IPHC Management Strategy Evaluation (MSE): update

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PURPOSE

To provide an update of International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) activities including definition of scale and distribution objectives, development of a framework to evaluate management procedures for distributing the TCEY, identification of management procedures to evaluate, and a summary of the MSE program of work.

ABSTRACT

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 and is now in the next phase of investigating management procedures consisting of scale and distribution components. Coastwide and area-specific objectives used for evaluation are defined under four general objectives: 1) keep female spawning biomass above a limit to avoid critical stock sizes and conserve spatial population structure, 2) maintain spawning biomass around a level that optimizes fishing activities, 3) limit catch variability, and 4) provide directed fishing yield. Using coastwide objectives updated in 2019, the best performing management procedures used fishing intensities (procedural Spawning Potential Ratio, SPR) in the range of 40% to 46% with a 30:20 control rule and one of three constraints on the annual change in the total mortality. A framework has been developed to assist the development of management procedures for distributing the TCEY to IPHC Regulatory Areas, and many potential elements to use in that framework were identified. Ten procedures for distributing the TCEY were identified for evaluation at MSAB015 along with a range of procedural SPRs and three types of constraints on the annual change in the TCEY. The program of work for 2020 includes completing the multi-area simulation framework and evaluating results at MSAB015 and MSAB016 before presentation of the MSE product at AM097 in 2021 with recommendations on scale and distribution components of the management procedure.

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), the 13th Session of the IPHC Management Strategy Advisory Board (MSAB013), and the 14th Session of the IPHC Management Strategy Advisory Board (MSAB014). The next phase investigates 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.

1 GOALS AND OBJECTIVES

The MSAB currently has four goals, each with multiple objectives related to scale and distribution. The four goals and their primary general objectives are:

1. **Biological Sustainability** (a conservation goal)
    1.1. Keep female spawning biomass above a limit to avoid critical stock sizes and conserve spatial population structure
2. **Optimize directed fishing opportunities** (a fishery goal)
    2.1. Maintain spawning biomass around a level that optimizes fishing activities
    2.2. Limit catch variability
    2.3. Provide directed fishing yield
3. **Minimize discard mortality in directed fisheries**
4. **Minimize discards and discard mortality in non-directed fisheries** (previously termed bycatch)

The biological sustainability goal (conservation) reflects the long-term need for sufficient spawning biomass distributed across the geographical range of the stock. The goal "optimize directed fishing opportunities" reflects the needs of the directed fisheries to optimize fishery yield with respect to stability and sustainability while ensuring access to the resource. Goals related to discard mortality in directed fisheries and non-directed fisheries have not yet been specifically considered in the current implementation of the MSE but are identified as important considerations for the future (i.e., after results are presented in 2021).

The general objectives 'keep the spawning biomass above a limit' and 'maintain the spawning biomass around a level that optimizes fishing activities' are prioritized over fishery stability and yield objectives. Management procedures that meet the defined tolerance of those two general objectives are then evaluated using fishery stability objectives (limit catch variability) and fishery yield objectives (provide directed fishing yield), taking into account the trade-offs that are inherently present (e.g., higher catch typically results in less stability). This initially reduces the set of management procedures for further evaluation while still allowing for flexibility in addressing trade-offs.

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 based on Spawning Potential Ratio (F_{SPR}) and various control rules determining the total coastwide mortality, thus focus has been on defining objectives 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. The primary general objectives identified by the MSAB and the Commission for evaluating MSE results contain more specific (measurable) coastwide and area-specific objectives. Many more secondary objectives and performance metrics were identified (IPHC-2019-MSAB013-07 Appendix I) to further evaluate MSE results. Metrics not specifically associated with an objective were labeled as "statistics of interest."

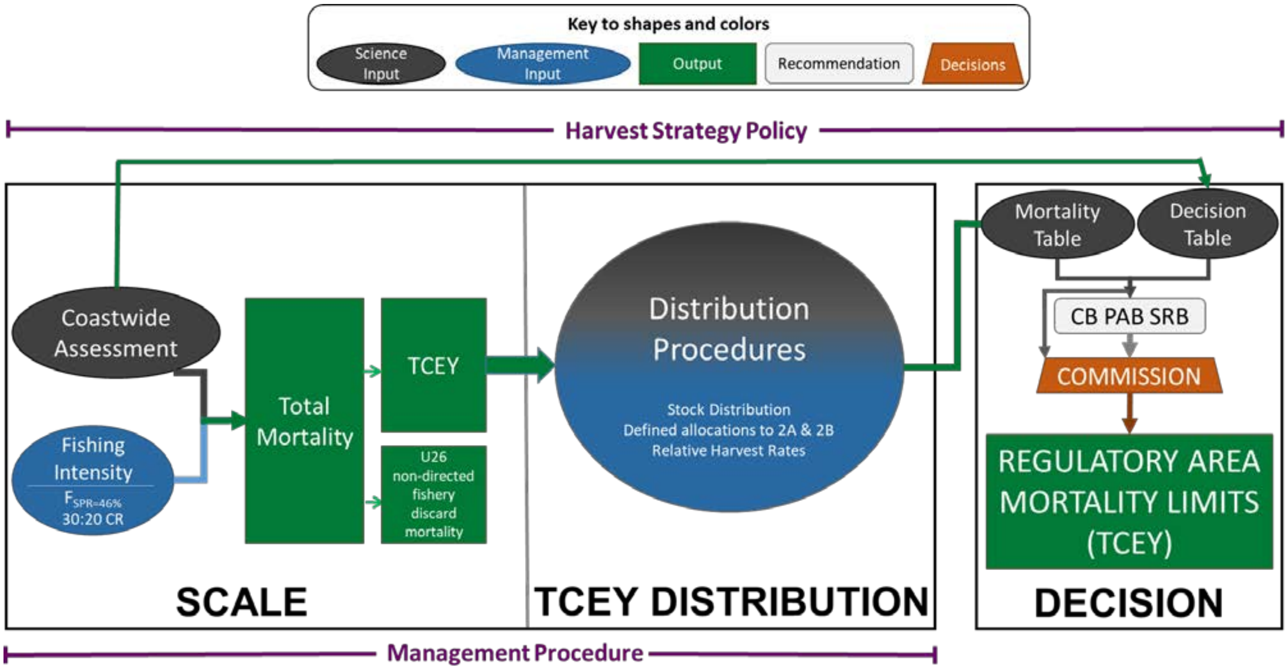

Figure 1: Illustration of the Commission interim IPHC harvest strategy policy (as revised for 2019-2022) process showing the coastwide scale and TCEY distribution components that comprise the management procedure. The decision component is the Commission decision-making procedure, which considers inputs from many sources.

1.1 OBJECTIVES RELATED TO COASTWIDE SCALE

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 MSAB 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 processes in the United States, Canada, and around the world revealed various proxies for a biomass limit and tolerances for falling below that limit. To remain consistent 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 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 and MSAB014. 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. In the absence 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.

Considering changes in productivity over time, an analysis of dynamic equilibrium reference points was performed to determine an appropriate MSY-based biomass proxy. Document IPHC-2019-SRB015-11 Rev_1 describes the methods and results from this analysis, with estimates of the dynamic equilibrium relative spawning biomass (RSB) at MSY (RSB_{MSY}) for Pacific halibut likely in the range of 20% to 30% and the Spawning Potential Ratio at MSY (SPR_{MSY}) likely between 30% and 35%. A reasonable RSB_{MSY} proxy, including a precautionary allowance for unexplored sources of uncertainty, would be 30%, putting a proxy for SB_{MEY} between 36% and 44% given the recommendations of Rayns (2007) and Pascoe *et al.* (2014). The MSAB determined that an appropriate target spawning biomass is 36% of unfished spawning biomass, which addresses uncertainty in estimating MSY and also offers benefits of catch stability and conservation (paragraph 34 of IPHC-2019-MSAB014-R), but at the cost of some foregone yield.

The objective of maintaining the spawning biomass around a target or above a level that optimizes 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 is to avoid a minimum stock size threshold (i.e. SB_{Lim}) with a high probability (Table 1). Maintaining the biomass around a target of $SB_{36\%}$ was defined as a fishery objective (Table 1) with a tolerance of 0.50.

The MSAB discussed the coastwide objective to limit annual changes in the TCEY and defined two metrics. The average annual variability (AAV) is an average of the annual change in the catch limit taken over a ten-year period. Using AAV means that even when meeting the objective (a defined threshold of 15% with a tolerance of 0.25) some of those annual changes in the TCEY will exceed the defined threshold. Additionally, MSAB members were more interested in the actual annual change from year to year and to limit it to a threshold that is never exceeded more than three times in a ten-year period. The MSAB therefore defined a new statistic called Annual Change (AC) to represent the actual annual change in the TCEY for each year in the ten year period, which can then be summarized using various statistics (e.g., maximum change in that period, probability any year exceeds a threshold, etc.). Both metrics are used since they both provide different interpretations of variability in the TCEY (paragraph 35 of IPHC-2019-

MSAB014-R). The tolerance for the stability objectives were not defined to allow for the examination of trade-offs between yield and variability.

1.2 OBJECTIVES RELATED TO THE DISTRIBUTION OF THE TCEY

1.2.1 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 (IPHC-2019-MSAB014-INF01).

Conserving spatial population structure includes maintaining the current biomass distribution across regions, maintaining the proportion of spawning biomass in each Biological Region (Figure 2) within a specified range, or maintaining a minimum spawning biomass or proportion of spawning biomass in each Biological Region. An *ad hoc* working group of the MSAB 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. The IPHC Secretariat proposed minimum proportions of 5%, 33%, 10%, and 2% for Biological Regions 2, 3, 4, and 4B, respectively after qualitatively investigating the modelled survey proportions of O32 stock distribution in each Biological Region since 1993 (the earliest period for which this information is available). Recognizing the short time-series, these minimum proportions were selected to be less than the lowest proportions observed, but no less than 40% of those values. These proportions will be discussed at future MSAB meetings.

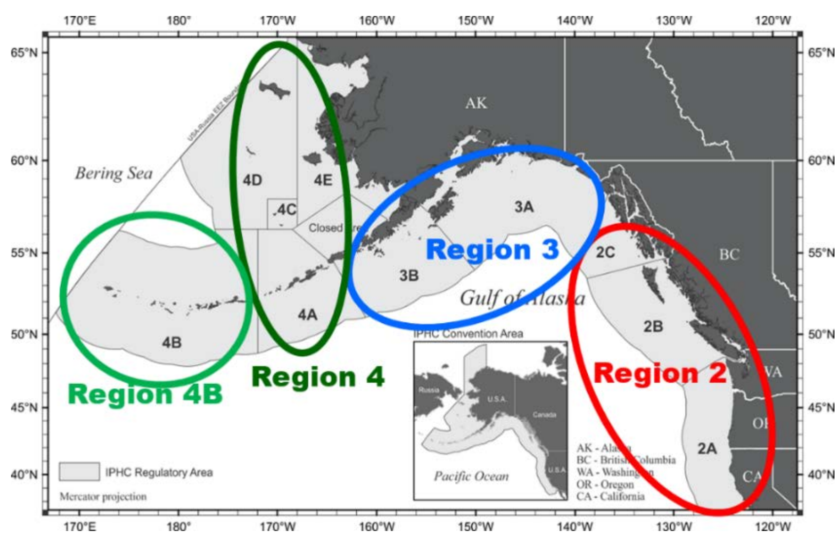

Figure 2. Biological Regions overlaid on IPHC Regulatory Areas with Region 2 comprised of 2A, 2B, and 2C, Region 3 comprised of 3A and 3B, Region 4 comprised of 4A and 4CDE, and Region 4B comprised solely of 4B.

Table 1: Primary measurable objectives, evaluated over a simulated ten-year period, recommended at MSAB014. Objective 1.1 is a biological sustainability (conservation) objective and objectives 2.1, 2.2, and 2.3 are fishery objectives.

GENERAL OBJECTIVE	MEASURABLE OBJECTIVE	MEASURABLE OUTCOME	TIME-FRAME	TOLERANCE	PERFORMANCE METRIC
1.1. KEEP FEMALE SPAWNING BIOMASS ABOVE A LIMIT TO AVOID CRITICAL STOCK SIZES AND CONSERVE SPATIAL POPULATION STRUCTURE	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	$P(SB < SB_{Lim})$
	Maintain a defined minimum proportion of female spawning biomass in each Biological Region	$p_{SB,2} > 5\%$ $p_{SB,3} > 33\%$ $p_{SB,2} > 10\%$ $p_{SB,2} > 2\%$	Long-term	0.05	$P(p_{SB,R} < p_{SB,R,min})$
2.1 MAINTAIN SPAWNING BIOMASS AROUND A LEVEL THAT OPTIMIZES FISHING ACTIVITIES	Maintain the coastwide female spawning biomass above a biomass target reference point at least 50% of the time	*SB*<Spawning Biomass Target (SB_{Targ}) SB_{Targ}=$SB_{36\%}$ unfished spawning biomass	Long-term	0.50	$P(SB < SB_{Targ})$
2.2. LIMIT CATCH VARIABILITY	Limit annual changes in the coastwide TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Median coastwide Average Annual Variability (AAV)	Short-term		*Median AAV*
	Limit annual changes in the Regulatory Area TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Average AAV by Regulatory Area (AAV_A)	Short-term		*Median* AAV_A
2.3. PROVIDE DIRECTED FISHING YIELD	Optimize average coastwide TCEY	Median coastwide TCEY	Short-term		*Median* $\overline{TCEY}$
	Optimize TCEY among Regulatory Areas	Median $TCEY_A$	Short-term		*Median* $\overline{TCEY_A}$
	Optimize the percentage of the coastwide TCEY among Regulatory Areas	Median $\%TCEY_A$	Short-term		*Median* $\overline{\left(\frac{TCEY_A}{TCEY}\right)}$
	Maintain a minimum TCEY for each Regulatory Area	Minimum $TCEY_A$	Short-term		*Median Min(TCEY)*
	Maintain a percentage of the coastwide TCEY for each Regulatory Area	Minimum $\%TCEY_A$	Short-term		*Median Min(%TCEY)*

1.2.2 Optimize Directed Fishing Opportunities

Three general objectives are currently defined for the fishery goal: 1) maintain the spawning biomass around a level that optimizes fishing activities, 2) limit catch variability, and 3) provide directed fishing yield. Under each general objective, there are coastwide TCEY measurable objectives, and distribution objectives are defined for the latter two. While Biological Regions are the spatial scale for the biological sustainability goal, fishery objectives are related to IPHC Regulatory Areas and Management Zones (the aggregation of IPHC Regulatory Areas that does not match Biological Regions) 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.

1.2.2.1 Maintain the spawning biomass around a level that optimizes fishing activities

There are no primary distribution objectives defined for this general objective, but secondary objectives may be defined at future meetings.

1.2.2.2 Limit catch variability

The MSAB discussed the coastwide objective to limit annual changes in the TCEY and proposed that the same objective be defined for IPHC Regulatory Areas with both the AC and AAV reported. This objective would capture the objective for stability in a stakeholder's area of interest and recognize that part of the variability in IPHC Regulatory Area catch limits is due to uncertainty in the distribution procedure. The MSAB decided to define both coastwide and distribution objectives for the time being, and to evaluate potential redundancy when results become available.

1.2.2.3 Maximize fishery yield

The MSAB defined two different types of area-specific yield objectives: 1) actual TCEY in an IPHC Regulatory Area and 2) a percentage of the coastwide TCEY in an IPHC Regulatory Area. Both types are useful to report since they suggest separate concepts. Use of the actual TCEY value is an objective specific to a desired mortality limit within an IPHC Regulatory Area, while using the percentage of the coastwide TCEY captures sharing among IPHC Regulatory Areas. The median of the average TCEY, the percentage of the TCEY over a ten-year period, the median minimum TCEY, and the minimum percentage of the TCEY over a ten-year period were defined as metrics.

The catch variability and yield objectives did not have a tolerance defined, thus performance metrics related to these objectives will be reported and used to evaluate the management procedures against each of the objectives as well as examine the trade-offs between the objectives and across IPHC Regulatory Areas.

2 FURTHER INVESTIGATIONS OF COASTWIDE FISHING INTENSITY

Simulation results presented at MSAB012 (IPHC-2018-MSAB012-07) showed that no management procedure met the primary stability objective defined at that time (average annual variability of the mortality limit less than 15% at least 75% of the time) when lacking a constraint on the change in annual mortality limit, 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). Document IPHC-2019-MSAB013-08 summarizes results pertaining to a constraint on the annual mortality limit that were presented at MSAB013. A maximum annual change in the catch limit of 15% ('maxChangeBoth15%'), an implemented annual change of 50% upwards and 33% downwards ('slowUpFastDown'), and setting the catch limit every third year ('multiYear') performed the best and were carried forward for additional analysis. Details of the coastwide closed-loop simulations can be found in IPHC-2018-MSAB012-07.

To summarize the results from the coastwide investigation of fishing intensity, long-term performance metrics showed little risk of falling below the 20% biomass limit for nearly all management procedures evaluated, except when no control rule was used (Figure 3). A procedural SPR value greater than 40% met the biomass target objective for all management procedures that used a 30:20 control rule (Figure 3). In the medium-term, variability in catches increased with higher fishing intensities (i.e., lower SPR), and only management procedures with a constraint met the stability objective (Figure 4). Median total mortality (TM) limits increased slightly with greater fishing intensity and the probability that the total mortality was less than 34 Mlbs (15,400 t, the historical minimum that occurred in the 1970s) was minimized in the range of 40% to 46% for management procedures using a 30:20 control rule (Figure 4).

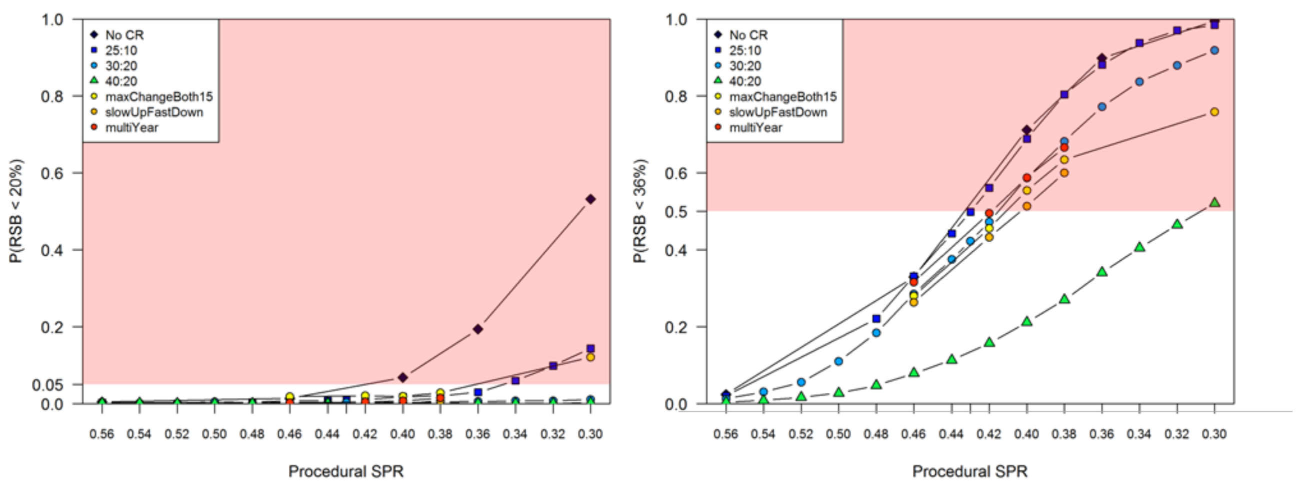

Figure 3: Performance metrics for the MSE simulation results when using 40:20, 30:20, and 25:10 control rules as well as no control rule, and constraints applied when using the 30:20 control rule. The left plot shows the probability that the relative spawning biomass (RSB) is less than the biomass limit (20%) and the right plot shows the probability that the RSB is less than the biomass target (36%). Pink colored areas indicate where the objective is not met (i.e., exceeds the defined tolerance).

Constrained management procedures reduced the annual variability in catch limits while meeting the biomass limit and biomass target objectives. If a constraint is implemented, it may be useful to introduce a precaution, such as defining a procedure where 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. . These additional controls have not yet been tested, but could be prioritized after initial results are available in 2021.

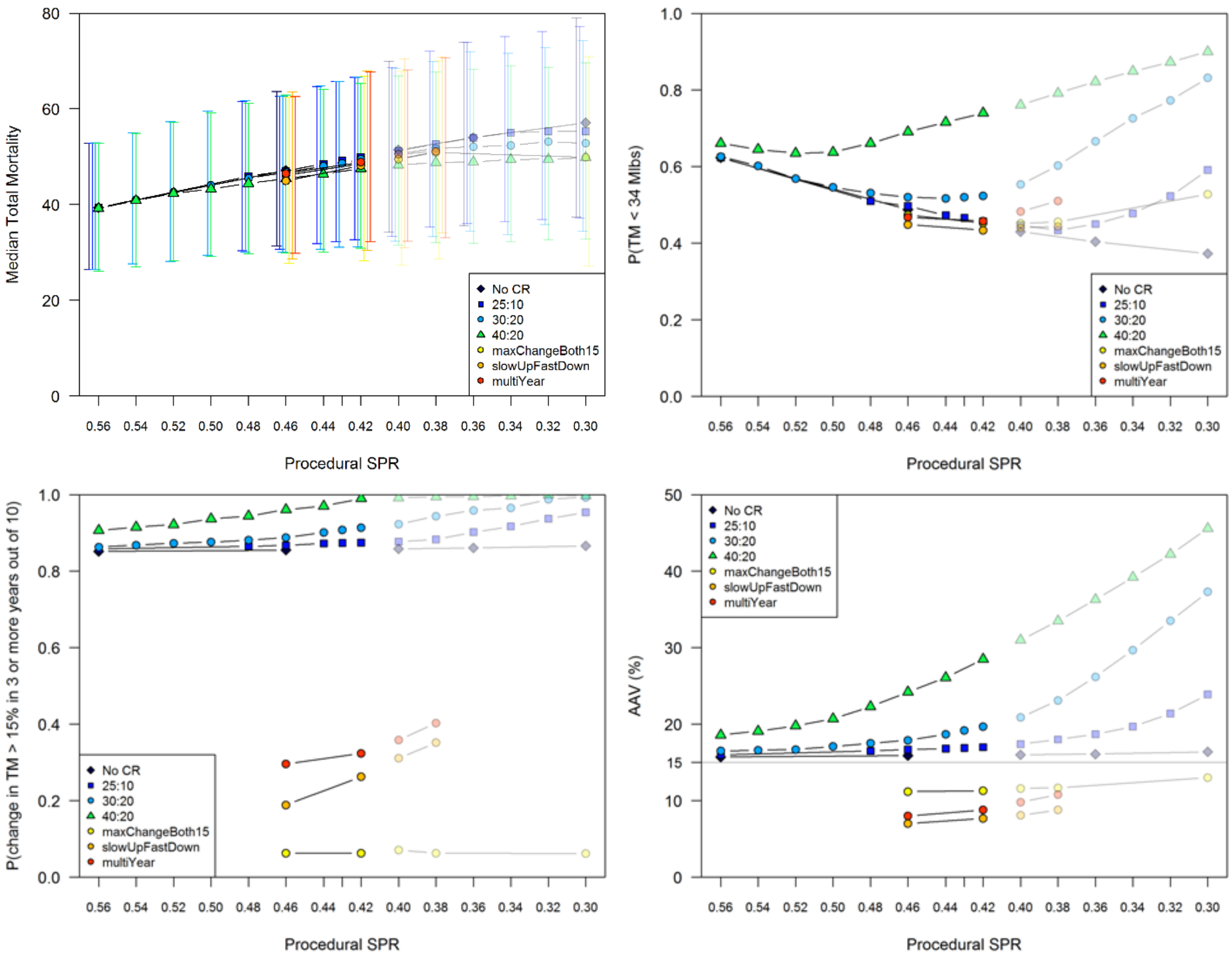

Figure 4: Performance metrics for the MSE simulation results when using 40:20, 30:20, and 25:10 control rules as well as no control rule, and constraints applied when using the 30:20 control rule. The lighter points and lines are SPR values that did not meet the objectives shown in Figure 3 for the 30:20 control rule and constraints. The top plots are related to yield and show the median total mortality with 25th to 75th percentiles shown as vertical lines and the probability that the total mortality is less than 34 Mlbs. The bottom plots are related to variability in catch limits and show the probability that the change in the total mortality is greater than 15% for at least 3 years out of 10, and the average annual variability (AAV) which is a measure of the average variability over a 10-year period.

The full set of simulated management procedures and performance metrics are available for interactively viewing at http://shiny.westus.cloudapp.azure.com/shiny/sample-apps/IPHC-MSAB013/.

3 MANAGEMENT PROCEDURES FOR COASTWIDE SCALE AND DISTRIBUTION OF 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.*

3.1 COMMISSION INTERIM MANAGEMENT PROCEDURE TO DISTRIBUTE THE TCEY

3.1.1 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 relative density observed at 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 in estimating the geographic distribution of the stock. The current interim management procedure uses the proportion of estimated over-32-inch (81.3 cm; O32) biomass in each IPHC Regulatory Area to determine stock distribution.

3.1.2 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. 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). The full MSE will evaluate management procedures with different harvest rates and distribution components that will account for these and other factors simultaneously.

3.1.3 Defined shares

Two different concepts of implementing defined shares for IPHC Regulatory Areas 2A and 2B were defined at AM095 (IPHC-2019-AM095-R paragraphs 69 b and c).

> *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.*

These two adjustments are applied by first applying the estimated stock distribution and relative harvest rates to generate a TCEY distribution. Next the percentage for 2B is adjusted via the weighted average above, then the TCEY is calculated for that area based on the total coastwide TCEY. Next, the 2A TCEY is set to 1.65. Finally, the remaining IPHC Regulatory Areas are scaled in proportion to the original TCEY distribution until the total coastwide TCEY is achieved, given the previously fixed values for 2A and 2B.

3.2 Alternative approaches to the distribution of the TCEY

Distributing the TCEY can be made up of multiple components such as those described above in Section 3.1. Below, alternative approaches to stock distribution and relative harvest rates are described.

3.2.1 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. Biological Regions, defined earlier and shown in Figure 2, are considered by the IPHC Secretariat, and supported by the SRB (paragraph 31 IPHC-2018-SRB012-R), to be the best currently available scale at which 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 would be most logically consistent.

3.2.2 Additional distribution procedures

Additional distribution procedures may be used to adjust the distribution of the TCEY among Biological Regions and subsequent distribution among IPHC Regulatory Areas within Biological Regions. 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.

3.2.2.1 Yield-per-recruit analysis

A yield-per-recruit analysis by Biological Region was performed to examine differences in productivity between the four Biological Regions (Figure 2). A yield-per-recruit analysis provides the harvest rate at which the yield would be optimized given natural mortality, fishery selectivity, and weight-at-age. The actual harvest rate is not of interest for this analysis, but relative harvest rates across Biological Regions provides information on relative productivity among regions. This method does not account for recruitment dynamics or movement rates, which would be addressed in the MSE.

The yield-per-recruit at various harvest rates and the harvest rates relative to Biological Region 3 were estimated for each Biological Region at three different points in time: 1985, 1999, and 2018. 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.

During the 1980s and the 1990s, the relative estimated harvest rates were similar for Biological Regions 2 and 3, near 0.8 for Biological Region 4, and 0.5 for Biological Region 4B (Table 2). However, using weight-at-age and selectivity from 2018 showed a relative harvest rate of 1.0 for Biological Region 4. 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 most appropriate tool to evaluate management procedures with static or annual adjustments (based on data and observations to reflect changing conditions) to relative harvest rates because an MSE also accounts for other factors such as movement, recruitment dynamics, and the effects of harvest levels in other areas. Therefore, a more complete investigation of relative harvest rates will be carried out using the MSE framework.

Table 2: Estimated harvest rates from the yield-per-recruit analysis in each Biological Region relative to Biological 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

3.2.2.2 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. 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 it. The connection of Biological Region 4B to the other Biological Regions is not well understood and there is a possibility that 4B is the most demographically distinct of the four. Considerable movement of older Pacific halibut is estimated to occur between Biological Regions 3 and 2. It is currently understood that Pacific halibut move considerably within (and, to a small extent among) Biological Regions within a year. The section on movement rates among Biological Regions in IPHC-2019-AM095-08 provides a summary of the current understanding of Pacific halibut movement and IPHC staff are currently writing a review of Pacific halibut movement and migration.

3.2.2.3 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 (e.g., Hare 2009) 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, science (e.g., analysing data and understanding the life-history of Pacific halibut) and policy (e.g., examining observations and uncertainty) in each Biological Region will help inform the construction of management procedures related to distributing the TCEY among Biological Regions and IPHC Regulatory Areas. The scale of IPHC Regulatory Areas is likely too small to make conclusions regarding differences in productivity, but other tools, such as fishery-dependent WPUE, may be used to develop distribution procedures to distribute the TCEY to IPHC Regulatory Areas. The MSE will evaluate the different procedures with respect to defined objectives.

3.2.2.4 Tools to distribute the TCEY

The MSAB013 report (IPHC-2019-MSAB013-R, paragraph 60) listed eleven potential tools for use in developing distribution procedures (both at a regional and at a regulatory area level), which were discussed at MSAB014. 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 1.2.2.3). Incorporating these tools in a management procedure can be done by defining specific steps, as in the example framework below (Section 3.3).

3.3 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 3.2.1) between Biological Regions may occur first to satisfy conservation objectives. This is followed by adjustments across Biological Regions and IPHC 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) or a maximum fishing intensity (minimum SPR) is not exceeded (also a zero-sum game when the maximum is exceeded). Using a target SPR that is maintained within the management procedure is consistent with the management of many fisheries around the world., If a target SPR were not maintained within the management procedure, the minimum SPR value (maximum fishing intensity) in the range produced by the management procedure would likely be considered both the target and limit by many reviewers of the harvest policy.

A general framework for a management procedure encompassing conservation and fishery objectives that ends with a TCEY for each IPHC Regulatory Area is described below. Only steps 1 (coastwide) and 3 (IPHC Regulatory Area) are essential; step 2 is optional. Some sub-components of each step are also optional.

1. **Coastwide (*required*)**

   1.1. **Estimation model (science-based, *required*)**: A statistical analysis of data to inform the current status of the stock and possibly projections given various mortality limits. This may be as complex as a stock assessment or as straightforward as the estimate of relative coastwide abundance/biomass from the modelled survey index.

   1.2. **Target Fishing Intensity (management-derived, *required for an assessment-based approach*):** Determine the coastwide total mortality using a target SPR that is most consistent with IPHC coastwide objectives defined by the Commission, removing the U26 non-directed fishing discard mortality from the Total Mortality to determine the coastwide TCEY.

2. **Regional (*optional*)**

   2.1. **Regional Stock Distribution (science-based, *required when using the Regional step*):** Distribute the coastwide TCEY to four (4) biologically-based Regions (Figure 2) 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 congruent metric to distribute the TCEY at this scale.

2.2. **Regional Relative Fishing Intensity (science-based, *optional*):** 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.

2.3. **Regional Allocation Adjustment (management derived, *optional*):** Adjust the distribution of the TCEY among Biological Regions to account for other factors. This may include evaluation of recent trends in estimated quantities (such as fishery-independent WPUE), inspection of historical trends in fishing intensity, recent or historical fishery performance, and uncertainty. Regional relative harvest rates may also be determined through negotiation, leading to an allocation agreement for further regional adjustment of the TCEY.

3. **Regulatory Area Allocation (*required with at least one sub-option*)**

3.1. **Regulatory Area Stock Distribution (science-based):** Distribute the coastwide (if step 2 is omitted) or regional TCEY to IPHC Regulatory Areas using the proportion of the stock estimated in each IPHC Regulatory Area for all sizes or O32 Pacific halibut using information from the IPHC space-time model.

3.2. **Regulatory Area Allocation (management derived):** Apply IPHC Regulatory Area allocation to the coastwide TCEY (if step 2 is omitted) or within each Biological Region to distribute the 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 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).

4. **Annual Regulatory Area Adjustment (policy, *optional*)**: 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.

3.4 MANAGEMENT PROCEDURES TO EVALUATE

At MSAB014, the MSAB recommended management procedures to evaluate that include both scale and distribution components (IPHC-2019-MSAB014-R, paragraphs 49 & 56).

3.4.1 Scale elements of management procedures.

The coastwide MSE investigated only the scale component of the management procedure and identified procedural SPR values, fishery triggers, and fishery limits, of the harvest control rule (Figure 5) as well as constraints that satisfied the coastwide objectives. The investigation of management procedures incorporating scale and distribution components will focus on the scale elements that satisfied the coastwide objectives, but span a wide range of SPR values (Table 3).

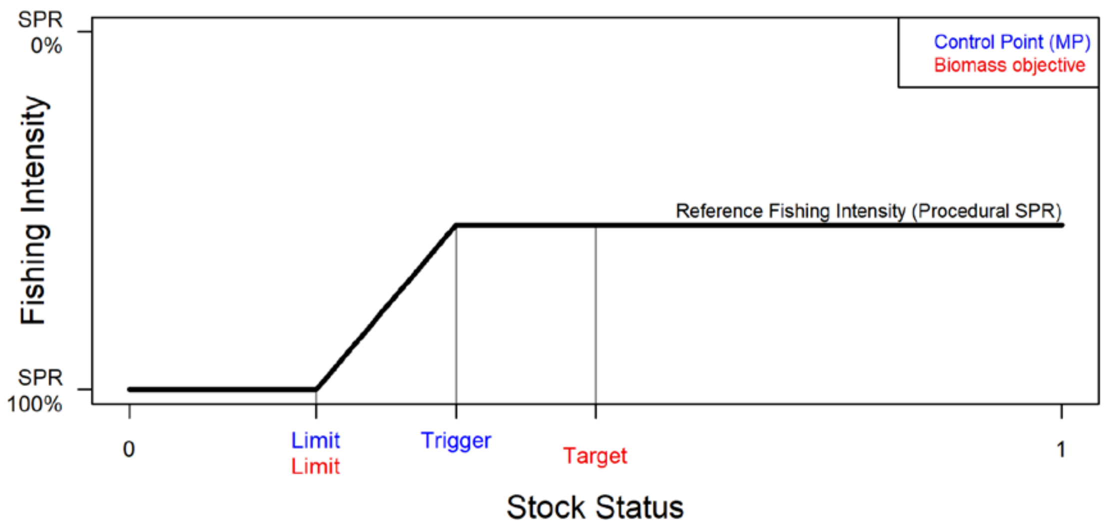

Figure 5: Example harvest control rule responsive to stock status based on Spawning Potential Ratio (SPR) to determine applied fishing intensity (vertical axis), a fishery trigger level of stock status that determines when the fishing intensity begins to be linearly reduced, and a fishery limit based on stock status that determines when there is theoretically no fishing intensity (SPR=100%). Quantities potentially related to objectives (biomass limit, and biomass target) may or may not align with the control points in the management procedure.

Table 3: Elements of the coastwide component of the management procedures to be evaluated at MSAB015.

Procedural SPR	Control Rule	Constraints
30%, 34%, 38%, 42%, 46%, 50%	30:20	• maxChange15% • SlowUupFastDown • MultiYear • maxChange15% combined with either of above

3.4.2 Distribution elements of management procedures

Appendix VI in IPHC-2019-MSAB014-R presents distribution management procedures to be evaluated at MSAB015. These ten management procedures contain various scale and distribution elements, as identified in paragraph 55 of IPHC-2019-MSAB014-R.

> MSAB014-R, para. 55: *The MSAB **REQUESTED** that a number of elements in distribution management procedures be included for evaluation at MSAB015:*
>
> a) *A coastwide constraint using a slow-up, fast-down approach with a maximum change in the TCEY of 15%;*
>
> b) *evaluating different relative harvest rates across IPHC Regulatory Areas or Biological Regions;*
>
> c) *distributing the TCEY directly to IPHC Regulatory Area;*
>
> d) *A fixed shares concept for all or some IPHC Regulatory Areas, Biological Regions, or Management Zones with options to distribute the TCEY to the areas without a fixed share. The determination of these shares may be fixed or varying over time; and*
>
> e) *A maximum fishing intensity defined by an SPR of 36% to act as a buffer when distributing the TCEY to IPHC Regulatory Areas.*

The concept of a buffer allows the fishing intensity to increase from the reference fishing intensity due to constraints on the TCEY and other elements that may result in a change to the coastwide SPR. However, the management procedure fishing intensity cannot exceed the defined maximum fishing intensity.

4 DEVELOPMENT OF THE CLOSED-LOOP SIMULATION FRAMEWORK

The MSE at IPHC has 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 at MSAB013. The next phase, which is underway, is to investigate management procedures related to the distribution of the TCEY. Document IPHC-2019-MSAB014-08 outlines the recent efforts related to developing the software underpinning the MSE simulations.

4.1 FRAMEWORK ELEMENTS

The MSE framework includes elements that simulate the Pacific halibut population and fishery (Operating Model, OM) and management procedures with a closed-loop feedback (Figure 6). Specifications of some elements are described below, with additional technical details in document IPHC-2019-MSAB014-INF02, which is a living document that is being updated as development occurs.

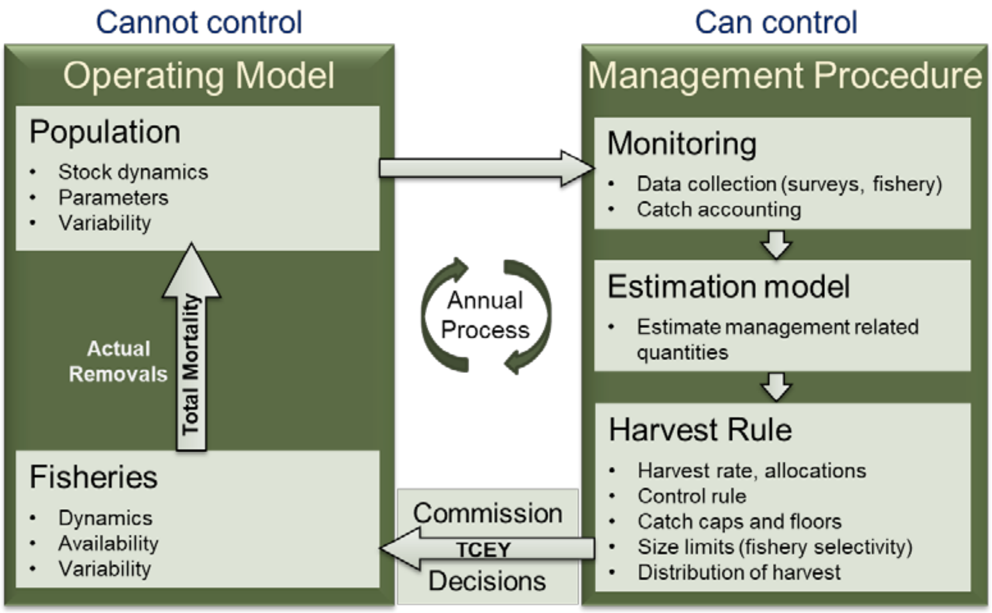

Figure 6: Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

4.1.1 Multi-area operating model

The generalized operating model will be able to model multiple spatial components, which is necessary because Pacific halibut migrate considerable distances and mortality limits are set at the IPHC Regulatory Area level and some objectives are defined at that level. Inter-annual population dynamics will be modelled by Biological Region and fisheries by IPHC Regulatory Area.

4.1.2 Management Procedure

The management procedure consists of three elements (Figure 6). Monitoring (data generation) is the code that simulates the data from the operating model and is used by the estimation model. It simulates the data collection and sampling process and can introduce variability, bias, and any other properties that are desired. The Estimation Model is analogous to the stock assessment and simulates estimation error in the process. Using the data generated, it produces an annual estimate of stock size and status and provides the output necessary for setting the mortality levels for the next time step. The estimation model may also consist of a simulated survey index. The Harvest Rule is the application of the estimation model output along with the scale and distribution management procedures to produce the catch limit for that year. Simulated management procedures must be clearly specified so that they can be implemented by computer code within the framework.

4.2 Technical Development

In concert with the ongoing scientific and procedural elaboration of the MSE framework, the initial development of computer software to simulate the population and offer input to analysis and management strategy is underway. Generally, the software underpinning the MSE simulations and analysis and reporting tools must be robust, return reproducible results, and be easy to use and well-documented so that the MSE scientific staff can focus on analysis rather than technical issues. From an engineering perspective, the software must be performant to reduce lengthy run times and extensible to facilitate the addition of new features, and therefore written with standard software development and testing processes and tools. Structurally, the software will include forecast models conditioned on historical data that characterize the stock, and results from a management procedure to be evaluated against conservation and fishery objectives.

Additional stages of development will focus on testing of the implemented algorithms and ongoing performance optimization.

5 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 4 and Figure 7. An independent peer review is scheduled to occur in spring of 2020 with a follow-up in late summer of 2020.

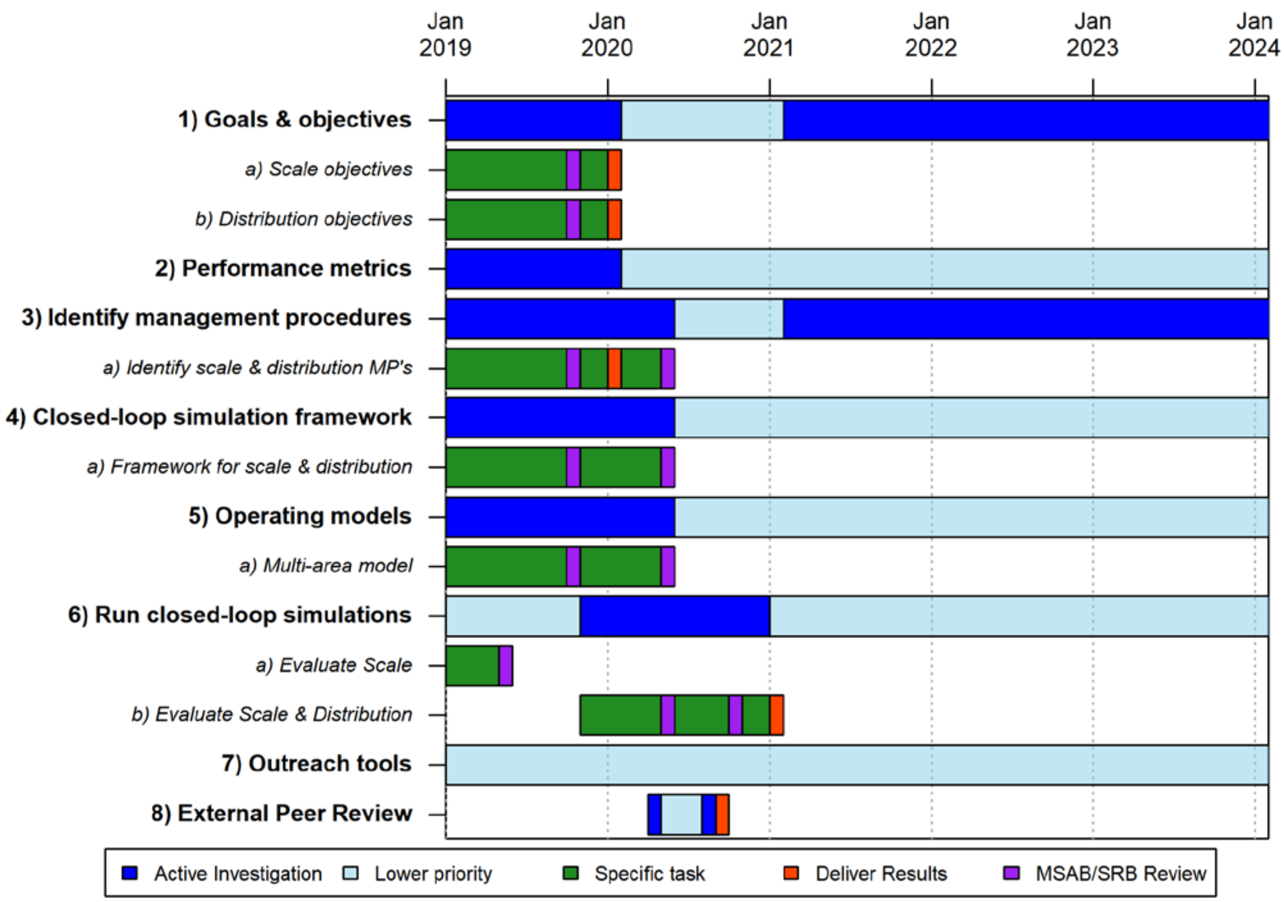

Figure 7: Five-year program of work shown as a Gantt chart format showing tasks down the right side and time along the horizontal axis.

Table 4: Program of work and tasks for 2019 and 2020 leading up to the delivery of the full MSE results at the 97th Annual Meeting in early 2021.

13th Session of the IPHC MSAB (MSAB013) - May 2019	**Status**
Evaluate additional Scale management procedures	Completed
Review goals and objectives	Completed
Spatial model complexity	Completed
Identify management procedures (Scale & Distribution)	Completed
Review Framework	Completed
14th Session of the IPHC MSAB (MSAB014) - October 2019	
Review Framework	Completed
Review multi-area model development	Completed
Spatial Model Complexity	Completed
Define Goals and Objectives (Scale & Distribution)	Completed
Identify management procedures (Scale & Distribution)	Completed
96th Session of the IPHC Annual Meeting (AM096) – January 2020	
Update on progress	
15th Session of the IPHC MSAB (MSAB015) - May 2020	
Review goals and objectives (Scale & Distribution)	
Review simulation framework	
Review multi-area model	
Review preliminary results	
Identify management procedures (Scale & Distribution)	
16th Session of the IPHC MSAB (MSAB016) - October 2020	
Review final results	
Provide recommendations on management procedures	
97th Session of the IPHC Annual Meeting (AM097) – January 2021	
Presentation of complete MSE product to the Commission	
Recommendations on Scale and Distribution management procedures	

6 RECOMMENDATIONS

That the Commission:

a) **NOTE** paper IPHC-2020-AM096-12 which provides the Commission 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 the primary coastwide biological sustainability objective of maintaining the female spawning biomass above a biomass limit of $SB_{20\%}$ at least 95% of the time be used to evaluate management procedures.

c) **RECOMMEND** primary coastwide fishery objectives to be used for evaluation of management procedures (Table 1), including
   a. maintain the female spawning biomass around a proxy target biomass of $SB_{36\%}$;
   b. limit annual changes in the TCEY; and
   c. optimize directed fishing yield.

d) **RECOMMEND** that the primary biological sustainability objective of conserving spatial population structure across Biological Regions be used to evaluate management procedures.

e) **RECOMMEND** primary fishery objectives at the IPHC Regulatory Area scale for evaluation of management procedures (Table 1), including
   a. limit annual changes in the TCEY for each IPHC Regulatory Area;
   b. optimize the TCEY among IPHC Regulatory Areas;
   c. optimize a percentage of the coastwide TCEY among IPHC Regulatory Areas;
   d. maintain the TCEY above a minimum absolute level within each IPHC Regulatory Area; and
   e. maintain a percentage of the coastwide TCEY above a minimum level within each IPHC Regulatory Area;

f) **RECOMMEND** that given the results from the coastwide MSE, the following elements from the scale (coastwide) component of the management procedure meet the coastwide objectives
   a. SPR values greater than 40%
   b. A control rule of 30:20,
   c. Constraints on the annual change in the TCEY that limit it to 15%, use a slow-up, fast-down approach, and fix the mortality limits for three-year periods.

g) **RECOMMEND** a reference SPR fishing intensity of 43% with a 30:20 control rule and allocations to 2A and 2B, as defined in IPHC-2019-AM095-R paragraphs 69 b and c, be used as an updated interim harvest policy consistent with MSE results pending delivery of the final MSE results at AM097.

h) **NOTE** that the various elements of the scale and distribution components of the management procedure, including those listed in IPHC-2019-MSAB014-R will be evaluated for consideration at AM097 in 2021.

i) **NOTE** that an independent peer review of the MSE will take place in April 2020 and August 2020 with a report supplied to the SRB, MSAB, and Commission.

j) **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.

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