An update on the IPHC Management Strategy Evaluation (MSE) process for SRB014

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PURPOSE

To provide an update of International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) activities including defining objectives, results for management procedures related to coastwide fishing intensity, development of a framework for distributing the TCEY, and the MSE program of work.

1 INTRODUCTION

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) completed a phase of looking at procedures management relative to the coastwide scale of the Pacific halibut stock and fishery. Results of the MSE simulations were presented at the 95th Session of the IPHC Annual Meeting (AM095) and the 13th Session of the IPHC Management Strategy Advisory Board (MSAB013). The next phase is to investigate management procedures related to the distribution of the Total Constant Exploitation Yield (TCEY). The TCEY is the mortality limit composed of mortality from all sources except under 26 inch (U26) bycatch, and is determined by the Commission at each Annual Meeting for each IPHC Regulatory Area.

This document first presents the objectives that the MSAB and Commission are using to evaluate management procedures. It then summarizes the results of the simulations investigating the coastwide scale portion of the management procedure. The framework describing the progress on developing a framework to investigate distributing the TCEY follows, and the program of work for the next two years is discussed.

2 GOALS AND OBJECTIVES

The MSAB currently has four goals, each one with multiple objectives. The four goals, and primary general objectives for each are

1. Biological Sustainability (also referred to as conservation goal)
   - 1.1. Keep biomass above a limit to avoid critical stock sizes
2. Optimise directed fishing opportunities (also referred to as fishery goal)
   - 2.1. Maintain spawning biomass around a level (i.e., a target biomass reference point) that optimises fishing activities
   - 2.2. Limit catch variability
   - 2.3. Maximize directed fishing yield
3. Minimize discard mortality
4. Minimize bycatch and bycatch mortality

The goal previously called "fishery sustainability, access, and stability" was refined to be "optimise directed fishing opportunities" to better reflect the desires of the directed fishery. In particular, this goal stresses optimising fishery yield with respect to stability and sustainability and optimizing the fishing opportunities ensures access. Discard and bycatch goals have not yet been specifically considered in the MSE but are identified as important goals to consider in the future.

There are two major components of the harvest strategy: coastwide scale and TCEY distribution (Figure 1). The MSE has recently focused on coastwide scale with an input fishing mortality rate (F_{SPR}) determining the total coastwide mortality, thus objectives have been focused at the coastwide level. The MSE program of work is now focusing on both components and the focus will be to refine coastwide objectives and define distributional objectives (i.e., area specific objectives).

In this section, we first present the MSAB-defined objectives related to coastwide scale, and performance metrics linked to those objectives. This is followed by a discussion of potential additional scale objectives. We then present the current proposed distribution objectives defined by the MSAB.

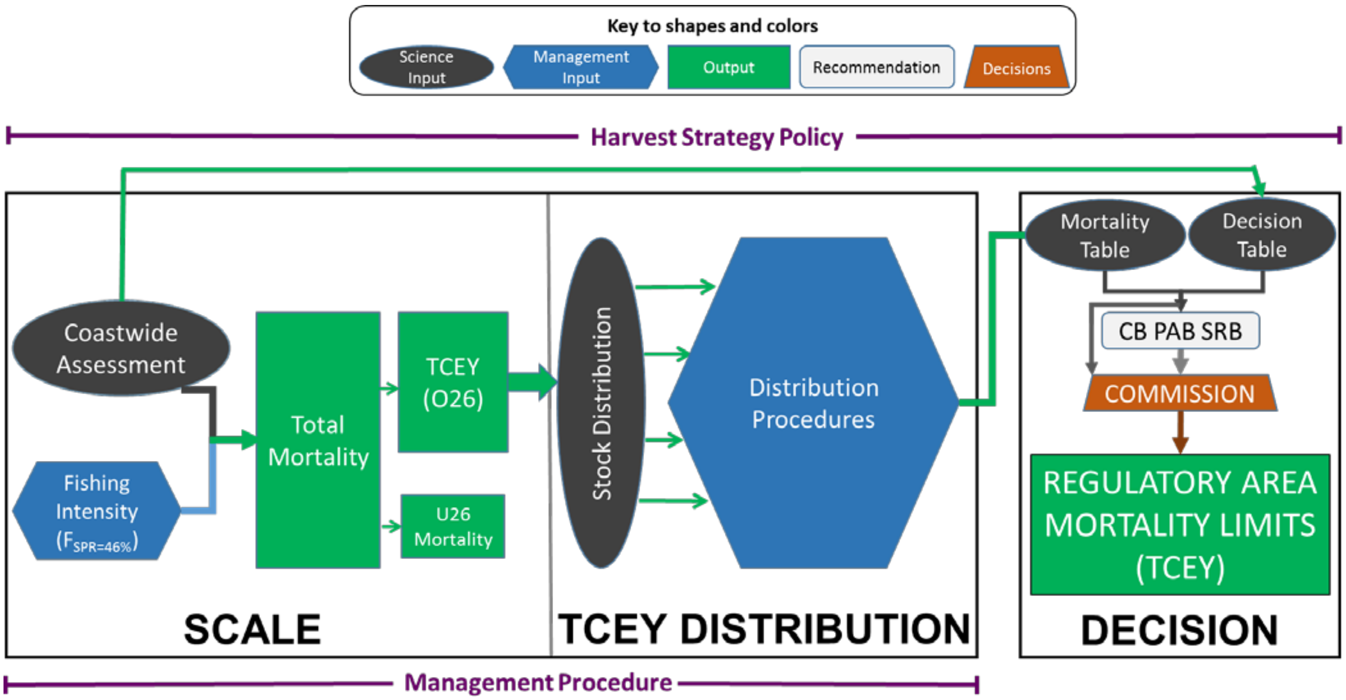

Figure 1: An illustration of the IPHC harvest strategy policy process showing the coastwide scale and TCEY distribution components which make up the management procedure. The decision step is the Commission decision-making procedure, which considers inputs from many sources.

2.1 OBJECTIVES RELATED TO COASTWIDE SCALE

Primary general objectives were identified by the MSAB and the Commission for the evaluation of MSE results related to coastwide fishing intensity that were presented at AM095. At that time, the biological sustainability objective (maintain biomass above a limit) was defined to be met before evaluating the fishery stability objective (limit catch variability), which must be met before evaluating the fishery yield objective (maximize the TCEY). Performance metrics were developed from these objectives by defining a measurable outcome, a tolerance (i.e., level of risk), and a timeframe over which it is desired to achieve that outcome. Many more objectives and performance metrics were identified (Appendix I) which were used to further evaluate the MSE results. Objectives that did not have a measurable outcome, tolerance, and timeframe defined were labeled as “statistics of interest.”

A directive from the Commission agreed with the three primary objectives, except that an objective to maintain a minimum catch was identified without a defined level or tolerance.

> *"While it is recognized that the MSAB has spent considerable time and effort in developing objectives for evaluating management procedures, for the purpose of expediting a recommendation on the level of the coast-wide fishing intensity, and noting SRB11–Rec.02 to develop an objectives hierarchy, the MSAB is requested to evaluate management procedure performance against objectives that prioritize long-term conservation over short-/medium-term (e.g. 3-8 years) catch performance. Where helpful in accelerating progress on scale, the MSAB is requested to constrain objectives to (1) maintain biomass above a limit to avoid critical stock sizes, (2) maintain a minimum average catch, and (3) limit catch variability."*

Without definitions of the measurable objective and a tolerance, it was not possible to use this objective in the evaluation of the MSE results. Instead, the third primary objective was to maximize the yield subject to satisfying the other two primary objectives.

Subsequent to the presentation of coastwide objectives and MSE results at the 95th Annual Meeting (AM095), the following paragraphs from the Report of the 95th Annual Meeting (IPHC-2019-AM095-R) have guided further refinement of coastwide objectives.

> **AM095-R, para 59a.** The Commission **ENDORSED** the primary objectives and associated performance metrics used to evaluate management procedures in the MSE process (as detailed in paper IPHC-2019-AM095-12)

> **AM095-R, para 59c.** The Commission **RECOMMENDED** the MSAB develop the following additional objective, as well as prioritize this objective in the evaluation of management procedures, for the Commission's consideration.
> i. A conservation objective that meets a spawning biomass target.

The development of a spawning biomass target (i.e. a biomass level to fluctuate around with a 50% probability to be above or below) was discussed extensively at MSAB013. Noting that the current IPHC harvest strategy policy suggests using a proxy for Maximum Economic Yield (MEY), which is related to Maximum Sustainable Yield (MSY), much of the discussion focused around these quantities and what appropriate proxies may be. The need to maximize the economic benefit has been widely recognized, however, the estimation of MEY and related quantities (B_{MEY} and F_{MEY}) is still quite challenging and requires a deep understanding of the economic variables relevant to the fishery. In absence of this information and of a bio-economic model of the fishery, a proxy for MEY may be obtained from MSY. For example, the Australian government's harvest strategy policy uses the relationship: $B_{MEY} = 1.2 \times B_{MSY}$ (Rayns, 2007), and Pascoe *et al*. (2014) suggested that $B_{MEY} = 1.45 \times B_{MSY}$ for data-poor single-species fisheries.

Currently, for halibut, there is no estimate of B_{MSY}. Preliminary analyses based on past stock assessments and equilibrium models has suggested that B_{MSY} may be in the range from 30% and 41% of unfished spawning biomass. However, given the dynamic nature of the stock (i.e. different regimes, changes in individual weight-at-age, and selectivity over time), as well as uncertainty in recruitment steepness, more investigation is needed to identify a robust range of possible estimates.

We plan to use three methods to investigate B_{MSY}. First, we will use a simple equilibrium model to determine B_{MSY}. Second, estimates of B_{MSY} from the current assessment will be determined. Lastly, the coastwide MSE can provide a range of B_{MSY} estimates given the uncertainty and scenarios assumed in the closed-loop simulations. For each of the methods, a grid of scenarios across different selectivity curves, weight-at-age (low, medium, and high), steepness, and environmental regimes (explicitly defined as positive/negative) will characterize the variability used to determine potential ranges of B_{MSY}.

The MSAB also discussed the potential to use a threshold spawning biomass level, instead of a target. This is simply a value to remain above with some tolerance to avoid additional management action due to the control rule and to keep the biomass in a range that would likely optimise fishing activities. An objective was proposed to maintain the spawning biomass above the fishery trigger at least 80% of the time (tolerances of 75% and 90% were also considered).

The objective of maintaining the spawning biomass around a target or above a level that optimises fishing activities can be viewed as a fishery objective (e.g., maximize yield and avoid additional management action from the control rule) as well as a biological sustainability objective (e.g., maintain a sustainable biomass). However, sustainability of the Pacific halibut stock would be satisfied by meeting the objective of avoiding low stock sizes that may result in an impairment to recruitment. Therefore, the main biological sustainability objective should be to avoid a minimum stock size threshold (i.e., B_{Lim}) with a high probability. Defining a fishery objective related to MSY or MEY, along with other fishery objectives, would be prioritized after meeting this single conservation objective.

The MSAB also reconsidered the biological sustainability objective to maintain the spawning biomass above a limit to avoid critical stock sizes. A review of the policies and MSE objectives of other agencies around the world showed various proxies for a biomass limit and tolerances for falling below that limit. For example, the Pacific Fishery Management Council defines a default minimum stock size threshold (MSST) as 25% of unfished spawning biomass, the status below which a stock is defined overfished, although the MSST for flatfish stocks is 12.5% (NPFMC 2016). In the North Pacific Fishery Management Council Fishery Management Plan (NPFMC 2018) the MSST is dependent on the tier that the stock assessment is classified as, but one definition is one-half of B_{MSY}. Fisheries and Oceans Canada defines a limit reference point as 40% of B_{MSY} in their fisheries policy document (DFO 2009). Lastly, the Marine Stewardship Council (MSC) fisheries standard V2.01 defines proxies for the point at which recruitment would be impaired (PRI) as one-half B_{MSY} or 20% of unfished spawning biomass for stocks with average productivity (MSC 2018). Furthermore, the certainty that the stock is greater than the PRI must be greater than 95% to reach the highest category of the MSC scoring criteria. On the basis of consistency with other fisheries management approaches, the MSAB retained the spawning biomass limit at 20% of unfished spawning biomass for the biological sustainability objective and updated the tolerance to 5% (Table 1).

The fishery objectives related to stability and maximizing yield were retained in the coastwide objectives (Table 1). The two fishery objectives discussed above that relate to a target and a threshold biomass level were added under a single general objective to maintain the spawning biomass around a level that optimises fishing activities. No specific prioritization of the fishery objectives has been determined.

2.2 OBJECTIVES RELATED TO THE DISTRIBUTION OF THE TCEY

2.2.1 Biological sustainability

Paragraph 30 of IPHC-2018-SRB012-R stated that "[t]he SRB … recognized that biocomplexity is not an appropriate concept because it is poorly defined and not understood for Pacific halibut, especially over large spatial scales. Further, the terms "preserve" and "preservation" should be "conserve" and "conservation" as most fisheries management is about conservation." In paragraph 31 of IPHC-2018-SRB012-R, "the SRB AGREED that the defined Bioregions (i.e. 2,3,4, and 4b described in paper IPHC-2018-SRB012-08) are presently the best option for implementing a precautionary approach given uncertainty about spatial population structure and dynamics of Pacific halibut." Therefore, objectives should be defined that relate to conserving some level of spatial population structure, and these can be included under the Biological Sustainability goal. Given the uncertainty about spatial population structure and dynamics of Pacific halibut, these objectives may be more difficult to define. The ad-hoc working group that met in 2018 to discuss objectives did not address spatial biomass objectives beyond identifying a general objective to conserve spatial population structure.

Table 1: Primary measurable objectives revised at MSAB013. Objective 1.1 is a biological sustainability (conservation) objective and objectives 2.1, 2.2, and 2.3 are fishery objectives. **Items in development*

General Objective	Measurable Objective	Measurable Outcome	Time-frame	Tolerance	Performance Metric
1.1. Keep spawning biomass above a limit to avoid critical stock sizes Biomass Limit	Maintain a minimum female spawning stock biomass above a biomass limit reference point at least 95% of the time	*SB* < Spawning Biomass Limit (SB_{Lim}) SB_{Lim}=20% unfished spawning biomass	Long-term	0.05	$P(SB < SB_{Lim})$
*2.1 Maintain spawning biomass around a level that optimises fishing activities	2.1A Spawning Biomass Trigger Maintain the female spawning biomass above a trigger reference point at least 80% of the time	SB<Spawning Biomass Trigger (SB_{Trig}) SB_{Trig}=$SB_{30\%}$ unfished spawning biomass	Long-term	0.20	$P(SB < SB_{Trig})$
	*2.1B Spawning Biomass Target Maintain the female spawning biomass above a biomass target reference point at least 50% of the time	SB<Spawning Biomass Target (SB_{Targ}) SB_{Targ}=$SB_{36\text{-}45\%}$ unfished spawning biomass	Long-term	0.50	$P(SB < SB_{Targ})$
2.2. Limit Catch Variability	Limit annual changes in the coastwide TCEY	Average Annual Variability (*AAV*) > 15%	Short-term	0.25	$P(AAV > 15\%)$
2.3. Maximize Directed Fishing Yield	Maximize average TCEY coastwide	Median coastwide TCEY	Short-term	*STATISTIC OF INTEREST*	$Median\ \overline{TCEY}$

Conserving spatial population structure may mean several different things, such as maintaining the current distribution across regions, maintaining the proportion of spawning biomass in each Region within a specified range, or maintaining a minimum spawning biomass or proportion of spawning biomass in a Region. Multiple measurable objectives may be defined for this general objective to incorporate these different concepts. Based on current knowledge, conserving spatial population structure should relate to the broad Biological Regions currently defined and not necessarily to the finer spatial definition of IPHC Regulatory Areas.

2.2.2 Optimise Directed Fishing Opportunities

Three general objectives are currently defined for this goal: 1) limit catch variability, 2) maximize directed fishery yield, and 3) minimize potential for no catch limit for the directed commercial fishery. Under each general objective, there are coastwide TCEY measurable objectives. An ad hoc working group of the MSAB identified potential measurable objectives specific to IPHC Regulatory Area, which are mostly based on the coastwide measurable objectives. While Biological Regions are the spatial scale for the biological sustainability goal, fishery objectives are related to IPHC Regulatory Areas because quotas are distributed to these areas and are therefore of interest to a quota holder. A finer spatial scale than IPHC Regulatory Areas may be important to individual fishers and may be considered in future evaluations.

It is easy to translate coastwide objectives into area-specific objectives, but additional objectives will be important to each IPHC Regulatory Areas and not all areas will have the same objectives. For example, the coastwide objective to avoid a change in the TCEY greater than 15% with a 25% tolerance can easily be applied to IPHC Regulatory Areas. However, specific areas may want to identify objectives that are important to that stakeholder group. For example, decisions made at AM095 (IPHC-2019-AM095-R) identified two potential measurable objectives for IPHC Regulatory Areas 2A and 2B.

69. The Commission ADOPTED:

a) a coastwide target SPR of 47% for 2019;

b) a share-based allocation for IPHC Regulatory Area 2B. The share will be defined based on a weighted average that assigns 30% weight to the current interim management procedure's target TCEY distribution and 70% on 2B's recent historical average share of 20%. This formula for defining IPHC Regulatory Areas 2B's annual allocation is intended to apply for a period of 2019 to 2022. For 2019, this equates to a share of 17.7%; and IPHC–2019–AM095–R Page 19 of 46

c) a fixed TCEY for IPHC Regulatory Area 2A of 1.65 mlbs is intended to apply for a period from 2019-2022, subject to any substantive conservation concerns.

IPHC Regulatory Area 2A appears to desire a minimum TCEY of 1.65 Mlbs and IPHC Regulatory Area 2B appears to desire a specific percentage of the coastwide TCEY. These objectives could be translated into performance metrics for evaluation or may be formulated directly in a management procedure. Objectives that may apply to IPHC Regulatory Areas are identified in Table 2 and objectives specific to each IPHC Regulatory Area will be defined at MSAB meetings in 2019 and 2020.

3 INVESTIGATIONS OF COASTWIDE FISHING INTENSITY

Simulation results presented previously at MSAB012 (IPHC-2018-MSAB012-07) showed that none of the management procedures without a constraint on the annual mortality limit met the primary stability objective (average annual variability of the mortality limit is less than 15% at least 75% of the time), as noted in paragraph 59,e,i in IPHC-2019-AM095-R. Therefore, various constraints on the annual mortality limit were introduced into the management procedure for evaluation (as was also recommended by the SRB in document IPHC-2018-SRB013-R, para. 29). This document presents the results documented in IPHC-2019-AM095-12 and presents the new results pertaining to a constraint on the annual mortality limit that were presented at MSAB013 (IPHC-2019-MSAB013-08). Details of the coastwide closed-loop simulations are not included here but can be found in IPHC-2018-MSAB012-07.

3.1 MANAGEMENT PROCEDURE

The elements of the management procedure include data generation, an estimation model, and a harvest rule, where the harvest rule consists of a coastwide Scale portion and a distribution portion to distribute the mortality limits to IPHC Regulatory Areas. The focus of these simulations was on the coastwide Scale portion of the general management procedure (Figure 1). Data were not generated in these simulations, but instead error in an estimation model was simulated for simplicity (IPHC-2018-MSAB012-07). The coastwide harvest rule portion of the management procedure is discussed below.

Table 2: Area-specific objectives that may be considered when evaluating management procedures for distributing the TCEY to IPHC Regulatory Areas.

General Objective	Measurable Objective	Measurable Outcome	Timeframe	Tolerance	Performance Metric
1.1A CONSERVE SPATIAL POPULATION STRUCTURE	Maintain a defined minimum proportion of spawning biomass in each Biological Region	$p_{SB,R} < p_{SB,R,min}$	Med-term Long-term	?? ??	$P(\ldots)$
	Proportion of Pacific halibut spawning biomass in each Biological Region	Proportion of Pacific halibut spawning biomass in each Biological Region	Long-term	*STATISTIC OF INTEREST*	$\frac{SB_A}{SB}$
2.1A MAINTAIN BIOMASS AROUND A TARGET THAT OPTIMISES FISHING ACTIVITIES	Maintain a proportion of O26 Pacific halibut in each area within the range estimated from the space-time model	$p_{B_{O26},A,min} < p_{B_{O26},A} < p_{B_{O26},A,max}$	Long-term Short-term	?? ??	$P(\ldots)$
	Proportion of O26 Pacific halibut biomass in each area	Proportion of O26 Pacific halibut biomass in each area	Long-term Short-term	*STATISTIC OF INTEREST*	$\frac{B_{O26,\ A}}{BO26}$

Table 2 : continued

General Objective	Measurable Objective	Measurable Outcome	Timeframe	Tolerance	Performance Metric
2.2A LIMIT CATCH VARIABILITY	Limit annual changes in the TCEY for each Regulatory Area	Average Annual Variability by Regulatory Area (AAVA) > 15%	Long-term Short-term	0.25	$P(AAV > 15\%)$
		AAV_A	Long-term Short-term	*STATISTIC OF INTEREST*	AAV and variability
		Change in TCEY by Regulatory Area > 15% in any year	Long-term Short-term	*STATISTIC OF INTEREST*	$\frac{TCEY_{i+1} - TCEY_i}{TCEY_i}$
2.3A MAXIMIZE DIRECTED FISHING YIELD	Maximize average TCEY by Regulatory Area	Median Reg Area TCEY	Long-term Short-term	*STATISTIC OF INTEREST*	Median $\overline{TCEY}$
	Maintain TCEY above a minimum level by Regulatory Area	$TCEY_A < TCEY_{A,min}$	Long-term Short-term	?? ??	$P(TCEY < TCEY_{A,min})$
	Maximize high yield (TCEY) opportunities by Regulatory Area	$TCEY_A$ > ?? Mlbs	Long-term Short-term	*STATISTIC OF INTEREST*	$P(TCEY <?? \ Mlbs)$
	Present the range of TCEY by Regulatory Area that would be expected	Range of TCEY by Regulatory Area	Long-term Short-term	*STATISTIC OF INTEREST*	5th and 75th percentiles of TCEY
2.4A MINIMIZE POTENTIAL OF NO CATCH LIMIT FOR DIRECTED FISHERY	Maintain catch limit for directed fishery in each Regulatory Area above zero	$DirectedYield_A = 0$	Long-term Short-term	?? ??	$P(DirY_A = 0)$

3.1.1 Harvest Rule

The coastwide part of the management procedure being evaluated is a harvest control rule (Figure 2) that is responsive to stock status and consists of i) a procedural SPR determining fishing intensity, ii) a fishery trigger based on stock status that determines when the fishing intensity begins to be linearly reduced, and iii) a fishery limit that determines when there is theoretically no fishing intensity (this may differ from the biological limit defined in Table 1). For these simulations, the two coastwide models were used, thus mortality was distributed to the five coastwide sources of mortality in those models (directed commercial, discard mortality, bycatch mortality, recreational, and subsistence). Simulations used a range of SPR values from 30% to 56% and fishery trigger:limit points of 40:20, 30:20, and 25:10.

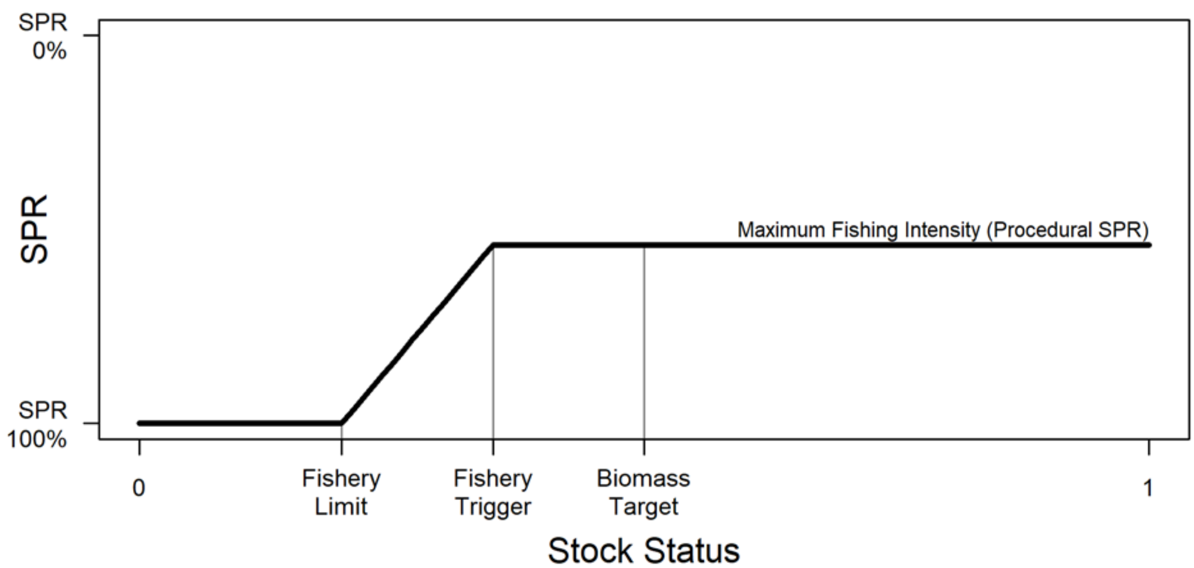

Figure 2: A harvest control rule responsive to stock status that is based on Spawning Potential Ratio (SPR) to determine fishing intensity, a fishery trigger level of stock status that determines when the fishing intensity begins to be linearly reduced, and a fishery limit based on stock status that determines when there is theoretically no fishing intensity (SPR=100%). In reality, it is likely that only the directed fishery would cease. The Procedural SPR, the Fishery Trigger, and the Fishery Limit are the elements that were evaluated by assigning a range of values for each.

3.1.2 Constraints on the change in the annual mortality limit

Some management procedures in the simulated set included an annual constraint on the change in the annual mortality limit. Eight different combinations of methods and parameterizations were tested. These included to simply constrain the maximum amount of change in the mortality limit from one year to the next, to enforce a maximum mortality limit, or to set a constant limit for three years before updating it. The eight methods are described below and a hypothetical comparison is shown in Figure 3.

- **MaxChangeBoth15%:** Not allow the mortality limit to change by more than 15% up or down, even if the harvest rule suggests a larger change. When the change in the mortality limit would be more than 15%, the mortality limit is set at the limit corresponding to a 15% change.
- **MaxChangeBoth20%**: Not allow the mortality limit to change by more than 20% up or down, even if the harvest rule suggests a larger change. When the change in the mortality limit would be more than 20%, the mortality limit is set at the limit corresponding to a 20% change.

- **MaxChangeUp15%**: Not allow the mortality limit to increase by more than 15%, even if the assessment suggests a larger change, but allow the mortality limit to decrease by any amount (as determined by the harvest rule). When the increase in the mortality limit would be more than 15%, the mortality limit is set at the limit corresponding to a 15% change.
- **SlowUpFastDown**: Increase the mortality limit by one-third of the change suggested by the harvest rule and decrease the mortality limit by one-half of the change suggested by the harvest rule. Therefore, the mortality limit from the harvest rule is never implemented in a given year, but potential inter-annual variability is dampened.
- **SlowUpFullDown**: Increase the mortality limit by one-third of the change suggested by the harvest rule and decrease the mortality limit fully to the value suggested by the harvest rule. Therefore, an increase in the mortality limit from the harvest rule is never implemented in a given year, but a decrease is fully implemented.
- **Cap60**: Not allow the total mortality limit to exceed 60 million pounds. When below 60 million pounds, the harvest rule is unconstrained.
- **Cap80**: Not allow the total mortality limit to exceed 80 million pounds. When below 80 million pounds, the harvest rule is unconstrained.
- **MultiYear**: Set a single mortality limit every third year to apply to a period of three years. Therefore, the mortality limit is constant for a three-year period, but the harvest rule results in an unconstrained change every third year.

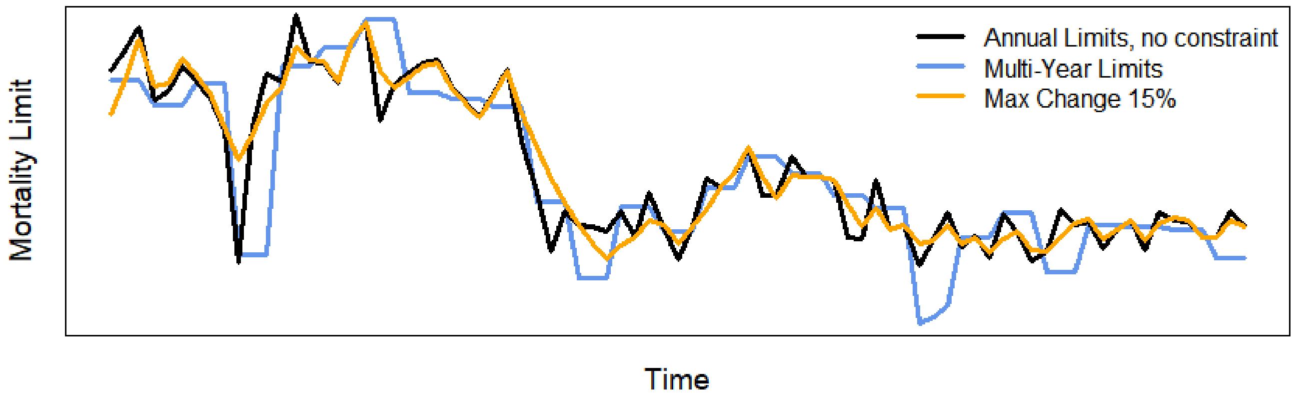

Figure 3: A hypothetical example of the difference between unconstrained and constrained management procedures when determining the total mortality limit. The multi-year limit (blue) is set every third year, but due to allocation to bycatch and other sectors, the limit may be adjusted in years when the total mortality limit is small. A maximum change of 15% is applied to “Max Change 15%”, shown in orange, and compared to the unconstrained mortality limit shown in black.

3.2 Simulation Results

Table 3 and Table 4 show the long-term primary biological performance metric and the medium-term (14-23 years) fishery sustainability performance metrics for the main management procedures requested at MSAB011 (IPHC-2018-MSAB011-R). Table 5 shows the same long-term performance metrics for a control rule of 25:10. Short-term performance metrics were similar for these management procedures because the current spawning biomass is likely to be above the fishery trigger (e.g., 30%), thus are not shown. For long-term results with a control rule, the probability that the stock is below 20% of the dynamic unfished equilibrium biomass is less than 0.01 (<1/100) for all cases using control rules 30:20 or 40:20. This is a result of the control rule limiting the fishing intensity as the stock approaches the 20% threshold even with estimation error present, and since dynamic relative spawning biomass is a measure of the effect of fishing, reducing the fishing intensity reduces the risk of dropping below this threshold. It is rare that positive estimation error persists for a long enough period that fishing intensity remains high and the stock falls below the 20% threshold. The outcome of this reduction in fishing intensity can be seen in the average annual variability (AAV), which is a measure of the change in the mortality limit from year to year. At fishing intensities greater than that associated with an SPR of 40% (i.e., SPR values less than 40%) the probability that the AAV is greater than 15% is more than two-thirds (>67/100) for all control rules tested. This probability declines to around 0.60 (60/100) at an SPR of 56% for the 30:20 and 25:10 control rules. The 40:20 control rule resulted in higher variability in the mortality limit, even though the slope is not as steep, because the reduction in fishing intensity occurs more often given the 40% fishery trigger value and the range of SPR values evaluated. The absolute value of the Total Mortality limit was highly variable for a given SPR (Figure 4).

The use of SPR values without a control rule (results not shown) also did not meet the stability objective for any SPR considered, which means that estimation error is a large part of the variability in the total mortality limits. Therefore, to meet the stability objective, additional elements of a management procedure need to be included to stabilize the limits (alternatively, the objective could be updated such that a management procedure will meet the objective). Eight different general options for constraining the limit were simulated to evaluate their potential to meet the primary objectives (see Section 3.1.2). With the 30:20 control rule and SPR values of 38%, 40%, 42%, and 46%, the biological sustainability goal was met for all constraint options (Table 6 and Table 7, Figure 5 and Figure 6). However, only the maxChangeBoth15%, slowUpFastDown, slowUpFullDown, and multiYear constraints had SPR options that were able to meet the stability objective. The top five ranked management procedures used the constraints slowUpFastDown, maxChangeBoth15%, and multiYear constraints with SPR values ranging from 42% to 38%. The median yield across these five ranged from 48.9 Mlbs to 51.1 Mlbs and the probability that the AAV was greater than 15% ranged from 0.05 to 0.19. The top ranked management procedure was slowUpFastDown with an SPR of 38%; maxChangeBoth15% with an SPR of 38% was very similar with a median TM 0.2 Mlbs less and a smaller probability of exceeding the AAV tolerance (Figure 6). However, the median AAV for slowUpFastDown was less than the median AAV for maxChangeBoth15%.

Setting the limit every third year (multiYear) was able to meet the stability objective (calculated on an annual basis) with little loss to median yield and no increase to biological sustainability risk. However, the change that occurs every third year (median of 27% with SPR=46%) was greater than the similar unconstrained management procedure (median change every third year of 25%).

Many more performance metrics calculated for a subset of management procedures are presented in Appendix I. The full set of simulated management procedures and performance metrics are available for interactively viewing in a table or on plots at http://shiny.westus.cloudapp.azure.com/shiny/sample-apps/IPHC-MSAB013/.

Table 3: Primary performance metrics for a 30:20 control rule, and a range of input SPRs from 0.3 to 0.56. P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Biological Sustainability (Long-term)											
P(all dRSB<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(any dRSB_y<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Fishery Sustainability (medium-term)											
P(all AAV > 15%)	0.60	0.66	0.69	0.72	0.76	0.80	0.84	0.88	0.93	0.96	0.98
Median average TM[3]	39.4	45.5	46.8	48.0	49.5	50.6	51.8	52.1	52.4	53.2	52.8
Rankings (lower is better) over all management procedures without a constraint (Table 3, Table 4, and Table 5)											
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?[2]	No	No	No	No	No	No	No	No	No	No	No
Maximum catch (TM)[3]	30	27	24	21	14	11	9	8	7	4	5
Overall Ranking	—	—	—	—	—	—	—	—	—	—	—

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that no procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error, for all management procedures without a constraint (Table 3, Table 4, and Table 5). Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

[4] The overall ranking applies to all management procedures without a constraint (Table 3, Table 4, and Table 5)

Table 4: Primary performance metrics for a 40:20 control rule, and a range of input SPRs from 0.3 to 0.56. P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Biological Sustainability (Long-term)											
P(all dRSB<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(any dRSB_y<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fishery Sustainability (medium-term)											
P(all AAV > 15%)	0.718	0.843	0.880	0.915	0.954	0.966	0.977	0.987	0.991	0.994	0.995
Median average TM[3]	39.2	44.4	45.5	46.4	47.6	48.3	48.8	48.9	49.4	49.5	49.8
Rankings (lower is better) over all management procedures without a constraint (Table 3, Table 4, and Table 5)											
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?[2]	No	No	No	No	No	No	No	No	No	No	No
Maximum catch (TM)[3]	32	29	27	25	22	20	18	17	16	14	13
Overall Ranking	—	—	—	—	—	—	—	—	—	—	—

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that no procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error, for all management procedures without a constraint (Table 3, Table 4, and Table 5). Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

[4] The overall ranking applies to all management procedures without a constraint (Table 3, Table 4, and Table 5)

Table 5: Primary performance metrics for a 25:10 control rule, and a range of input SPRs from 0.3 to 0.56. P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Biological Sustainability (Long-term)											
P(all dRSB<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.02	0.03	0.05
P(any dRSB_y<20%)	<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.02	0.03	0.06	0.10	0.14
Fishery Sustainability (medium-term)											
P(all AAV > 15%)	0.58	0.60	0.63	0.65	0.66	0.67	0.69	0.74	0.77	0.83	0.88
Median average TM[3]	39.4	45.9	47.1	48.5	49.9	51.2	52.6	54.0	55.0	55.3	55.3
Rankings (lower is better) over all management procedures without a constraint (Table 3, Table 4, and Table 5)											
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Meet stability objective?[2]	No	No	No	No	No	No	No	No	No	No	—
Maximum catch (TM)[3]	30	26	23	19	12	10	6	3	2	1	—
Overall Ranking[4]	—	—	—	—	—	—	—	—	—	—	—

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective, except for an SPR of 30%.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that no procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error, for all management procedures without a constraint (Table 3, Table 4, and Table 5). Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

[4] The overall ranking applies to all management procedures without a constraint (Table 3, Table 4, and Table 5)

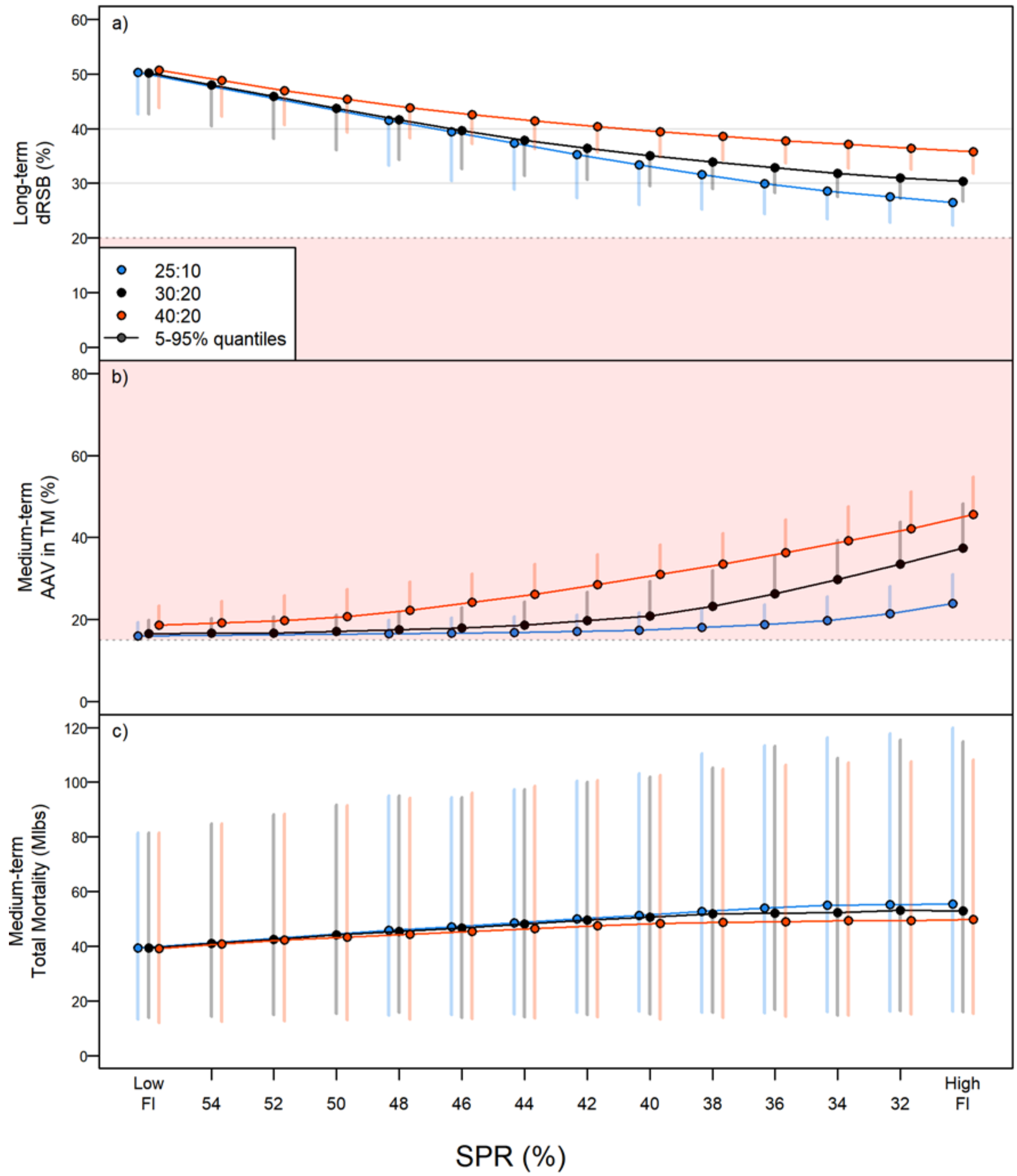

Figure 4. Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term fishery sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.3 to 0.56 and control rules 40:20, 30:20, and 25:10. The points are the median values from the simulations and the vertical bars indicate the tolerance defined for that biological sustainability objective (plot a) and the catch stability objective (plot b); if the bar is in the red area, the objective is not met. The vertical bars for total mortality are the 90% intervals (i.e. 5th and 95th percentiles from the simulations).

Table 6: Primary performance metrics and ranking of management procedures for a 30:20 control rule, input SPRs, and various constraints on the annual change in the total mortality (see Section 3.1.2). P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**30:20**											
Constraint	**maxChangeBoth15%**				**slowUp FastDown**				**multiYear**			
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**
Biological Sustainability (Long-term)												
P(all dRSB<20%)	0.02	0.02	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(any dRSB_y<20%)	0.02	0.02	0.02	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
Fishery Sustainability (medium-term)												
P(all AAV > 15%)	0.04	0.05	0.05	0.06	0.07	0.11	0.14	0.15	0.14	0.19	0.26	0.3
Median average TM[3]	46.1	48.6	49.5	50.9	45	48.2	49.5	51.1	46.5	48.9	50.5	51.2
Rankings (lower is better) over all management procedures with a constraint (Table 6 and Table 7)												
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?[2]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Maximum catch (TM)[3]	20	14	9	4	23	15	9	2	17	13	6	1
Overall Ranking	**10**	**6**	**3**	**2**	**11**	**7**	**3**	**1**	**9**	**5**	**---**	**---**

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that some procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error. Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

Table 7: Primary performance metrics and ranking of management procedures for a 30:20 control rule, input SPRs, and various constraints on the annual change in the total mortality (see Section 3.1.2). P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**30:20**													
Constraint	**maxChangeBoth20%**				**maxChangeUp**		**slowUp FullDown**			**Cap80**		**Cap60**		
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**40%**	**46%**	**42%**	**40%**	**46%**	**40%**	**46%**	**40%**
Biological Sustainability (Long-term)													
P(all dRSB<20%)	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(any dRSB_y<20%)	0.01	0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fishery Sustainability (medium-term)													
P(all AAV > 15%)	0.26	0.3	0.34	0.39	0.27	0.35	0.13	0.21	0.26	0.58	0.61	0.45	0.48
Median average TM[3]	46.5	49.1	49.9	51.1	44	45.3	44.7	47.5	49.3	46.4	50.7	46.1	50
Rankings (lower is better) over all management procedures with a constraint (Table 6 and Table 7)													
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?[2]	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No
Maximum catch (TM)[3]	17	12	8	2	25	22	24	16	11	19	5	20	7
Overall Ranking	---	---	---	---	---	---	**12**	**8**	---	---	---	---	---

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that some procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error. Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

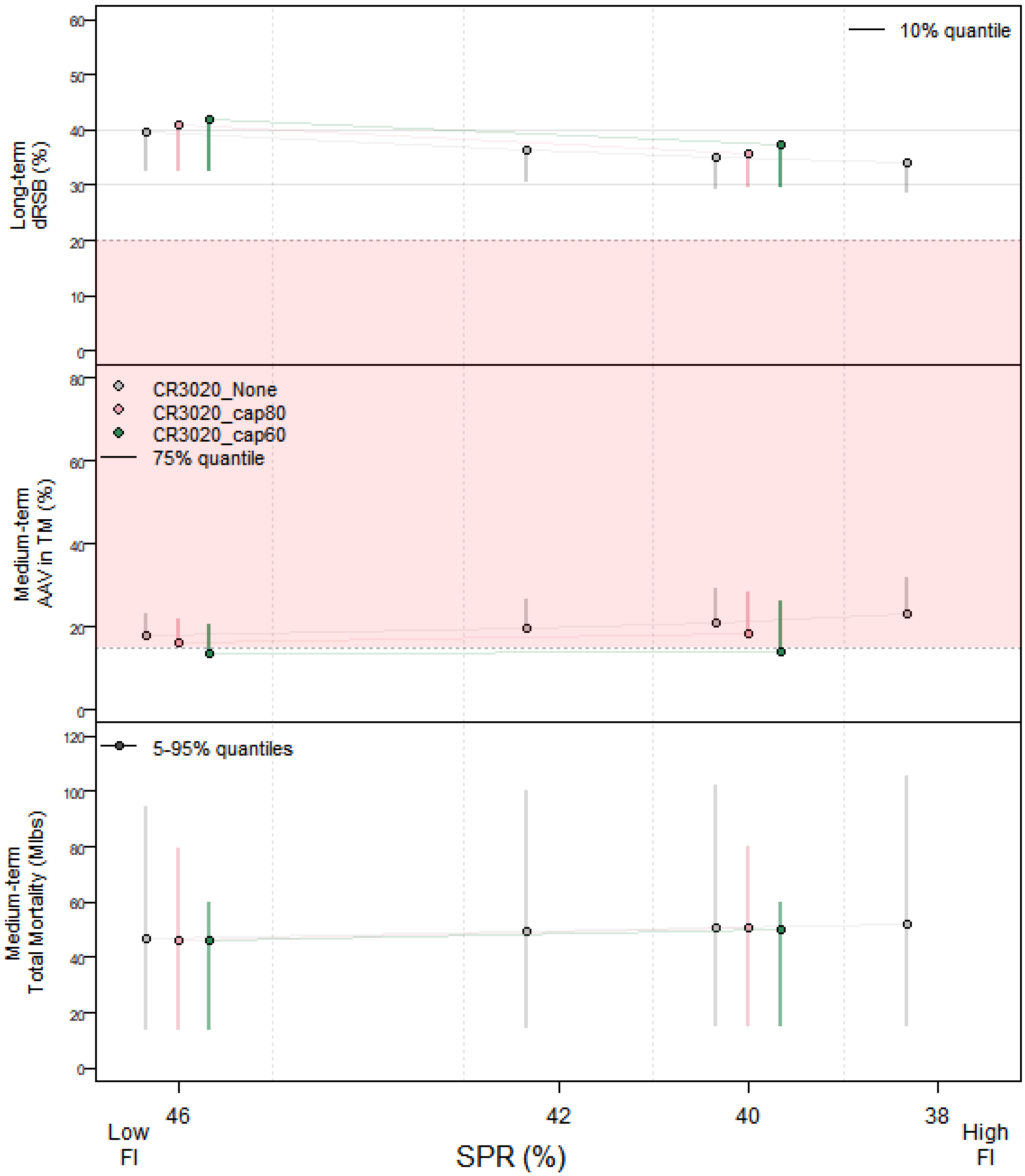

Figure 5. Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term fishery sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.38 to 0.46 and the 30:20 control rule using caps on the total mortality limit of 60 and 80 Mlbs. The points are the median values from the simulations and the vertical bars indicate the tolerance defined for that biological sustainability objective (plot a) and the catch stability objective (plot b); if the bar is in the red area, the objective is not met. The vertical bars for total mortality are the 90% intervals (i.e. 5th and 95th percentiles from the simulations).

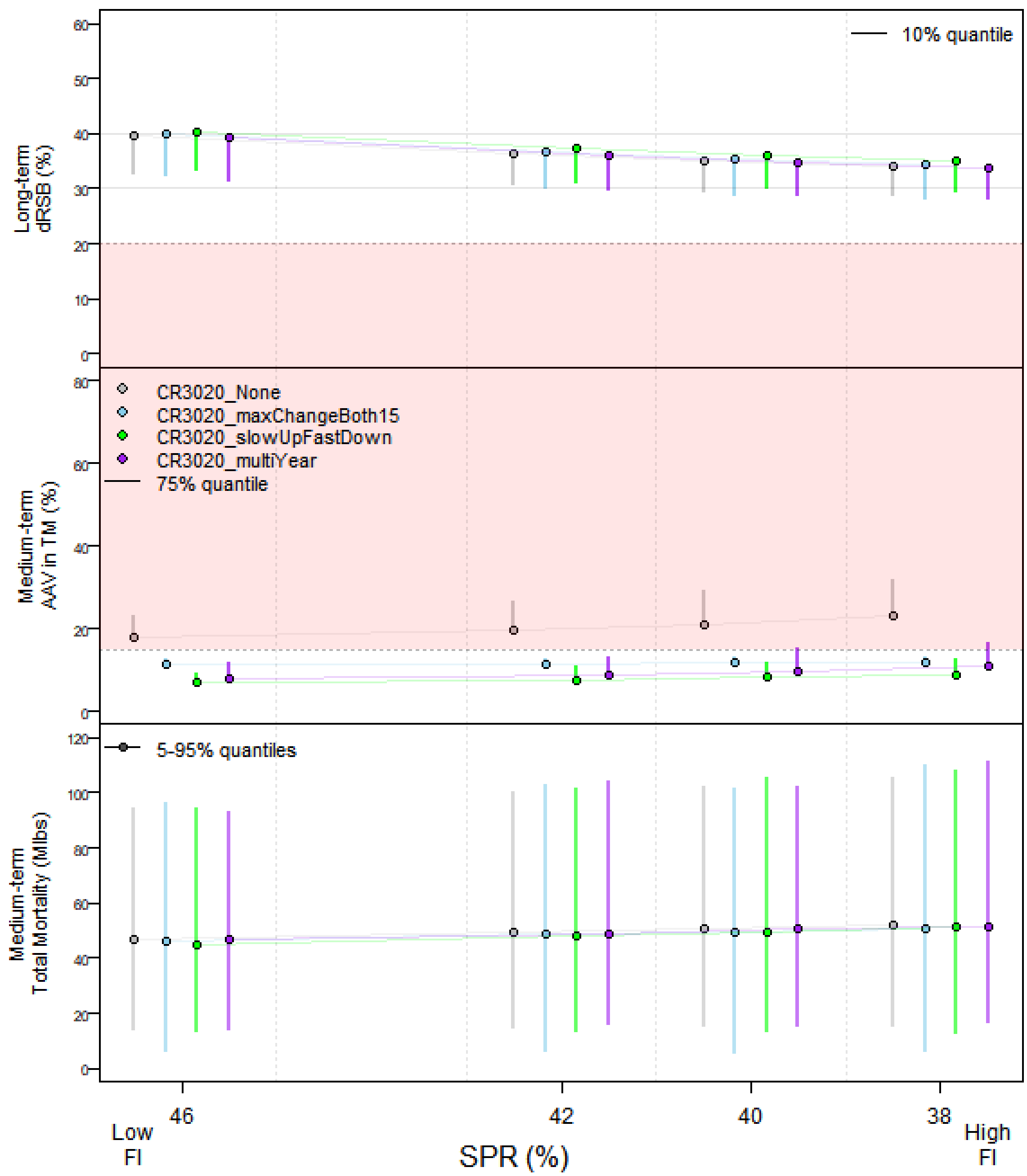

Figure 6. Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term fishery sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.38 to 0.46 and the 30:20 control rule using three different constraints on the total mortality limit: maxChange15, slowUpFastDown, and multiYear (see Section 3.1.2). The points are the median values from the simulations and the vertical bars indicate the tolerance defined for that biological sustainability objective (plot a) and the catch stability objective (plot b); if the bar is in the red area, the objective is not met. The vertical bars for total mortality are the 90% intervals (i.e. 5th and 95th percentiles from the simulations).

The additional measurable objectives related to maintaining the spawning biomass around a level that optimises fishing activities (Table 1) define a target biomass related to B_{MSY} or B_{MEY} as well as a tolerance to remain above the fishery trigger threshold. Past assessments and equilibrium models suggest that B_{MSY} is likely within the range of 30% to 41% of unfished spawning biomass. Using B_{MSY} as a target, the SPR that would meet the objective would be in the range of less than 30% to greater than 44% with a 30:20 or 40:20 control rule (Figure 7). In fact, very high fishing intensities (low SPR) could be chosen because the control rule reduces the input fishing intensity to a stable level as the stock is fished lower (see the upper left plot in Figure 7). With a 25:10 control rule, the fishing intensity is allowed to increase to higher levels and the SPR values that would meet a B_{MSY} target objective are within the range of 36% to 48%. Using the objective to maintain the biomass above the fishery trigger at least 80% of the time would choose an SPR between 42 and 43% with a 30:20 control rule (Figure 7).

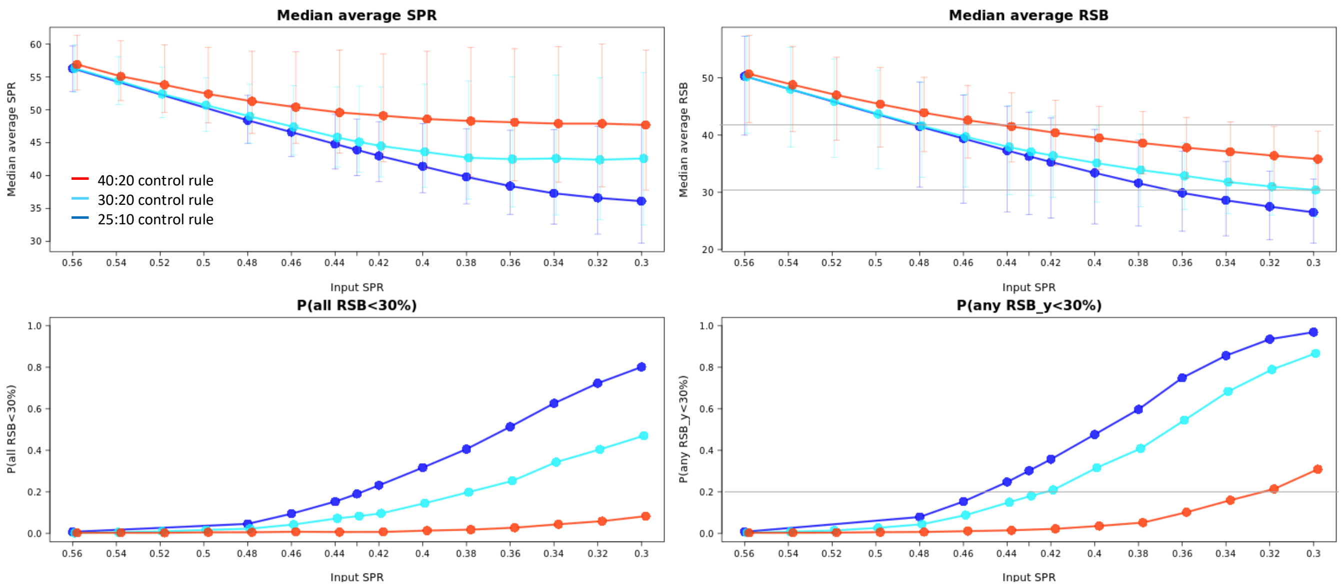

Figure 7: Performance metrics for the MSE simulation results when using 40:20, 30:20, and 25:10 control rules. The vertical lines represent the 5th and 95th percentiles of the simulation results. The P(all RSB<30%) represents the probability that the event may occur in a single year. The P(any RSB<30%) represents the probability that the event may occur in at least 1 out of 10 years.

Even though there is a specific procedural (input) SPR (Figure 2), this is not the fishing intensity that would typically be realized in a specific year. There is the applied SPR that is a result of applying the control rule. Often, the applied SPR will be equal to the procedural SPR, except when the stock status is estimated to be below the fishery trigger. Then, there is the realized SPR which is a result of applying the control rule and accounting for estimation error and implementation variability (e.g., not catching the entire mortality limit), and is realized in a specific year. This variability is seen in recent IPHC stock assessments which estimate a confidence interval for SPR and have produced estimates of past SPR values that are not equal to the SPR chosen by the Commission for that year (which also includes implementation variability).

Figure 7 (upper left panel) shows the three SPR quantities. The procedural SPR is shown along the x-axis. The applied SPR is represented by the dots, which are affected by the control rule and stabilizes as the input SPR increases. The realized SPR is represented by the vertical bars showing the percentiles of SPR values that were realized in the simulations as a result of estimation and variability in the operating model. With an input SPR of 46% and a 30:20 control rule, the median average SPR is 47% and the realized SPR ranges from approximately 43% to 54%.

In summary, long-term performance metrics showed little risk of falling below the 20% dynamic biomass limit for nearly all management procedures evaluated. In the medium-term, high variability in catches increased with higher fishing intensities (i.e. lower SPR), and median Total Mortality limits increased slightly with greater fishing intensity. Therefore, all SPR's greater than 30% met the biological sustainability objective, but no unconstrained management procedure met the stability objective, mainly due to estimation error. However, the procedural SPR values that would likely meet target objectives is between 36% and 48%. Constrained management procedures were able to meet biological and stability objectives and maxChangeBoth15%, slowUpFastDown, and multiYear performed the best. Additionally, at fishing intensities greater than those associated with an SPR of 40% (i.e., SPR values less than 40%) the variability in total mortality increased rapidly and median total mortality made minimal gains (Figure 4). If a constraint was to be implemented, it may be useful to introduce a precaution, such as the constraint is not applied if the estimated stock status is nearing the biomass limit, and vice versa, a measure that allows for increased harvest if the stock status is highly likely to be much greater than the target biomass.

4 A FRAMEWORK TO DISTRIBUTE THE TCEY

The report from the 95th Session of the IPHC Annual Meeting (AM095) contained one paragraph that noted the TCEY distribution component of the IPHC harvest strategy policy (IPHC-2019-AM095-R).

> *62. The Commission **RECOMMENDED** that the MSAB and IPHC Secretariat continue its program of work on the Management Procedure for the Scale portion of the harvest strategy, NOTING that Scale and Distribution components will be evaluated and presented no later than at AM097 in 2021, for potential adoption and subsequent implementation as a harvest strategy.*

There are many notes, requests, and recommendations from past Annual Meetings and MSAB meetings that pertain to distributing the TCEY (see Appendix I of IPHC-2019-MSAB013-09). Some important themes from these paragraphs are

- Distributing the TCEY to IPHC Regulatory Areas may result in a change to the coastwide total mortality or to the coastwide SPR.
- There are science-based and management derived elements to distributing the TCEY. A framework has been proposed that incorporates these elements.
- The IPHC Secretariat has described four biological Regions (consistent with IPHC Regulatory Area boundaries) based on the best available science.
- The MSAB has identified many potentials tools for use in distribution procedures.

This document summarizes IPHC-2019-MSAB013-09 and reports progress on the topic of distributing the TCEY.

In 2017, the Commission agreed to move to an SPR-based management procedure to account for the mortality of all sizes and from all fisheries (Figure 1). The procedure uses a coastwide fishing intensity based on spawning potential ratio (SPR), which defines the "scale" of the coastwide catch. The current interim management procedure for distributing the TCEY among IPHC Regulatory Areas contains two inputs: 1) the current estimated stock distribution and 2) relative target harvest rates.

4.1 CURRENT INTERIM MANAGEMENT PROCEDURE TO DISTRIBUTE THE TCEY

4.1.1 Stock distribution

The IPHC uses a space-time model to estimate annual Weight-Per-Unit-Effort (WPUE) for use in estimating the annual stock distribution of Pacific halibut (IPHC-2019-AM095-07). Briefly, observed WPUE is fitted with a model that accounts for correlation between setline survey stations over time (years) and space (within Regulatory Areas). Competition for hooks by Pacific halibut and other species, the timing of the setline survey relative to annual fishery mortality, and observations from other fishery-independent surveys are also accounted for in the approach. This fitted model is then used to predict WPUE (a measure of relative density) of Pacific halibut for every setline survey station in the design, including all setline survey expansion stations, regardless of whether it was fished in a particular year. These predictions are then averaged within each IPHC Regulatory Area, and combined among IPHC Regulatory Areas, weighting by the "geographic extent" (calculated area within the survey design depth range) of each IPHC Regulatory Area. It is important to note that this produces relative indices of abundance and biomass, but does not produce an absolute measure of abundance or biomass because it is weight-per-unit-effort scaled by the geographic extent of each IPHC Regulatory Area. These indices are useful for determining trends in stock numbers and biomass and are also useful to estimate the geographic distribution of the stock. The proportion of estimated biomass in each IPHC Regulatory Area is used in the current interim management procedure to determine stock distribution.

4.1.2 Relative Harvest Rates

The distribution of the TCEY for 2019 was shifted from the estimated stock distribution based on relative harvest rates of 1.00 for IPHC Regulatory Areas 2A–3A and 0.75 for IPHC Regulatory Areas 3B–4CDE. This application shifted the target TCEY distribution away from the stock distribution by moving TCEY into IPHC Regulatory Areas 2A, 2B, 2C, and 3A and removing TCEY from IPHC Regulatory Areas 3B, 4A, 4B, and 4CDE (Table 8), thus harvesting at a higher rate in eastern IPHC Regulatory Areas.

Table 8. IPHC Regulatory Area stock distribution estimated from the 2018 space-time model O32 WPUE, IPHC Regulatory Area-specific relative target harvest rates, and resulting 2019 target TCEY distribution based on the IPHC's 2019 interim management procedure (reproduced from the mortality projection tool https://iphc.int/data/projection-tool).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O32 stock distribution	1.8%	11.2%	14.3%	37.2%	9.0%	6.7%	5.9%	13.9%	100%
Relative harvest rates	1.00	1.00	1.00	1.00	0.75	0.75	0.75	0.75	--
Target TCEY Distribution	1.9%	12.3%	15.6%	40.9%	7.4%	5.5%	4.9%	11.5%	100%

4.2 REDEFINING THE DISTRIBUTION OF THE TCEY

Distributing the TCEY is composed of a purely scientific component to distribute the TCEY in proportion to its estimated biomass and steps to further modify the distribution of the TCEY based on additional considerations (distribution procedures). These two components are described below.

4.2.1 Stock Distribution

The overarching conservation goal for Pacific halibut is to maintain a healthy coastwide stock, which implies an objective to retain viable spawning activity in all pertinent portions of the stock. One method for addressing this objective, without knowing the relative importance of each portion of the stock, is to distribute the fishing mortality relative to the distribution of observed stock biomass. This requires defining appropriate areas for which the distribution is to be conserved, hence balancing the removals to protect against localized depletion of spatial and demographic components of the stock that may produce differential recruitment success under changing environmental and ecological conditions. Splitting the coast into many small areas for conservation objectives can result in complications, including i) making it cumbersome to determine if conservation objectives are met, ii) making it difficult to accurately determine the proportion of the stock in that area resulting in inter-annual variability in estimates of the proportion, iii) forcing arbitrary delineation among areas despite evidence of strong stock mixing, and iv) not representing biological importance. Emerging understanding of Pacific halibut diversity across the geographic range of the Pacific halibut stock indicates that IPHC Regulatory Areas should only be considered as management units and do not represent relevant sub-populations (Seitz et al. 2017). Biological Regions, defined earlier and shown in Figure 8, are considered by the IPHC Secretariat, and supported by the SRB (paragraph 31 IPHC-2018-SRB012-R), to be the best current option for biologically-based areas to meet management needs and conserve spatial population structure. Biological Regions are also the most logical scale over which to consider conservation objectives related to distribution of the fishing mortality.

In addition to using Biological Regions for stock distribution, the "all sizes" WPUE from the space-time model (Figure 9), which is largely composed of over 26 inch (O26) Pacific halibut, due to selectivity of the setline gear, is more congruent with the TCEY (O26 catch levels) than over 32 inch (O32) WPUE. Therefore, when distributing the TCEY to Biological Regions, the estimated proportion of "all sizes" WPUE from the space-time model should be used for consistency.

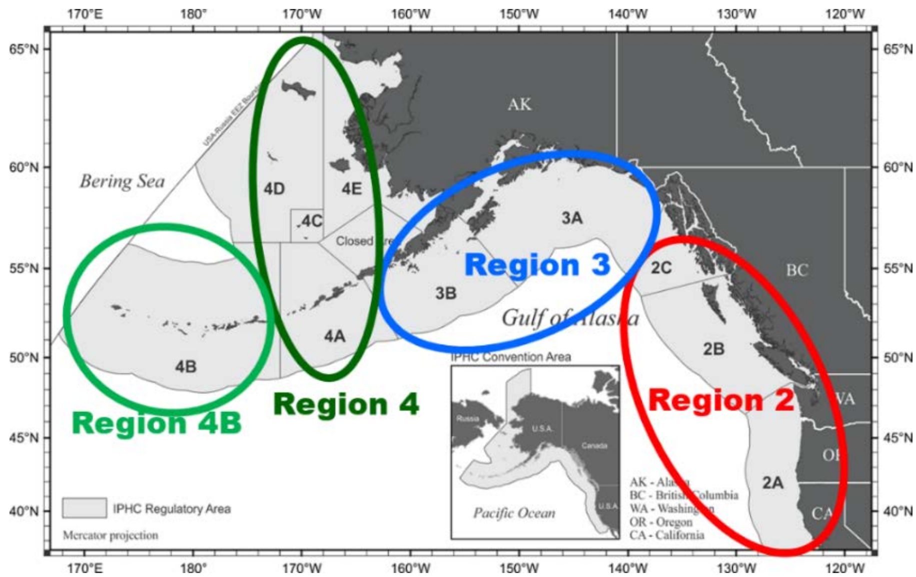

Figure 8. Biological Regions overlaid on IPHC Regulatory Areas with Region 2 comprised of 2A, 2B, and 2C, Region 3 comprised of 3A and 3B, Region 4 comprised of 4A and 4CDE, and Region 4B comprised solely of 4B.

4.2.2 Distribution Procedures

The Distribution Procedures component contains additional steps of further modifying the distribution of the TCEY among Biological Regions and then distributing the TCEY among IPHC Regulatory Areas within Biological Regions (Figure 10). Modifications at the level of Biological Regions or IPHC Regulatory Areas may be based on differences in productivity between areas, observations in each area relative to other areas (e.g. fishery-dependent WPUE), uncertainty of data or mortality in each area, defined allocations, national shares, or other methods. Data may be used as indicators of stock trends in each Region or IPHC Regulatory Area and are included in the Distribution Procedures component because they may be subject to certain biases or include factors unrelated to the biomass in that Biological Region or IPHC Regulatory Area. For example, fishery-dependent WPUE may not always be proportional to biomass, but is a popular source of data used to infer trends in a population and is at least useful to understand fishery trends.

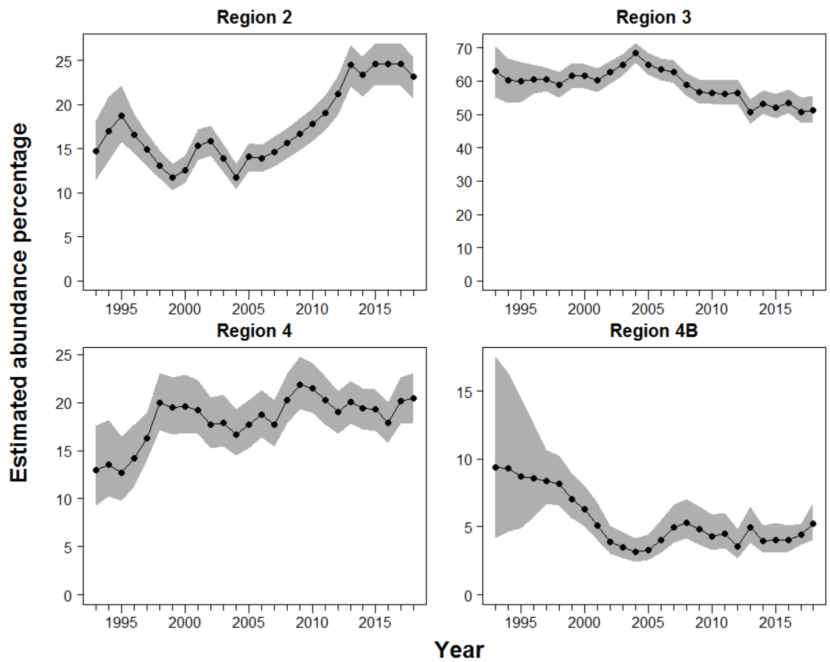

Figure 9. Estimated stock distribution (1993-2018) based on estimate "all sizes" WPUE for Pacific halibut from the space-time model. Shaded zones indicate 95% credible intervals. Reproduced from IPHC-2019-AM095-08.

The MSAB013 report (IPHC-2019-MSAB013-R) listed eleven potential tools for use in developing distribution procedures

60. *The MSAB* ***NOTED*** *the following potential elements of management procedures for the distribution of the TCEY:*

   a) *IPHC fishery-independent setline survey estimates by IPHC Regulatory Area, biological regions, or multi-area management zones;*

   b) *relative harvest rates;*

   c) *O32:O26 ratios or other proxies to represent discard mortality in directed fisheries;*

   d) *trends in the IPHC fishery-independent setline survey WPUE/NPUE by IPHC Regulatory Area, biological regions, or multi-area management zones;*

   e) *Trends in fishery CPUE by IPHC Regulatory Area, biological regions, or multi-area management zones;*

   f) *Smoothing algorithms on area-specific catch limits;*

   g) *Percentage allocation to an IPHC Regulatory Area (e.g., a method to calculate a proportion of the TCEY for IPHC Regulatory Area 2B);*

   h) *a floor on the TCEY (e.g. a minimum of 1.65 Mlbs in IPHC Regulatory Area 2A);*

   i) *A maximum SPR with catch distribution by IPHC Regulatory Area determined from the IPHC fishery-independent setline survey WPUE;*

   j) *Coastwide TCEY target and maximum calculated; distribution by target, but with ability to adjust TCEY up to the maximum;*

There are many other tools that could be used, and AM095 implemented two tools for IPHC Regulatory Areas 2A and 2B (IPHC-2019-AM095-R).

69. The Commission ADOPTED:

a) a coastwide target SPR of 47% for 2019;

b) a share-based allocation for IPHC Regulatory Area 2B. The share will be defined based on a weighted average that assigns 30% weight to the current interim management procedure's target TCEY distribution and 70% on 2B's recent historical average share of 20%. This formula for defining IPHC Regulatory Areas 2B's annual allocation is intended to apply for a period of 2019 to 2022. For 2019, this equates to a share of 17.7%; and IPHC–2019–AM095–R Page 19 of 46

c) a fixed TCEY for IPHC Regulatory Area 2A of 1.65 mlbs is intended to apply for a period from 2019-2022, subject to any substantive conservation concerns.

These elements can easily be incorporated into a management procedure.

The steps in the Distribution Procedures may consider conservation objectives, but they will mainly be developed with respect to fishery objectives, which will likely be diverse and in conflict across IPHC Regulatory Areas. Pacific halibut mortality levels are defined for each IPHC Regulatory Area and quota is accounted for by those IPHC Regulatory Areas. Therefore, IPHC Regulatory Areas are the appropriate scale to consider fishery objectives.

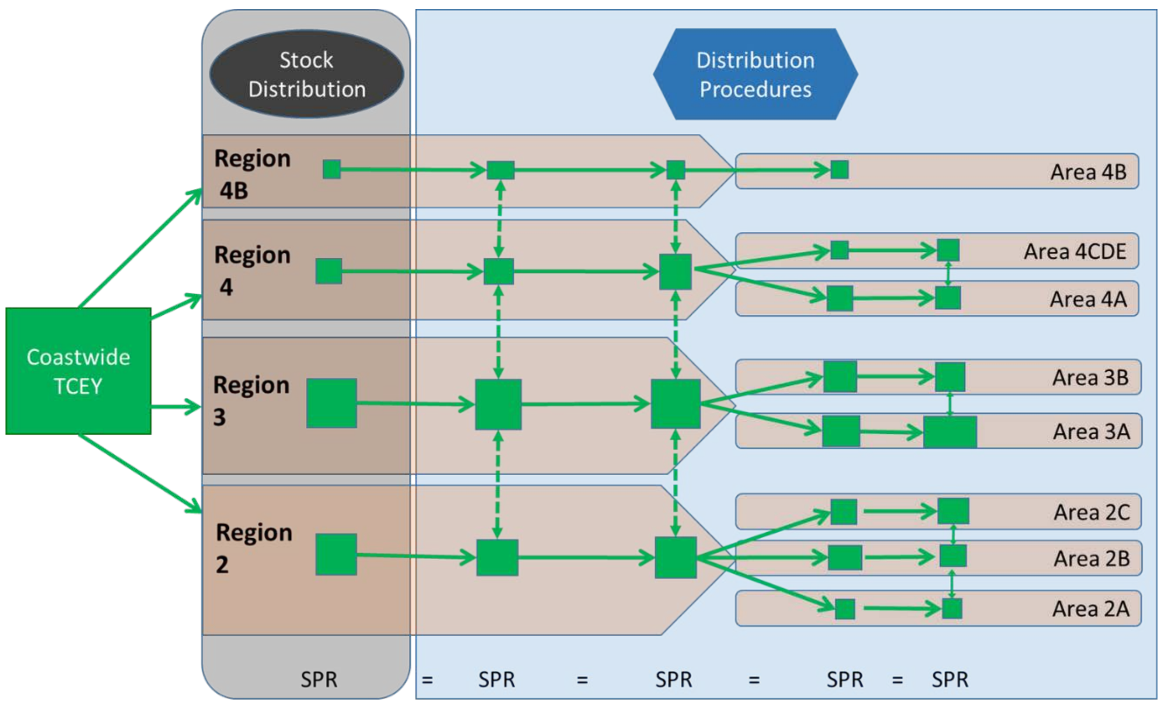

Figure 10. The process of distributing the TCEY to IPHC Regulatory Areas from the coastwide TCEY. The first step is to distribute the TCEY to Biological Regions based on the estimate of stock distribution. Following this, a series of adjustments may be made based on observations or social, economic, and other considerations. Finally, the adjusted regional TCEY's are allocated to IPHC Regulatory Areas. The allocation to IPHC Regulatory Areas may occur at any point after regional stock distribution. The dashed arrows represent the balancing required to maintain a constant coastwide SPR.

4.3 A Framework for Distributing the TCEY among IPHC Regulatory Areas

The harvest strategy policy begins with the coastwide TCEY determined from the stock assessment and fishing intensity determined from a target SPR (Figure 1). To distribute the TCEY among regions, stock distribution (Section 4.2.1) occurs first to satisfy conservation objectives. This is followed by adjustments across Biological Regions and Regulatory Areas based on distribution procedures to further encompass conservation objectives and consider fishery objectives. A constraint could be enforced such that given relative adjustments, the overall fishing intensity (i.e., target SPR) is maintained (i.e., a zero-sum game relative to fishing intensity). This is consistent with many management procedures for fisheries around the world. If a target SPR is not maintained, the minimum SPR value in the range produced by the distribution procedure would be considered the *de facto* target.

A framework for a management procedure that ends with the TCEY distributed among IPHC Regulatory Areas and would encompass conservation and fishery objectives is described below.

1. **Coastwide Assessment (science-based) and Target Fishing Intensity (management-derived):** Determine the coastwide total mortality using a target SPR that is most consistent with IPHC objectives defined by the Commission. Separate the total mortality into ≥26 inches (O26) and under 26 inches (U26) components. The O26 component is the coastwide TCEY.
2. **Regional Stock Distribution (science-based):** Distribute the coastwide TCEY to four (4) biologically-based Regions (Figure 8) using the proportion of the stock estimated in each Biological Region for all sizes of Pacific halibut using information from the IPHC setline survey and the IPHC space-time model. “All sizes” WPUE is the most appropriate metric to distribute the TCEY.
3. **Regional Relative Fishing Intensity (science-based):** Adjust the distribution of the TCEY among Biological Regions to account for migration, productivity, data availability/uncertainty, and other biological characteristics of the Pacific halibut observed in each Biological Region.
    - 3.1. The IPHC Secretariat may be able to provide Yield-Per-Recruit (YPR) and/or surplus production calculations as further supplementary information to inform this step.
4. **Regional Allocation Adjustment (management derived):** Adjust the distribution of the TCEY among Biological Regions to account for other factors.
    - 4.1. Further adjustments are part of a management/policy decision that may be informed by data and observations. This may include evaluation of recent trends in estimated quantities (such as fishery-independent WPUE), inspection of historical trends in fishing intensity, recent or historical fishery performance. The regional relative harvest rates may also be determined through negotiation, leading to an allocation agreement for further Regional adjustment of the TCEY.
5. **Regulatory Area Allocation (management derived):** Apply IPHC Regulatory Area allocation percentages within each Biological Region to distribute the Region-specific TCEY’s to Regulatory Areas.
    - 5.1. This management or policy decision may be informed by data, based on past or current observations, or defined by an allocation agreement. For example, recent trends in estimated all sizes WPUE from the setline survey or fishery, age composition, or size composition may be used to distribute the TCEY to IPHC Regulatory Areas. Inspection of historical trends in fishing intensity or catches by IPHC Regulatory Area may also be used. Finally, predetermined fixed percentages are also an option. This allocation to IPHC Regulatory Areas may be a procedure with multiple adjustments using different data, observations, or agreements

The four steps described above would be contained within the IPHC Harvest Strategy Policy as part of the Management Procedure and are predetermined steps with a predictable outcome. The decision-making process would then occur (Figure 1).

6. **Annual Regulatory Area Adjustment (policy)**: Adjust individual Regulatory Area TCEY limits to account for other factors as needed. This is the policy part of the harvest strategy policy and occurs as a final step where other objectives are considered (e.g., economic, social, etc.).
   6.1. A departure from the target SPR may be a desired outcome for a particular year (short-term, tactical decision making based on current trends estimated in the stock assessment) but would deviate from the management procedure and the long-term management objectives. Departures from the management procedure could take advantage of current situations but may result in unpredictable longer-term outcomes.

5 DEVELOPMENT OF THE CLOSED-LOOP SIMULATION FRAMEWORK

An MSE is a scientifically defensible, forecast-driven study of the tradeoffs between fisheries management scenarios, and requires that the software underpinning these simulations be robust, well-documented, performant, and extensible. It should return reproducible results, maximize ease-of-use, and be written with standard software development and testing processes and tools. With these guidelines in mind, the IPHC MSE development project will produce a simulation, analysis, and visualization tool set that can support Pacific halibut fisheries management in the future.

The structure of the software to be developed resembles the MSE process, highlighting the interplay between forecast models conditioned on historical data that characterize the stock, and a management procedure to be evaluated against conservation and fishery objectives. Aspects include

- the creation of an operating model
- an ability to condition model parameters using historical catches, survey data, and other observations
- integration with stock assessment tools or data
- application of a management procedure with closed-loop feedback into the operating model
- production of performance metrics to evaluate management procedures
- support for hypothesis testing, stock performance investigation, and detailed tradeoff analysis
- a platform and data source for customizable visualizations and analytics
- standardization of the computer-based format, structure, and content of management procedures
- leveraging existing high-performance scientific computing methodologies, software, and infrastructure

In practical terms, the operating model and related high-performance scientific and statistical codes will be written in C++ and heavily leverage available libraries, such as the AD Model Builder package. Configuration files and templates will utilize YAML, a human-readable but machine-parseable text specification. Additional statistical tooling used for analysis and visualization will utilize R. A workflow management system will be used to manage and monitor the execution of computational jobs, and will support their execution both locally and on third-party (e.g., cloud or HPC center) resources.

A summary of the framework components is below.

1. Operating Model
    1.1. An open-source C++ codebase developed at the IPHC, simulating the dynamics of
        - fish biology and population dynamics
        - ocean regime
        - environmental and ecological effects
        - partitions for year, age, sex, and more
        - variability in various processes
    1.2. Customizable spatial mapping, but at minimum per Region and IPHC Regulatory Area
    1.3. Fleet mapping for consistency with stock assessment models (commercial, discards, bycatch, sport, personal use by IPHC Regulatory Area as necessary).
    1.4. Uncertainty of parameters and model structure, and simulated variability in factors such as future weight-at-age and recruitment.
2. Management Procedure
    2.1. Estimation Models, including
        - Perfect information, as if we knew population values exactly when applying the harvest rule.
        - Simulate error in the total mortality limit and relative spawning biomass (i.e., stock status), and their autocorrelation, from the simulated time-series to mimic an unbiased stock assessment.
        - Use a single existing stock assessment
        - Use an ensemble of stock assessment techniques
        - Survey-based harvest rules that eliminate a complex stock assessment
    2.2. Data Generation
        - Use the operating model to generate simulated realizations of data products (e.g., survey index) at the Region or IPHC Regulatory Area level with variability and bias
    2.3. Harvest Rule
        - Coastwide fishing intensity (FSPR) using a procedural input SPR.
        - A control rule to reduce the fishing intensity (increase SPR) between a fishery trigger and fishery limit.
        - Constraints on the annual change in the mortality limit
        - Other coastwide and area-specific elements as defined by the MSAB
3. Analysis, Visualization, and Reporting tools
    3.1. Statistical tools for data analysis and quick-look visualization, written in R and C++
    3.2. Web-based visualization tools, written in R and Javascript, for easy stakeholder viewing and data manipulation
    3.3. Reporting tools, allowing customizable summaries of MSE output for later analysis, inclusion in documents, and stakeholder review
4. Computing infrastructure
    4.1. Human- and machine-readable configuration files for operating model and management procedures (YAML)
    4.2. Workflow management system for the management and monitoring of computational tasks (e.g., Drake, Airflow, Dask)
    4.3. Ability to run locally, on cloud providers (Amazon Web Services, Microsoft Azure, Google Cloud) or on third-party supercomputing resources (Open Science Grid, XSEDE)

5.1 Multi-area operating model

The operating model will be generalized and able to model a single-area or multiple areas such as IPHC Regulatory Areas. However, based on current knowledge, biology and inter-annual movement of Pacific halibut is best modeled with Biological Regions (Figure 8). Distribution of the TCEY will still occur to IPHC Regulatory Areas by modelling multiple sectors within a Biological Region, and sector-specific performance metrics will be calculated at the IPHC Regulatory Area level.

6 MSE program of work

The presentation of results for the MSE investigating the full harvest strategy policy is scheduled to occur at the 97th Annual Meeting in early 2021. The tasks to be delivered at each MSAB meeting before then are listed in Table 9. The SRB will review the technical details of the framework and operating model in September 2019, see preliminary results in June 2020, and review the full MSE in September 2020.

Table 9: Program of work and tasks for 2019 and 2020 to deliver the full MSE results at the 97th Annual Meeting in early 2021.

May 2019 MSAB Meeting
Evaluate additional Scale MPs
Review Goals
Spatial Model Complexity
Identify MPs (Distribution & Scale)
Review Framework
October 2019 MSAB Meeting
Review Goals and Objectives
Spatial Model Complexity
Identify MPs (Distribution & Scale)
Review Framework
Review multi-area model development
Annual Meeting 2020
Update on progress
May 2020 MSAB Meeting
Review Goals and Objectives
Review multi-area model
Review final results to be presented at AM097
October 2020 MSAB Meeting
Review Goals and Objectives
Review final results
Annual Meeting 2021
Presentation of first complete MSE product to the Commission Recommendations on Scale and Distribution MP

7 RECOMMENDATIONS

That the SRB **NOTE**:

a) paper IPHC-2019-SRB014-08 which provides the SRB with an update on the IPHC MSE process including defining objectives, results for management procedures related to coastwide fishing intensity, a framework for distributing the TCEY, and a program of work.

b) the primary objectives used to evaluate management procedures related to coastwide scale and the additional primary objectives related to a target biomass.

c) that no coastwide management procedure without constraints met the stability objective.

d) that the three different constraints were ranked in the top 5 management procedures (a slow-up fast-down approach, a maximum change of 15%, and a multi-year limit).

e) the distribution framework consisting of a coastwide TCEY distributed to Biological Regions based on stock distribution, relative fishing intensities, and other allocation adjustments, then distributed to IPHC Regulatory Areas based other data, observations, or agreement.

f) the development of a closed-loop simulation framework to evaluate management procedures related to coastwide scale and distribution of the TCEY.

g) that the SRB will review the technical details of the MSE framework and operating model in September 2019, and review the full MSE in September 2020.

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9 APPENDICES

Appendix I: Additional long- and medium-term performance metrics for the coastwide simulations

APPENDIX I: ADDITIONAL LONG- AND SHORT-TERM PERFORMANCE METRICS FOR THE COASTWIDE SIMULATIONS

Table A1. Long-term performance metrics for an estimation error CV of 0.15, autocorrelation of 0.4, a 30:20 control rule, and a range of input SPRs.

Input Est Error	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**
Input Autocorrelation	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Input Control Rule	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Median SPR	56.3%	49.0%	47.4%	45.8%	44.5%	43.6%	42.7%	42.5%	42.6%	42.4%	42.6%
Biological Sustainability											
Median average dRSB	50.2%	41.6%	39.7%	37.9%	36.4%	35.1%	33.9%	32.9%	31.8%	31.0%	30.4%
P(all dRSB<20%)	0.002	0.002	0.003	0.004	0.002	0.003	0.004	0.005	0.005	0.004	0.004
P(any dRSB_y<20%)	0.002	0.003	0.004	0.004	0.003	0.004	0.005	0.006	0.008	0.008	0.011
P(all dRSB<30%)	0.002	0.023	0.043	0.073	0.096	0.146	0.199	0.253	0.343	0.405	0.470
P(any dRSB_y<30%)	0.003	0.044	0.088	0.151	0.209	0.317	0.409	0.545	0.684	0.789	0.867
P(all dRSB<40%)	0.052	0.408	0.531	0.658	0.769	0.856	0.911	0.948	0.969	0.980	0.989
P(any dRSB_y<40%)	0.087	0.574	0.721	0.854	0.939	0.979	0.992	0.999	1.000	1.000	1.000
Fishery Sustainability											
P(all AAV > 15%)	0.606	0.689	0.717	0.767	0.812	0.849	0.905	0.927	0.957	0.988	0.993
P(all TM < 34 Mlbs)	0.507	0.455	0.460	0.453	0.446	0.450	0.440	0.439	0.465	0.458	0.465
P(any TM < 34 Mlbs)	0.662	0.627	0.637	0.644	0.666	0.686	0.721	0.758	0.808	0.862	0.891
5^{th} percentile of TM	9.47	9.08	8.8	8.94	9.56	9.33	9.28	9.74	8.41	9.16	9.28
Median average TM	33.95	37.39	37.56	38.08	38.98	38.79	40.33	40.6	39.35	41.84	42.06
75^{th} percentile of TM	55.14	62.11	62.49	64.15	65.37	66.49	68.28	70.61	69.21	70.94	72.26
P(all decrease TM > 15%)	0.221	0.236	0.247	0.263	0.274	0.286	0.301	0.319	0.337	0.352	0.365
P(any decrease TM > 15%)	0.921	0.932	0.942	0.946	0.955	0.963	0.973	0.982	0.990	0.992	0.997
median AAV TM	16.3%	17.5%	18.4%	19.6%	21.3%	23.6%	26.4%	30.2%	34.0%	37.3%	41.8%

Table A2. Medium-term (14-23 annual time-steps) performance metrics for an estimation error CV of 0.15, autocorrelation of 0.4, a 30:20 control rule, and a range of input SPRs.

Input Est Error	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**
Input Autocorrelation	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Input Control Rule	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Median SPR	56.7%	49.2%	47.4%	45.7%	44.1%	42.6%	41.4%	40.7%	40.4%	40.2%	40.5%
Biological Sustainability											
Median average dRSB	49.5%	42.9%	41.4%	39.8%	38.3%	36.8%	35.4%	34.1%	33.0%	32.0%	31.1%
P(all dRSB<20%)	0.013	0.013	0.011	0.011	0.011	0.011	0.011	0.013	0.011	0.014	0.014
P(any dRSB_y<20%)	0.019	0.019	0.017	0.017	0.017	0.016	0.015	0.020	0.019	0.023	0.027
P(all dRSB<30%)	0.042	0.055	0.072	0.082	0.100	0.124	0.151	0.193	0.263	0.331	0.410
P(any dRSB_y<30%)	0.054	0.083	0.115	0.140	0.180	0.236	0.313	0.432	0.574	0.698	0.816
P(all dRSB<40%)	0.174	0.346	0.433	0.531	0.642	0.747	0.841	0.903	0.943	0.967	0.980
P(any dRSB_y<40%)	0.249	0.486	0.606	0.742	0.856	0.944	0.982	0.997	0.999	1.000	1.000
Fishery Sustainability											
P(all AAV > 15%)	0.604	0.656	0.694	0.719	0.756	0.799	0.841	0.884	0.929	0.964	0.980
P(all TM < 34 Mlbs)	0.415	0.330	0.323	0.306	0.296	0.286	0.277	0.279	0.296	0.299	0.318
P(any TM < 34 Mlbs)	0.626	0.531	0.520	0.517	0.524	0.554	0.603	0.666	0.727	0.773	0.832
5^{th} percentile of TM	13.78	15.71	13.9	14.17	15.01	15.23	15.71	16.71	14.71	16.37	15.88
Median average TM	39.37	45.5	46.76	48.04	49.51	50.64	51.78	52.11	52.38	53.15	52.82
75^{th} percentile of TM	52.87	61.7	62.67	64.76	66.67	68.46	69.93	71.99	71.64	72.74	74.21
P(all decrease TM > 15%)	0.196	0.218	0.226	0.234	0.247	0.258	0.276	0.295	0.313	0.337	0.357
P(any decrease TM > 15%)	0.909	0.921	0.929	0.937	0.948	0.956	0.965	0.977	0.983	0.992	0.995
median AAV TM	16.5%	17.5%	17.9%	18.7%	19.7%	20.9%	23.1%	26.2%	29.7%	33.5%	37.3%

Table A3. Long-term performance metrics for an estimation error CV of 0.15, autocorrelation of 0.4, a 30:20 control rule, three different constraints on the annual change in the mortality limit, and a range of input SPRs.

Input Est Error	**0.15**											
Input Autocorrelation	**0.4**											
Input Control Rule	**30:20**											
Constraint	**maxChangeBoth15%**				**slowUp FastDown**				**multiYear**			
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**
Median SPR	48.4%	44.9%	43.2%	41.7%	48.8%	45.3%	43.7%	42.1%	47.8%	44.3%	42.7%	41.3%
Biological Sustainability												
Median average dRSB	42.5%	39.6%	38.1%	36.9%	42.9%	40.0%	38.5%	37.1%	41.5%	38.4%	36.9%	35.4%
P(all dRSB<20%)	0.053	0.053	0.058	0.053	0.018	0.018	0.018	0.019	0.011	0.013	0.011	0.014
P(any dRSB_y<20%)	0.066	0.066	0.072	0.066	0.023	0.023	0.023	0.025	0.017	0.021	0.018	0.023
P(all dRSB<30%)	0.094	0.107	0.133	0.138	0.054	0.074	0.088	0.109	0.072	0.102	0.137	0.172
P(any dRSB_y<30%)	0.140	0.185	0.239	0.274	0.079	0.140	0.186	0.234	0.131	0.209	0.296	0.395
P(all dRSB<40%)	0.370	0.537	0.639	0.720	0.366	0.524	0.616	0.716	0.431	0.617	0.709	0.795
P(any dRSB_y<40%)	0.549	0.776	0.874	0.931	0.528	0.758	0.851	0.921	0.637	0.839	0.934	0.967
Fishery Sustainability												
P(all AAV > 15%)	0.042	0.047	0.054	0.055	0.068	0.109	0.143	0.151	0.144	0.187	0.256	0.296
P(all TM < 34 Mlbs)	0.340	0.319	0.323	0.314	0.336	0.304	0.292	0.267	0.324	0.283	0.283	0.280
P(any TM < 34 Mlbs)	0.474	0.453	0.452	0.456	0.449	0.434	0.440	0.444	0.468	0.458	0.483	0.510
5th percentile of TM	6.16	6.13	5.86	6.18	13.33	13.52	13.88	12.97	14.19	15.98	15.81	16.62
Median average TM	46.13	48.55	49.52	50.88	44.99	48.17	49.47	51.11	46.53	48.88	50.49	51.18
75th percentile of TM	62.46	66.75	67.82	70.06	63.49	67.98	70.43	70.77	62.58	67.73	68.19	70.68
P(all decrease TM > 15%)	0.091	0.098	0.104	0.112	0.045	0.064	0.078	0.088	0.093	0.101	0.111	0.117
P(any decrease TM > 15%)	0.549	0.582	0.600	0.614	0.298	0.385	0.435	0.491	0.664	0.699	0.746	0.760
median AAV TM	11.2%	11.3%	11.6%	11.7%	7.0%	7.7%	8.1%	8.8%	8.0%	8.8%	9.8%	10.8%

Table A4. Medium-term (14-23 annual time-steps) performance metrics for an estimation error CV of 0.15, autocorrelation of 0.4, a 30:20 control rule, three different constraints on the annual change in the mortality limit, and a range of input SPRs.

Input Est Error	**0.15**											
Input Autocorrelation	**0.4**											
Input Control Rule	**30:20**											
Constraint	**maxChangeBoth15%**				**slowUp FastDown**				**multiYear**			
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**
Median SPR	48.4%	44.9%	43.2%	41.7%	48.8%	45.3%	43.7%	42.1%	47.8%	44.3%	42.7%	41.3%
Biological Sustainability												
Median average dRSB	42.5%	39.6%	38.1%	36.9%	42.9%	40.0%	38.5%	37.1%	41.5%	38.4%	36.9%	35.4%
P(all dRSB<20%)	0.053	0.053	0.058	0.053	0.018	0.018	0.018	0.019	0.011	0.013	0.011	0.014
P(any dRSB_y<20%)	0.066	0.066	0.072	0.066	0.023	0.023	0.023	0.025	0.017	0.021	0.018	0.023
P(all dRSB<30%)	0.094	0.107	0.133	0.138	0.054	0.074	0.088	0.109	0.072	0.102	0.137	0.172
P(any dRSB_y<30%)	0.140	0.185	0.239	0.274	0.079	0.140	0.186	0.234	0.131	0.209	0.296	0.395
P(all dRSB<40%)	0.370	0.537	0.639	0.720	0.366	0.524	0.616	0.716	0.431	0.617	0.709	0.795
P(any dRSB_y<40%)	0.549	0.776	0.874	0.931	0.528	0.758	0.851	0.921	0.637	0.839	0.934	0.967
Fishery Sustainability												
P(all AAV > 15%)	0.042	0.047	0.054	0.055	0.068	0.109	0.143	0.151	0.144	0.187	0.256	0.296
P(all TM < 34 Mlbs)	0.340	0.319	0.323	0.314	0.336	0.304	0.292	0.267	0.324	0.283	0.283	0.280
P(any TM < 34 Mlbs)	0.474	0.453	0.452	0.456	0.449	0.434	0.440	0.444	0.468	0.458	0.483	0.510
5^{th} percentile of TM	6.16	6.13	5.86	6.18	13.33	13.52	13.88	12.97	14.19	15.98	15.81	16.62
Median average TM	46.13	48.55	49.52	50.88	44.99	48.17	49.47	51.11	46.53	48.88	50.49	51.18
75^{th} percentile of TM	62.46	66.75	67.82	70.06	63.49	67.98	70.43	70.77	62.58	67.73	68.19	70.68
P(all decrease TM > 15%)	0.091	0.098	0.104	0.112	0.045	0.064	0.078	0.088	0.093	0.101	0.111	0.117
P(any decrease TM > 15%)	0.549	0.582	0.600	0.614	0.298	0.385	0.435	0.491	0.664	0.699	0.746	0.760
median AAV TM	11.2%	11.3%	11.6%	11.7%	7.0%	7.7%	8.1%	8.8%	8.0%	8.8%	9.8%	10.8%