An update of the IPHC Management Strategy Evaluation process for SRB017

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PURPOSE

To provide an update of International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) activities including updates to the framework and preliminary results on the evaluation of management procedures for distributing the TCEY.

1 INTRODUCTION

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) has completed an initial phase of evaluating management procedures (MPs) relative to the coastwide scale of the Pacific halibut stock and fishery, and has developed a framework to investigate MPs related to distributing the Total Constant Exploitation Yield (TCEY) to IPHC Regulatory Areas. The TCEY is the mortality limit composed of mortality from all sources except under-26-inch (66.0 cm, U26) non-directed commercial discard mortality, and is determined by the Commission at each Annual Meeting for each IPHC Regulatory Area (Figure 1).

The development of an MSE framework aims to support the scientific, forecast-driven study of the trade-offs between fisheries management scenarios. Crafting this tool 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;
- identification and development of management procedures with closed-loop feedback into the operating model;
- definition and calculation of performance metrics and statistics based on defined objectives to evaluate the efficacy of applied management procedures.

Updates on the recent efforts in these areas are outlined below.

2 FRAMEWORK ELEMENTS

The MSE framework includes elements that simulate the Pacific halibut population and fishery (Operating Model, OM) and management procedures (MPs) with a closed-loop feedback (Figure 2). Specifications of some elements are described below, with additional technical details in document IPHC-2020-SRB017-10.

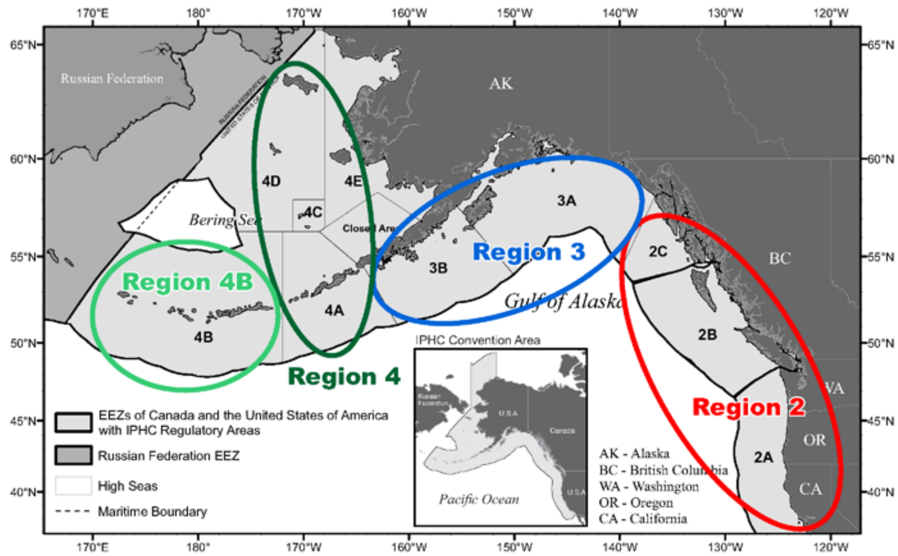

Figure 1. Biological Regions overlaid on IPHC Regulatory Areas. Region 2 comprises 2A, 2B, and 2C, Region 3 comprises 3A and 3B, Region 4 comprises 4A and 4CDE, and Region 4B comprises solely 4B.

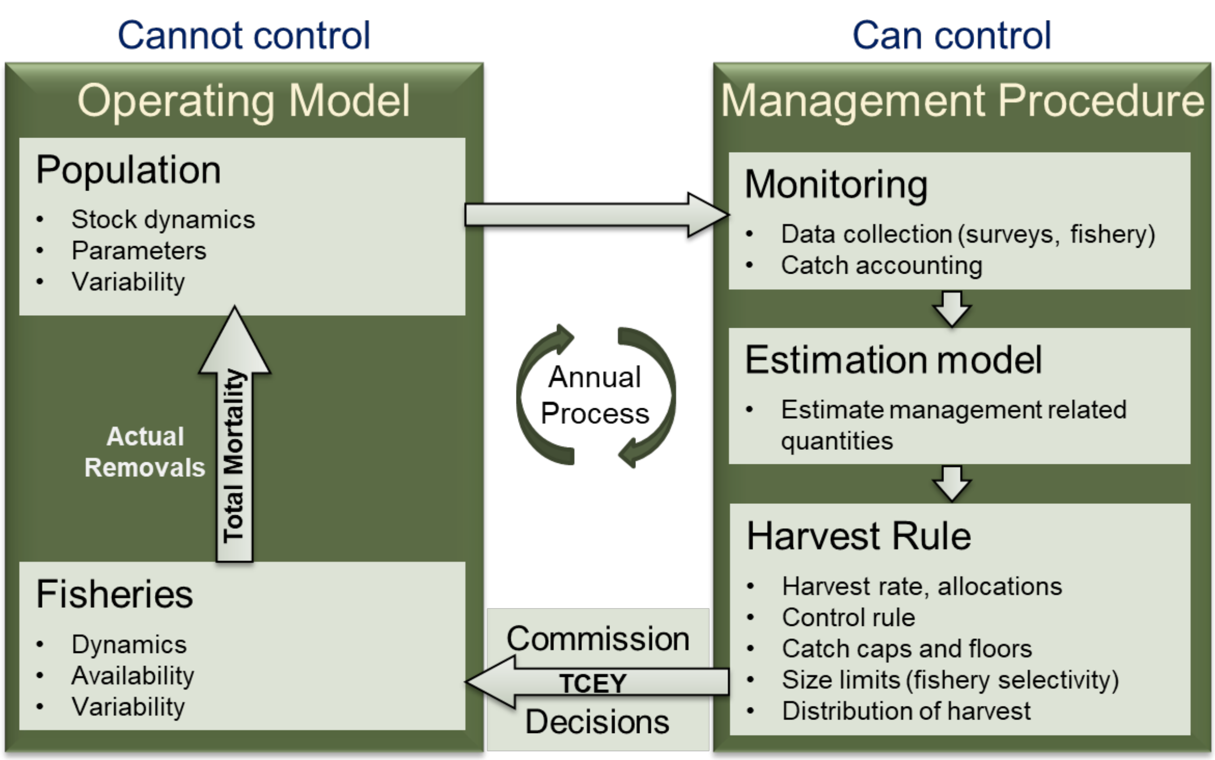

Figure 2. Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

2.1 Multi-area operating model

The generalized operating model is able to model multiple spatial components, which is necessary because mortality limits are set at the IPHC Regulatory Area level (Figure 1) and some objectives (Appendix I) are defined at that level. Written in the programming language C++ with JavaScript Object Notation (JSON) input files, the OM is flexible, fast, modular, and easily adapted to many different assumptions. The operating model is a simulation tool and uses external optimisation tools for estimation of parameters. It will be a useful tool for many investigations of the Pacific halibut fishery in the future.

The technical details of the multi-area operating model, which continues to be under development, are supplied in document IPHC-2020-SRB017-10. Some background information on specific components and the incorporation of uncertainty is supplied below.

2.1.1 General process of running the operating model

The use of multiple input JSON-formatted files allows for the simulation of many configurations of the Pacific halibut population and associated fisheries. Any number of areas/regions can be specified along with any number of fisheries that operate in those areas at a specified time in the year. Various parameters, such as natural mortality, movement probabilities, selectivity, etc., are inputs and most can vary over time, region, sex, fishery, and age where relevant.

The OM is called from a script written in the R statistical language (R Core Team 2020) that defines the number of simulations (i.e., unique individual projections), creates all the necessary folders, copies all necessary files over to the new folders, and sets the number of projection years. This script also calls the OM which begins by calculating the unfished equilibrium population given an input set of biological parameters. It then simulates the annual process during what is called an “initial period” which allows for the stock to distribute across modelled areas to an equilibrium state given recruitment deviations and fishing mortality. During a subsequent “main period”, the population and dynamics are simulated using the input annual fishing mortality and time-varying parameters such as selectivity, recruitment variability, and annual movement between areas. The parameterized model that is run through these three periods is called the conditioned model. At the end of the main period the projection period begins.

An R script containing all the details of the management procedure being evaluated as well as changes in weight-at-age is called during the projection period, which does the following. It reads the current OM state from ‘csv’ files written by the OM. It projects weight-at-age as a random process, as described below. It generates data with observation error that are needed for estimation models (EMs) and MPs. It runs the estimation models if required to determine mortality limits and realized mortality for each fishery. The mortalities for each fishery are written to a JSON file and read back into the OM along with other projected annual processes (e.g., weight-at-age) to simulate the fish population one year forward.

2.1.2 Population and fishery spatial specification

The 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). Therefore, four Biological Regions (Figure 1) were defined with boundaries that matched some of the IPHC Regulatory Area boundaries for the following reasons. First, 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. Second, it is necessary to distribute TCEY to IPHC Regulatory Areas for quota management. 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. Further, the structure of the current directed fisheries does not delineate fishing zones inside individual IPHC Regulatory Areas, so there would be no way to introduce management at that spatial resolution.

To a certain degree, Pacific halibut within the same Biological Region share common biological traits different from adjacent Biological Regions. These traits include sex ratios, age composition, and size-at-age, and historical trends in these data may be indicative of biological diversity within the greater Pacific halibut population. Furthermore, 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 and Seitz 2006; Seitz et al. 2007; Webster et al. 2013).

Given the goals to divide the Pacific halibut stock into somewhat biologically distinct regions and preserve biocomplexity across the entire range of the Pacific halibut stock, Biological Regions are considered by the IPHC Secretariat, and supported by the SRB (paragraph 31 IPHC-2018-SRB012-R), to be the best option for biologically-based areas to meet management needs. They also offer a 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 (Appendix I), the TCEY will need to be distributed to 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 within Biological Regions. This requires modelling each fleet with separate selectivity and harvest rates that operate on the biomass occurring in the entire Biological Region in each year. The following is a discussion of the pros and cons of this method.

First, modelling the population dynamics at the IPHC Regulatory Area scale would require intra-annual dynamics to be modelled, dividing the year into seasons to model movement between IPHC Regulatory Areas. There is evidence that such intra-annual movements occur (Loher and Seitz, 2006) and fisheries in adjacent IPHC Regulatory Areas may intercept the same pool of fish (Loher 2011). Using Biological Regions assumes that all fisheries within a Region have access to the pool of Pacific halibut in that Region in that year. This greatly simplifies the calculations and eliminates the need to parameterize intra-annual movement.

Additionally, calculating statistics specific to IPHC Regulatory Areas requires assumptions about mechanisms determining future distribution of biomass within each Biological Region. For example, simulating the observed 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. Likewise, determining some performance metrics related to IPHC Regulatory Area objectives 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 is currently approximated assuming specified proportions of the population in each IPHC Regulatory Area within a Biological Region that are based on historical observations. These proportions are constant over ages and allows for the calculation of statistics specific to IPHC Regulatory Areas. Future improvements to the framework will allow for different options such as modelling proportions based on population attributes and accounting for year to year variability.

Fisheries were defined by IPHC Regulatory Areas (or combinations of areas if fishing mortality in that area was small) and for five general sectors consistent with the definitions in the recent IPHC stock assessment (IPHC-2020-AM096-09 Rev_2):

- **directed commercial** representing the O32 mortality from the directed commercial fisheries including O32 discard mortality;
- **directed commercial discard** representing the U32 discard mortality from the directed commercial fisheries, comprised of Pacific halibut that die on lost or abandoned fishing gear, and Pacific halibut discarded for regulatory compliance reasons;
- **non-directed commercial discard** representing the mortality from incidentally caught Pacific halibut in non-directed commercial fisheries;
- **recreational** representing recreational landings (including landings from commercial leasing) and recreational discard mortality; and
- **subsistence** representing non-commercial, customary, and traditional use of Pacific halibut for direct personal, family, or community consumption or sharing as food, or customary trade.

Table 1 shows the summed mortality realized from 1992 through 2019 for each of these sectors by IPHC Regulatory Area or Biological Region. Thirty-three (33) fisheries were defined as a sector/area combination based on the amount of mortality in the combination, data availability, and MSAB recommendations (Table 2).

The Fishery-Independent Setline Survey (FISS) is included as a fishery with no mortality to output summaries of observations such as indices and observed proportions-at-age in the population available to the survey at a specific time and in a specific region. Mortality from the FISS is included with the directed commercial fishery mortality, although it could be kept separate.

Table 1. Summed mortality (millions of net pounds) from 1992 through 2019 by fisheries and IPHC Regulatory Area or Biological Region.

Year	2A	2B	2C	3A	3B	4A	4CDE	4B
Directed commercial	17.5	259.8	205.5	551.2	252.4	78.2	72.5	62.8
Directed commercial discard mortality	0.5	7.1	5.2	16.7	10.7	2.1	1.3	0.8
Non-directed commercial discard mortality	11.8	12.0	4.5	73.6	36.2	39.2	16.2	128.6
Recreational	13.7	31.8	71.1	152.2	0.5	1.4	<0.1	<0.1
Subsistence	0.7	9.6	10.3	7.6	1.0	0.6	<0.1	2.4

2.1.3 Fishery and survey selectivity and retention

Selectivity and retention determine the age composition of fishery mortality and ensure the removal of appropriate numbers-at-age from the population when mortality occurs in the annual time-step. Selectivity represents the proportion at each age that is captured by the gear. Retention represents the proportions-at-age that are retained and landed if caught (i.e., 1 - retention is the proportion-at-age that is released). The product of selectivity and retention is called the "keep curve" and represents the proportions-at-age from the population that are landed. Some fish that are not retained may survive; thus, a discard mortality rate is used to indicate the proportion of fish that are not retained and die after release.

Retention is not modelled specifically at this time because directed commercial discard mortality is modelled as a separate sector, and discard mortality for other sectors is included in the total mortality for those sectors. Parameters for selectivity when conditioning models were determined from the estimated parameters from the long AAF model in the recent stock assessment (IPHC-2020-SA-01) including annual deviations in selectivity for the directed fisheries and the survey. These parameters could be modified as necessary to improve fits to data and to reflect differences in implied availability of a spatially explicit model compared to the coastwide stock assessment, but were not at this time.

2.1.4 Weight-at-age

Empirical weight-at-age by region for the population, fisheries, and survey are determined using observations from the FISS and the fisheries, as is done with the stock assessment models (IPHC-2020-SA-02) and as described in detail in Stewart and Martell (2016). Smoothed observations of weight-at-age from NMFS trawl surveys were used to augment weight-at-age for ages 1–6 in the fishery sectors and survey. Population weight-at-age is smoothed across years to reduce observation error. Finally, survey and population weight-at-age prior to 1997 is scaled to fishery data because survey observations are limited if present at all.

Table 2. The thirty-three fisheries in the OM, the IPHC Regulatory Areas they are composed of, and the 2019 mortality (millions of net pounds and tonnes) for each.

Fishery	IPHC Regulatory Areas	2019 Mortality Mlbs	2019 Mortality tonnes
Directed Commercial2A	2A	0.89	404
Directed Commercial 2B	2B	5.22	2,368
Directed Commercial 2C	2C	3.67	1,665
Directed Commercial 3A	3A	8.16	3,701
Directed Commercial 3B	3B	2.31	1,048
Directed Commercial 4A	4A	1.45	658
Directed Commercial 4B*	4B	1.00	454
Directed Commercial 4CDE	4CDE	1.65	748
Directed Commercial Discards 2A	2A	0.03	14
Directed Commercial Discards 2B	2B	0.13	59
Directed Commercial Discards 2C	2C	0.06	27
Directed Commercial Discards 3A	3A	0.32	145
Directed Commercial Discards 3B	3B	0.15	68
Directed Commercial Discards 4A	4A	0.09	41
Directed Commercial Discards 4B	4B	0.03	14
Directed Commercial Discards 4CDE	4CDE	0.07	32
Non-directed Commercial Discards 2A	2A	0.13	59
Non-directed Commercial Discards 2B	2B	0.24	109
Non-directed Commercial Discards 2C	2C	0.09	41
Non-directed Commercial Discards 3A	3A	1.65	748
Non-directed Commercial Discards 3B	3B	0.48	218
Non-directed Commercial Discards 4A	4A	0.35	159
Non-directed Commercial Discards 4CDE	4CDE	3.50	1,588
Non-directed Commercial Discards 4B	4B	0.15	68
Recreational 2B	2B	0.86	390
Recreational 2C	2C	1.89	857
Recreational 3A	3A	3.69	1,674
Subsistence 2B	2B	0.41	186
Subsistence 2C	2C	0.37	168
Subsistence 3A	3A	0.19	86
Recreational/Subsistence 2A	2A	0.48	218
Recreational/Subsistence 3B	3B	0.02	9
Recreational/Subsistence 4	4A, 4CDE	0.06	27

*The small amount of recreational and subsistence mortality from IPHC Regulatory Area 4B is included in Directed Commercial 4B

2.1.5 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. The conceptual model of halibut ontogenetic and seasonal migration, including main spawning and nursery grounds, as per the most current knowledge, was presented in IPHC-2019-MSAB014-08 and was used to assist in parameterizing movement rates in the OM.

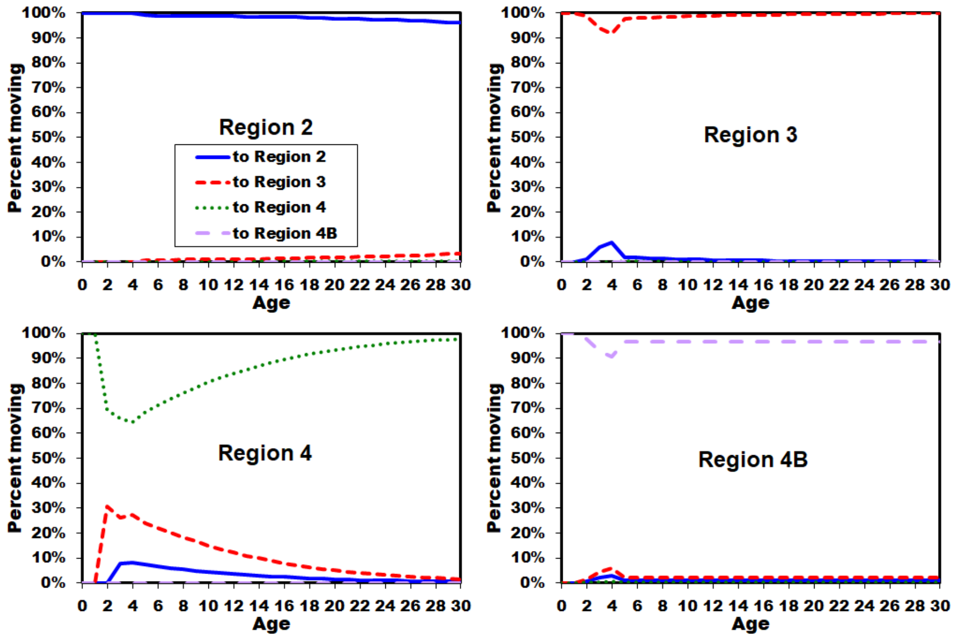

Figure 3. Estimated aggregate annual movement rates by age from Biological Regions (panels) based on currently available data (from IPHC-2019-AM095-08).

In 2015, the many sources of information were assembled into a single framework representing the IPHC's best available information regarding movement-at-age among Biological Regions. Key assumptions in constructing this hypothesis included:

- ages 0-1 do not move (most of the young Pacific halibut reported in Hilborn et al. (1995) were aged 2-4),
- movement generally increases from ages 2-4,
- age-2 Pacific halibut cannot move from Region 4 to Region 2 in a single year, and
- relative movement rates of Pacific halibut of age 2-4 to/from Region 4 are similar to those observed for 2-4-year-old Pacific halibut in Region 3, relative to older Pacific halibut.

Based on these assumptions, appreciable emigration is estimated to occur from Region 4, decreasing with age. Pacific halibut age-2 to age-4 move from Region 3 to Region 2 and from Region 4B to Regions 3 and 2, and some movement of older Pacific halibut is estimated to occur from Region 2 back to Region 3 (Figure 3).

The conceptual model and assembled movement rates were used to inform the development of the MSE operating model framework and were used as a starting point to incorporate variability and alternative movement hypotheses in Pacific halibut movement dynamics. Movement in the OM is modelled using a transition matrix as the proportion of individuals that move from one Biological Region to another for each age class in each year.

The transition matrix with movement probabilities from one region to another (including staying in the region of origin) can either be entered directly or parameterized using several functional forms. Current functional forms include *constant*, *exponential*, and *double exponential*, as shown in equations 1-4, and can closely mimic the movement probabilities described in IPHC-2019-AM095-08 that are based on data.

Constant
$$\omega_{a|j\to k} = \begin{cases} 0 & a \le lastAge0 \\ c & a > lastAge0 \end{cases} \tag{1}$$

Exponential
$$\omega_{a|j\to k} = \begin{cases} 0 & a \le lastAge0 \\ \dfrac{e^{\lambda(a-lastAge0+1)}}{\max(\omega_{a|j\to k})} \times (\gamma_2 - \gamma_1) & a > lastAge0 \end{cases} \tag{2}$$

Double-exponential
$$\omega_{a|j\to k} = \begin{cases} 0 & a \le lastAge0 \\ \dfrac{e^{\lambda(a-lastAge0)} - 1}{\max(\omega_{a|j\to k})} \times \gamma_2 & lastAge0 < a < peak \\ (\gamma_2 - \alpha) e^{-\lambda(a-lastAge0+1)} + \alpha & a > peak \end{cases} \tag{3}$$

Values
$$\omega_{a|j\to k} = \begin{cases} v_a & a \le lastAge \\ v_{lastAge} & a > lastAge \end{cases} \tag{4}$$

where $lastAge0$ is the oldest age with a movement probability of zero before the first non-zero movement probability, α is the asymptote, γ_1 is the minimum probability in that range of ages, and γ_2 is the maximum probability in that range of ages. These parameters are used to scale the relationship to the appropriate range and λ determines the rate of increase or decrease.

These parameterizations overcome an impediment identified in the development of the spatially explicit stock assessment model using stock synthesis. The functional forms allow for efficient and easy modifications to input files to depart from the estimated movement rates based on data, which occurs when conditioning the models. This is useful because there are many assumptions in the estimates, especially for young ages, and the OM will need to include uncertainty as well as possibly time-varying aspects.

2.1.6 Maturity

Spawning biomass for Pacific halibut is currently calculated from weight-at-age and a maturity-at-age ogive that is assumed to be constant over years. There is currently no evidence (IPHC-2020-SA-02) for skip spawning or maternal effects (increased reproductive output or offspring survival for larger/older females) and therefore are not modelled, but could be added. Stewart & Hicks (2017) examined the sensitivity of the estimated biomass to a trend in declining spawning potential (caused by a shift in maturity or increased skip spawning) and found that under that condition there was a bias in both scale and trend of recent estimated spawning biomass. The

SRB document IPHC-2020-SRB016-07 tested maternal effects on estimates of recruitment and concluded "there appears to be no evidence in the current data that the addition of a simple age-based maternal effects relationship improves the ability of the current stock assessment models to explain the time-series of estimated recruitments." Ongoing research on maturity and skip spawning will help to inform future implementations of the basis for and variability in the determination of spawning output.

2.1.7 Uncertainty and variability in the operating model

Uncertainty and variability are important to consider, as the goal of an MSE is to develop management procedures that are robust to both. The OM should simulate potential states of the population in the future, uncertainties within the management procedure, and variability when implementing the management procedure.

2.1.7.1 Uncertainty in the conditioned OM

The conditioned OM is a representation of the Pacific halibut population and matches observations from the fishery, survey, and research. Uncertainty in these observations are included in the OM by varying parameters in two different ways. First, parameters vary between simulated trajectories and are drawn from correlated probability distributions that are derived from estimation procedures (e.g., the stock assessment). Second, specific parameters are fixed at different values representing potential states. Trajectories may be simulated using both methods and then integrated appropriately to produce distributions of potential outcomes. At this time, the second method of fixing specific parameters at alternative values is not being used but can easily be implemented in the future.

Table 3: Major sources of parameter uncertainty and variability in the conditioned operating model (OM).

Process	**Uncertainty**
Natural Mortality (*M*)	Variability determined from assessment
Average recruitment (R_0)	Effect of the coastwide environmental regime shift and variability determined from conditioning
Recruitment	Random lognormal deviations. Variability on distribution to Biological Regions determined from conditioning
Movement	Change in parameters synchronized with PDO regime shift

2.1.7.2 Projected population variability

Variability in the projected population is a result of initializing the population with a range of parameters to recreate a range of historical trajectories and including additional variability in certain population processes in the projection. The major sources of variability in the projections are shown in Table 4 and some are described in more detail below.

Table 4: Major sources of projected variability in the operating model (OM).

Process	Variability
Average recruitment (R_0)	Effect of the coastwide environmental regime shift, modelled as an autocorrelated indicator based on properties of the PDO
Recruitment	Random lognormal deviations. Variability on distribution to Biological Regions.
Movement	Variability on movement parameters determined from conditioning process
Size-at-age	Annual and cohort deviations in weight-at-age by Biological Region, with approximate historical bounds
Sector mortality	Sector mortality allocation variability on non-directed commercial discard mortality, directed discard mortality, and unguided recreational mortality within an area
Movement	Change in parameters synchronized with PDO regime shift

2.1.7.3 Linkage between average coastwide recruitment and environmental conditions

The average recruitment (R_0) is related to the Pacific Decadal Oscillation index[1], expressed as a positive or negative regime (IPHC-2020-SA-02). R_0 is multiplied by $e^{I\delta}$, where I is an indicator of the negative (0) or positive (1) regime, and δ is a parameter determining the magnitude of that multiplier. The parameter δ, and uncertainty, was determined from the stock assessment.

The regime was simulated in the MSE by generating a 0 or 1 to indicate the regime of each future year, as described in IPHC-2018-MSAB011-08. To encourage regimes between 15 and 30 years in length (assuming a common periodicity, although recent years have suggested less), the environmental index was simulated as a semi-Markov process, where each subsequent year depends on recent years. However, the probability of changing to the opposite regime was a function of the length of the current regime, with a change probability equal to 0.5 at 30 years, and a probability near 1 at 40 or greater years. This default parameterization results in simulated regime lengths most often between 20 and 30 years, with occasional runs between 5 and 20 years or greater than 30 years. However, this can be modified to test other scenarios.

2.1.7.4 Projected weight-at-age

Weight-at-age varies over time historically, and the projections capture that variation using a random walk from the previous year. It is important to simulate time-varying weight-at-age because it is an influential contributor to the yield and scale of the Pacific halibut stock. This variability was implemented using the same ideas as in the coastwide MSE (IPHC-2018-MSAB011-08), but was modified to incorporate autocorrelation in a more straightforward manner, and allow for slight departures between regions and fisheries.

The method used to simulate weight-at-age was described in IPHC-2020-SRB016-08 Rev1. Two example projections are shown in Figure 4.

[1] https://oceanview.pfeg.noaa.gov/erddap/tabledap/cciea_OC_PDO.htmlTable?time,PDO

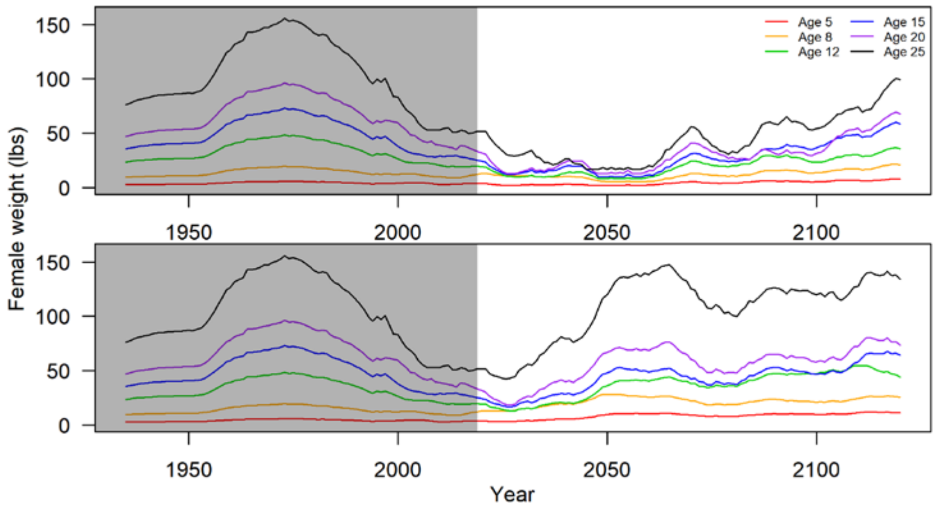

Figure 4: Past observed (shaded area) and two examples of possible one-hundred-year projections of weight at ages 5, 8, 12, 15, 20, and 25.

2.2 Management Procedures for coastwide scale and distribution of the TCEY

The management procedure consists of three elements (Figure 2). Monitoring (data generation) is the code that simulates the data from the operating model that are used by the estimation model as well as O32 or all-sizes stock distribution, which is needed for the distribution procedure. It simulates the 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 includes estimation error in the simulation. 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. Two methods were investigated for mimicking the estimation procedures to determine a coastwide total mortality limit, as described below. Finally, the Harvest Rule contains additional procedures when determining the mortality limits, such as the application of a control rule and distribution of the limits to IPHC Regulatory Areas.

The first EM was to use an approach to simulate estimation error, as was done in the coastwide MSE. The OM determines the stock status and the TM consistent with the input fishing intensity (i.e., F_{SPR}). Correlated deviates randomly generated with a bivariate normal distribution including an autocorrelation of 0.4 with previous deviates was applied to the stock status and TM. Details of this method can be found in Section 4.2.2. of IPHC-2018-SRB012-08. This method is useful to provide perfect information, bridge the multi-region MSE to the coastwide MSE, and speed up simulations while providing a reasonable approximation of the assessment process. Additionally, it may be used to test the effects of different levels of estimation error.

A second approach was to use estimation models based on stock synthesis (SS). Initial investigations showed biases with the models as additional data were added. The assessment models that these EMs were based on are complicated and developed for short-term forecasts using currently available data. Increasing the number of years of data in the models, possibly not simulated with the exact processes that the assessment was tuned to, can cause the models to perform less than optimal. However, the use of EMs based on the assessment models provides a more accurate representation of the assessment process and of the bias associated with it. Additional details are described below.

2.2.1 Estimation models using stock synthesis

The short and long coastwide models used in the ensemble stock assessment require between one and seven minutes to estimate parameters without a Hessian. Two approaches were used to speed up these two estimation models for use in the MSE simulations: reducing the reading time and reducing the computation time.

To reduce the reading time, the amount of data included in the model was reduced compared to the full assessment, while ensuring similar trajectories in the estimated quantities such as spawning stock biomass, exploitation and virgin biomass. Once this condition was met, the trend in dynamic B0 for the most recent period and the forecasted TM were also verified. The number of years of age composition data was shortened, and for each additional year of age data added during the projection period, an early year in the time series was removed. A minimum of at least 50 years of age composition for the directed commercial fleet is required before the removal of historical data begins. For the long coastwide estimation model, only the beginning of the CPUE time series was maintained, removing all subsequent years starting from 1994. Additionally, the start year of the long coastwide estimation model was set to 1935 instead of 1888.

The major change to the data is the use of an absolute index of abundance to replace the NPUE from the survey. The index is generated with error from the numbers at age and the survey selectivity at age for the whole time series. The catchability is fixed to 1.

To reduce the computation time, the ‘opt’ (optimized) version of stock synthesis was used, and the number of estimated parameters was reduced, mostly by removing some time-varying options. The remaining annual deviations in selectivity parameters were fixed at the values estimated by the original assessment model, and only the deviations for the most recent 10 or 20 years (depending on the parameter) were left free to be estimated. In the first projected year, optimization was initiated using the parameters estimated by this streamlined version of the assessment model (i.e., the ‘ss.par’ file). For each subsequent year in the projection, the ‘ss.par’ file from the previous year was used, manually adding one extra parameter where necessary. The parameter estimation was also set to start from the last phase.

Finally, the convergence criterion was set to 0.1, the Hessian was not estimated (therefore uncertainty is not calculated), and the amount of information printed on screen was reduced to a minimum. The number of iterations for a model to reach convergence was fixed to a maximum of 800. If the model did not converge after 800 iterations (i.e., convergence > 0.1), the initial value for the R0 parameter was increased by 5% and the model was restarted. If the model still did not converge, it was restarted for a third time, but estimation was started from phase 1. The replacement of the NPUE with an absolute index of abundance has reduced the computation time of both models and initial investigations did not show any convergence issues.

For each OM, data for the historical period were generated and input files for both the short and long coastwide assessment models were created, so to have each set of estimation models consistent with the historical period of the correspondent OM. The initial parameter files used are the same across all simulations.

The observation model generates the data for the EMs during projections from the OM with error. In particular, deviates to the absolute index of abundance and the stock distribution are generated by region from a lognormal distribution with standard deviation equal to the average standard error by region from the last 5 years. Age composition data are simulated using a Dirichlet distribution. The nominal sample size is used as the scale parameter of the Dirichlet distribution, to control the variance of the distribution, i.e. a higher sample size implies lower variance. The nominal sample size is generated using an average fixed proportion of the sector mortality. The resulting sample size values are bounded between a minimum and a maximum which varies between sectors: these limits have been chosen looking at the historical minimum and maximum sample size and help both to stabilize the EMs, as well as to avoid unrealistic distribution in the simulated age composition.

The two estimation models are called in parallel from an R script that is called by the C++ OM code.

2.2.2 Harvest rule and distribution procedures

The harvest rule for distributing the TCEY begins with the coastwide TCEY determined from the stock assessment and fishing intensity defined by the reference SPR (with application of the control rule). Figure 5 is an illustration of the harvest strategy policy at IPHC, which includes the harvest rule as part of the management procedure. The TCEY may be distributed to Biological Regions first and then to IPHC Regulatory Areas, or directly to IPHC Regulatory Areas. Relative adjustments can be applied in each step of the distribution process. Typically, the distribution procedure does not appreciably alter the coastwide fishing intensity (although a slight change may occur due to different selectivity patterns accessing the population), however there is interest in management procedures that are only limited to being less than a maximum fishing intensity (i.e., above a minimum SPR) that would account for modifications in the TM during the distribution procedures.

The Coastwide TCEY is calculated from the TM by removing the U26 portion of the non-directed discard mortality, which is approximated by a fixed length-at-age key determined from historical observations applied to non-directed discard mortality observed the previous year.

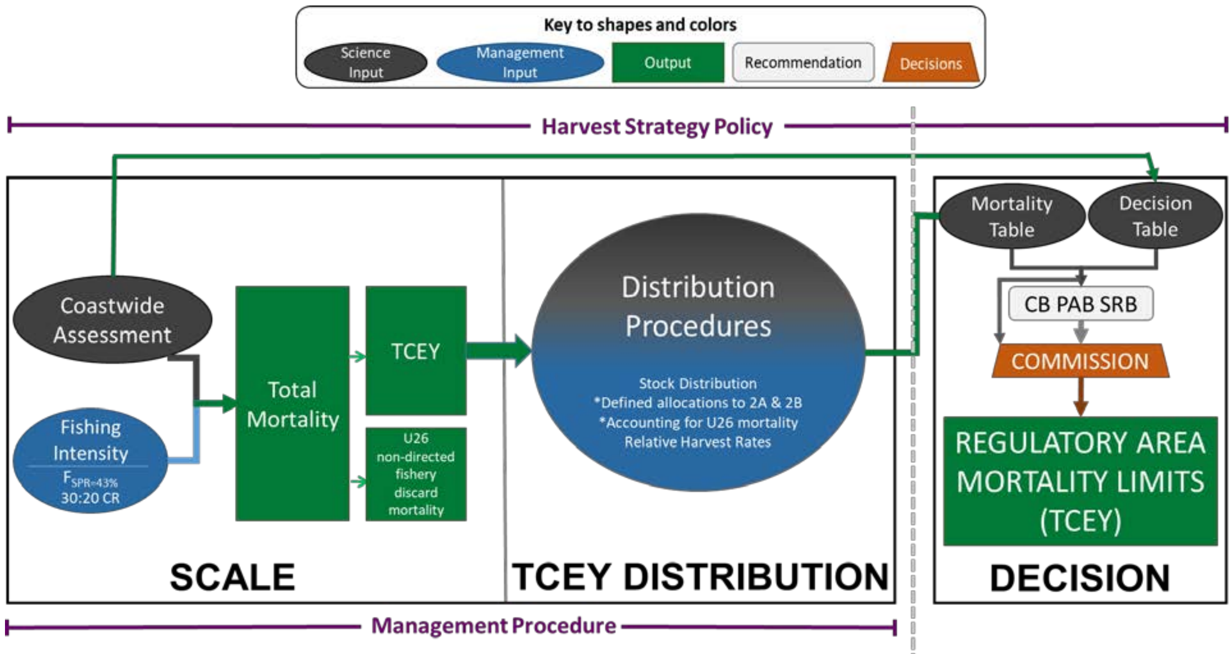

Figure 5: Illustration of the Commission interim IPHC harvest strategy policy (reflecting paragraph ID002 in IPHC CIRCULAR 2020-007) showing the coastwide scale and TCEY distribution components that comprise the management procedure. Items with an asterisk are three-year interim agreements to 2022. The decision component is the Commission decision-making procedure, which considers inputs from many sources.

The MSAB has defined coastwide and distribution elements of management procedures that are important for future evaluation, including the following listed in paragraph 42 of IPHC-2020-MSAB015-R.

> ***IPHC-2020-MSAB015-R, para. 42****.The MSAB* ***AGREED*** *that the following elements of interest for defining constraints on changes in the TCEY, and distribution procedures be considered for the Program of Work in 2020:*
>
> a) *constraints on the change in the TCEY can be applied annually or over multiple years at the coastwide or IPHC Regulatory Area level. Constraints on the change in TCEY currently considered include a maximum annual change in the TCEY of 15%, a slow-up fast down approach, multi-year mortality limits, and multi-year averages on abundance indices;*
>
> b) *indices of abundance in Biological Regions or IPHC Regulatory Area (e.g. O32 or All sizes from modelled survey results);*
>
> c) *a minimum TCEY for an IPHC Regulatory Area;*
>
> d) *defined shares by Biological Region, Management Zone, or IPHC Regulatory Area;*
>
> e) *maximum coastwide fishing intensity (e.g. SPR equal to 36% or 40%) not to be exceeded when distributing the TCEY;*
>
> f) *relative harvest rates between Biological Regions or IPHC Regulatory Areas.*

At MSAB014 and MSAB015, elements specifying candidate management procedures were defined for simulation and subsequent evaluation (Table II.1 in Appendix II, reproduced from IPHC-2020-MSAB015-R).

The estimated values from the data generation and estimation model/estimation error steps are used in the application of the harvest rule to determine mortality limits by IPHC Regulatory Area. The simulated application of the harvest rule will therefore include errors in the status as well as the size of the population, both of which will be propagated into management quantities.

2.2.3 Allocating simulated total mortality to sectors

The outputs of the management procedure are TCEY limits for each IPHC Regulatory Area, which then need to be allocated to the different sectors specific to the IPHC Regulatory Area. See Table 2 for a complete list of the fishing sectors by IPHC Regulatory Area.

There are two parts to the allocation procedure: the calculation of the upcoming mortality limits by sector, and the calculation of the realized mortality by sector. The calculation of mortality limits is necessary because some sector's mortality limits are determined from the limits for other sectors. In the current framework, the calculation of the realized mortality differs from the calculation of the mortality limits for the non-directed discard, directed discard, subsistence, and unguided recreational mortalities. Mortality limits and realized mortality for the recreational and directed commercial sectors are assumed to be equal (i.e., no implementation error for these sectors).

The allocation procedure begins by subtracting the non-directed commercial O26 discard mortality by IPHC Regulatory Area from the corresponding IPHC Regulatory Area TCEY. The remainder is referred to as the directed TCEY for convenience (it is not used as a management quantity). The directed TCEY is then allocated to directed fishery sectors. Each IPHC Regulatory Area has a unique catch-sharing plan (CSP) or allocation procedure, and these CSPs were matched as closely as possible. When the TCEY for an IPHC Regulatory Area is low, the CSP may deteriorate and alternative decisions may be necessary. It is unknown what the allocation procedure may be at low TCEYs, so working with MSAB members, an appropriate assumption will be made. One simple assumption is to assume that the sum of the directed non-FCEY components would not exceed the directed TCEY, and the FCEY components would be set to zero.

Non-directed commercial discard mortality: the O26 component of the non-directed discard mortality limit is calculated as an average of the previous three years non-directed discard mortality for each IPHC Regulatory Area. However, the realized non-directed discard mortality is determined from a linear relationship between the non-directed discard mortality by region and the total biomass in that region. Given changes in non-directed commercial discard mortality in recent years the fit was forced through the last observed year (2019). The realized non-directed discard mortality was then randomly drawn from the value determined from total biomass by region using a log normal distribution with a 20% CV (Figure 6). The non-directed commercial discard mortality by region is then distributed to IPHC Regulatory Area using the proportion of non-directed commercial discard mortality recently observed in each IPHC Regulatory Area.

Directed commercial discard mortality: directed commercial discard mortality limits are calculated using the ratio of directed discard mortality to directed commercial mortality from the previous year. The realized directed discard mortality is modelled as a function of the directed commercial plus directed discard mortality and the weight at age 8 for a male Pacific halibut. The resulting proportion of directed discard mortality relative to different values of the commercial plus directed discard mortality is shown in Figure 7. A minimum of 0.05% of directed discard mortality over commercial plus directed discard mortality is applied.

Subsistence: subsistence mortality limits are set equal to the values observed in the previous year, except for IPHC Regulatory Area 2A, for which the subsistence value is set to 30,000 pounds (13.6 t). The realized subsistence mortality is randomly drawn from a lognormal distribution with a median equal to the limit subsistence mortality and a CV of 15%. The coastwide subsistence is then compared to the coastwide TCEY: if the allocation to the subsistence sector is higher than half of the overall TCEY, then the subsistence mortality in each regulatory area is adjusted so that the coastwide value will not exceed 50% of the coastwide TCEY.

Unguided recreational mortality: unguided recreational mortality is relevant only for IPHC Regulatory Areas 2C and 3A and it is randomly drawn from a lognormal distribution with a median equal to an average historical value (1.257 Mlb or 570 t for 2C and 1.579 Mlb or 716 t for 3A) and a 5% CV.

Recreational mortality: recreational mortality follows the catch sharing plans (CSPs) for IPHC Regulatory Areas in Region 2 and IPHC Regulatory Area 3A, noting that guided recreational mortality limits are only under the CSP in IPHC Regulatory Areas 2C and 3A and the total recreational mortality is the sum of guided and unguided. In IPHC Regulatory Areas 3B, 4A, 4B, and 4CDE, recreational mortality is included with subsistence because almost negligible.

Commercial mortality: is the remainder of the total mortality after subtracting all other sources of mortality.

Figure 8 and Figure 9 illustrate the results of the allocation procedure for each IPHC Regulatory Area when non-directed commercial discard mortality and unguided recreational are held constant at an average value. The recreational and subsistence allocations for IPHC Regulatory Areas 4A and 4CDE are fixed at low values and aggregated to Biological Region in the OM. For this reason, these two sectors are not shown in Figure 9.

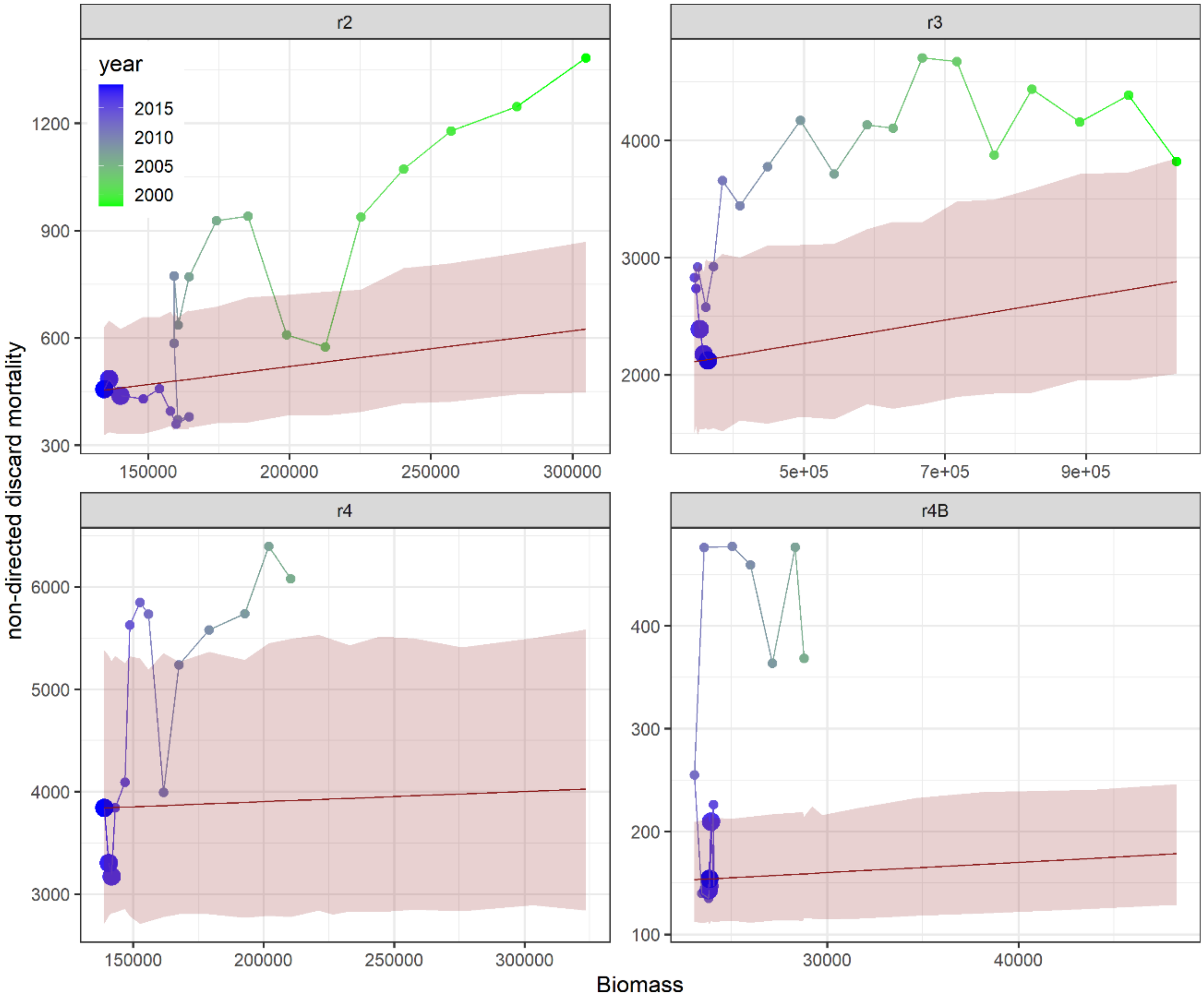

Figure 6: Non-directed commercial discard mortality plotted against total biomass from the conditioned multi-region OM. The colors in the points represent the sequence of time from 1998 to 2019. The years 2017–2019 are represented by larger dots. The red line represents the linear relationship used for predicting the non-directed discard mortality from the biomass. The shaded red area around it represents the 0.05 and 0.95 quantiles of the non-directed discard mortality simulated from a log-normal distribution with a 20% CV.

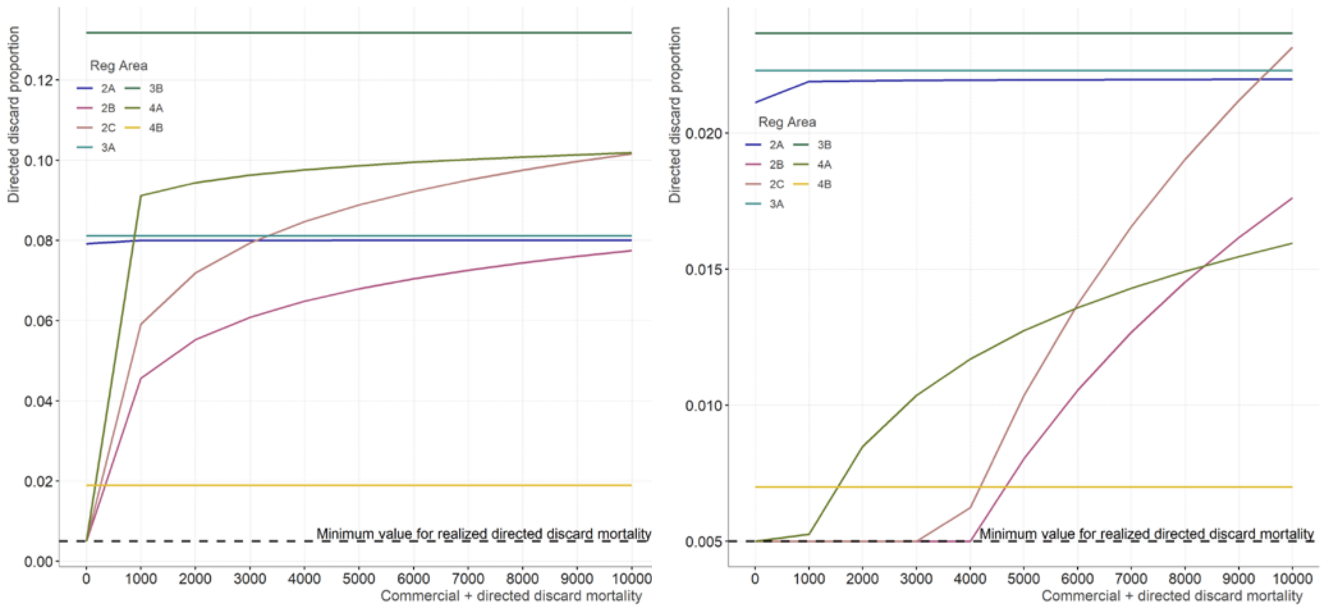

Figure 7: Proportion of directed discard mortality by IPHC Regulatory Area relative to different values of the commercial plus directed discard mortality with a male weight at age 8 equal to 4 lb (left) and 8 lb (right). The dashed line shows the 0.5% minimum.

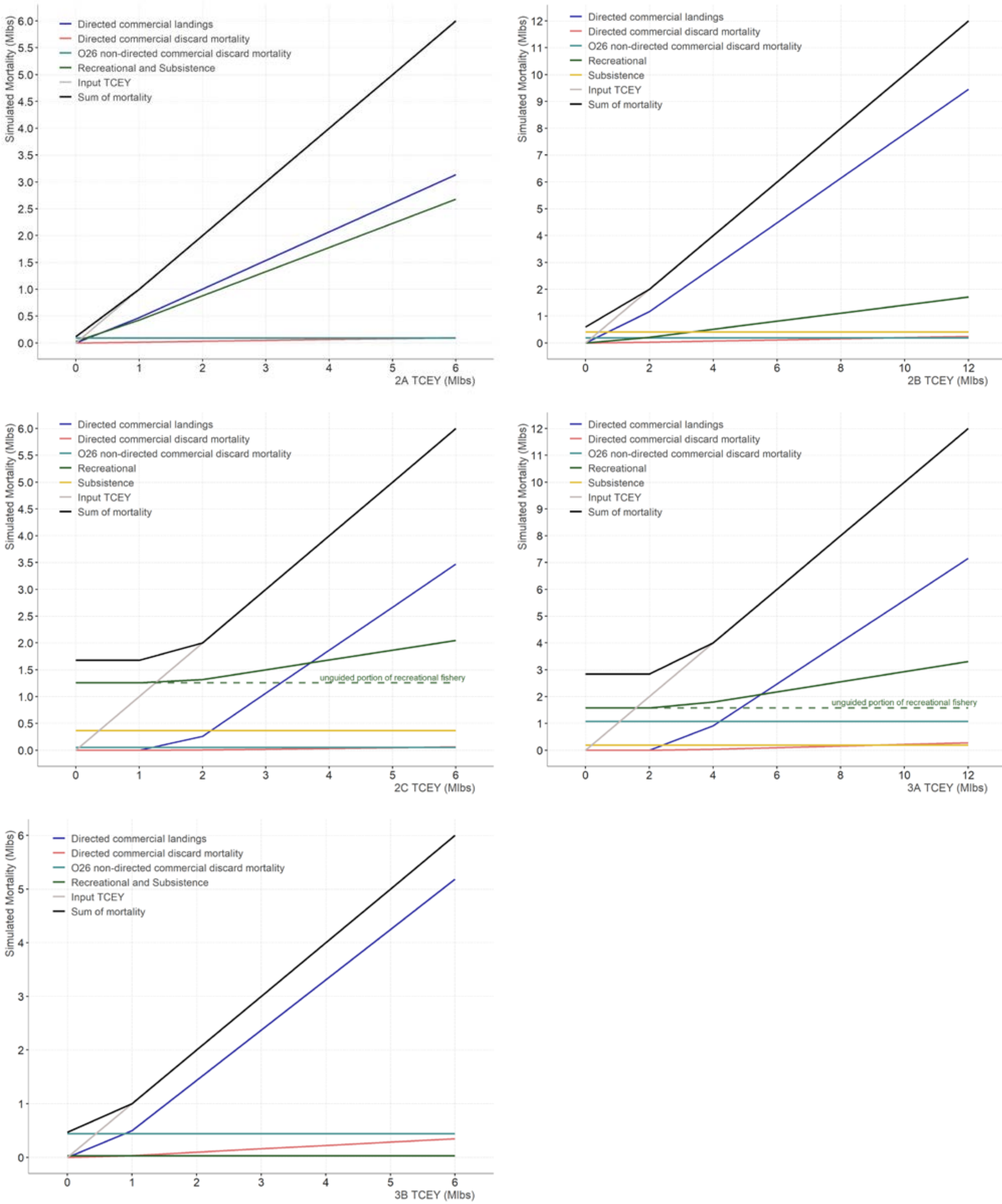

Figure 8: Allocation of the TCEY to sectors for IPHC Regulatory Areas 2A (top left) to 3B (bottom left) when O26 non-directed commercial discard mortality and unguided recreational are is assumed constant at average values. The input TCEY provided to the allocation function is shown in light gray, while the sum of mortalities after allocation is shown in black.

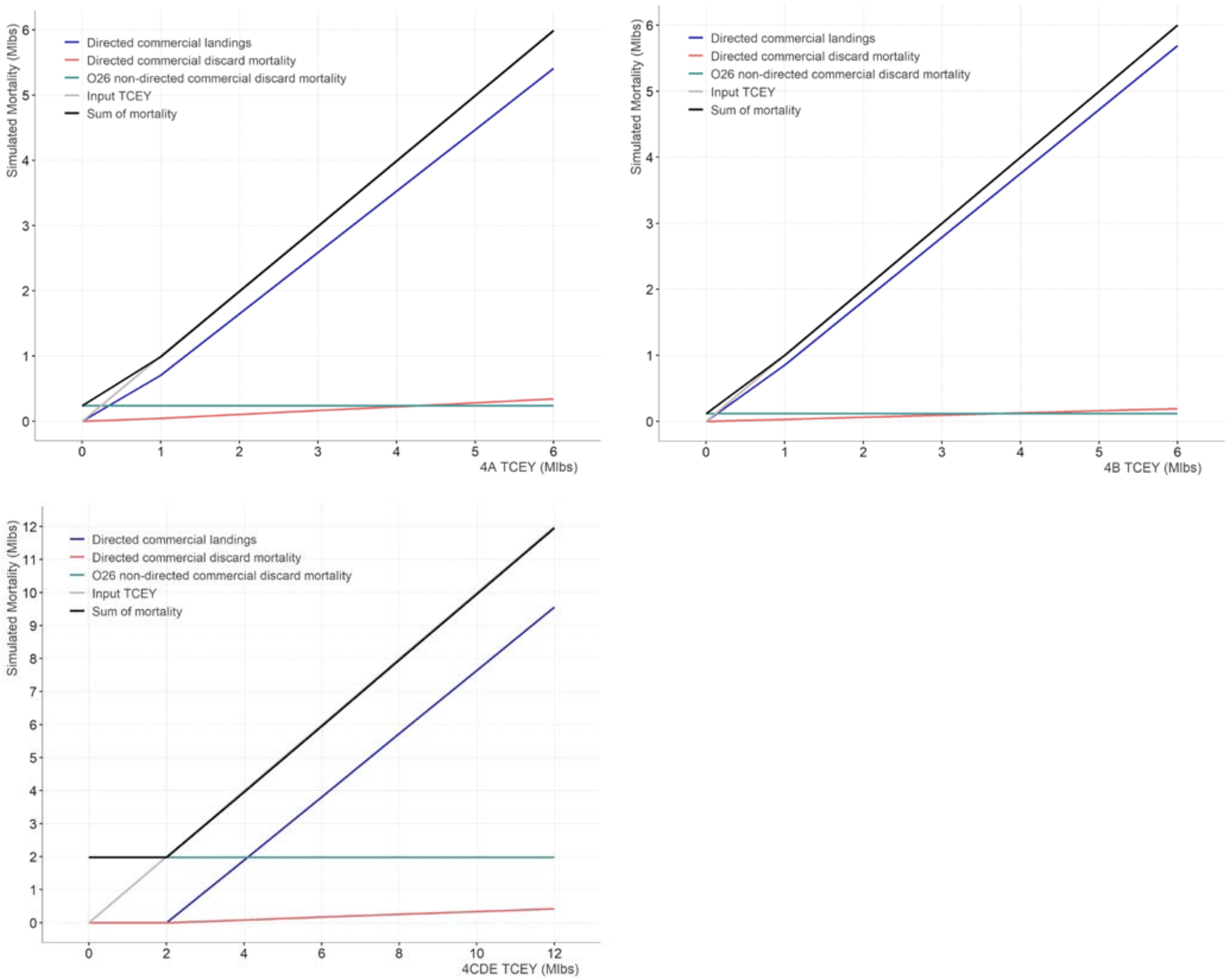

Figure 9: Allocation of the TCEY to sectors for IPHC Regulatory Areas 4A (top left), 4B (top right), and 4CDE (lower left) when O26 non-directed commercial discard mortality is assumed constant at an average value. The input TCEY provided to the allocation function is shown in light gray, while the sum of mortalities after allocation is shown in black.

3 RESULTS

Results of testing the conditioning of a four-region operating model are presented below.

3.1 Four-region operating model

A multi-area OM was specified with four Biological Regions (2, 3, 4, and 4B; Figure 1), thirty-three (33) fisheries (Table 2), and four (4) surveys. The model was initiated in 1888 and initially parameterized using estimates from the long areas-as-fleets (AAF) assessment model. Selectivity was kept the same as the regional estimates from the long AAF assessment model except that the directed commercial and survey selectivities were made asymptotic (i.e., no descending limb) since movement in the spatially explicit OM accounted for availability among the Biological Regions.

Parameters for R0, proportion of recruitment to each Biological Region, movement from 2 to 3, 3 to 2, and 4 to 3 were estimated by minimizing an objective function based on lognormal likelihoods for spawning biomass predictions and region-specific modelled survey indices, robustified multivariate normal likelihoods for the proportion of survey biomass in each region, and observed proportions at age from the FISS. Other movement parameters were fixed to estimates from data (Figure 3) except that movement probabilities from 4 to 2, 2 to 4, 4B to 2, and 2 to 4B were set to zero for all ages. This makes the assumption that a Pacific halibut cannot travel between these areas in an annual time step even though significant probabilities of movement-at-age from 4 to 2 are predicted to occur from the data (Figure 3).

The OM was conditioned using five sets of observations: the average predicted spawning biomass from the long AAF and long coastwide stock assessment models (1888–1992), predicted spawning biomass from the stock assessment ensemble (1993–2019), survey indices of abundance for each Biological Region, survey proportions-at-age for each Biological Region, and the proportion of “all selected sizes” modelled survey biomass in each Biological Region (stock distribution). The lognormal likelihood (assuming that the observed value was the median) was used to fit to the predicted stock assessment spawning biomass and the survey indices.

$$-\ln(L) = \sum \left(\frac{\ln\left({O_y}/{E_y} \right)}{\sigma_y} \right)^2 \qquad (5)$$

where O_y is the predicted spawning biomass from the stock assessment, E_y is the predicted spawning biomass from the OM, and σ_y is the standard deviation of the stock assessment spawning biomass on a natural log scale calculated as $\sigma_y = \sqrt{ln(1 + cv^2)}$.

A robustified multivariate normal (Fournier et al 1990, Starr et al 1999) was used to fit to the survey proportions-at-age and the regional stock distribution estimates.

$$-\ln(L) = -\sum \ln\left[\exp\left(\frac{-\left(O_y - E_y\right)^2}{2O'_y/N'} + 0.01\right)\right] \qquad (6)$$

where $O_y^{'} = (1 - O_y)O_y + 0.1/n$ and N' is the effective sample size as entered in the stock assessment (before data weighting). Estimates of uncertainty were available for the proportion of survey biomass in each Biological Region, thus the denominator was the standard deviation instead of O'_y/N'.

A subset of all possible parameters was used for conditioning by estimating the parameters that minimized the summed weighted negative log likelihood components for each observation type. The parameters estimated are listed in Table 5.

Table 5: Descriptions of the parameters estimated when conditioning the OM. Separate sets of parameters were estimated for movement in poor and good PDO regimes.

Parameters	# parameters	Description
$\ln(R_0)$	1	Natural log of unfished equilibrium recruitment. Determines the scale of the population trajectory.
$p_{y,r}^{R}$	3	Proportion of R_0 distributed to each Biological Region. Only three of the four parameters need to be estimated to sum to 1.
$\Psi_{2\to3}$	5 + 5	Probability of movement-at-age from Region 2 to Region 3, modelled using a double exponential function (equation 3). The left and right λs, left maximum probability, right maximum probability, and right asymptote were estimated.
$\Psi_{3\to2}$	5 + 5	Probability of movement-at-age from Region 3 to Region 2, modelled using a double-exponential function (equation 3). The left and right λs, left maximum probability, right maximum probability, and right asymptote were estimated.
$\Psi_{4\to3}$	5 + 5	Probability of movement-at-age from Region 4 to Region 3, modelled using a double-exponential function (equation 3). The left and right λs, left maximum probability, right maximum probability, and right asymptote were estimated.

The parameters in Table 5 were fit to the five data sources individually to determine similarities and differences in the estimates of parameters and derived quantities that each data source implied. This was done for different parameterizations of movement to understand how changes to the structure affected the fit to the different data sets. Those results (not shown here) identified that fitting to the modelled survey distribution of biomass in each Biological Region was important because fitting to no other single data source resulted in a close prediction of the distribution. Stock distribution is an important component of many management procedures to be tested, thus must be represented accurately by the conditioned OM. Secondly, fitting to index data resulted in predicted spawning biomass trajectories that were generally in the envelope of predicted spawning biomass from the stock assessment models. Index data are an important data source as they reflect trends in abundance by Biological Region. Fitting to proportion-at-age did not greatly improve the overall general trends in recent estimates of proportion-at-age in each region but did result in low predicted spawning biomass. Therefore, the final model was fit to the modelled survey proportion of biomass in each Biological Region, the modelled survey indices of abundance (NPUE) as used in the stock assessment, the estimated spawning biomass from 1888 to 1992 from the two long assessment models, and the estimated spawning biomass from the ensemble assessment from 1993–2019 with each given *ad hoc* weights of 1.0, 0.1, 0.4, and 0.4, respectively, in the joint likelihood.

The predicted spawning biomass fell mostly within the range of estimated spawning biomass from the four stock assessment models in the ensemble (Figure 10). The multi-region operating model predicted a female spawning biomass at the upper part and slightly above the 90% credible interval from about 1930 to 1960 for the long assessment models due to a large amount of predicted total biomass in Biological Regions 3 and 4. The predicted stock distribution matched closely for most years, although the end of the time-series in Biological Regions 2 and 3 and beginning of the time-series in Biological Regions 4 and 4B showed departures. These departures from the observed stock distribution were consistent for all models examined and suggest that the current structural specifications cannot capture these trends.

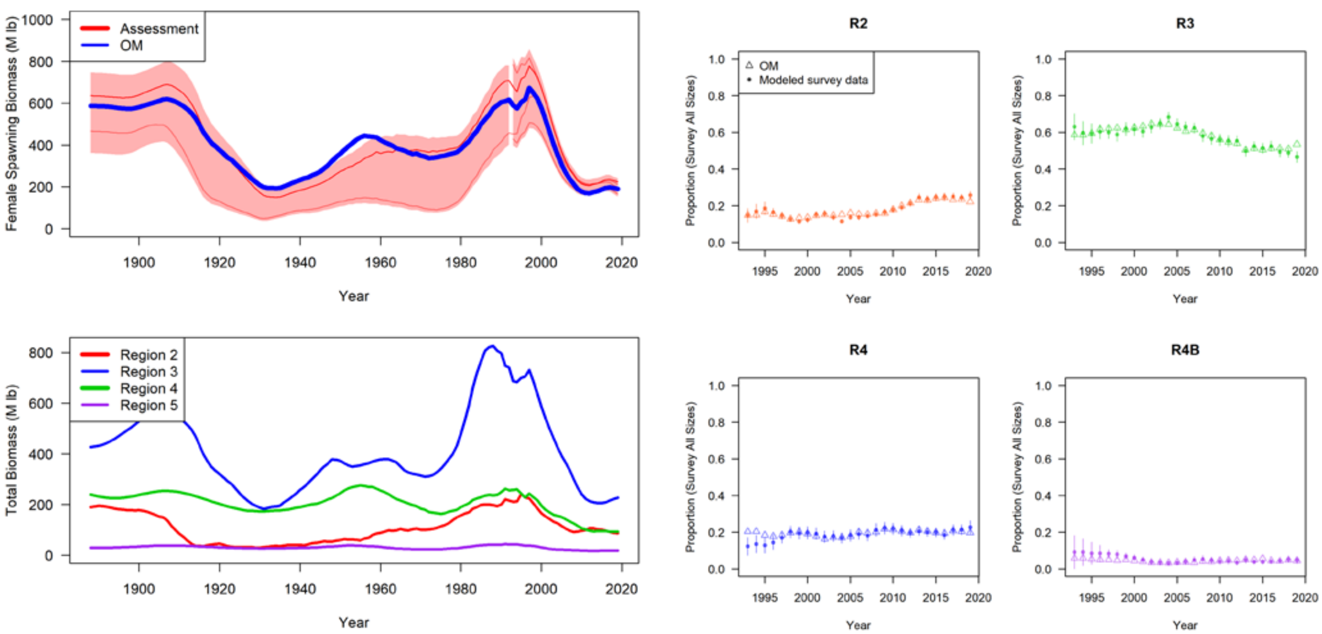

Figure 10: Predicted coastwide spawning biomass (top left), total biomass by Biological Region (bottom left), and the proportion of biomass in each Biological Region (right plots; Region 4B is denoted by "Region 5") from the final OM. The blue line is predicted spawning biomass from the OM and red lines are the predicted spawning biomass from each model in the stock assessment ensemble and the red shaded area in the 90% credible interval from the ensemble stock assessment (top left). The proportion of biomass from the modelled survey results by year and Biological Region (filled circles) with estimated uncertainty are compared to the predicted proportion of biomass from the OM by year and Biological Region in the plots on the right.

Fits to the modelled survey index were reasonable for all Biological Regions, but showed some patterns in residuals in Biological Region 2 (Figure 11). Few models that were examined were able to fit the time-series in Biological Region 2 much better, and those that did show an improved fit had poor fits to stock distribution.

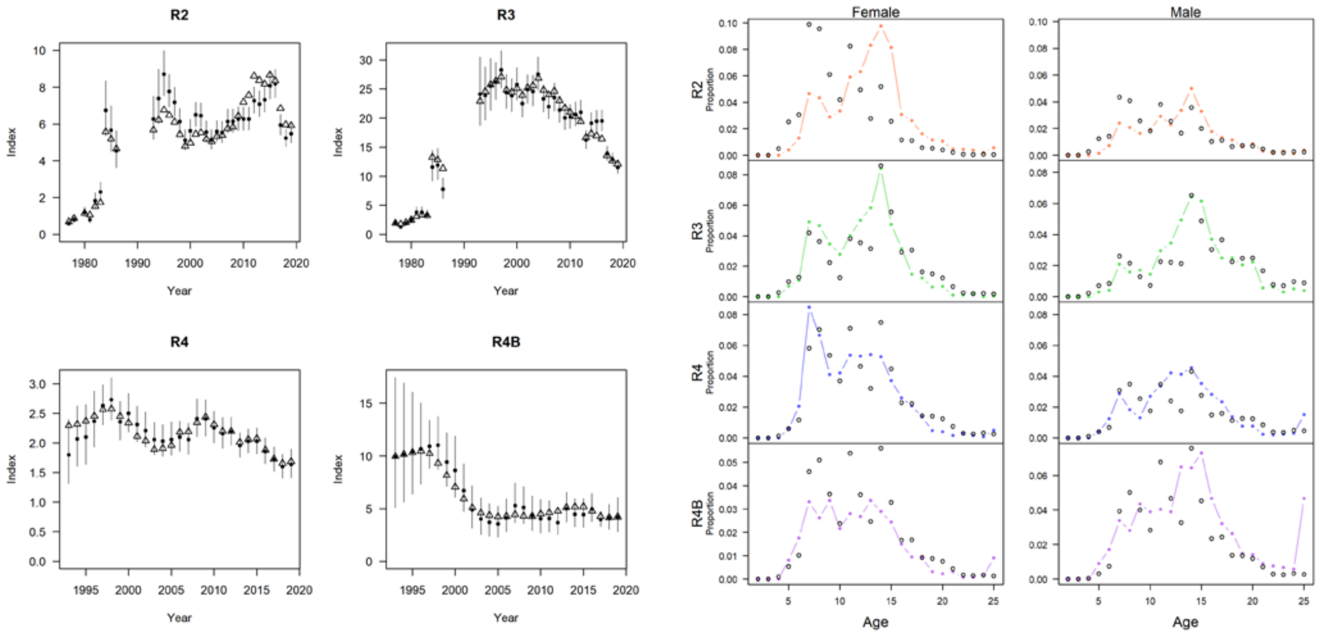

Figure 11: Fits to modelled survey NPUE index data (four panels on the top left), fits to proportions-at-age by sex and Biological Region from the year 2019 (eight panels on the top right), and estimated movement-at-age for the final OM (bottom row). Filled circles in the index plots are modelled survey NPUE with 95% credible intervals and the open triangles are predictions from the final OM. Filled circles connected by lines are the proportions-at-age determined from FISS data and the open circles are predictions from the final OM.

Estimated and assumed movement probabilities-at-age from one Biological Region to another are shown in Figure 12. Movement from 2 to 3 is estimated to be much greater than the data suggest with higher movement of very young fish and lower movement rates of older fish during high PDO regimes. The generally higher movement of older fish from 2 to 3 may be to counter-balance the high movement rates of young fish from 3 to 2. The OM has movement rates near 5% for movement of older fish from 3 to 2. Younger fish tend to move at higher rates from 4 to 3 with little movement once they are age 8 and older. The OM assumes that this is a closed population with no movement in or out of the four Biological Regions, which may explain some of the differences observed from the movement rates based on observations.

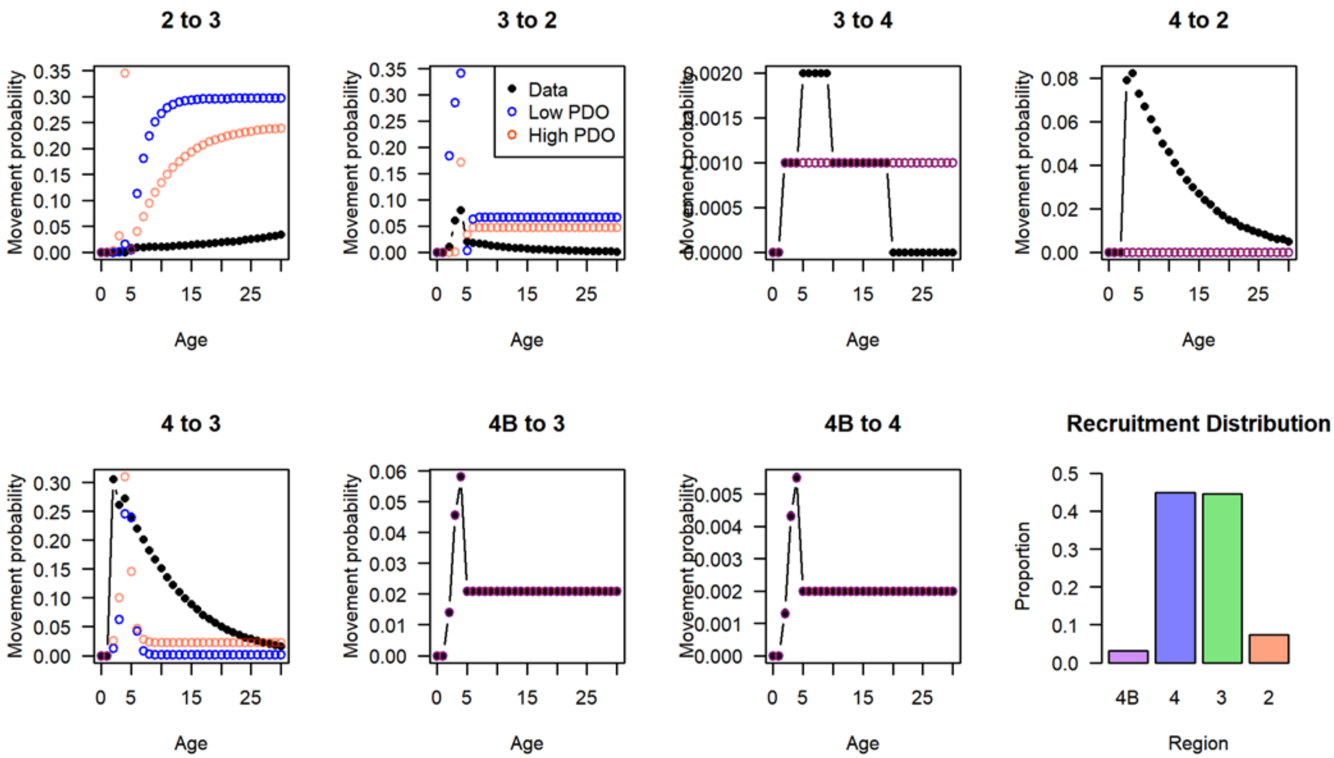

Figure 12: Probabilities of movement-at-age from the data and assumptions (Figure 3) and the conditioned OM (blue and red circles for low and high PDO regimes, respectively). The proportion of recruitment distributed to each Biological Region is shown in the lower right.

The final OM shown here is a reasonable representation of the Pacific halibut population but has some shortcomings. For example, the lack of fit to the 2019 stock distribution in Biological Regions 2 and 3 (Figure 10) and the high predictions of young fish in Biological Region 2 in 2019 (Figure 11). The lack of fit to the proportions-at-age in 2019 are balanced by better fits in previous years (not shown). There are many changes to the model and conditioning process that could be made to potentially improve these fits. For example, movement may be sex-specific, but tagging data are lacking this information.

Overall, the conditioned multi-region model represents the general trends of the Pacific halibut population and is a useful model to simulate the population forward in time and test management strategies.

3.1.1 Uncertainty in the four-region operating model

Uncertainty in population trajectories was captured by adding variability to the parameters of the operating model as specified in Table 3. The correlation matrix estimated from the long AAF model for the R_0, natural mortality (female and male), and recruitment deviations was combined with the correlation matrix for the movement and recruitment distribution parameters as estimated from the conditioning process. The R_0 parameter was estimated in both models and correlations with R_0 were available for all parameters. Otherwise only the correlations for the parameters within a model were available. Parameters were drawn from a multivariate normal distribution to add variability. Correlations and standard deviations for the movement and recruitment distribution parameters were divided by 4 to ensure that the covariance matrix was invertible and to avoid large deviations in movement that may have unknown and undesirable consequences. Hypotheses of movement extremely different than the OM will be investigated through sensitivities and robustness tests.

Fifty trajectories of the OM with parameter variability show a wider range than the 90% credible interval from the ensemble stock assessment (Figure 13). Prior to 1993, the trajectories are in and above the upper portion of the ensemble assessment 90% credible interval, but from 1993 to 2019 the trajectories encompass and extend beyond the credible interval. Therefore, the OM is a reasonable representation of the Pacific halibut population in recent decades and is modelled with variability that will allow for the robust testing of MPs.

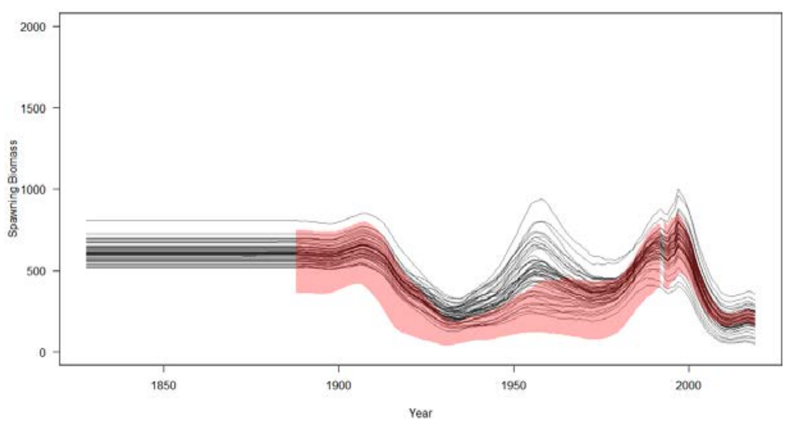

Figure 13: Fifty trajectories of the OM with parameter variability included, shown agains the 90% credible interval of the ensemble stock assessment (two models before 1993 and four models for 1993–2019).

The stock distribution with variability does not show a large departure from the observed stock distribution (Figure 14). The variability is consistent with the observations except at the beginning of the time-series in Biological Region 4 and in 2019 for Biological Regions 2 and 3. The beginning of the time-series in Biological Region 4 was estimated with few data. The recent year may have seen a shift in movement that is not explained by the OM.

Projections with the OM incorporated parameter variability (Table 3) and projection variability (Table 4) produced a wide range of trajectories. Figure 15 shows the median of one-hundred simulations to 2099 without mortality due to fishing along with the interval between the 5^{th} and 95^{th} percentiles. Individual trajectories show that a single trajectory may cover a wide range of that interval in this 80-year period. The variability looks like it has reached its full range after 30 years, although there is an increasing trend near year 2090. This could be due to the small number of simulations and the expected high variability without fishing mortality.

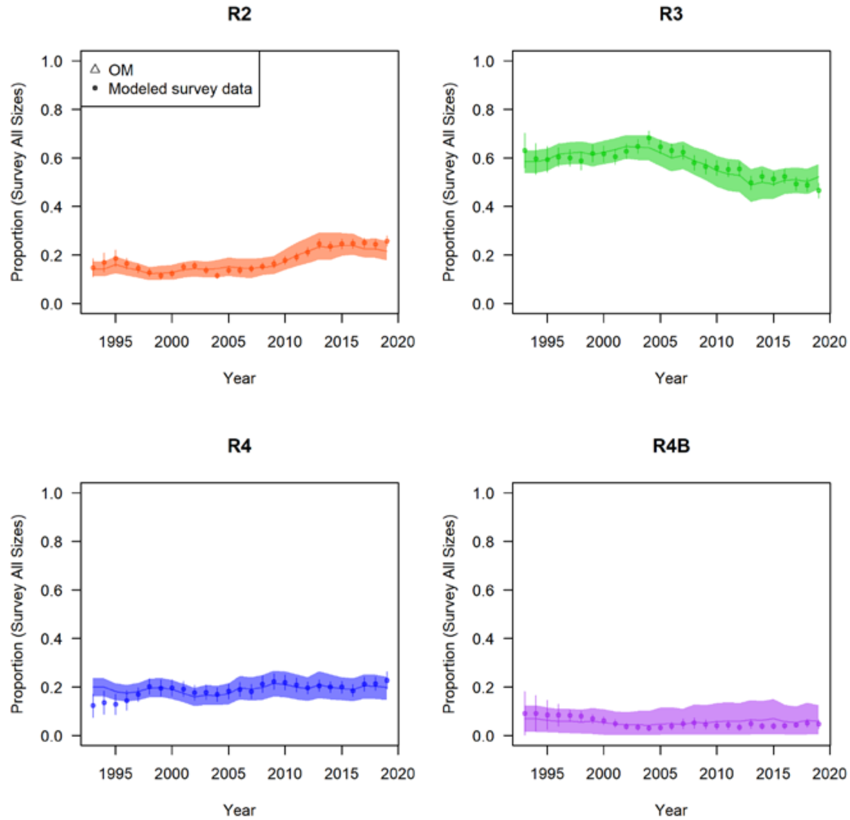

Figure 14: Stock distribution determined from FISS observations (points) and from the OM with variability (shaded areas).

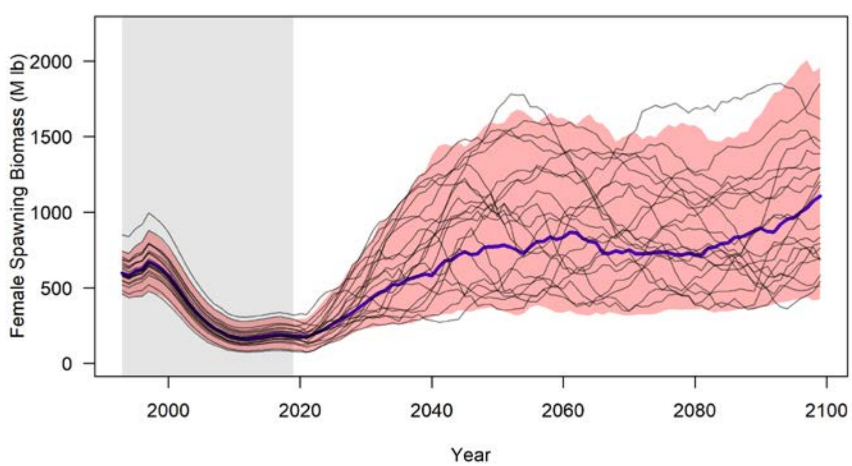

Figure 15: One-hundred simulations for 80 years without fishing mortality. The blue line is the median and the pink shaded area show the interval between the 5th and 95th percentiles. The light shaded grey area between 1993 and 2019 is the historical period, and 2020 has fixed fishing mortality based on the already defined catch limits for 2020. The grey lines are the first 20 individual trajectories.

3.2 Closed-loop simulation results

Simulation results will be made available in a revision of the document.

4 PROGRAM OF WORK

Many important MSE tasks have already been completed; past accomplishments include the following:

1. Familiarization with the MSE process.
2. Defining conservation and fishery goals.
3. Defining objectives and performance metrics for those goals.
4. Developing coast-wide (single-area) and spatial (multiple-area) operating models.
5. Identifying management procedures for the coastwide fishing intensity and distributing the TCEY to IPHC Regulatory Areas.
6. Presentation of results investigating coastwide fishing intensity.

Management Strategy Evaluation is a process that can develop over many years with many iterations. It is also a process that needs monitoring and adjustments to make sure that management procedures are performing adequately. Therefore, the MSE work for Pacific halibut fisheries will be ongoing as new objectives are defined, more complex models are built, and results are updated. This time will include continued consultation with stakeholders and managers via the MSAB meetings, defining and refining goals and objectives, developing alternative operating models, running simulations, and reporting results. Along the way, there will be useful outcomes that may be used to improve existing management and will influence recommendations for future work. Embracing this iterative process, the program of work identifies the tasks to continue to make progress on the investigation of management strategies.

4.1 Five-year program of work

Eight (8) categories have been define in the five-year program of work (Figure 16).

Task 1: Review, update, and further define goals and objectives

Task 2: Develop performance metrics to evaluate objectives

Task 3: Identify realistic management procedures of interest to evaluate

Task 4: Design and code a closed-loop simulation framework

Task 5: Further the development of operating models

Task 6: Run closed-loop simulations and evaluate results

Task 7: Develop tools that will engage stakeholders and facilitate communication

Details of many tasks have not been specified beyond 2021, and the description below focuses on 2020 leading up to the 97th Annual Meeting (AM097) in January 2021.

The first full MSE results incorporating coastwide scale and distribution components of the management procedure (Figure 5) will be presented at the 97th IPHC Annual Meeting (AM097) in January 2021. There are three main tasks to accomplish in 2020: 1) identify management procedures incorporating coastwide and distribution components to simulate, 2) condition a multi-area operating model and prepare a framework for closed-loop simulations, and 3) present results in various ways in order to evaluate the management procedures. These three main tasks are described below and Table 6 identifies the tasks that will be undertaken at each MSAB and SRB meeting in 2020.

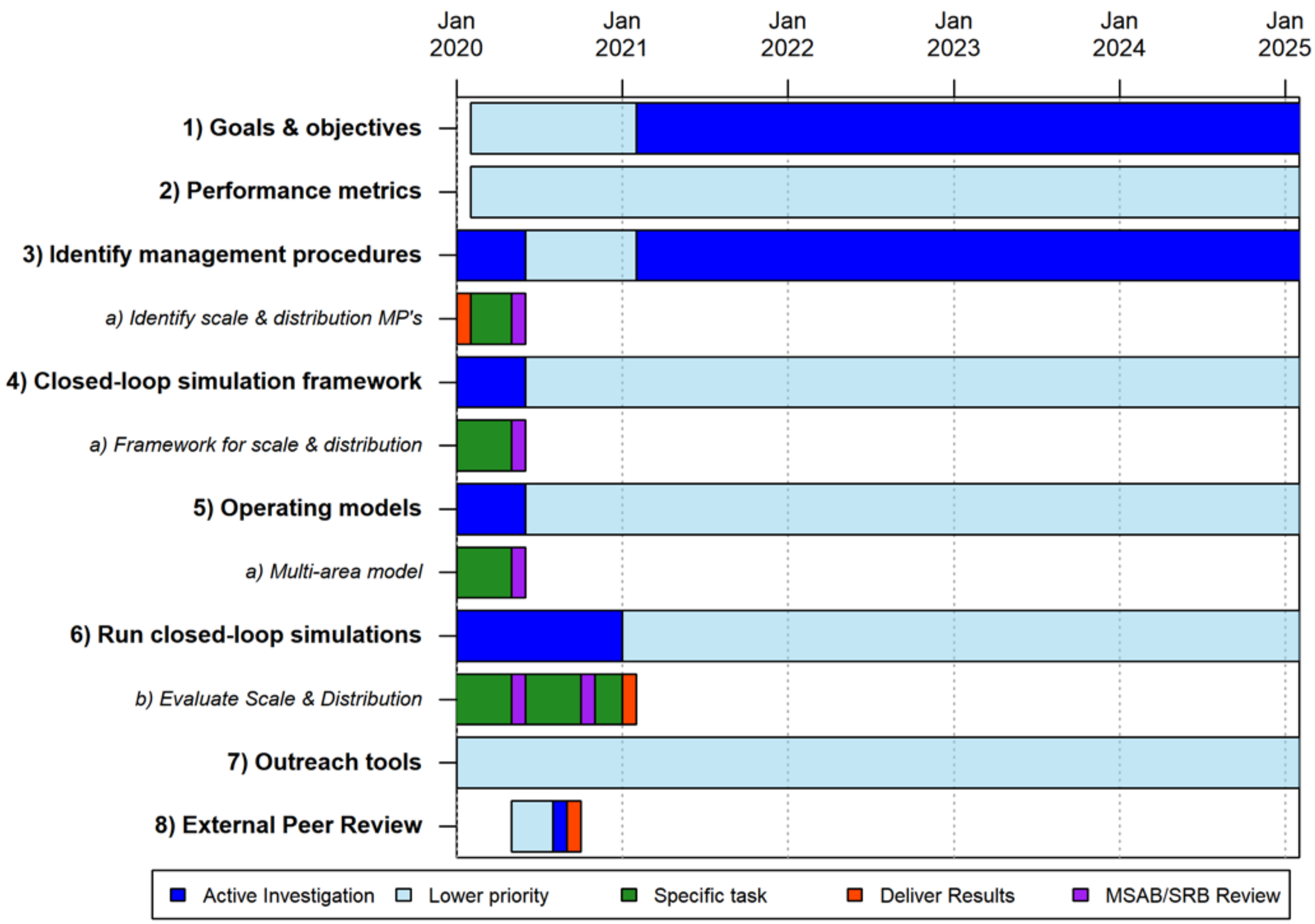

Figure 16: Gantt chart for the five-year work plan. Tasks are listed as rows. Dark blue indicates when the major portion of the main tasks work will be done. Light blue indicates when preliminary or continuing work on the main tasks will be done. Dark green indicates when the work on specific sub-topics will be done. Red areas show when results will be presented to the Commission. Purple areas show when the task will be reviewed by the MSAB and/or the SRB.

Table 6: Tasks to complete in 2020 at the MSAB and SRB meetings.

May 2020 MSAB Meeting (MSAB015)	**Progress**
Review Goals and Objectives (Distribution & Scale)	Completed
Review simulation framework	Completed
Review multi-area model	Completed
Review preliminary results	
Identify MPs (Distribution & Scale)	Completed
June 2020 SRB Meeting (SRB016)	
Review simulation framework	Completed
Review multi-region operating model	Completed
Review preliminary results	
August 2020 MSAB Ad Hoc 03	
Examine preliminary results	Completed
September 2020 SRB Meeting (SRB017)	
Review multi-region operating model	
Review penultimate results	
October 2020 MSAB Meeting (MSAB016)	
Review final results	
Provide recommendations on MPs for scale and distribution	
Annual Meeting 2021	
Presentation of first complete MSE product to the Commission Recommendations on Scale and Distribution MP	

5 Recommendations

That the SRB:

a) **NOTE** paper IPHC-2020-SRB017-09 which provides a description of the IPHC MSE framework, a description of the specifications of the multi-area operating model, results from conditioning the multi-area operating model, and an overview of the implementation of management procedures.

b) **RECOMMEND** the use of the MSE framework to evaluate management procedures incorporating scale and distribution elements.

c) **RECOMMEND** improvements for the MSE framework including data generation, estimation models, multi-region operating models, and methods to simulate processes.

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7 APPENDICES

Appendix I: Primary objectives defined by the Commission for the MSE

Appendix II: Proposed and Recommended Management Procedures from MSAB015

APPENDIX I
PRIMARY OBJECTIVES DEFINED BY THE COMMISSION FOR THE MSE

Table 7: Primary measurable objectives, evaluated over a simulated ten-year period, accepted by the Commission at the 7th Special Session of the Commission (SS07). Objective 1.1 is a biological sustainability (conservation) objective and objectives 2.1, 2.2, and 2.3 are fishery objectives.

GENERAL OBJECTIVE	MEASURABLE OBJECTIVE	MEASURABLE OUTCOME	TIME-FRAME	TOLERANCE	PERFORMANCE METRIC
1.1. KEEP FEMALE SPAWNING BIOMASS ABOVE A LIMIT TO AVOID CRITICAL STOCK SIZES AND CONSERVE SPATIAL POPULATION STRUCTURE	Maintain a female spawning stock biomass above a biomass limit reference point at least 95% of the time	*SB* < Spawning Biomass Limit (SB_{Lim}) SB_{Lim}=20% unfished spawning biomass	Long-term	0.05	$P(SB < SB_{Lim})$
	Maintain a defined minimum proportion of female spawning biomass in each Biological Region	$p_{SB,2} > 5\%$ $p_{SB,3} > 33\%$ $p_{SB,2} > 10\%$ $p_{SB,2} > 2\%$	Long-term	0.05	$P\left(p_{SB,R} < p_{SB,R,min}\right)$
2.1 MAINTAIN SPAWNING BIOMASS AROUND A LEVEL THAT OPTIMIZES FISHING ACTIVITIES	Maintain the coastwide female spawning biomass above a biomass target reference point at least 50% of the time	*SB*<Spawning Biomass Target (SB_{Targ}) SB_{Targ}=$SB_{36\%}$ unfished spawning biomass	Long-term	0.50	$P\left(SB < SB_{Targ}\right)$
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)*

APPENDIX II
PROPOSED AND RECOMMENDED MANAGEMENT PROCEDURES FROM MSAB015

Recommended management procedures to be evaluated by the MSAB in 2020 and the priority of investigation. A priority of 1 denotes a focus on producing precise performance metrics. Reproduced from IPHC-2020-MSAB015-R.

Table II.1: Recommended management procedures to be evaluated by the MSAB in 2020 and the priority of investigation. A priority of 1 denotes a focus on producing precise performance metrics. A priority of 2 denotes potentially fewer simulations are desired, if time is constrained.

MP	Coastwide	Regional	IPHC Regulatory Area	Priority
MP 15-A	SPR 30:20		• O32 stock distribution • Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) • 1.65 Mlbs floor in 2A[1] • Formula percentage for 2B[2]	1
MP 15-B	SPR 30:20 MaxChange15%		• O32 stock distribution • Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) • 1.65 Mlbs floor in 2A[1] • Formula percentage for 2B[2]	1
MP 15-C	SPR 30:20 MaxChange15%	Biological Regions, O32 stock distribution Rel HRs[3]: R2=1, R3=1, R4=0.75, R4B=0.75	• O32 stock distribution • Relative harvest rates not applied • 1.65 Mlbs floor in 2A[1] • Formula percentage for 2B[2]	2
MP 15-D	SPR 30:20 MaxChange15% Max FI (36%)		First • O32 stock distribution • Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) Second within buffer (pro-rated if exceeds buffer) • 1.65 Mlbs floor in 2A[1] • Formula percentage for 2B[2]	2
MP 15-E	SPR 30:20 MaxChange15%		• O32 stock distribution • Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) • 1.65 Mlbs floor in 2A[1]	2
MP 15-F	SPR 30:20 MaxChange15%	National Shares: 20% to 2B, 80% to other	• O32 stock distribution to areas other than 2B • Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)	1
MP 15-G	SPR 30:20 MaxChange15%		• O32 stock distribution • Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)	1

MP	Coastwide	Regional	IPHC Regulatory Area	Priority
MP 15-H	SPR 30:20 MaxChange15%		• O32 stock distribution • Relative harvest rates (1 for 2-3, 4A, 4CDE, 0.75 for 4B)	1
MP 15-I	SPR 30:20 MaxChange15%		• All sizes stock distribution • Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)	2
MP 15-J	SPR 30:20 MaxChange15%		• O32 stock distribution (5-year moving average) • Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)	1
MP 15-K	SPR 30:20 MaxChange15%		• 5-year shares determined from 5-year O32 stock distribution (vary over time but change only every 5th year)	2

[1] paragraph 97b IPHC-2020-AM096-R

[2] paragraph 97c of IPHC-2020-AM096-R

[3] R2 refers to Biological Region 2 (2A, 2B, 2C); R3 refers to Biological Region 3 (3A, 3B); R4 refers to Biological Region 4 (4A, 4CDE), and R4B refers to Biological Region 4B