An update on the IPHC Management Strategy Evaluation (MSE) process for SRB015

PREPARED BY: IPHC SECRETARIAT (A. HICKS, P. CARPI, S. BERUKOFF, & I. STEWART; 24 AUGUST 2019)

PURPOSE

To provide an update of International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) activities including defining scale and distribution objectives, development of a framework to evaluate management procedures 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 an initial phase of evaluating management procedures 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 (66.0 cm, U26) non-directed discard mortality, 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 progress on developing a framework to investigate distributing the TCEY follows, and the program of work for the next year and a half 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 in directed fisheries
4. Minimize discards and discard mortality in non-directed fisheries (bycatch)

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 fisheries. In particular, this goal stresses optimising fishery yield with respect to stability and sustainability and optimising the fishing opportunities ensures access. Goals related to discard mortality in directed fisheries and non-directed fisheries have not yet been specifically considered in the MSE but are identified as important 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, and thus objectives have been focused at the coastwide level. The MSE program of work is now focusing on both components with the intent to refine coastwide objectives and define regional- and area-specific distributional 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.

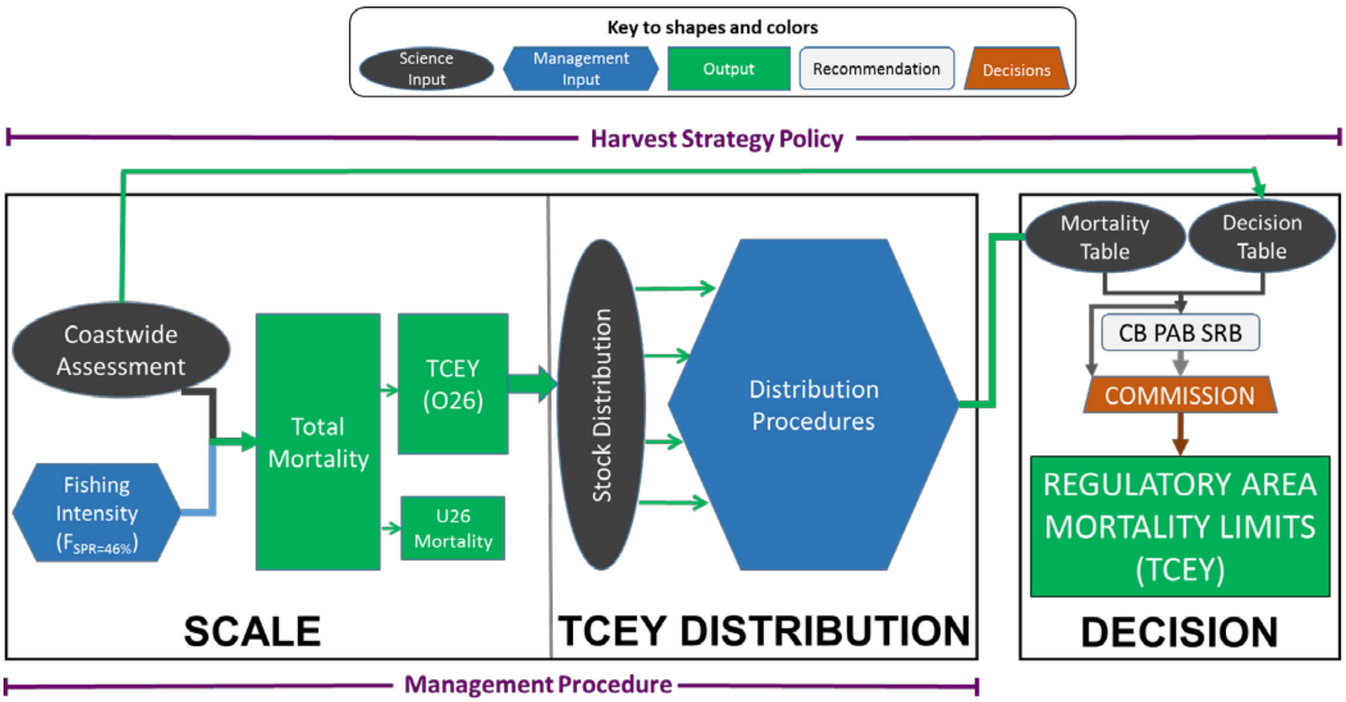

Figure 1: An illustration of the IPHC harvest strategy policy process showing the coastwide scale and TCEY distribution components that comprise the management procedure. The decision component is the Commission decision-making procedure, which considers inputs from many sources.

2.1 Objectives related to coastwide scale

Primary general objectives were identified by the MSAB and the Commission for evaluating MSE results related to coastwide fishing intensity as presented at AM095. At that time, the biological sustainability objective (maintain the biomass above a limit) was prioritized 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 (IPHC-2019-MSAB013-07 Appendix I) which were used to further evaluate the MSE results. Objectives that did not have a measurable outcome, tolerance, and/or 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 minimum or level or tolerance. Without these specifications, 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 with a 50% probability of being above or below) was discussed extensively at MSAB013. Noting that the current IPHC harvest strategy policy (https://iphc.int/the-commission/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 maximise economic benefit rather than maximising only yield has been widely recognized. However, the estimation of MEY and related quantities (SB_{MEY} and F_{MEY}) for specific fisheries remains challenging and requires a deep understanding of the economic variables relevant to the fishery. In the 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: $SB_{MEY} = 1.2 \times SB_{MSY}$ (Rayns, 2007), and Pascoe *et al*. (2014) suggested that $SB_{MEY} = 1.45 \times SB_{MSY}$ may be appropriate for data-poor single-species fisheries.

Four dynamic equilibrium reference points were estimated for the Pacific halibut stock: 1) unfished equilibrium dynamic spawning biomass (SB_0), 2) MSY, 3) B_{MSY} as a percentage of SB_0 (RSB_{MSY}), and 4) the equilibrium fishing intensity to achieve MSY using spawning potential ratio (SPR_{MSY}), using three different methods (IPHC-2019-SRB015-10). First, we used a simple equilibrium model. Second, estimates of B_{MSY} from the most recent assessment (IPHC-2019-AM095-09) were determined. Lastly, the coastwide MSE operating model was used to provide a range of SB_{MSY} estimates given the uncertainty and scenarios assumed in the closed-loop simulations. Two approaches were used to characterize variability in the reference points: 1) different scenarios to represent various states of weight-at-age (low, medium, and high relative to the historical observations), environmental regimes (explicitly defined as positive/negative), and values of other parameters, or 2) variability in parameters and weight-at-age were integrated into the simulations and the estimated reference points. Document IPHC-2019-SRB015-11 describes the methods and results from this analysis, and estimates the dynamic equilibrium RSB_{MSY} for Pacific halibut to likely be in the range of 20% to 30% and SPR_{MSY} to likely be between 30% and 35%. A reasonable RSB_{MSY} proxy, including a precautionary allowance for unexplored sources of uncertainty, would be 30%, and would put a proxy for SB_{MEY} between 36% and 44% given the recommendations of Rayns (2007) and Pascoe et al. (2014).

The MSAB also discussed the potential to use a threshold spawning biomass level related to the trigger spawning biomass in the control rule, instead of a target. This is simply a value to remain above with a defined tolerance (likely greater than 50%) 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). However, the SRB noted (IPHC-2019-SRB014-R, para. 36) that this conflates the objective and the management procedure, and the objective should not use the trigger but simply a defined threshold. A reasonable threshold is the RSB_{MSY} proxy of 30% of unfished spawning biomass.

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) 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 primary 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 revealed various proxies for a biomass limit and tolerances for falling below that limit. For example, the U.S. 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 U.S. 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. Further discussion of these objectives will occur at MSAB014.

An *ad hoc* working group that met in July 2019 discussed the coastwide objective to limit annual changes in the TCEY, which is measured by the average annual variability (AAV), which is an average taken over a ten-year period. Using this performance metric means that when meeting the objective (a defined threshold) some of those annual change in the TCEY will exceed the defined threshold. Instead, stakeholders may be more interested in the actual annual change from year to year and to limit it to a threshold that is never exceeded in a ten-year period or allow it to be exceeded in a small number of years. A new statistic called Annual Change (AC) was defined to represent actual annual change in the TCEY and may be used as the priority stability objective.

2.2 Objectives related to the distribution of the TCEY

2.2.1 Biological sustainability

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 related to conserving some level of spatial population structure should be included under the Biological Sustainability goal. The *ad hoc* working group that met in July 2019 discussed spatial biomass objectives and a report from that meeting is available as an informational paper for discussion at SRB015.

Table 1. Primary measurable objectives, evaluated over a simulated ten-year period, revised at MSAB013 and by the *ad hoc* working group that met in July 2019. 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	Maintain a 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 Threshold Maintain the female spawning biomass above a threshold reference point at least 80% of the time	*SB*<Spawning Biomass Threshold (SB_{Thres}) SB_{Thres}=$SB_{30\%}$ unfished spawning biomass	Long-term	0.20	$P(SB < SB_{Thres})$
	*2.1B Spawning Biomass Target Maintain the female spawning biomass	*SB*<Spawning Biomass Target (SB_{Targ}) SB_{Targ}=$SB_{36\text{-}45\%}$ unfished spawning biomass	Long-term	0.50	$P(SB < SB_{Targ})$

	above a biomass target reference point at least 50% of the time				
2.2. LIMIT CATCH VARIABILITY	Limit annual changes in the coastwide TCEY	Annual Change (*AC*) > 15% in any year	Short-term	0.25	$P(AC > 15\%)$
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 imply several meanings, such as maintaining the current biomass distribution across regions, maintaining the proportion of spawning biomass in each Biological Region within a specified range, or maintaining a minimum spawning biomass or proportion of spawning biomass in each Biological Region. The *ad hoc* working group proposed objectives to maintain a defined minimum proportion of spawning biomass in each Biological Region, which will complement the coastwide biological sustainability objective of maintaining the coastwide spawning biomass above a limit.

2.2.2 Optimise Directed Fishing Opportunities

Four general objectives are currently defined for this goal: 1) maintain the spawning biomass around a level that optimises fishing activities, 2) limit catch variability, 3) maximize directed fishery yield, and 4) minimize the potential of a catch limit equal to zero for the directed commercial fishery. Under each general objective, there are coastwide TCEY 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 defined within 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.

2.2.2.1 Maintain the spawning biomass around a level that optimises fishing activities

The objective to maintain the spawning biomass around a level that optimises fishing activities was not discussed by the July 2019 *ad hoc* working group, except for the consideration of an objective related to the amount of biomass that the fishery encounters (i.e., approximately those fish over 26 inches, 66 cm, in length; ~O26).

2.2.2.2 Limit catch variability

The *ad hoc* working group discussed the coastwide objective to limit annual changes in the TCEY and proposed that the same objective be defined for IPHC Regulatory Areas as well. This objective would capture the objective for stability in a stakeholder's area of interest as well as recognize that there is uncertainty in the distribution procedure that will likely result in variability in IPHC Regulatory Area catch limits. The working group discussed the potential for redundancy when having the same objectives at a coastwide and IPHC regulatory area scale and it was noted that, even though this could be the case, the two will address two different issues: the coastwide objective will address the annual variability as a result of the assessment error, while at the regulatory area level the objective will address the uncertainty in the distribution procedure. For this reason, the working group decided to carry both forward for the time being, and to evaluate redundancy when results are available.

2.2.2.3 Maximize fishery yield

Three different types of objectives related to fishery yield in an IPHC Regulatory Area were defined.

1. A minimum catch/yield/mortality level. This identifies what is needed for economic viability or for a fishery to occur. This requires stakeholders in an area to only consider what is desired within that area.
2. A proportional share of the coastwide catch/yield/mortality. This would be a defined percentage of the coastwide mortality limit and would provide for sharing among areas even in times of low abundance and maintain a sense of equity among areas (if appropriately agreed upon). This requires within- and among-area considerations.
3. The annual mortality limit reflects local abundance and changes accordingly. For example, if the abundance in the area increases the mortality should also increase, and vice versa. This requires only within-area considerations. Some examples of measurable outcomes are
    a. the mortality limit increases or decreases with true local abundance at least X% of the time,
    b. the mortality limit increases or decreases with survey abundance at least X% of the time,
    c. the mortality limit increases or decreases within X% of the rate of increase or decrease in actual local abundance, and
    d. the mortality limit increases or decreases within X% of the rate of increase or decrease of the survey abundance.

It is useful for each area to define an objective for the first two items above, and the third item is an objective related to transparency and consistency with observations from an IPHC Regulatory Area. The third item does not need to be defined, but the first two items should be defined as objectives to capture the separate concepts in each. Each of the items may be prioritized differently for each area during the evaluation.

As an example, decisions made at AM095 (IPHC-2019-AM095-R) identified two potential measurable objectives for IPHC Regulatory Areas 2A (a minimum catch level) and 2B (a proportional share of the coastwide mortality limit).

> **AM095-R, para 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*
>
> *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.*

2.2.2.4 Minimize potential of a catch limit equal to zero for the directed fisheries

This objective was not discussed by the *ad hoc* working group but would be defined as maintaining a catch limit above zero for the directed fisheries in each IPHC Regulatory Area. It is potentially redundant with defining a minimum catch level for an IPHC Regulatory Area, although different tolerances may be assigned.

3 INVESTIGATIONS OF COASTWIDE FISHING INTENSITY

Simulation results presented at MSAB012 (IPHC-2018-MSAB012-07) showed that none of the management procedures without a constraint on the change in annual mortality limit met the primary stability objective (average annual variability of the mortality limit less than 15% at least 75% of the time), as noted in paragraph 59,e in IPHC-2019-AM095-R. Therefore, various constraints on the change in 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). Appendix I of this document summarises the results documented in IPHC-2019-AM095-12 and additional 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 can be found in IPHC-2018-MSAB012-07.

It is worth noting that, despite defining a specific procedural (input) SPR[1] (Figure 0-1 and horizontal axis of the upper left plot in Figure 2), the fishing intensity typically realized in a specific year would differ due to various sources of variability. There is the applied SPR that is a result of applying the control rule (points in the upper left plot of Figure 2), which will often be equal to the procedural SPR. However, when the stock status is estimated to be below the fishery trigger, which results in a reduction in fishing intensity, the applied SPR will be greater than the procedural SPR. Furthermore, the realized SPR for a specific year (error bars in the upper left plot of Figure 2) results from applying the control rule, accounting for estimation error, and determining implementation variability (e.g., not catching the entire mortality limit). For example, with an input SPR of 46% and a 30:20 control rule, the median average SPR is 47% (slightly greater than the procedural SPR) and the realized SPR ranges from approximately 43% to 54%. This variability has been observed in recent IPHC stock assessments which estimated a confidence interval for SPR and produced estimates of past (realized) SPR values that were not equal to the procedural SPR chosen by the Commission for that year.

To summarise the results from the coastwide investigation of fishing intensity (Appendix I), long-term performance metrics showed little risk of falling below the 20% biomass limit for nearly all management procedures evaluated. In the medium-term, variability in catches increased with higher fishing intensities (i.e. lower SPR), and median total mortality (TM) limits increased slightly with greater fishing intensity. Therefore, all procedural SPR's greater than 30% met the biological sustainability objective, but no unconstrained management procedure met the stability objective, mainly due to estimation error. Constrained management procedures were able to meet biological and stability objectives and maxChangeBoth15%, slowUpFastDown, and multiYear performed the best. Additionally,

[1] The procedural SPR is the SPR that is defined by the management procedure. In practice, this SPR may be modified by a control rule, and is unlikely to be exactly achieved due to implementation variability and estimation uncertainty.

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	$p_{SB,R} < p_{SB,R,min}$	Long-term		$P(p_{SB,R} < p_{SB,R,min})$
	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, estimated from the IPHC Fishery-Independent Setline Survey (FISS) data, greater than a threshold	$p_{B_{O26},A} > p_{B_{O26},A,min}$	Short-term Long-term		$P(p_{B_{O26},A} > p_{B_{O26},A,min})$
	Proportion of O26 Pacific halibut biomass in each area	Proportion of O26 Pacific halibut biomass in each area	Short-term Long-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	Annual Change by Regulatory Area (AC_A) > 15%	Long-term Short-term	0.25	$P(AC > 15\%)$
		Maximum AC by Regulatory Area (AC_A)	Long-term Short-term	*STATISTIC OF INTEREST*	Maximum AC
		Average Annual Variability by Regulatory Area (AAV_A)	Long-term Short-term	*STATISTIC OF INTEREST*	AAV
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 absolute level by Regulatory Area	$TCEY_A < TCEY_{A,min}$	Long-term Short-term		$P(TCEY < TCEY_{A,min})$
	Maintain a percentage of the coastwide TCEY above a minimum absolute level by Regulatory Area	$\%TCEY_A > \%TCEY_{A,min}$	Long-term Short-term		$P(\%TCEY < TCEY_{A,min})$
	TCEY changes with local abundance	To be discussed at MSAB014			
	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 above zero for the directed fishery in each Regulatory Area	$DirectedYield_A = 0$	Long-term Short-term	?? ??	$P(DirY_A = 0)$

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 while the median total mortality made minimal gains. If a constraint is to be implemented, it may be useful to introduce a precaution, such as defining a procedure that the constraint should not be applied if the estimated stock status is nearing or is below the biomass limit. Vice versa, a measure may be applied that allows for increased harvest if the stock status is highly likely to be much greater than the target biomass.

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. However, the procedural SPR values that would likely meet biomass target objectives (SB_{MEY} proxy between 36% and 44%) are between 30% and 48% depending on the specific target and the control rule (Figure 0-3). Assuming a relative spawning biomass target based on an SB_{MEY} proxy between 36% and 44%, procedural SPR values between 30% and 48% would satisfy that target objective, depending on the specific target and the control rule (Figure 2 and Figure 0-3). An SPR of approximately 38% to 48% with a 30:20 control rule and an SPR of approximately 42% to 48% with a 25:10 control rule would meet the biomass target objective. With a 40:20 control rule, the relative spawning biomass would rarely fall below a 36% target because the fishing intensity is reduced by the control rule, and 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 2). Using the objective to maintain the biomass above a relative spawning biomass of 30% at least 80% of the time (instead of 50% as assumed for a target) would imply a choice of an SPR between 42 and 43% with a 30:20 control rule (Figure 2).

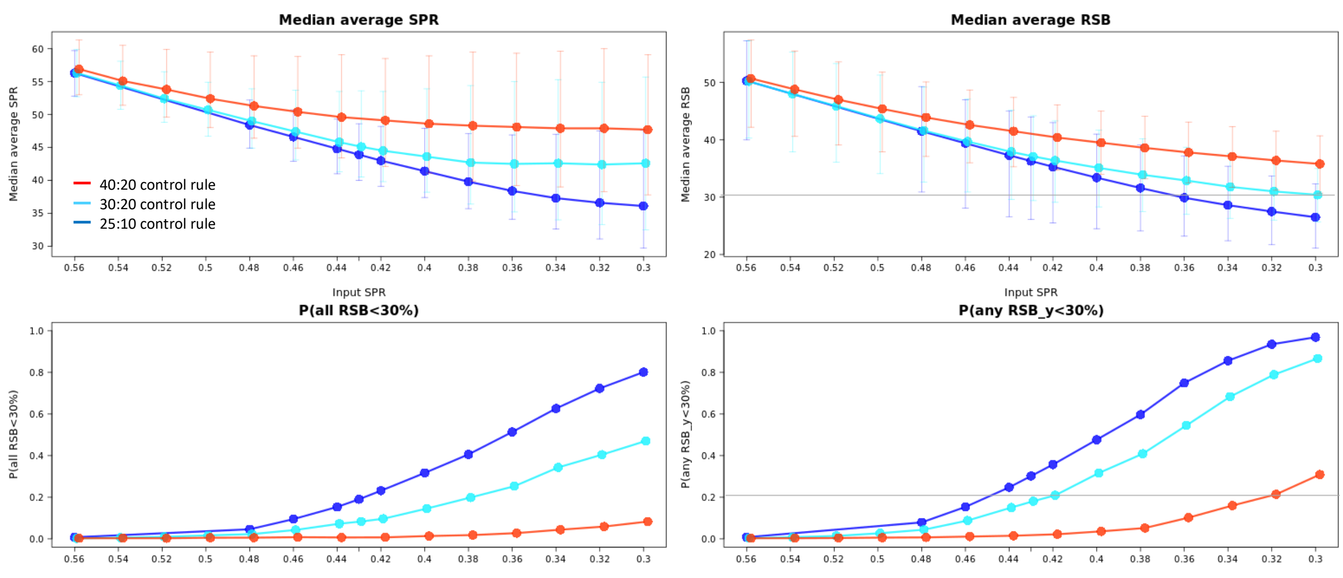

Figure 2: Performance metrics for the MSE simulation results when using 40:20, 30:20, and 25:10 control rules. Vertical lines represent the 5th and 95th percentiles of the simulation results. The horizontal line in the top-right plot indicates the 30% limit for RSB and the one in the bottom right indicates the 20% tolerance level. P(all RSB<30%) represents the probability that the event may occur in a single year. P(any RSB<30%) represents the probability that the event may occur in at least one out of ten years.

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 section provides a brief report of 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 the 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, the observed WPUE for Pacific halibut 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 in estimating the geographic distribution of the stock. The proportion of estimated over 32 inches (81.3 cm; O32) 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 target distribution of the TCEY is 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 (Table 3).

Table 3. 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%

The lower harvest rates in IPHC Regulatory Areas 3B, 4A, 4CDE, and 4B, compared to IPHC Regulatory Areas 2 and 3A, were first implemented over a number of years starting at least in 2004 (Clark & Hare 2005, Hare 2005, Hare 2006, Hare 2009). The reductions in harvest rates were partly described as 'precautionary' based on declining trends in spawning biomass and CPUE, the presence of small fish, differences in yield-per-recruit, differences in emigration and immigration, and greater uncertainty in the data and analyses available at the time (Hare 2009). For example, the reduction in the harvest rate in IPHC Regulatory Area 3B was described as a precautionary decision after observing steady declines in catch rates, sharp declines in survey WPUE, an increase in effort expended to take the mortality limit, a contracted age distribution, indication that emigration is greater than immigration, and observed results of reduced harvest rates in IPHC Regulatory Areas 4A, 4B, and 4CDE (Hare 2009).

Recently, the modelled survey numbers-per-unit-effort (NPUE) have shown a decline coastwide since the early 2000's (Figure 3). Most IPHC Regulatory Areas have shown both increases and decreases in NPUE since the early 2000's, but IPHC Regulatory Areas 3B and 4A have shown the largest and most consistent declines. Relative to surplus production (the harvest that stabilizes the biomass) harvest rates in IPHC Regulatory Areas 3B and 4A have been above the surplus as they resulted in declines. Higher harvest rates in the eastern areas (3A and 2) did not lead to declines over the same period. Movement among areas, interacting with actual patterns of harvest, can lead to a confounding of the actual surplus production by area. Such patterns are not able to be considered in a simple look at observed time-series. The full MSE will evaluate management procedures with different harvest rates and distribution components that will account for these and other factors simultaneously.

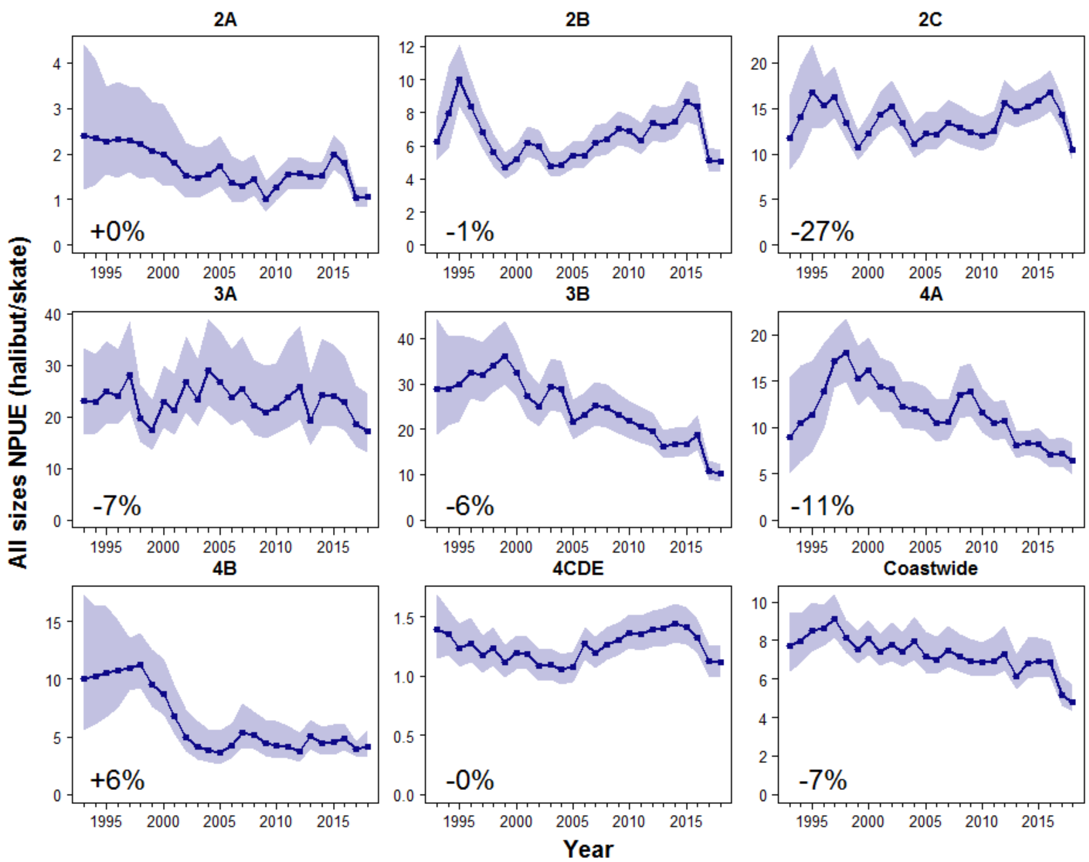

Figure 3: Trends in modelled survey NPUE by IPHC Regulatory Area, 1993-2018 (reproduced from IPHC-2019-AM095-08). Percentages indicate the change from 2017 to 2018. Shaded zones indicate 95% credible intervals

4.2 Redefining the Distribution of the TCEY

Distributing the TCEY has two components: 1) a purely scientific component to describe the stock distribution, and 2) steps to modify the distribution of the TCEY from that of the stock 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 geographic components of the stock. This requires defining the scale of spawning components from which distribution is to be conserved and balancing the removals to protect against 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 to satisfy 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 sub-populations (Seitz et al. 2017). Biological Regions, defined earlier and shown in Figure 4, 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, which is largely composed of O26 Pacific halibut due to the selectivity of the setline gear, is more congruent with the TCEY (O26 catch levels) than 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.

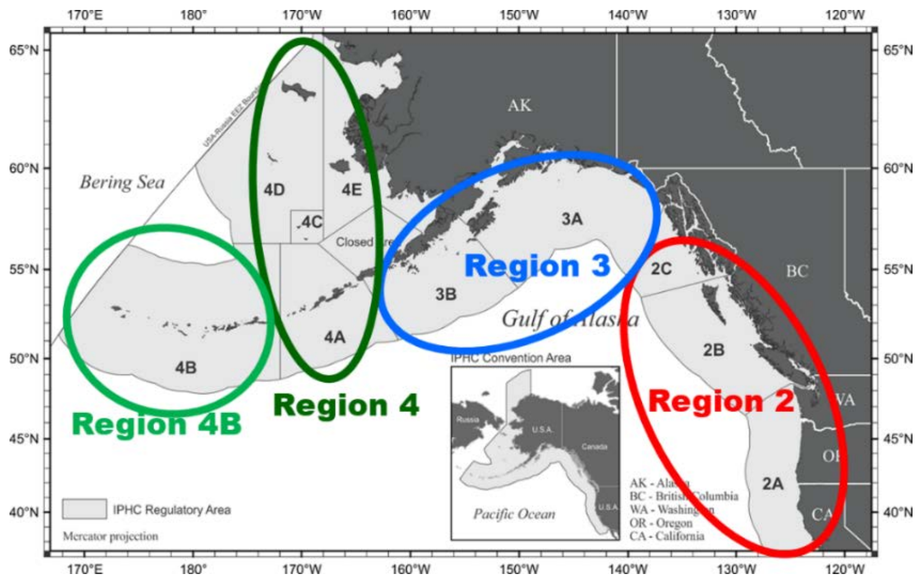

Figure 4. Biological Regions overlaid on IPHC Regulatory Areas with Region 2 comprised of 2A, 2B, and 2C, Region 3 comprised of 3A and 3B, Region 4 comprised of 4A and 4CDE, and Region 4B comprised solely of 4B.

4.2.2 Distribution Procedures

Distribution procedures describes additional steps for further modification of the distribution of the TCEY among Biological Regions and subsequent distribution among IPHC Regulatory Areas within Biological Regions (Figure 4). 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 for understanding fishery performance.

4.2.2.1 Yield-per-recruit analysis

A yield-per-recruit analysis by Biological Region was completed to examine differences in productivity between the four Biological Regions (Figure 4). A yield-per-recruit analysis provides the harvest rate at which the yield would be maximized, given natural mortality, fishery selectivity, and weight-at-age. A common reference point used in fisheries management is the harvest rate at which the slope in the yield-per-recruit curve is 10% of the steepest slope (the steepest slope occurs at the origin when the harvest rate increases from zero). This reference point, $F_{0.1}$, is preferred over the harvest rate that maximizes yield-per-recruit because it is precautionary, and some yield-per-recruit curves do not peak until very high harvest rates are reached due to the biology of the fish stock. This occurs for Pacific halibut because the weight-at-age continues to increase almost linearly at older ages meaning that growth is still occurring at a significant rate that may outweigh the mortality at older ages. The actual harvest rate is not of interest for this analysis, but relative $F_{0.1}$ across areas provides information on relative per-recruit harvest rates among regions. This method does not account for recruitment dynamics or movement rates.

The yield-per-recruit at various harvest rates and the reference point $F_{0.1}$ relative to the estimated $F_{0.1}$ in Biological Region 3 was estimated for each Biological Region at three different points in time: 1985, 1999, and 2018 (Figure 6). The year 1985 was used because weight-at-age was then very high in Biological Regions 2 and 3. The year 1999 was used because it is representative of data from a period that would have informed previous yield-per-recruit analyses performed to justify reductions in harvest rates in western IPHC Regulatory Areas (e.g., Hare 2009), and because annual changes in selectivity curves were estimated from 1997 to 2018 in the stock assessment for Biological Regions 4 and 4B. The year 2018 represents the current state. Weight-at-age and selectivity for each year and Biological Region were used in the yield-per-recruit analysis. A sensitivity analysis was done using a selectivity curve for each Biological Region that was shifted from the median selectivity curve for each Biological Region to have higher probabilities of selecting younger ages (i.e., selecting more young fish).

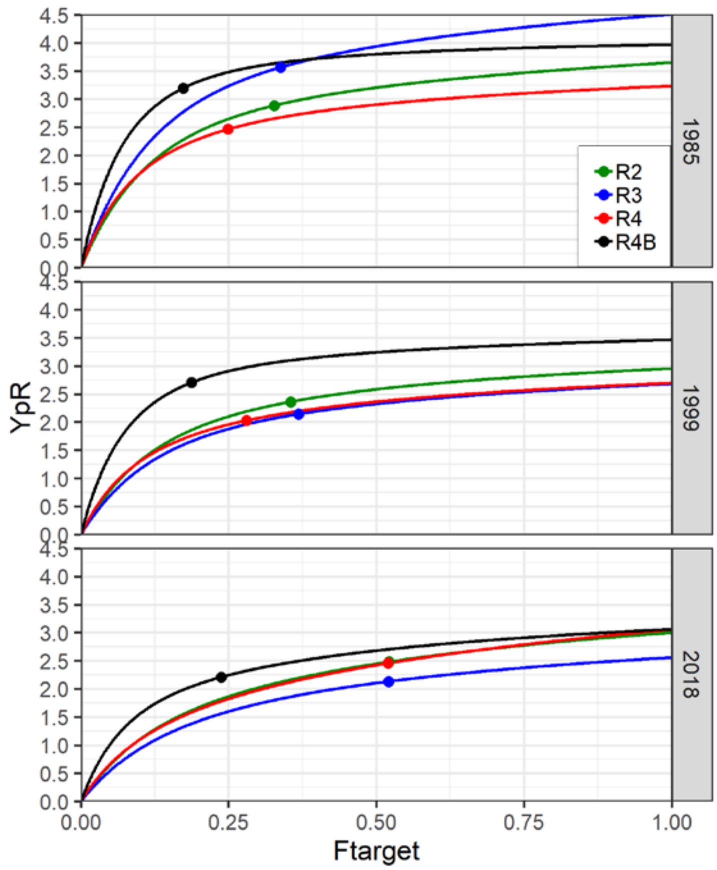

Figure 5

Figure 6: Yield-per-recruit at different harvest rates (Ftarget as an exploitation rate) estimated for each Biological Region (2, 3, 4, and 4B; Figure 4) using weight-at-age and selectivity (as estimated in the long areas-as-fleets stock assessment model) from 1985 (top panel), 1999 (middle panel), and 2018 (bottom panel). The colored points on each curve correspond to the reference point $F_{0.1}$ for each Biological Region.

During the 1980's and the 1990's, the relative estimates of $F_{0.1}$ show similar harvest rates for Biological Regions 2 and 3, a relative harvest rate near 0.8 for Biological Region 4, and a relative harvest rate of 0.5 for Biological Region 4B (Table 4). However, using weight-at-age and selectivity from 2018 showed a relative harvest rate of 1.0 for Biological Region 4. Shifting the selectivity curve to select younger fish showed a similar pattern except that Biological Region 2 has a lower relative harvest rate than Biological Region 3. This supports the application of a lower relative harvest rate in western areas in the historical harvest strategy, but also shows changes in productivity over time that may affect the appropriate current application of relative harvest rates. An MSE is the appropriate tool to evaluate management procedures with static or annual adjustments (based on data and observations to reflect changing conditions) to relative harvest rates. An MSE will also account for other factors such as movement, recruitment dynamics, and the effects of harvest levels in other areas.

Table 4: The reference point $F_{0.1}$ from the yield-per-recruit analysis in each Biological Region relative to the $F_{0.1}$ in Region 3.

		Biological Region			
Weight-at-age	**Selectivity**	**2**	**3**	**4**	**4B**
1985	1985	1.0	1.0	0.7	0.5
1999	1999	1.0	1.0	0.8	0.5
2018	2018	1.0	1.0	1.0	0.5
1985	Shift younger	0.8	1.0	0.8	0.5
1999	Shift younger	0.8	1.0	0.8	0.5
2018	Shift younger	0.9	1.0	1.1	0.5

4.2.2.2 Net movement in and out of Biological Regions

The net movement of Pacific halibut in and out of Biological Regions is an important factor to consider when determining appropriate relative harvest rates in Biological Regions. It is generally understood that the net movement of Pacific halibut is from west to east and the net movement out of Biological Region 4 is likely greater than movement of adults into Biological Region 4. The connection of Biological Region 4B to the other Biological Regions is not well understood and there is a possibility that this Biological Region has some demographic separation from the others. Considerable movement of older Pacific halibut is estimated to occur between Biological Regions 2 and 3. The section on movement rates among Biological Regions in IPHC-2019-AM095-08 provides a summary of the current understanding of Pacific halibut movement.

4.2.2.3 Uncertainty of productivity and harvest levels in Biological Regions

Additional justification, other than yield-per-recruit, for reducing harvest rates in IPHC Regulatory Areas 3B, 4A, 4B, and 4CDE were provided in the past (e.g., Hare 2009). These included varying levels of uncertainty in each area. For example, the historical harvest in Biological Regions 4 and 4B developed after the fisheries in Biological Regions 2 and 3, and a shorter time-series of observations is available from 4 and 4B. This results in an increased historical uncertainty about productivity and optimal harvest levels in these Biological Regions. However, recent modelled survey information is of roughly equal and adequate precision for all Biological Regions (IPHC-2019-AM095-08).

Overall, analysing data, examining observations, and understanding the life-history of Pacific halibut in each Biological Region will help inform the construction of management procedures related to distributing the TCEY among Biological Regions and IPHC Regulatory Areas. It is currently understood that Pacific halibut have considerable movement within (and some movement among) Biological Regions within a year, and the scale of IPHC Regulatory Areas is likely too small to make conclusions regarding differences in productivity. However, other tools, such as fishery-dependent WPUE, may be used to develop distribution procedures to distribute the TCEY to IPHC Regulatory Areas, and the MSE will evaluate the different procedures with respect to defined objectives.

The MSAB013 report (IPHC-2019-MSAB013-R, paragraph 60) listed eleven potential tools for use in developing distribution procedures, which will be discussed at MSAB014. Also, the Commission adopted two tools (minimum catch limit and a percent share) for IPHC Regulatory Areas 2A and 2B (IPHC-2019-AM095-R, paragraph 69) that could easily be incorporated into a management procedure (or objectives as noted in Section 2.2.2.3).

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 limits 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 at which to consider fishery objectives.

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 coastwide objectives defined by the Commission. Separate the total mortality into O26 and 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 4) using the proportion of the stock estimated in each Biological Region for all sizes of Pacific halibut using information from the IPHC space-time model. "All sizes" WPUE is the most appropriate metric to distribute the TCEY at this scale.
3. **Regional Relative Fishing Intensity (science-based):** Adjust the distribution of the TCEY among Biological Regions to account for migration, productivity, and other biological characteristics of the Pacific halibut observed in each Biological Region.
4. **Regional Allocation Adjustment (management derived):** Adjust the distribution of the TCEY among Biological Regions to account for other factors. Further adjustments are part of a management/policy decision 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 to Regulatory Areas. This management or policy decision may be informed by data or defined by an allocation agreement. For example, recent trends in estimated all sizes WPUE from the modelled survey or

fishery data, 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 information or agreements.

The five 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 component of the harvest strategy policy and occurs as a final step where other objectives are considered (e.g., economic, social, etc.). 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 scientific, 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

5.1 MULTI-AREA OPERATING MODEL

The operating model will be generalized and able to model multiple spatial components 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 4). 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. The technical details of the multi-area operating model are supplied in the document IPHC-2019-SRB015-10 that is currently under development.

5.1.1 Maturity

Spawning biomass for Pacific halibut is currently calculated from a maturity-at-age ogive that is assumed to be constant over years and the potential for skip spawning is not modelled. Stewart & Hicks (2017) examined a sensitivity to a trend in declining spawning potential (caused by a shift in maturity or increased skip spawning) and found that under that condition there was a bias in both scale and trend of recent estimated spawning biomass. Ongoing research on maturity and skip spawning will help to inform future implementations of the basis for and variability in the determination of spawning output.

5.1.2 Movement

Many data sources are available to inform Pacific halibut movement. Decades of tagging studies and observations have shown that important migrations characterize both the juvenile and adult stages which apply across all regulatory areas. The Pacific halibut spawning season spans from November to March. Spawning is reported to occur on grounds located along the continental slope and in depressions on the continental shelf, concentrated mainly in the central part of the Gulf of Alaska and Eastern Bering Sea (St-Pierre 1984). In early spring, adults undertake a migration to the feeding areas they were occupying before the spawning migration, while eggs and larvae are dispersed northwards and westward (Valero and Webster 2011). Young Pacific halibut between the age of 2 and 5 years old show a backward southerly and easterly migration (Hilborn et al. 1995). More recent tagging results have also shown that adults continue to migrate throughout their whole life, even though the percentage decreases as fish grow older (Valero and Webster 2011m Webster et al. 2013). Despite evidences of a fully mixed stock, genetic studies and additional tagging experiments have suggested a degree of basin scale segregation among spawning groups (Seitz et al. 2017; Seitz et al. 2011). In particular, older Pacific halibut spend the summer feeding season around the Aleutian Islands and in the Bering Sea and appear to also spawn there, indicating a high retention rate for these older Pacific halibut in the region (Seitz et al. 2011). Genetic studies have also identified a different genetic structure in the western Aleutian Islands compared to the rest of the stock, suggesting a low migration rate outside this region (Drinan et al. 2016). In light of the evidences presented above, a framework was developed in 2015 to represent the IPHC working hypothesis concerning movement-at-age among Biological Regions (IPHC-2019-AM095-08). This framework will be used as a starting point in the MSE operating model and an appropriate method to incorporate variability and alternative movement hypotheses will be determined.

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, SRB, and Annual meeting before then are listed in Table 5.

Table 5. Program of work and tasks for 2019 and 2020 to deliver the full MSE results at the 97th Annual Meeting in early 2021.

September 2019 SRB Meeting
Review goals and objectives
Review technical details of multi-area OM
Review development of distribution 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
June 2020 SRB Meeting
Review goals and objectives
Review multi-area operating model
Review preliminary results
September 2020 SRB Meeting
Review goals and objectives
Review multi-area operating model
Review final results
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:

a) **NOTE** paper IPHC-2019-SRB015-09 which provides the SRB with an update on the IPHC MSE process including defining objectives, developing management procedures for scale and distribution, a framework for distributing the TCEY, and a program of work.

b) **RECOMMEND** that a precautionary RSB_{MSY} proxy of 30% of unfished spawning biomass, putting a proxy for SB_{MEY} between 36% and 44%, provides a reasonable range of values for the coastwide objective to maintain the spawning biomass around a target (objective 2.1B).

c) **RECOMMEND** that use of the trigger from the control rule in coastwide objective 2.1A conflates the objective and management procedure, and it would be better to define the threshold at the RSB_{MSY} proxy of 30% of unfished spawning biomass.

d) **RECOMMEND** that a biomass limit of 20% with a tolerance of 0.05 is an appropriate conservation objective based on the analysis MSY-related reference points and International standards.

e) **RECOMMEND** that SPR values between 38% and 48% would satisfy the coastwide conservation objective and the biomass target objective based on a proxy for SB_{MEY} between 36% and 44%, and the stability objective may be met by applying one of two constraints: a maximum annual change in the mortality limit of 15% or a slow-up fast-down approach.

f) **NOTE** the definition of new objectives to evaluate management procedures by IPHC Regulatory Area and **RECOMMEND** that an objective for a minimum catch level and a proportional share should be defined for each IPHC Regulatory Area because they are separate concepts.

g) **NOTE** that having an objective relating the annual mortality limit to local abundance will be useful for transparency reasons and **RECOMMEND** that such objective should be based on the survey abundance in each IPHC Regulatory Area.

h) **NOTE** the yield-per-recruit analysis and the changes in relative estimated $F_{0.1}$ between Biological Regions in the recent year compared to the past three decades and **RECOMMEND** that this analysis along with a general understanding of the life-history of Pacific halibut in each Biological Region shows that eastern areas may be able to sustain higher harvest rates than western areas, at least in some years.

i) **RECOMMEND** that the distribution framework consisting of a coastwide TCEY distributed to Biological Regions based on stock distribution, relative fishing intensities, and other allocation adjustments, and then distributed to IPHC Regulatory Areas based on other data, observations, or agreement is a useful starting point for developing management procedures to distribute the TCEY.

j) **NOTING** document IPHC-2019-SRB015-10, **RECOMMEND** technical details that should be updated or added to the document for the development of a closed-loop simulation framework to evaluate management procedures related to coastwide scale and distribution of the TCEY.

k) **NOTE** that the SRB will review MSE results in September 2020, and these results including scale and distribution management procedures will be presented to the Commission at AM097 in 2021.

8 References

DFO 2009. http://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/precaution-eng.htm. Accessed 21 May 2019.

Clark WG, & Hare SR. 2005. Assessment of the Pacific halibut stock at the end of 2004. IPHC Report of Assessment and Research Activities 2004: 103-124.

Drinan, D. P., Galindo, H. M., Loher, T., & Hauser, L. 2016. Subtle genetic population structure in Pacific halibut *Hippoglossus stenolepis*. *Journal of Fish Biology*, 89(6), 2571–2594.

Hare SR. 2005. Investigation of the role of fishing in the Area 4C CPUE decline. IPHC Report of Assessment and Research Activities 2004: 185-197.

Hare SR. 2006. Area 4B population decline - should yield be lowered?. IPHC Report of Assessment and Research Activities 2005: 145-149.

Hare SR. 2009. Assessment of the Pacific halibut stock at the end of 2009. IPHC Report of Assessment and Research Activities 2009. 91-170. https://www.iphc.int/library/documents/report-of-research-assessment-and-research-activities-rara/2009-report-of-assessment-and-research-activities.

Hilborn, R., Skalski, J., Anganuzzi, A., & Hoffman, A. 1995. Movements of juvenile halibut in IPHC regulatory Areas 2 and 3.IPHC, Tech. Report. No. 31, 1–44.

Pascoe S, Thebaud O, & Vieira S. (2014). Estimating proxy economic target reference points in data-poor single-species fisheries. M*arine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, 6(1), 247–259. https://doi.org/10.1080/19425120.2014.966215

MSC. 2018. MSC fisheries standard. Version 2.01, 31 August 2018. 156 p. https://www.msc.org/docs/default-source/default-document-library/for-business/program-documents/fisheries-program-documents/msc-fisheries-standard-v2-01.pdf

NPFMC 2018. Fishery Management plan for groundfish of the Bering Sea and the Aleutian Islands management area. https://www.npfmc.org/wp-content/PDFdocuments/fmp/BSAI/BSAIfmp.pdf. Accessed 22 May 2019.

PFMC 2016. Pacific Coast groundfish fishery management plan for the California, Oregon, and Washington groundfish gishery. August 2016. Pacific Fishery Management Council, Portland OR. 148 p. http://www.pcouncil.org/wp-content/uploads/2017/03/GF_FMP_FinalThruA27-Aug2016.pdf

IPHC-2019-AM095-08. Stewart I, Webster R. 2019. Overview of data sources for the Pacific halibut stock assessment, harvest policy, and related analyses. 76 p. https://www.iphc.int/uploads/pdf/am/2019am/iphc-2019-am095-08.pdf

IPHC-2019-AM095-09. Stewart I, Hicks A. 2019. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2018. 26 p. https://iphc.int/uploads/pdf/am/2019am/iphc-2019-am095-09.pdf

IPHC-2019-AM095-12. Hicks A; Stewart I. 2019. IPHC Management Strategy Evaluation (MSE): update. 36 p. https://www.iphc.int/uploads/pdf/am/2019am/iphc-2019-am095-12.pdf

IPHC-2019-AM095-R. 2019. Report of the 95th Session of the IPHC Annual Meeting (AM095). 46 p. https://www.iphc.int/uploads/pdf/am/2019am/iphc-2019-am095-r.pdf

IPHC-2018-MSAB011-R. 2018. Report of the 11th Session of the IPHC Management Strategy Advisory Board (MSAB011). 29 p. https://iphc.int/uploads/pdf/msab/msab11/iphc-2018-msab011-r.pdf

IPHC-2018-MSAB012-07 Rev_1. Hicks A; Stewart I. 2018. IPHC Management Strategy Evaluation to investigate fishing intensity. 33 p. https://iphc.int/uploads/pdf/msab/msab12/iphc-2018-msab012-07.pdf

IPHC-2018-SRB012-08. Hicks A; Stewart I. 2018. IPHC Management Strategy Evaluation: update for 2018. 38 p. https://www.iphc.int/uploads/pdf/srb/srb012/iphc-2018-srb012-08.pdf

IPHC-2018-SRB012-R. Report of the 12th Session of the IPHC Scientific Review Board (SRB012). 17 p. https://www.iphc.int/uploads/pdf/srb/srb012/iphc-2018-srb012-r.pdf

IPHC-2018-SRB013-R. Report of the 13th Session of the IPHC Scientific Review Board (SRB013). 17 p. https://www.iphc.int/uploads/pdf/srb/srb013/iphc-2018-srb013-r.pdf

IPHC-2019-MSAB013-08. Hicks A; Stewart I. 2019. Further investigation of management procedures related to coastwide fishing intensity. 18 p. https://www.iphc.int/uploads/pdf/msab/msab13/iphc-2019-msab013-08.pdf

IPHC-2019-MSAB013-09. Hicks A; Berukoff S; Stewart I. 2019. Development of a framework to investigate fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries. 15 p. https://www.iphc.int/uploads/pdf/msab/msab13/iphc-2019-msab013-09.pdf

Rayns, N. (2007). The Australian government's harvest strategy policy. *ICES Journal of Marine Science*, 64, 596–598.

Seitz, A. C., Farrugia, T. J., Norcross, B. L., Loher, T., & Nielsen, J. L. 2017. Basin-scale reproductive segregation of Pacific halibut (*Hippoglossus stenolepis*). *Fisheries Management and Ecology*, 24(4), 339–346.

Seitz, A. C., Loher, T., Norcross, B. L., & Nielsen, J. L. 2011. Dispersal and behavior of pacific halibut H*ippoglossus stenolepis* in the Bering sea and Aleutian islands region. *Aquatic Biology*, 12(3), 225–239.

St-Pierre, G. 1984. Spawning locations and season for Pacific Halibut. Int. Pac. Halibut Comm. Scientific Report No.70. 45pp.

Stewart, I. J. and Hicks, A. C. 2017. Assessment of the Pacific halibut stock at the end of 2016. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2016: 365-394.

Valero, J. L., & Webster, R. A. 2011. Current understanding of Pacific halibut migration patterns. IPHC Report of Assessment and Research Activities 2011: 341–380.

Webster, R.A., Clark, W.G., Leaman, B.M., and Forsberg, J.E. 2013. Pacific halibut on the move: a renewed understanding of adult migration from a coastwide tagging study. Can. J. Fish. Aquat. Sci. 70(4): 642-653. doi:10.1139/cjfas-2012-0371.

9 APPENDICES

Appendix I: Results from the investigation of coastwide fishing intensity

Appendix I: Results from the investigation of coastwide fishing intensity

I.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 generation and the estimation model were combined into simulated estimation error for efficiency (IPHC-2018-MSAB012-07). The coastwide harvest rule portion of the management procedure is discussed below.

I.1.1. Harvest Rule

The coastwide component of the management procedure being evaluated is a harvest control rule (Figure 0-1) 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, directed fishery discard mortality, non-directed fishery discard mortality (bycatch), 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.

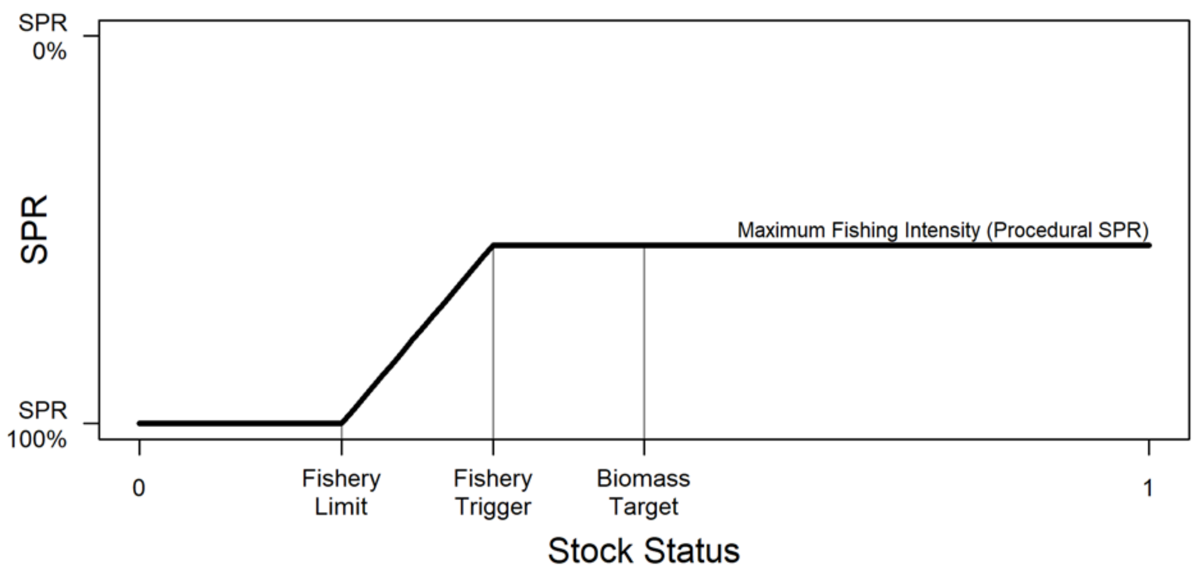

Figure 0-1: A harvest control rule responsive to stock status that is based on Spawning Potential Ratio (SPR) to determine fishing intensity, a fishery trigger level of stock status that determines when the fishing intensity begins to be linearly reduced, and a fishery limit based on stock status that 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.

I.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 0-2.

- **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.

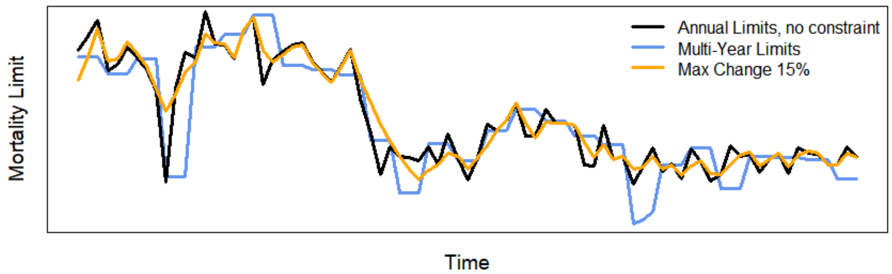

Figure 0-2: A hypothetical example of the difference between unconstrained and constrained management procedures when determining the total mortality limit. The multi-year limit (blue) is set every third year, but due to allocation to other sectors, the limit may be adjusted in years when the total mortality 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.

I.2. Simulation Results

Table 0-1 and Table 0-2 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 0-3 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 0-3).

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 0). 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 0-4 and Table 0-5, Figure 0-4 and Figure 0-5). 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 0-5). 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 Tables I-6 to I-9. 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 0-1: 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 0-1, Table 0-2, and Table 0-3)											
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 0-1, Table 0-2, and Table 0-3). 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 0-1, Table 0-2, and Table 0-3)

Table 0-2: 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 0-1, Table 0-2, and Table 0-3)											
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 0-1, Table 0-2, and Table 0-3). 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 0-1, Table 0-2, and Table 0-3).

Table 0-3: 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 0-1, Table 0-2, and Table 0-3)											
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 0-1, Table 0-2, and Table 0-3). 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 0-1, Table 0-2, and Table 0-3)

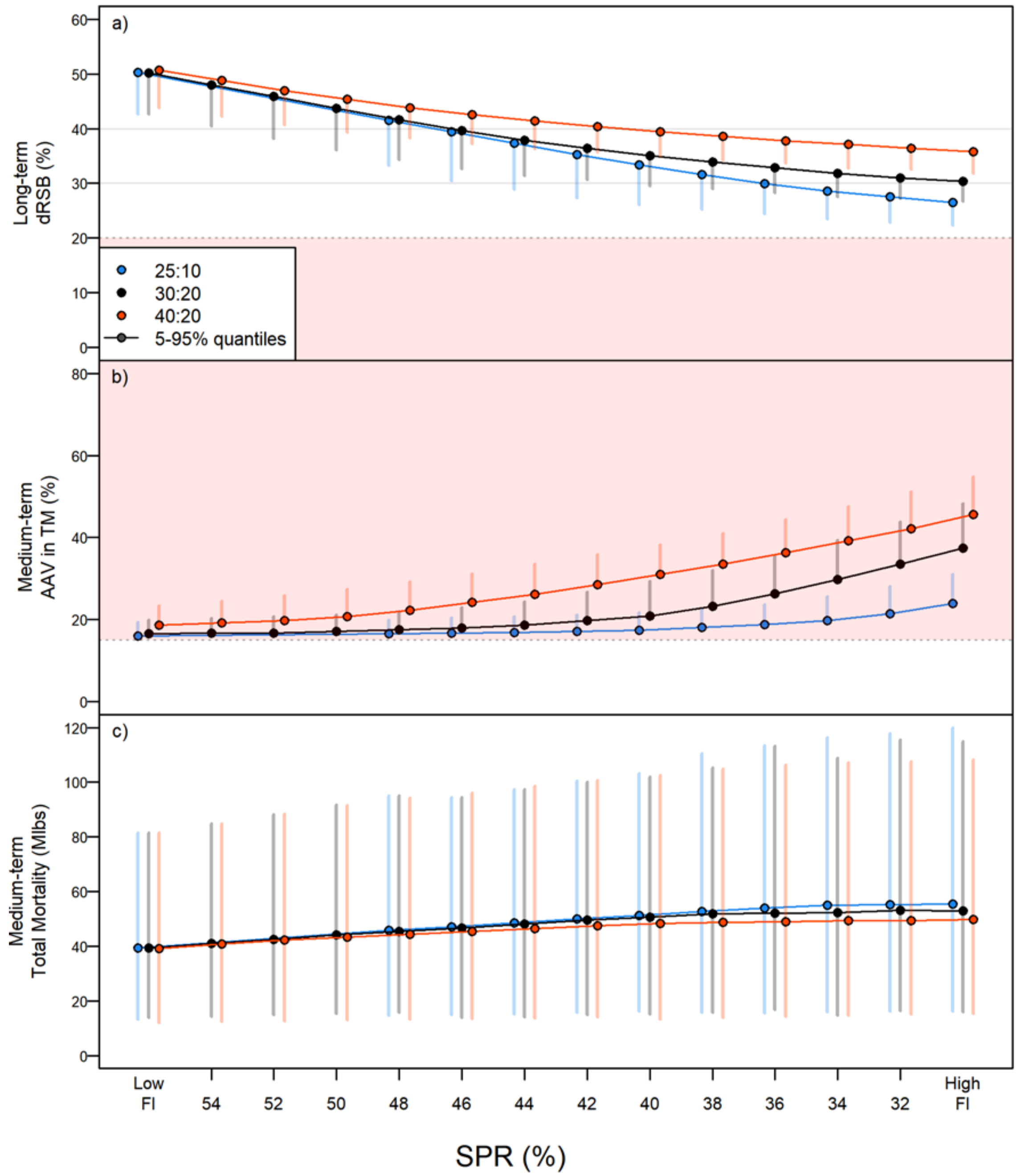

Figure 0-3: Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term fishery sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.3 to 0.56 and control rules 40:20, 30:20, and 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 0-4: 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 0). 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 0-4 and Table 0-5)												
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 0-5: 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 0). 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 0-4 and Table 0-5)													
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.

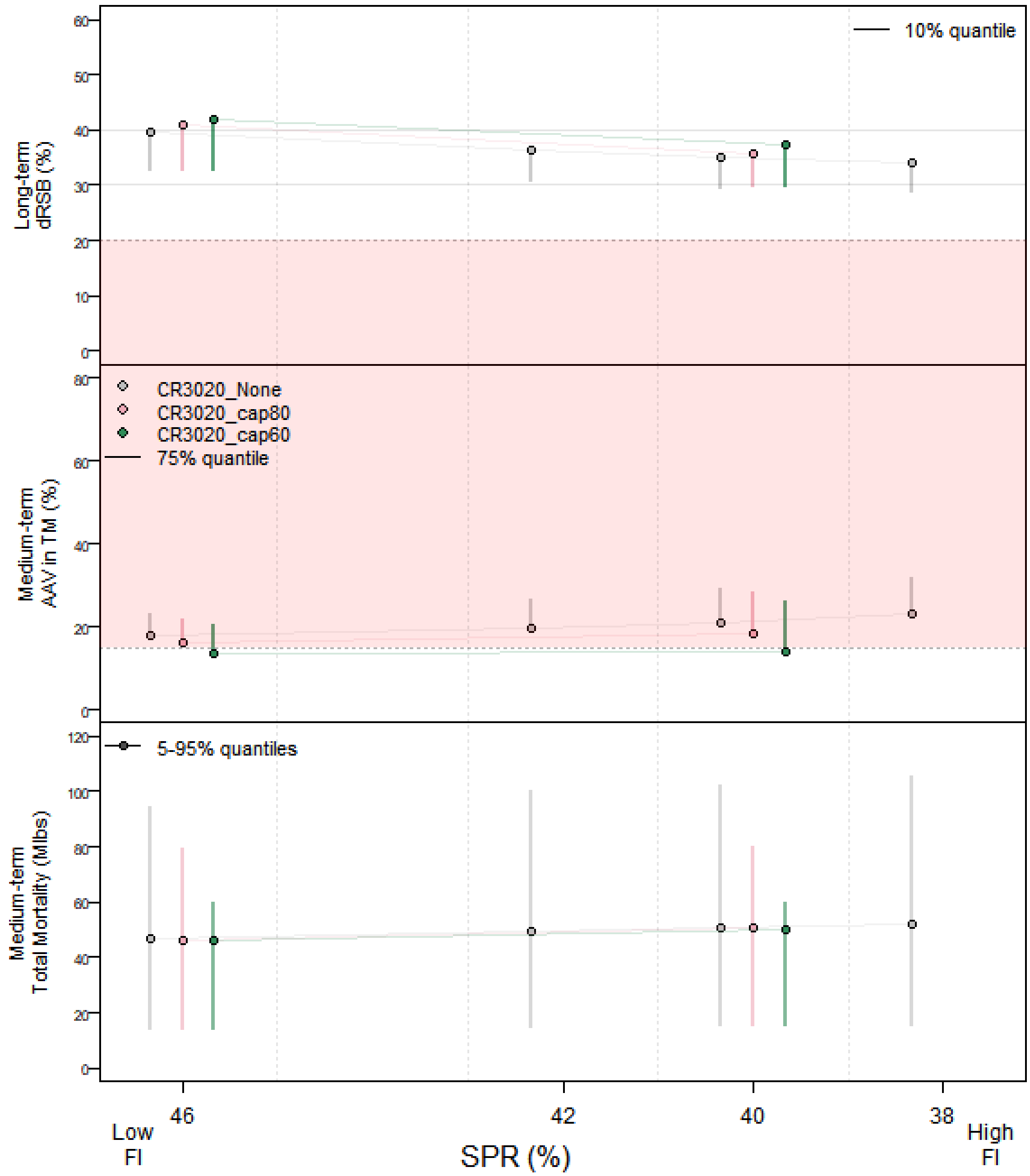

Figure 0-4: Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term fishery sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.38 to 0.46 and the 30:20 control rule using caps 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).

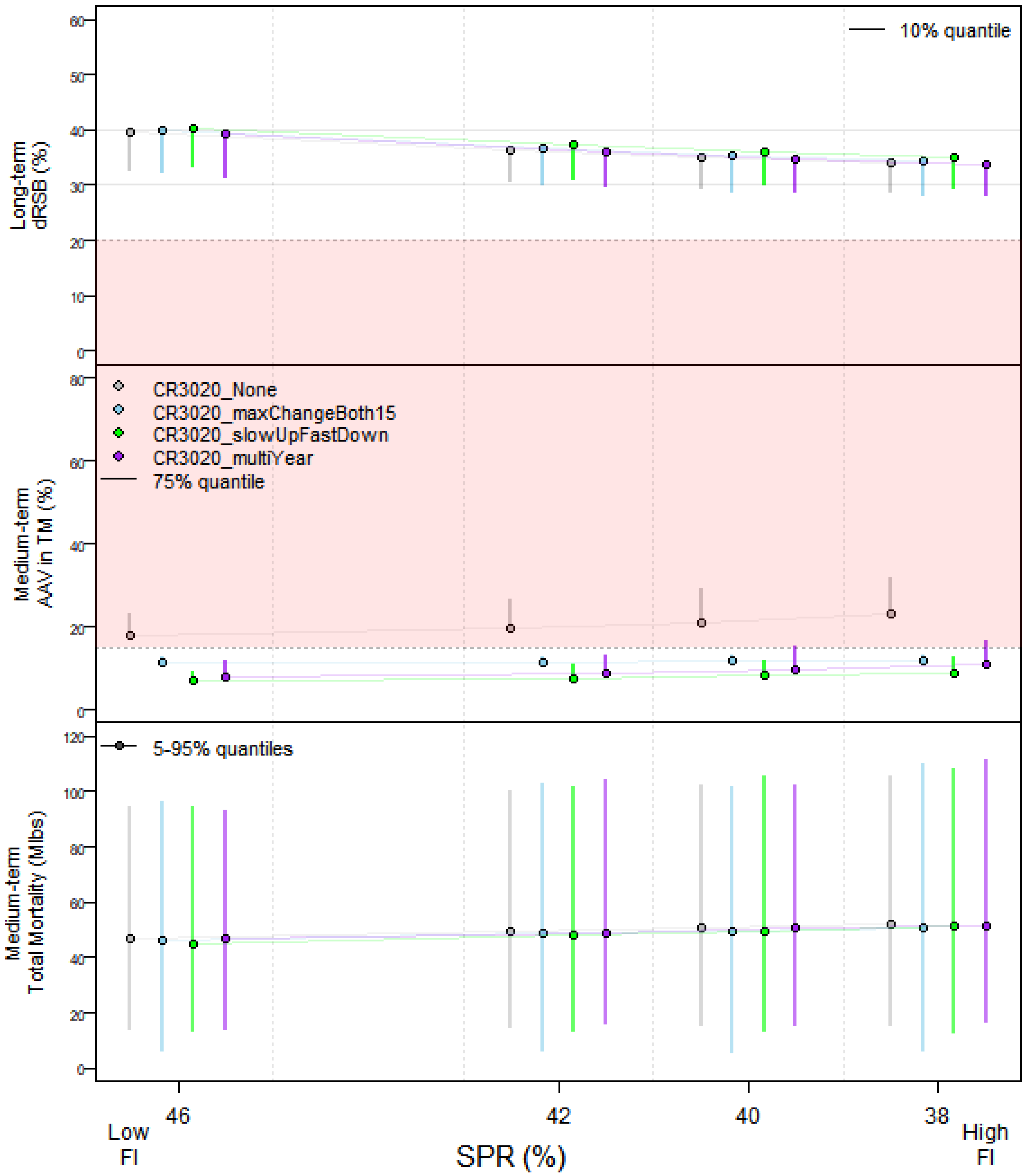

Figure 0-5: Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term fishery sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.38 to 0.46 and the 30:20 control rule using three different constraints on the total mortality limit: maxChange15, slowUpFastDown, and multiYear (see Section 0). 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 0-6: 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**										
Input Autocorrelation	**0.4**										
Input Control Rule	**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
5th 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
75th 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 0-7: 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**										
Input Autocorrelation	**0.4**										
Input Control Rule	**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 0-8: 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
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%

Table 0-9: 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%