{LATEST} * F_{TARGET}) - TAC_{MIN}] * (SSB - SSB_{LIMIT}) / (SSB_{THRESHOLD} - SSB_{LIMIT})$, or TAC_{MIN}, whichever is greater TAE_{MIN} and TAC_{MIN} are the TAEs and TACs when $SSB \leq SSB_{LIMIT}$, without the rebuilding plan (see below)
$SSB \leq SSB_{LIMIT}$	TAE = 0 TAC = 0	TAE = 0	TAE = 0 TAC = 0
$F > F_{LIMIT}$		TAE = 0	
F > Ftarget		$TAE = E(F_{TARGET})$	
		Harvest Control Rules 2	
$Prob(SSB > SSB_{LIMIT})$	50%	90%	50%
$Prob(SSB > SSB_{THRESHOLD})$	50%		50%
$Prob(F < F_{LIMIT})$		90%	

	Harvest Strategy 1	Harvest Strategy 2	Harvest Strategy 3
Additional Assumptions			
Allocation	Average of 1999-2015	Average of 1999-2015	Average of 1999-2015
HCRs controls on albacore targeting and/or non-targeting	Both targeting and non-targeting	Both targeting and non-targeting	Both targeting and non-targeting
Assessment periodicity	Once every 3 years	Once every 3 years	Once every 3 years

Table 8. Updated management objectives for the North Pacific albacore tuna, October 2017. $SSB_{CURRENT, F=0}$ refers to dynamic virgin (unfished) spawning stock biomass and fluctuates depending on changes in recruitment. $SSB_{0.5R0}$ is the spawning biomass that leads to a 50% reduction in the virgin recruitment level given a steepness value of 0.75. SPR is the SSB per recruit that would result from the current year's pattern and intensity of fishing mortality relative to the unfished stock. For objective 2, depletion refers to the ratio of the latest projected total stock biomass and the unfished total stock biomass.

Objective[A]	**Quantity**	**Proposed Performance Indicators[B, C, D]**	**Example Output[B]**
1. Maintain spawning biomass above the limit reference point	• 20%$SSB_{CURRENT, F=0}$ • 14%$SSB_{CURRENT, F=0}$ (calculated as (1-M)*SSB20%) • $SSB_{0.5R0}$, where h = 0.75 (IATTC SAC)	• SSB for each projected year / SSB-based LRP	• % of runs in which ratio ≥1 for 29/30, 27/30, 24/30; • Each run = 30 years
2. Maintain total biomass, with reasonable variability, around the historical average depletion of total biomass	• Historical depletion is estimated as the-depletion level of total biomass for 2006-2015	• Depletion of projected total biomass over 30 yrs /minimum historical depletion of total biomass (minimum of 2006 - 2015)	• % of runs in which ratio ≥1 for 29/30, 27/30, 24/30; • Each run = 30 years
3. Maintain harvest ratios by fishery (fraction of fishing impact with respect to SSB) at historical average	• Historical harvest ratio by fishery estimated as the average of 2006 – 2015 • Historical variability in harvest ratio estimated from 2006 – 2015	• Harvest ratio (H) by fishery (i) for each year is calculated as $(1\text{-}SPR_i)/1\text{-}SPR_{total}$ • Projected harvest ratio by fishery over 30 yrs >= minimum historical harvest ratio by fishery (minimum of 2006 - 2015) and <= maximum historical harvest ratio by fishery (maximum of	• % of runs within minimum and maximum for 29/30, 27/30, 24/30; • Each run = 30 years

Objective[A]	**Quantity**	**Proposed Performance Indicators**[B, C, D]	**Example Output**[B]
		2006 - 2015)	
4. Maintain catches by fishery above average historical catch	• Average catch by fishery over the 30 year period, 1981-2010	• Total catch of each projected year / average total historical catch (1981 – 2010) • Catch by fishery of each projected year / average historical catch of the fishery (1981 – 2010) • Projected catch by fisheries over 30 yrs /lower 25% of historical catch (1981 - 2010) • Projected catch by fisheries over 30 yrs /upper 25% of historical catch (1981 - 2010)	• % of runs in which ratio ≥1 for 29/30, 27/30, 22/30, 15/30; • Each run = 30 years;
5. If a change in total allowable effort and/or total allowable catch occurs, the rate of change should be relatively gradual		• % change in TAE and/or TAC between years (separate increases vs decreases)	• Median ± 5 and 95% percentiles of maximum % change in TAE and/or TAC for all years over all runs • Median ± 5 and 95% percentiles of % of projected years where change (0-15%, 15-30%, >30%) in TAE and/or TAC for all years over all runs

Objective[A]	Quantity	Proposed Performance Indicators[B, C, D]	Example Output[B]
6. Maintain F at the target value with reasonable variability	Various potential target values previously suggested by NC	• F-ratio-target = F-based TRP/ F of each projected year	• Median ± 5 and 95% percentiles of median of F-ratio-target over all runs • Median ± 5 and 95% percentiles of 10%, 95% of F-ratio-target over all runs
The objectives shown below were suggested as ideas requiring further work to implement. They are shown here as an indication of future direction.			
I. Maximize economic returns of existing fisheries II. Maintain interests of artisanal, subsistence and small-scale fishers, including limiting the regulatory impact on these fisheries			
NOTES A - Objectives 1-6 for the first round of MSE were reviewed and agreed upon by the 3rd MSE Workshop participants, October 17-19, 2017. B - Performance indicators and example output proposed by the Albacore Working Group C - Performance indicators are configured so that higher estimated values mean better performance and lower estimated values means poorer performance, i.e., they have consistent directionality to reduce confusion in interpreting results. The exception to this practice is the first indicator (% change due to HCR between years) for objective 5 for which there is no directionality. D - Definition of each fishery for fishery-specific performance indicators should be based on flag and gear.			

Table 9. List of proposed performance indicators.

Management Objective	Label	Performance Indicator
Maintain SSB above the limit reference point (LRP)	p(no drastic management action)	Probability that SSB in any given year of the MSE forward simulation is above the LRP
Maintain depletion of total biomass around historical average depletion	p(depletion)	Probability that depletion in any given year of the MSE forward simulation is above minimum historical (2006-2015) depletion
Maintain catches above average historical catch	p(catch)	Probability that catch in any given year of the MSE forward simulation is above average historical (1981-2010) catch
Change in total allowable catch between years should be relatively gradual	TAC stability	1-%absolute change in TAC between years. Calculated excluding years TAC=0.
Maintain fishing intensity (F) at the target value with reasonable variability	F_{TARGET}/F	F_{TARGET}/F

7. Figures

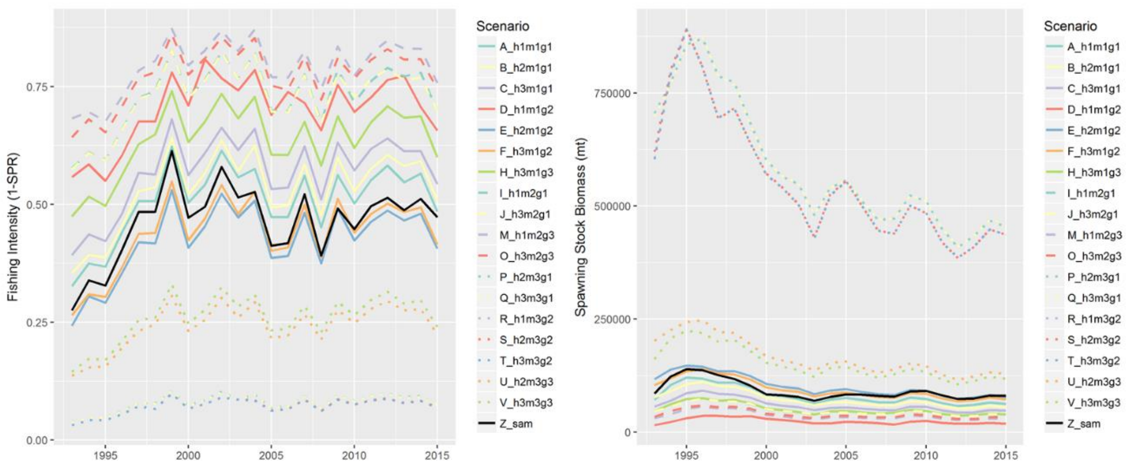

Figure 1. Trends in fishing intensity (1-SPR) and female spawning stock biomass (SSB) of the 18 out 27 OMs that converged during the conditioning process. 1-SPR is the reduction in female SSB per recruit due to fishing and is used to describe the overall fishing intensity on the NPALB. Refer to Table 3 and 4 for a list of the specific steepness (h), natural mortality (m), and growth (g) parameters of each model.

Figure 2. Trends in fishing intensity (1-SPR), female spawning stock biomass (SSB), and depletion (SSB/unfished SSB) for the final set of 8 OMs selected after the conditioning process. 1-SPR is the reduction in female SSB per recruit due to fishing and is used to describe the overall fishing intensity on the NPALB. Refer to Table 3 and 4 for a list of the specific steepness (h), natural mortality (m), and growth (g) parameters of each model.

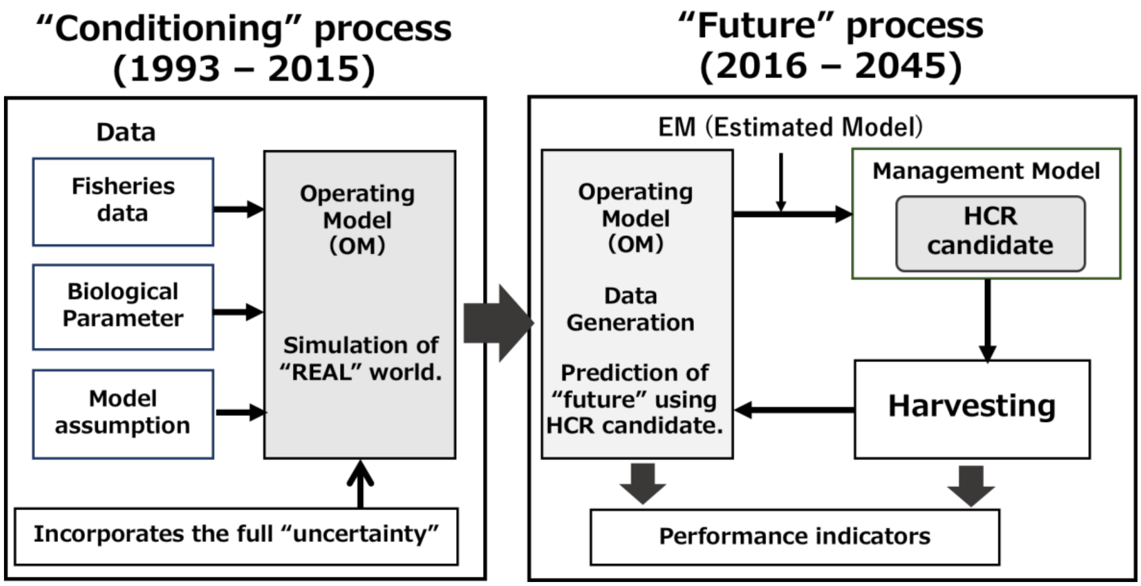

Figure 3. Overview of NPALB MSE framework.

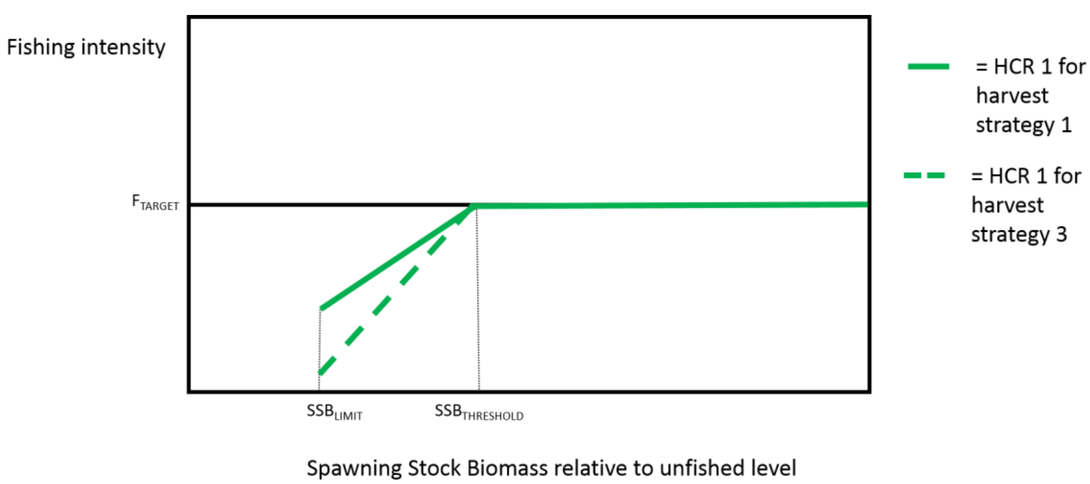

Figure 4. Example of harvest strategy 1 and 3.

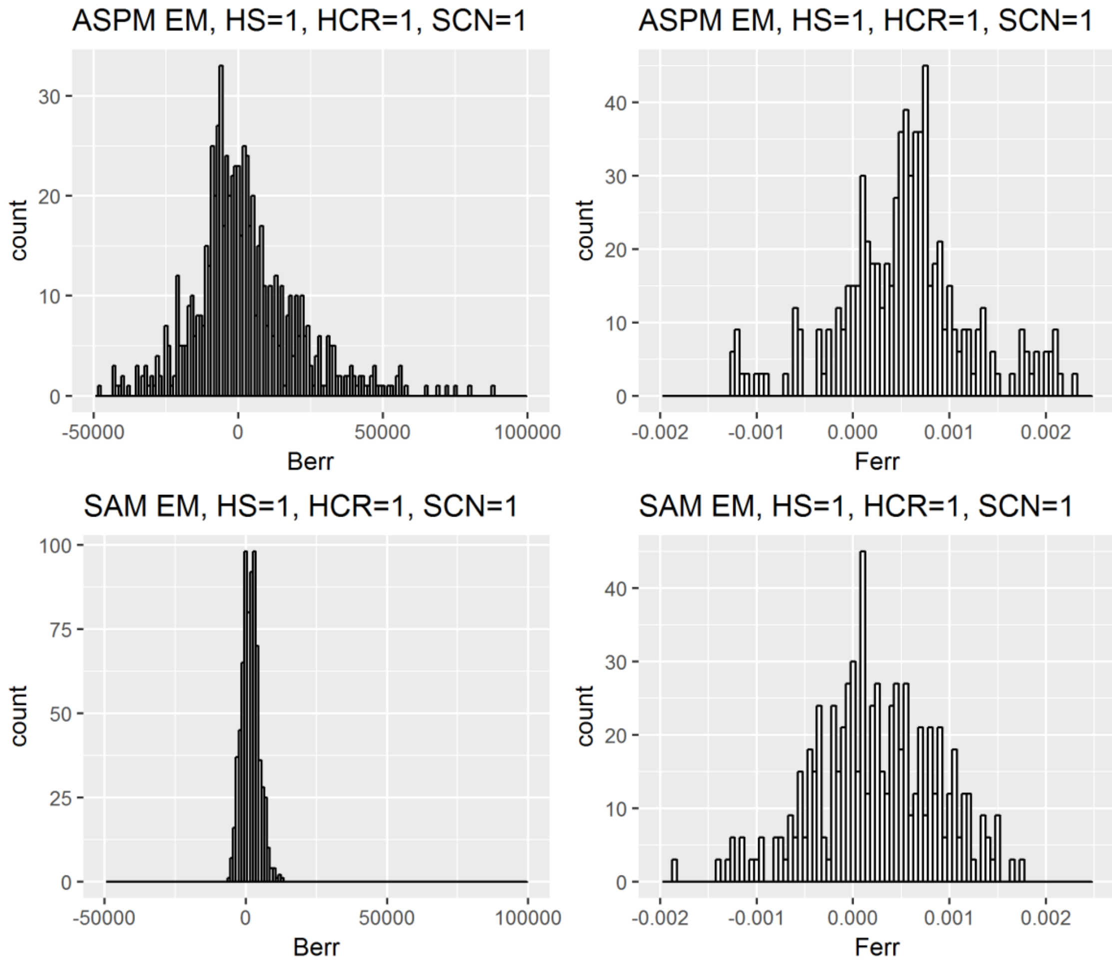

Figure 5. Error (OM – EM estimate) distribution for the dynamic unfished spawning stock biomass (left) and the FTARGET exploitation rate. This is the exploitation rate that produces the specified SPR-based fishing intensity. Error distributions using the fully integrated stock assessment model (SAM) EM are on the bottom, errors using the ASPM are on the top. These results are for the base case and HCR1 of HS1.

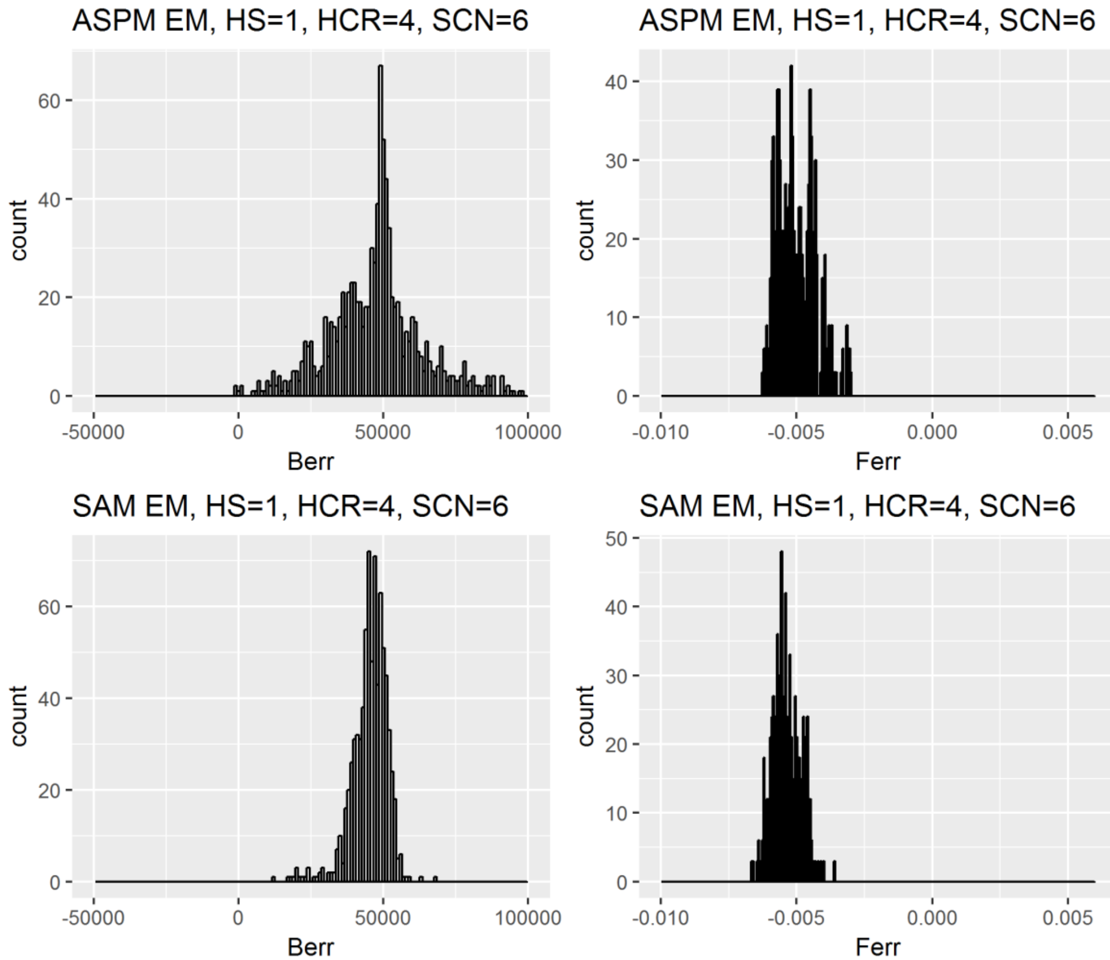

Figure 6. Same as Figure 5 but for the low productivity scenario and HCR4.

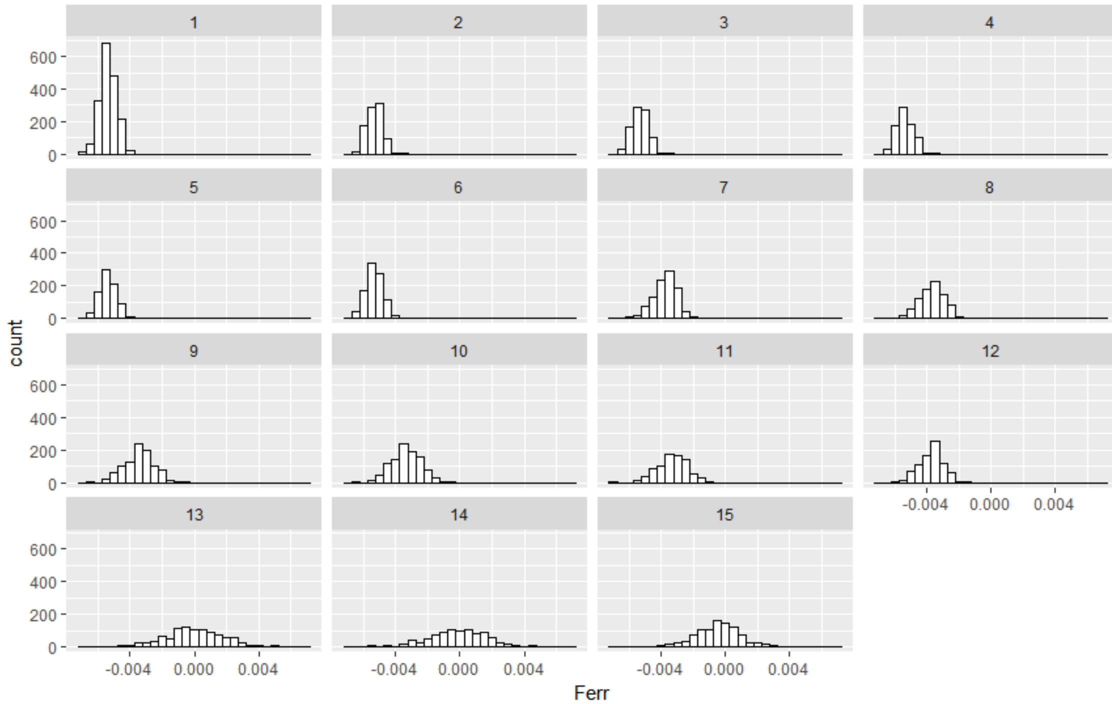

Figure 7. Error (OM – EM estimate) distribution using the fully integrated stock assessment model as the EM for the FTARGET exploitation rate. This is the exploitation rate that produces the specified SPR-based fishing intensity. These results are for the low productivity scenario and HCR1 to 15 of HS1.

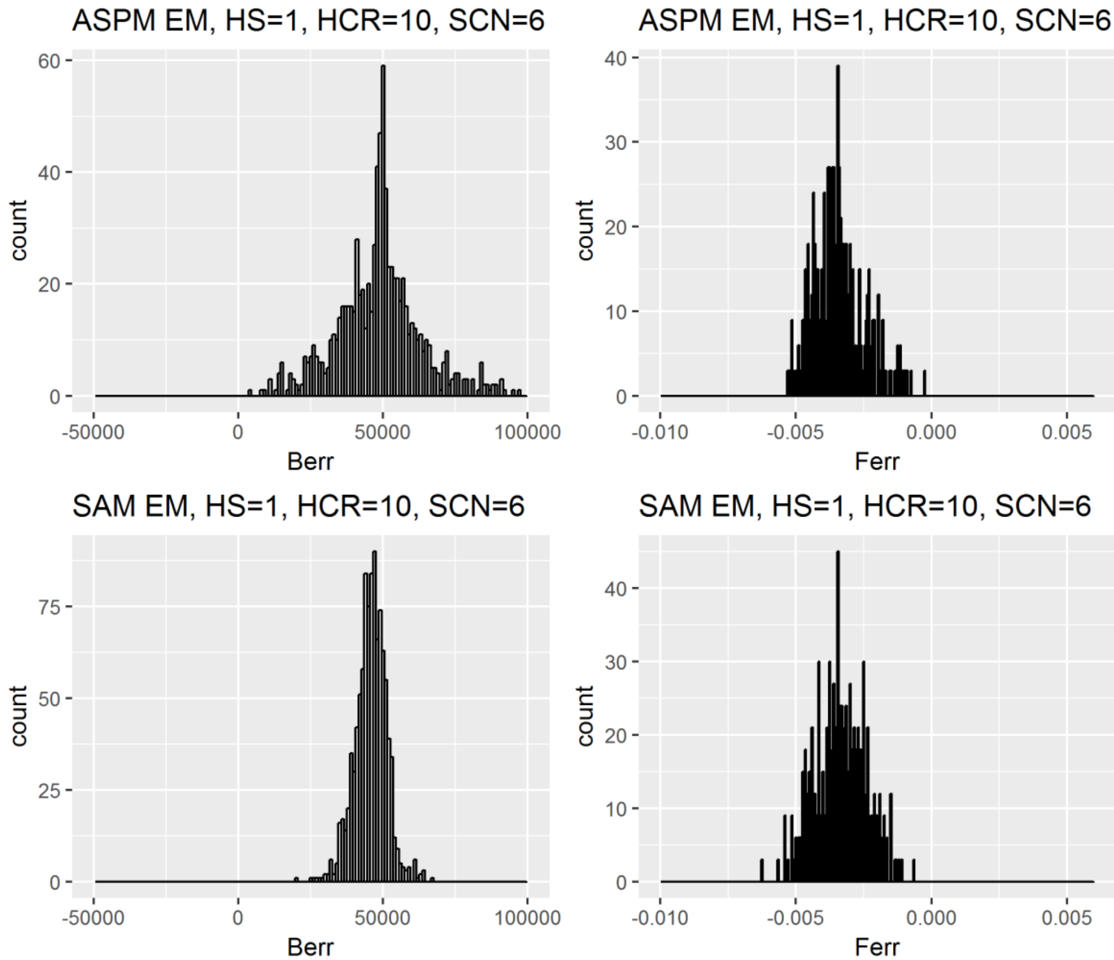

Figure 8. Same as Figure 5 but for the low productivity scenario and HCR10.

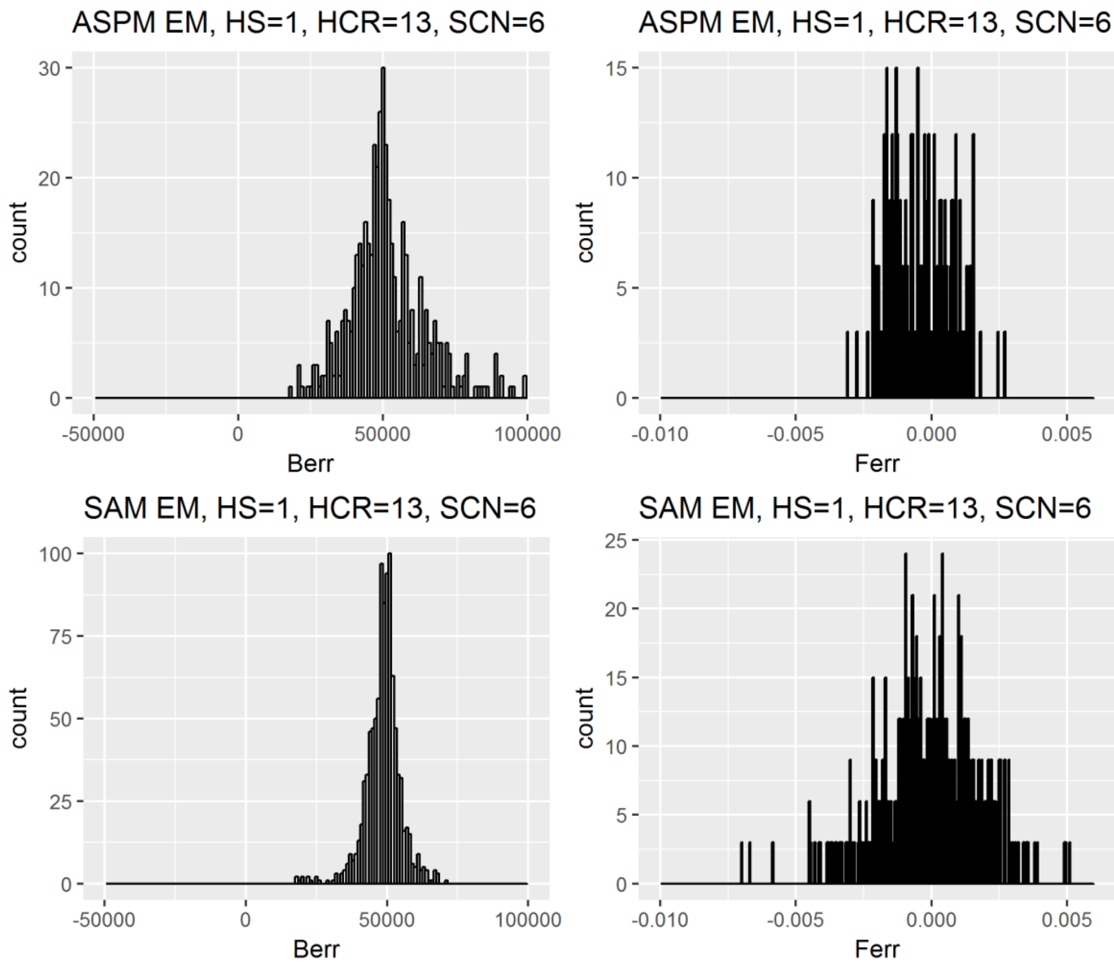

Figure 9. Same as Figure 5 but for the low productivity scenario and HCR13.

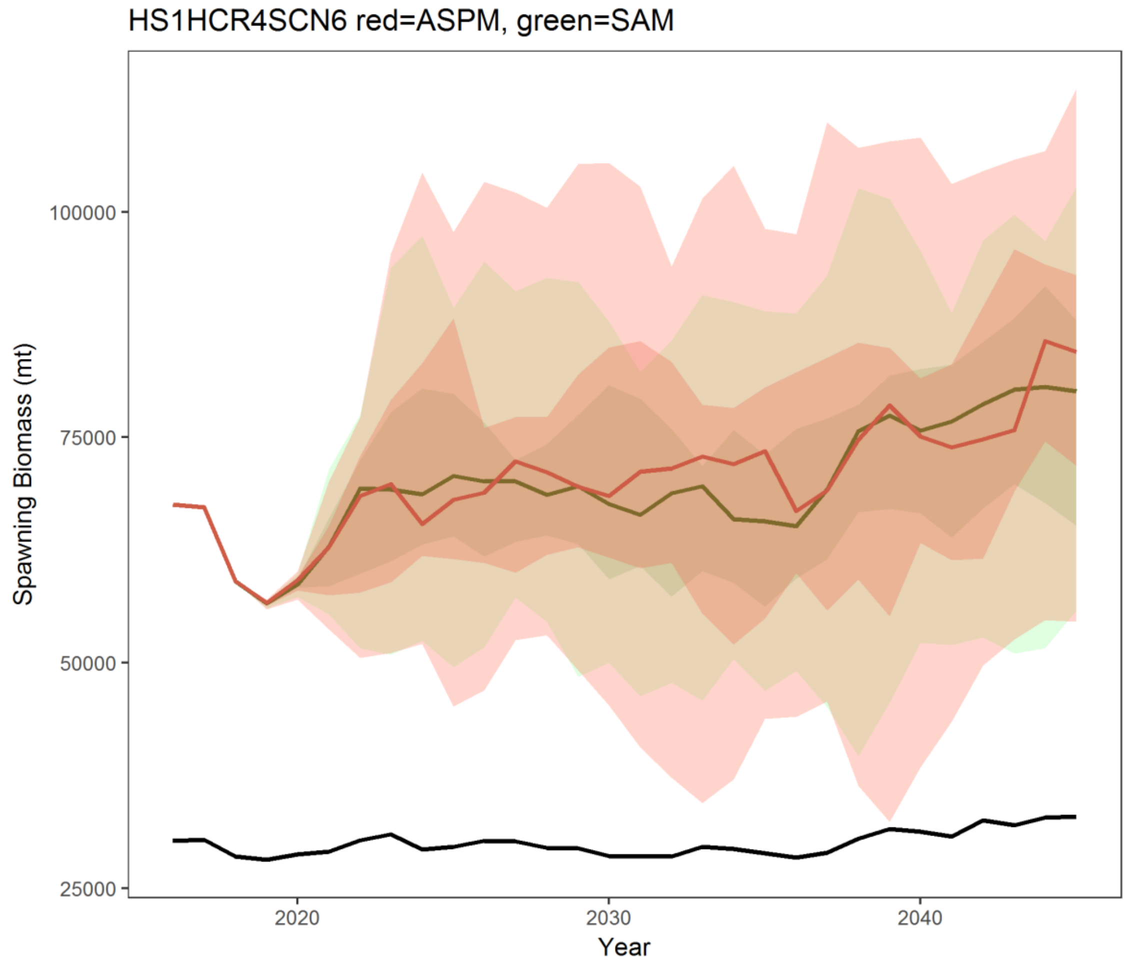

Figure 10. Trends in SSB from the OM of the ASPM-MSE (red) and the OM of the fully integrated MSE (green). The black line represents the limit reference point. Lighter colored shading represents the 5-95th interquartile range and the darker shades the 25-75th interquartile range, solid line represents the median across all iterations.

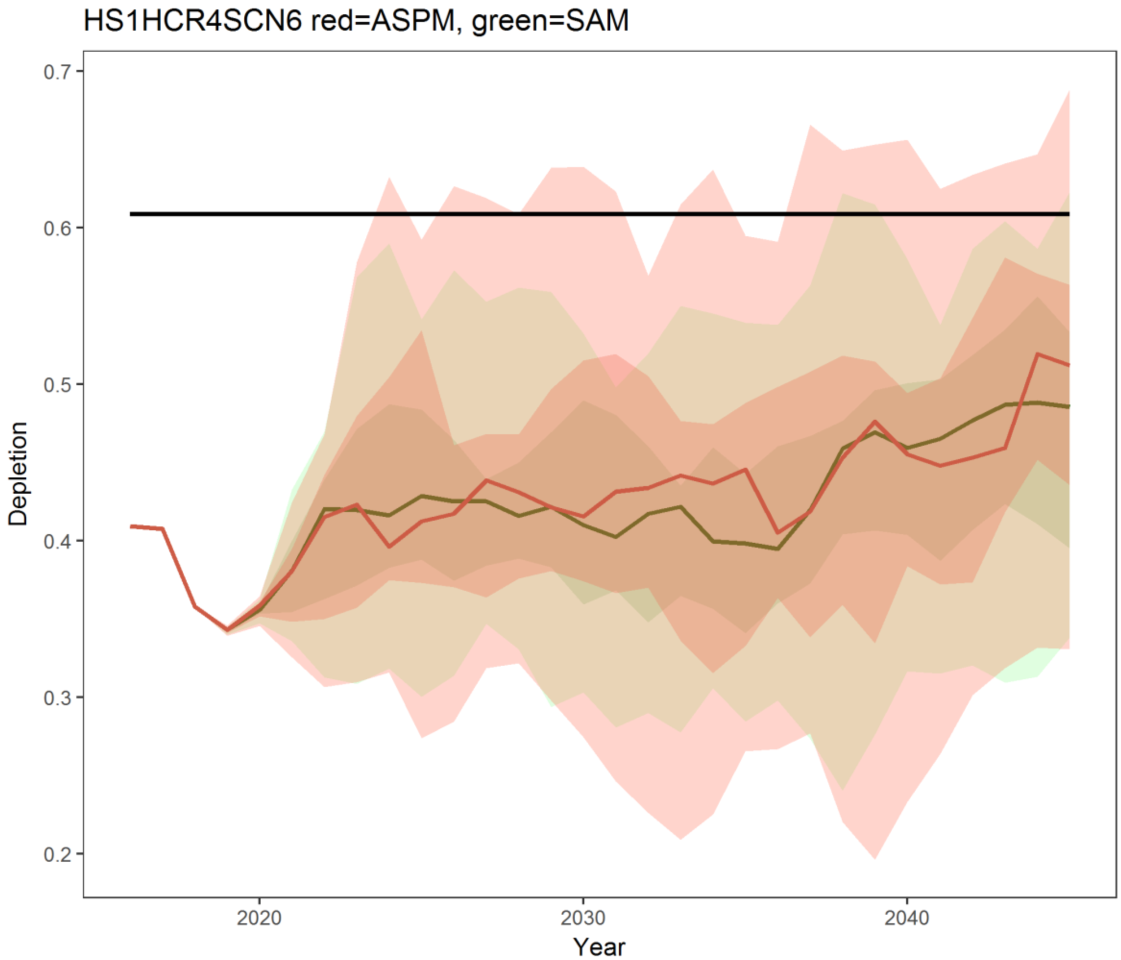

Figure 11. As figure 9 but for depletion (SSB/unfished SSB). The black represents historical minimum depletion from 2006 to 2015.

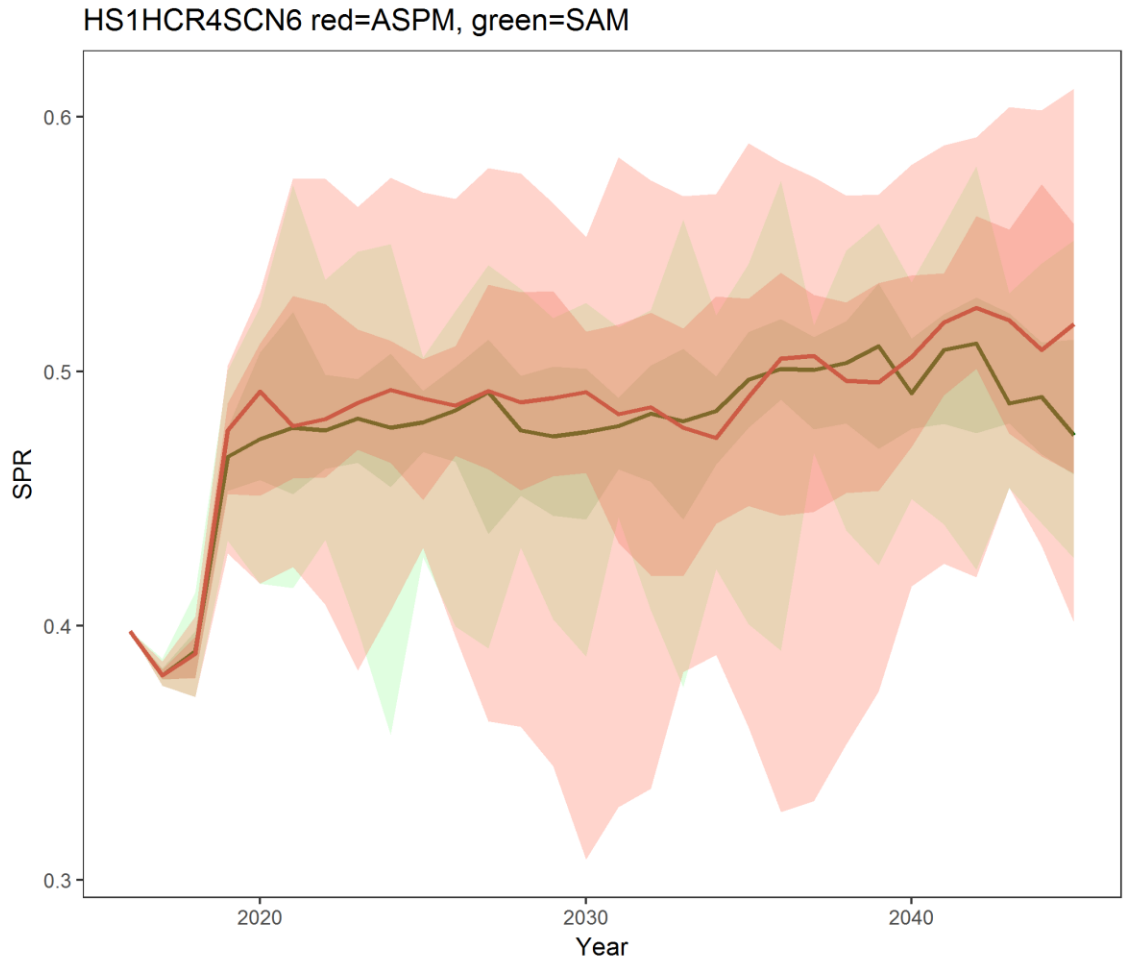

Figure 12. As for Figure 9 but for SPR.

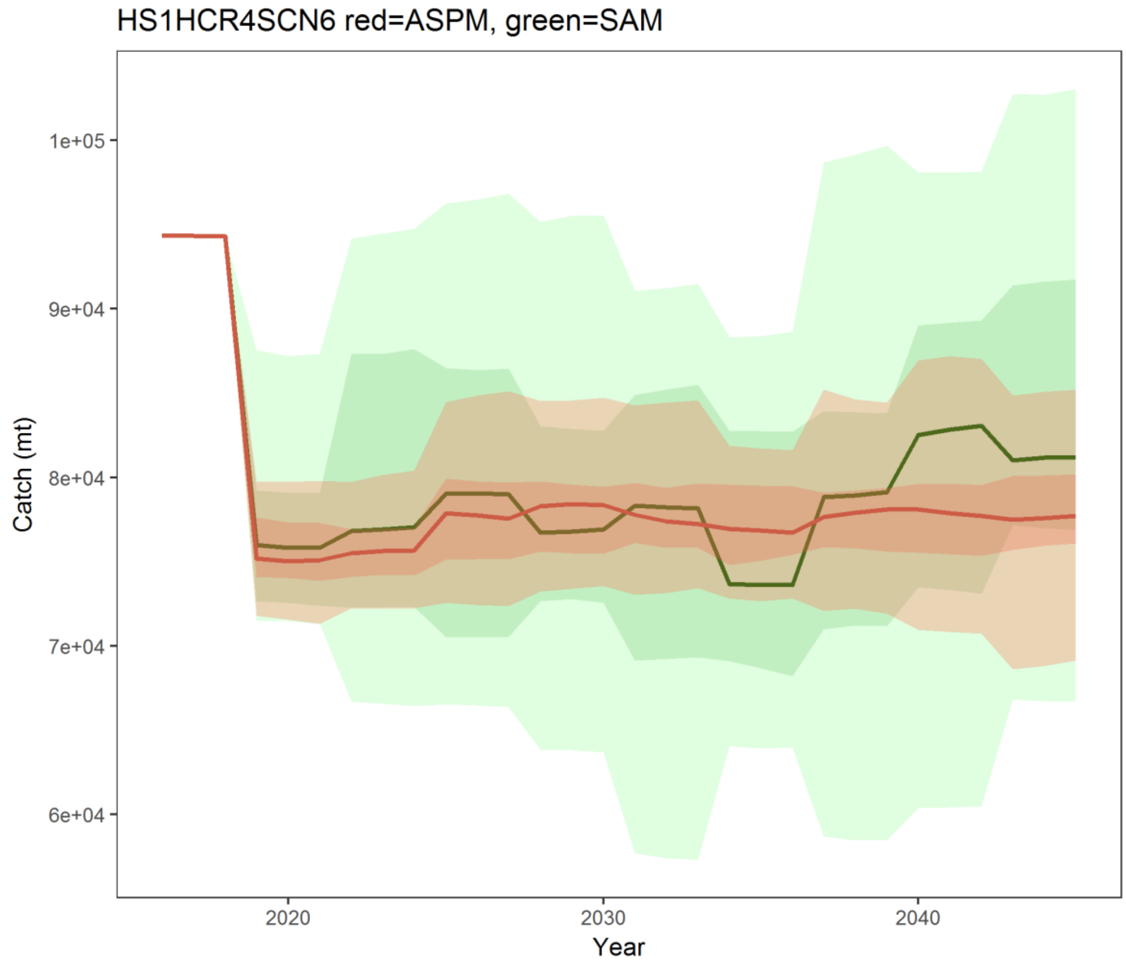

Figure 13. As for Figure 9 but for catch.

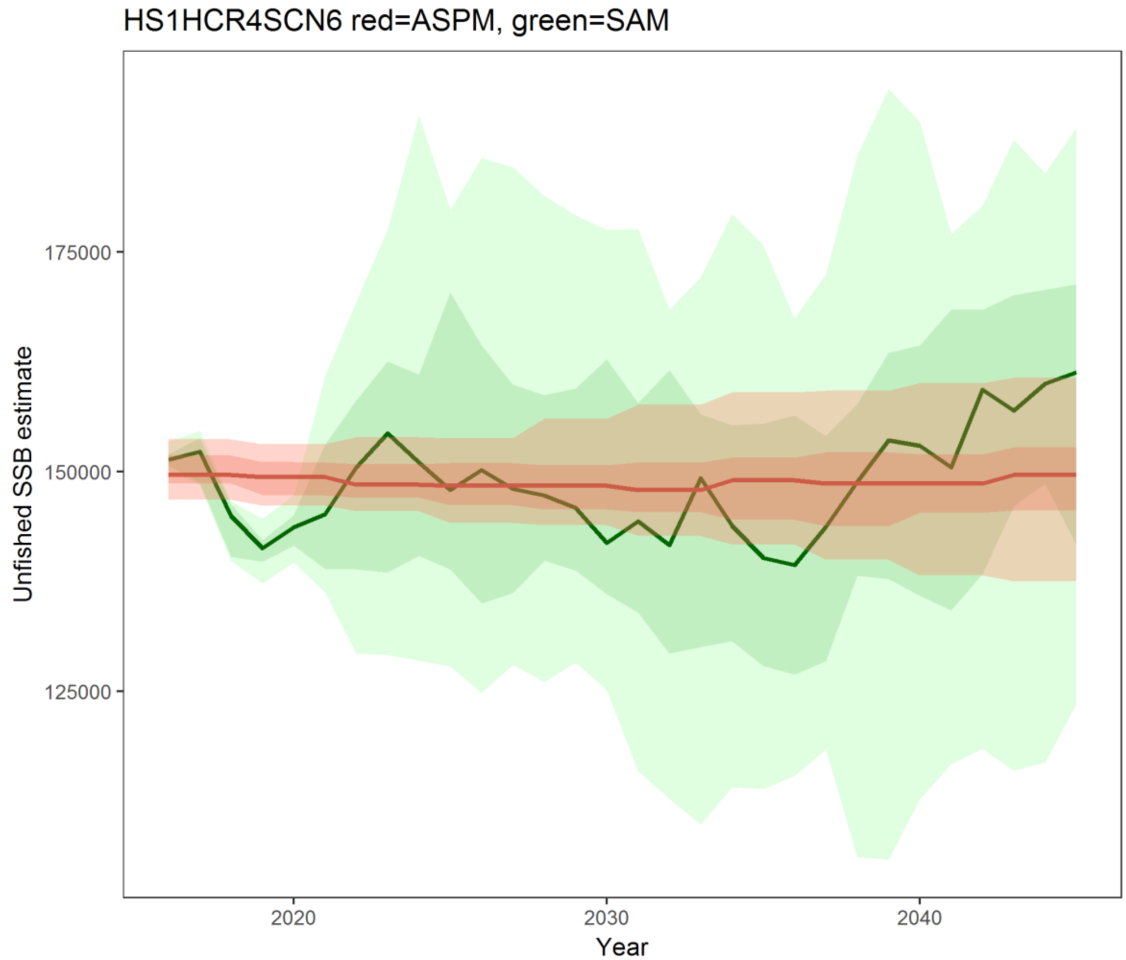

Figure 14. As for Figure 9 but for $SSB_{current, F=0}$ in the estimation models.

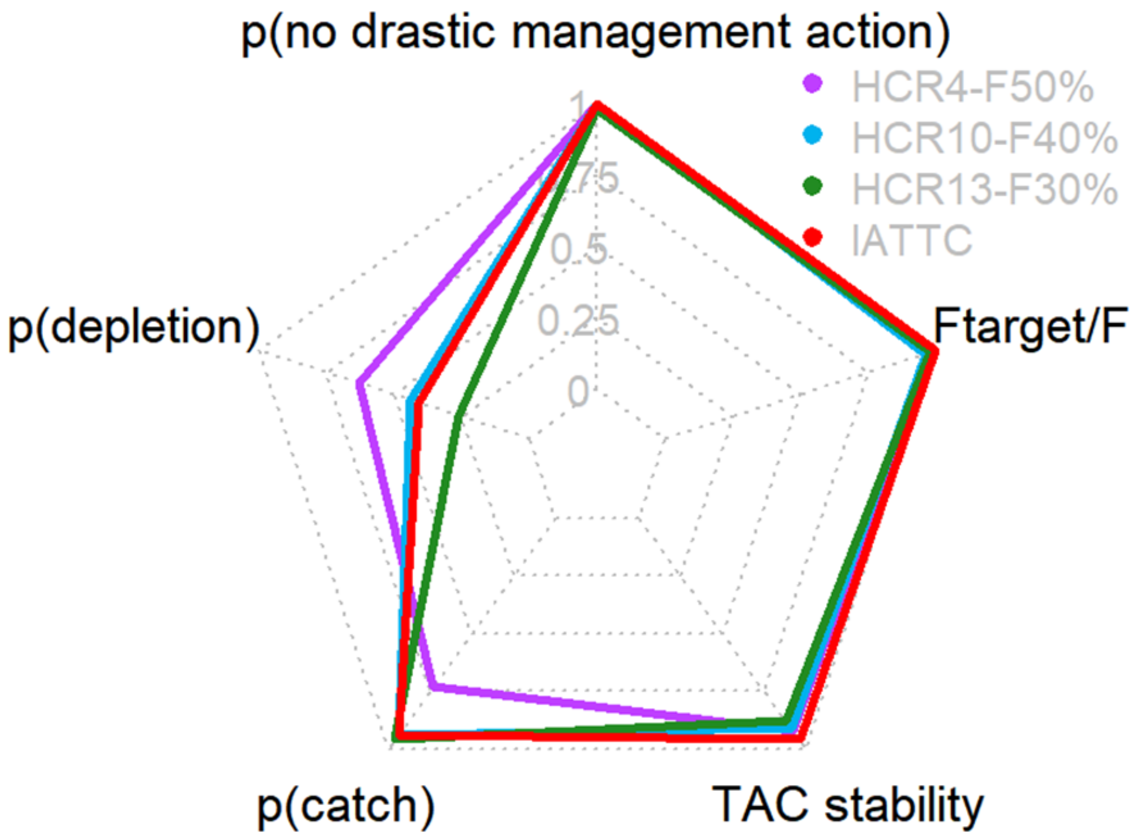

Figure 15. Cobweb plot depicting performance indicators for HCRs 4,10, 13 and 17 (IATTC rule) for the base case scenario. Values close to the outer web signify a more positive outcome for that performance indicator. Refer to Table 9 for a description of the performance indicators.

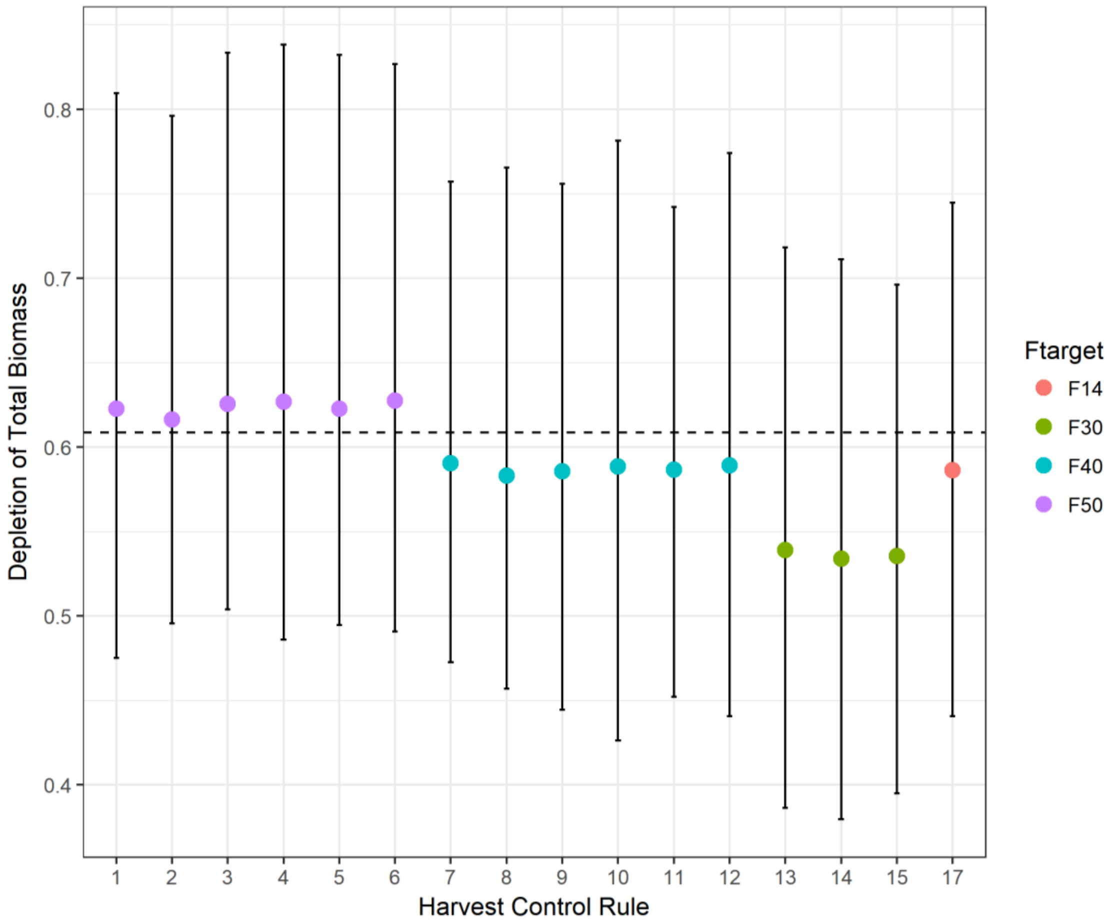

Figure 16. Median, 5th and 95th percentiles of depletion of total biomass for HCRs 1 to 15 of HS1 and HCR17 (HS2, IATTC rule). The horizontal dotted line represents minimum historical (2006-2015) depletion.

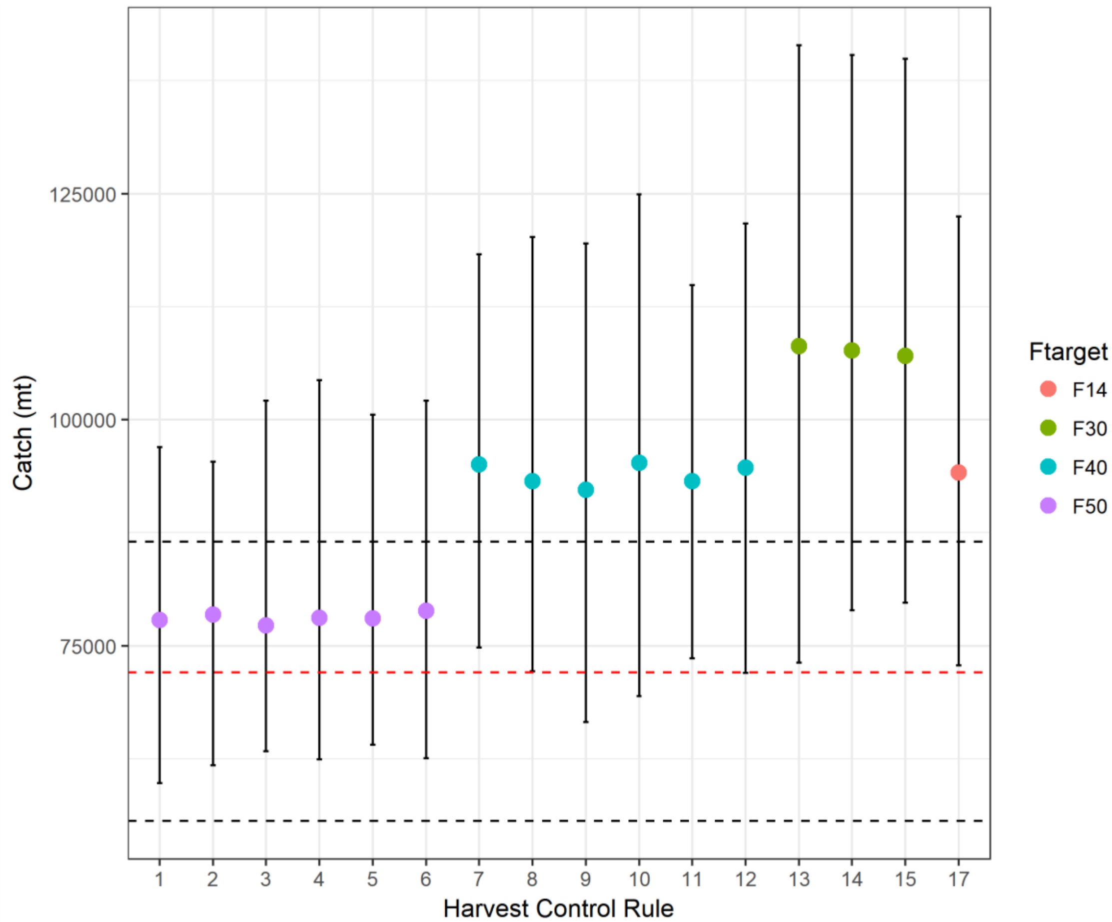

Figure 17. Same as Figure 6 but for catch. The red horizontal dotted line represents average historical (1981-2010) catch; the upper dotted line maximum historical catch; and the lower minimum historical catch.

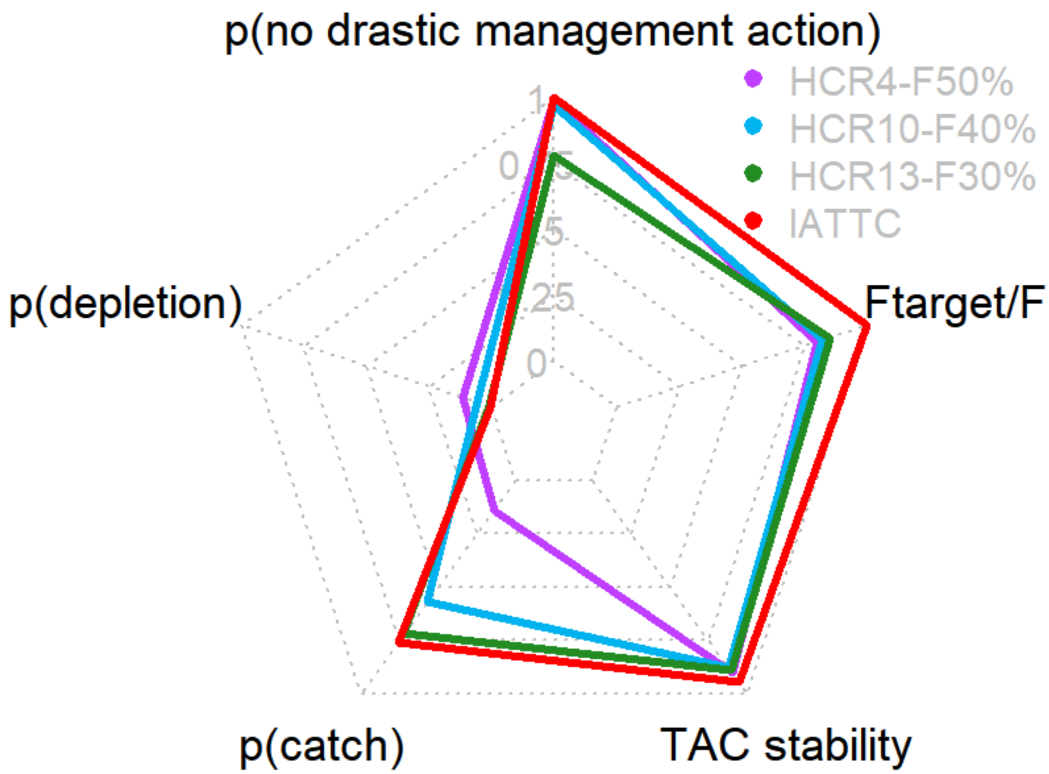

Figure 18. Same as Figure 4, but for the low productivity scenario.

Attachment 5

Workplan

Date	Location	Task/Event
May 2018	La Jolla, CA, USA	9th SAC of IATTC: provide MSE progress report
July 2018	Yeosu, Korea	ISC18 Plenary: provide MSE progress report
August 2018	Busan, Korea	SC14: provide MSE progress report
September 2018	TBD, Japan	NC14: provide MSE progress report
March 2019	Yokohama, Japan	4th ISC MSE workshop (tentative)
		ALBWG: to discuss MSE framework
November, 2019	Shimizu, Japan	ALBWG: data preparatory (tentative)
April, 2020	La Jolla, CA, USA	ALBWG: stock assessment (tentative)