Management Strategy Evaluation results for distribution management procedures

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PURPOSE

To provide a description of the International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) framework and simulations of management procedures for distributing the TCEY.

SUMMARY

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) has completed an evaluation of 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. A MSE framework has been developed containing the Operating Model (OM) that simulates the Pacific halibut population and fisheries, and the Management Procedure (MP) with a closed-loop feedback. A four-region operating model was conditioned to match historical data and then simulated forward in time with uncertainty and using eleven MPs, defined at the 15th Session of the IPHC Management Strategy Evaluation Board (MSAB015), to determine distributed mortality limits. There are many trade-offs between objectives and between IPHC Regulatory Areas that must be considered in the evaluation. Biological sustainability objectives were met for all MPs, except that the percentage of spawning biomass in IPHC Regulatory Area 4B was less than 2% in more than 5% of the simulations for all MPs. This particular result may be due to a number of factors, including a misspecification of the population dynamics in that Biological Region. Yield objectives were similar for coastwide performance metrics, but varied across IPHC Regulatory Areas depending on the elements of the MPs. Stability objectives were ranked higher when methods to dampen variability, such as constraints on the annual change in the TCEY and averaging of stock distribution estimates, were included in the MP. The full set of MSE results and visualizations to evaluate the MPs are available on the MSE Explorer online tool.

1 INTRODUCTION

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) has completed an evaluation of 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 this MSE framework aimed to support the scientific, forecast-driven study of the trade-offs between fisheries management scenarios. Crafting this tool required:

- the definition and specification of a multi-area operating model (OM);

- an ability to condition operating model parameters using historical catch and IPHC Fishery-Independent Setline FISS (FISS) 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 relative to pre-defined objectives.

The MSE framework is briefly described below, followed by a description of the management procedures being evaluated that distribute the TCEY to IPHC Regulatory Areas, and then the presentation of simulation results.

2 FRAMEWORK ELEMENTS

The MSE framework includes elements that simulate the Pacific halibut population and fishery (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-MSAB016-INF01.

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. The OM is flexible, fast, modular, and easily adapted to many different assumptions. It will be a useful tool for many investigations of the Pacific halibut fishery in the future.

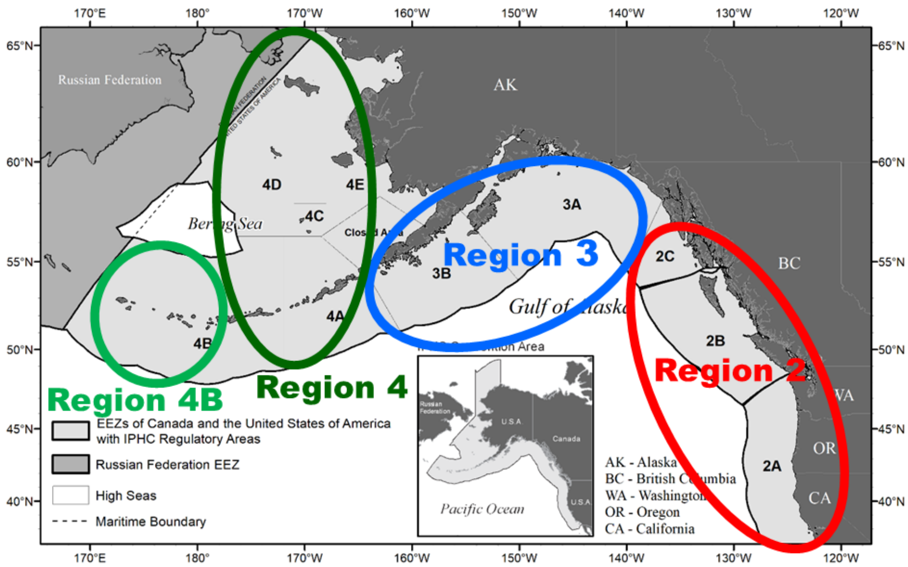

Figure 1: Biological Regions overlaid on IPHC Regulatory Areas. Region 2 comprises 2A, 2B, and 2C, Region 3 comprises 3A and 3B, Region 4 comprises 4A and 4CDE, and Region 4B comprises solely 4B.

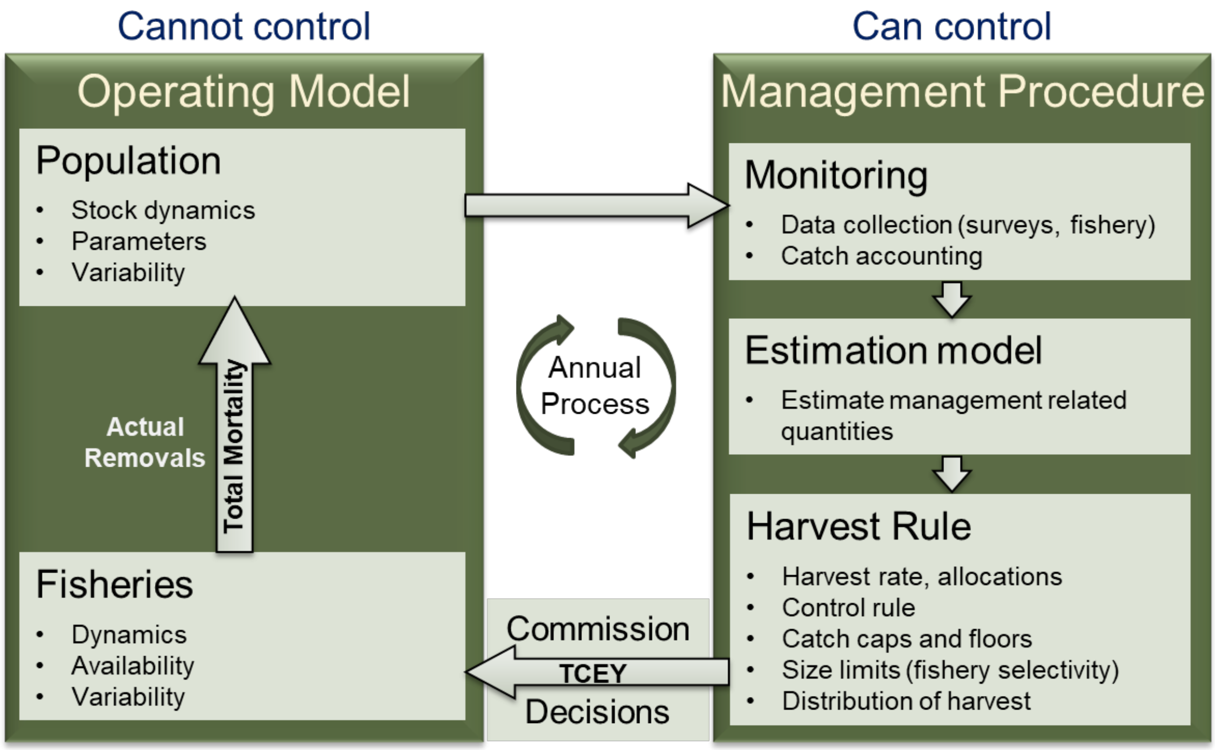

Figure 2. Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

2.1.1 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 (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 and fisheries in adjacent IPHC Regulatory Areas may intercept the same pool of fish. 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 that represents the observations from FISS . 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 allow 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.

2.1.1.1 Recruitment

Recruitment at age 0 to the population is determined at the coastwide level and is a function of the coastwide spawning biomass using a Beverton-Holt spawner-recruit relationship with a steepness of 0.75. The recruitment to each Biological Region is simply a proportion of the coastwide recruitment and those proportions (constrained to sum to 1) are time-invariant.

2.1.1.2 Fisheries

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 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 FISS 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. The survey sector mimicking the FISS is simply referred to as ‘survey’ here to avoid confusion with actual FISS observations.

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

Selectivity determines the age composition of fishery mortality and ensures the removal of appropriate numbers-at-age from the population when mortality occurs in the annual time-step. Selectivity in this OM represents the proportion at each age that is captured and retained (i.e., landed) by the gear. Directed commercial discard mortality is modelled as a separate sector with its own selectivity, 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 Areas-As-Fleets (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 were modified to make the selectivity curves for directed commercial fisheries and the survey asymptotic (i.e., no descending limb) because movement should account for implied availability of a spatially explicit model compared to the coastwide stock assessment. Selectivity could be further modified as necessary to improve fits to data.

2.1.1.3 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.

2.1.1.4 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.

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.

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 Commercial 2A	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

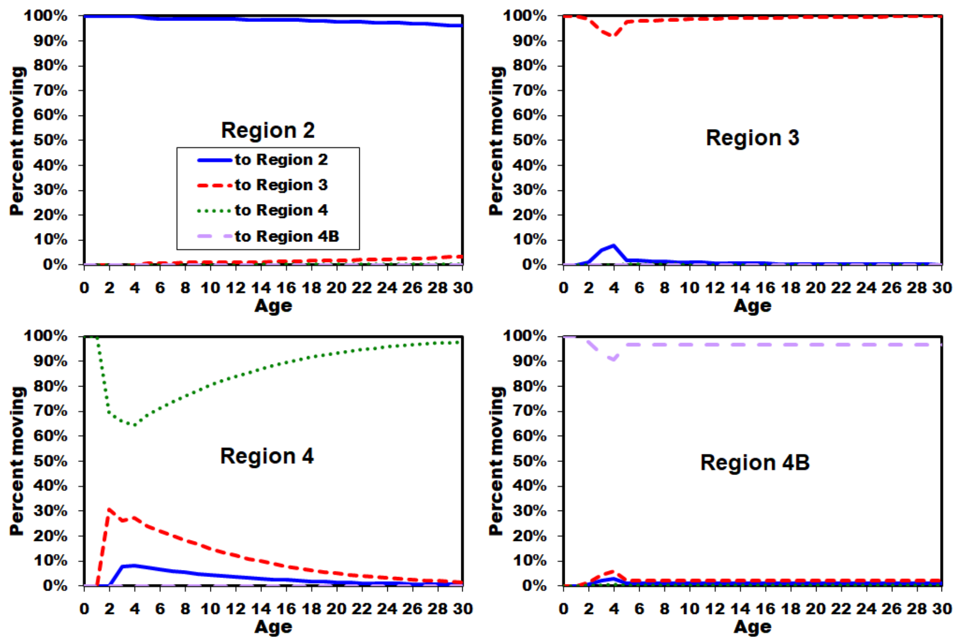

Figure 3: Estimated aggregate annual movement rates by age from Biological Regions (panels) based on currently available data (from IPHC-2019-AM095-08).

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, which allows for uncertainty and variability to be easily applied.

2.1.1.5 Maturity

Spawning biomass for Pacific halibut is currently calculated from annual 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.

2.1.2 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.

2.1.2.1 Uncertainty in the conditioned OM

The conditioned OM is a representation of the Pacific halibut population and matches observations from the fishery, FISS, 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*)	Uncertainty determined from assessment
Average recruitment (R_0)	Effect of the coastwide environmental regime shift based on the PDO and variability determined from conditioning
Recruitment	Random lognormal deviations. Variability on distribution to Biological Regions determined from conditioning
Movement	Uncertainty estimated when conditioning.

2.1.2.2 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.

2.1.2.3 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). The regime was simulated in the MSE by

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

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.

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.
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 (uncertainty)	Variability on movement parameters determined from conditioning process
Movement (variability)	Change in parameters synchronized with simulated PDO-linked regime shift

2.1.2.4 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.

2.2 Conditioned four-region operating model

A multi-region OM was specified with four Biological Regions (2, 3, 4, and 4B; Figure 1), thirty-three (33) fisheries (Table 2), and four (4) survey. The model was initiated in 1888 and initially parameterized using estimates from the long AAF assessment model.

Parameters for R0, the 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 FISS indices, robustified multivariate normal likelihoods for the proportion of FISS 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).

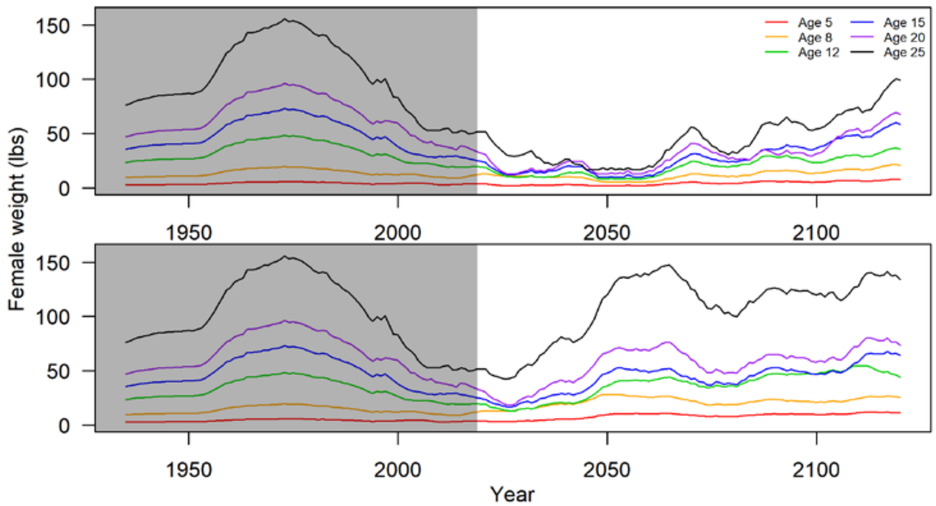

Figure 4: Past observed (shaded area) and two examples of possible one-hundred-year projections of weight at ages 5, 8, 12, 15, 20, and 25.

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), FISS indices of abundance for each Biological Region, FISS proportions-at-age for each Biological Region, and the proportion of "all selected sizes" modelled FISS biomass in each Biological Region (stock distribution). The subset of parameters estimated during the conditioning process are listed in Table 5.

The predicted spawning biomass from the conditioned OM fell mostly within the range of estimated spawning biomass from the four stock assessment models in the ensemble (Figure 5). 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.

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.
$p^R_{y,r}$	3	Proportion of R_0 distributed to each Biological Region. Only three of the four parameters need to be estimated to sum to 1.
$\Psi_{2\rightarrow3}$	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.
$\Psi_{3\rightarrow2}$	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.
$\Psi_{4\rightarrow3}$	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.

Fits to the modelled FISS index were reasonable for all Biological Regions, but showed some patterns in residuals in Biological Region 2 (Figure 6). 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.

Estimated and assumed movement probabilities-at-age from one Biological Region to another are shown in Figure 7. 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.

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 5) and the high predictions of young fish in Biological Region 2 in 2019 (Figure 6). 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.

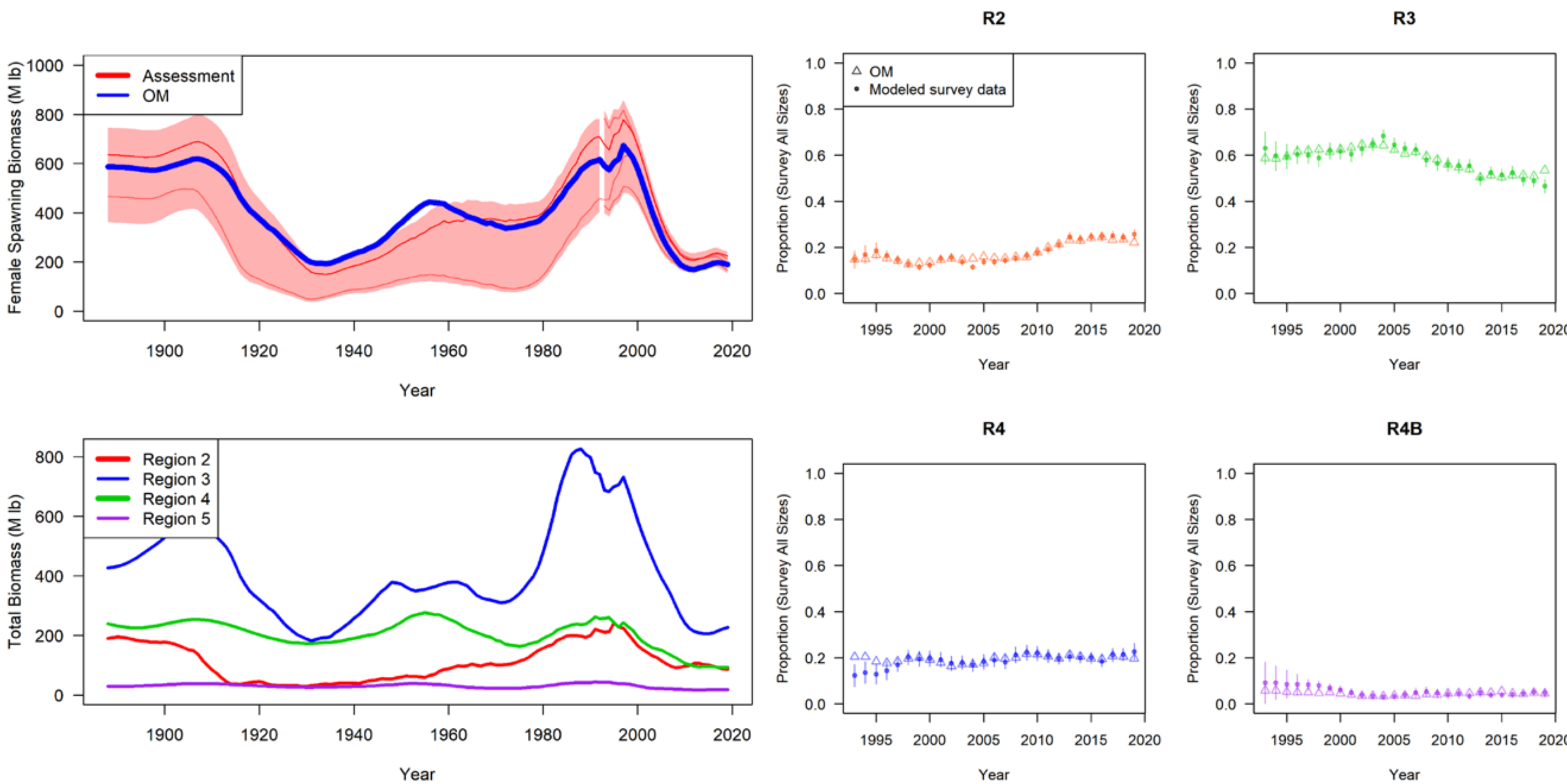

Figure 5: Predicted coastwide spawning biomass (top left) where the blue line is the predicted spawning biomass from the OM, the red lines are the predicted spawning biomass from each model in the stock assessment ensemble, and the red shaded area is the 90% credible interval from the ensemble stock assessment. Total biomass by Biological Region in millions of pounds (bottom left) where Region 4B is denoted by “Region 5”. Predicted annual proportions of biomass in each Biological Region (right plots) from the conditioned OM (unfilled symbols) compared to the modelled FISS results (filled circles) with 95% credible intervals.

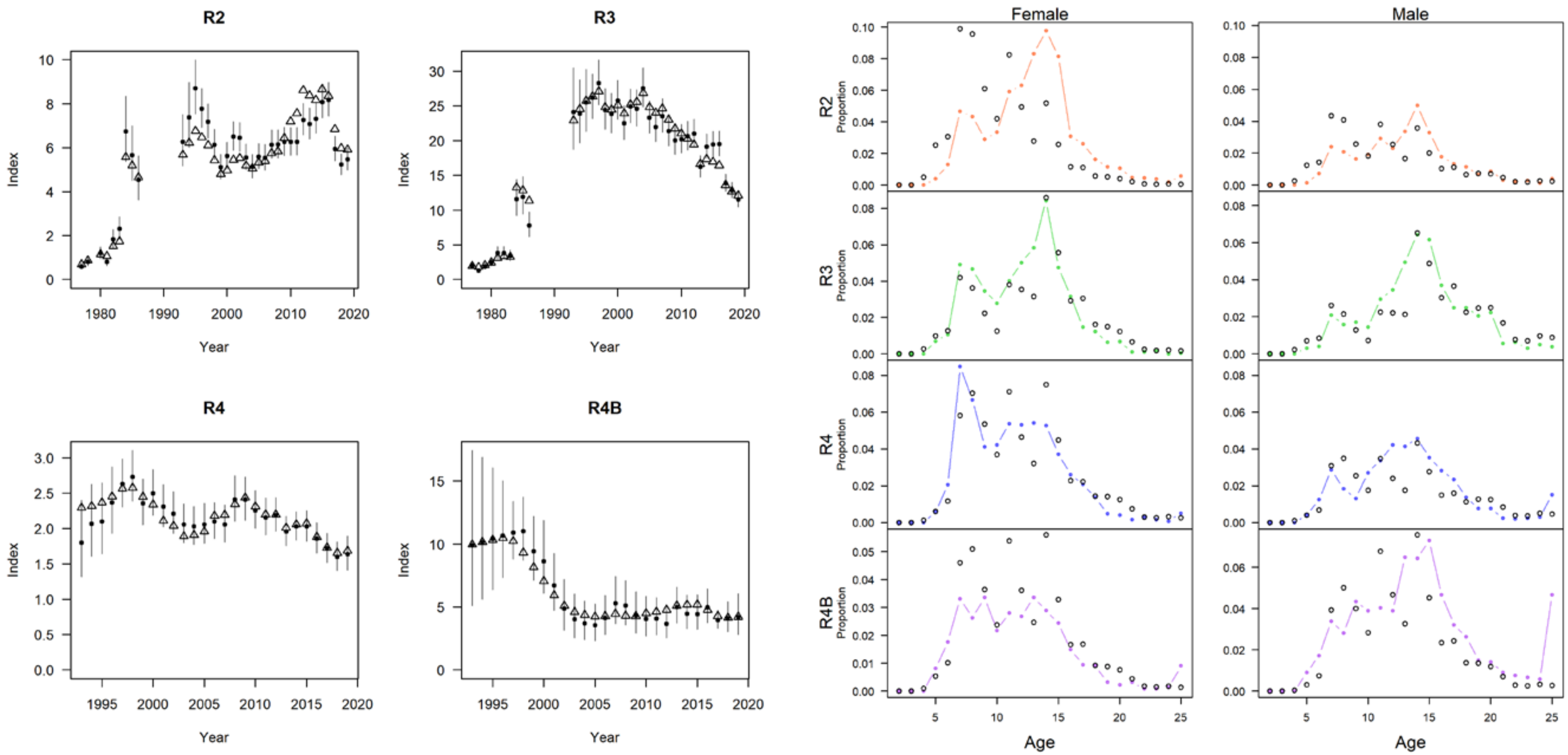

Figure 6: Fits to modelled FISS NPUE index data (four panels on the left) where filled circles are modelled FISS NPUE with 95% credible intervals and the open triangles are predictions from the conditioned OM. Fits to proportions-at-age by sex and Biological Region from the year 2019 (eight panels on the right) with filled circles connected by lines showing the proportions-at-age determined from FISS data and the open circles showing predictions from the conditioned OM.

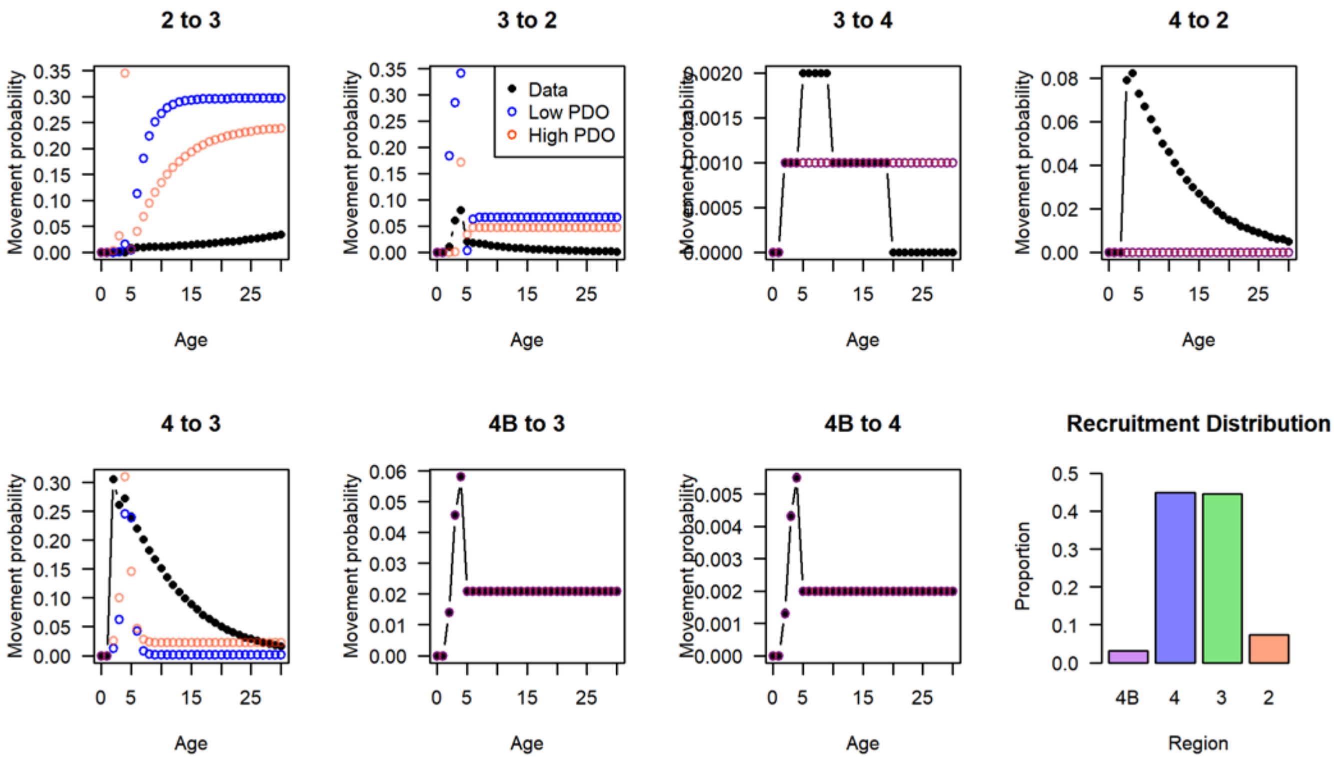

Figure 7: Probabilities of movement-at-age from the data and assumptions (Figure 3) and the conditioned OM (blue and red circles for low and high PDO regimes, respectively). The proportion of recruitment distributed to each Biological Region is shown in the lower right.

2.2.1 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 with correlations between these parameters taken into account. Extremely different hypotheses of specific parameterizations (e.g. movement or steepness) may 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 8). 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.

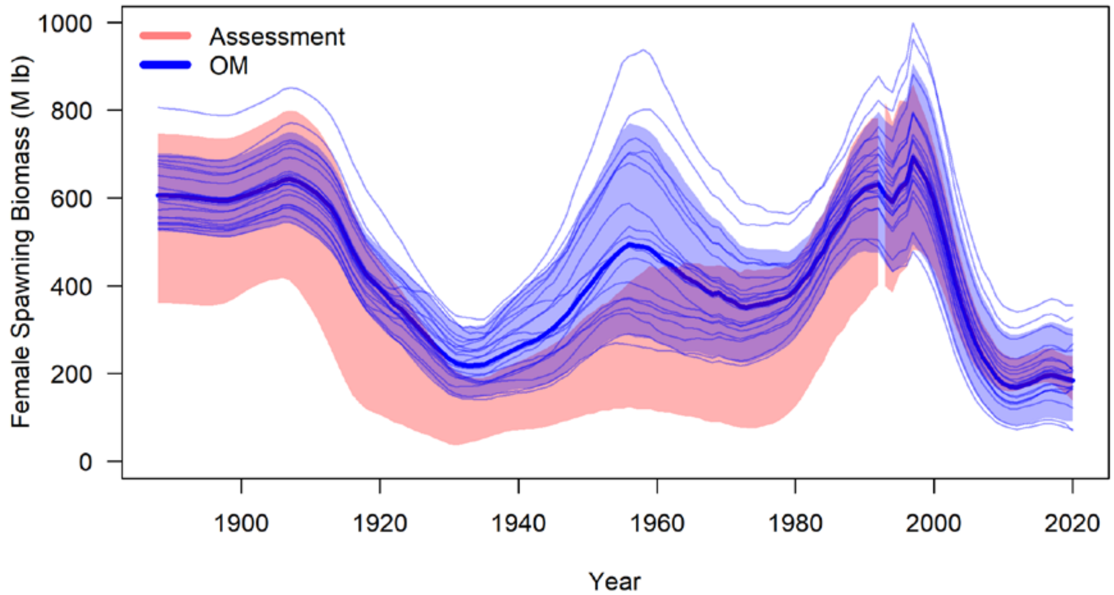

Figure 8: The 90% credible interval from six-hundred trajectories of the OM with parameter variability included (blue shaded area), shown against the 90% credible interval of the ensemble stock assessment (two models before 1993 and four models for 1993–2019, red shaded area). An example twenty trajectories are shown (thin blue lines) along with the median of all 600 trajectories (thick blue line).

The stock distribution with variability does not show a large departure from the observed stock distribution (Figure 9). 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 10: Six hundred 100-year simulations without fishing mortality. The dark blue line is the median and the blue shaded area shows the interval between the 5th and 95th percentiles. The thin blue lines are the first 20 individual trajectories. shows the median of six-hundred simulations to 2119 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 one-hundred year period.

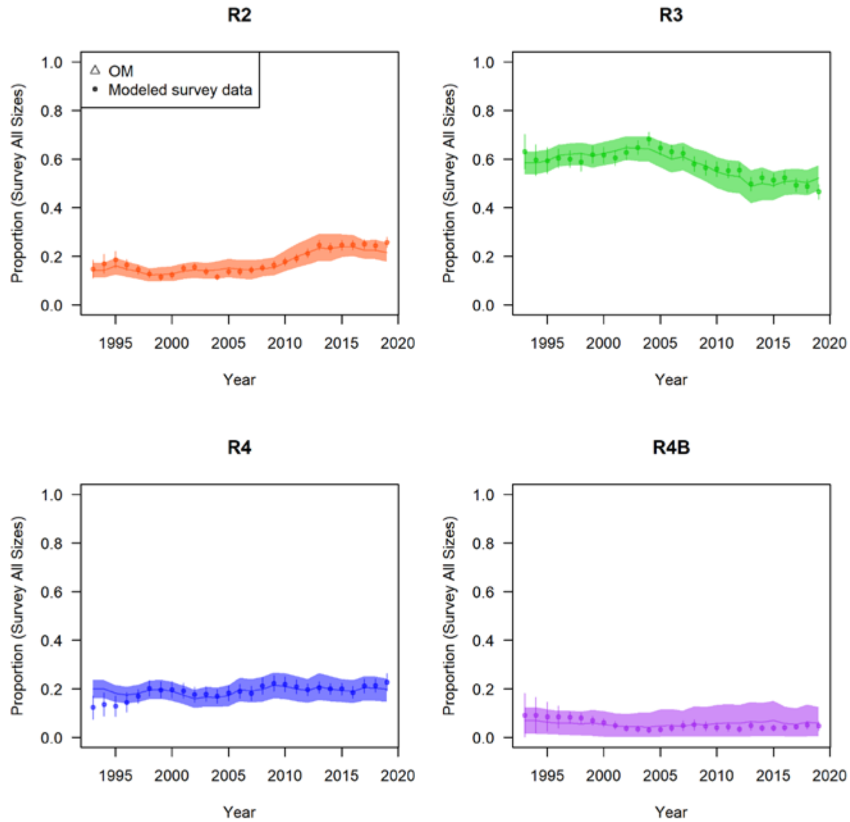

Figure 9: Stock distribution determined from FISS observations (points) and from the OM with variability (shaded areas).

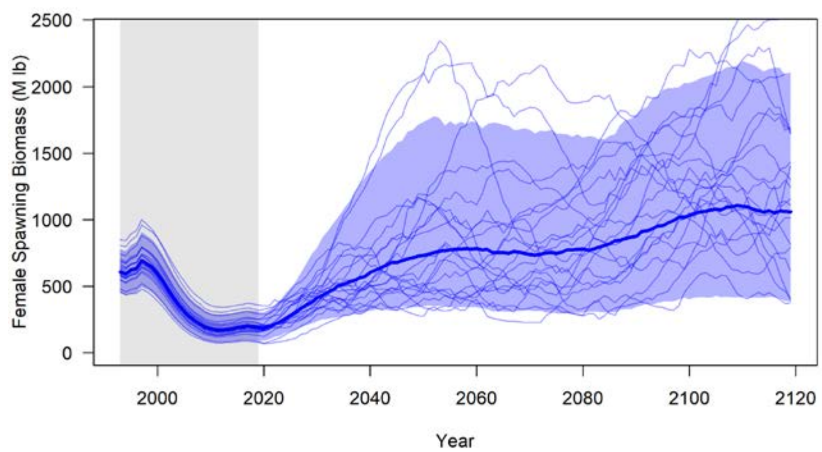

Figure 10: Six hundred 100-year simulations without fishing mortality. The dark blue line is the median and the blue shaded area shows the interval between the 5th and 95th percentiles. The thin blue lines are the first 20 individual trajectories.

2.3 Management Procedures for coastwide scale and distribution of the TCEY

The management procedure consists of three elements (Figure 2): monitoring, estimation, and the harvest rule. Monitoring (data generation) is the code that simulates the data from the operating model that are used by the estimation model (estimation) as well as O32 or all-sizes stock distribution, which is then passed to the harvest rule to determine the total mortality, the distribution of the TCEY to IPHC Regulatory Areas, and subsequent allocation to sectors.

2.3.1 Monitoring (data generation)

The MSE framework generates data by simulating the sampling process and can incorporate variability, bias, and any other properties that are desired. Fishery data are generated as needed by the estimation model (e.g., age compositions and CPUE). Data are generated from the survey in the OM (NPUE, WPUE, age compositions, and stock distribution) that are used by the estimation model and management procedures.

2.3.2 Estimation model

The Estimation Model (EM) is analogous to the stock assessment and introduces estimation error in the simulations. Three approaches to introduce and investigate estimation error were included in the MSE framework.

2.3.2.1 No estimation error

The estimates and predictions needed for the harvest rule are taken directly from the operating model and do not include estimation error. This provides an indication of the best possible outcome given the natural variability in the population, although is unrealistic because the population quantities are never known without error.

2.3.2.2 Simulate estimation error

This approach simulated the error in estimates and predictions needed for the harvest rule using random number generation from probability distributions, 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 were applied to the stock status and TM. Details can be found in Section 4.2.2. of IPHC-2018-SRB012-08. This method is useful to provide a reasonable approximation of the assessment process while speeding up the simulation process and allowing of investigation of specific levels of bias and variability.

2.3.2.3 Model estimation error

This method uses a model similar to the stock assessment (i.e., stock synthesis) with generated data to determine the estimates and predictions needed for the harvest rule. The assessment models that this EM was based on are complex 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 an EM based on the assessment models provides a more accurate representation of the assessment process and of the bias associated with it. This method is currently in development and will be available for future iterations of the

MSE. Some results using only one of the four assessment models used in the ensemble are available for preliminary comparison to the other methods.

2.3.3 Harvest Rule

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 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 11 is an illustration of the current interim 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.

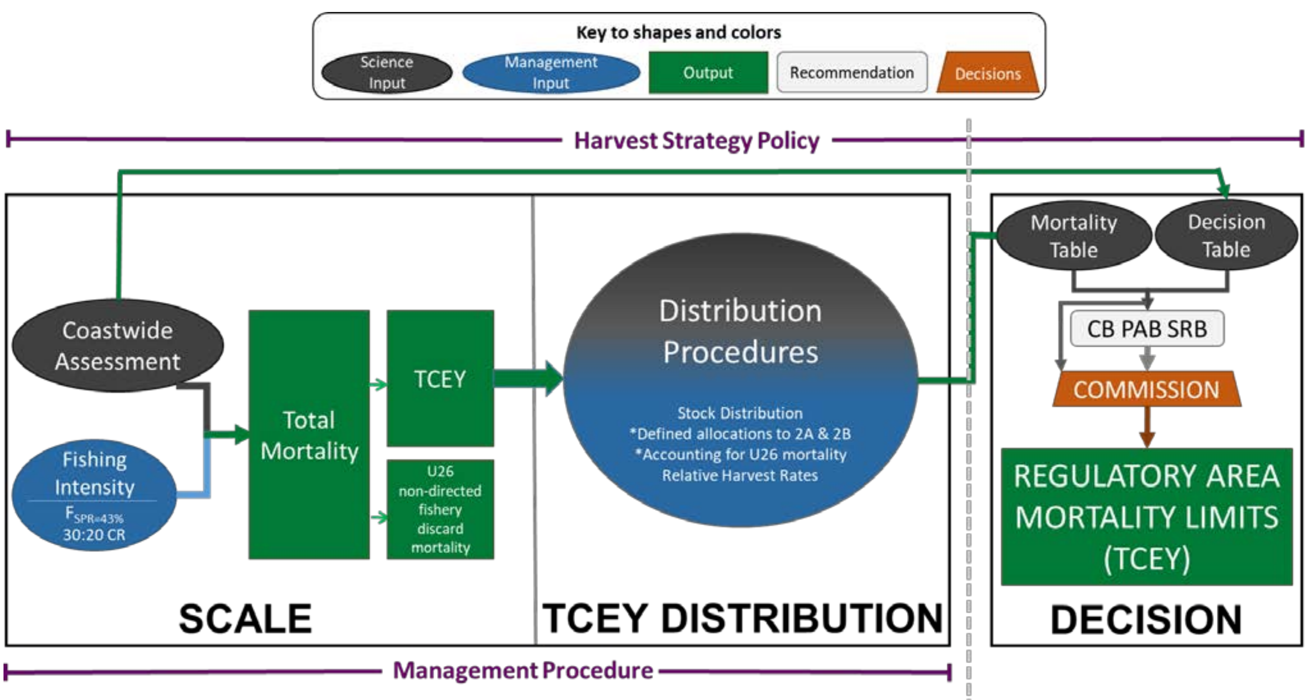

Figure 11: Illustration of the Commission interim IPHC harvest strategy policy (reflecting paragraph ID002 in IPHC CIRCULAR 2020-007) showing the coastwide scale and TCEY distribution components that comprise the management procedure. Items with an asterisk are three-year interim agreements to 2022. The decision component is the Commission decision-making procedure, which considers inputs from many sources.

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

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 (i.e., implementation error). Mortality limits and realized mortality are equal for the various recreational and directed commercial sectors (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, and the remainder 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 mimicked as closely as possible in the MSE framework. When the TCEY for an IPHC Regulatory Area is very low, the CSP may no longer be applicable and alternative decisions may be necessary. It is unknown what the allocation procedure may be at very low TCEYs (far below levels actually observed in the historical time-series), so working with MSAB members, a simple assumption was to assume that the sum of the directed non-FCEY components would not exceed the TCEY without non-directed commercial O26 discard mortality, and the FCEY components would be set to zero.

Overall, 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 stock status as well as the size of the population, both of which are propagated into management quantities.

2.3.4 Management procedures for evaluation

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).

Table 6: A comparison of management procedures (MPs) showing the elements included in defined MPs. See Appendix II and Appendix III for additional details of the MPs.

Element	MP-A	MP-B	MP-C	MP-D	MP-E	MP-F	MP-G	MP-H	MP-I	MP-J	MP-K
Maximum coastwide TCEY change of 15%		■	■	■	■	■	■	■	■	■	■
Maximum Fishing Intensity buffer (SPR=36%)				■							
O32 stock distribution	■	■	■	■	■	■	■	■			
O32 stock distribution (5-year moving average)										■	
All sizes stock distribution									■		
Fixed shares updated in 5th year from O32 stock distribution											■
Relative harvest rates of 1.0 for 2-3A, and 0.75 for 3B-4	■	■		■	■	■	■		■	■	
Relative harvest rates of 1.0 for 2-3, 4A, 4CDE, and 0.75 for 4B								■			
Relative harvest rates by Region: R2=1, R3=1, R4=0.75, R4B=0.75			■								
1.65 Mlbs fixed TCEY in 2A	■	■	■	■	■						
Formula percentage for 2B	■	■	■	■							
National Shares (2B=20%)						■					

3 CLOSED-LOOP SIMULATION RESULTS

For brevity, only the simulated estimation error (EE) results are reported to compare across SPR values and some figures and tables only present results using an SPR of 43%. Simulations with alternative estimation error methods and additional SPR values are available on the interactive MSE Explorer for MSAB016 website. Pertinent results with these additional values are discussed below.

Figure 12 shows coastwide performance metrics linked to the primary coastwide objectives. The relative spawning biomass (RSB) is similar across all management procedures, but varies with SPR. No MP exceeds the 10% tolerance for RSB dropping below 20% SPR (Table 7), and the median RSB resulting from an SPR of 40% is slightly less than 36%. Table 7 shows that the probability of being below 36% is slightly less for MP-A compared to all other MPs. The AAV was higher for MP-A as well, especially at lower SPR values, because MP-A was the only MP without an annual constraint of 15% on the TCEY. For the same reason, the probability that the annual change (AC) was greater than 15% was greater than zero for MP-A and zero for all other MPs, except MP-D which allowed the coastwide TCEY to accommodate agreements in 2A and 2B. Short-term median TCEY was near 40 Mlbs for all MPs and SPR values, with larger values for lower SPR values (higher fishing intensity) and slight variations between MPs. The difference in the short-term median TCEY was less than 2.5 Mlbs between MPs for an SPR of 43% (Table 7).

Short-term performance metrics for the TCEY in each IPHC Regulatory Area are shown in Figure 13 as well as Table 8, Table 9, and Table 10. These are the median-minimum and median-average TCEY over a ten-year period and the median-minimum and median-average percentage of TCEY in each IPHC Regulatory Area over a ten-year period (short-term). MPs F–K show decreased TCEY in 2A and MPs E and G–K show decreased TCEY in 2B along with increased TCEY in all other IPHC Regulatory Areas because the current agreements from 2A and 2B, or national shares for 2B, are not included in those MPs. The TCEY increases in 3B, 4A, and 4B with the increased relative harvest rate included in MP-H and MP-K, while it decreases in other IPHC Regulatory Areas. MP-J, which uses a 5-year average of stock distribution, shows similar TCEY values as MP-G, but with lower AAV for most IPHC Regulatory Areas (Table 10). Stability related performance metrics differences are evident at the IPHC Regulatory Area level with MP-J, even though stability was not much different than MP-G at the coastwide level (e.g., median AAV). Additional performance metrics presented in the MSE Explorer may assist in the evaluation of the MPs.

Overall, the eleven MPs show minor differences at the coastwide level but showed some important differences at the IPHC Regulatory Area level. Trade-offs between IPHC Regulatory Areas are an important consideration when evaluating the MSE results. Ranking the performance metrics across management procedures and then averaging group of ranks (e.g., over IPHC Regulatory Areas) can assist in identify MPs that perform best overall.

The Biological Sustainability objectives have a tolerance defined, thus it can be determined if the objective is met by a management procedure. All management procedures met the Biological Sustainability objectives, except for the objective to maintain a minimum percentage of female spawning biomass above 2% in IPHC Regulatory Area 4B with a tolerance of 0.05 (Table 11). This distribution of the projected percentage of spawning biomass in Biological Region 4B has a probability of 0.19 to be less than 2% with no fishing mortality (Figure 14). This probability is slightly less with fishing mortality (Table 11) because the spawning biomass is less variable with fishing. The fact that this objective is not met without fishing or with any of the management procedures suggests two things: 1) the objective should be revisited and/or 2) the operating model is possibly mischaracterizing the population in Biological Region 4B, and thus the distribution of the population in this Biological Region.

The operating model was conditioned to the observed stock distribution and the predicted range of historical stock distribution from the operating model for Biological Region 4B is wider than the confidence intervals for the observed stock distribution (Figure 8 in IPHC-2020-MSAB016-08). Biological Region 4B is a unique region in the IPHC convention area, possibly with a separate stock (genetic research is ongoing to better understand the connectivity of 4B with the rest of the stock), and the operating model may not be completely capturing the stock dynamics in that area. Additionally, with mostly out-migration from 4B and little recruitment distributed to that area, large increases in spawning biomass in the other Biological Regions may result in Biological Region 4B containing a small percentage of the spawning biomass even though the absolute spawning biomass is at a high level. Regardless, the spawning biomass persists in that Biological Region and in addition to revisiting the assumptions in the operating model, it would be prudent to revisit the regional spawning biomass objective.

The ranking of short-term performance metrics for the Fishery Sustainability objectives are shown in Table 12, Table 13, Table 14, and Table 15. Higher ranks generally occurred for MPs D, I, J, and K, although not necessarily for IPHC Regulatory Areas 2A and 2B when compared to MPs where agreements for those areas are in place. The general objectives were averaged over IPHC Regulatory Areas to produce a summary of ranks as shown in Table 16. This summary shows that MPs D and J generally have higher ranks for stability and yield objectives specific to IPHC Regulatory Areas, although better stability at the IPHC Regulatory Area level does not imply stability at the coastwide level. Further summarizing the ranks to general objectives are shown in Table 17, with better averaged performance for MPs D, I, J, and K, in general.

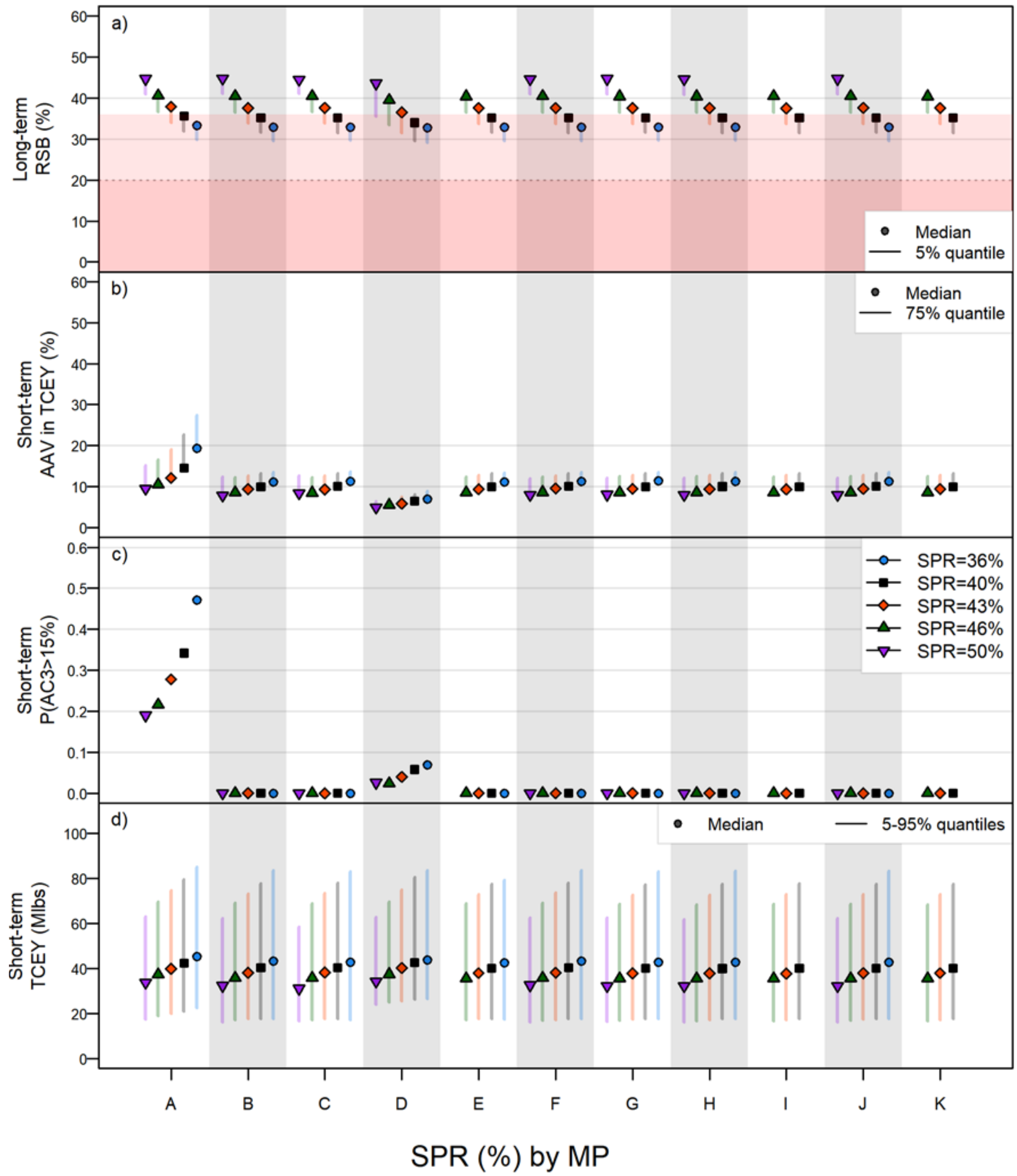

Figure 12: Coastwide performance metrics for MPs A through K using simulated estimation error with SPR values of 40%, 43%, and 46% for all and 36% and 50% for some. The relative spawning biomass and the thresholds of 20% and 36% are shown in a). The AAV for TCEY is shown in b). The probability that the annual change exceeds 15% in 3 or more years is shown in c). The median TCEY with 5th and 95th quantiles is shown in d).

Table 7: Coastwide long-term performance metrics for the biological sustainability objective and P(all RSB<36%) and short-term performance metrics for the remaining fishery sustainability objectives for MPs A through K for an SPR value of 43% using simulated estimation error.

Input SPR/TM	**43**	**43**	**43**	**43**	**43**	**43**	**43**	**43**	**43**	**43**	**43**
Management Procedure	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Number of Simulations	500	500	500	500	500	500	500	500	500	500	500
Biological Sustainability											
P(any RSB_y<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fishery Sustainability											
P(all RSB<36%)	0.25	0.28	0.28	0.44	0.28	0.28	0.28	0.29	0.29	0.28	0.28
Median average TCEY	39.92	38.17	38.32	40.22	38.01	38.18	37.89	37.87	37.86	37.90	37.95
P(any3 change TCEY > 15%)	0.44	0	0	0.10	0	0	0	0	0	0	0
Median AAV TCEY	12.1%	9.4%	9.3%	5.9%	9.4%	9.5%	9.5%	9.4%	9.4%	9.5%	9.4%

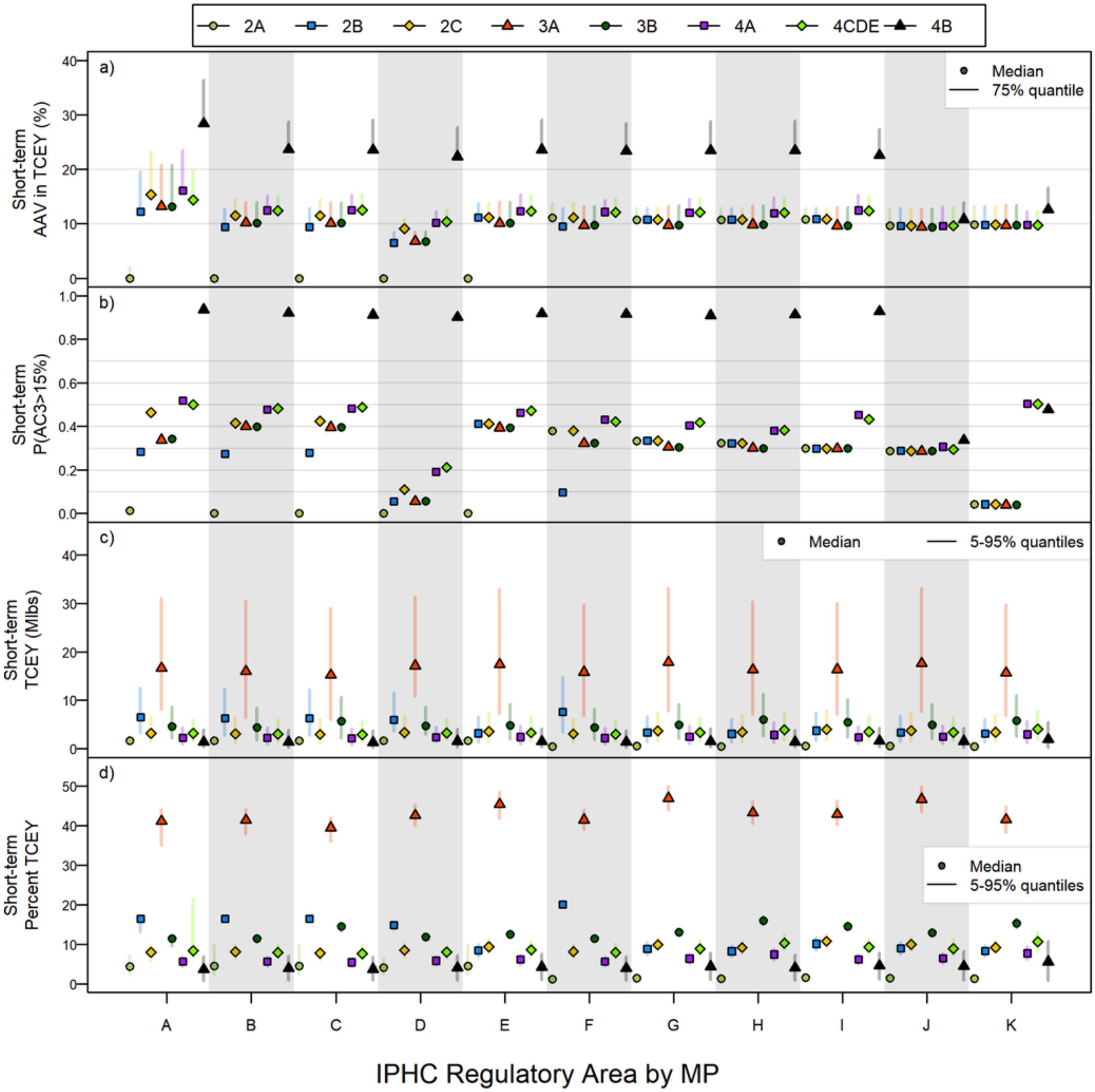

Figure 13: Performance metrics by IPHC Regulatory Areas for MPs A through K using simulated estimation error with an SPR value of 43%. The AAV for TCEY is shown in a). The probability that the annual change exceeds 15% in 3 or more years is shown in b). The median TCEY with 5th and 95th quantiles is shown in c). The median percentage of the TCEY in each IPHC Regulatory Area is shown in d).

Table 8: Long-term spawning biomass performance metrics by Biological Region and TCEY short-term performance metrics by IPHC Regulatory Areas for MPs A through K with an SPR value of 43% using simulated estimation error.

Input SPR/TM **Distribution Procedure**	**43%** **A**	**43%** **B**	**43%** **C**	**43%** **D**	**43%** **E**	**43%** **F**	**43%** **G**	**43%** **H**	**43%** **I**	**43%** **J**	**43%** **K**
Number of Simulations	500	500	500	500	500	500	500	500	500	500	500
Biological Sustainability											
P(%$SB_{R=2}$ < 5%)	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(%$SB_{R=3}$ < 33%)	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(%$SB_{R=4}$ < 10%)	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(%$SB_{R=4B}$ < 2%)	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.15	0.16	0.16	0.18
Fishery Sustainability											
Median Minimum TCEY 2A	1.65	1.65	1.65	1.65	1.65	0.33	0.39	0.36	0.44	0.40	0.38
Median Minimum TCEY 2B	3.76	4.79	4.75	4.76	2.34	5.78	2.48	2.28	2.84	2.52	2.37
Median Minimum TCEY 2C	1.79	2.27	2.18	2.65	2.61	2.30	2.76	2.53	3.03	2.80	2.64
Median Minimum TCEY 3A	9.06	11.67	11.16	13.57	12.81	11.81	13.34	12.19	12.18	13.20	11.50
Median Minimum TCEY 3B	2.51	3.24	4.13	3.76	3.55	3.28	3.70	4.51	4.10	3.66	4.25
Median Minimum TCEY 4A	1.23	1.62	1.56	1.81	1.76	1.62	1.82	2.11	1.72	1.86	2.25
Median Minimum TCEY 4CDE	1.74	2.21	2.12	2.48	2.41	2.22	2.49	2.88	2.56	2.53	3.08
Median Minimum TCEY 4B	0.65	0.90	0.85	1.04	0.97	0.89	1.00	0.92	1.02	1.20	1.42
Median average TCEY 2A	1.65	1.65	1.65	1.65	1.65	0.44	0.53	0.49	0.58	0.53	0.49
Median average TCEY 2B	6.55	6.32	6.31	5.94	3.18	7.64	3.33	3.08	3.73	3.34	3.09
Median average TCEY 2C	3.19	3.08	2.94	3.35	3.54	3.08	3.71	3.43	3.98	3.71	3.44
Median average TCEY 3A	16.68	15.99	15.24	17.15	17.42	15.84	17.83	16.34	16.39	17.67	15.71
Median average TCEY 3B	4.63	4.43	5.64	4.76	4.83	4.40	4.95	6.04	5.52	4.90	5.81
Median average TCEY 4A	2.30	2.22	2.15	2.37	2.41	2.21	2.46	2.86	2.37	2.47	2.96
Median average TCEY 4CDE	3.15	3.04	2.94	3.25	3.30	3.02	3.37	3.92	3.52	3.38	4.05
Median average TCEY 4B	1.41	1.36	1.31	1.55	1.48	1.37	1.52	1.41	1.59	1.57	1.93

Table 9: Percentage of TCEY short-term performance metrics by IPHC Regulatory Areas for MPs A through K with an SPR value of 43% using simulated estimation error.

Input SPR/TM	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**
Distribution Procedure	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Number of Simulations	500	500	500	500	500	500	500	500	500	500	500
Fishery Sustainability											
Median Minimum % TCEY 2A	2.9%	3.4%	3.4%	3.3%	3.4%	1.0%	1.3%	1.2%	1.4%	1.4%	1.3%
Median Minimum % TCEY 2B	16.1%	16.2%	16.1%	14.5%	7.6%	20.0%	8.0%	7.5%	9.1%	8.5%	7.9%
Median Minimum % TCEY 2C	6.9%	7.2%	6.9%	7.5%	8.5%	7.2%	8.9%	8.3%	9.7%	9.5%	8.8%
Median Minimum % TCEY 3A	37.9%	39.2%	37.4%	40.4%	42.8%	39.4%	44.4%	40.8%	40.4%	45.1%	39.8%
Median Minimum % TCEY 3B	10.5%	10.9%	13.8%	11.2%	11.9%	10.9%	12.3%	15.1%	13.6%	12.5%	14.7%
Median Minimum % TCEY 4A	4.9%	5.0%	4.8%	5.1%	5.4%	5.0%	5.6%	6.5%	5.4%	6.0%	6.9%
Median Minimum % TCEY 4CDE	6.9%	6.9%	6.7%	7.0%	7.5%	6.9%	7.7%	8.9%	8.1%	8.3%	9.5%
Median Minimum % TCEY 4B	2.5%	2.8%	2.7%	3.0%	3.1%	2.8%	3.2%	2.9%	3.2%	3.9%	4.5%
Median average % TCEY 2A	4.4%	4.5%	4.5%	4.2%	4.5%	1.2%	1.4%	1.3%	1.6%	1.4%	1.3%
Median average % TCEY 2B	16.4%	16.5%	16.4%	14.8%	8.4%	20.0%	8.9%	8.3%	10.1%	9.0%	8.3%
Median average % TCEY 2C	8.0%	8.1%	7.8%	8.5%	9.4%	8.2%	9.9%	9.2%	10.8%	10.0%	9.2%
Median average % TCEY 3A	41.2%	41.4%	39.4%	42.6%	45.4%	41.5%	46.9%	43.2%	42.9%	46.7%	41.5%
Median average % TCEY 3B	11.4%	11.5%	14.6%	11.8%	12.6%	11.5%	13.0%	16.0%	14.5%	12.9%	15.4%
Median average % TCEY 4A	5.6%	5.7%	5.5%	5.9%	6.2%	5.7%	6.4%	7.5%	6.2%	6.4%	7.7%
Median average % TCEY 4CDE	8.3%	8.0%	7.7%	8.0%	8.6%	8.0%	8.9%	10.3%	9.3%	8.9%	10.7%
Median average % TCEY 4B	3.7%	3.9%	3.8%	4.1%	4.3%	3.9%	4.4%	4.1%	4.6%	4.5%	5.6%

Table 10: Short-term fishery stability performance metrics by IPHC Regulatory Areas for MPs A through K with an SPR value of 43% using simulated estimation error.

Input SPR/TM	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**
Distribution Procedure	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Number of Simulations	500	500	500	500	500	500	500	500	500	500	500
Fishery Sustainability											
P(any3 change TCEY 2A > 15%)	0.012	0.000	0.000	0.000	0.000	0.380	0.334	0.322	0.298	0.288	0.042
P(any3 change TCEY 2B > 15%)	0.284	0.274	0.278	0.056	0.412	0.096	0.334	0.322	0.298	0.288	0.042
P(any3 change TCEY 2C > 15%)	0.464	0.414	0.424	0.110	0.412	0.380	0.334	0.322	0.298	0.288	0.042
P(any3 change TCEY 3A > 15%)	0.338	0.400	0.396	0.056	0.394	0.322	0.306	0.300	0.298	0.286	0.038
P(any3 change TCEY 3B > 15%)	0.342	0.398	0.396	0.056	0.394	0.322	0.304	0.298	0.298	0.288	0.040
P(any3 change TCEY 4A > 15%)	0.518	0.476	0.482	0.192	0.462	0.430	0.404	0.380	0.452	0.306	0.504
P(any3 change TCEY 4CDE > 15%)	0.500	0.482	0.488	0.212	0.472	0.422	0.418	0.382	0.432	0.294	0.502
P(any3 change TCEY 4B > 15%)	0.936	0.920	0.912	0.902	0.918	0.916	0.910	0.914	0.928	0.336	0.478
Median AAV TCEY 2A	0.0%	0.0%	0.0%	0.0%	0.0%	11.2%	10.8%	10.7%	10.8%	9.6%	9.8%
Median AAV TCEY 2B	12.2%	9.4%	9.4%	6.5%	11.1%	9.5%	10.8%	10.8%	10.8%	9.6%	9.8%
Median AAV TCEY 2C	15.3%	11.5%	11.5%	9.1%	11.1%	11.2%	10.8%	10.8%	10.8%	9.6%	9.8%
Median AAV TCEY 3A	13.2%	10.2%	10.1%	6.8%	10.1%	9.7%	9.8%	9.9%	9.7%	9.4%	9.7%
Median AAV TCEY 3B	13.2%	10.2%	10.1%	6.8%	10.1%	9.7%	9.8%	9.9%	9.7%	9.4%	9.7%
Median AAV TCEY 4A	16.1%	12.5%	12.5%	10.2%	12.3%	12.2%	12.1%	12.0%	12.5%	9.6%	9.8%
Median AAV TCEY 4CDE	14.4%	12.4%	12.5%	10.4%	12.3%	12.1%	12.1%	12.0%	12.4%	9.6%	9.8%
Median AAV TCEY 4B	28.4%	23.7%	23.6%	22.4%	23.6%	23.4%	23.5%	23.5%	22.6%	10.8%	12.6%

Table 11: Long-term performance metrics for biological sustainability objectives for MPs A through K with an SPR value of 43% using simulated estimation error. Red shading indicates that the currently defined objective is not met, and green shading indicates that the objective is met. Values in the cells are the calculated probability.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Maintain a coastwide female SB above a biomass limit reference point 95% of the time	$P(SB < SB_{Lim})$	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintain a minimum proportion of female SB	$P(\%SB_{R=2} < 5\%)$	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintain a minimum proportion of female SB	$P(\%SB_{R=3} < 33\%)$	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintain a minimum proportion of female SB	$P(\%SB_{R=4} < 10\%)$	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintain a minimum proportion of female SB	$P(\%SB_{R=4B} < 2\%)$	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.15	0.16	0.16	0.18

Table 12: Long-term performance metrics for fishery objective 2.1 for MPs A through K with an SPR value of 43% using simulated estimation error. The ranks are determined by how close the long-term probability is to 0.5 after rounding to two decimal places. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Maintain the coastwide female SB above a target at least 50% of the time	$P(SB < SB_{36\%})$	11	4	4	1	4	4	4	2	2	4	4

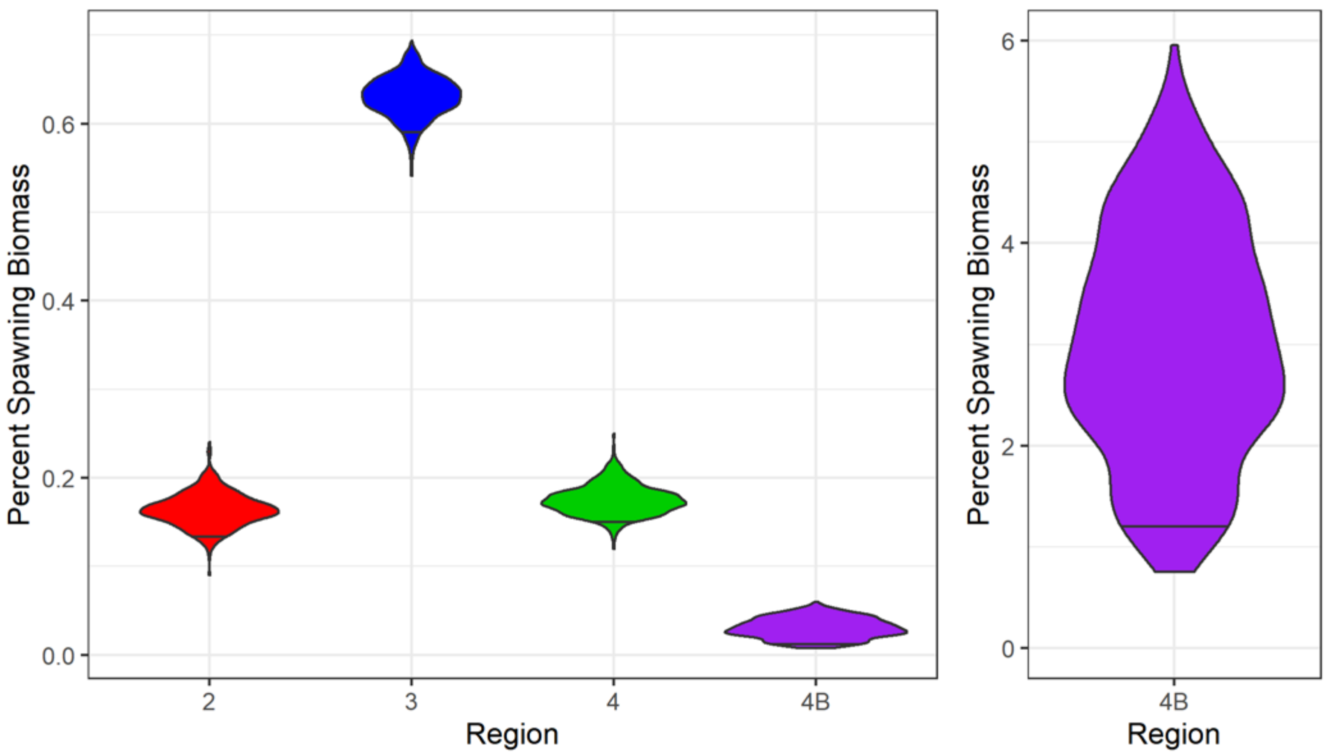

Figure 14: Distribution of the percentage of spawning biomass in each Biological Region after 60 years of projections with no fishing mortality. The right panel is zoomed in on Biological Region 4B. A horizontal line shows the 5% quantile in each plot.

Table 13: Short-term performance metrics for fishery stability objectives for MPs A through K with an SPR value of 43% using simulated estimation error. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures. Ranks were determined after rounding probabilities (i.e. $P(AC_3>15\%)$) to two decimals and percentages (i.e. AAV) to one decimal.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Limit TCEY AC	$P(AC_3 > 15\%)$	11	1	1	10	1	1	1	1	1	1	1
Limit TCEY AAV	Median AAV TCEY	11	3	2	1	3	8	8	3	3	8	3
Limit AC in Reg Areas TCEY	$P(AC_3$ 2A $> 15\%)$	5	1	1	1	1	11	10	9	8	7	6
	$P(AC_3$ 2B $> 15\%)$	5	4	5	2	11	3	10	9	8	7	1
	$P(AC_3$ 2C $> 15\%)$	11	8	10	2	8	7	6	5	4	3	1
	$P(AC_3$ 3A $> 15\%)$	8	10	10	2	9	7	6	4	4	3	1
	$P(AC_3$ 3B $> 15\%)$	8	10	10	2	9	7	4	4	4	3	1
	$P(AC_3$ 4A $> 15\%)$	11	8	8	1	7	5	4	3	6	2	10
	$P(AC_3$ 4CDE $> 15\%)$	10	8	9	1	7	4	4	3	6	2	10
	$P(AC_3$ 4B $> 15\%)$	11	7	4	3	7	7	4	4	10	1	2
Limit AAV in Reg Areas TCEY	Median AAV 2A	1	1	1	1	1	11	9	8	9	6	7
	Median AAV 2B	11	2	2	1	10	4	7	7	7	5	6
	Median AAV 2C	11	9	9	1	7	8	4	4	4	2	3
	Median AAV 3A	11	10	8	1	8	3	6	7	3	2	3
	Median AAV 3B	11	10	8	1	8	3	6	7	3	2	3
	Median AAV 4A	11	8	8	3	7	6	5	4	8	1	2
	Median AAV 4CDE	11	8	10	3	7	5	5	4	8	1	2
	Median AAV 4B	11	10	8	3	8	5	6	6	4	1	2

Table 14: Short-term performance metrics for fishery yield objectives related to the TCEY for MPs A through K with an SPR value of 43% using simulated estimation error. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures. Ranks were determined after rounding to the nearest one million pound.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Optimize TCEY	Median TCEY	1	3	3	1	3	3	3	3	3	3	3
Maintain minimum TCEY by Reg Areas	Median Min 2A	1	1	1	1	1	6	6	6	6	6	6
	Median Min 2B	5	2	2	2	8	1	8	8	6	6	8
	Median Min 2C	8	8	8	1	1	8	1	1	1	1	1
	Median Min 3A	11	5	10	1	2	5	2	5	5	2	5
	Median Min 3B	9	9	2	2	2	9	2	1	2	2	2
	Median Min 4A	11	1	1	1	1	1	1	1	1	1	1
	Median Min 4CDE	5	5	5	5	5	5	5	1	1	1	1
	Median Min 4B	1	1	1	1	1	1	1	1	1	1	1
Optimize Reg Areas TCEY	Median TCEY 2A	1	1	1	1	1	9	6	9	6	6	9
	Median TCEY 2B	2	3	3	3	7	1	7	7	6	7	7
	Median TCEY 2C	5	5	5	5	1	5	1	5	1	1	5
	Median TCEY 3A	3	6	11	3	3	6	1	6	6	1	6
	Median TCEY 3B	5	10	1	5	5	10	5	1	1	5	1
	Median TCEY 4A	3	3	3	3	3	3	3	1	3	3	1
	Median TCEY 4CDE	4	4	4	4	4	4	4	1	1	4	1
	Median TCEY 4B	6	6	6	1	6	6	1	6	1	1	1

Table 15: Short-term performance metrics for fishery yield objectives related to the percentage of TCEY in each IPHC Regulatory Area for MPs A through K with an SPR value of 43% using simulated estimation error. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures. Ranks were determined after rounding to two decimals.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Maintain minimum % TCEY by Reg Areas	Median Min % 2A	5	1	1	4	1	11	8	10	6	6	8
	Median Min % 2B	3	2	3	5	10	1	8	11	6	7	9
	Median Min % 2C	10	8	10	7	5	8	3	6	1	2	4
	Median Min % 3A	10	9	11	5	3	8	2	4	5	1	7
	Median Min % 3B	11	9	3	8	7	9	6	1	4	5	2
	Median Min % 4A	10	8	11	7	5	8	4	2	5	3	1
	Median Min % 4CDE	8	8	11	7	6	8	5	2	4	3	1
	Median Min % 4B	11	8	10	6	5	8	3	7	3	2	1
Optimize TCEY percentage among Reg Areas	Median % TCEY 2A	4	1	1	5	1	11	7	9	6	7	9
	Median % TCEY 2B	3	2	3	5	9	1	8	10	6	7	10
	Median % TCEY 2C	10	9	11	7	4	8	3	5	1	2	5
	Median % TCEY 3A	10	9	11	6	3	7	1	4	5	2	7
	Median % TCEY 3B	11	9	3	8	7	9	5	1	4	6	2
	Median % TCEY 4A	10	8	11	7	5	8	3	2	5	3	1
	Median % TCEY 4CDE	7	8	11	8	6	8	4	2	3	4	1
	Median % TCEY 4B	11	8	10	6	5	8	4	6	2	3	1

Table 16: Ranks for the target biomass, fishery yield, and stability short-term performance metrics averaged with equal weighting over IPHC Regulatory Areas for those that are reported by IPHC Regulatory Areas (Tables 13–15). Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Maintain the coastwide female SB above a target	$P(SB < SB_{36\%})$	11	4	4	1	4	4	4	2	2	4	4
Limit AC in coastwide TCEY	$P(AC_3 > 15\%)$	11	1	1	10	1	1	1	1	1	1	1
Limit AAV in coastwide TCEY	Median AAV TCEY	11	3	2	1	3	8	8	3	3	8	3
Optimize average coastwide TCEY	Median TCEY	9.75	7.25	6.75	1.75	7	5.62	6	5.88	5.75	2.5	3.5
Limit AC in Reg Areas TCEY	$P(AC_3 > 15\%)$ Reg Areas	8.62	7	7.12	1.75	7.38	6.38	6	5.12	6.25	3.5	4
Limit AAV in Reg Areas TCEY	Median AAV TCEY Reg Areas	1	3	3	1	3	3	3	3	3	3	3
Optimize Reg Areas TCEY	Median TCEY Reg Areas	8.5	6.62	7.5	6.12	5.25	7.62	4.88	5.38	4.25	3.62	4.12
Optimize TCEY % among Reg Areas	Median % TCEY Reg Areas	6.38	4	3.75	1.75	2.62	4.5	3.25	3	2.88	2.5	3.12
Maintain minimum TCEY by Reg Areas	Median Min(TCEY) Reg Areas	3.62	4.75	4.25	3.12	3.75	5.5	3.5	4.5	3.12	3.5	3.88
Maintain minimum % TCEY by Reg Areas	Median Min(% TCEY) Reg Areas	8.25	6.75	7.62	6.5	5	7.5	4.38	4.88	4	4.25	4.5

SB: Spawning Biomass
AC: Annual Change
AAV: Average Annual Variability
Regulatory Areas: IPHC Regulatory Areas
TCEY: Total mortality minus under 26" (U26) non-directed commercial discard mortality

Table 17: Ranks for the target biomass, fishery yield, and stability short-term performance metrics averaged with equal weighting over IPHC Regulatory Areas for those that are reported by IPHC Regulatory Areas (Tables 13–15) and equally over objectives within each general category. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
2.1 Maintain the coastwide female SB above a target	$P(SB < SB_{Targ})$	11	4	4	1	4	4	4	2	2	4	4
2.2 Limit catch variability	Limit annual change	10.09	4.56	4.22	3.62	4.59	5.25	5.25	3.75	4	3.75	2.88
2.3 Provide directed fishing yield	Optimize TCEY and maintain minimum TCEY in Regulatory Areas	5.55	5.02	5.22	3.7	3.92	5.62	3.8	4.15	3.45	3.37	3.72

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.
7. Development of an MSE framework to investigate coastwide scale and distribution components of the harvest strategy.

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 for Pacific halibut fisheries could continue with new objectives being defined, more complex models being built with improved understanding of the Pacific halibut population, and the development of new management procedures to evaluate. Consultation with stakeholders and managers would be continued. Along the way, there will be useful outcomes that may be used to improve existing management and will influence recommendations for future work.

4.1 MSE tasks

Seven (7) categories have been defined in the MSE program of work plus the recent external review which was completed in September 2020.

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 these tasks have not been specified beyond 2021, and the description below focuses on 2020 leading up to the 97th Session of the IPHC Annual Meeting (AM097) in January 2021 followed by potential activities beyond 2021.

The full MSE results incorporating coastwide scale and distribution components of the management procedure (Figure 11) will be presented at the 97th Session of the IPHC Annual Meeting (AM097) in January 2021. There were 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 17 identifies the tasks that were undertaken at each MSAB and SRB meeting in 2020.

Table 18: Tasks completed and in progress in 2020 and 2021 for MSAB, SRB, and IPHC meetings.

15th Session of the IPHC MSAB - May 2020	**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
16th Session of the IPHC SRB - June 2020	
Review simulation framework	Completed
Review multi-region operating model	Completed
Review preliminary results	
3rd Ad-hoc meeting of the MSAB – August 2020	
Examine preliminary results	Completed
17th Session of the IPHC SRB - September 2020	
Review multi-region operating model	Completed
Review penultimate results	Completed
17th Session of the IPHC MSAB - October 2020	
Review final results	In Progress
Provide recommendations on MPs for scale and distribution	In Progress
97th Session of the IPHC Annual Meeting (AM097)	
Presentation of first complete MSE product to the Commission Recommendations on Scale and Distribution MP	

4.2 Potential elements for a program of work moving forward

The MSE program has been focused on the delivery of simulation results examining management procedures incorporating scale and distribution components in January 2021. Future MSE-related research may fall under any of the seven tasks listed in Section 4.1. In reports from previous MSAB, SRB, and Commission meetings, some potential MSE-related research has been identified.

> **IPHC-2018-SRB013-R, para. 29**: *The SRB REQUESTED that in future iterations of the MSE, the IPHC Secretariat and MSAB consider: […] c) the current conditioned operating model used to simulate coast-wide survey index and that such data be used to consider an alternative survey-based management procedure (this may provide a more transparent TMq-setting algorithm than the current SPR based control-rule and help with MSAB deliberations).*

> **IPHC-2020-AM096-R, para. 83.** *The Commission NOTED that MSE is the appropriate tool to evaluate management procedures related to discard mortality for non-directed fisheries (bycatch) because it can capture downstream effects, biological implications, and the management performance relative to objectives.*

> **IPHC-2020-AM096-R, para. 89.** *The Commission REQUESTED the MSAB to confirm the proposed topics of work beyond the 2021 deliverables in time for the Interim Meeting (IM096), including work to investigate and provide advice on approaches for accounting for the impacts of bycatch in one Regulatory Area on harvesting opportunities in other Regulatory Areas.*

> **IPHC-2020-MSAB015-R, para. 20.** *The MSAB REQUESTED that a procedure to distribute the coastwide TCEY be flexible to allow for distribution directly to IPHC Regulatory Areas, or to Biological Regions or Management Zones before distributing to IPHC Regulatory Areas. Methods of distribution may be based on stock distribution, relative fishing intensities, and other allocation adjustments.*

> **IPHC-2020-MSAB015-R, para. 22**. *The MSAB NOTED that alternative management procedures may use area-specific data (e.g. modelled survey results) without using a coastwide TCEY, rather than the procedure described in paragraph 21. This example is a sub-category of a broader category of management procedures that are data-based rather than assessment-based.*

Additionally, management procedures that have been developed for many fisheries are reviewed at regular intervals given new observations and data that are collected after adoption (Punt et al 2014; Sharma et al. 2020). For example, tuna Regional Fisheries Management Organizations (RFMOs) have defined exceptional circumstances to determine when an OM should be reconditioned given updated information, and the SRB recommended defining exceptional circumstances for the Pacific halibut MSE.

> **IPHC-2020-SRB017-R, para. 60**: *The SRB RECOMMENDED that Exceptional Circumstances be defined to determine whether monitoring information has potentially departed from their expected distributions generated by the MSE. Declaration of Exceptional Circumstances may warrant re-opening and revising the operating models and testing procedures used to justify a particular management procedure.*

5 RECOMMENDATIONS

That the Commission:

a) **NOTE** paper IPHC-2020-IM096-11 Rev_1 which provides a description of the IPHC MSE framework and simulations of management procedures for distributing the TCEY.

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

c) **RECOMMEND** a management procedure that best meets Commission objectives and accounts for trade-offs between yield in IPHC Regulatory Areas and yield stability in IPHC Regulatory Areas.

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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 III: Description of Management Procedures proposed from MSAB015

APPENDIX I
PRIMARY OBJECTIVES DEFINED BY THE COMMISSION FOR THE MSE

Table I.1: Primary 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	$P(p_{SB,R} < p_{SB,R,min})$
2.1 MAINTAIN SPAWNING BIOMASS AROUND A LEVEL THAT OPTIMIZES FISHING ACTIVITIES	Maintain the coastwide female spawning biomass above a biomass target reference point at least 50% of the time	*SB*<Spawning Biomass Target (SB_{Targ}) SB_{Targ}=$SB_{36\%}$ unfished spawning biomass	Long-term	0.50	$P(SB < SB_{Targ})$
2.2. LIMIT CATCH VARIABILITY	Limit annual changes in the coastwide TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Median coastwide Average Annual Variability (AAV)	Short-term		*Median AAV*
	Limit annual changes in the Regulatory Area TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Average AAV by Regulatory Area (AAV_A)	Short-term		*Median* AAV_A
2.3. PROVIDE DIRECTED FISHING YIELD	Optimize average coastwide TCEY	Median coastwide TCEY	Short-term		*Median* $\overline{TCEY}$
	Optimize TCEY among Regulatory Areas	Median $TCEY_A$	Short-term		*Median* $\overline{TCEY_A}$
	Optimize the percentage of the coastwide TCEY among Regulatory Areas	Median $\%TCEY_A$	Short-term		*Median* $\overline{\left(\frac{TCEY_A}{TCEY}\right)}$
	Maintain a minimum TCEY for each Regulatory Area	Minimum $TCEY_A$	Short-term		*Median Min(TCEY)*
	Maintain a percentage of the coastwide TCEY for each Regulatory Area	Minimum $\%TCEY_A$	Short-term		*Median Min(%TCEY)*

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	1

MP	Coastwide	Regional	IPHC Regulatory Area	Priority
			• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)	
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

APPENDIX III
DESCRIPTION OF MANAGEMENT PROCEDURES PROPOSED FROM MSAB015

The proposed management procedures from the 15th Session of the Management Strategy Advisory Board (MSAB015) are described here. Each management procedure has a coastwide component and a distribution component (Appendix II). The distribution component can distribute directly to IPHC Regulatory Areas or distribute to Biological Regions first.

For all the MPs considered, the coastwide component sees the application of a coastwide SPR and of a 30:20 control rule. The 30:20 harvest control rule adjusts the reference SPR if the estimated stock status falls below the 30% trigger value. Specifically, the fishing intensity is reduced linearly if the stock status falls below 30% of unfished spawning stock biomass to a value of zero at and below an estimated status of 20% of unfished spawning stock biomass.

MP15-A: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory Area 2A (when possible) and a percentage allocation for IPHC Regulatory Area 2B calculated from a 30% weight on the current interim management procedure's target TCEY distribution (i.e., O32 stock distribution and relative harvest rates) and 70% weight to 20%.

MP15-B: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory Area 2A (when possible) and a percentage allocation for IPHC Regulatory Area 2B calculated from a 30% weight on the current interim management procedure's target TCEY distribution (i.e., O32 stock distribution and relative harvest rates) and 70% weight to 20%.

MP15-C: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to Biological Regions using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to Biological Regions such that the relative harvest rate in Biological Regions 4 and 4B is 0.75 and the relative harvest rate in Biological Regions 2 and 3 is 1.0. The regional TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory Area 2A (when possible) and a percentage allocation for IPHC Regulatory Area 2B calculated from a 30% weight on the current interim management procedure's target TCEY distribution (i.e., O32 stock distribution and relative harvest rates) and 70% weight to 20%.

MP15-D this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory Area 2A (when possible) and a percentage allocation for IPHC Regulatory Area 2B calculated from a 30% weight on the current interim management procedure's target TCEY distribution (i.e., O32 stock distribution and relative harvest rates) and 70% weight to 20%. These 2A and 2B adjustments are made by adding to the total coastwide TCEY, rather than reallocating among IPHC Regulatory Areas (as in other MPs). Once this last step is complete, the sum of the distributed TCEY is compared with the TCEY corresponding to a SPR value of 36% (maximum fishing intensity). If the sum of the distributed TCEY is higher than the TCEY corresponding to the maximum fishing intensity, IPHC Regulatory Areas 2A and 2B are adjusted so that the sum of the distributed TCEY is equal to the TCEY corresponding to the maximum fishing intensity. If the sum of the distributed TCEY is lower than the TCEY corresponding to the maximum fishing intensity, no further adjustments are made.

MP15-E: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory Area 2A (when possible).

MP15-F: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. A National Share of 20% is then applied to IPHC Regulatory Area 2B and the remaining 80% is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0.

MP15-G: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0.

MP15-H: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in IPHC Regulatory Area 4B is 0.75 and the relative harvest rate in all other IPHC Regulatory Areas is 1.0.

MP15-I: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the 'all-sizes' stock distribution, which is determined from the biomass of all sizes of Pacific halibut caught in the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0.

MP15-J: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using a 5 year moving average of the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0.

MP15-K: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the previous 5-year average of the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS, calculated only every 5^{th} year.