**Report of the North Pacific Albacore Tuna Management Strategy Evaluation: A Summary for Managers and Stakeholders[1]**

## Introduction

Management strategy evaluation (MSE) is a process that uses computer simulations to assess the performance of candidate harvest strategies, given management objectives conveyed by stakeholders and managers. The Western and Central Pacific Fisheries Commission (WCPFC) established a limit reference point (LRP) for North Pacific albacore (NPALB) based on a dynamic unfished female spawning stock biomass (SSB0_d). Dynamic unfished SSB refers to the biomass there would be at the present time if no fishing had occurred but everything else had stayed the same, including recruitment changes. The unfished SSB is "dynamic" as it fluctuates over time in response to changes in recruitment. The LRP is 20% of the dynamic unfished SSB (20%SSB0_d). Unlike the WCPFC, the Inter American Tropical Tuna Commission (IATTC) has not adopted a limit reference point. However, both the IATTC and WCPFC 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 for NPALB by any regional fishery management organization.

## Goal

The goal of this MSE was to examine the performance of alternative harvest strategies for NPALB. A harvest strategy establishes management actions (such as setting a total allowable catch) with the aim of achieving stated management objectives (such as maintaining historical total biomass or maintaining historical harvest ratios of each fishery). It specifies (1) what harvest control rule will be applied and under what conditions, (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 two types of management actions for the MSE to evaluate: (1) use catch control for all fleets by setting Total Allowable Catch (TAC) for all fleets; or (2) use mixed control by managing longline fleets with TAC and surface fleets by Total Allowable Effort (TAE). However, managers and stakeholders 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 to obtain a fishery-specific TAC or TAE. 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.

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[1] This summary is based on a preliminary draft of the *Report of the North Pacific Albacore Tuna Management Strategy Evaluation*. It should be noted that the *Report* is subject to change and this summary may not reflect the contents of the final *Report*.

**How does MSE work?**
The MSE uses what is currently known about the NPALB stock to simulate the impact of different harvest strategies on that stock and on all the fleets fishing on it in the future. The MSE accounts for future uncertainty in the environment and biology (e.g., recruitment, movement) by running many simulations with different recruitment trajectories or availability of juvenile NPALB to the Eastern Pacific Ocean (EPO) fishery and by using different "what if" scenarios for stock productivity or fleet dynamics. For example, what if growth is slower than assumed in the stock assessment or what if an unmanaged fleet enters the fishery? These "what if" scenarios were based on the ALBWG's best estimate of the uncertainty or were specified by the managers and stakeholders. In addition, the MSE also simulates future stock assessments based on data from the simulated fleets to account for any errors in observations and the stock assessment (Fig. 1).

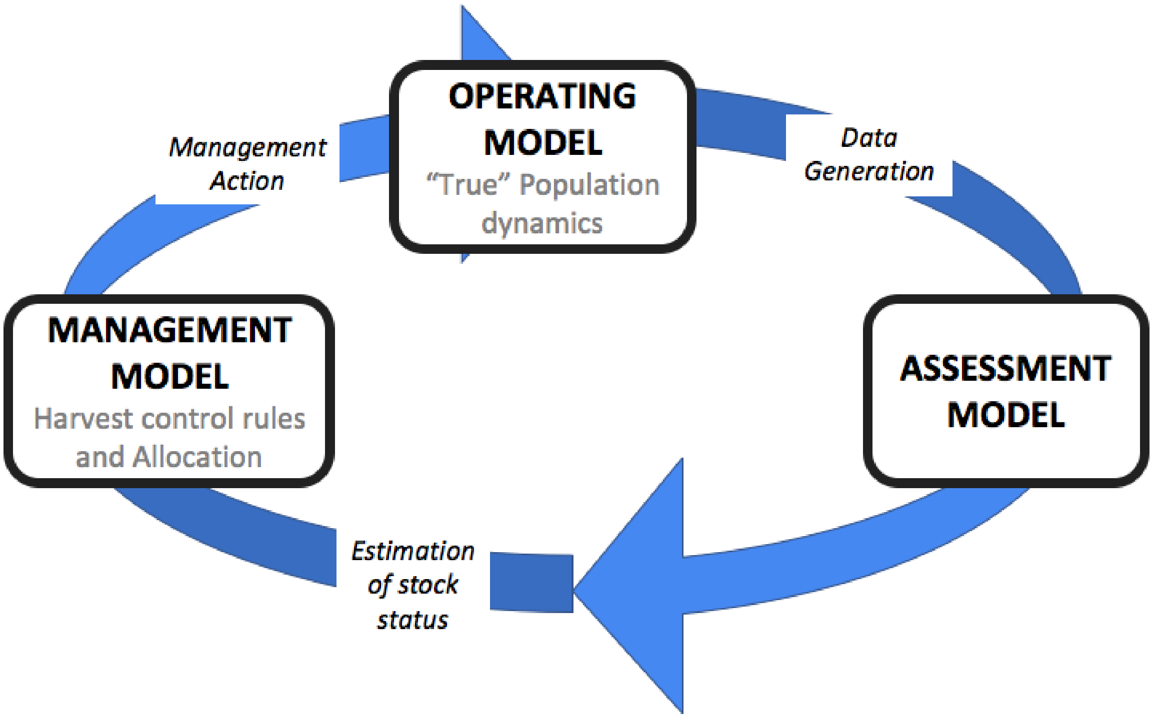


**Figure 1** Schematic of the NPALB MSE framework showing the MSE feedback loop where data is sampled with error from the operating model and fed into the simulated assessment model, which determines stock status and informs the management model. The resulting management action (e.g., TAC) then affects the dynamics of the "true" population in the operating model.

As in the real world, the simulated stock assessment estimates the condition of the NPALB stock relative to reference points. The results from the simulated assessment are then used to simulate management of the NPALB fishing fleets, based on the candidate harvest strategy and harvest control rule being tested (Fig. 1). The resulting management action then impacts the simulated fleet and NPALB stock (Fig. 1). The simulated NPALB stock responds not only to changes in fishing by the simulated fleets but also to changes in the environment and biology. This cycle (Fig. 1) is simulated for 30 years into the future to test what are the odds of the management objectives being met over a period of time under the range of uncertainties (i.e., "what if" scenarios) considered. Testing of the harvest strategies under different "what if" uncertainty scenarios for stock productivity, availability to the Eastern Pacific Ocean (EPO) fishery, assessment error, or management implementation error will help ensure that the proposed harvest strategies can meet management goals in the real world.

**Harvest Control Rules and Reference Points**

The first round of NPALB MSE simulations included three harvest strategies (see the report here). After the first round of NPALB MSE simulations, managers and stakeholders identified Harvest Strategy 3 (HS3, Fig. 2) as the best performing, and recommended removing the two remaining candidate harvest strategies from further consideration. It was also recommended that future MSE analyses focus on assessing the performance of candidate harvest control rules (HCRs) with the best performing target reference points (TRPs) of F40 and F50. These latest analyses incorporate those suggestions by focusing on the evaluation solely on HS3 HCRs with TRPs of F40 and F50. **This latest round of simulations completes the evaluation of all the candidate HCRs and associated reference points proposed at MSE workshops and represents the final set of MSE analyses in support of development of a harvest strategy for NPALB.**

HCRs in Harvest Strategy 3 all share the same shape illustrated in Figure 2. HCRs define the management action to be taken given the ratio of spawning stock biomass (SSB) to the biomass-based threshold ($SSB_{threshold}$) and limit reference points (LRP; so: $SSB/SSB_{threshold}$ and SSB/LRP). Under HCRs for Harvest Strategy 3 the fishing intensity remains constant at a desirable level (the green line in Figure 2) unless biomass falls below specific thresholds (vertical dotted lines in Figure 2), at which point fishing intensity is reduced (yellow line in Figure 2), down to a minimum level (red line in Figure 2), to allow biomass to increase back above the threshold (Fig. 2).

A TRP refers to the desired state that management wants to achieve. The best-performing target reference points in the first round of MSE simulations and those analyzed here are:

- F40 represents a fishing intensity (F; calculated in terms of spawning potential ratio) that leads to a SSB that fluctuates around 40% of the unfished SSB (i.e., removing about 60% of the SSB).
- F50 leads to a SSB that is around 50% of unfished SSB (i.e., removing about 50% of the SSB).

With a TRP of F40 there is more fishing than with a TRP of F50, resulting in a lower SSB. In the MSE, the level of total harvest was affected primarily by the TRP.

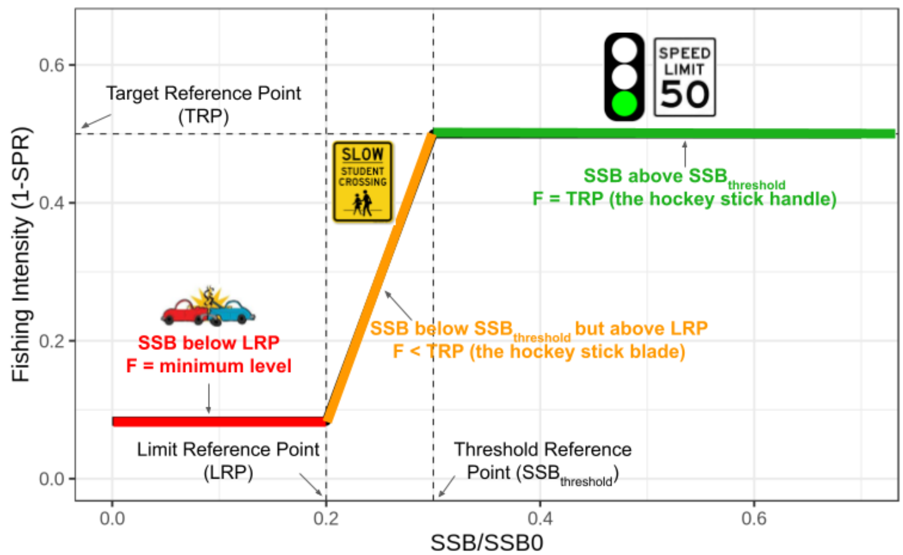


**Figure 2** Example of a generic harvest control rule (HCR) for Harvest Strategy 3. SSB0 on the x-axis refers to dynamic unfished SSB (SSB0_d).

### "What if" scenarios

Four reference scenarios were used in this latest round of MSE:

Scenario 1 with high plausibility and moderately high productivity

Scenario 3 with medium plausibility and the highest productivity

Scenario 4 with medium plausibility and moderately low productivity

Scenario 6 with low plausibility and the lowest productivity.

All scenarios were considered plausible, albeit with different levels of biological plausibility, and were able to adequately reproduce historical trends in catches, indices of abundance, and age composition data. However, their different growth or mortality settings required different levels of historical fishing intensity to meet historical catches. The different "what if" scenarios for stock productivity (i.e., reference scenarios) considered in this MSE estimate different levels of historical F ($F_{historical}$, Fig. 3).

For Scenario 1, which the ALBWG considered the most biologically plausible:

- average fishing intensity over the past 20 years was F51
- F averaged over the 2002-2004 period was F42 (Fig. 3)
- since 1993, fishing intensity has only exceeded F40 (i.e., a fishing intensity of 0.6) in 1999 and 2002 (Fig. 3).

In addition to the four reference "what if" scenarios, the MSE also tested the performance of HCRs 9-16 under a robustness scenario. The robustness scenario simulated a change in fleet dynamics whereby an unmanaged ghost fleet enters the fishery and its catches increase annually up to a maximum of 50,000 mt. The robustness scenario used the stock productivity characteristics of scenario 1.

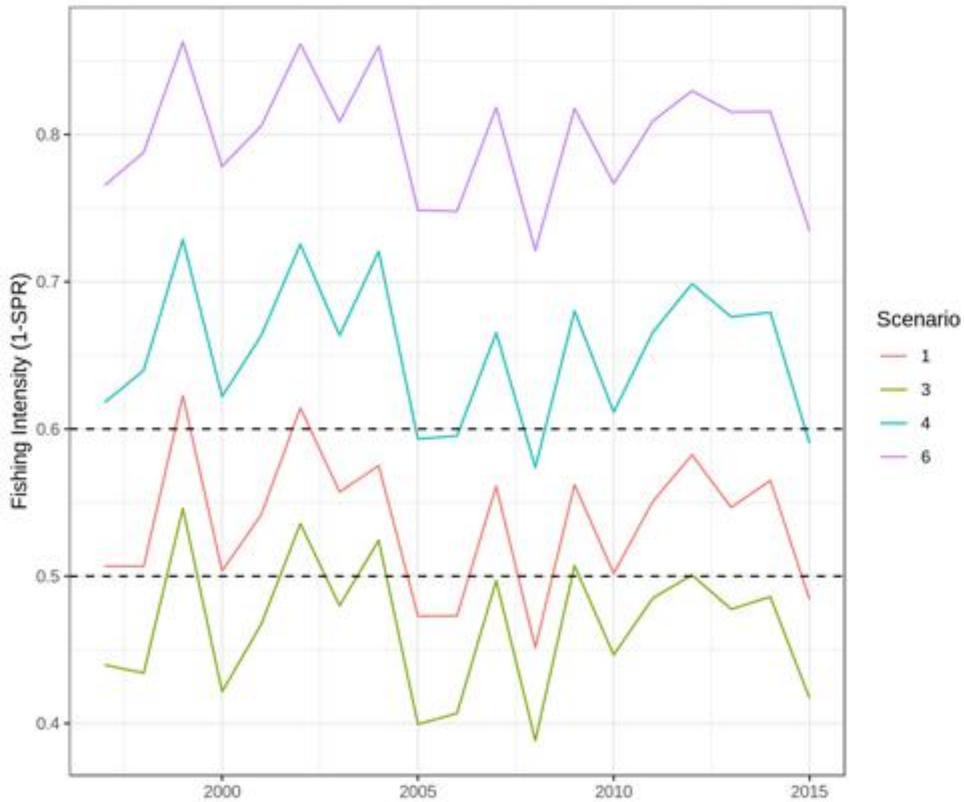


**Figure 3.** Trends in fishing intensity (1-SPR) from 1997-2015 estimated for each of the operating models used in the four reference "what if" scenarios. 1-SPR is the reduction in female SSB per recruit due to fishing and is used to describe the overall fishing intensity on the stock. The dotted lines represent the fishing intensity associated with each of the target reference points (TRP) under consideration, 0.6 for the F40 TRP and 0.5 for the F50 TRP.

**Harvest Control Rule Elements**

Figure 4 depicts how fishing intensity varies according to changes in SSB relative to unfished SSB for each of the 16 HCRs tested. For each HCR:

- **If SSB is above $SSB_{threshold}$ (green line in Figure 2)**

  The level of fishing intensity is set to the TRP if the historical time series of fishing intensities ($F_{historical}$) exceeds the TRP (scenarios 4 and 6) or is sampled from $F_{historical}$ if $F_{historical}$ is lower than the TRP (scenarios 1 and 3).

  In other words, fishing intensity is set at the lower of the two values. Using $F_{historical}$ can prevent fishing intensity from increasing to a level higher than what has been estimated for the historical period and to simulate historical limits on the capacity of the NPALB fleets.

  Setting fishing intensity to the TRP or $F_{historical}$ is like setting a speed limit for the stretch of road with green lights.

- **If SSB falls below $SSB_{threshold}$ but is still above the LRP (yellow line in Figure 1)**

  The level of fishing intensity is reduced to below the TRP.

  A HCR will initiate management action at a threshold rather than a LRP in order to reduce the chances of ever reaching the LRP and to avoid severe management actions, like extremely reduced catch/effort limits that could occur when the LRP is breached.

  This is somewhat like reaching a school zone, where you have to begin reducing speed because the risks will be greater.

- **If SSB falls below the LRP**

  The level of fishing intensity is kept at a low level to allow the stock to rebuild.

  SSB is considered to be below the LRP if the simulated assessment and associated projection software in the MSE determine that the odds of SSB>LRP are less than 80% or 90% depending on the HCR (Table 1, i.e., there is a 10% or 20% risk of the LRP being breached).

  This is akin to an accident happening ahead and the police only allowing a very slow flow of traffic.

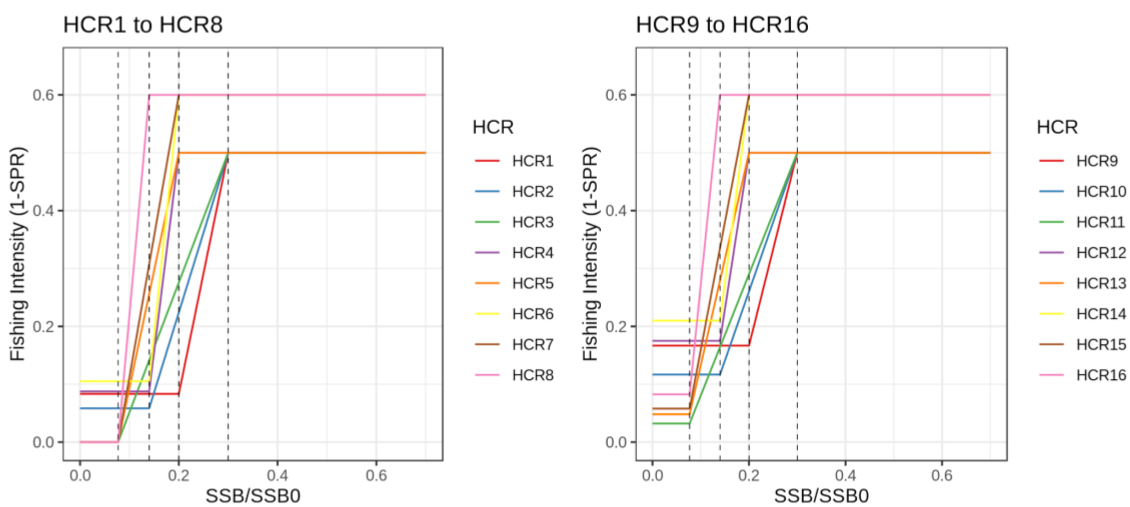


**Figure 4.** Harvest control rules (HCRs) tested in the final round of MSE analyses for NPALB. Vertical dotted black lines indicate the limit or threshold reference points listed in Table 1.

For each HCR, different values of TRPs, $SSB_{threshold}$, LRPs, and rebuilding plans (i.e. management actions when SSB is below the LRP) can be tested. We analyzed the performance of 16 HCRs with different combinations of TRPs, $SSB_{threshold}$, and LRPs (Fig. 4, Table 1).

**Table 1.** List of harvest control rules (HCRs) tested in the final MSE analyses for NPALB. The TRP is an indicator of fishing intensity based on SPR. SPR is the female spawning stock biomass (SSB) per recruit that would result from the current year's pattern and intensity of fishing mortality relative to the unfished stock. A TRP of F50 would result in the SSB fluctuating around 50% of the unfished SSB. A TRP of F40 implies a higher fishing intensity (i.e., removing about 60% of unfished SSB) and would result in a SSB of around 40% of the unfished SSB. The threshold and limit reference points, $SSB_{threshold}$ and LRP, are SSB-based and refer to the specified percentage of unfished SSB. The unfished SSB is dynamic and fluctuates depending on changes in recruitment. Each HCR considers the LRP as being breached (i.e. SSB<LRP) if the odds of SSB > LRP are less than those specified in the table for each HCR. The fraction used to calculate the minimum level of fishing intensity (F) refers to the fraction of the F associated with the LRP.

| HCR | Target reference point (TRP) | Threshold reference point ($SSB_{threshold}$) | Limit reference point (LRP) | Odds SSB > LRP | Fraction used to calculate minimum level of F |
|---|---|---|---|---|---|
| 1 | F50 | 30% | 20% | 0.8 | 0.25 |
| 2 | F50 | 30% | 14% | 0.9 | 0.25 |
| 3 | F50 | 30% | 7.7% | 0.9 | 0 |
| 4 | F50 | 20% | 14% | 0.9 | 0.25 |
| 5 | F50 | 20% | 7.7% | 0.9 | 0 |
| 6 | F40 | 20% | 14% | 0.9 | 0.25 |
| 7 | F40 | 20% | 7.7% | 0.9 | 0 |
| 8 | F40 | 14% | 7.7% | 0.9 | 0 |
| 9 | F50 | 30% | 20% | 0.8 | 0.5 |
| 10 | F50 | 30% | 14% | 0.9 | 0.5 |
| 11 | F50 | 30% | 7.7% | 0.9 | 0.25 |
| 12 | F50 | 20% | 14% | 0.9 | 0.5 |
| 13 | F50 | 20% | 7.7% | 0.9 | 0.25 |
| 14 | F40 | 20% | 14% | 0.9 | 0.5 |
| 15 | F40 | 20% | 7.7% | 0.9 | 0.25 |
| 16 | F40 | 14% | 7.7% | 0.9 | 0.25 |

## Management Objectives and Performance Metrics

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 conceptual management objectives provided by managers and stakeholders for the 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.

These were translated to the operational management objectives and quantifiable performance indicators listed in Table 2 by the ISC ALBWG in collaboration with managers and stakeholders.

Management objective 3 (maintain historical harvest ratios of each fishery) was not evaluated for this 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, as quantitative performance indicators (Table 2). These performance indicators were used to quantitatively evaluate the performance of the harvest strategies tested relative to the management objectives.

**Table 2.** List of management objectives, their performance indicators, and their corresponding labels for figures and tables. Management objective #3 was not included because it was not evaluated in this MSE. SSB refers to female spawning stock biomass, LRP to limit reference point, SSB0 to unfished female spawning stock biomass. Unless specified as “equilibrium SSB0”, the SSB0 is dynamic (i.e., equal to SSB0_d) and fluctuates depending on changes in recruitment. Depletion refers to the ratio of current total biomass to unfished equilibrium total biomass and is a measure of relative biomass. Management objectives are not ranked according to importance.

| **Management Objective** | **Label** | **Performance Indicator** |
|---|---|---|
| 1. Maintain SSB above the limit reference point (maintain historical spawning biomass) | Odds of not breaching the LRP | Probability that SSB in any future year of the MSE simulation is above the LRP |
| | Odds SSB > 20%SSB0_d | Probability that SSB in any future year of the MSE simulation is above 20% of the dynamic unfished SSB (20%SSB0_d). This is the LRP currently adopted by the WCPFC for NPALB. |

| | | |
|---|---|---|
| | Odds SSB > 7.7%SSB0_d | Probability that SSB in any future year of the MSE simulation is above 7.7% of the dynamic unfished SSB. |
| | Odds SSB > equilibrium 7.7%SSB0 | Probability that SSB in any future year of the MSE simulation is above 7.7% of the equilibrium unfished SSB. This is the interim LRP currently adopted by the IATTC for tropical tunas. |
| 2. Maintain depletion of total biomass around historical average depletion (maintain historical total biomass) | Odds depletion > minimum historical | Probability that the depletion of total biomass in any future year of the MSE simulation is above minimum historical (2006-2015) depletion. |
| 4. Maintain catches above average historical catch (maintain catches above historical average) | Odds catch >historical | Probability that catch in any future year of the MSE simulation is above average historical (1981-2010) catch. |
| | Odds medium term catch > historical | Probability that catch averaged over years 7-13 of the simulation is above average historical (1981-2010) catch. |
| | Odds long term catch > historical | Probability that catch averaged over years 20-30 of the simulation is above average historical (1981-2010) catch. |
| 5. Change in total allowable catch between years should be relatively gradual (minimize changes in management over time) | Catch stability | Probability that TAC (or catch for mixed control) decreases <30% between consecutive assessment periods (once every 3 years), excluding years where TAC=0. |
| | Odds of no management action | Probability of SSB > $SSB_{threshold}$ |
| 6. Maintain fishing intensity (F) at the target value with reasonable variability (maintain fishing impact around the target value) | $F_{target}/F$ | $F_{target}/F$ |

## Results

The results of the MSE analysis can be summarized in five main points (additional details are provided below).

1. *Under both TAC and mixed control, all harvest control rules (HCRs) were able to maintain the stock biomass above the WCPFC's limit reference point (20% SSB0_d), the IATTC interim limit reference point used for tropical tunas (7.7%SSB0), and the LRP specified by each HCR with high probability (>0.8).*

2. *Under mixed control, there was a tradeoff between the odds of biomass being above the 20%SSB0_d LRP (Management Objective 1) and the catch performance metrics (Management Objective 4).*

3. *Under TAC control, there are comparable odds of catch in any given year being above historical catch for F50 and F40 HCRs despite different fishing intensities due to a tradeoff between fishing intensity and catch stability.*

4. *HCRs with LRP and $SSB_{threshold}$ reference points closer to the SSB associated with the $TRP_t$ resulted in a higher frequency of management interventions.*

5. *Both mixed and TAC control are able to maintain the stock above the WCPFC's limit reference point (20% SSB0_d) and the IATTC interim limit reference point used for tropical tunas (7.7%SSB0) with high probability (>0.8), even with increasing catches from an unknown, unmanaged fleet. However, this comes at the expense of reduced catches for the managed fleets.*

***1. Under both TAC and mixed control, all harvest control rules (HCRs) were able to maintain the stock biomass above the WCPFC's limit reference point (20% SSB0_d), the IATTC interim limit reference point used for tropical tunas (7.7%SSB0), and the LRP specified by each HCR with high probability (>0.8).***

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The NPALB stock is in good condition and, even when considering the range of uncertainties in stock productivity, recruitment variability, availability to the EPO surface fleet, observation, assessment, and implementation error, all HCRs were highly likely (>0.8) to result in an SSB above the current 20%SSB0_d LRP for WCPFC, the 7.7%SSB0 interim LRP for IATTC tropical tuna, and all candidate LRPs in this MSE (Table 3 and 4, Fig. 5) under both TAC and mixed control. Furthermore, all HCRs under both TAC and mixed control showed at least even (>0.4) odds of meeting each of the performance indicators (Table 3 and 4, Fig. 5). Given tradeoffs between different performance indicators, the choice of a preferred HCR is dependent on what each manager and stakeholder most value among the different management objectives and their level of risk aversion.

**Table 3.** Performance of indicators for each harvest control rule under mixed control across all iterations and uncertainty scenarios. HCR refers to harvest control rule, LRP to limit reference point, $SSB_{threshold}$ to the threshold reference point, SSB to female spawning biomass, SSB0 to unfished female spawning stock biomass. Colors represent odds categories and associated risk levels as defined in the legend. The $F_{target}/F$ indicator does not represent odds and so can be greater than 1. Its levels follow the same as those for the odds-based performance indicators presented in the legend, except that the almost certain level applies to values of 0.9 and higher. Some HCRs have $F_{target}/F$ of >1 because on average, the Fs for those HCRs are below the $F_{target}$. The LRP and $SSB_{threshold}$ are SSB-based and refer to the specified fraction of SSB0. Unless specified as equilibrium SSB0, the unfished SSB is dynamic and fluctuates depending on changes in recruitment. See Table 2 for a detailed definition of performance indicators.

Mixed Control

Across Reference Scenarios

| | | | | Management Objective 1 | | | | Management Objective 2 | Management Objective 4 | | | Management Objective 5 | | Management Objective 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hcr | TRP | LRP | SSB threshold | Odds of Not Breaching the LRP | Odds SSB > 20% SSBo | Odds SSB > Equilibrium 7.7% SSBo | Odds SSB > 7.7% SSBo | Odds Depletion > Minimum Historical | Odds Mean Annual Catch > Historical | Odds Mean Medium Term Catch > Historical Catch | Odds Mean Long Term Catch > Historical Catch | Catch Stability | Odds No Management Action | Ftarget/F |
| 1 | F50 | 0.20 | 0.30 | 0.98 | 0.98 | 0.96 | 1.00 | 0.75 | 0.59 | 0.59 | 0.67 | 0.99 | 0.88 | 0.92 |
| 2 | F50 | 0.14 | 0.30 | 0.99 | 0.97 | 0.96 | 1.00 | 0.74 | 0.60 | 0.59 | 0.68 | 1.00 | 0.87 | 0.92 |
| 3 | F50 | 0.08 | 0.30 | 1.00 | 0.98 | 0.96 | 1.00 | 0.74 | 0.59 | 0.58 | 0.68 | 1.00 | 0.88 | 0.92 |
| 4 | F50 | 0.14 | 0.20 | 0.99 | 0.98 | 0.96 | 1.00 | 0.74 | 0.60 | 0.59 | 0.68 | 1.00 | 0.98 | 0.92 |
| 5 | F50 | 0.08 | 0.20 | 1.00 | 0.98 | 0.96 | 1.00 | 0.75 | 0.60 | 0.59 | 0.68 | 1.00 | 0.98 | 0.92 |
| 6 | F40 | 0.14 | 0.20 | 0.97 | 0.93 | 0.93 | 0.99 | 0.72 | 0.69 | 0.68 | 0.77 | 1.00 | 0.93 | 1.04 |
| 7 | F40 | 0.08 | 0.20 | 0.99 | 0.92 | 0.93 | 0.99 | 0.72 | 0.69 | 0.68 | 0.77 | 0.99 | 0.92 | 1.04 |
| 8 | F40 | 0.08 | 0.14 | 0.99 | 0.92 | 0.93 | 0.99 | 0.72 | 0.69 | 0.68 | 0.77 | 1.00 | 0.97 | 1.04 |
| 9 | F50 | 0.20 | 0.30 | 0.98 | 0.98 | 0.96 | 1.00 | 0.74 | 0.60 | 0.59 | 0.68 | 1.00 | 0.88 | 0.92 |
| 10 | F50 | 0.14 | 0.30 | 0.99 | 0.98 | 0.96 | 1.00 | 0.74 | 0.60 | 0.58 | 0.68 | 1.00 | 0.88 | 0.92 |
| 11 | F50 | 0.08 | 0.30 | 1.00 | 0.98 | 0.96 | 1.00 | 0.75 | 0.60 | 0.59 | 0.68 | 1.00 | 0.88 | 0.92 |
| 12 | F50 | 0.14 | 0.20 | 0.99 | 0.98 | 0.96 | 1.00 | 0.75 | 0.60 | 0.59 | 0.69 | 1.00 | 0.98 | 0.92 |
| 13 | F50 | 0.08 | 0.20 | 1.00 | 0.98 | 0.96 | 1.00 | 0.75 | 0.60 | 0.59 | 0.68 | 1.00 | 0.98 | 0.92 |
| 14 | F40 | 0.14 | 0.20 | 0.97 | 0.92 | 0.93 | 0.99 | 0.72 | 0.69 | 0.68 | 0.77 | 1.00 | 0.92 | 1.04 |
| 15 | F40 | 0.08 | 0.20 | 0.99 | 0.93 | 0.93 | 0.99 | 0.72 | 0.69 | 0.68 | 0.77 | 1.00 | 0.93 | 1.04 |
| 16 | F40 | 0.08 | 0.14 | 0.99 | 0.93 | 0.93 | 0.99 | 0.72 | 0.69 | 0.68 | 0.77 | 1.00 | 0.97 | 1.04 |

Odds

- Almost Certain - 0.9-<1
- Highly Likely - 0.8-0.89
- Likely - 0.7-0.79
- Better than Even - 0.6-0.69
- Even - 0.4-0.59
- Less than Even - 0.3-0.39
- Unlikely - 0.2-0.29
- Highly Unlikely - 0.1-0.19
- Almost Never - >0-0.09

**Table 4.** Performance of indicators for each harvest control rule under TAC control across all iterations and uncertainty scenarios. HCR refers to harvest control rule, LRP to limit reference point, $SSB_{threshold}$ to the threshold reference point, SSB to female spawning biomass, SSB0 to unfished female spawning stock biomass. Colors represent risk categories as defined in the legend. The $F_{target}$/F indicator does not represent odds and so can be greater than 1. Its levels follow the same as those for the odds-based performance indicators presented in the legend, except that the almost certain level applies to values of 0.9 and higher. Some HCRs have $F_{target}$/F of >1 because on average, the Fs for those HCRs are below the $F_{target}$. The LRP and $SSB_{threshold}$ are SSB-based and refer to the specified fraction of SSB0. Unless specified as equilibrium SSB0, the unfished SSB is dynamic and fluctuates depending on changes in recruitment. See Table 2 for a detailed definition of performance indicators.

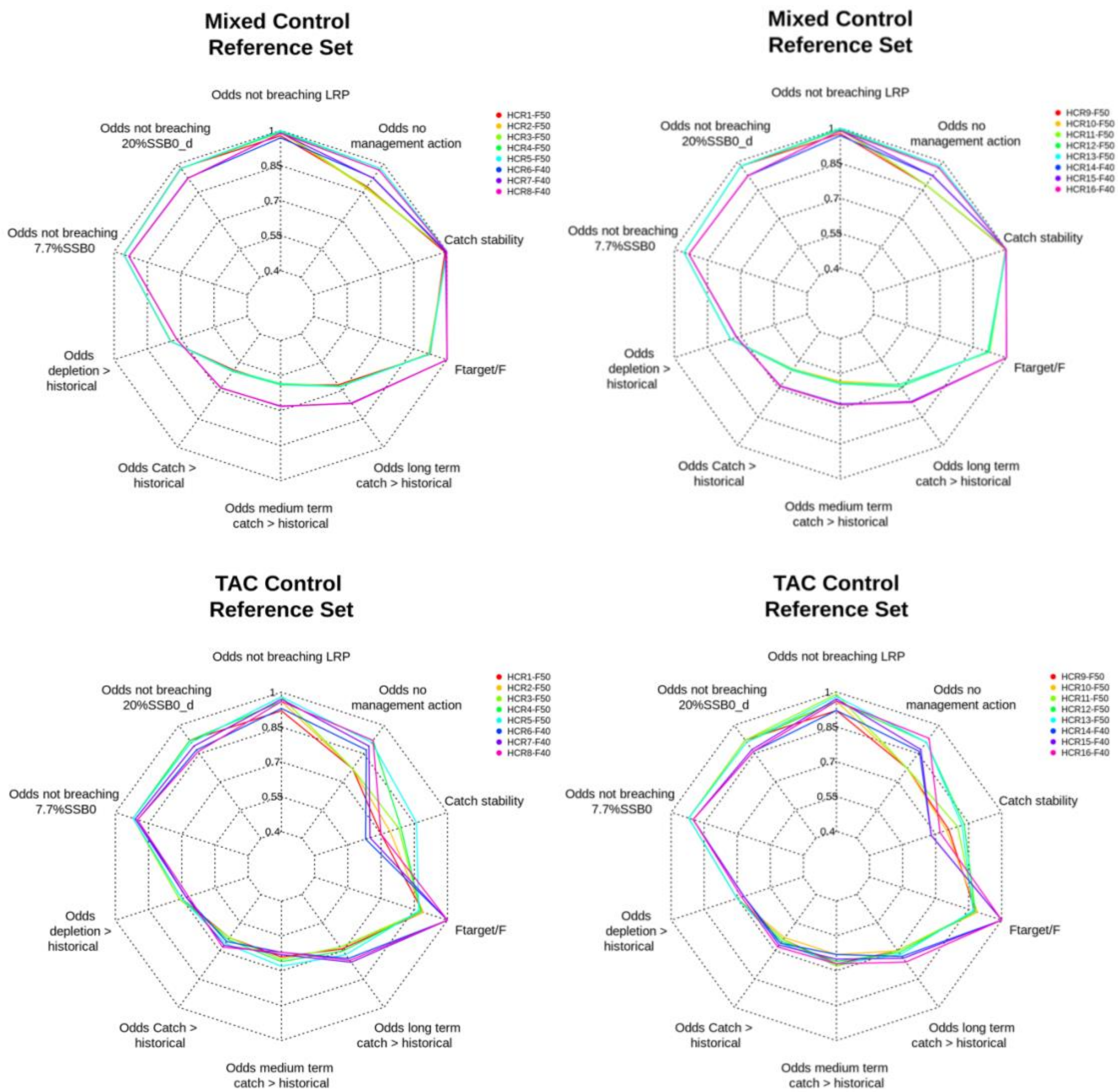
TAC Control

Across Reference Scenarios

| | | | | Management Objective 1 | | | | Management Objective 2 | Management Objective 4 | | | Management Objective 5 | | Management Objective 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hcr | TRP | LRP | SSB threshold | Odds of Not Breaching the LRP | Odds SSB > 20% SSBo | Odds SSB > Equilibrium 7.7% SSBo | Odds SSB > 7.7% SSBo | Odds Depletion > Minimum Historical | Odds Mean Annual Catch > Historical | Odds Mean Medium Term Catch > Historical Catch | Odds Mean Long Term Catch > Historical Catch | Catch Stability | Odds No Management Action | Ftarget/F |
| 1 | F50 | 0.20 | 0.30 | 0.92 | 0.92 | 0.92 | 0.99 | 0.70 | 0.63 | 0.64 | 0.68 | 0.70 | 0.77 | 0.88 |
| 2 | F50 | 0.14 | 0.30 | 0.96 | 0.92 | 0.92 | 0.98 | 0.70 | 0.62 | 0.64 | 0.68 | 0.72 | 0.77 | 0.89 |
| 3 | F50 | 0.08 | 0.30 | 0.98 | 0.91 | 0.92 | 0.98 | 0.70 | 0.62 | 0.64 | 0.67 | 0.75 | 0.76 | 0.89 |
| 4 | F50 | 0.14 | 0.20 | 0.96 | 0.91 | 0.92 | 0.98 | 0.70 | 0.63 | 0.65 | 0.68 | 0.78 | 0.91 | 0.88 |
| 5 | F50 | 0.08 | 0.20 | 0.98 | 0.91 | 0.92 | 0.98 | 0.69 | 0.65 | 0.67 | 0.71 | 0.82 | 0.91 | 0.87 |
| 6 | F40 | 0.14 | 0.20 | 0.93 | 0.87 | 0.90 | 0.97 | 0.68 | 0.64 | 0.61 | 0.73 | 0.63 | 0.87 | 1.06 |
| 7 | F40 | 0.08 | 0.20 | 0.97 | 0.88 | 0.90 | 0.97 | 0.68 | 0.66 | 0.63 | 0.75 | 0.66 | 0.88 | 1.05 |
| 8 | F40 | 0.08 | 0.14 | 0.96 | 0.86 | 0.90 | 0.96 | 0.67 | 0.67 | 0.63 | 0.75 | 0.70 | 0.92 | 1.02 |
| 9 | F50 | 0.20 | 0.30 | 0.91 | 0.91 | 0.92 | 0.98 | 0.70 | 0.63 | 0.66 | 0.68 | 0.75 | 0.76 | 0.89 |
| 10 | F50 | 0.14 | 0.30 | 0.96 | 0.92 | 0.92 | 0.99 | 0.70 | 0.62 | 0.64 | 0.69 | 0.74 | 0.77 | 0.89 |
| 11 | F50 | 0.08 | 0.30 | 0.99 | 0.92 | 0.92 | 0.99 | 0.70 | 0.63 | 0.67 | 0.69 | 0.79 | 0.77 | 0.89 |
| 12 | F50 | 0.14 | 0.20 | 0.96 | 0.91 | 0.92 | 0.98 | 0.70 | 0.64 | 0.66 | 0.70 | 0.82 | 0.91 | 0.88 |
| 13 | F50 | 0.08 | 0.20 | 0.98 | 0.91 | 0.92 | 0.98 | 0.69 | 0.65 | 0.66 | 0.71 | 0.82 | 0.91 | 0.87 |
| 14 | F40 | 0.14 | 0.20 | 0.92 | 0.86 | 0.90 | 0.96 | 0.67 | 0.65 | 0.63 | 0.73 | 0.67 | 0.86 | 1.02 |
| 15 | F40 | 0.08 | 0.20 | 0.97 | 0.87 | 0.90 | 0.97 | 0.67 | 0.66 | 0.64 | 0.74 | 0.67 | 0.87 | 1.01 |
| 16 | F40 | 0.08 | 0.14 | 0.96 | 0.86 | 0.90 | 0.96 | 0.67 | 0.66 | 0.65 | 0.75 | 0.71 | 0.92 | 1.03 |

Odds

- Almost Certain - 0.9-<1
- Highly Likely - 0.8-0.89
- Likely - 0.7-0.79
- Better than Even - 0.6-0.69
- Even - 0.4-0.59
- Less than Even - 0.3-0.39
- Unlikely - 0.2-0.29
- Highly Unlikely - 0.1-0.19
- Almost Never - >0-0.09




| HCR | TRP | $SSB_{threshold}$ | LRP | Prob SSB > LRP | $TAC_{min}$ or $TAE_{min}$ Fraction |
|---|---|---|---|---|---|
| 1 | F50 | 30% | 20% | 0.8 | 0.25 |
| 2 | F50 | 30% | 14% | 0.9 | 0.25 |
| 3 | F50 | 30% | 7.7% | 0.9 | 0 |
| 4 | F50 | 20% | 14% | 0.9 | 0.25 |
| 5 | F50 | 20% | 7.7% | 0.9 | 0 |
| 6 | F40 | 20% | 14% | 0.9 | 0.25 |
| 7 | F40 | 20% | 7.7% | 0.9 | 0 |
| 8 | F40 | 14% | 7.7% | 0.9 | 0 |

| HCR | TRP | $SSB_{threshold}$ | LRP | Prob SSB > LRP | $TAC_{min}$ or $TAE_{min}$ Fraction |
|---|---|---|---|---|---|
| 9 | F50 | 30% | 20% | 0.8 | 0.5 |
| 10 | F50 | 30% | 14% | 0.9 | 0.5 |
| 11 | F50 | 30% | 7.7% | 0.9 | 0.25 |
| 12 | F50 | 20% | 14% | 0.9 | 0.5 |
| 13 | F50 | 20% | 7.7% | 0.9 | 0.25 |
| 14 | F40 | 20% | 14% | 0.9 | 0.5 |
| 15 | F40 | 20% | 7.7% | 0.9 | 0.25 |
| 16 | F40 | 14% | 7.7% | 0.9 | 0.25 |

**Figure 5** Cobweb plot depicting performance indicators for HCRs 1-8 (left) and HCRs 9-16 (right) under mixed control (top) and TAC control (bottom) for all runs across the four "what if" reference scenarios. 20%SSB0_d corresponds to 20% of the unfished dynamic SSB and corresponds to the current WCPFC limit reference point (LRP). 7.7%SSB0 refers to 7.7% of unfished equilibrium SSB and is the interim LRP used by IATTC for tropical tunas. Values close to the outer web signify a more positive outcome for that performance indicator.

***2. Under mixed control, there is a tradeoff between the odds of biomass being above the 20%SSB0_d LRP (Management Objective 1) and the catch performance metrics (Management Objective 4) (see Table 3 on page 11).***

Under mixed control, there was a clear trade-off between biomass and catch metrics. HCRs with a TRP of F40 (HCRs 6, 7, 8, 13, 14, 15) had a higher target fishing intensity and maintained higher odds of catch being above average historical catch than HCRs with a TRP of F50, but lower odds of SSB being above the WCPFC LRP of 20%SSB0_d (Fig. 6). In other words, if the stock is fished at a higher intensity, the odds of SSB being above the 20%SSB0_d LRP declines.

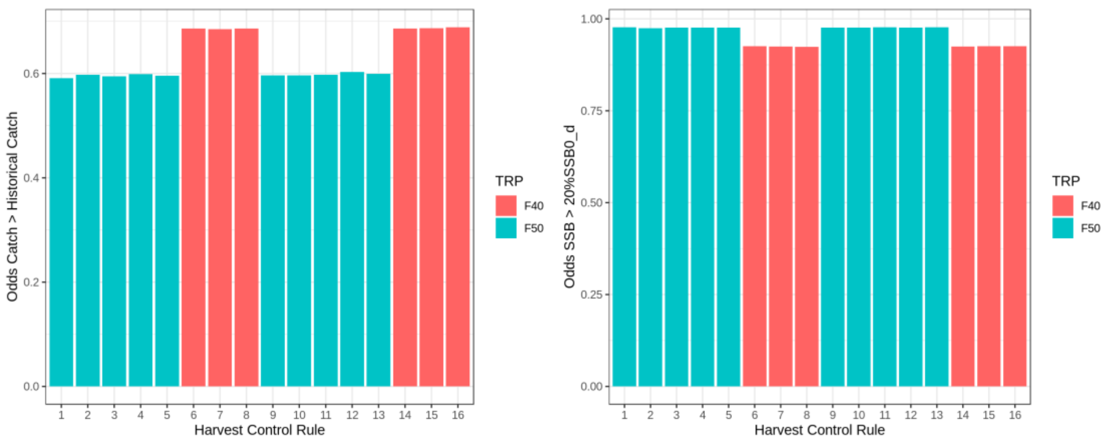



**Figure 6 Odds** of **catch** in any given year of the simulation being **greater than historical catch** (1981-2010) (left panel) and **odds** of **SSB** in any given year of the simulation being **greater than 20%SSB0_d** (right panel) for each harvest control rule (HCR) and across all reference ("what if") scenarios under **mixed control.** Different colors represent the target reference point (TRP) associated with each HCR: salmon for F40, teal for F50. This figure demonstrates the trade off between catch and SSB. Higher catch (salmon-color columns, F40, on right panel), is associated with lower SSB (salmon-color columns, F40, on left panel). Similarly, lower catch (teal-color columns, F50, on right panel), is associated with higher SSB (teal-color columns, F50, on left panel).

***3. Under TAC control, there are comparable odds of catch in any given year being above historical catch for F50 and F40 HCRs despite different fishing intensities due to a tradeoff between fishing intensity and catch stability.***

Under TAC control, for the same $SSB_{threshold}$ and LRP, HCRs with TRPs of F50 and with F40 had relatively comparable odds of catch being above the historical average, despite the different target fishing intensities (compare height of bars in left panel of Fig. 7 for HCRs 5 and 7 with 13 and 15, and 4 and 12 with 6 and 14; note that there is no large difference between teal and salmon bars). This is because the higher fishing intensity of HCRs with TRPs of F40 led to less stable catches (Fig. 7, right panel; note the lower height of salmon bars), and the higher catch variability decreased the odds of catch being higher than historical. The largest difference in performance between HCRs with TAC control was for catch stability (Table 4, Fig. 5).

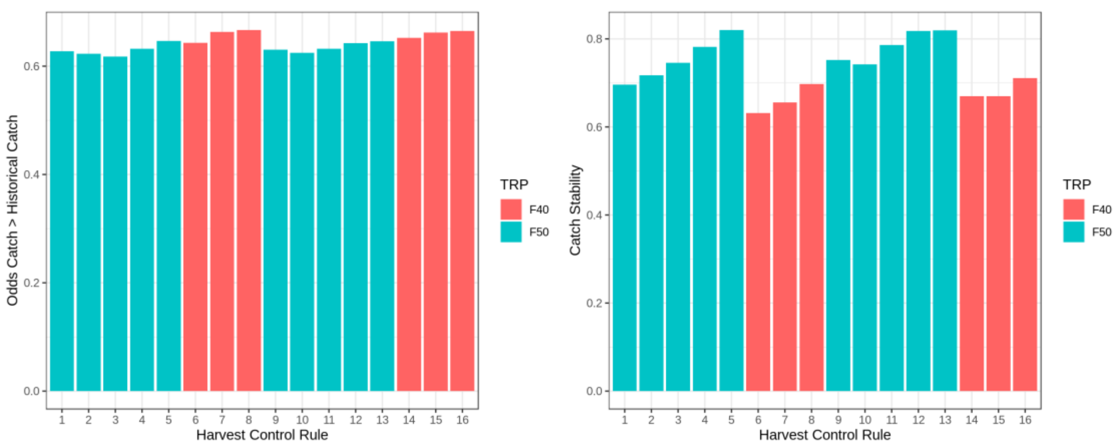



**Figure 7. Odds** of **catch** in any given year of the simulation being **greater than historical catch** (1981-2010) (left panel) and **catch stability** (right panel) for each harvest control rule (HCR) and across all ("what if") reference scenarios under **TAC control.** Different colors represent the target reference point (TRP) associated with each HCR: salmon for F40, teal for F50.

The tradeoff between fishing intensity and catch stability was apparent for TAC but not mixed control. This is due to lower and more variable biomass under TAC control, which led to more variable catch and higher odds of management intervention. With mixed control, surface fleets were under effort control and thus their catches responded quickly to changes in biomass and their catch levels were not impacted by errors in biomass estimates (i.e., assessment errors). While it may appear that being more responsive to changes in biomass would lead to less catch stability, effort controls also resulted in lower odds of breaching the reference points and, therefore, lower odds of management intervention to reduce catch (i.e., more catch stability).

***4. HCRs with LRP and $SSB_{threshold}$ reference points closer to the SSB associated with the TRP resulted in a higher frequency of management interventions under both mixed and TAC controls.***

In the long-term, implementation of HCRs with TRPs of F50 (e.g., HCR2 and HCR 4) would result in a biomass that is approximately 50% of unfished SSB, while F40 HCRs (e.g., HCR6 and HCR8) would be associated with a biomass that is approximately 40% of unfished SSB. For F50 HCRs, a $SSB_{threshold}$ of 0.3SSB0_d is closest to the SSB associated with the TRP. Figure 8 shows an example of how, for F50 HCRs such as HCR2 and HCR4, a $SSB_{threshold}$ of 30%SSB0_d (HCR 2) is closer to the SSB associated with the TRP than a $SSB_{threshold}$ of 20%SSB0_d (HCR 4).

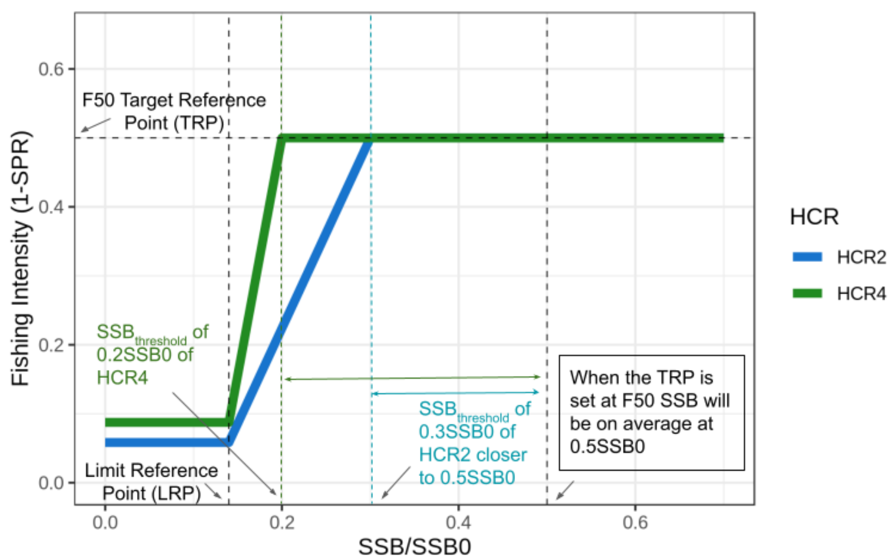



**Figure 8.** Plot contrasting harvest control rules (HCRs) 2 and 4. SSB0 on the x-axis refers to dynamic unfished SSB (SSB0_d). The two HCRs share the same TRP and LRP. However, the $SSB_{threshold}$ of HCR2 is 0.3SSB0_d while that of HCR4 is 0.2SSB0_d. The $SSB_{threshold}$ of HCR2 is closer to 0.5SSB_d, what SSB would be on average if fishing intensity (F) was set at the TRP.

***4. HCRs with LRP and SSB<sub>threshold</sub> reference points closer to the SSB associated with the TRP resulted in a higher frequency of management interventions under both mixed and TAC controls.***

Among the F50 HCRs, the HCRs with the $SSB_{threshold}$ of 30%SSB0_d (i.e., HCR1 to HCR3 and HCR9 to HCR11) had higher odds of management intervention than the $SSB_{threshold}$ of 20% SSB0_d under both mixed and TAC control (Fig. 9, top panels). Similarly, for F40 HCRs, the HCRs with the 20%SSB0_d $SSB_{threshold}$ (i.e., HCR6, HCR7, HCR14, and HCR15) had higher odds of management intervention than the $SSB_{threshold}$ of 14% SSB0_d (Fig. 9, top panels). Higher odds of management intervention, however, were not associated with improved performance in biomass metrics (Table 3 and 4, Fig. 5). For instance, given the same TRP, the odds of SSB being above 20%SSB0_d were comparable across HCRs (Fig. 9, bottom panels). Variability in performance in both biomass and catch metrics was instead largely driven by the TRP.

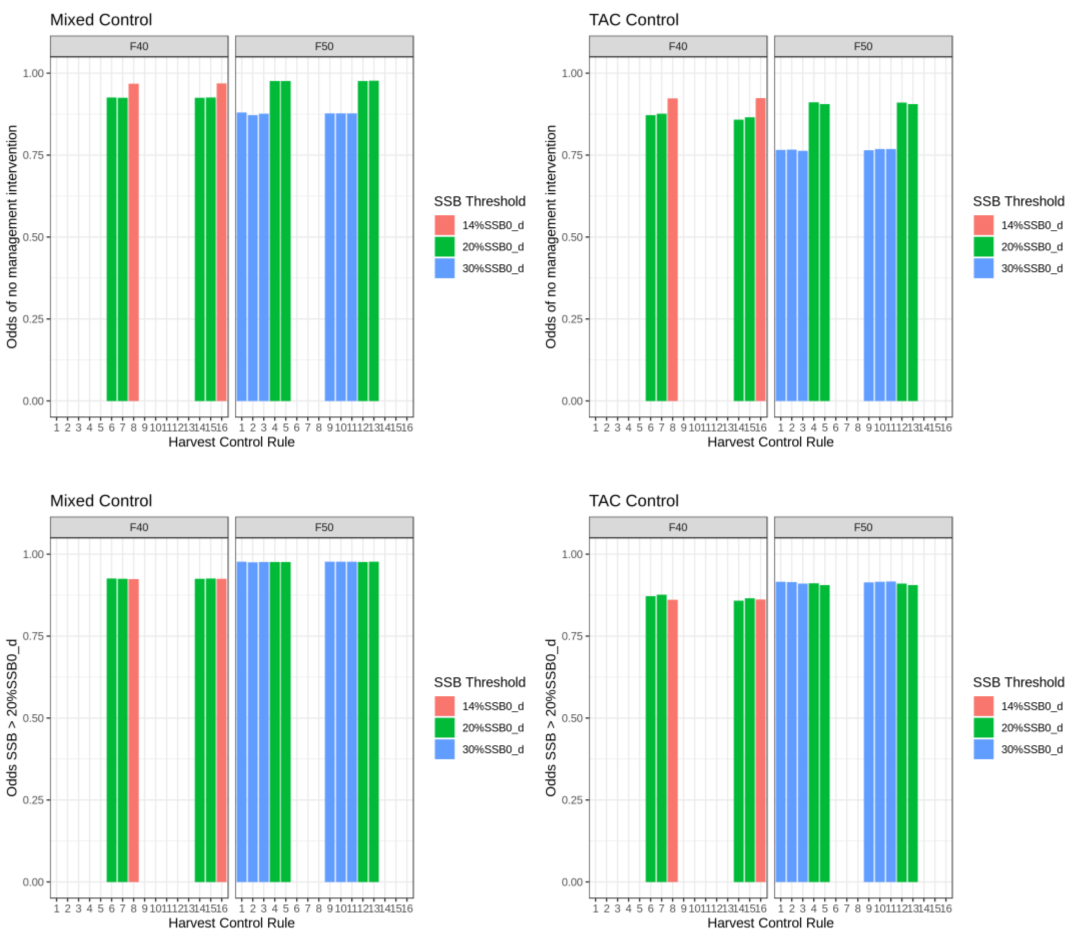



**Figure 9. Odds of no management intervention** under **mixed control** (top left panel) and **TAC control** (top right panel) and odds of **SSB** being **higher than 20%SSB0_d** under **mixed control** (bottom left panel) and **TAC control** (bottom right panel) for each HCR across "what if" scenarios. Different colors represent the $SSB_{threshold}$ reference point. HCRs are grouped by their target reference point (TRP) of F40 or F50.

***5. Both mixed and TAC control are able to maintain the stock above the WCPFC's limit reference point (20% SSB0_d) and the IATTC interim limit reference point used for tropical tunas (7.7%SSB0) with high probability (>0.8), even with increasing catches from an unknown, unmanaged fleet. However, this comes at the expense of reduced catches for the managed fleets.***

Results from the robustness scenario, where catches of an unknown, unmanaged fleet increase over time up to 50,000 mt, demonstrate that the current NPALB stock would be resilient to an increase in unreported catches if under mixed or TAC control and if the TRP is at or below F40. Indeed, the odds of SSB being above the LRP or other conservation limits are highly likely (> 0.8) (Fig. 10). This is because the simulated stock assessment correctly detects the decrease in biomass from the abundance indices and composition data despite observation error and the TAC and TAE of the managed fleet are decreased in response to the biomass change. As the TAC and TAE of the managed fleets depend on stock biomass, they are reduced over time and catches of the managed fleets diminish. Thus, maintenance of stock biomass comes at the cost of decreased catches for the managed fleets (Fig. 11).

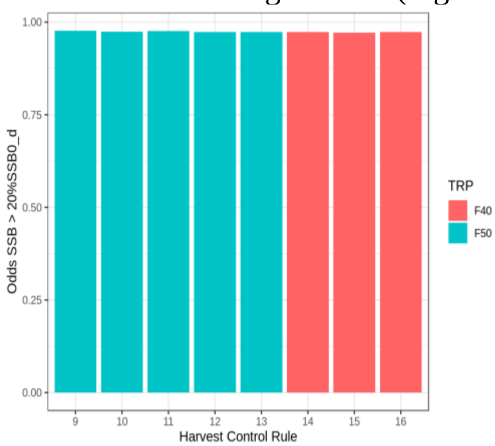



**Figure 10.** Odds of **SSB** in any given year of the simulation being **greater than 20%SSB0_d** for each harvest control rule (HCR) tested in the unknown fleet robustness scenario (HCRs 9-16) under **mixed control.** Different colors represent the target reference point (TRP) associated with each HCR.

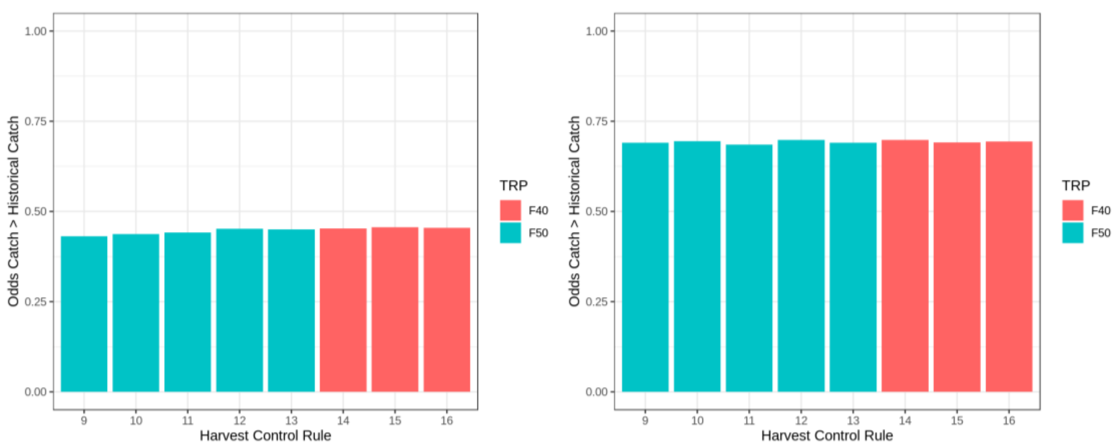



**Figure 11.** Odds of **catch** (managed fleets only) in any given year of the simulation being **greater than historical** under **mixed control** and scenario 1 for the unknown fleet **robustness scenario** (left panel) and without the unknown fleet (right panel)**.** Different colors represent the target reference point (TRP) associated with each HCR.

**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 that current stock status is compared to and that should not be exceeded with a high probability. It can be biomass-based (e.g. SSBLIMIT) or fishing intensity-based (e.g. FLIMIT).
- **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.
- **SSB0_d** – 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 that a current stock level 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 ($SSB_{threshold}$)** – 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.

**Key Limitations**

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

- The uncertainty in the relationship between the measure of effort in the MSE (i.e., exploitation rate that generates the F specified by the HCR) and real-world effort in number of fishing days for the EPO surface fleet increases at smaller effort levels. Therefore, at very low annual exploitation rates, implementation error for the EPO fleet under mixed control may be greater in the real world than the implementation error assumed in the MSE simulation. However, impact of this underestimation of implementation error for the EPO on MSE results is likely low as such low values comprised only 5% of all the simulated exploitation rates.

- It is assumed that catch control is implemented equally effectively across all fisheries, including both NPALB targeting and non-targeting (e.g., surface fleets vs. longline). This may not be true in the real world but there is no prior experience or information on implementation error of catch control between albacore targeting and non-targeting fisheries.

- 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.

- 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 area specific operating models 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.