DOCUMENT SAC-10 INF-L

Report for the 1st round of North Pacific Albacore Management Strategy Evaluation

EXECUTIVE SUMMARY

Goal of Management Strategy Evaluation. Management strategy evaluation (MSE) is a process that, given management objectives conveyed by stakeholders and managers, uses computer simulations to assess the performance of candidate harvest strategies under uncertainty. The Western and Central Pacific Fisheries Commission (WCPFC) established a limit reference point (LRP) of 20%$SSB_{CURRENT, F=0}$ (SSB: Female Spawning Stock Biomass) for North Pacific albacore (NPALB). In addition, the Inter American Tropical Tuna Commission (IATTC) and WCPFC also adopted measures in 2005 that restricted NPALB fishing effort to below "current" (current is undefined but assumed to be the average of 2002 – 2004) levels. However, no formal harvest strategy or target reference point (TRP) has been established. The goal of this MSE was to examine the performance of alternative harvest strategies and associated reference points for NPALB. Performance was evaluated based on management objectives pre-agreed upon with managers and stakeholders.

Management Objectives and Performance Indicators. The management objectives for this MSE were: 1) maintain historical spawning biomass; 2) maintain historical total biomass; 3) maintain historical harvest ratios of each fishery; 4) maintain catches above historical average; 5) minimize changes in management over time; and 6) maintain fishing impact around the target value. It should, however, be noted that management objective #3 (maintain historical harvest ratios of each fishery) was not evaluated for this round of MSE because there were no allocation rules specific to each fishery. Instead, harvest ratios of each fishery were maintained at the average of 1999 – 2015 into the future. The ALBWG represented these management objectives, except #3, into quantitative performance metrics (Table 1). These performance metrics were used to quantitatively evaluate the performance of the harvest strategies tested relative to the management objectives.

Table 1. List of proposed performance indicators. Management objective #3 was not included because it could not be evaluated in this round of MSE.

Management Objective	Label	Performance Indicator
1. Maintain SSB above the limit reference point (LRP)	Odds of no fishery closure	Probability that SSB in any given year of the MSE forward simulation is above the LRP
2. Maintain depletion of total biomass around historical average depletion	Relative Total Biomass	Probability that depletion in any given year of the MSE forward simulation is above minimum historical (2006-2015) depletion
4. Maintain catches above average historical catch	Relative Total Catch	Probability that catch in any given year of the MSE forward simulation is above average historical (1981-2010) catch

5. Change in total allowable catch between years should be relatively gradual	Catch Stability	Probability that a decrease in TAC is <30% between consecutive assessment periods (once every 3 years), excluding years where TAC=0.
6. Maintain fishing intensity (F) at the target value with reasonable variability	F_{TARGET}/F	F_{TARGET}/F

Harvest Strategies and Harvest Control Rules. Three harvest strategies were evaluated in the first round of the NPALB MSE. Within each harvest strategy, different levels of total allowable harvest are set by a harvest control rule that specifies a management action to be taken (or not), based on the condition of the simulated albacore population relative to reference points. The management action is implemented as either Total Allowable Catch (TAC) or Total Allowable Effort (TAE). Figure 1 depicts example harvest control rules (HCRs) that specify management actions for two of the three harvest strategies tested: Harvest Strategy 1 (HS1) and Harvest Strategy 3 (HS3). If spawning stock biomass (SSB) is above the threshold reference point ($SSB_{threshold}$), then the level of fishing intensity (F; calculated in terms of spawning potential ratio; see Reference Points section) is set by the target reference point (TRP) (F_{target} in Figure 1) for both HS1 and HS3. If SSB is below the threshold reference point but above the limit reference point (LRP; SSB_{limit}), the level of F is reduced to below the TRP, for both HS1 and HS3. However, as shown by the steeper drop in F for HS3 (dotted line) in Fig. 1, this reduction is steeper for HS3 than HS1. The reason for an HCR to initiate management action at $SSB_{threshold}$ rather than the LRP is to reduce the chances of ever reaching the LRP and to avoid severe management actions that could occur when the LRP is breached. If SSB falls below the LRP, the F is drastically reduced for both HS1 and HS3, which in this first MSE round is assumed to go to 0 and all fisheries that catch NPALB are closed. For each harvest strategy, different values of TRPs, threshold reference points, LRPs, and rebuilding plans (i.e. management actions when SSB is below the LRP) can be tested.

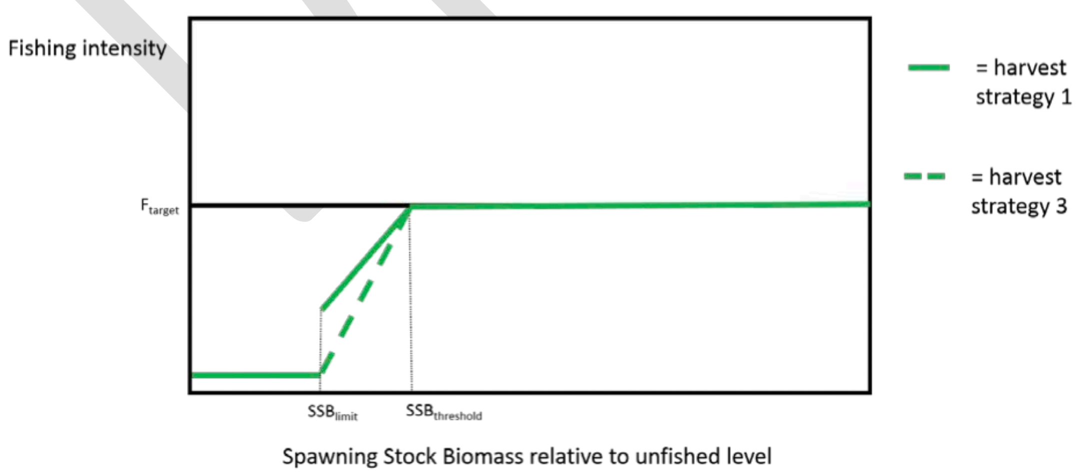

Figure 1. Example harvest control rule (HCR) for Harvest Strategy 1 and 3.

For HS1 and HS3, 11 harvest control rules with different combinations of TRPs, threshold reference points, and LRPs were tested. These are listed in Table 2. For HS1 and HS3 output control occurs either via a Total Allowable Catch (TAC) or a Total Allowable Effort (TAE).

Table 2. List of harvest control rules for harvest strategies 1 and 3. The target reference point (TRP) 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 TRP of F40 would result in the SSB fluctuating around 40% of the unfished SSB. A TRP of F30 implies a higher fishing intensity, and would result in a SSB of around 30% of the unfished SSB. F0204 is a fishing intensity corresponding to the average fishing intensity from 2002 to 2004. The threshold and limit reference points are SSB-based and refer to the specified percentage of unfished SSB. The unfished SSB fluctuates depending on changes in recruitment.

Harvest Strategy	Output Control	Harvest Control Rule Label	Target reference point (F_{target})	Threshold reference point ($SSB_{threshold}$)	Limit reference point (SSB_{limit})
1 or 3	TAC or TAE	1	F50	30%	20%
1 or 3	TAC or TAE	4	F50	20%	14%
1 or 3	TAC or TAE	6	F50	14%	7.7%
1 or 3	TAC or TAE	7	F40	30%	20%
1 or 3	TAC or TAE	10	F40	20%	14%
1 or 3	TAC or TAE	12	F40	14%	7.7%
1 or 3	TAC or TAE	13	F30	20%	14%
1 or 3	TAC or TAE	15	F30	14%	7.7%
1 or 3	TAE	16	F0204	30%	20%
1 or 3	TAE	17	F0204	20%	14%
1 or 3	TAE	18	F0204	14%	7.7%

Harvest Strategy 2 (HS2) is based on the IATTC's Resolution C-16-02, which is aimed at tropical tunas. This harvest strategy is TAE based and has no $SSB_{threshold}$ (i.e. a biomass-based threshold reference point). Instead of gradually reducing F upon breaching $SSB_{threshold}$, management measures are established if the probability that the current SSB is below the biomass-based LRP is greater than 10% or if the probability that the current fishing intensity exceeds the F-based LRP (F_{limit}) is greater than 10%. Similar to HS1 and HS3, all fisheries that catch NPALB are assumed to be closed if the LRP is breached in this first MSE round. For HS2, the biomass-based LRP is $SSB_{0.5r0}$ and F-based LRP (F_{limit}) is $F_{0.5r0}$. This is the SSB or F 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 corresponds to an SSB that is approximately 7.7% of the unfished biomass. Hence, we refer to these LRPs as SSB7.7% and F7.7. For HS2, if SSB is above the LRP, management actions only occur if the current F is above the TRP (F_{MSY}), whereby F is set to the TRP. For NPALB, F_{MSY} corresponds to an F that would produce approximately 14% of the unfished SSB. Otherwise, the current F is maintained. This is different from HS1 and HS3, where if SSB is above $SSB_{threshold}$, F is always set to the TRP (i.e. F_{target}), no matter the current F.

Reference Points. A TRP refers to a desired state that management wants to achieve. The TRPs for all three harvest strategies evaluated during this round of MSE are based on fishing intensity (F). Fishing intensity is defined as 1-SPR, where SPR is the spawning potential ratio, or the SSB per recruit relative to the unfished population. For HS1 and HS3, the level of total harvest given four TRPs: F50, F40, F30, and F0204 were evaluated. F40 represents a F that leads to a SSB per recruit that fluctuates around 40% of the unfished (i.e., removing about 60% of the SSB). In contrast, a TRP of F30 leads to a SSB that is around 30% of unfished SSB per recruit (i.e., a fishing intensity of 0.7 removing about 70% of the SSB). A TRP of F30 means fishing harder than F40, so the level of biomass desired is lower. F0204 corresponds to the average F from 2002-2004 (F42 for the base case). For HS2, the TRP is F_{MSY}. In the MSE, the level of total harvest was affected primarily by the TRP.

According to the latest assessment in 2017, the average F for 2012-2014 was about F50. This is close to the average over the past 20 years, which was F51 (Fig. 2). Since 1993, F has never reached F30 and only exceeded F40 in 1999 (Fig. 2).

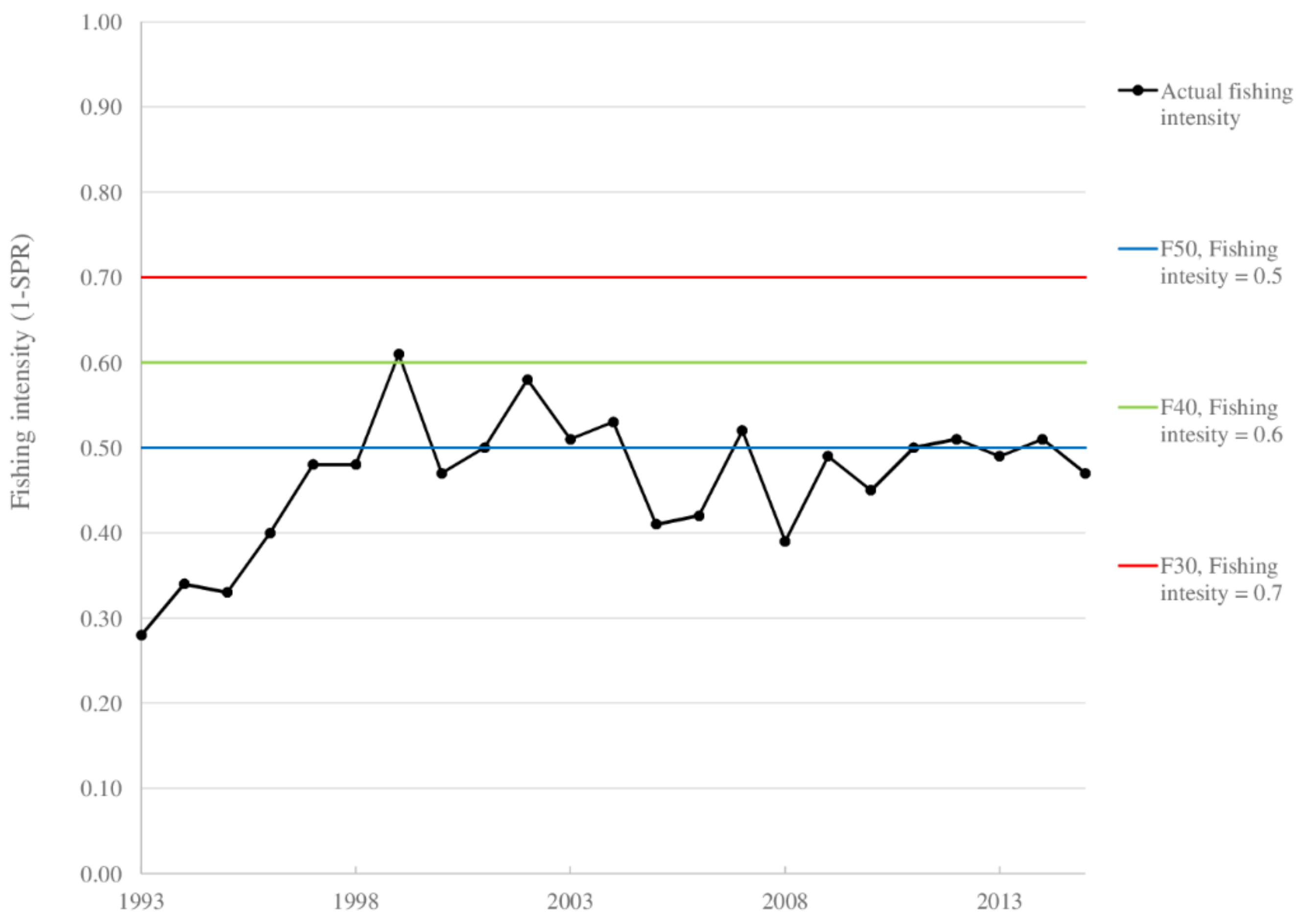

Figure 2. Past trend in fishing intensity (1-SPR) from the 2017 NPALB stock assessment model. The fishing intensity associated with the three target reference points used in the MSE is also shown. Higher fishing intensity implies lower spawning potential as fraction of unfished (SPR).

For HS1 and HS3, three different threshold reference points were evaluated: SSB30%, SSB20%, and SSB14% (Table 2), which were associated with three respective LRPs: SSB20%, SSB14%, and SSB7.7% (Table 2). For example, SSB30% roughly means that the reference point is at 30% of unfished SSB. The actual reference point in terms of tons will change depending on the level of estimated recruitment. HS2 had no threshold reference point, only a SSB-based LRP of SSB7.7%, and an F-based LRP of F7.7.

Overview of MSE Framework. To test the performance of each harvest strategy given the set of management objectives, the MSE had to simulate the biological, fisheries, and management processes acting on the NPALB stock. When modelling the "future" processes, the MSE simulation is run forward in time for a period of 30 years (Fig. 3). At each time step of the 30-year simulation, an operating model (OM) simulates the true population dynamics of the NPALB and the fisheries operating on it given the catch set by the candidate HCR. Before the "future" simulation starts, a "conditioning" process is undertaken to determine if the OM is a realistic representation of the stock by "conditioning" the OM on historical data (Fig. 3; See *Operating Models and Conditioning Process* section for details). If the OM can adequately recreate past trends in catch, CPUE, and size composition data, it is used to simulate the population dynamics of stock forward in time. Catch, CPUE, and size composition data with error are sampled from the OM every three years (based on the current 3-year stock assessment frequency) and input in a simulated stock assessment model (i.e. the estimation model or EM) (Fig. 3). As in the real world, the stock assessment model estimates the current population levels and fishing intensity as well as reference points. A management model then sets a total allowable catch (TAC) or effort (TAE) based on the specific harvest control rule being tested (Fig. 3). The harvest control rule specifies a management action to be taken (or not), based on the condition of the simulated albacore population relative to reference points. The TAC or TAE is then split into catch by fishery using the 1999-2015 average allocation and input into the OM with some implementation error for simulation of population dynamics in the next time step.

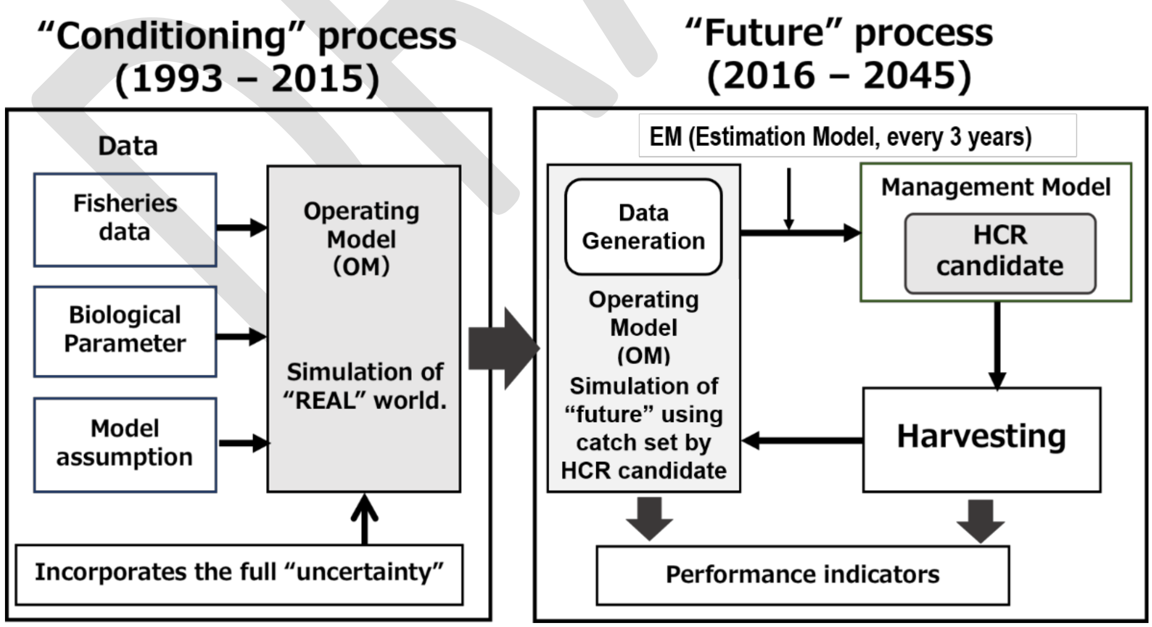

Figure 1. Overview of North Pacific albacore management strategy evaluation framework.

Uncertainties considered. The computer simulations allowed for testing the harvest strategies under different "what if" scenarios for stock productivity, recruitment variability, availability to the Eastern Pacific Ocean (EPO) fishery, observation error, assessment error, or management implementation error to make sure that the proposed harvest strategies could meet management goals in the real world. These "what if" scenarios were based on the ALBWG's best estimate of the uncertainty, or were specified by the managers and stakeholders.

Five scenarios were developed to represent the range of uncertainty in stock productivity. They required different operating model (OM) structures in terms of the parametrization of biological factors such as growth or natural mortality (See *Operating Models and Conditioning Process* section for details).

NPALB recruitment can vary greatly between years due to unknown environmental factors, even when SSB remains the same. To account for uncertainty in recruitment, recruitment deviations in the OM were sampled from a distribution with σ_R=0.5 and an autocorrelation of 0.42. The autocorrelation implies that a good recruitment year was more likely to be followed by another good recruitment event, giving rise to good and bad recruitment cycles.

There is also uncertainty in the number of juveniles migrating to the EPO every year. To account for changes in the availability of specific age classes to the EPO fishery between years, in the OM, the age selectivity for the EPO fleet was made time-varying using additive random walk deviations for ages one to four. For each HS/HCR/productivity scenario combination, 45 iterations with different random trajectories in recruitment and EPO age selectivity were run.

In addition to the five stock productivity scenarios, two potential future fishing effort scenarios prioritized during the 3rd ISC ALB 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

Operating Models and Conditioning Process. All the OMs consisted of a population dynamics model of NPALB with a fishery model component relating the modeled dynamics to catch, catch-per-unit-effort (CPUE), and size composition data. To capture the uncertainty in stock productivity, the MSE simulation included a set of different operating models (OMs). The base case OM (Scenario 1) structure was similar to the latest stock assessment model (SAM) in 2017. One difference consisted of the addition of a new CPUE based juvenile index, which was based on the Japanese longline fishery targeting juvenile albacore. Growth in the SAM and base case OM both follow sex-specific von Bertalanffy growth functions. However, the SAM in 2017 used fixed growth parameters that were obtained externally, whereas the OM used growth parameters that were estimated internally during the conditioning phase by fitting to age-length data, in addition to length composition data from the catch. Finally, unlike the SAM, recruitment deviations in the OM were autocorrelated and age selectivity for the EPO fleet was time varying. 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+.

Consideration of uncertainties in growth, natural mortality, and steepness was deemed important by the ALBWG, and three different levels for these parameters were tested: 1) base case value,

2) lower than base, and 3) higher than base. This led to 27 different OMs being developed from all the possible combinations of growth, natural mortality, and steepness.

To determine if these OMs were realistic representation of the stock, these models were "conditioned" on historical data (1993-2015) by fitting the simulated data over the historical period to observed catch, CPUE, and length composition data using maximum likelihood. Nine out of the 27 OMs failed to converge and five produced unrealistic SSB estimates and were not considered further. Given the long run times, time constraints on MSE development, and similarities in terms of stock productivity trends between scenarios, the ALBWG proposed a reduced set of five scenarios to be tested. See Table 3 for a list of parameter specifications for the five OMs used to characterize uncertainty in stock productivity. The five scenarios showed a wide range in potential stock productivity trends (Fig. 4). Scenario 7 was a high productivity trial with a much higher biomass and lower fishing intensity as compared to the base case (Fig. 4) and was treated as a robustness (less plausible) scenario. Most figures present results across the four reference scenarios (Scenarios 1, 3, 4, 6).

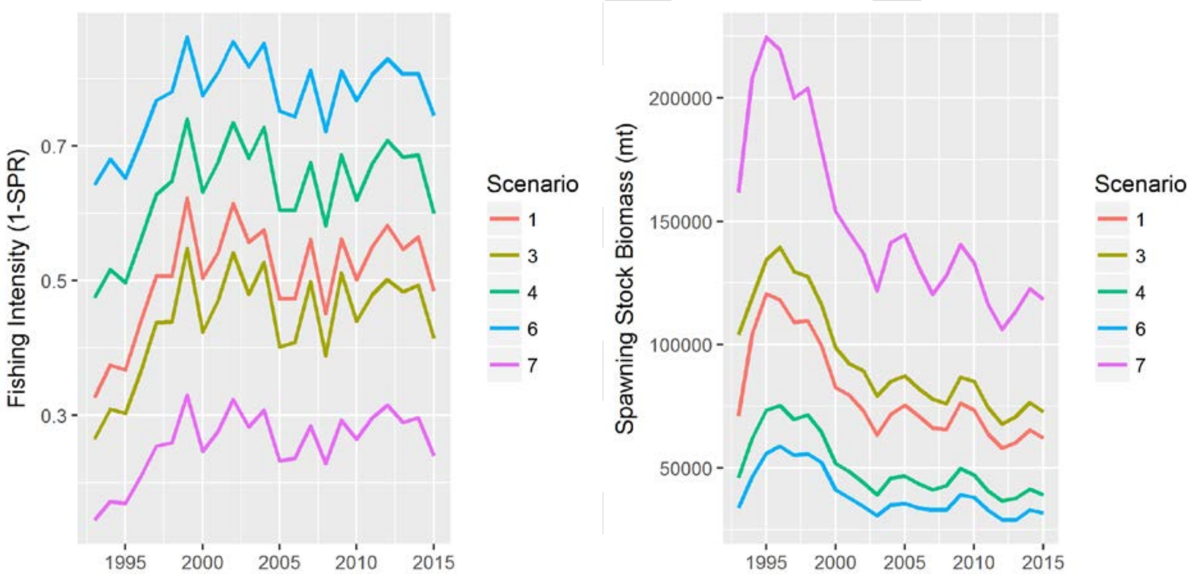

Figure 4. Trends in fishing intensity (1-SPR) and female spawning stock biomass (SSB) for the five operating models used in the first round of MSE. 1-SPR is the reduction in female SSB per recruit due to fishing and is used to describe the overall fishing intensity on the stock.

Table 3. List of the five operating models (OMs) representing different uncertainty scenarios and their parameter specifications. H refers to steepness, G to growth, and M to natural mortality. The OMs are ordered from the one simulating the most productive NPALB population to the least productive.

OM No.	h	G	M	Age selectivity	Recruitment autocorrelation
7	high	high	high	Time varying	0.42
3	high	low	medium	Time varying	0.42
Base/1	medium	medium	medium	Time varying	0.42
4	high	high	medium	Time varying	0.42
6	high	high	low	Time varying	0.42

Data Generation. Catch, CPUE, and size composition data with error was generated from the OM using the Stock Synthesis data generation routine and subsequently used as inputs into the simulated stock assessment (i.e. the estimation model). The data generation routine created a data set of 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 and the expected value for each datum.

Estimation Model. The estimation model (EM) was the simulated stock assessment model in the MSE simulation. It had the same structure as the 2017 SAM but it employed the new juvenile abundance index and the same growth parameters as the base case OM. The EM was used to determine the current SSB and fishing intensity and reference points to be used in the harvest control rule to determine the TAC or TAE. Integration of the EM in the MSE framework allowed for consideration of the stock assessment error.

Implementation Error. An implementation error was added to the TAC or TAE to account for the fact that the realized catch can differ from that set by the TAC or TAE. The NPALB stock has not been subjected to TACs or TAEs, and assumptions therefore had to be made about the implementation error. The implementation error was assumed to be always positive, varied randomly between 5 and 20%, and was the same for all fisheries.

Results. The results of the MSE analysis can be summarized in five main points:

1. *A lower fishing intensity TRP (i.e. F50), maintains the population at a higher level than F40 and F30, requiring less management intervention and resulting in lower catch variability between years. However, lower fishing intensity results in lower overall catch.*

There was a clear trade-off between relative total biomass and relative catch. HCRs with F50 (HCRs 1, 4, and 6; blue bars in Fig. 5) had the highest relative total biomass but lowest relative catch, given the same LRP (Compare Fig. 5a and 5b). For the same LRP, a TRP of F50 also had the lowest odds of a fishery closure (Fig. 5c) and the highest catch stability (Fig. 5d).

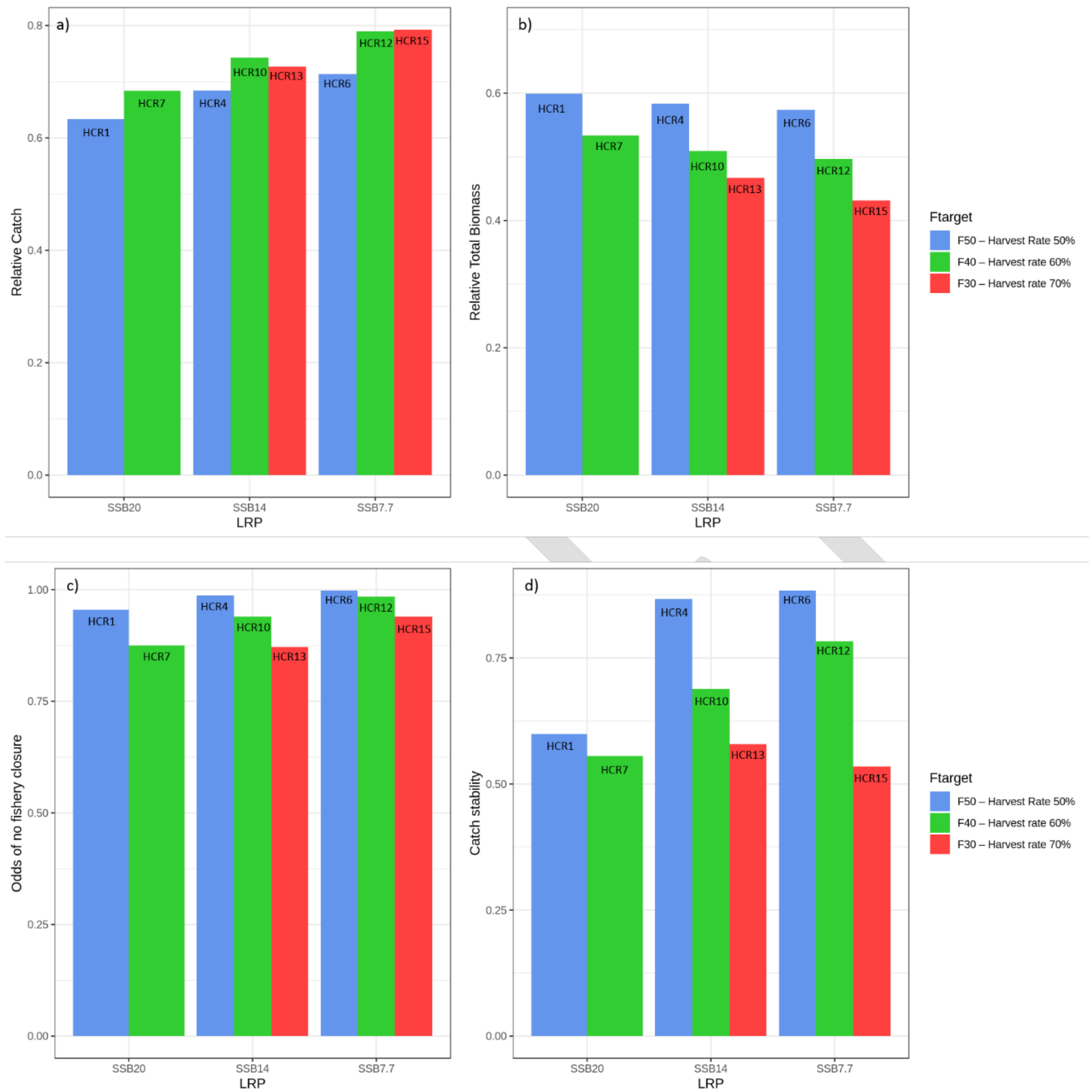

Figure 5. Comparison of the *relative catch*, *relative total biomass*, *odds of no fishery closures*, and *catch stability* performance metrics across limit reference points (LRP) for all the harvest control rules (HCRs) tested in Harvest Strategy 3 with TAC (total allowable catch) control. Performance metrics were computed across all runs of the four reference scenarios. *Relative catch* is defined as the odds of catch in any given year of the MSE forward simulation being above average historical (1981-2010) catch. *Relative total biomass* is defined as the odds of depletion in any given year of the MSE forward simulation being above minimum historical (2006-2015) depletion. *Odds of no fishery closure* is the probability that SSB in any given year of the MSE forward simulation is above the LRP. *Catch stability* is defined as the probability that a decrease in TAC is <30% between consecutive assessment periods (once every 3 years), excluding years where TAC=0.

2. *HCRs with a TRP of F40 have less closures and higher catch stability as compared to a TRP of F30, resulting in comparable or higher catch despite lower fishing intensity.*

The trade-off between more catch and less biomass was as evident when comparing TRPs of F40 against F30. HCRs with a TRP of F40 performed as well or better than a TRP of F30 not only in terms of relative biomass (green vs. red bars in Fig. 5b), fishery closures (green vs. red bars in Fig. 5c), and catch stability (green vs. red bars in Fig. 5d), but also for relative catch (green vs. red bars in Fig. 5a). For the same LRP, relative catch of HCRs with a TRP of F40, was comparable to that of HCRs with a TRP of F30 (green vs. red bars in Fig. 5a). Improved catch stability and lower management intervention led to higher or comparable odds of projected catch being more than average historical catch for a TRP of F40 as compared to F30, even if the F was lower.

3. *An LRP and threshold reference point closer to the TRP results in a higher frequency of management interventions, fishery closures and lower catch stability.*

A LRP closer to the desired target biomass set by the F-based TRP is more likely to be breached. This leads to lower catch stability and higher probability of fishery closures for HCRs with an LRP set at 20% of unfished SSB (SSB20%). Fig. 6 shows that for HCRs with the same F40 TRP, HCR 7, the one with the highest LRP of SSB20%, had the lowest relative catch, lowest catch stability, and lowest odds of no fishery closure.

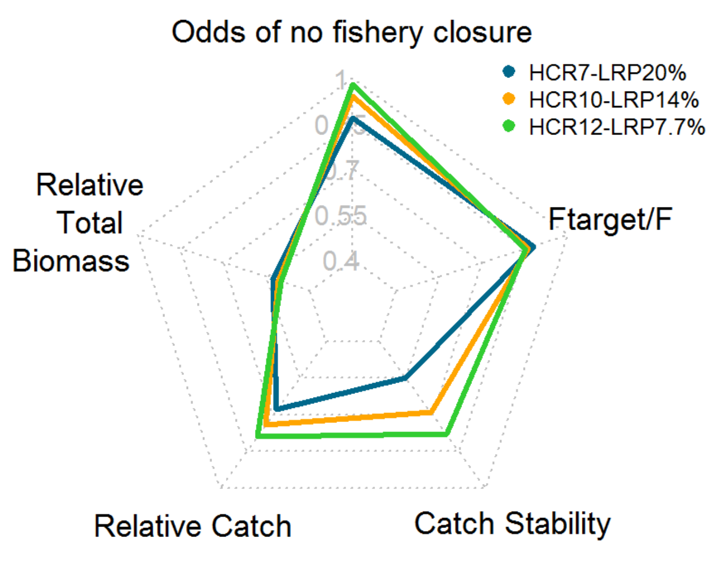

Figure 6. Cobweb plot depicting performance indicators for TAC-based HCR7, HCR10, and HCR12 for HS3 across all runs and reference scenarios. All use a TRP of F40. Values close to the outer web signify a more positive outcome for that performance indicator (i.e., further out is better). Refer to Table 1 for a description of the performance indicators. *Relative catch* is defined as the odds of catch in any given year of the MSE forward simulation being above average historical (1981-2010) catch. *Relative total biomass* is defined as the odds of depletion in any given year of the MSE forward simulation being above minimum historical (2006-2015) depletion. *Odds of no fishery closure* is the probability that SSB in any given year of the MSE forward simulation is above the LRP. *Catch stability* is defined as the probability

that a decrease in TAC is <30% between consecutive assessment periods (once every 3 years), excluding years where TAC=0. *Ftarget/F* is the ratio of the F specified by the TRP to the actual fishing intensity in the operating model (OM).

4. *HS3 showed lower catch stability than HS1, but had less fishery closures.*

Harvest Strategy 3 showed less stability in catch between years (Fig. 7) because steeper changes in TAC or TAE were required once the threshold reference point was crossed. However, these steeper reductions in TAC or TAE resulted in a slightly lower frequency of fishery closures because the probability of breaching the LRP was lower (Fig. 7).

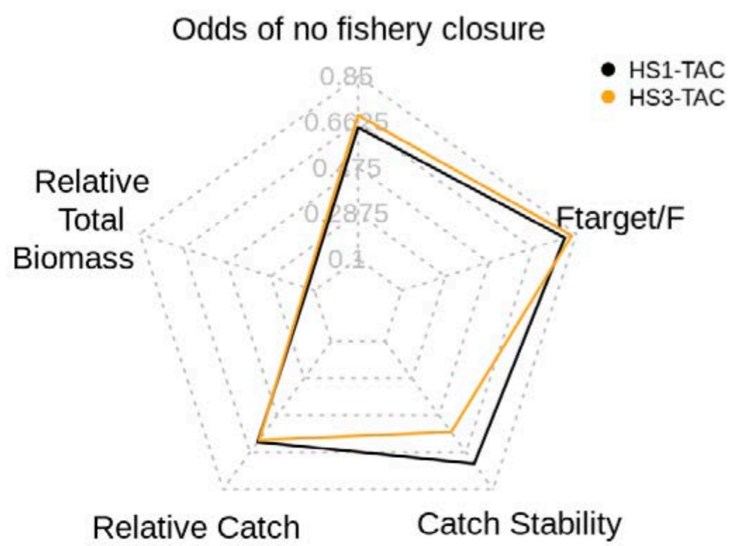

Figure 7. Cobweb plot depicting performance indicators for TAC-based HCR13 for HS1 and HS3 for all runs in the lowest productivity scenario (Scenario 6). Scenario 6 was chosen as it was the scenario with the most fisheries closures and hence best depicted the trade-off between higher catch variability and lower fisheries closures. Values close to the outer web signify a more positive outcome for that performance indicator. *Relative catch* is defined as the odds of catch in any given year of the MSE forward simulation being above average historical (1981-2010) catch. *Relative total biomass* is defined as the odds of depletion in any given year of the MSE forward simulation being above minimum historical (2006-2015) depletion. *Odds of no fishery closure* is the probability that SSB in any given year of the MSE forward simulation is above the LRP. *Catch stability* is defined as the probability that a decrease in TAC is <30% between consecutive assessment periods (once every 3 years), excluding years where TAC=0. *Ftarget/F* is the ratio of the F specified by the TRP to the actual fishing intensity in the operating model (OM).

5. *Harvest strategies with Total Allowable Effort (TAE) had a lower frequency of fisheries closures and higher catch stability than ones with Total Allowable Catch (TAC) control.*

Fig. 8 provides an overview of results for HCR 13 for HS1 with both a TAC and TAE output control. The TAC based rules underperformed TAE ones across most performance indicators. The largest difference occurred for catch stability. Given the 3 years assessment frequency, in a

TAC-based rule the TAC is maintained constant over a 3-year period. Hence, if biomass is reduced because of random, biologically driven variability, fishing intensity can increase and drive the population below the threshold and limit reference points more often, requiring more management intervention. This resulted in TAC-based rules having lower catch stability and being closed more often. However, it should be noted that potential difficulties in measuring and implementing TAEs relative to TACs in the real world were not evaluated for this MSE.

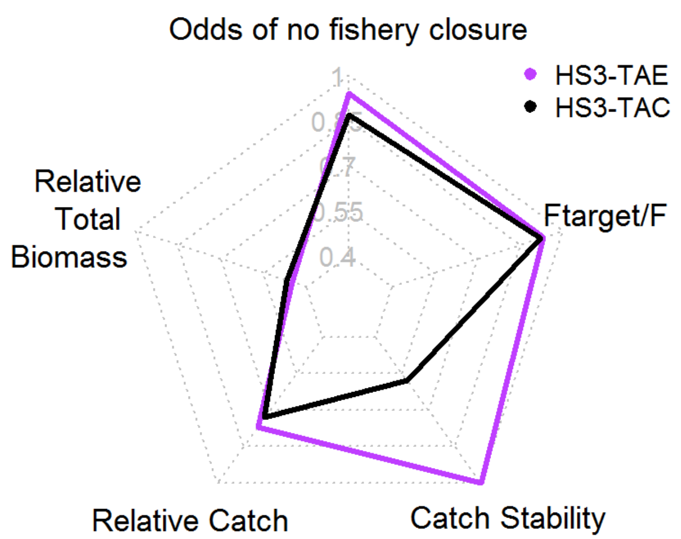

Figure 8. Cobweb plot depicting performance indicators for TAC-based and TAE-based HCR13 for HS3 for all runs and reference scenarios. Values close to the outer web signify a more positive outcome for that performance indicator. *Relative catch* is defined as the odds of catch in any given year of the MSE forward simulation being above average historical (1981-2010) catch. *Relative total biomass* is defined as the odds of depletion in any given year of the MSE forward simulation being above minimum historical (2006-2015) depletion. *Odds of no fishery closure* is the probability that SSB in any given year of the MSE forward simulation is above the LRP. *Catch stability* is defined as the probability that a decrease in TAC is <30% between consecutive assessment periods (once every 3 years), excluding years where TAC=0. *Ftarget/F* is the ratio of the F specified by the TRP to the actual fishing intensity in the operating model (OM).

For HS1 and HS3, a TRP of F0204, which was only used with TAE control, performed most similarly to F30. For the same LRP, a TRP of F0204 had lower catch stability and more fishery closures than TRPs of F40 or F50 (Fig. 9). Relative catch, while higher than F50, was comparable to that of F40 and F30 (Fig. 9). HS2 had a LRP of SSB7.7% and performed similarly to F0204 and F30. It had lower catch stability and relative total biomass than F40 or F50, but higher relative catch (Fig. 9).

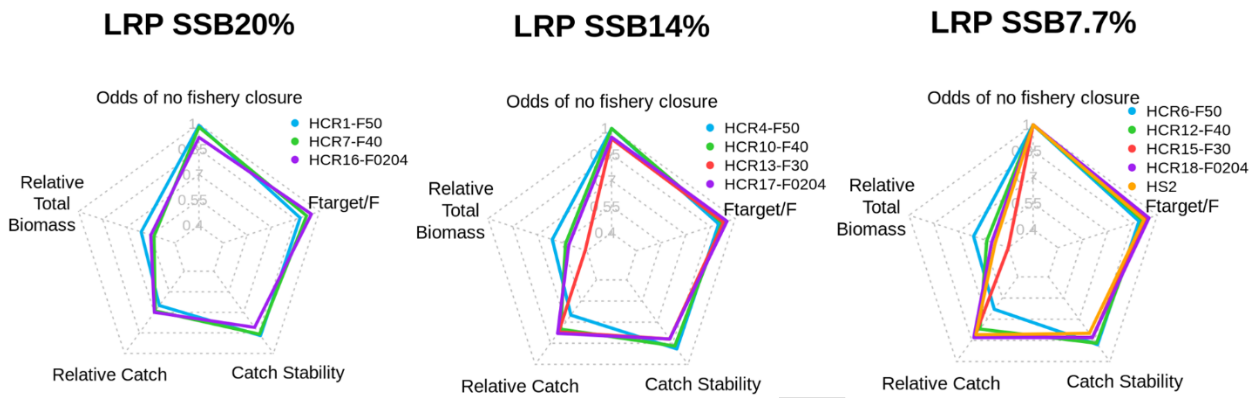

Figure 9. Cobweb plot depicting performance indicators for TAE-based HCRs for HS3 grouped by LRP for all runs and reference scenarios. Values close to the outer web signify a more positive outcome for that performance indicator. Note that because catch variability between consecutive assessment periods was rarely greater than 30% for all TAE-based rules, to better contrast HCRs here catch stability is defined as the probability that a decrease in catch between consecutive assessment periods is <15%. *Relative catch* is defined as the odds of catch in any given year of the MSE forward simulation being above average historical (1981-2010) catch. *Relative total biomass* is defined as the odds of depletion in any given year of the MSE forward simulation being above minimum historical (2006-2015) depletion. *Odds of no fishery closure* is the probability that SSB in any given year of the MSE forward simulation is above the LRP. *Catch stability* is defined as the probability that a decrease in TAC is <30% between consecutive assessment periods (once every 3 years), excluding years where TAC=0. *Ftarget/F* is the ratio of the F specified by the TRP to the actual fishing intensity in the operating model (OM).

Key Limitations.

The ALBWG examined the MSE models in detail and identified the following key limitations.

- Effort is modeled as fishing intensity rather than being modeled explicitly as the number of fishing days or number of hooks. However, in the real world, managers would manage effort as the number of hooks or the number of fishing days rather than fishing intensity. If TAE control was to be implemented, more work would be needed to quantify how fishing intensity would be translated into effort in terms of number of fishing days and number of hooks.
- Given the uncertainty in the relationship between fishing intensity in the MSE and real world effort in number of fishing days and number of hooks, effort control may be more effective in the simulation than in the real world and is assumed to be as effective as TAC control, which may not be realistic.
- It is assumed that effort or catch control is implemented equally effectively across all fisheries, including both NPALB targeting and non-targeting (e.g. surface fleets vs. longline).
- Allocation is assumed to be constant at the average of 1999-2015 levels throughout the simulation. This formulation prevents an assessment of management objective 3, *maintain harvest ratios by fishery*, as the harvest ratios are kept constant by design.

Testing of different allocation schemes would require input from managers as to what those allocation rules might be.

- In the simulations for HS1 and HS3, if the fishing intensity is lower than the target reference point, the simulated fishing intensity is increased to the target level when setting the TAC or TAE. This assumes no limitations in the capacity of the NPALB fleets.
- Given the lack of computer and personnel resources, only one rebuilding plan (fishery is closed) was tested. Further work could examine other rebuilding measures proposed by managers and stakeholders at the 3rd MSE workshop in Vancouver during 2017.
- Given the lack of computer and personnel resources, when determining stock status, only the probability of SSB being higher than the LRP or threshold reference point at a 50% level was tested. Further work could examine other probabilities proposed at the 3rd MSE workshop in Vancouver during 2017.
- NPALB is a highly migratory species whose movement rates to given areas in the North Pacific are highly variable. This affects availability to the fisheries operating in those areas. However, the simulations do not explicitly model these movement processes and instead only approximate the availability to various fleets. Further work could include the development of an area specific model to better capture uncertainty in migration rates, and their relationship to availability.
- The simulations are conditioned on data from 1993 onwards, although available data dates back to1966. Therefore, the simulations may not include the full range of uncertainty in the population dynamics of NPALB. Thus, the MSE results are most applicable to recent conditions. Nevertheless, inclusion of the lowest productivity scenario (Scenario 6) was an attempt to accommodate some of this uncertainty.

Recommendations from the 4th ISC ALB MSE Workshop

Participants of the 4th ISC ALB MSE Workshop reviewed the results here presented and brought forward a series of recommendations (ISC 2019), summarized below.

Presentation of MSE Results

1. The ALBWG should be more explicit in the labelling of performance indicators and specify if an indicator is based on a probability. For example, for Management Objective #2, the performance indicator labelled “Relative total biomass” was actually the probability of the depletion of total biomass being over the minimum historical depletion and could instead be labelled “probability of total biomass > minimum historical”.
2. Performance indicators using relative total or spawning biomass are likely to be better understood than indicators using probabilities. Separate plots of the mean or median of the relative biomasses coupled with plots of the variability of those relative biomasses may be preferable to a single plot of probabilities. Comparison with historical levels could be done by including indications of the historical levels to be compared.
3. The ALBWG should provide guidance on how to interpret fishing intensity in terms of implications to fleet management. For example, it would be useful for managers to be shown the changes in fishing intensity relative to current fishing intensity.

<u>Management Objectives</u>

4. Managers and stakeholders should prioritize, rank, or weight the management objectives to assist decision making and help resolve tradeoffs in management objectives.
5. Management Objective #6 was considered of relatively low priority by managers and stakeholders in evaluating candidate reference points and harvest control rules.
6. The ALBWG should try to obtain the necessary expertise to evaluate the Management Objective of "Maximizing the economic returns of existing fisheries". However, this would be a longer-term goal beyond the 2nd round of MSE.
7. As the MSE process continues, it should be emphasized that the overarching objective running through all the management objectives of the MSE is to maintain the viability and sustainability of the current NPALB stock and fisheries.

<u>Candidate harvest strategies, reference points and harvest control rules</u>

8. The 2nd round of MSE should focus on Harvest Strategy 3 using the specific reference points and harvest control rules listed in Table 4.
9. Harvest Strategy 1 should be removed from further consideration because it performed poorer in terms of Management Objective #1 relative to Harvest Strategy 3, and it was considered undesirable to have a discontinuity in fishing intensity once the limit reference point was breached. In addition, participants of the 3rd MSE Workshop intended to evaluate Harvest Strategy 3 rather than Harvest Strategy 1.
10. Harvest Strategy 2 should be removed from further consideration because the absence of a threshold reference point required a large drop in fishing intensity once the limit reference point was breached and it performed poorer than Harvest Strategy 3 with F50 or F40 in terms of Management Objective #2.
11. The candidate target reference point of F30 should be removed from further consideration because it was the worst performing in terms of Management Objectives #1, 2, and 5, and had a similar performance to F40 for Management Objective #4.
12. The candidate target reference point of F0204 should be removed from further consideration because the actual fishing intensity of this reference point varied substantially between productivity scenarios. It also performed poorer than TRP40 and TRP50 for Management Objectives #1, 2, and 5.
13. A stricter risk level of 90% (rather than 50%) should be used when evaluating the risk of breaching the candidate limit reference points of SSB7.7% and SSB14% (i.e., the LRP is breached if the probability of being above the limit reference point drops below 90%). Given that the candidate limit reference point of SSB20% is relatively conservative, a risk level of 80% was considered appropriate for that reference point. This risk level should be calculated in the same way as is currently done in NPALB stock assessments, by using future projection software over a period of 10 years and calculating the probability of breaching the limit reference point.
14. In addition to harvest control rules where all fisheries are managed by total allowable effort (TAE) or total allowable catch (TAC), there should be an evaluation of harvest control rules where surface fisheries (i.e., Japan pole-and-line and EPO surface) are managed by TAE and all other fisheries are managed by TAC.
15. The levels of fishing intensity should be limited by the historical (1997 – 2015) levels (or distributions of historical fishing intensity levels) achieved by the NPALB fisheries. However,

if these levels of fishing intensity are not high enough to compare performance of threshold and limit reference points, low productivity scenario should be used in the operating models to evaluate these reference points, where appropriate.

16. A future fishing effort scenario where an unmanaged new fishery is removing an increasing amount of unreported catch should be evaluated to understand how large amounts of unreported catch may affect the performance of the harvest control rules.
17. Implementation error distribution should include both positive and negative errors.

MSE Workplan

18. The ISC ALBWG should continue working on the MSE process for a 2nd round because the results presented at the 4th ISC ALB MSE Workshop were useful for understanding the tradeoffs and potential performance of candidate reference points and harvest control rules. However, some candidate reference points and harvest control rules developed at the 3rd MSE Workshop were not evaluated in time due to computer resource limitations. Therefore, the workshop participants developed a focused list of candidate reference points and harvest control rules to be examined for the 2nd round of MSE.
19. Pending approval by the ISC Plenary and resolving potential conflicts with the workload of the ALBWG, results of the 2nd round of MSE should be presented at the 5th ISC ALB MSE Workshop as soon as possible, and no later than late 2020.
20. Given the timeline and previous computer resource limitations, it is important that improved computer resources be available for the 2nd round of ISC ALB MSE.

Others

21. The adequacy of 45 replicates per "run" (i.e., each OM-MP combination) should be examined to a) determine if the rank order of each run for each performance indicator was stable as more replicates are added; and b) determine if and how the value of each performance indicator varied with increasing numbers of replicates.
22. The relationship between how effort is modelled in the MSE operating models (i.e., fishing intensity) and effort in the real world should be examined by the ALBWG and included in the future round of MSE to help managers and stakeholders, if possible.
23. Economic expertise, even though now is not available for the ALBWG, may be needed for future round of MSE since economic aspects are important incentives for the fishery industry.

Changes for 2nd round of MSE analysis

Following recommendations from the 4th ISC ALB MSE Workshop, the ALBWG proposed to focus the second round of MSE analysis on the HCRs presented in Table 4. These are based on HS3 and TRPs of F50 and F40 with different combinations of LRPs and threshold reference points. Furthermore, when $SSB > SSB_{threshold}$, an additional option of no harvest control will be examined in addition to F=TRP, and additional management actions (see Table 4) when SSB < LRP will also be examined.

In terms of the MSE modelling framework, the following changes are going to be underaken:

- The TAC or TAE will be capped to a level of fishing intensity or mortality not exceeding maximum levels over the period of 1997-2015.

- Implementation error will be bidirectional (i.e., fleets can fish at, less or more than the TAE or TAC).
- Additional options will be added to the management model to simulate no harvest control if $SSB \geq SSB_{THRESHOLD}$.
- Use stricter risk levels (80% for HCRs with an LRP of SSB20%; 90% for HCRs with an LRP of SSB14% or SSB7%) in evaluation of risk of breaching candidate LRPs. This risk will be calculated using the current NPALB future projection software.
- When LRP is breached, in addition to TAC or TAE =0, the management model will be modified to include two additional levels of minimum TAC or TAE. For HCRs with LRPs of SSB20% or SSB14% these levels will be 0.5 and 0.25 of the fishing intensity or catch at the LRP. For HCRs with an LRP of 7.7% these levels will be 0.25 of the fishing intensity or catch at the LRP or a fishery closure.

Table 4. List of control-type, candidate target, threshold, and limit reference points to be evaluated for the 2nd round of NPALB MSE. Mixed control-type indicates that surface fleets (i.e., Japan pole-and-line, and EPO surface) are under Total Allowable Effort (TAE) control while all other fleets are under Total Allowable Catch (TAC) control.

Output Control	Harvest Control Rule Label	Target reference point (F_{target})	Threshold reference point ($SSB_{threshold}$)	Limit reference point (SSB_{limit})	Action if SSB > $SSB_{threshold}$
All Fleets under TAC	1	F50	30%	20%	F = TRP or No harvest control (F sampled from historical distribution)
All Fleets under TAC	2	F50	30%	14%	
All Fleets under TAC	3	F50	30%	7.7%	
All Fleets under TAC	4	F50	20%	14%	
All Fleets under TAC	5	F50	20%	7.7%	
All Fleets under TAC	6	F40	20%	14%	
All Fleets under TAC	7	F40	20%	7.7%	
All Fleets under TAC	8	F40	14%	7.7%	
All Fleets under TAE	9	F40	30%	20%	
All Fleets under TAE	10	F50	30%	14%	
All Fleets under TAE	11	F50	30%	7.7%	
All Fleets under TAE	12	F50	20%	14%	
All Fleets under TAE	13	F50	20%	7.7%	
All Fleets under TAE	14	F40	20%	14%	
All Fleets under TAE	15	F40	20%	7.7%	
All Fleets under TAE	16	F40	14%	7.7%	
Mixed	17	F50	30%	20%	
Mixed	18	F50	30%	14%	
Mixed	19	F50	30%	7.7%	
Mixed	20	F50	20%	14%	
Mixed	21	F50	20%	7.7%	
Mixed	22	F40	20%	14%	
Mixed	23	F40	20%	7.7%	
Mixed	24	F40	14%	7.7%	

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Glossary

- **Depletion -** can be defined as spawning biomass depletion or total biomass depletion. It shows what fraction of unfished biomass (spawning or total) the current biomass is. It is calculated as the ratio of the current to unfished biomass (spawning or total).
- **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.
- **Fishing intensity –** a harvest rate 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 of F30 would result in 30% of the SSB per recruit relative to the unfished state. This is approximately equivalent to a harvest rate of 70%.
- **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.
- **Harvest strategy (or management strategy) -** a framework for deciding which fisheries management actions (such as setting a TAC) will achieve stated management objectives. It specifies (1) what harvest control rule will be applied, (2) how stock status estimates will be calculated (e.g. via a stock assessment), and (3) how catch or effort will be monitored.
- **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}).
- **Management Objectives –** High-level goals of a management plan (e.g. prevent overfishing or promote profitability of the fishery).
- **Management Strategy Evaluation (MSE) –** a simulation-based analysis to evaluate trade-offs achieved by alternative harvest (or management) strategies and to assess the consequences of uncertainty in achieving management objectives
- **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.

- **Performance metrics** - Quantitative indicators that are used to evaluate each HCR and serve as a quantitative representation of the management objectives.
- **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.
- **SSB –** female spawning stock biomass.
- **SSBCURRENT,F=0 or SSBX% –** unfished spawning stock biomass that fluctuates with changes in recruitment. Also referred to as dynamic unfished spawning stock biomass.
- **Target reference point (TRP)** - A benchmark which a current stock levels is compared to. It represents a desired state that management intends to achieve. It can be biomass-based (e.g. SSBTARGET) or fishing intensity-based (e.g. FTARGET).
- **Threshold reference point –** A benchmark current stock status is compared to. Its value is between that of a target and limit reference point. It represents a control point below which a management action is undertaken to bring the stock back to a target state.