IPHC Management Strategy Evaluation: Update for 2018

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1 PURPOSE

To provide an update on the progress of the IPHC Management Strategy Evaluation process and seek guidance from the SRB regarding the following topics.

- Appropriate biological sustainability objectives, as well as biological reference points
- Conditioning the OM
- Introducing estimation error
- Simulation of weight-at-age
- Presentation of short-, medium-, and long-term results
- The TCEY distribution framework

Also, the MSAB requested that the SRB clarify paragraphs 24 and 28 of the report from SRB011 (IPHC-2018-SRB011-R).

2 INTRODUCTION

At the 2017 Annual Meeting (AM093) Commissioners supported a revised harvest policy that separates the scale and distribution of fishing mortality (Figure 1). Furthermore, the Commission identified an interim “hand-rail” or reference for harvest advice based on a status-quo SPR, which uses the average estimated coastwide SPR for the years 2014–2016 from the stock assessment. The justification for using an average SPR from recent years is that this corresponds to fishing intensities that have resulted in a stable or slightly increasing stock, indicating that, in the short-term, this may provide an appropriate fishing intensity that will result in a stable or increasing spawning biomass.

The 2017 stock assessment updated the population estimates and determined that the SPR resulting from actual total mortality from all sources in 2017 was 40%, instead of the 45% adopted by Commissioners at AM093. This was an example of estimation error and something that is inherent in the process due to uncertainty in the data. The SPR of 40% was well within the confidence bounds for SPR reported in the 2017 stock assessment (30-59%), and was most likely less than the adopted SPR because of the updated estimation of recent poor recruitment. The estimation may easily go either way (above or below the adopted value).

This document for the Scientific Review Board (SRB) focuses on the six topics listed above, and provides the necessary background, or reference to documents, needed to discuss those six topics. Useful documents to reference are IPHC-2018-MSAB011-07 for a description of objectives (with an update in Appendix Va in IPHC-2018-MSAB011-R, and reproduced here in Appendix II), IPHC-2018-MSAB011-08 for a description of the simulation framework, and IPHC-2018-MSAB011-09 for a discussion of the TCEY distribution framework. The 5-year program of work is described in document IPHC-2018-MSAB011-10, with a detailed description of deliverables up to and including the Annual Meeting in 2021 (AM097).

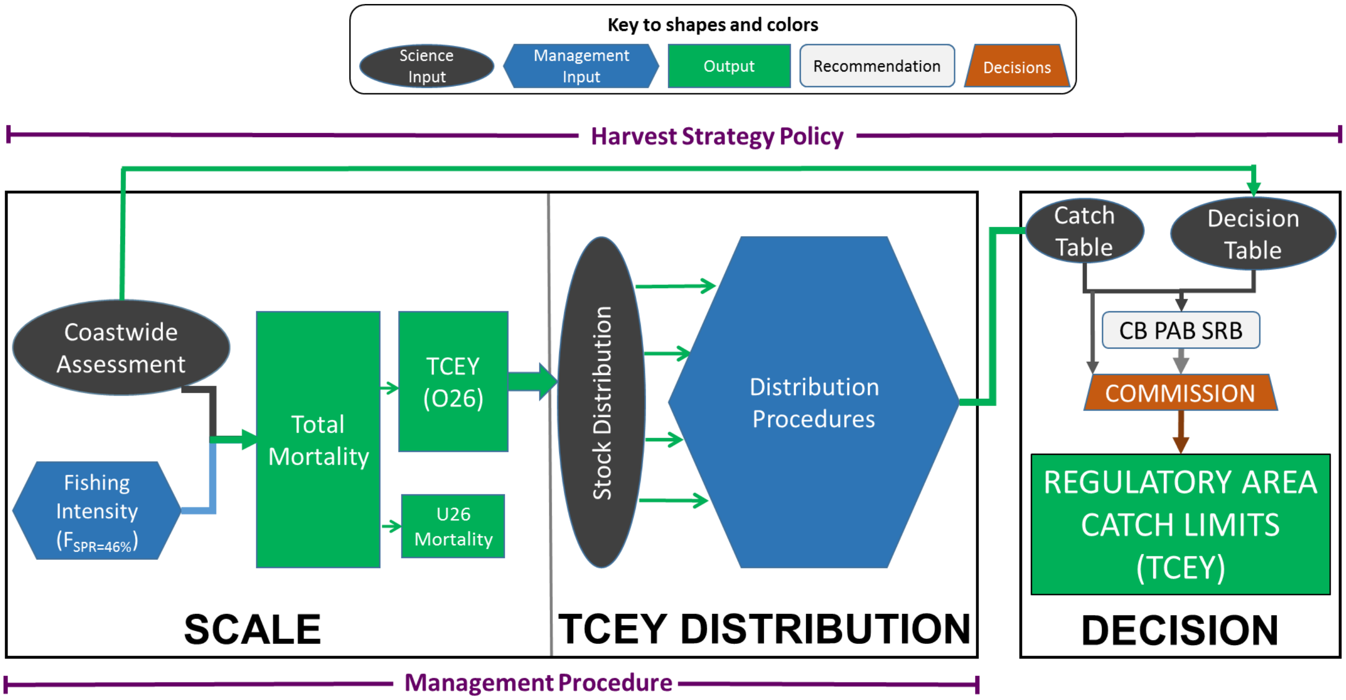

Figure 1: A pictorial description of the interim IPHC harvest strategy policy showing the separation of scale and distribution of fishing mortality. The "decision step" is when policy and decision making (not a procedure) influences the final mortality limits.

The six topics above were also highlighted at the 11th Management Strategy Advisory Board meeting (MSAB011). Specific paragraphs from the MSAB011 report (IPHC-2018-MSAB011-R) mentioning the SRB are included in Appendix I.

3 GOALS AND OBJECTIVES

Defining goals and objectives is a necessary part of a management strategy evaluation (MSE) which should be revisited often to make sure that they are inclusive and relevant. The MSAB has developed five goals with multiple objectives for each (Appendix II). Performance metrics have also been developed from the goals and objectives by defining a measurable outcome, a tolerance (i.e., level of risk), and time-frame over which it is desired to achieve that outcome.

The five goals defined by the MSAB are:

- biological sustainability,
- fishery sustainability, access, and stability,
- minimize discard mortality,
- minimize bycatch and bycatch mortality, and
- serve consumer needs.

This section will focus on the biological sustainability goal and its related objectives.

3.1 BIOLOGICAL SUSTAINABILITY

There are currently two general objectives defined for the biological sustainability goal (Appendix I). These are 1) keep the biomass above a critical limit, and 2) mitigate for uncertainty. The MSAB is currently redefining these with more meaningful descriptions, but the intent is as follows.

3.1.1 Keep spawning biomass above a critical limit

For the general objective of keeping the spawning biomass above a critical limit, the intent is to avoid low coastwide spawning biomass levels, below which severe consequences to the population may occur. IPHC uses the term “biomass limit” to describe this level, and has been using a value of 20% of unfished equilibrium spawning biomass. The probability of the spawning biomass going below the biomass limit should be low, and the MSAB has adopted a tolerance of 5% for that probability.

3.1.2 Mitigate for uncertainty

The intent of the general objective “mitigate for uncertainty” is to buffer against uncertainty in the assessment process and avoid reducing the spawning biomass to near critical levels. Due to uncertainty, it may not be realized that the stock is near critical levels, thus a threshold is defined (greater than the limit) that is not necessarily a target, but is a spawning biomass level that is more acceptable.

There are two measurable objectives associated with this general objective. The first is to maintain the spawning biomass mostly above a biomass threshold. This is similar to the measurable objective of keeping the spawning biomass above a biomass limit, except that the tolerance is higher and the threshold is greater than the limit. The MSAB has requested that the SRB comment on appropriate biomass limit and biomass threshold values. The second measurable objective is to limit the probability of declines in spawning biomass when the spawning biomass is between the biomass limit and the biomass threshold. In other words, when the spawning biomass is below the biomass threshold, the stock should increase towards the biomass threshold. This makes the biomass threshold similar to a target. However, the tolerance for declines is a sliding scale that is higher when the spawning biomass is closer to the biomass threshold.

The IPHC has the opportunity to define a biomass limit and biomass threshold to meet the management objectives for the Pacific halibut fishery. The biomass limit has specific biological meaning because it is a critical level, which may be interpreted as a level below which recruitment would be severely impaired, a level from which the population has a low chance of recovery, or another definition related to the population’s ability to recover. The biomass threshold can be interpreted in many ways. It may be a target, as mentioned earlier. Or it may be a value associated with a tolerance of being below it (for example, a value expected to be above 80% of the time). Appropriate thresholds can be informed by science but are also dependent on the biological sustainability objectives.

3.1.3 Preserving Biocomplexity

An additional objective, preserve biocomplexity, was considered at MSAB009, but no measurable objectives were associated with it. Preserve biocomplexity would fit best as an objective under the goal of biological sustainability, but before defining measurable objectives for preserving biocomplexity, it may help to understand what is meant by preserve biocomplexity.

The term biocomplexity does not have a simple definition, as it spans across many scientific disciplines. The National Science Foundation describes biocomplexity as referring “to phenomena that arise from the dynamic interactions that take place between biological systems, including the influence of humans and the physical environment."[1] The Oxford dictionary defines biocomplexity as "complexity as exhibited by living organisms in their structure, composition, function, and interactions; complexity of a kind considered distinctive of biological systems." It also mentions that the term biocomplexity became more common in the 1980s. It is important to note that biodiversity has a slightly different definition that typically refers to different species. The Oxford dictionary defines biodiversity as "the variety of plant and animal life in the world or in a particular habitat, a high level of which is usually considered to be important and desirable."

In the context of Pacific halibut, preserving biocomplexity would be a useful objective to buffer against potential changes in environmental conditions. The current understanding of biocomplexity across the geographic range of the Pacific halibut stock indicates that IPHC Regulatory Areas do not represent relevant segments of the population (Seitz et al. 2017). Even with migration along the entire coast (Valero and Webster 2012; Webster et al 2013), there are hydrographic and bathymetric obstacles that appear to delineate spawning components in the Gulf of Alaska (GOA), Bering Sea (BS), and Aleutian Islands (AI) (Seitz et al. 2017). Genetic evidence further suggests weak population structure (Drinan et al. 2016).

Population structure and spawning components are likely to buffer a population against changes in the environment. Hilborn et al. (2003) concluded that biocomplexity in stock structure plays a critical role in stability and sustainability of a fish stock. Furthermore, preserving biocomplexity in a fish stock may buffer against population declines in a variable or changing environment. Schindler et al (2010) presented evidence that population diversity within sockeye salmon has reduced the variability in the population and reduced the frequency of fishery closures. This concept can be extended to multiple species in an ecosystem (biodiversity) providing ecosystem stability, just as a diversity of assets adds stability to a financial portfolio. Schindler et al (2010) referred to the diversity in a population or in an ecosystem as a "portfolio effect."

There is evidence of population structure in the population of Pacific halibut, but it is not completely understood. Recruitment to the Pacific halibut population is variable, and it is not clear what the major driving force to recruitment success is. It could be that subcomponents of the population have varying success rates in different environmental instances. Balancing the removals against the current stock distribution to preserve biocomplexity is likely to protect against localized depletion of spatial and demographic components of the stock that may produce differential recruitment success under changing environmental and ecological conditions. This approach could also provide an additional precautionary buffer against spatial recruitment overfishing and may maintain sub-population structure that is not completely understood, but important to the long-term health of the coastwide population.

The structure of two of the four current stock assessment models is developed around identifying portions of the data (both FISS and fishery) that correspond to differing biological and population processes within the larger Pacific halibut stock. This approach, referred to as "Areas-As-Fleets," is commonly used in stock assessments (Waterhouse et al. 2014), and was recommended by the SRB during review of models developed in 2014 (Cox et al. 2016, Stewart and Martell 2015, 2016). This led to defined areas that are referred to as biological Regions.

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[1] https://www.nsf.gov/news/news_summ.jsp?cntn_id=100687&org=NSF&from=news

Biological Regions (hereafter referred to as Regions) were defined with boundaries that matched IPHC Regulatory Areas to correspond to biological differences. The boundaries of IPHC Regulatory Areas were used for many reasons. First, data (particularly historical data) for stock assessment and other analyses are most often reported at the IPHC Regulatory Area scale and are largely unavailable for sub-Regulatory Area evaluation. Particularly for historical sources, there is little information to partition data to a portion of a Regulatory Area. The use of these data is mainly a stock assessment issue. Second, it is necessary to distribute TCEY to IPHC Regulatory Area for quota management, and the final outcome of a distribution procedure will reflect this. If a Region is not defined by boundaries of IPHC Regulatory Areas (i.e. a single IPHC Regulatory Area is in multiple Regions) it will be difficult to create a distribution procedure that accounts for biological stock distribution and distribution of the TCEY to Regulatory Areas for management purposes. Overall, it is highly unlikely that there is a set of Regions that perfectly delineates the stock biologically since different aspects of the stock differ over varying scales, and movement occurs between Regions. However, if the goal is to preserve biocomplexity across the entire range of the Pacific halibut stock, Regions are considered by the IPHC Secretariat to be the best option for biologically-based areas to meet management needs.

Each Region had some qualities that identified it as differing biologically from adjacent Regions, despite clear evidence from tagging studies of movement among all areas at some point in the life cycle of Pacific halibut (Valero and Webster 2012; Webster et al 2013). These qualities include sex ratios, age composition, size-at-age, historical trends, and others that could be indicative of important diversity within the greater Pacific halibut population. The four Regions are labeled as follows and composed of the listed IPHC Regulatory Areas (Figure 1):

Region 2: 2A, 2B, and 2C
Region 3: 3A and 3B
Region 4: 4A and 4CDE
Region 4B: 4B

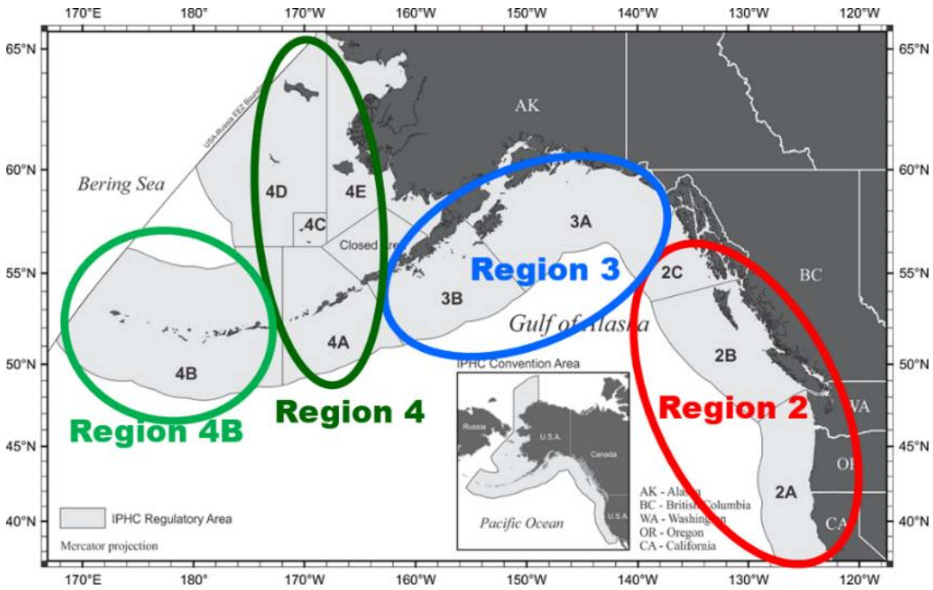

Figure 2. Four biological Regions. They are overlaid on IPHC Regulatory Areas with Region 2 comprised of 2A, 2B, and 2C, Region 3 comprised of 3A and 3B, Region 4 comprised of 4A and 4CDE, and Region 4B comprised solely of 4B.

4 SIMULATION FRAMEWORK

The framework of the closed-loop simulations is a map to how the simulations will be performed (Figure 3). There are four main modules to the framework:

1. The **Operating Model (OM)** is a representation of the population and the fishery. It produces the numbers-at-age, accounting for mortality and any other important processes. It also incorporates uncertainty in the processes and may be composed of multiple models to account for structural uncertainty.
2. **Management Procedure**
    a. **Monitoring (data generation)** is the code that simulates the data from the operating model that is used by the estimation model. It can introduce variability, bias, and any other properties that are desired.
    b. 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. However, simplifications may be necessary to keep simulation times within a reasonable time.
    c. **Harvest Rule** is the application of the estimation model output along with the scale and distribution management procedures (Figure 1) to produce the catch limit for that year.

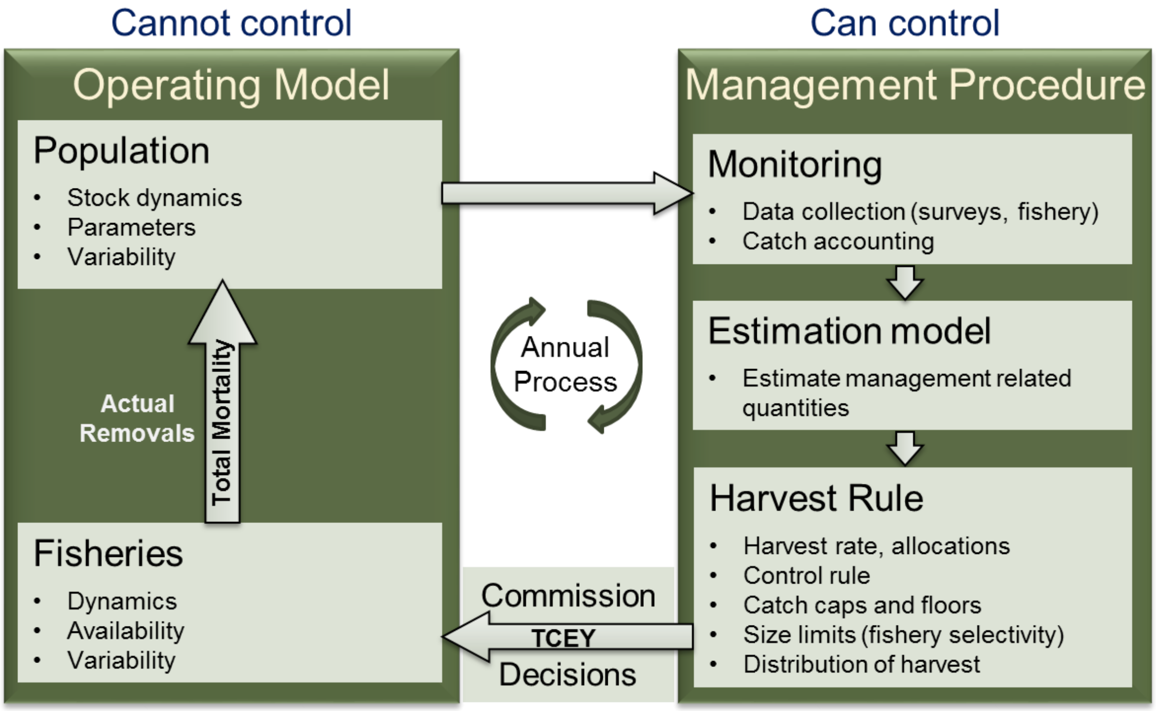

Figure 3: Diagram of the relationship between the four modules in the framework. The simulations run each module on an annual time-step, producing output that is used in the next time-step. See text for a description of operating model, monitoring, estimation model, and harvest rule.

4.1 OPERATING MODEL

For the simulations to investigate a coastwide fishing intensity, the stock synthesis (Methot and Wetzel 2013) assessment software was used as an operating model. This platform is currently used for the stock assessment, and the operating model was comprised of the two coastwide assessment models (short and long time-series) currently used in the ensemble. For future MSE evaluations (in particular, investigating the Distribution component of the harvest policy) a more complex operating model will be developed that can provide outputs by defined areas or regions and can account for migration between these areas. This model has been referred to as a multi-area model.

The current stock assessment ensemble, composed of four different assessment models, includes a cross between coastwide or fleets-as-areas structuring of the data, and the length of the time series. Using an areas-as-fleets model would require generating data and distributing catch to four areas of the coast, which would involve many assumptions. In addition, without a multi-area model, there would not be feedback from migration and productivity of harvesting in different areas. Therefore, only the two coastwide models were used, but with additional variability. These models are structured to use five general sources of removals (these are aggregated for modelling purposes and do not necessarily correspond to specific fisheries or sectors): the directed commercial halibut fishery (including research landings), commercial discard mortality (previously known as wastage), bycatch (from non-halibut-target fisheries), recreational, and subsistence. The TCEY was distributed to each source in an ad hoc manner using current available information (see below).

4.1.1 Conditioning the Operating Model

The operating model (OM) should be a reasonable depiction of reality with an appropriate level of uncertainty, which is accomplished through a process called conditioning. Each individual model (i.e., the two coastwide models) is conditioned by fitting to the same data used in the 2016 stock assessment (Stewart & Hicks 2017), which will be updated to use the 2017 stock assessment (Stewart & Hicks 2018). To evaluate and choose management procedures that are robust to uncertainty in future states of the population, many assumptions in the assessment model were freed up to characterize a wider range of possibilities in the future. Estimating natural mortality for both sexes in both models and estimating steepness were the only changes to estimated parameters from the assessment model when conditioning.

Parameter variability was characterized by randomly sampling parameters for each simulation from a truncated multivariate normal distribution conditioned to data. Unrealistic simulated historical trajectories were eliminated, and were defined by the criteria:

- the population could not support the observed catch
- the steepness parameter was less than 0.6 (based on investigations of what was causing the population trajectories to crash given observed catch)

The SRB requested that a quasi-extinction threshold be established to eliminate OMs that do not meet this criteria in the historical period. The above criteria is an extinction criteria and the IPHC Secretariat is currently working on defining a quasi-extinction level for the historical period to improve the process of conditioning the operating model.

The conditioned OM has a considerable amount of extra variability compared to the ensemble stock assessment (Figure 4). The assessment ensemble contains four individual models while the OM contains only two, which is why the trend at the end of the time series is slightly different, although well within the uncertainty.

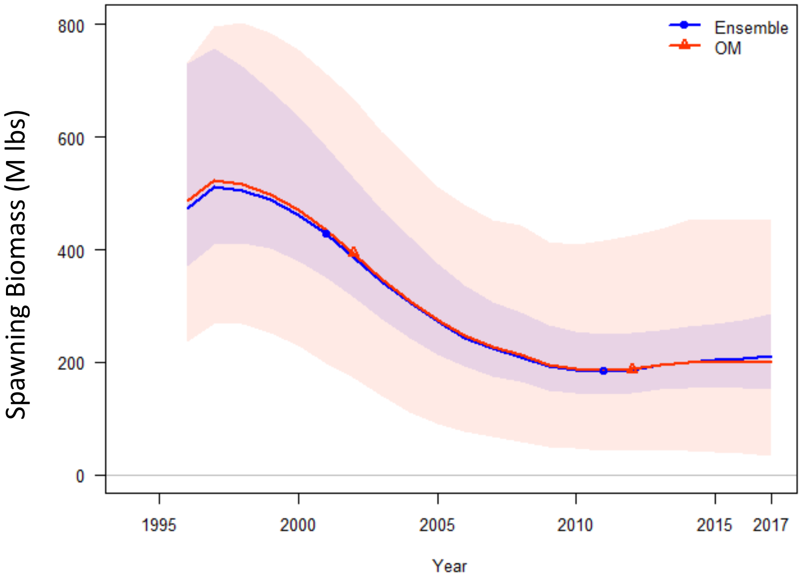

Figure 4: The conditioned operating model (red) compared to the stock assessment ensemble (blue) with 95% confidence intervals.

A potential issue highlighted at SRB11 was that starting the OM in 2017 with such a wide range of uncertainty will not adequately characterize our best knowledge of the near future (short-term) and the medium-term. However, the long-term results are appropriate since the current state would not affect long-term, equilibrium results, and the wide range of uncertainty is a result of the chosen uncertainties to evaluate harvest strategies against. One solution to provide short-term results would be to use predictions from the assessment model and its uncertainty (the blue shaded region in Figure 4) just as is done for annual decision making (i.e., decision table), except present short-term performance metrics (1-3 years from the end of the time-series; 8-11 years from the most recent information on recruitment) associated with MSAB objectives. This method can be used to evaluate the immediate consequences to the fishery that would result if a particular management procedure were implemented.

Medium-term results are more problematic because we have very little predictive power for that time period. In the short-term, we have an idea of where we currently are and what may occur in the next few years (e.g., we have some data indicating recent recruitment and weight-at-age). In the long term, we are summarizing statistics over a wide range of uncertainty and all possible states (we do not need to know anything about the current state of the population). Figure 5 shows the hypothetical utility of the assessment model and the operating model for a range of time frames, and shows that neither model has high utility in the medium term. However, that uncertainty is not well described in the medium term because it is partially dependent on the current state and may show artificial transitory effects from assumptions made to start the OM (cyclical behaviors), but is also affected by the wide range of variability in the OM.

It could be misleading to simply present medium-term results from the OM simulations as unbiased and informative predictions. However, describing the trends of various trajectories (e.g., catch or spawning biomass) between the short term or long term may be useful, and reporting selected medium-term performance metrics for combinations of weight-at-age and recruitment regime (e.g., four combinations of low/high weight-at-age and low/high recruitment) will provide insight into the possible range of outcomes in the medium-term.

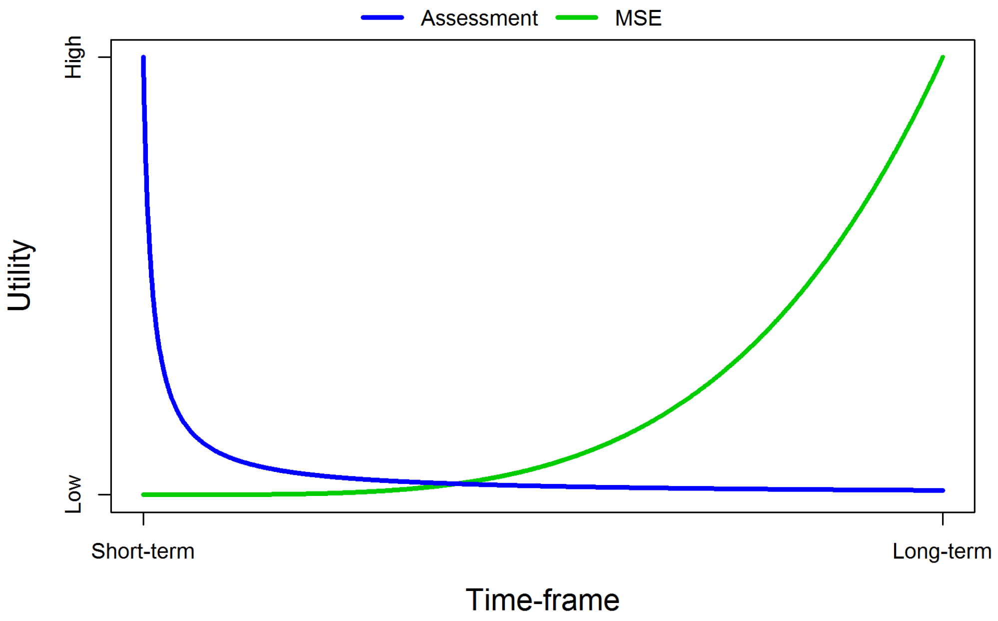

Figure 5: The hypothetical utility of the assessment model (blue with high utility in the short-term) and the operating model in the MSE (green with high utility in the long-term).

4.2 MANAGEMENT PROCEDURE

The elements of the management procedure are described in reverse order because it is easier to understand the decisions made for modelling them since they are dependent on each other. Therefore, the harvest rule is presented first, followed by the estimation model, and finishing with monitoring.

4.2.1 Harvest Rule

The generalized management procedure to evaluate is shown in Figure 1, but the focus will be on the Scale portion to produce results for the MSAB to evaluate before AM095 in 2019. Specifically, the portion of the management procedure being evaluated is a harvest control rule (Figure 6) that is responsive to stock status and consists of a procedural SPR determining fishing intensity, a fishery trigger based on stock status that determines when the fishing intensity begins to be linearly reduced (note that this may differ from the biological threshold), and a fishery limit that determines when there is theoretically no fishing intensity (this may differ from the biological limit). For these simulations, the two coastwide models were used, thus mortality only needed to be distributed to the five coastwide sources of mortality (directed commercial, discard mortality, bycatch mortality, recreational, and subsistence).

Simulations have been used to evaluate a range of SPR values from 25% to 60% and trigger values of 30% and 40% (IPHC-2017-MSAB10-09 Rev 1). Those simulations provided insight into how those different levels of SPR would meet the objectives defined by the MSAB, but few values of SPR below 40% were tested. Future simulations will use a finer resolution of SPR values ranging from 30% to 55% and fishery trigger points of 30% and 40%.

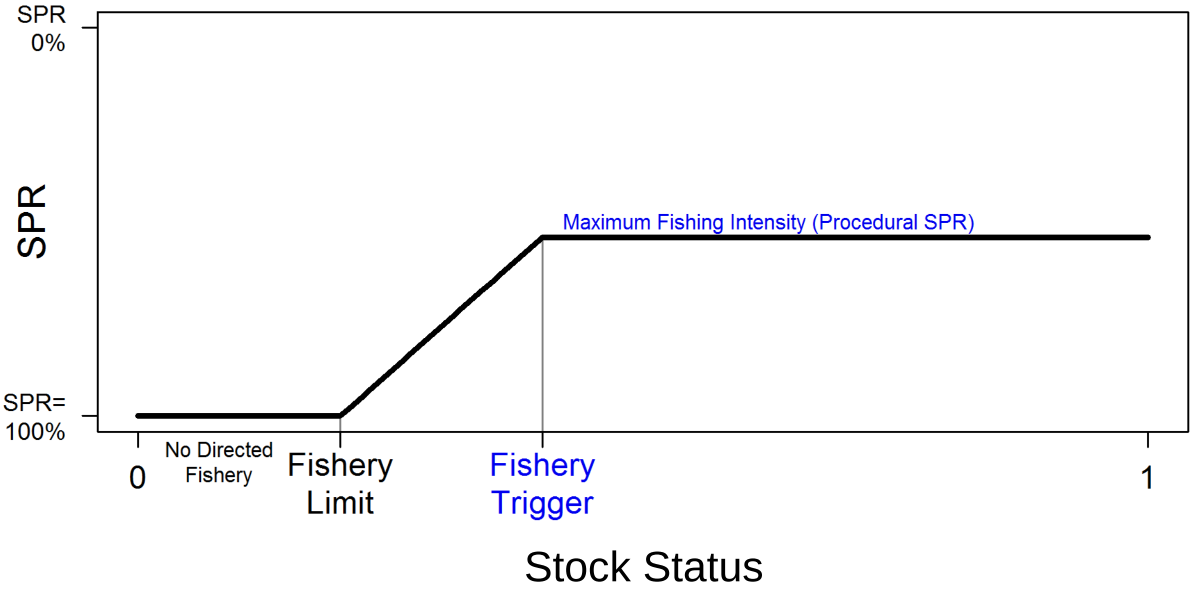

Figure 6: A harvest control rule responsive to stock status that is based on Spawning Potential Ratio (SPR) to determine fishing intensity, a fishery trigger level of stock status that determines when the fishing intensity begins to be linearly reduced, and a fishery limit based on stock status that determines when there is theoretically no fishing intensity (SPR=100%). In reality, it is likely that only the directed fishery would cease. The Procedural SPR and the Fishery Trigger (in blue) are the two values that were evaluated.

4.2.2 Estimation Model

Of the four options to simulate an estimation model presented in IPHC-2017-MSAB10-09 Rev1, the No Estimation Model (previously called Perfect Information) option was used in past simulations. The No Estimation Model method assumes that the population values needed to apply the management procedure are exactly known (e.g., spawning biomass). This option is useful as a reference to better understand the performance with and without uncertainty in an estimation model. Due to time constraints, the only other option to be considered for simulations in 2018 is the Simulate Error option, which will be suitable to understand the effects of estimation error. This method is described after the harvest rule section below.

The harvest control rule contains two components that have estimation error. The first component is the estimated total mortality determined from the specified SPR. The second component is the estimated stock status that is used to reduce the fishing intensity when stock status is low (fishery trigger and fishery limit). These components are dependent on the estimated biomass, but it is more straightforward and computationally efficient to introduce error into these two components, rather than introducing error on the estimated biomass and then determining the resulting estimates of total mortality and stock status.

The 2017 stock assessment (Hicks & Stewart 2018) was used to determine a reasonable amount of variability in these two components. First, they are each investigated separately, and then, because they are intrinsically linked, the bivariate variability is also investigated.

4.2.2.1 Error in Total Mortality

The error in total mortality was determined by fixing the SPR at 46% in the stock assessment and the allocation between sectors at recent levels to determine the estimated total mortality and variability. This is slightly different than how the assessment provides annual catch advice, which uses a fixed total mortality (since that is what decision makers can control) and estimates the variability in the SPR associated with that total mortality. Determining the variability in the total mortality with a fixed SPR is the difference between tactical decision making (short-term, assessment) and strategic decision making (long-term, focused on a harvest strategy).

The coefficient of variation (CV) for estimated total mortality in 2018 for an SPR equal to 46% was 14.1% and includes within- and between-model uncertainty. A boxplot of the estimates of total mortality, standardized to its mean, from the ensemble of four models is shown in Figure 7.

4.2.2.2 Error in stock status

Stock status (measured as dynamic relative spawning biomass, dRSB) is subject to estimation error. Using stock synthesis, dRSB is simply the current biomass divided by dynamic B0. Unfortunately, there is no easily available estimate of error for dRSB or dynamic B0 from stock synthesis, and an assumption had to be made.

The assumption was made that the relative error in dRSB is the same as the error in the current spawning biomass, and was determined by the following logic. Relative spawning biomass is calculated as the current spawning biomass divided by unfished spawning biomass (equilibrium or dynamic). In the equilibrium calculation, B0 is determined separately from current spawning biomass but there is likely covariance between the two. In the dynamic calculation, the covariance is likely greater because the dynamic B0 is calculated in a similar manner as the current spawning biomass, except that fixed catch is set to zero. The calculation is complicated, but if the two quantities vary similarly then the ratio of the two variables should have a similar CV as each variable on its own.

The CV for the estimated spawning biomass in 2018 is 13.7% including within- and among-model uncertainty.

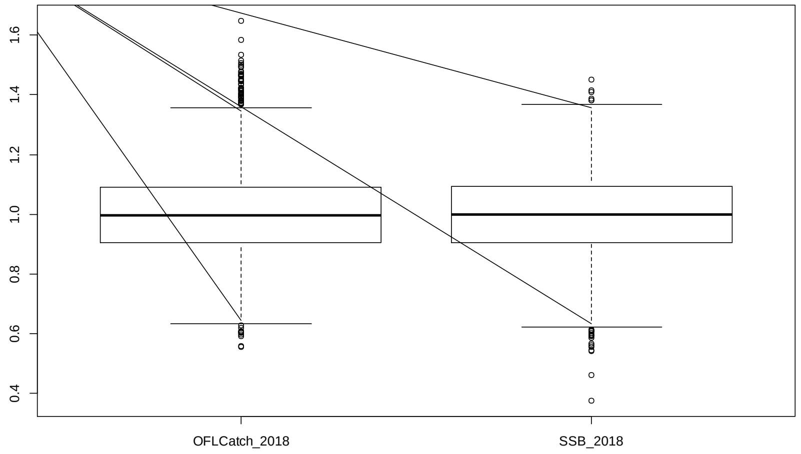

Figure 7: Boxplots of the catch level for 2018 determined for an SPR equal to 46% and 2018 female spawning biomass, each standardized to their respective means.

4.2.2.3 Bivariate Error in Total Mortality and dRSB

Using 2018 spawning biomass as a proxy for dRSB, the bivariate distribution of total mortality and spawning biomass predicted for 2018 is shown in Figure 8. The two quantities are positively correlated with a correlation of 0.51.

4.2.2.4 Autocorrelation for the error in Total Mortality and dRSB

Assessment errors are likely autocorrelated in time because the assessment uses the same historical data with few updates other than an additional year of data. Therefore, there are likely a periods of time where the error is persistently negative or positive. Autocorrelation is likely a very important process to consider in these simulations because it will capture trends in error that has important feedback to a management procedure.

We have not investigated autocorrelation or implemented autocorrelation in the MSE simulation framework. However, we plan to investigate autocorrelation in the assessment, although details have not been determined. We also plan to implement autocorrelation through a random walk or similar procedure that will introduce persistent time periods of negative or positive errors.

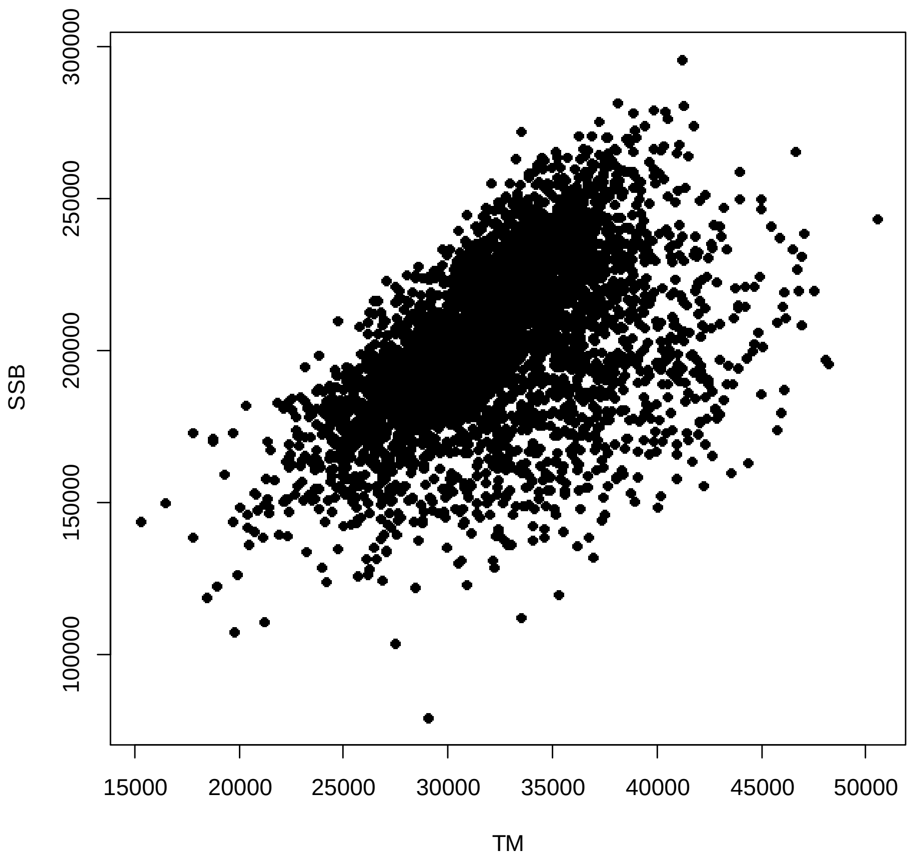

Figure 8: Scatterplot of estimates of total mortality (TM) for 2018 with SPR=46% and female spawning biomass (SSB) in 2018.

4.2.2.5 Introducing Estimation Error in the MSE simulations

The simulations can use each source of error independently, or the bivariate distribution of error to account for correlation between the two. The bivariate distribution is most representative of stock assessment error, but investigating the effect of each source of error would provide a better understanding of the effects of these two sources of error. Assessment error is much more complicated than described by this bivariate distribution and includes many more factors which make it nonparametric and dependent on the data being input. Time permitting, assessment error from an assessment model runs may be introduced into the simulations in the future or as comparison cases.

Using the correlation and CVs, the covariance matrix can be calculated and the simulations can simulate the error using a bivariate normal distribution (in log space) that scales with the level of “perfect information” current spawning biomass and “perfect information” total mortality.

Overall, there are many assumptions in this incorporation of estimation error, but we are only trying to determine a reasonable amount of error for the simulations. Other levels of error would likely be simulated to determine how sensitive the results are to the estimation error.

4.2.3 Monitoring (Data Generation)

The simplified incorporation of estimation error will be used due to time constraints, thus no data are required to be generated. However, if a stock assessment were simulated, there would be many sources of data to generate.

4.3 SUMMARY OF THE FRAMEWORK

A summary of the major specifications for each component is provided below, with the components listed in a specific order where the next component is dependent on the decisions for the previous components.

1) Operating Model
   a) Stock synthesis, based on coastwide assessment models (short and long models).
   b) Five fleets, as in the assessment models (commercial, discards, bycatch, sport, personal use).
   c) Uncertainty incorporated through parameter uncertainty and model uncertainty. See Scenarios.
2) Management Procedure
   a) Estimation Models
      i) Perfect Information (as a reference if we knew population values exactly when applying the harvest rule).
      ii) Simulate error in total mortality and spawning biomass from the simulated time-series to mimic a stock assessment.
   b) Data Generation
      i) Not needed at this time.
   c) Harvest Rule
      i) Coastwide fishing intensity (F_{SPR}) using a procedural SPR.
      ii) A fishing trigger to reduce the fishing intensity (increase SPR) when stock status is below a specified level.
      iii) A fishing limit to cease directed fishing when the stock status is less than a specified value (20%).
      iv) Catch assigned to sectors based on historical information (with variability).

5 SCENARIOS AND VARIABILITY

Scenarios are alternative states of nature in the operating model, which are represented by parameter and model uncertainty, as described in Hicks (2017). These alternative states of nature integrate over the uncertainty in the system that we cannot, or choose not to, control. The scenarios for the MSE simulations include variability in the operating model processes as described in Table 1.

Table 1: Processes and associated variability in the operating model (OM). TM refers to total mortality.

Process	Uncertainty
Natural Mortality (M)	Estimate appropriate uncertainty when conditioning OM
Recruitment	Random, lognormal deviations
Size-at-age	Annual and cohort deviations in size-at-age with bounds
Steepness	Estimate appropriate uncertainty when conditioning OM
Regime Shifts	Autocorrelated indicator based on properties of the PDO for regime shift
TM to sectors	See section on allocating TM to sectors
Proportion of TCEY	Sector specific. Sum of mortality across sectors may not equal coastwide TM

5.1 ALLOCATING SIMULATED TOTAL MORTALITY TO SECTORS

The simulated management strategy returns a coastwide recommended TCEY, which is then allocated to each of the five sectors, with variability. The MSAB09 meeting in May 2017 noted that catch history, in conjunction with uncertainties and sensitivities, can be used to allocate TM to each sector. Recent sector-specific mortality or proportions of TM for each sector were used to guide the allocation using relationships between the sector-specific mortality or proportions to the TM. For example, at low TM the bycatch is likely a larger proportion. Figure 9 shows the percentage of TM attributed for each sector for the past 40 years.

A summary of the methods used to allocate total mortality to the five sources is provided in Table 2. Additional details can be found in IPHC-2017-MSAB10-09.

Due to specified minimum levels of subsistence and bycatch mortality, as well as random variability, it is possible that, at low levels of total mortality, there is no directed commercial mortality and that the actual total mortality exceeds the mortality determined from the management procedure. Expected values of the mortality and proportion by source plotted against Total Mortality is shown in Figure 10.

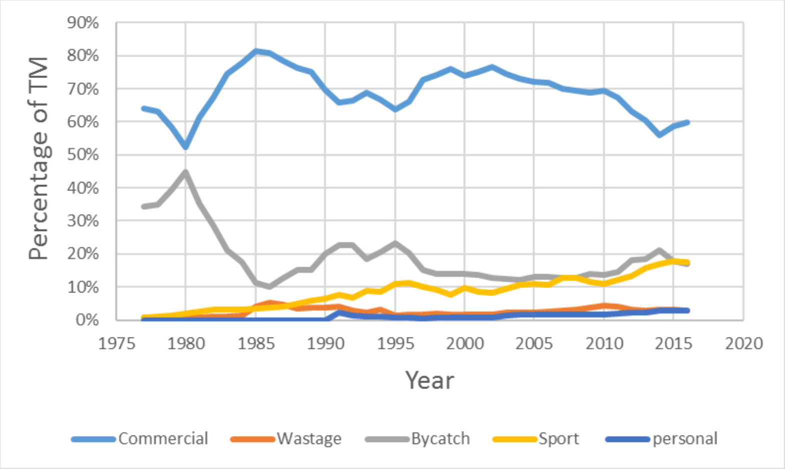

Figure 9: Percentage of Total Mortality (TM) for each sector used in the assessment model from 1976 to 2016.

Table 2: A summary of the methods to allocate total mortality to each of the five sources used in the operating model.

Source	**Method of allocating Total Mortality**
Subsistence	Randomly drawn from a lognormal distribution with a median of 1.2 million pounds (544 t) and a coefficient of variation (CV) of 15%. The 5th and 95th percentiles are approximately 0.9 million pounds (410 mt) and 1.5 million pounds (680 mt), respectively.
Bycatch	The non-directed component of the total mortality is randomly drawn from a lognormal distribution with a median of 7.0 million pounds (3,175 mt) and a CV of 20%. The 5th and 95th percentile are approximately 5.0 million pounds (2,300 mt) and 9.7 million

	pounds (4,400 mt), respectively. Potential improvements to the simulation of bycatch mortality will be discussed.
Recreational	The percentage of recreational mortality was linearly decreasing with total mortality when the total mortality was less than 57 million pounds (25,855 mt). The recreational mortality was randomly drawn from a lognormal distribution with a median of 7.7 million pounds (3,493 mt) and a CV of 20% when the total mortality was greater than 57 million pounds (25,855 mt).
Discard Mortality	The discard mortality was modelled as a function of the commercial plus discard mortality (total mortality minus subsistence, bycatch, and recreational mortality) and the size at age 8 for a male Pacific halibut (smaller fish likely results in more discard mortality).
Commercial	The commercial mortality is the remainder of the total mortality after subtracting the subsistence, bycatch, sport, and discard components. In reality, there is a slight difference between the Total Mortality (TM) and the TCEY because of shortfalls and overages, and adding variability here could simulate this process.

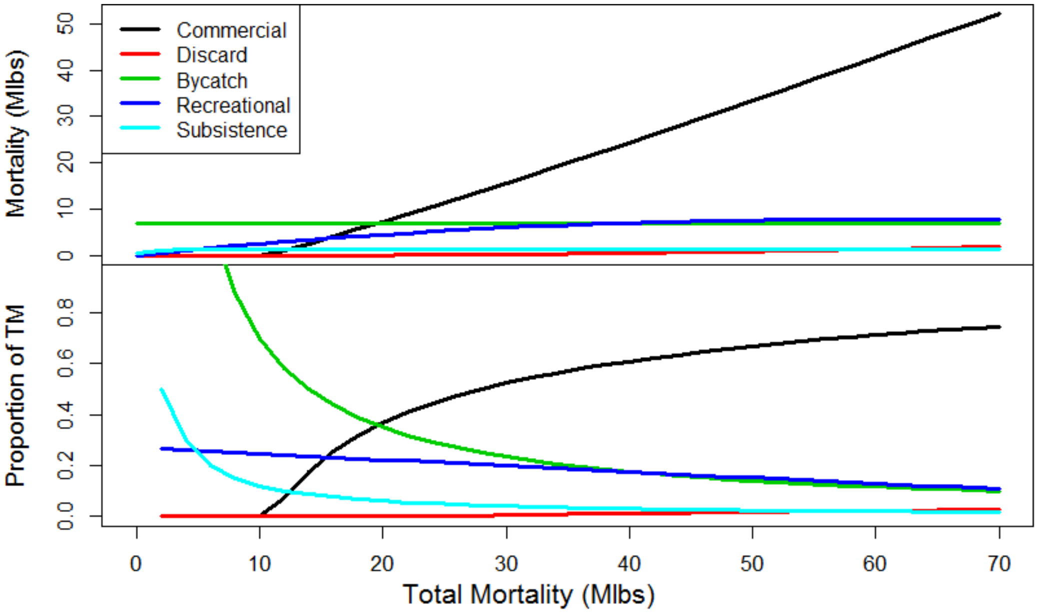

Figure 10: Average sector specific mortality (top, millions of pounds) and the sector-specific proportion of Total Mortality (TM) plotted against TM. For plotting purposes, age 8 males are 6 pounds and random variability is not included.

5.2 SIMULATING WEIGHT-AT-AGE

It is important to simulate time-varying weight-at-age because it is an influential contributor to the yield and status of Pacific halibut. There are 82 years of weight-at-age observations in the long time-series assessment models, with an observed wide range over the years (Figure 11 and Figure 12). Many years of these data have been estimated from sparse data, and the entire time-series has been smoothed to eliminate large deviations from year to year.

Important behaviors of the historical weight-at-age time-series to consider when simulating future weight-at-age are

1. the age-specific weights-at-ages tend to increase and decrease in the same year (little evidence of lags due to specific cohort effects; Figure 11 upper plot),
2. the time-series appears to be similar to a random walk with smooth trends and few large jumps in observations (partly due to the smoothing that was done; Figure 11), and
3. there appears to be some ages that do not strictly follow the general trend (evident at the end of the time series where the sampling was likely greater; Figure 11 lower plot).

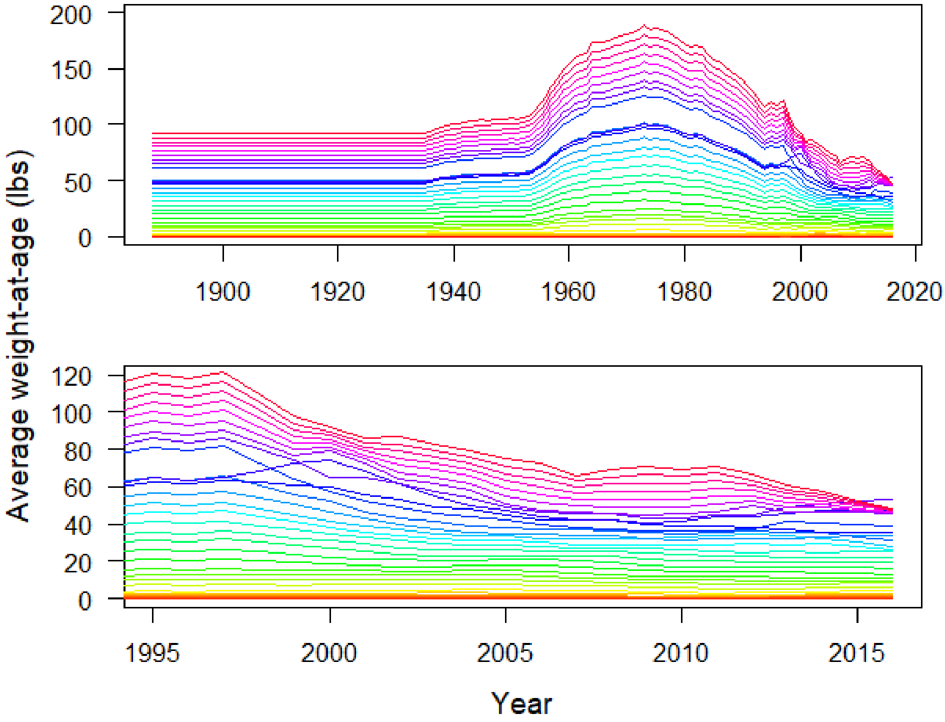

Figure 11: Historical female weight-at-age as used in the long time-series assessment models. Note that the observations are smoothed over years to reduce spurious observations.

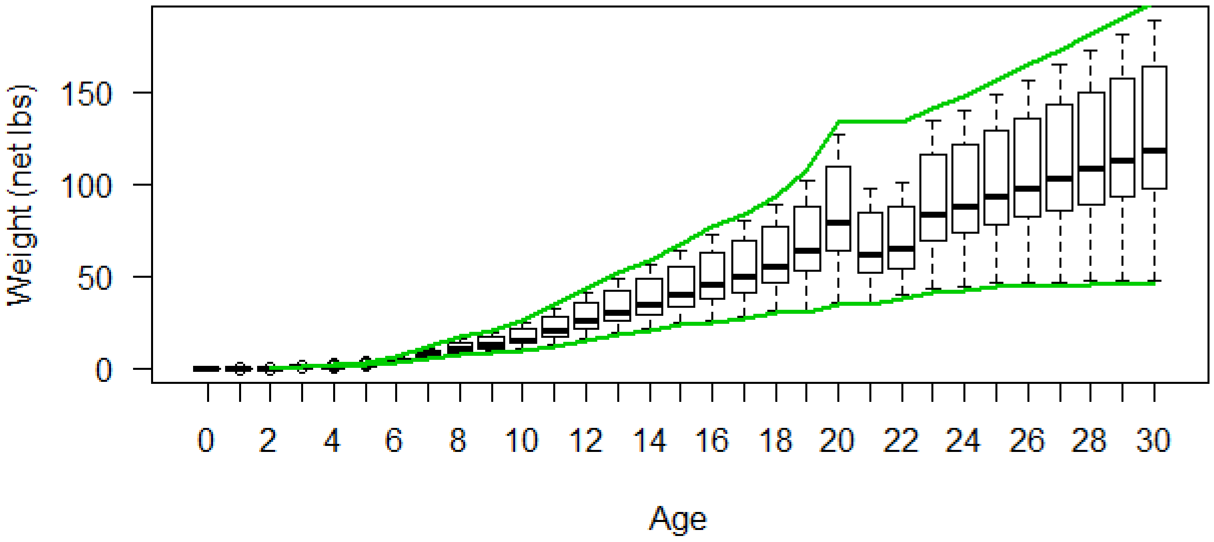

Figure 12: Boxplots of female weight at ages 0 to 30 over all historical years. The green line shows the lower and upper bounds used in the simulations.

The method used to simulate weight-at-age addressed each of these behaviors in the following ways.

1. A single deviation was generated from a normal distribution with a constant standard deviation (0.05), and was a multiplier on the current year's weight-at-age to determine the weight-at-age in the next year. This made all weights for each age increase or decrease similarly.
2. A random walk was used where the weight-at-age in the next year was generated from the weight-at-age in the current year. The deviation in (1) was also correlated with past deviations to simulate periods of similar trends (ρ=0.5).
3. Deviations for each age 6 and greater were generated from a normal distribution with a constant coefficient of variation for each age (0.01), resulting in standard deviations scaled by the mean weight-at-age observed over all historical years with observations. This allows for larger deviations for older fish and provides a mechanism for the mean weight of a specific age to depart from the overall trend simulated in step 1.

The random walk could potentially traverse to extremely high values or low values (obviously negative weight-at-age is not valid). Therefore, boundary conditions were set to limit the range over which weight-at-age could vary. The boundary limits were determined from the observed range of weight at each age, and expanded 5% beyond the minimum and maximum weight at each age observed. Two upper boundaries (ages 21 and 22) were expanded further to equal the upper boundary of age 20 (Figure 12). The random walk simulations remained within the bounds by applying the following algorithm.

1. If a weight-at-age was simulated to be beyond the bounds, the deviations for only the ages where the age-specific bounds were exceeded were reduced by one-half and applied again to determine if it still exceeded the bounds.
2. Repeat step (1) until no age-specific bounds were exceeded.

Example simulated weight-at-age time series are shown in Figure 13.

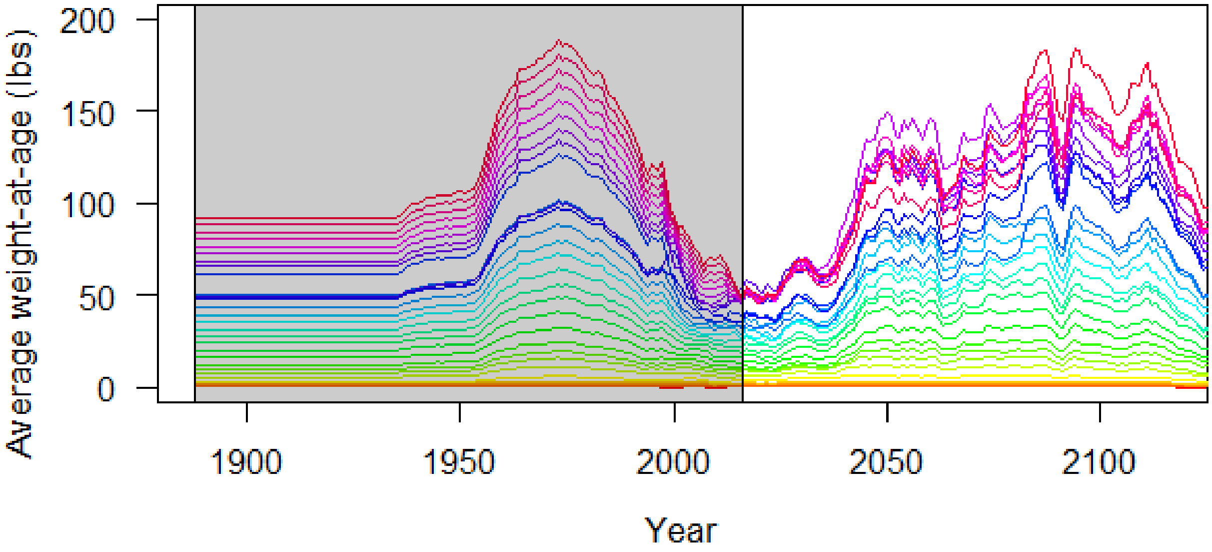

Figure 13: One potential simulated female weight at age in the historical period (1888-2016, shaded) and the simulated period (2017-2116).

5.3 SIMULATING REGIME SHIFTS

An environmental regime is used in the stock assessment to determine if average recruitment is high or low. This is based on the Pacific Decadal Oscillation (PDO, http://research.jisao.washington.edu/pdo/, Mantua et al. 1997, Figure 14) and the value is 0 or 1 depending on classified cool or warm years, respectively (Figure 15).

The regime was simulated in the MSE by generating a 0 or 1 to indicate the regime in that future year. To encourage runs of a regime between 15 and 30 years (an assumption of the common periodicity, although recent years have suggested less), the environmental index was simulated as a semi-Markov process, where the next year depends on the current year. However, the probability of changing to the opposite regime was a function of the length of the current regime with a probability of changing equal to 0.5 at 30 years, and a very high probability of changing at 40 years.

The simulated length of a regime was most often between 20 and 30 years, with occasional runs between 5 and 20 years.

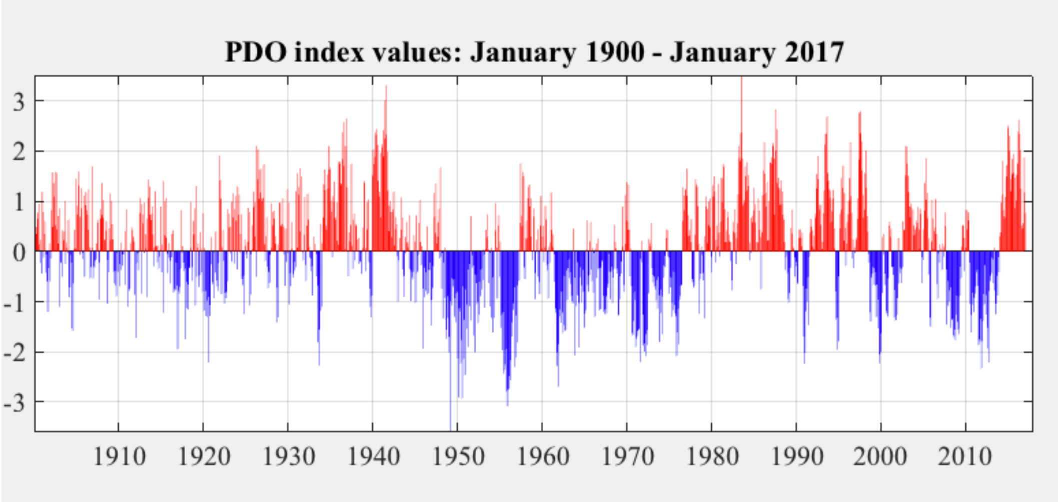

Figure 14: Pacific Decadal Oscillation (PDO) (figure from http://research.jisao.washington.edu/pdo/).

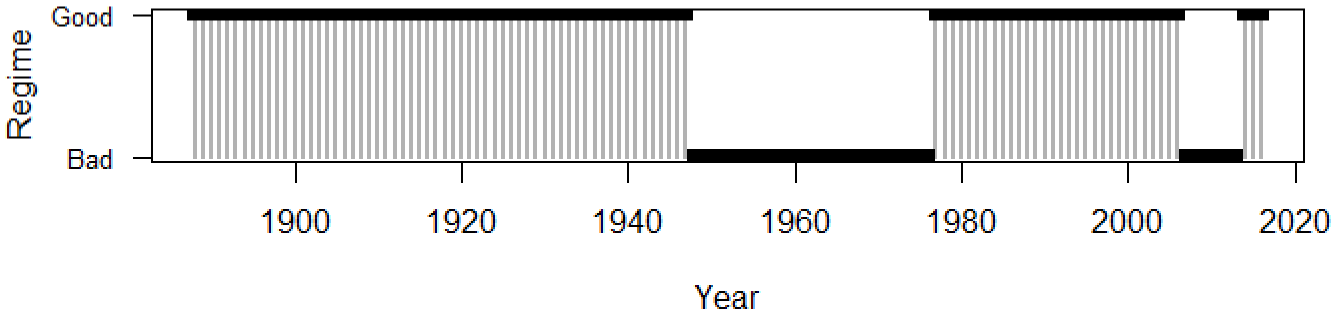

Figure 15: Good and bad regimes in the Pacific halibut stock assessment for 1888-2016.

5.4 SOME ADDITIONAL SCENARIOS NOT CURRENTLY CONSIDERED

Some scenarios that were not considered, but will likely be considered in the future are:

Selectivity: It may be desirable for the time-varying selectivity for at least commercial gears to be linked to changes in weight-at-age. Also, changes in technology to avoid bycatch could also lead to changes in selectivity.

Migration: Migration will require a multi-area model and hypotheses about movement. A multi-area model is being developed with four regions. Migration hypotheses will be informed by tagging data as well as other observations from various fisheries and surveys.

5.5 MSE RESULTS

Results from the simulations will report short-term and long-term performance statistics, and qualitatively describe transitions from the short- to long-term. More specifically, the short-term will use the assessment ensemble and a three-year projection to calculate MSAB determined objectives. The long-term will summarize performance statistics over the last 10 years of 100-year simulations.

Results from initial simulations were provided at MSAB010. Preliminary results from additional simulations incorporating estimation error are presented here for comparison. The SPR was fixed at 46% and the 30:20 control rule was used. Estimation error was introduced for two cases: error in only the total mortality (CV=0.1), and error in both total mortality and stock status (CV=0.1 for both). Autocorrelation in errors was not simulated. Performance metrics associated with these two cases are compared to the "No Estimation Error" case in **Table 3**.

Table 3: Performance metrics for simulations with no estimation error, error in only total mortality (CV=0.1), and error in total mortality and stock status (CV=0.1 for both).

Metric	**No Estimation Error**	**TM Error = 0.10**	**Both Error = 0.10**
Median average SPR	0.47	0.47	0.43
Biological Sustainability			
Median average dRSB	0.40	0.40	0.31
Median average # mature females	7.38	7.50	6.39
P(all dRSB<20%)	0.04	0.04	0.05
P(all dRSB<30%)	0.09	0.10	0.45
Fishery Sustainability			
Median average TM (Mlbs)	35.68	38.94	38.31
10th and 90th TM (Mlbs)	12 &103	12 & 101	12 & 109
Median average FCEY (Mlbs)	28.65	31.81	31.20
P(all Comm=0)	0.11	0.10	0.18
P(all FCEY < 50.6 Mlbs)	0.71	0.70	0.68
P(all decrease TM > 15%)	0.06	0.18	0.30
median AAV TM	0.06	0.14	0.31

6 DISTRIBUTION OF THE TCEY

A considerable amount of discussion related to a description of the harvest strategy policy occurred at previous MSAB meetings. Figure 1 shows an updated depiction of the harvest strategy policy with terms describing the various components. These terms are defined in the IPHC glossary[2], but of note for this paper are TCEY distribution, stock distribution, and distribution procedures. The management procedure is the sequence of elements including the assessment, fishing intensity, stock distribution, and distribution procedures. The goal of the MSAB is to define a management procedure that will be used to output O26 mortality limits for each Regulatory Area that meet the long-term objectives of managers and stakeholders. The "decision" step on the right of Figure 1 is where a deviation from the management

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[2] https://iphc.int/the-commission/glossary-of-terms-and-abbreviations

procedure may occur due to input from other sources and decisions of the Commissioners that may reflect current biological, environmental, social, and economic conditions.

As tasked by the Commission, an evaluation of the previous IPHC informal “harvest policy” was undertaken and presented at MSAB08. That harvest policy used a procedure that took the coastwide stock assessment as an input, and output 1) the coastwide Total Constant Exploitation Yield (TCEY) (across all Regulatory Areas), and 2) the TCEY and Fishery Constant Exploitation Yield (FCEY) for each Regulatory Area. The integral input to that harvest policy was the coastwide stock assessment. The scaling of catch for that harvest policy revolved around the concept of exploitable biomass (EBio) and defined harvest rates. EBio was based on numbers-at-age, weight-at-age, and externally derived selectivity-at-age.

Given the complex but static definition of EBio, there was a divergence between EBio and the assessment which updated selectivity each year, and later allowed it to vary over time. In other words, EBio was not representative of the stock assessment results because the selectivity curves used to define EBio were out of date. It is difficult to exactly characterize what EBio is because it is a single value meant to describe a complex amalgamation of fleets, areas, stock size, and size-at-age. Ebio was not the biomass of fish over 26 inches (O26, 66 cm) or 32 inches (O32, 81 cm), and it was not the biomass of the stock that is encountered by the fisheries.

Ebio was apportioned to IPHC Regulatory Areas using the estimated distribution of O32 biomass from the setline survey. Then, IPHC Regulatory Area-specific catch levels (TCEY) were calculated from defined harvest rates. A harvest rate of 16.125% was used for western areas (3B, 4A, 4B, and 4CDE) and 21.5% for eastern areas (3A, 2C, 2B, and 2A). These harvest rates were based on the selection of O26 fish for TCEY (Hare 2011) and were converted from values originally based on O32 fish, reflecting the size limit (Clark and Hare 2006). They were lower in the west due to the presence of small fish, a lower estimated yield-per-recruit, and greater uncertainty in historical analyses. These harvest rates were explicitly linked to EBio.

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. The procedure uses a coastwide fishing intensity based on spawning potential ratio (SPR), which defines the “scale” of the coastwide catch. This eliminates the use of EBio and area-specific absolute harvest rates. Therefore, there are currently two inputs to the current management procedure for distributing the TCEY among IPHC Regulatory Areas: 1) the current estimated stock distribution and 2) relative target harvest rates.

6.1 A BACKGROUND ON 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 (Webster 2018). Briefly, observed WPUE is fitted with a model that accounts for correlation between setline survey stations over time (years) and space (within Regulatory Areas). Competition for hooks by Pacific halibut and other species, the timing of the setline survey relative to annual fishery mortality, and observations from other fishery-independent surveys are also accounted for in the approach. This fitted model is then used to predict WPUE (relative density) of Pacific halibut for every setline survey station in the design (including all setline survey expansion stations), regardless of whether it was fished in a particular year. These predictions are then averaged within each IPHC Regulatory Area, and combined among IPHC Regulatory Areas, weighting by the “geographic extent” (calculated area within the survey design depth range) of each IPHC Regulatory Area. It is important to note that this produces relative indices of abundance and biomass, but does not produce an absolute measure of abundance or biomass because it is weight-per-unit-effort scaled by the geographic extent of each IPHC Regulatory Area. These indices are useful for determining trends in stock numbers and biomass, and are also useful to estimate the geographic distribution of the stock.

6.2 USING RELATIVE HARVEST RATES

The distribution of the TCEY for 2018 was shifted from the estimated stock distribution to account for additional factors related to productivity and paucity of data in each IPHC Regulatory Area. Previously, this was accomplished by applying different harvest rates in western areas (16.125% in IPHC Regulatory Areas 3B, 4A, 4B, and 4CDE)) and eastern areas (21.5% in IPHC Regulatory Areas 2A, 2B, 2C, and 3A). However, with the elimination of EBio and the use of SPR-based fishing intensity to determine the coastwide scale, the TCEY, rather than the esoteric concept of exploitable biomass was distributed. Therefore, an absolute measure of harvest rate is not necessary, but it may still be desired to shift the distribution of the TCEY away from the estimated stock distribution to account for other factors. Consistent with the previous approach, relative harvest rates were used with a ratio of 1.00:0.75, being equal to the ratio between 21.5% and 16.125%. This application shifted the target TCEY distribution away from the stock distribution by moving more TCEY into IPHC Regulatory Areas 2A, 2B, 2C, and 3A and less TCEY from IPHC Regulatory Areas 3B, 4A, 4B, and 4CDE (Table 4), thus harvesting at a higher rate in eastern IPHC Regulatory Areas.

Table 4: IPHC Regulatory Area stock distribution estimated from the 2017 space-time model O32 WPUE, IPHC Regulatory Area-specific relative target harvest rates, and resulting 2018 target TCEY distribution based on the IPHC’s 2018 interim management procedure (reproduced from Table 1 in IPHC-2018-AM094-11 Rev_1).

	2A	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Total**
O32 stock distribution	1.7%	11.3%	16.6%	35.6%	10.0%	6.6%	4.8%	13.3%	100.0%
Relative harvest rates	1.00	1.00	1.00	1.00	0.75	0.75	0.75	0.75	--
Target TCEY Distribution	1.9%	12.4%	18.2%	38.9%	8.2%	5.4%	3.9%	10.9%	100.0%

6.3 REDEFINING THE TCEY DISTRIBUTION PROCEDURE

TCEY distribution is the part of the management procedure for distributing the TCEY among Regulatory Areas and is composed of a purely scientific component to distribute the TCEY in proportion to its estimated biomass in each area (stock distribution) and steps to further modify the distribution of the TCEY based on additional considerations (distribution procedures). Those two components are described below.

6.3.1 Redefining Stock Distribution

Emerging understanding of biocomplexity across the geographic range of the Pacific halibut stock indicates that IPHC Regulatory Areas should only be considered as management units and do not represent relevant sub-populations (Seitz et al. 2017). Balancing the removals against the current stock distribution is likely to protect against localized depletion of spatial and demographic components of the stock that may produce differential recruitment success under changing environmental and ecological conditions. Biological Regions, defined earlier and shown in Figure 2, are considered by the IPHC Secretariat to be the best option for biologically-based areas to meet management needs.

The overarching conservation goal for Pacific halibut is to maintain a healthy coastwide stock. However, given the wide geographic range of the Pacific halibut stock, there likely is stock structure that we do not fully understand, and this stock structure may be important to coastwide stock health. Therefore, conservation objectives relate to where harvesting occurs, with an objective to retain viable spawning activity in all portions of the stock. One method for addressing this objective is to distribute the fishing mortality relative to the distribution of observed stock biomass. This requires defining appropriate areas for which the distribution is to be conserved. Splitting the coast into many small areas for conservation objectives can result in complications including being cumbersome to determine if conservation objectives are met, being difficult to accurately determine the proportion of the stock in that area, being subject to inter-annual variability in estimates of the proportion, forcing arbitrary delineation among areas with evidence of strong stock mixing, and not being representative of biological importance. Therefore, Biological Regions represent the most logical scale over which to consider conservation objectives related to distribution of the fishing mortality. Adjusting the distribution of the TCEY among Biological Regions to account for additional considerations, and further distributing the TCEY to IPHC Regulatory Areas would be done through steps defined in the Distribution Procedures component (Figure 1).

In addition to using Biological Regions for stock distribution, the “all sizes” WPUE from the space-time model (Figure 16), which is largely composed of O26 Pacific halibut (due to 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.

6.4 DISTRIBUTION PROCEDURES

Distribution Procedures contains the steps of further modifying the distribution of the TCEY among Biological Regions and then distributing the TCEY among IPHC Regulatory Areas within Biological Regions (Figure 17). Modifications at the Biological Region or IPHC Regulatory Area level may be based on differences in production between areas, observations in each area relative to other areas (e.g., WPUE), uncertainty of data or mortality in each area, defined allocations, or national shares. Data may be used as indicators of stock trends in each Region or IPHC Regulatory Area, and are included in the Distribution Procedures component because they may be subject to certain biases and include factors that may be unrelated to biomass in that Biological Region or IPHC Regulatory Area. For example, commercial WPUE is a popular source of data used to indicate trends in a population, but may not always be proportional to biomass. Types of data may be used include fishery WPUE, survey observations (not necessarily the IPHC fishery-independent setline survey), age-compositions, size-at-age, and environmental observations.

The steps in the Distribution Procedures may consider conservation objectives, but they will mainly be developed with respect to fishery objectives. Yield and stability in catch levels are two important fishery objectives that often contradict each other (i.e. higher yield often results in less stability). Additionally, area-specific fishery objectives may be in conflict across IPHC Regulatory Areas. Pacific halibut catch levels are defined for each IPHC Regulatory Area and quota is accounted for by those Regulatory Areas. Therefore, IPHC Regulatory Areas are the appropriate scale to consider fishery objectives.

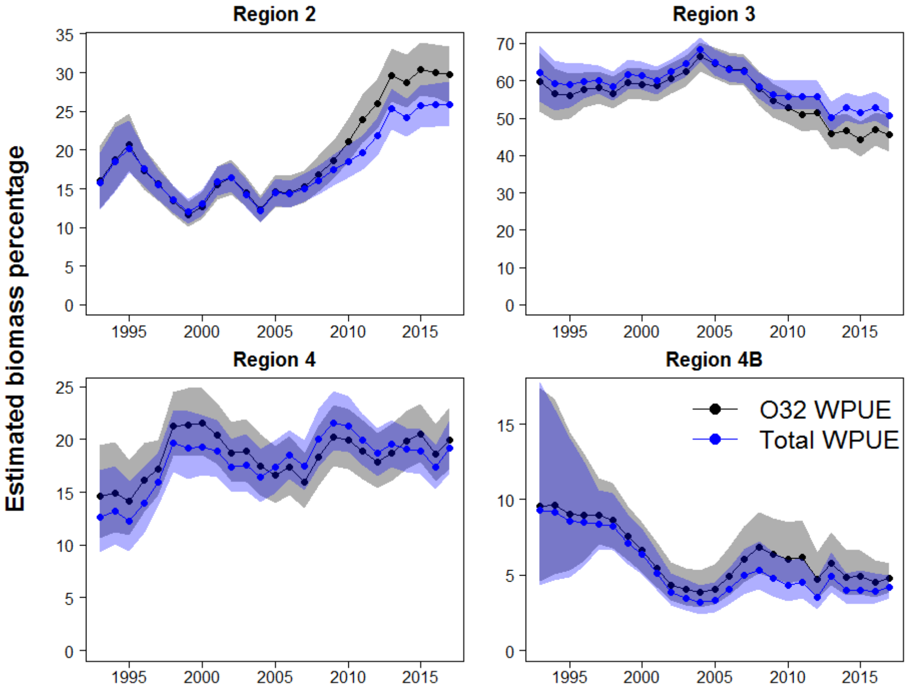

Figure 16: Estimated stock distribution (1993-2017) based on estimate WPUE from the space-time model of O32 (black series) and all sizes (blue series) of Pacific halibut. Shaded zones indicate 95% credible intervals.

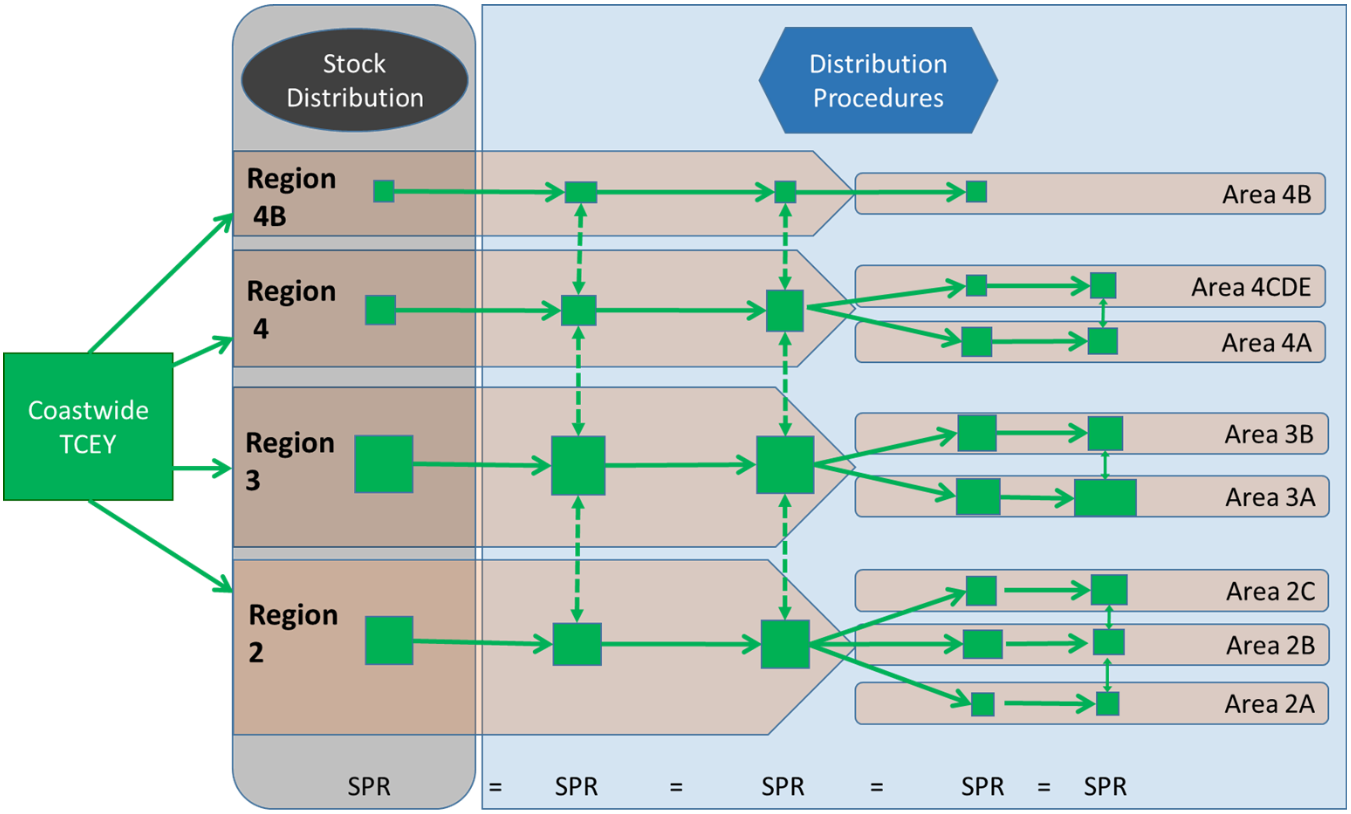

Figure 17: The process of distributing the TCEY to Regulatory Areas from the coastwide TCEY. The first step is to distribute the TCEY to Biological Regions based on the estimate of stock distribution. Following this, a series of adjustments may be made based on observations or social, economic, and other considerations. Finally, the adjusted regional TCEY's are allocated to IPHC Regulatory Areas. The allocation to IPHC Regulatory Areas may occur at any point after regional stock distribution. The dashed arrows represent balancing that is required to maintain a constant coastwide SPR.

6.5 A SUMMARY OF THE MANAGEMENT PROCEDURE FOR DISTRIBUTING TCEY ACROSS THE COAST

The harvest strategy policy begins with the coastwide TCEY determined from the stock assessment and fishing intensity determined from a target SPR (Figure 1). When distributing the TCEY among regions, stock distribution occurs first to distribute the harvest in proportion to biomass and satisfy conservation objectives, and then is followed by adjustments across Regions and Regulatory Area based on distribution procedures to further encompass conservation objectives and consider fishery objectives. The key to these adjustments is that they are relative adjustments such that the overall fishing intensity (target SPR) is maintained (i.e., a zero sum game). Otherwise, the procedure is broken and it is uncertain if the defined objectives will be met.

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

1. **Coastwide Target Fishing Intensity:** Determine the coastwide total mortality using a target SPR that is most consistent with IPHC objectives defined by the Commission. Separate the total mortality in ≥26 inches (O26) and under 26 inches (U26) components. The O26 component is the coastwide TCEY.
   1.1. Target SPR is scheduled for evaluation at the 2019 Annual Meeting. The current interim target SPR is 46%.
2. **Regional Stock Distribution:** Distribute the coastwide TCEY to four (4) biologically-based Regions using the proportion of the stock estimated in each Biological Region for all sizes of Pacific halibut using information from the IPHC setline survey and the IPHC space-time model.
   2.1. Four Regions (2, 3, 4, and 4B) are defined above (Figure 2).
3. **Regional Allocation Adjustment:** Adjust the distribution of the TCEY among Biological Regions to account for other factors.
   3.1. For example, relative target harvest rates are part of a management/policy decision that may be informed by data and observations. This may include evaluation of recent trends in estimated quantities (such as fishery-independent WPUE), inspection of historical trends in fishing intensity, recent or historical fishery performance, and biological characteristics of the Pacific halibut observed in each Biological Region. The IPHC Secretariat may be able to provide Yield-Per-Recruit (YPR) and/or surplus production calculations as further supplementary information for this discussion. The regional relative harvest rates may also be determined through negotiation, which is simply an allocation agreement for further Regional adjustment of the TCEY.
4. **Regulatory Area Allocation:** Apply IPHC Regulatory Area allocation percentages within each Biological Region to distribute the Region-specific TCEY's to Regulatory Areas.
   4.1. This part represents a management/policy decision, and may be informed by data, based on past or current observations, or defined by an allocation agreement. For example, recent trends in estimated all sizes WPUE from the setline survey or fishery, age composition, or size composition may be used to distribute the TCEY to IPHC Regulatory Areas. Inspection of historical trends in fishing intensity or catches by IPHC Regulatory Area may also be used. Finally, agreed upon percentages are also an option. This allocation to IPHC Regulatory Areas may be a procedure with multiple adjustments using different data, observations, or agreements

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

5. **Seasonal Regulatory Area Adjustment**: Adjust individual Regulatory Area TCEY limits to account for other factors as needed. This is the policy part of the harvest strategy policy and occurs as a final step where other objectives are considered (e.g. economic, social, etc.).
   5.1. Departing 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 may result in unpredictable outcomes, but could also take advantage of current situations.

7 RECOMMENDATION/S

That the SRB:

1) **NOTE** paper IPHC-2018-SRB011-08 which provided an update on the IPHC management strategy evaluation.
2) **CONSIDER** the goals and objectives listed in Appendix II and the definitions of biological and fishing reference points.
3) **RECOMMEND** appropriate biological sustainability objectives and biological reference points from a scientific point of view.
4) **CONSIDER** the simulation framework and assumptions as described, including introducing variability to the OM, simulating weight-at-age and environmental regimes, and distribution of the Total Mortality to different sources of mortality.
5) **RECOMMEND** improvements to conditioning the operating model, simulating variability in different processes (especially weight-at-age), and introducing estimation error into the simulations.
6) **CONSIDER** the interpretation of short-term, medium-term, and long-term results.
7) **RECOMMEND** additional methods for presenting short-, medium-, and long-term results.
8) **CONSIDER** the distribution frame-work and the separation of scientific and management elements of distribution procedures, and how distributing the TCEY may contribute to conserving the coastwide stock of Pacific halibut.
9) **RECOMMEND** modifications that may improve the TCEY distribution framework and which components the MSAB should consider when developing management procedures to evaluate.
10) **CLARIFY** paragraphs 24 and 28 of the report from SRB011 (IPHC-2018-SRB011-R).

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9 APPENDICES

Appendix I MSAB requests requesting SRB input

Appendix II Measurable objectives and associated performance metrics

APPENDIX I: MSAB REQUESTS REQUESTING SRB INPUT

28. The MSAB **REQUESTED** that the IPHC Secretariat continue to discuss the Biological Sustainability (conservation) objectives with the IPHCs Scientific Review Board (SRB), including the appropriate female spawning biomass limit and female spawning biomass threshold.

41. The MSAB **REQUESTED** that the IPHC Secretariat present the methods for producing short-, medium-, and long-term results to the SRB for their review and comment.

45. The MSAB **REQUESTED** that the SRB clarify the meaning of paragraphs 24 and 28 in the SRB report, IPHC-2017-SRB011-R.

54. The MSAB **AGREED** that estimation error should be simulated from a joint distribution representing error in the estimated Total Mortality and the estimated stock status, with autocorrelation. The MSAB **REQUESTED** that the SRB review these methods to incorporate estimate error.

60. The MSAB **REQUESTED** that the simulations incorporate:

   d) autocorrelation at a level determined appropriate by the IPHC Secretariat and the SRB.

61. The MSAB **REQUESTED** that when reporting results:

   a) the long-term be represented by 100 simulated annual cycles from the Operating Model and performance metrics summarized over the 10 annual cycles.
   b) short- and medium-term performance metrics be presented for management procedures that meet long-term objectives.
   c) the short-term be represented by the assessment ensemble and performance metrics presented for the immediate three years. These performance metrics are not necessarily the same as for long-term metrics, and may be actual values (e.g. catch in 2019) instead of a summary over years.
   d) the medium-term be summarized qualitatively by describing the transition from the short-term to the medium-term using the closed-loop simulations. Sensitivities (e.g. holding weight-at-age at low levels or constant) can help to inform the medium-term transitions.
   e) phase-in procedures are considered when appropriate.

62. The MSAB **REQUESTED** that IPHC Secretariat discuss the time-frames detailed in paragraph 61, with the SRB

63. The MSAB **REQUESTED** that the IPHC Secretariat consider the following improvements to the simulation framework:

   a) investigate improvements to simulating weight-at-age with input from the SRB.

64. The MSAB **NOTED** that the Operating Model and how it is conditioned is adequate for the evaluation of the HCR, and **REQUESTED** that the IPHC Secretariat present these methods to the SRB.

69. The MSAB **NOTED** that:

a) if the goal of a procedure is to maintain a constant SPR through all steps of distributing the TCEY, then a change in distribution may change the total coastwide mortality to maintain that SPR.

b) there are science-based and management-derived elements in the TCEY distribution procedure. Some distribution procedures may incorporate one or both elements.

c) stock distribution is science-based and is linked to biological sustainability objectives. WPUE from the space-time model is used to determine stock distribution to biological regions, and using “all sizes” in the calculation of WPUE is more congruent with the TCEY, while acknowledging that the IPHC fishery-independent setline survey catches a small number of Pacific halibut below 26 inches.

d) the IPHC Secretariat has described four biological Regions (consistent with IPHC Regulatory Area boundaries) based on the best available science, and will be used for stock distribution as the first step, after which distribution procedures would distribute the TCEY to meet fishery objectives.

e) relative harvest rates among Regions are science-based and management-derived, and within Regions are management-derived. Science-based foundations could include productivity analyses, while management-derived elements may include quantity and quality of data in each area and other area-specific objectives.

f) many more elements of the TCEY distribution procedure may be developed and include management-derived elements.

g) TCEY distribution procedures are to be evaluated against objectives and reported at AM097 in 2021. Biological sustainability objectives are related to biological Regions and Fishery objectives are related to IPHC Regulatory Areas. Because IPHC Regulatory Areas are nested within Regions, distribution to Regions can affect fishery objectives.

70. The MSAB **NOTED** that the proposed TCEY distribution procedure contains four main components, each of which may contain multiple elements. These four components are listed below and have a computational outcome:

a) **Coastwide Target Fishing Intensity**: this defines the TCEY to be distributed.

b) **Regional Stock Distribution**: this distributes the TCEY to biological Regions to satisfy the Biological Sustainability objective of preserving biocomplexity.

c) **Regional Allocation Adjustment (optional)**: this adjusts the distribution of the TCEY among Regions to account for additional Biological Sustainability objectives and fishery objectives.

d) **Regulatory Area Allocation**: this distributes the TCEY from Regions to Regulatory Areas to satisfy fishery objectives.

71. The MSAB **NOTED** that the output of the TCEY distribution procedure will be a catch table describing proposed mortality (allocation) in each IPHC Regulatory Area…

72. The MSAB **REQUESTED** that the proposed TCEY distribution framework described in paragraphs 69, 70 and 71, be reviewed by the SRB in 2018.

APPENDIX II

MEASURABLE OBJECTIVES AND ASSOCIATED PERFORMANCE METRICS

GOAL: Biological Sustainability

GENERAL OBJECTIVE	MEASURABLE OBJECTIVE	NEGATIVE OUTCOME	TIME-FRAME	TOLERANCE	PERFORMANCE METRICS
1.1. KEEP BIOMASS ABOVE A LIMIT TO AVOID CRITICAL STOCK SIZES	Maintain a minimum spawning stock biomass above a biomass limit reference point	RSB < Biomass Limit	Long-term 10 year period	0.05	$P(dRSB < Limit)$
1.2. MITIGATE FOR UNCERTAINTY	Maintain spawning stock biomass mostly above a biomass threshold reference point to avoid stock sizes that could become critical	RSB < Biomass Threshold	Long-term 10-year period	0.25	$P(dRSB < Threshold)$
	When the Estimated Biomass < Biomass Threshold, limit the probability of declines	SSB declines when RSB < Biomass Threshold	Long-term 10 year period	0.05-0.5	$P(SSB_{i+1} < SSB_i)$ given *RSB* < biomass threshold
ABSOLUTE MEASURE	An absolute measure	Number of mature female halibut	Long-term 10 year period	NA	Median $\overline{MatureFemales}$
ABSOLUTE MEASURE	An absolute measure	Spawning Biomass	Long-term 10 year period	NA	Median $\overline{RSB}$

GOAL : Fishery Sustainability, Stability, and Access

GENERAL OBJECTIVE	MEASURABLE OBJECTIVE	NEGATIVE OUTCOME	TIME-FRAME	TOLERANCE	PERFORMANCE METRICS
2.1. MAINTAIN AN ECONOMICALLY SUFFICIENT LEVEL OF CATCH (I.E, TARGET) ACROSS REGULATORY AREAS	Maintain an average catch	FCEY <- averageCatch	Long-term, 10 yr Short-term, 3 yr	?? ??	$P(FCEY < AvCatch)$
	Maintain a minimum catch	FCEY < min	Long-term, 10 yr Short-term, 3 yr	?? ??	$P(FCEY < min)$
	Maintain an above average catch	< 70% of historical 1993-2012 average	Long-term, 10 yr Short-term, 3 yr	0.1 ??	$P(FCEY < 70\%)$
	Maintain a consistent level of catch	Outside of ±10% of 1993-2012 average	Long-term, 10 yr Short-term, 3 yr	0.1 0.	$P(FCEY > 110\% \text{ or } FCEY < 90\%$
2.2. LIMIT CATCH VARIABILITY	Limit annual changes in TAC, coast-wide and/or by Regulatory Area	Change in Mortality > 15%	Long-term, 10 yr Short-term, 3 yr	?? ??	$P\left(\frac{FCEY_{i+1} - FCEY_i}{FCEY_i} > 15\%\right)$
		AAV > 15%	Long-term, 10 yr Short-term, 3 yr	?? ??	$P(AAV > 15\%)$
ABSOLUTE MEASURE	An absolute measure	Mortality (TM, TCEY, FCEY, Commercial)	Long-term, 10 yr Short-term, 3 yr	NA	Median $\overline{Mort}$
ABSOLUTE MEASURE	An absolute measure	Range of mortality	Long-term, 10 yr Short-term, 3 yr	NA	5th and 75th percentiles of mortality
ABSOLUTE MEASURE	An absolute measure	Variability in mortality (TM, TCEY, FCEY, Commercial)	Long-term, 10 yr Short-term, 3 yr	NA	Median Average Annual Variability (AAV)

Statistic	Chance of being “on the ramp”	Estimated stock status is below the fishery trigger	Long-term, 10 yr Short-term, 3 yr	NA	$P(\widehat{dRSB} < Trigger)$

GOAL : Minimize Discard Mortality

General Objective	Measurable Objective	Negative Outcome	Time-frame	Tolerance	Performance Metrics
3.1. Harvest efficiency	Discard mortality is a small percentage of the longline fishery annual catch limit	>10% of annual catch limit	Long-term, 10 yr Short-term, 3 yr	0.25	$P(DM > 10\%FCEY)$
Absolute measure	Absolute	Discard Mortality (DM)	Long-term, 10 yr Short-term, 3 yr	**NA**	Median $\overline{DM}$

GOAL : Minimize Bycatch and Bycatch Mortality

General Objective	Measurable Objective	Negative Outcome	Time-frame	Tolerance	Performance Metrics