# 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.

## 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), 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.

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, followed by the identification of management procedures incorporating scale and distribution components for evaluation at MSAB meetings in 2020. The progress on developing a framework to investigate distributing the TCEY follows, and the program of work for the next year is discussed.

## 2 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 (also referred to as a conservation goal)
    1.1. Keep female spawning biomass above a limit to avoid critical stock sizes and conserve spatial population structure
2. Optimise directed fishing opportunities (also referred to as a fishery goal)
    2.1. Maintain spawning biomass around a level that optimises 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 (bycatch)

The biological sustainability goal is also referred to as a conservation goal, and the goal "optimise directed fishing opportunities" is often referred to as a fishery goal. The fishery goal stresses optimising fishery yield with respect to stability and sustainability and optimising the fishing opportunities to ensure access. Goals related to discard mortality in directed fisheries and non-directed fisheries have not yet been specifically considered in the MSE but have been identified as important to consider after 2021.

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 ($F_{SPR}$) and 30:20 control rule 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. We then present the distribution objectives defined at MSAB014.

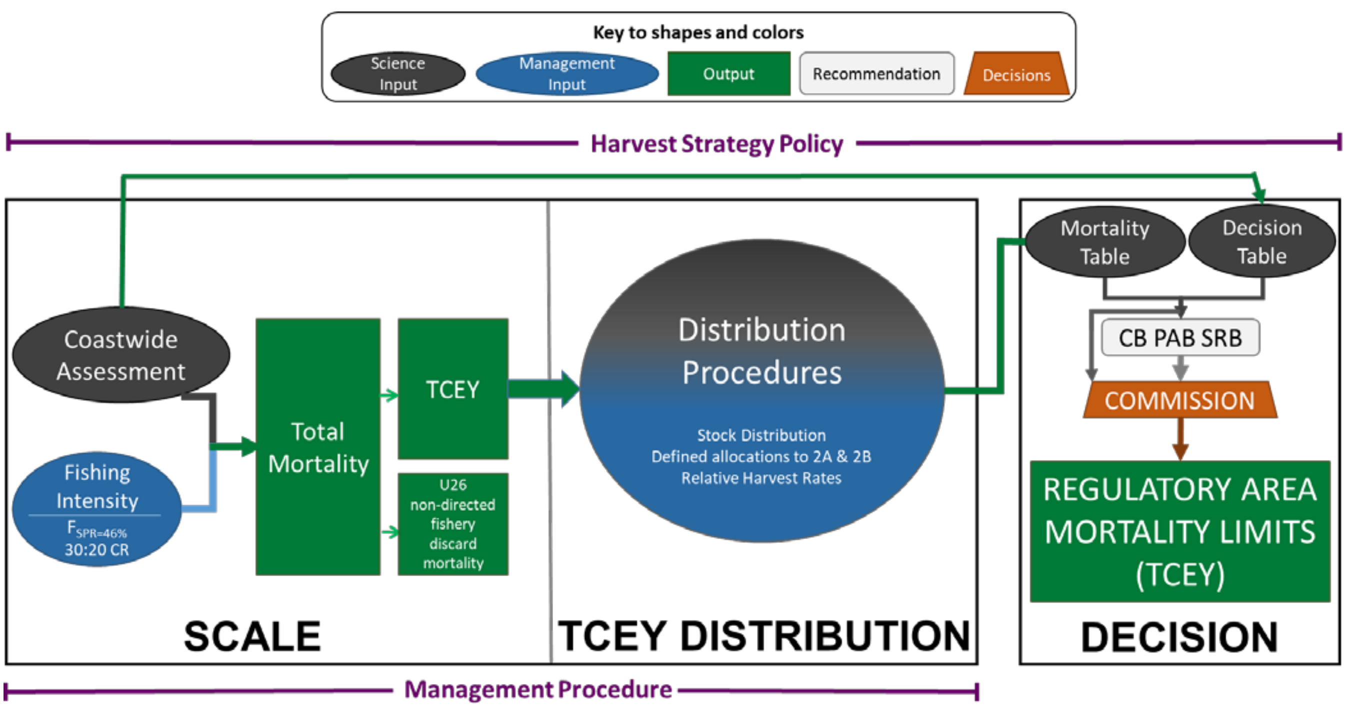


**Figure 1**: Illustration of the Commission interim IPHC harvest strategy policy (as revised for 2019-2022) process showing the coastwide scale and TCEY distribution components that comprise the management procedure. The decision component is the Commission decision-making procedure, which considers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

## 2.1 OBJECTIVES RELATED TO COASTWIDE SCALE

Primary general objectives were previously 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 tolerance defined can still be reported as performance metrics, and metrics not specifically associated with an objective 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 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 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% (PFMC 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. 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 by the MSAB. 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 to determine appropriate proxy reference points (IPHC-2019-SRB015-11 Rev_1). 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 Rev_1 describes the methods and results from this analysis, with estimates of 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 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 optimises fishing activities can be viewed as a fishery objective (e.g., maximise 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). The fishery objective to maintain the biomass around a target of $SB_{36\%}$ (Table 1) would be prioritised after meeting this single conservation objective.

The MSAB discussed the coastwide objective to limit annual changes in the TCEY. Up to now, the performance metric for this objective was the average annual variability (AAV), which is an average taken over a ten-year period. Using this performance metric 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. Instead, 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. A new statistic called Annual Change (AC) was defined to represent actual annual change in the TCEY and used with the stability objective along with AAV since they both provide different interpretations of variability in the TCEY (paragraph 35 of IPHC-2019-MSAB014-R).

The different interpretation of the results when looking at AC or AAV can be seen in Table 2. The probability that the Total Mortality changes by more than 15% in at least one year of the ten-year period is high (0.61 to 0.76) for the slow-up fast-down constraint, and low for the maxChangeBoth15 constraint (0.10 to 0.12, which is a result of mortality that is not "constrained" under the management procedure). However, the median absolute value of the change in the Total Mortality (changes in both directions) is 15% for the maxChangeBoth15 constraint and near 7% for the slow-up fast-down constraint. Furthermore, the probability that the percent change in the TM is greater than 15% in two or more years nearly halves for the slow-up fast-down approach. This shows that the maxChangeBoth15 constraint rarely exceeds a 15% annual change in TM but is often at 15%. In contrast, the slow-up fast-down constraint often results in an annual change less than 15%, but at least one year in a ten-year period is likely to be greater than 15%. On average, the maxChangeBoth15 is more variable than the slow-up fast-down constraint, as seen in the median AAV. Therefore, to evaluate management procedures with respect to stability, it may be beneficial to examine multiple performance metrics. Additionally, the tolerance for the stability objective was removed so that the evaluation would be examining trade-offs between yield and variability.

**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.

| 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 ($SB_{Lim}$)<br><br>$SB_{Lim}$=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 | $p_{SB,2} > 5\%$<br>$p_{SB,3} > 33\%$<br>$p_{SB,2} > 10\%$<br>$p_{SB,2} > 2\%$ | Long-term | 0.05 | $P\left(p_{SB,R} < p_{SB,R,min}\right)$ |
| **2.1** Maintain spawning biomass around a level that optimises fishing activities | Maintain the coastwide female spawning biomass above a biomass target reference point at least 50% of the time | *SB*<Spawning Biomass Target ($SB_{Targ}$)<br><br>$SB_{Targ}$=$SB_{36\%}$ unfished spawning biomass | Long-term | 0.50 | $P\left(SB < SB_{Targ}\right)$ |
| **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)* |

**Table 2**: MSE coastwide results for primary objectives with management procedures using the 30:20 control rule with SPR values of 0.38, 0.42, and 0.46 for unconstrained annual changes in the Total Mortality (TM) and three constraint options. The term “any” denotes a threshold exceeded at least one year in the ten-year period and a number after “any” (e.g., “any2”) refers the threshold being exceeded in at least that number of years in the ten-year period. Non-primary objectives are shown in grey.

| **Input Control Rule** | **30:20** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Constraint** | **No Constraint** | | | **maxChangeBoth15** | | | **slowUpFastDown** | | | **Multi-year (3)** | | |
| **Input SPR** | **0.46** | **0.42** | **0.38** | **0.46** | **0.42** | **0.38** | **0.46** | **0.42** | **0.38** | **0.46** | **0.42** | **0.38** |
| **Biological Sustainability** | | | | | | | | | | | | |
| P(any RSB_y<20%) | <0.01 | <0.01 | <0.01 | 0.02 | 0.02 | 0.03 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.02 |
| **Fishery Sustainability** | | | | | | | | | | | | |
| P(all RSB<36%) | 0.29 | 0.47 | 0.68 | 0.28 | 0.46 | 0.63 | 0.26 | 0.43 | 0.60 | 0.32 | 0.50 | 0.67 |
| Median absolute change TM | 15.6% | 16.9% | 19.1% | 15.0% | 15.0% | 15.0% | 6.5% | 7.1% | 7.7% | 0.0% | 0.0% | 0.0% |
| P(any1 AC TM > 15%) | 1 | 1 | 1 | 0.11 | 0.11 | 0.10 | 0.61 | 0.68 | 0.76 | 0.94 | 0.96 | 0.96 |
| P(any2 AC TM > 15%) | 0.97 | 0.98 | 0.99 | 0.09 | 0.08 | 0.08 | 0.32 | 0.41 | 0.52 | 0.7 | 0.72 | 0.77 |
| P(any3 AC TM > 15%) | 0.89 | 0.91 | 0.94 | 0.06 | 0.06 | 0.06 | 0.19 | 0.26 | 0.35 | 0.30 | 0.32 | 0.40 |
| P(all AAV > 15%) | 0.69 | 0.76 | 0.84 | 0.04 | 0.05 | 0.06 | 0.07 | 0.11 | 0.15 | 0.14 | 0.19 | 0.3 |
| Median AAV TM | 17.9% | 19.7% | 23.1% | 11.2% | 11.3% | 11.7% | 7.0% | 7.7% | 8.8% | 8.0% | 8.8% | 10.8% |
| Median average TM (Mlbs) | 46.76 | 49.51 | 51.78 | 46.13 | 48.55 | 50.88 | 44.99 | 48.17 | 51.11 | 46.53 | 48.88 | 51.18 |

## 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 which is reported in IPHC-2019-MSAB014-INF01.

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 (Figure 2) 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. 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.

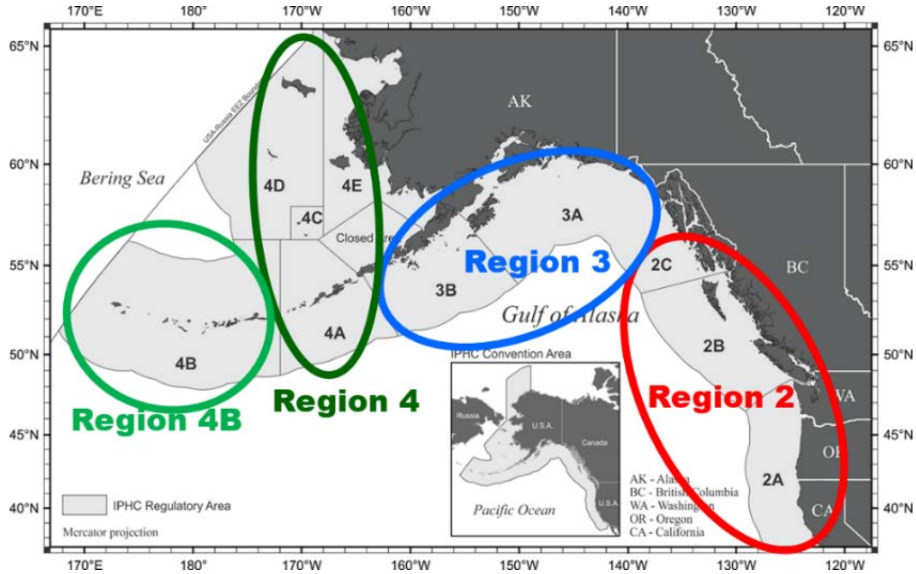


**Figure 2.** Biological Regions overlaid on IPHC Regulatory Areas with Region 2 comprised of 2A, 2B, and 2C, Region 3 comprised of 3A and 3B, Region 4 comprised of 4A and 4CDE, and Region 4B comprised solely of 4B.

### 2.2.2 Optimise Directed Fishing Opportunities

Three general objectives are currently defined for the fishery goal: 1) maintain the spawning biomass around a level that optimises fishing activities, 2) limit catch variability, and 3) provide directed fishing yield. Under each general objective, there are coastwide TCEY measurable objectives, but distribution objectives are only 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.

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

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

#### *2.2.2.2 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 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 MSAB decided to define both coastwide and distribution objectives for the time being, and to evaluate potential redundancy when results become available.

#### *2.2.2.3 Maximize fishery yield*

Two different types of objectives related to fishery yield in an IPHC Regulatory Area were defined. These were related to an actual TCEY and a proportion of the coastwide TCEY. 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 the using proportion of coastwide TCEY captures its distribution sharing among IPHC Regulatory Areas. The median of the average TCEY and the proportion of the TCEY over a ten-year period were reported along with the median minimum TCEY and minimum proportion of the TCEY over a ten-year period.

The catch variability and yield objectives did not have a tolerance defined, thus simple performance metrics 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 IPHC Regulatory Areas.

## 3 INVESTIGATIONS OF COASTWIDE FISHING INTENSITY

Simulation results presented at MSAB012 (IPHC-2018-MSAB012-07) showed that no management procedure met the primary stability objective (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). 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 I-1 and horizontal axis of the upper left plot in Figure 3), 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 3), 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 3) 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 the unconstrained management procedure showed high variability in mortality limits, mainly due to estimation error. Constrained management procedures were able to meet biological and stability objectives and maxChangeBoth15%, slowUpFastDown, and multiYear performed the best. Management procedures with an SPR greater than 40% met the fishery objective of maintaining the biomass around a target of $SB_{36\%}$. Additionally, at fishing intensities greater than those associated with an SPR of 40% (i.e., SPR values less than 40%) the variability in total mortality increased rapidly 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.

[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.

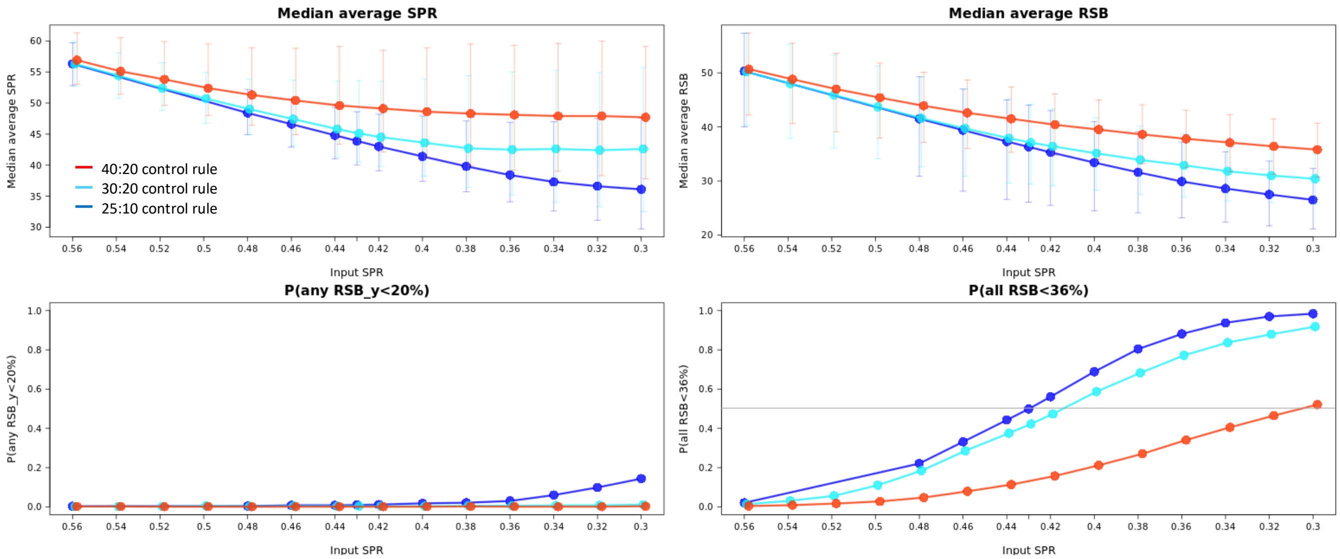


**Figure 3**: Performance metrics for the MSE simulation results when using 40:20, 30:20, and 25:10 control rules. Vertical lines represent the 5th and 95th percentiles of the simulation results. The horizontal line in the top-right plot indicates the 30% limit for RSB and the one in the bottom right 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 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.*

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.
- Science-based and management-derived elements exist for 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.

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 Commission 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-inch (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 4). 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.

#### 4.1.3 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.*

The values are used first to define the TCEY in 2A and 2B, after which the estimated stock distribution and relative harvest rates relative to these values distribute the TCEY to the other IPHC Regulatory Areas.

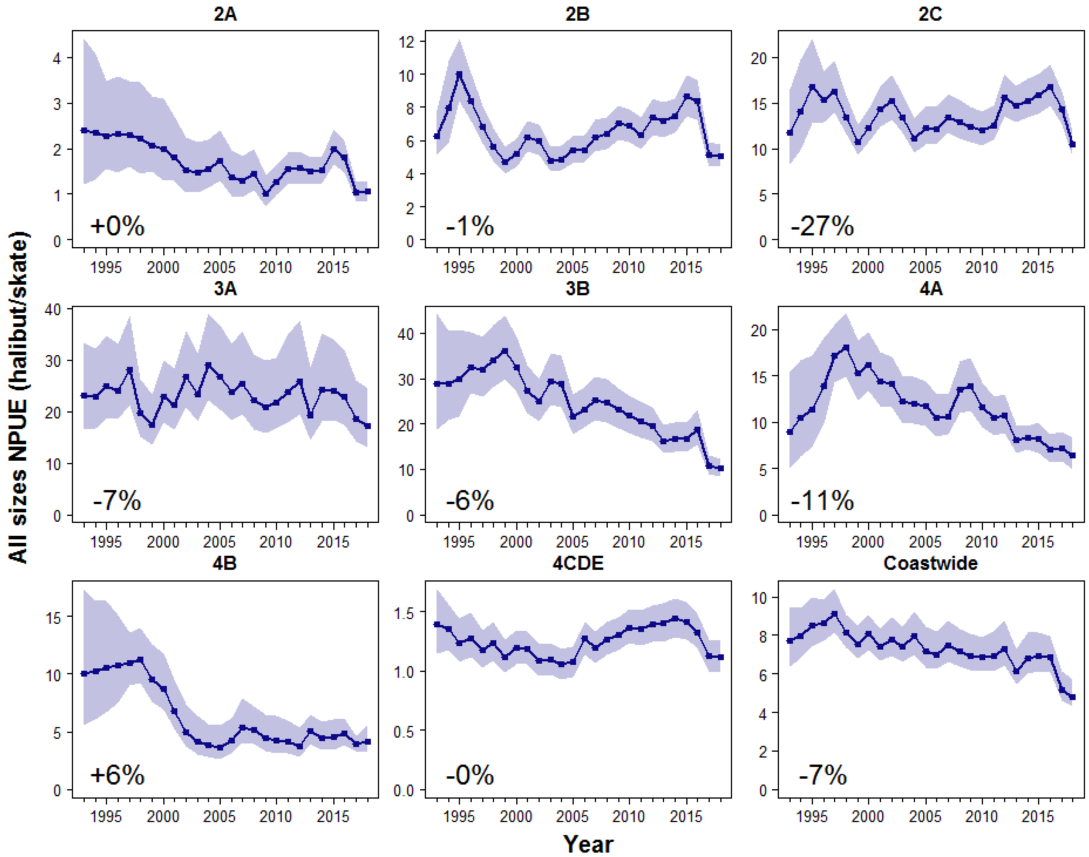


**Figure 4**: Trends in modelled survey NPUE by IPHC Regulatory Area, 1993-2018 (reproduced from [IPHC-2019-AM095-08](IPHC-2019-AM095-08)). Percentages indicate the change from 2017 to 2018. Shaded zones indicate 95% credible intervals.

## 4.2 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 4.1. Below, alternative approaches to stock distribution and relative harvest rates are described.

### 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 2, 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.

### 4.2.2 Additional distribution procedures

Distribution procedures in addition to stock distribution may be used to make further modification to 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.

#### *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 2). 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 Biological Regions 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 were estimated for each Biological Region at three different points in time: 1985, 1999, and 2018 (Figure 5). 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 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. 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 also accounts for other factors such as movement, recruitment dynamics, and the effects of harvest levels in other areas.

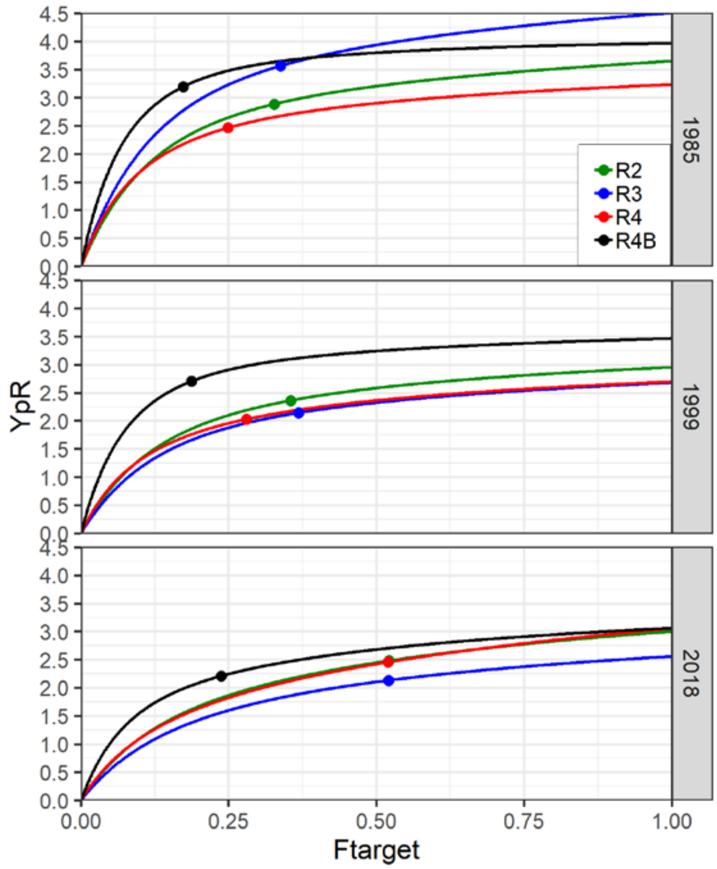


**Figure 5**: Yield-per-recruit at different harvest rates (Ftarget as an exploitation rate) estimated for each Biological Region (2, 3, 4, and 4B; Figure 2) using weight-at-age and selectivity (as estimated in the long areas-as-fleets stock assessment model) from 1985 (top panel), 1999 (middle panel), and 2018 (bottom panel). The colored points on each curve correspond to the reference point $F_{0.1}$ for each Biological Region.

**Table 4**: 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 |

#### *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 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 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 was 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, 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. It is currently understood that Pacific halibut have move considerably within (and, to some extent 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 (both at a regional and at a regulatory area level), which will have been 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).

Incorporating these tools in a management procedure can be done by defining specific steps, as in the example framework below (Section 4.3). For example, one management procedure may be to simply assign a fixed proportion of the TCEY to each IPHC Regulatory Area, or calculate the proportions based on recent landings. Another management procedure may be to determine the stock distribution, shift the proportion of the TCEY to eastern regions, further modify the distribution across regions based on the sizes of Pacific halibut in each region, distribute the TCEY to IPHC Regulatory Areas within each Region using trends in the survey abundance, and modify that distribution to match a define minimum proportions in each IPHC Regulatory Area. The point is that Management Procedures can be built by piecing together different tools that are designed to meet different objectives.

The steps in the Distribution Procedures may consider conservation objectives, but the steps 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. Once a reasonable set of management procedures is defined, it can be modelled in the simulation framework and evaluated against the objectives. A possible framework to populate with various tools is described below.

### 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) 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). 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 “worst-case scenario” target, although after many years of application, an analysis of the chosen SPR could reflect the realized target.

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 and 5 are essential; steps 2 to 4 are optional.

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, removing the U26 non-directed fishing discard mortality from the Total Mortality to determine the coastwide TCEY.
2. **Regional Stock Distribution (science-based):** 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 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, and recent or historical fishery performance. 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 (or from coastwide if steps 2-4 are omitted) to distribute the coastwide or 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.

### 4.4 Management procedures to evaluate

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

> MSAB014–Rec.04 (para. 49): *The MSAB **RECOMMENDED** that SPR values of 0.3, 0.34, 0.38, 0.40, 0.42, 0.46, and 0.50 with a 30:20 control rule be evaluated at MSAB015 along with constraints defined by a maximum change in the TCEY of 15%, a slow-up fast-down approach, and/or setting quotas every third year*
>
> MSAB014–Rec.05 (para. 56): *The MSAB **RECOMMENDED** that the management procedures listed in Table 2 in Appendix VI be evaluated at MSAB015.*

#### *4.4.1.1 Scale elements of management procedures.*

The coastwide MSE investigated only the scale component of the management procedure and identified a range of procedural SPR values associated with control rules and 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 (Table 5).

**Table 5**: Elements of the coastwide componenet of the management procedures that will be evaluated at MSAB015.

| **Procedural SPR** | **Control Rule** | **Constraints** |
|---|---|---|
| 30%, 34%, 38%, 42%, 46%, 50% | 30:20 | • maxChange15%<br>• Slow-up/Fast-down<br>• Multi-year<br>• maxChange15% combined with either of above |

#### *4.4.1.2 Distribution elements of management procedures*

Table 6 presents the management procedures recommended at MSAB014 for evaluation 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.

**Table 6**: Recommended management procedures from MSAB014 for evaluation at MSAB015.

| **MP** | **Coastwide** | **Regional** | **IPHC Regulatory Area** |
|---|---|---|---|
| MP A | SPR<br>30:20 | | • O32 stock distribution<br>• Proportional Relative harvest rates (starting with 1.0 for 2-3A, 0.75 for 3B-4) relative to below<br>• 1.65 Mlbs floor in 2A (para 69c AM095-R)<br>• Formula percentage for 2B (para 69b AM095-R) |
| MP B | SPR<br>30:20<br>Slow-up, fast-down<br>MaxChange15% | | • O32 stock distribution<br>• Proportional Relative harvest rates (starting with 1.0 for 2-3A, 0.75 for 3B-4) relative to below<br>• 1.65 Mlbs floor in 2A (para 69c AM095-R)<br>• Formula percentage for 2B (para 69b AM095-R) |
| MP C | SPR<br>30:20 | | • O32 stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) |
| MP D | SPR<br>30:20<br>Slow-up, fast-down<br>MaxChange15% | | • O32 stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) |
| MP E | SPR<br>30:20 | | • O32 stock distribution<br>• Relative harvest rates (0.75 for 4B, 1 for others)<br>• |

**Table 6** (continued)

| MP | Coastwide | Regional | IPHC Regulatory Area |
|---|---|---|---|
| MP F | SPR<br>30:20 | Biological Regions, O32 stock distribution<br>Rel HRs: R2=1, R3=1, R4=0.75, R4B=0.75 | • O32 stock distribution<br>• Relative harvest rates not applied<br>• 1.65 Mlbs floor in 2A (para 69c AM095-R)<br>• Formula percentage for 2B (para 69b AM095-R) |
| MP G | SPR<br>30:20 | Biological Regions, O32 stock distribution<br>Rel HRs: R2=1, R3=1, R4=1, R4B=0.75 | • O32 stock distribution<br>• Relative harvest rates not applied<br>• 1.65 Mlbs floor in 2A (para 69c AM095-R)<br>• Formula percentage for 2B (para 69b AM095-R) |
| MP H | SPR<br>30:20<br>Max FI (36%) | | First<br>• O32 stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>Second within buffer<br>• 1.65 Mlbs floor in 2A (para 69c AM095-R)<br>• Formula percentage for 2B (para 69b AM095-R) |
| MP I | SPR<br>30:20 | | • 5-year shares determined from 5-year O32 stock distribution (vary over time) |
| MP J | SPR<br>30:20 | National Shares: 20% to 2B, 80% to other | • O32 stock distribution |

## 5 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, investigates management procedures related to the distribution of the TCEY.

The development of an MSE framework aims to support the scientific, forecast-driven study of the trade-offs between fisheries management scenarios. Crafting this tooling requires

- the definition and specification of a multi-area operating model;
- an ability to condition model parameters using historical catch and survey data and other observations;
- integration with, use of, or comparison against stock assessment tools or data;
- identification and development of management procedures with closed-loop feedback into the operating model;
- definition and validation of performance metrics to evaluate the efficacy of applied management procedures.

Updates on the recent efforts in these areas are outlined in Section 5.1. Likewise, a significant effort developing the software underpinning these simulations is underway, which is outlined in section 5.2.

### 5.1 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.

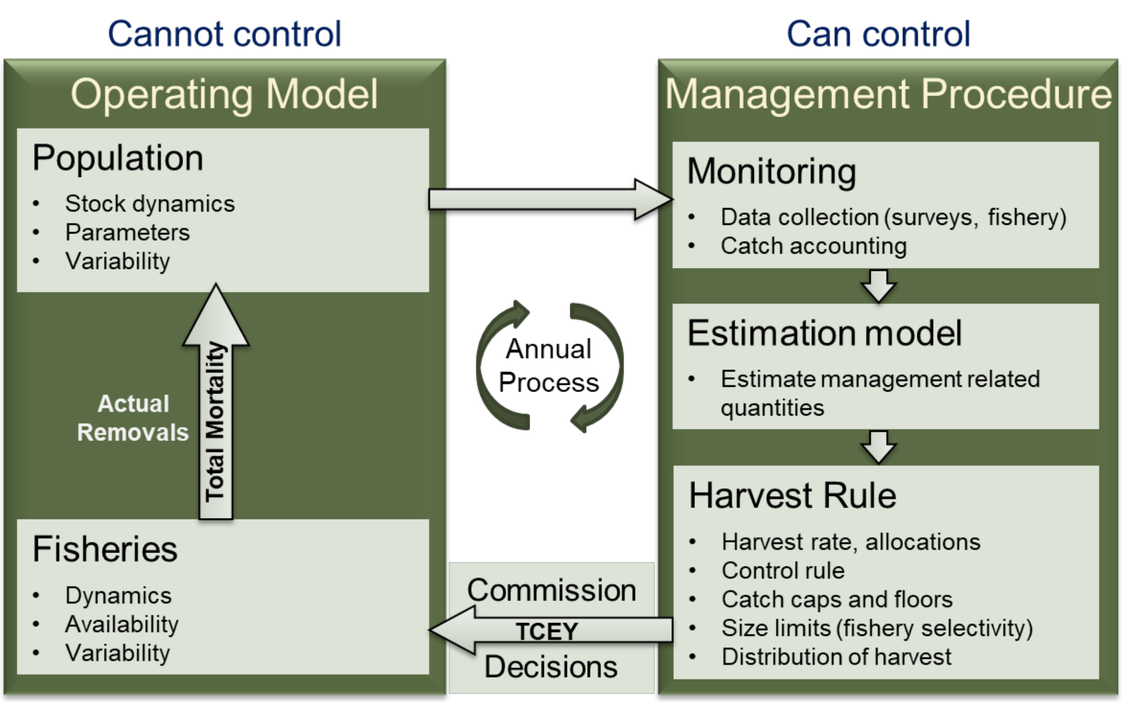


**Figure 6**: Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

### 5.1.1 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.

#### *5.1.1.1 Population and fishery spatial specification*

As mentioned above, emerging understanding of Pacific halibut diversity across the geographic range of its stock indicates that IPHC Regulatory Areas should be only considered as management units and do not represent relevant sub-populations (Seitz et al. 2017). The structures of two of the four current Pacific halibut stock assessment models was developed around identifying portions of the data (fishery-independent and fishery-dependent data) that correspond to differing biological and population processes within the larger Pacific halibut stock. Biological Regions (Figure 2) were therefore defined with boundaries that matched some of the IPHC Regulatory Area boundaries. Tagging studies have indicated that within a year, larger Pacific halibut tend to undertake feeding and spawning migrations within a Biological Region, and movement between Biological Regions typically occurs between years (Loher & Seitz 2006; Seitz et al. 2007; Webster et al. 2013). It is unlikely that there is a set of regions that accurately delineates the stock biologically since different aspects of the stock differ over varying scales, but Biological Regions are the best approximation that also satisfy management needs (paragraph 31 IPHC-2018-SRB012-R). They also offer an appropriate and parsimonious spatial separation for modeling inter-annual population dynamics.

However, as mentioned earlier, mortality limits are set for IPHC Regulatory Areas and thus directed fisheries operate at that spatial scale. Furthermore, since some fishery objectives have been defined at the IPHC Regulatory Area level, the TCEY will need to be distributed at that scale. Even though the population is modelled at the Biological Region scale, fisheries can be modelled at the IPHC Regulatory Area scale by using an areas-as-fleets approach (Waterhouse et al. 2014) within Biological Regions. This requires modelling each fleet with separate selectivities and harvest rates that operate on the exploitable biomass in the entire Biological Region.

Additionally, calculating statistics specific to IPHC Regulatory Areas may be difficult. For example, simulating the proportion of biomass in each IPHC Regulatory Area (e.g., to mimic the current interim management procedure) requires simulating a survey biomass for each IPHC Regulatory Area, and likewise determining some objectives related to IPHC Regulatory Area may be difficult to calculate (such as the proportion of O26 fish in each IPHC Regulatory Area). The distribution of the population within a Biological Region would have to be approximated, which could be done assuming a probability density function based on past observations with some variability (e.g., a Beta distribution with different shapes). This concept is currently under development.

#### *5.1.1.2 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 and apply across all Regulatory Areas. A conceptual model of halibut ontogenetic and seasonal migration, including main spawning and nursery grounds, as per the most current knowledge, is presented in Figure 7 and detailed below. Figure 7 is a live map and will be updated as new information becomes available.

The Pacific halibut spawning season spans from November to March. Spawning has been 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 occupied before the spawning migration, while eggs and larvae are dispersed to the north and west (Skud 1977; Valero & Webster 2011).

Larval stages are found in deep waters and exploit the deepwater circulation pattern to move inshore (Thompson & van Cleve 1936; Skud 1977; Bailey et al. 2008; Sohn et al. 2016). Some larvae may enter the Alaskan gyre and be carried offshore, far from the common nursery grounds, where they eventually die (Skud 1977). Between the larval stages and the settlement of juveniles, individuals move to shallow waters undertaking abrupt vertical ontogenetic migrations (Sohn et al. 2016). Halibut juveniles settle on sand substrata mixed with mud and granule in shallow waters, or near or outside mouths of bays (Norcross et al. 1997; Moles et al. 1995; Bailey et al. 2008). In the Bering Sea, juveniles are found over the shelf, along the west side of the Alaskan Peninsula and close to Pribilof Island, while in the Gulf of Alaska they are most abundant around Kodiak Island and along the western and central Gulf. Almost no individuals zero to three years old are found in Southeast Alaska and British Columbia, where the population is characterized by individuals 4 years of age and older (IPHC 1998). Young Pacific halibut in the Gulf of Alaska between 2 and 5 years old undertake a backward southerly and easterly migration (Hilborn et al. 1995). More recent tagging results have also shown that adults continue to migrate throughout their life, even though the percentage of migrating fish decreases as they age (Valero & Webster 2011, Webster et al. 2013).

Despite evidence 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). Also, results from an ocean circulation model suggest that the contribution of Gulf of Alaska spawners to Eastern Bering Sea juveniles is small (Vestfals et al. 2014). Genetic studies have also identified a different genetic structure of the population in the western Aleutian Islands compared to the rest of the stock, suggesting a low migration rate to (and possibly from) this region (Drinan et al. 2016).

In light of this, a framework was developed in 2015 to represent the IPHC working hypothesis concerning movement-at-age among Biological Regions (IPHC-2019-AM095-08). Each

Biological Region spans multiple Regulatory Areas (Figure 7). Within a year, halibut move from one Regulatory Area to another but tend to remain within the same Biological Region. The definition of Biological Regions is supported by several lines of evidence. Genetic studies have separated components of the Pacific halibut population in the Aleutian islands west of Samalga Pass (Drinan et al. 2016). Additionally, environmental conditions in the Northeast Pacific suggest a loose division into three main oceanographic regions, the west coast of US and Canada, the Gulf of Alaska, and the Bering Sea (Sadorus et al. 2016). Further, analysis of size-at-age and growth parameters by region have shown differences that maybe explained by different environmental conditions, e.g., habitat quality, prey availability, or water temperature (Martell et al. 2012; Sullivan et al. 2016). Finally, a study on the zoogeography of halibut parasites in the Northeast Pacific has shown breakpoints between the parasites' species composition between fish in Region 3 (Gulf of Alaska) and in southern areas (Blaylock et al. 1998).

This conceptual model will inform the development of the MSE operating model framework and will be used as a starting point to incorporate variability and alternative movement hypotheses in Pacific halibut movement dynamics. Movement will be modelled as the proportion of individuals that move from one region to another. For this purpose, a transition matrix for each age class or group of ages and sex will be used. The matrix dimension will correspond to the number of regions considered. In the case of halibut, a 4x4 matrix (for four Biological Regions) will be used, with each matrix cell *jk* corresponding to the proportion of fish moving from Region *j* to Region *k*. Tagging data will be used to inform the values in the transition matrix, and different hypothesis will be tested. Also, all hypotheses will be compared to similar approaches used in the past (i.e., Quinn et al. 1990; Hilborn 1995). It will be important to include a range of transition probabilities that encompass both historical and future potential movement patterns.

### 5.1.2 Management Procedure

The management procedure consists of three elements. 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 (EM) 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 advice for setting the catch levels for the next time step. Simplifications may be necessary to keep simulation times within a reasonable time. The Harvest Rule is the application of the estimation model output along with the scale and distribution management procedures (Figure 6) 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.

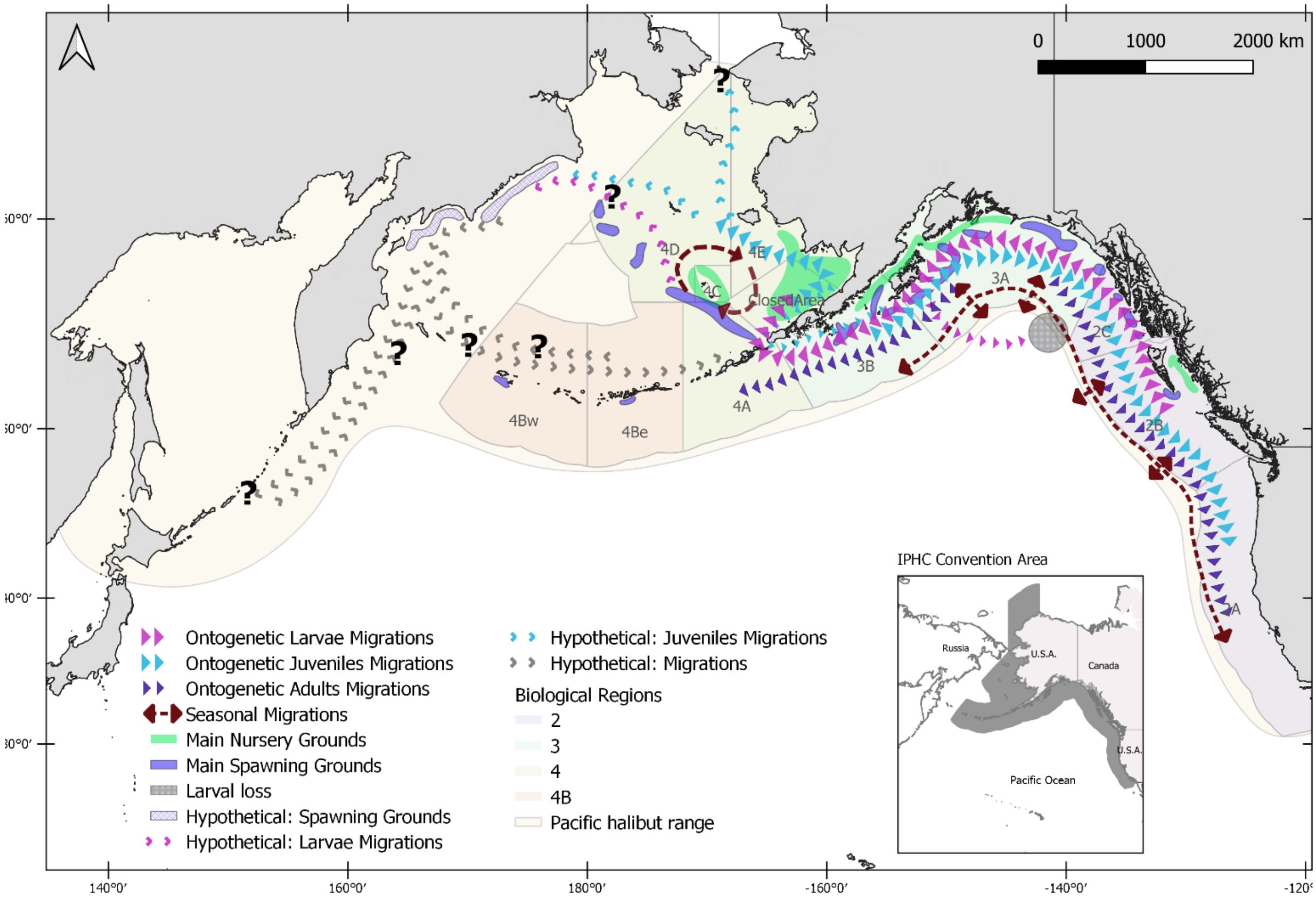


**Figure 7**: Conceptual model of halibut movement and migration. Broken arrows indicate main seasonal movements (to spawning and to feeding grounds). Arrow-shaped lines indicate ontogenetic movements and the possibility to stop anywhere along the lines. Round polygons indicate main settlement areas for juveniles and main spawning grounds. The grey circle represents the possibility of larvae loss when these enter the Alaskan Gyre. Biological Regions are represented by the four large irregular shaded polygons.

## 5.2 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 ease the addition of new features, and therefore written with standard software development and testing processes and tools. Structurally, the software will resemble 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.

To date, several areas have begun development, including

- Implementation of an operating model in the C++ programming language;
- Integration of the Automatic Differentiation Model Builder (ADMB) for conditioning the initial model to the present day;
- Creation of flexible templates for management procedures, for fast prototyping and analysis;
- Development of user-friendly configuration tools to ease and parallelize model runs and analysis;
- Use of flexible, open-source libraries to ease data analysis and processing;
- Visualization and reporting tools written in R and related packages.

Later stages of development will focus on robust testing of the implemented algorithms, comparison of its outputs with other implementations to validate accuracy, and, ultimately, ongoing performance optimization (through code restructuring or various forms of parallelization) to reduce runtimes.

# 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 7 and Figure 8. An independent peer review is schedule to occur in Spring of 2020 with a follow-up in late Summer of 2020.

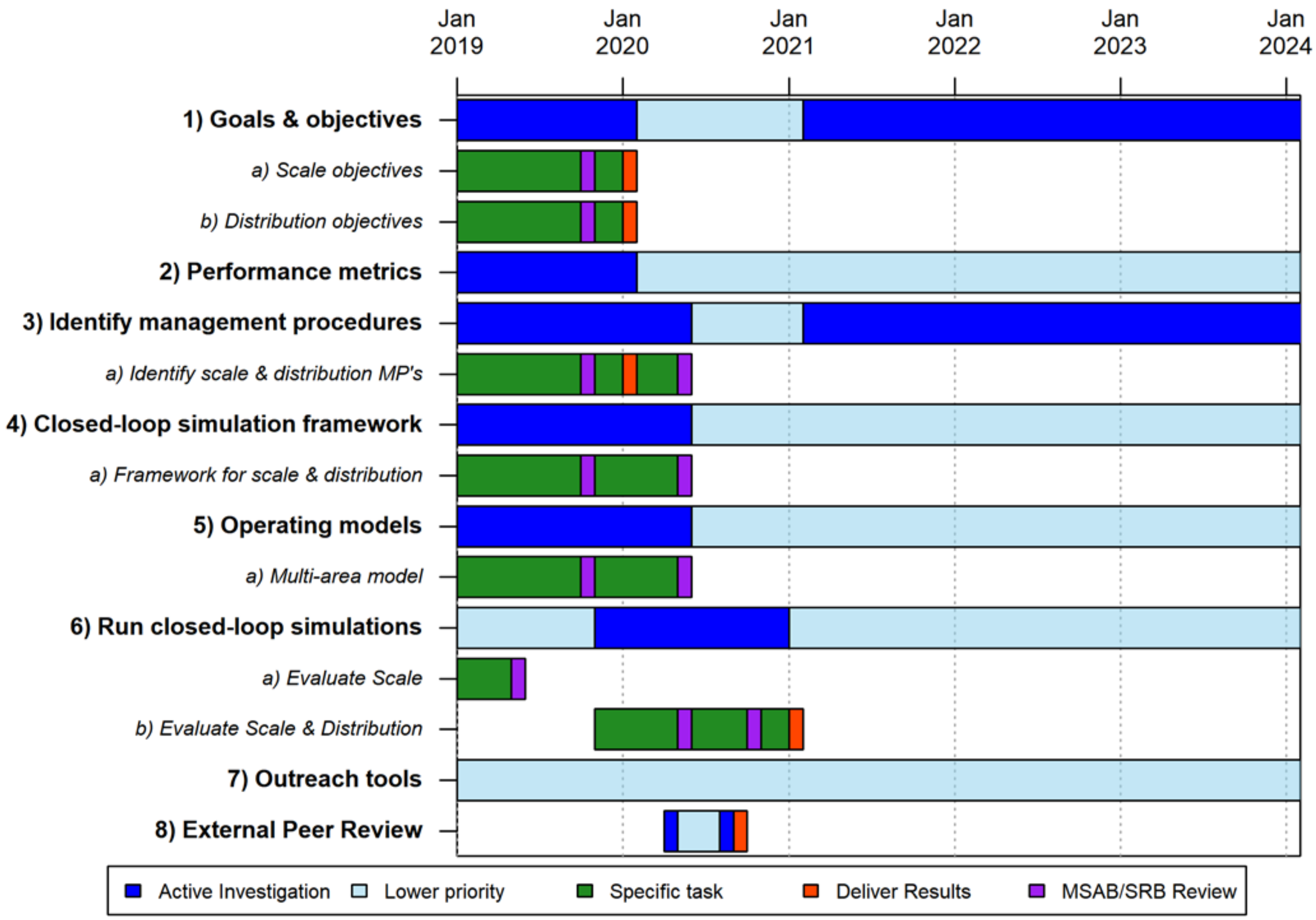


**Figure 8**: Five-year program of work shown as a Gantt chart format showing tasks down the right side and time along the horizontal axis.

**Table 7**: Program of work and tasks for 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<br>Recommendations on Scale and Distribution management procedures | |

## 7 RECOMMENDATIONS

That the Commission:

a) **NOTE** paper IPHC-2019-IM095-14 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) **NOTE** the priority coastwide biological sustainability objective of maintaining the female spawning biomass above a biomass limit.

c) **NOTE** the priority coastwide fishery objectives to be used to evaluate management procedures, including
    a. maintaining the female spawning biomass around a proxy target biomass of 36%;
    b. limit annual changes in the TCEY; and
    c. optimise directed fishing yield.

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

e) **NOTE** the priority fishery objectives at the IPHC Regulatory Area scale to evaluate management procedures, including
    a. limit annual changes in the TCEY for each IPHC Regulatory Area;
    b. optimise the TCEY among IPHC Regulatory Areas;
    c. optimise 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) **NOTE** 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) **NOTE** the various elements of the scale and distribution components of the management procedure, including those listed in Tables 5 and 6 will be evaluated for consideration at AM097 in 2021.

h) **NOTE** that the operating model for the MSE will model movement of Pacific halibut across Biological Regions and fisheries within IPHC Regulatory Areas.

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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## 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 I-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 (which may differ from the biological limit defined in Table 1). For these simulations, two coastwide models were used and mortality was distributed to five coastwide sources of mortality (directed commercial, directed fishery discard, non-directed fishery discard (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.

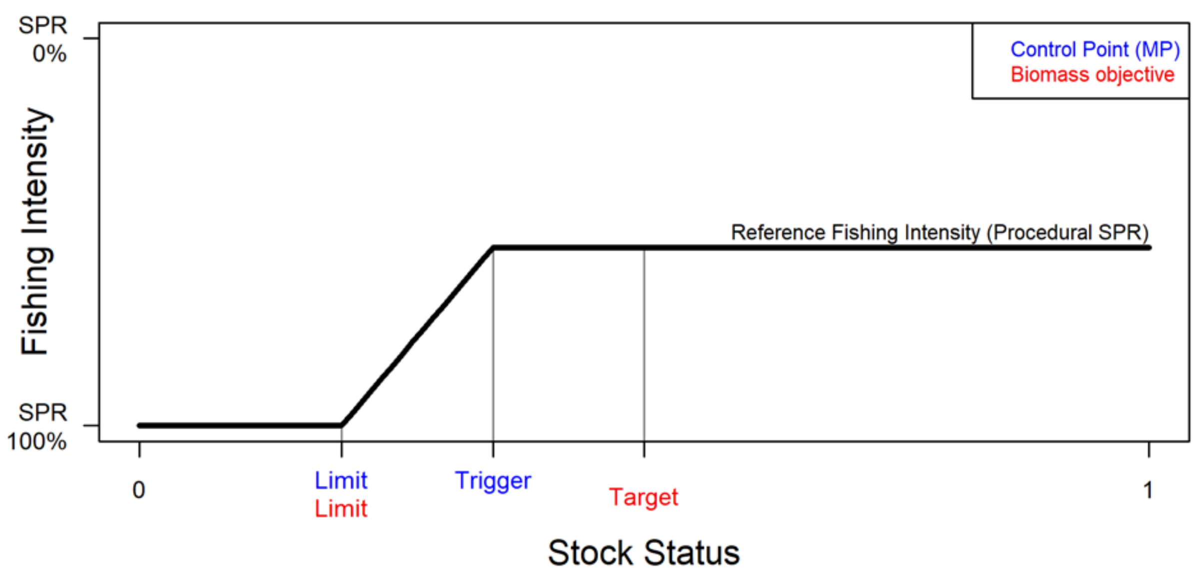


**Figure I-1**: Example harvest control rule responsive to stock status based on Spawning Potential Ratio (SPR) to determine fishing intensity, a fishery trigger level of stock status that determines when the fishing intensity begins to be linearly reduced, and a fishery limit based on stock status that determines when there is theoretically no fishing intensity (SPR=100%). 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 I-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.

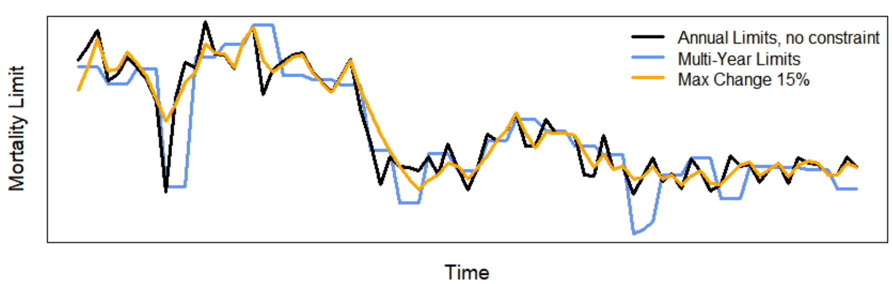


**Figure I-2: H**ypothetical example of the difference between unconstrained and constrained management procedures when determining the total mortality limit. The multi-year limit (blue) is set every third year, but due to allocation to other sectors, the limit may be adjusted in years when the total 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 I-1 and Table I-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 I-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 performance metrics associated with the stability objective (i.e. Annual Change (AC) and Average Annual Variability (AAV)). The AC is a measure of the change in the mortality limit from one year to the next, while the AAV is measure of the average change in the TCEY over a ten-year period. At any fishing intensity and for all control rules tested, the probability of an AC in any 3 years greater than 15% is more than 85%. The AAV ranges between 16–46% for different SPR values and the 3 control rules. The 40:20 control rule resulted in higher variability for the AAV and higher probabilities for the AC, because the reduction in fishing intensity occurs more often given the 40% fishery trigger value and the range of SPR values evaluated. The top ranked management procedure was the 30:20 control rule with a SPR of 42% given the current primary objectives (Table 1). The absolute value of the Total Mortality limit was highly variable for a given SPR.

The use of SPR values without a control rule (results not shown) also did not meet the stability objective for any SPR considered, implying that estimation error formed 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 (or, alternatively, the objective can 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 I.1.2). With the 30:20 control rule and SPR values of 38%, 40%, 42%, and 46%, the biological sustainability goal was met for all constraint options (Table I-4 and Table I-5). However, only the maxChangeBoth15%, slowUpFastDown, slowUpFullDown, and multiYear constraints had SPR options that significantly limited variability in the total mortality according to both performance metrics. The best management procedures used the constraints slowUpFastDown, maxChangeBoth15%, and multiYear constraints. The probability of AC greater than 15% in any 3 years is below 10% for all SPR values tested when using the maxChangeBoth15 constraint, while is greater than 10% for the slowUpFastDown and the MultiYear constraints. However, the maxChangeBoth15% results in the higher AAV among the three rules, with values greater than 10% for all SPRs tested. Setting the limit every third year (multiYear) resulted in high probability of an AC in total mortality greater than 15% (30%-

40%) in any 3 years, which is because it sets the mortality limit every third year. The median yield across the three rules ranged from 45 Mlbs to 51.2 Mlbs.

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/MSE-Explorer/.

**Table I-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 one year out of a ten-year period. Long-term is a ten-year period after simulating 90 annual cycles and is used for the biomass objectives (i.e., RSB). Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23) and is used for the stability and yield fishery objectives.

| 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 | | | | | | | | | | | |
| P(any RSB_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 | | | | | | | | | | | |
| P(all RSB<36%) | 0.01 | 0.18 | 0.29 | 0.38 | 0.47 | 0.59 | 0.68 | 0.77 | 0.84 | 0.88 | 0.92 |
| P(any3 AC > 15%) | 0.86 | 0.88 | 0.89 | 0.90 | 0.91 | 0.92 | 0.94 | 0.96 | 0.97 | 0.99 | >0.99 |
| Median AAV | 16.5% | 17.5% | 17.9% | 18.7% | 19.7% | 20.9% | 23.1% | 26.2% | 29.7% | 33.5% | 37.3% |
| Median average TM | 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 I-1, Table I-2, and Table I-3) | | | | | | | | | | |
| Meet biological objective?[1] | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Meet target objective?[2] | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No |
| Minimize P($AC_3$>15%) | 1 | 6 | 7 | 8 | 9 | | | | | | |
| Minimize AAV | 2 | 6 | 7 | 9 | 10 | | | | | | |
| Maximum yield (TM) | 17 | 14 | 11 | 8 | 1 | — | — | — | — | — | — |
| Average of Ranks[3] | 9.25 | 8.75 | 7.5 | 6.5 | 3.25 | — | — | — | — | — | — |

[1] This is determined using P(any RSB < 20%) for the objective to maintain RSB above 20% at least 95% of the time.

[2] This is determined using P(all RSB >36%) for the objective to maintain RSB above a target of 36% at least 50% of the time.

[3] The overall ranking applies to all management procedures without a constraint (Table I-1, Table I-2, and Table I-3)

**Table I-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 one year out of a ten-year period. Long-term is a ten-year period after simulating 90 annual cycles and is used for the biomass objectives (i.e., RSB). Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23) and is used for the stability and yield fishery objectives.

| 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 | | | | | | | | | | | |
| P(any RSB<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 | | | | | | | | | | | |
| P(all RSB<36%) | <0.01 | 0.05 | 0.08 | 0.11 | 0.16 | 0.21 | 0.27 | 0.34 | 0.41 | 0.46 | 0.52 |
| P(any3 AC > 15%) | 0.91 | 0.94 | 0.96 | 0.97 | 0.99 | >0.99 | >0.99 | >0.99 | >0.99 | >0.99 | >0.99 |
| Median AAV | 18.6% | 22.3% | 24.2% | 26.1% | 28.5% | 31.0% | 33.5% | 36.3% | 39.2% | 42.2% | 45.6% |
| Median average TM | 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 I-1, Table I-2, and Table I-3) | | | | | | | | | | |
| Meet biological objective?[1] | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Meet target objective?[2] | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No |
| Minimize P($AC_3$>15%) | 9 | 11 | 12 | 13 | 14 | 15 | 15 | 15 | 15 | 15 | |
| Minimize AAV | 8 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | |
| Maximum yield (TM) | 19 | 16 | 14 | 12 | 9 | 7 | 5 | 4 | 3 | 1 | — |
| Average of Ranks[4] | 11.75 | 11 | 10.25 | 9.5 | 8.25 | 7.5 | 6.75 | 6.5 | 6.25 | 5.5 | — |

[1] This is determined using P(any RSB < 20%) for the objective to maintain RSB above 20% at least 95% of the time.

[2] This is determined using P(all RSB >36%) for the objective to maintain RSB above a target of 36% at least 50% of the time.

[3] The overall ranking applies to all management procedures without a constraint (Table I-1, Table I-2, and Table I-3)

**Table I-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 one year out of a ten-year period. Long-term is a ten-year period after simulating 90 annual cycles and is used for the biomass objectives (i.e., RSB). Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23) and is used for the stability and yield fishery objectives.

| 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 | | | | | | | | | | | |
| P(any RSB<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 | | | | | | | | | | | |
| P(all RSB<36%) | 0.0207 | 0.2209 | 0.3316 | 0.4425 | 0.5609 | 0.6888 | 0.8040 | 0.8813 | 0.9378 | 0.9701 | 0.9843 |
| P(any3 AC > 15%) | 0.86 | 0.87 | 0.87 | 0.87 | 0.87 | 0.88 | 0.88 | 0.90 | 0.92 | 0.94 | 0.95 |
| Median AAV | 16.0% | 16.5% | 16.7% | 16.8% | 17.0% | 17.4% | 18.0% | 18.7% | 19.7% | 21.4% | 23.9% |
| Median average TM | 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 I-1, Table I-2, and Table I-3) | | | | | | | | | | |
| Meet biological objective?[1] | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No |
| Meet target objective?[2] | Yes | Yes | Yes | Yes | No | No | No | No | — | — | — |
| Minimize P(AC3>15%) | 1 | 3 | 3 | 3 | | | | | | | |
| Minimize AAV | 1 | 2 | 4 | 5 | | | | | | | |
| Maximum yield (TM) | 17 | 13 | 10 | 6 | — | — | — | — | — | — | — |
| Average of Ranks[4] | 9 | 7.25 | 6.25 | 4.5 | — | — | — | — | — | — | — |

[1] This is determined using P(any RSB < 20%) for the objective to maintain RSB above 20% at least 95% of the time.

[2] This is determined using P(all RSB >36%) for the objective to maintain RSB above a target of 36% at least 50% of the time.

[3] The overall ranking applies to all management procedures without a constraint (Table I-1, Table I-2, and Table I-3)

**Table I-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 I.1.2). P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least one year out of a ten-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** | | | | | | | | | | | | |
| P(any RSB<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** | | | | | | | | | | | | |
| P(all RSB<36%) | 0.28 | 0.46 | 0.55 | 0.63 | 0.26 | 0.43 | 0.51 | 0.60 | 0.32 | 0.50 | 0.59 | 0.67 |
| P(any3 AC > 15%) | 0.06 | 0.06 | 0.07 | 0.06 | 0.19 | 0.26 | 0.31 | 0.35 | 0.30 | 0.32 | 0.36 | 0.40 |
| Median AAV | 11.2% | 11.3% | 11.6% | 11.7% | 7.0% | 7.7% | 8.1% | 8.8% | 8.0% | 8.8% | 9.8% | 10.8% |
| Median average TM | 46.1 | 48.6 | 49.5 | 50.9 | 45.0 | 48.2 | 49.5 | 51.1 | 46.5 | 48.9 | 50.5 | 51.2 |

**Table I-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 I.1.2). P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least one year out of a ten-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** | | | | | | | | | | | | | |
| 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** | | | | | | | | | | | | | |
| P(all RSB > 36%) | 0.26 | 0.45 | 0.55 | 0.63 | 0.10 | 0.23 | 0.16 | 0.32 | 0.40 | 0.26 | 0.50 | 0.24 | 0.44 |
| P(any3 AC > 15%) | 0.88 | 0.91 | 0.92 | 0.93 | 0.22 | 0.27 | 0.34 | 0.42 | 0.48 | 0.78 | 0.76 | 0.60 | 0.57 |
| Median AAV | 13.2% | 13.5% | 13.8% | 14.1% | 12.7% | 13.1% | 9.2% | 9.9% | 10.3% | 16.1% | 18.2% | 13.3% | 13.9% |
| Median average TM3 | 46.5 | 49.1 | 49.9 | 51.1 | 44.0 | 45.3 | 44.7 | 47.5 | 49.3 | 46.4 | 50.7 | 46.1 | 50.0 |