Management Strategy Evaluation for North Pacific Albacore (*Thunnus alalunga*) Tuna: A Summary for Managers and Stakeholders

Introduction

Management strategy evaluation (MSE) is a process that, given the management objectives that stakeholders and managers have conveyed, uses computer simulations to assess the performance of candidate harvest strategies. The two Regional Fisheries Management Organizations (RFMOs) tasked with managing north Pacific albacore (NPALB), namely the Northern Committee of the Western and Central Pacific Fisheries Commission (WCPFC NC) and the Inter American Tropical Tuna Commission (IATTC), requested the Albacore Working Group (ALBWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) to start developing an MSE for NPALB. The WCPFC NC established a limit reference point (LRP) of $20\%SSB_{CURRENT,\ F=0}$ (SSB: Spawning Stock Biomass) for NPALB, but no formal harvest strategy or target reference point (TRP).

Goal

Examine the performance of alternative harvest strategies and associated reference points for NPALB. A harvest strategy is a framework for establishing which fisheries management actions (such as setting a total allowable catch) are appropriate for achieving 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 data (such as catch or effort) will be monitored.

A harvest strategy can also include allocation rules. For this MSE, managers and stakeholders at previous workshops specified management actions as the setting of Total Allowable Catch (TAC) or Total Allowable Effort (TAE) but did not develop any fishery-specific allocation rules. The TAC or TAE for the entire NPALB stock was instead assumed to be split between all the fisheries using the average harvest ratios from 1999-2015. As such, this MSE was not designed to test the performance of different allocation schemes or domestic allocation issues.

Note that most fisheries are split by gear (longline vs. surface) and country, except for the EPO surface fishery, which combines harvest from the US and Canada.

How does MSE work?

The MSE tested the effect of changing the total harvest amount on achieving the management objectives. Within each harvest strategy, the 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. These reference points were estimated by a stock assessment using data extracted from the simulated albacore population and fisheries. The results are different levels of total allowable harvest over time, as the simulated albacore population responds to different harvest rules.

The computer simulations allowed for testing the harvest strategies under different “what if” scenarios for stock productivity, availability to the Eastern Pacific Ocean (EPO) fishery, 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.

Management Objectives

The performance of each harvest strategy was evaluated based on how well each met the management objectives that managers and stakeholders specified during previous workshops. 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 well 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.

Harvest Strategies and Harvest Control Rules

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).

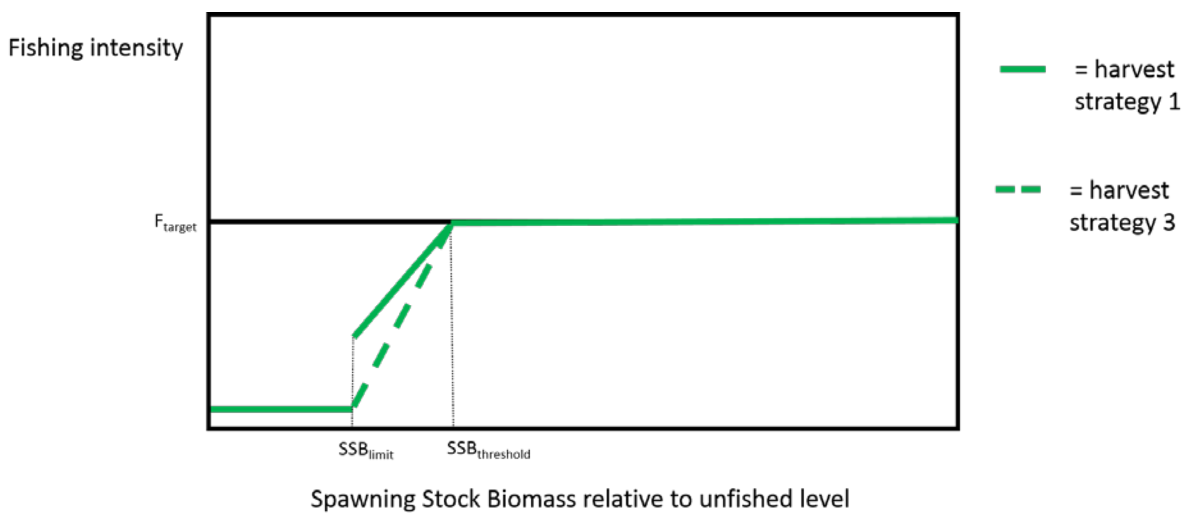

Figure 1. Example harvest control rule (HCR) for harvest strategy 1 and 3.

In this example HCR, if spawning stock biomass (SSB) is above the threshold reference point ($SSB_{threshold}$), then the level of total harvest is set by the target reference point (TRP) (F_{target} in Figure 1) for both HS1 and HS3. This situation is like seeing green traffic lights but having to obey a speed limit for the stretch of road.

Reaching the threshold reference point is somewhat like reaching a school zone, where you have to begin reducing speed because the risks are now larger. If SSB is below the threshold reference point but above the limit reference point (LRP; SSB_{limit}), the level of total harvest is reduced to below the TRP, for both HS1 and HS3. However, as shown by the steeper drop in fishing intensity 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 a threshold rather than a limit reference is to reduce the chances of ever reaching the limit reference point and to avoid severe management actions like closing the fishery that would occur when the limit reference point is breached.

If SSB falls below the LRP, the level of total harvest is drastically reduced for both HS1 and HS3. In this example, harvest goes to 0 and all fisheries that catch NPALB are closed. This is akin to an accident happening ahead and the police having stopped all traffic or only allowing a very slow flow of traffic. 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.

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 1.

Table 1. 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. F_{0204} 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	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%

Reference Points

A TRP refers to a desired state that management wants to achieve. The level of total harvest given three TRPs: F50, F40, and F30 were evaluated. F40 represents a fishing intensity that leads to a SSB that fluctuates around 40% of the unfished SSB (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 (i.e., removing about 70% of the SSB). A TRP of F30 means fishing harder than F40, so the level of biomass desired is lower. In the MSE, the level of total harvest was affected primarily by the TRP.

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

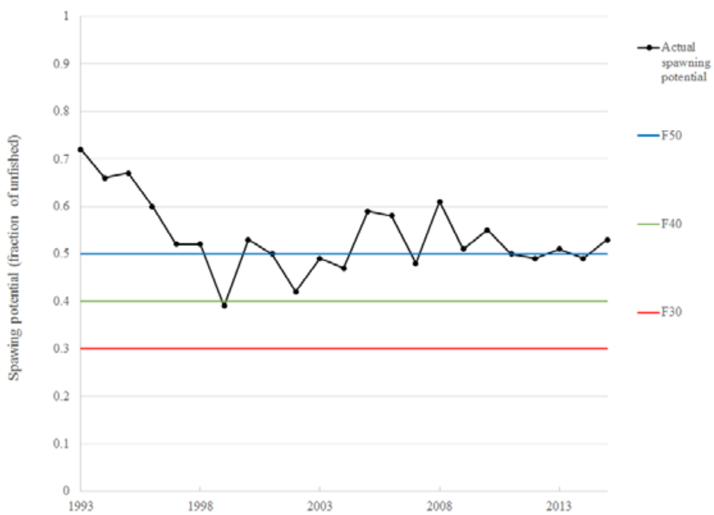

Figure 2. Past trend in spawning potential as fraction of the unfished spawning potential from the 2017 NPALB stock assessment model. The spawning potential one wants to achieve with the three target reference points used in the MSE is also shown. Lower spawning potential is higher fishing intensity.

Three different threshold reference points, SSB30%, SSB20%, and SSB14% (Table 1), were also evaluated. These were associated with three different LRPs: SSB20%, SSB14%, and SSB7.7% (Table1). 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.

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 (HCRs 1, 4, and 6) with F50 had the highest biomass but lowest catch, given the same LRP (Fig. 3).

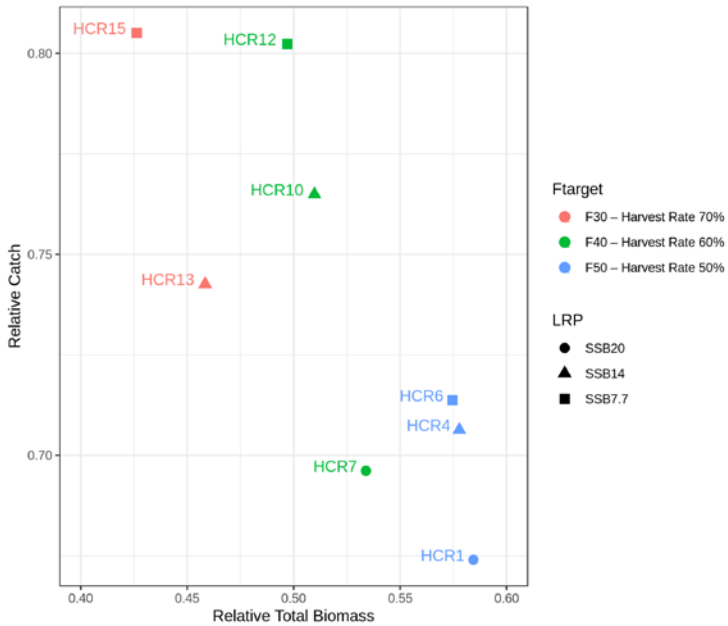

Figure 3. Relative catch and relative total biomass across all runs and reference scenarios for all the HCRs tested in Harvest Strategy 1 with TAC (total allowable catch) control. Here, relative catch is defined as the odds of catch in any given year of the MSE forward simulation being above average 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.

Similarly, for the same LRP, a TRP of F50 had the lowest catch, but the highest catch stability (Fig. 4) and lowest odds of a fishery closure (Fig. 5). See Table 2 for a description of how the catch, biomass, catch stability and odds of a fishery closure metrics were calculated.

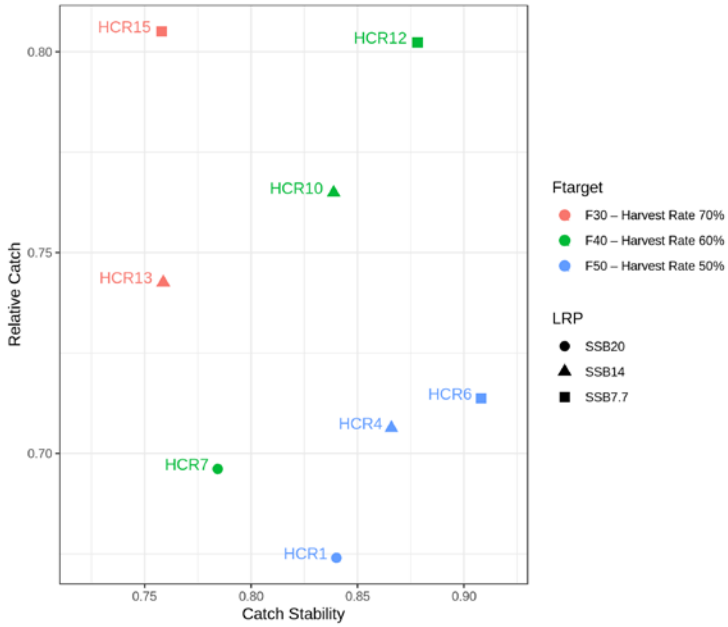

Figure 4. Relative catch and catch stability across all runs and reference scenarios for all the HCRs tested in harvest strategy 1 with TAC (total allowable catch) control. Here relative catch is defined as the odds of catch in any given year of the MSE forward simulation being above average historical (1981-2010) catch. Catch stability is defined as the odds of a decrease in TAC being <30% between consecutive assessment periods (once every 3 years), excluding years where TAC=0.

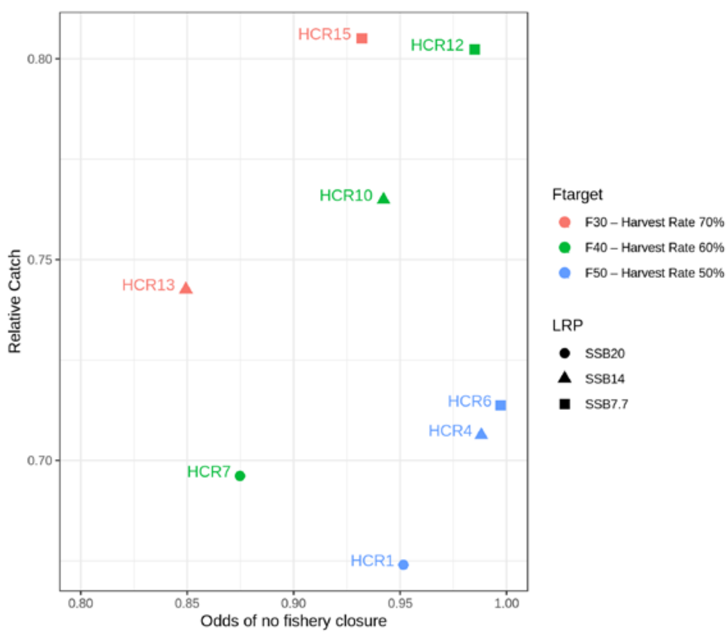

Figure 5. Relative catch and odds of no fishery closures across all runs and reference scenarios for all the HCRs tested in harvest strategy 1 with TAC (total allowable catch) control. Here relative catch is defined as the odds of catch in any given year of the MSE forward simulation being above average historical (1981-2010) catch. Odds of no fishery closure is defined as the odds of spawning stock biomass in any given year of the MSE forward simulation being above the LRP.

Table 2. 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

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 not apparent 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, catch stability, and fishery closures, but also for relative catch. For the same LRP, relative catch of HCRs with a TRP of F40, was higher or comparable to that of HCRs with a TRP of F30 (Fig. 3 to 5). 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 fishing intensity 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.

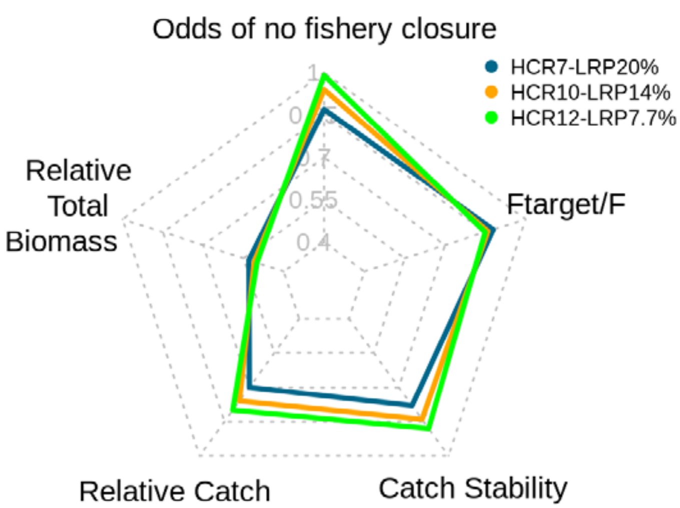

Figure 6. Cobweb plot depicting performance indicators for TAC-based HCR7, HCR10, and HCR12 for HS1 across all runs and reference scenarios. All use a TRP of F40. Values close to the outer web signify a more positive outcome for that performance indicator (i.e., further out is better). Refer to Table 2 for a description of the performance indicators.

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 (Fig. 7).

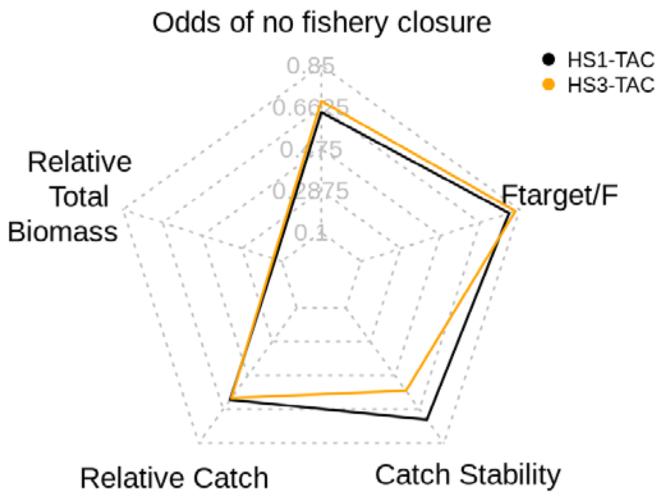

Figure 7. Cobweb plot depicting performance indicators for TAC-based HCR13 for HS1 and HS3 for all runs in the lowest productivity scenario (Scenario 6). Scenario 6 was chosen as it was the scenario with the most fisheries closures and hence best depicted the trade-off between higher catch variability and lower fisheries closures. Values close to the outer web signify a more positive outcome for that performance indicator. Refer to Table 2 for a description of the performance indicators.

5. *Harvest strategies with Total Allowable Effort (TAE) control performed better than ones with Total Allowable Catch (TAC) control across all performance metrics.*

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 all 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.

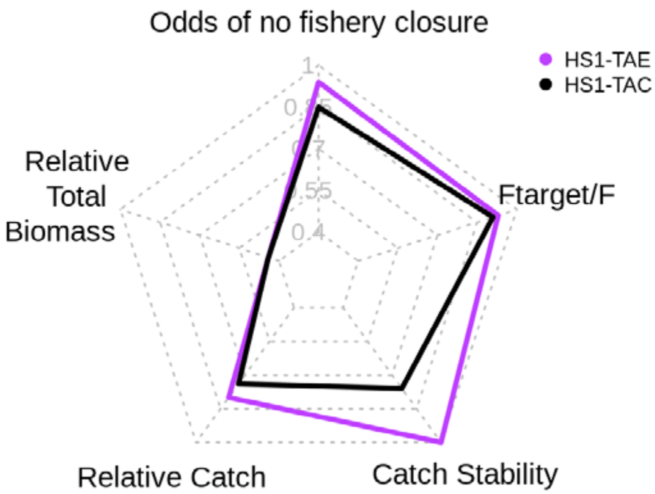

Figure 8. Cobweb plot depicting performance indicators for TAC-based and TAE-based HCR13 for HS1 for all runs and reference scenarios. Values close to the outer web signify a more positive outcome for that performance indicator. Refer to Table 2 for a description of the performance indicators.

Limitations of current NPALB MSE Framework

- 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 to 1966. 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.

Goals of Yokohama MSE Workshop

On March 5th to 7th the ISC will host an MSE Workshop for NPALB in Yokohama, Japan. The main goals of the workshop are to 1) examine with managers and stakeholders the preliminary results of the North Pacific Albacore (NPALB) MSE, 2) collate feedback from managers and stakeholders on future MSE improvements, and 3) begin developing recommendations for the WCPFC NC and IATTC.

For example, the ISC ALBWG will be looking for feedback on:

1. the clarity of the presentation of results,
2. the current assumption in the MSE that all fleets (including longline and surface fleets) are managed in the same manner,
3. potential modifications to the HCRs tested (for instance in terms of the level of risk used when comparing the reference points to the current SSB),
4. reducing the current set of HCRs to a smaller set of the most viable candidates if further analyses are deemed necessary.

Frequently Asked Questions

Will the MSE replace the stock assessment?
No. A MSE is a tool that is used in the process of developing new management strategies for a stock. It highlights trade-offs in the performance of candidate harvest control rules under a wide range of potential "what if" scenarios in terms of biology, observation, implementation, and assessment errors. It assesses the effect of a new TAC or TAE on a set of management objectives (e.g. catch, biomass, catch variability) pre-agreed upon with stakeholders. A MSE does not identify a best estimate of current and near term stock status. That remains the role of the assessment and the projection software associated with it.

How does the NPALB MSE determine how much harvest goes to each fishery every year?
Managers and stakeholders at previous workshops did not propose any fishery-specific allocation rules. Instead, the total harvest amount set by the management strategy via a TAC or TAE is split among the participating fisheries using the average historical allocation from 1999-2015. Each fishery receives the same share of the harvest, but the total harvest changes from year to year depending on recruitment trends and the status of the stock relative to the reference points.

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 asses 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.
- **$SSB_{CURRENT,F=0}$ 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. SSB_{TARGET}) or fishing intensity-based (e.g. F_{TARGET}).
- **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.