MSE Framework to investigate management procedures for Pacific halibut

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PURPOSE

To provide the Management Strategy Advisory Board (MSAB) with an update of improvements to the Management Strategy Evaluation (MSE) framework.

1 INTRODUCTION

The most recent interim management procedure (MP) at the International Pacific Halibut Commission (IPHC) is shown in Figure 1.

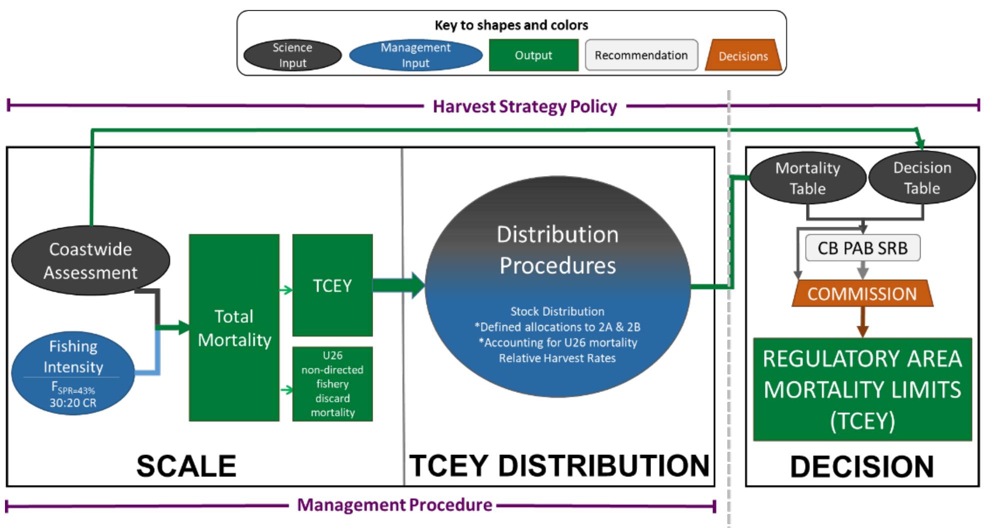

Figure 1. Illustration of the Commission interim IPHC harvest strategy policy (reflecting paragraph ID002 in IPHC-2020-CR-007) showing the coastwide scale and TCEY distribution components that comprise the management procedure. Items with an asterisk are interim agreements in place through 2022. The decision component is the Commission decision-making procedure, which considers inputs from many sources.

The Management Strategy Evaluation (MSE) at the IPHC completed an evaluation in 2021 of management procedures (MPs) relative to the coastwide scale and distribution of the Total Constant Exploitation Yield (TCEY) to IPHC Regulatory Areas for the Pacific halibut fisheries using a recently developed closed-loop simulation framework. The development of this closed-loop simulation framework supports the evaluation of the trade-offs between fisheries management procedures. Descriptions of the MPs evaluated and simulation results are presented in Hicks et al. (2021). Additional tasks were identified at the 11th Special Session of the IPHC (IPHC-2021-SS011-R) to supplement and extend this analysis for future evaluation (Table 1). Document IPHC-2021-MSE-02 contains details of the current MSE Program of Work.

Table 1. Tasks recommended by the Commission at SS011 (IPHC-2021-SS011-R para 7) for inclusion in the IPHC Secretariat MSE Program of Work for 2021–2023.

ID	Category	Task	Deliverable
F.1	Framework	Develop migration scenarios	Develop OMs with alternative migration scenarios
F.2	Framework	Implementation variability	Incorporate additional sources of implementation variability in the framework
F.3	Framework	Develop more realistic simulations of estimation error	Improve the estimation model to more adequately mimic the ensemble stock assessment
F.5	Framework	Develop alternative OMs	Code alternative OMs in addition to the one already under evaluation.
M.1	MPs	Size limits	Identification, evaluation of size limits
M.3	MPs	Multi-year assessments	Evaluation of multi-year assessments
E.3	Evaluation	Presentation of results	Develop methods and outputs that are useful for presenting outcomes to stakeholders and Commissioners

This document provides updates on the progress for the framework related tasks.

2 Closed-Loop Simulation Framework

The closed-loop framework (Figure 2) with a multi-area operating model (OM) and three options for examining estimation error was initially described in Hicks et al. (2020b). Technical details are updated as needed in IPHC-2022-MSE-01 on the IPHC MSE webpage. Improvements to the framework have been made in accordance with the MSE program of work and a new OM has been developed.

2.1 Development of a new Operating Model

The IPHC stock assessment (Stewart & Hicks 2022) consists of four stock synthesis models integrated into an ensemble to provide probabilistic management advice accounting for observation, process, and structural uncertainty. A similar approach was taken when developing the models for the closed-loop simulation framework along with some other specifications to improve the efficiency when conditioning models and running simulations.

2.1.1 General specifications of the OM

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 3) were defined with boundaries that matched some of the IPHC Regulatory Area boundaries (see Hicks et al 2020b for more description). The OM is a multi-regional model with population dynamics modelled within and among Biological Regions, and fisheries mostly operating at the IPHC Regulatory Area scale. Multiple fisheries within a Biological Region may have different selectivity and retention patterns to mimic differences similar to that of an Areas-

As-Fleets (AAF) approach. Thirty-three fisheries were defined for five general sectors consistent with the definitions in the recent IPHC stock assessment:

- **directed commercial** representing the O32 mortality from the directed commercial fisheries including O32 discard mortality (from lost gear or regulatory compliance);
- **directed commercial discard** representing the U32 discard mortality from the directed commercial fisheries, comprised of Pacific halibut discarded due to the minimum size limit;
- **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.

Additionally, there are four modelled surveys, one for each Biological Region.

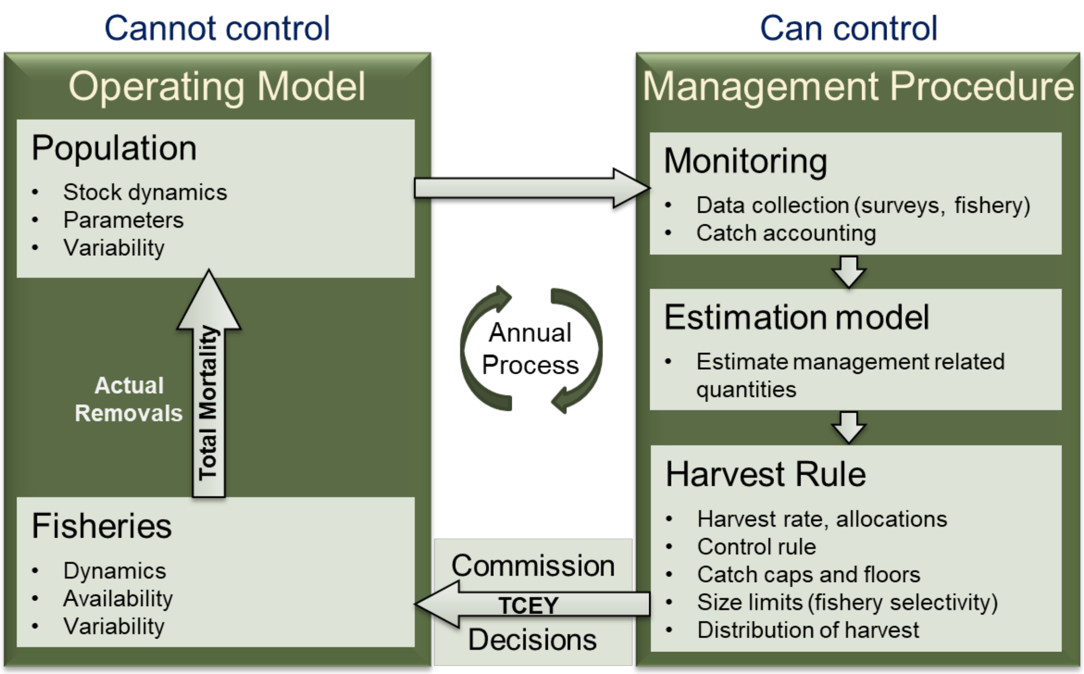

Figure 2. Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

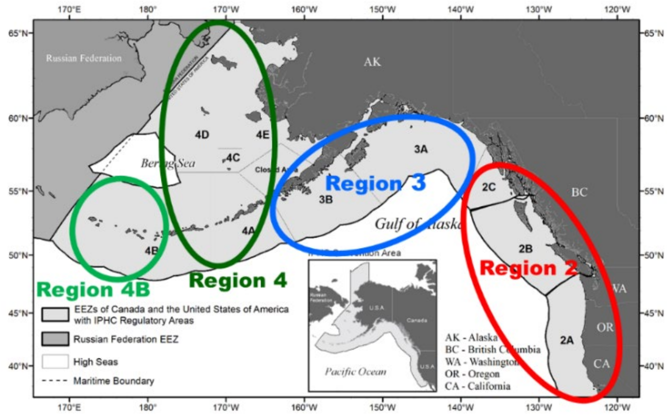

Figure 3. IPHC Regulatory Areas, Biological Regions, and the Pacific halibut geographical range within the territorial waters of Canada and the United States of America.

Two of the four models in the IPHC stock assessment (Stewart & Hicks 2022) consider a long time-series of observations beginning in 1888. One model specifies coastwide fisheries (called the coastwide (CW) long model) and the other model specifies four regions in an areas-as-fleets approach (called the AAF long model). The previous MSE OM also started in 1888 and simulated the entire time-series up to recent years before starting the forward simulations. However, the early portion of the time-series is challenging to model due to relatively little data, some significant catches in Biological Region 2, and the potential for unknown differences in population dynamics (e.g. movement between Biological Regions) compared to recent periods. To reduce the technical complexity and focus on information contained in the richer data set in the later period, the 2022 OM models were started in 1958. In order to allow for flexible starting conditions, 30 years of initial recruitment and an average fishing mortality were estimated for each fleet. This initialized the models after a bottleneck of potentially high fishing mortality in the 1930's that is confounded with the estimation of movement, while allowing for a sufficient period of time to burn-in the population such that projections began at an appropriate population size and age composition. The period from 1958 to the present includes major changes in fishery catches, weight-at-age in the population, and population size.

To account for structural uncertainty, as with the ensemble stock assessment, four individual models are integrated into a single OM. The first model was parameterised from and conditioned to results from the long AAF stock assessment model. The second model was parameterised from and conditioned using results from the long CW stock assessment model. Because these two OM models started in 1958, they are called the medium AAF (medAAF) and medium CW (medCW) models. The two remaining models also started in 1958 and were conditioned to the same observations, but parameterised with lower values of natural mortality, as in the 2021 'short' assessment models. These two models are noted as medAAF_lowM and medCW_lowM. All four models are regional models with movement between the four biological regions. The four models combined as an OM produced projections of fishing mortality that were reasonably similar to the short-term projections from the ensemble stock assessment (Figure 4).

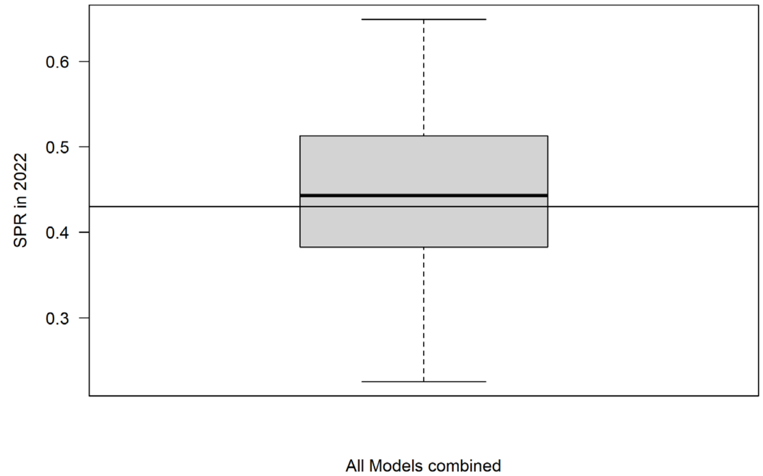

Figure 4. SPR in 2022 from the OM given fixed catches and distribution set by the Commission at the 98th IPHC Annual Meeting (IPHC-2022-AM098-R). The gray horizontal line is an SPR of 43%, corresponding to the coastwide mortality limit.

Many parameters used in the OM were drawn from the corresponding stock assessment model. Natural mortality was fixed in each model, separately for males and females. Maturity, mean weight-at-age, recruitment deviations, the relationship between R_0 and the Pacific Decadal Oscillation (PDO), selectivity, and fishing mortality were fixed at the values from the stock assessment. Parameters for initial average recruitment, recruitment distribution, initial fishing mortality, and movement were estimated during conditioning.

The models were independently conditioned to historical spawning biomass from the corresponding stock assessment model, recent ensemble spawning biomass from the stock assessment, fishery Independent Setline Survey (FISS) indices of abundance for each Biological Region, FISS estimates of proportions-at-age for each Biological Region, and proportion of all-sizes weight-per-unit-effort (WPUE) in each Biological Region from the space-time model analysis of FISS observations. The conditioning was heavily weighted to the stock distribution and spawning biomass components. The goal was to have models adequately representing stock distribution and spawning biomass in recent years, with some variability.

There is considerable confounding between the recruitment distribution and movement parameters (which was evident during the conditioning process), thus some parameters for movement between Biological Regions were fixed at values estimated from previous analyses (see Figure 3 in Hicks et al 2020b). The previous OM estimated considerably higher movement rates-at-age from Biological Region 2 back to Biological Region 3, which was unexpected. Fixing movement from Biological Region 2 to Biological Region 3 at values estimated directly from data resulted in more stable estimation with similar outputs.

Even though many parameters were fixed when conditioning the models, variability was propagated from the estimated as well as some fixed parameters, accounting for correlations between parameters. Bounds were enforced on some parameters and randomly drawn parameter sets that resulted in unrealistically low population sizes or extremely poor fits to stock distribution or spawning biomass were rejected. Multiple trajectories from 1958 through 2021 were produced for each model.

2.1.2 OM results and outputs

The four individual OM models showed important structural differences in terms of movement rates-at-age, recruitment distribution, and historical spawning biomass trends. The long AAF and long CW stock assessment models, which are the basis for conditioning each OM model, estimate significantly different historical spawning biomass trajectories before the early 2000s and subtle differences in recent trajectories (Figure 5). These differences are attributable to the very different assumptions about how the stock was distributed and connected via movement in relation to historical fishing mortality, and it is important to capture these differences in the OM.

The four OM models generally captured these trends in spawning biomass with the medCW models fitting the lower spawning biomass trend of the long CW assessment model and the medAAF model fitting the higher spawning biomass trend of the long AAF assessment model (Figure 6). The lowM models showed a higher probability that the spawning biomass is declining in recent years. The uncertainty in the OM also spanned the 2021 ensemble stock assessment uncertainty, except for the low spawning biomass in the 1970’s (Figure 7).

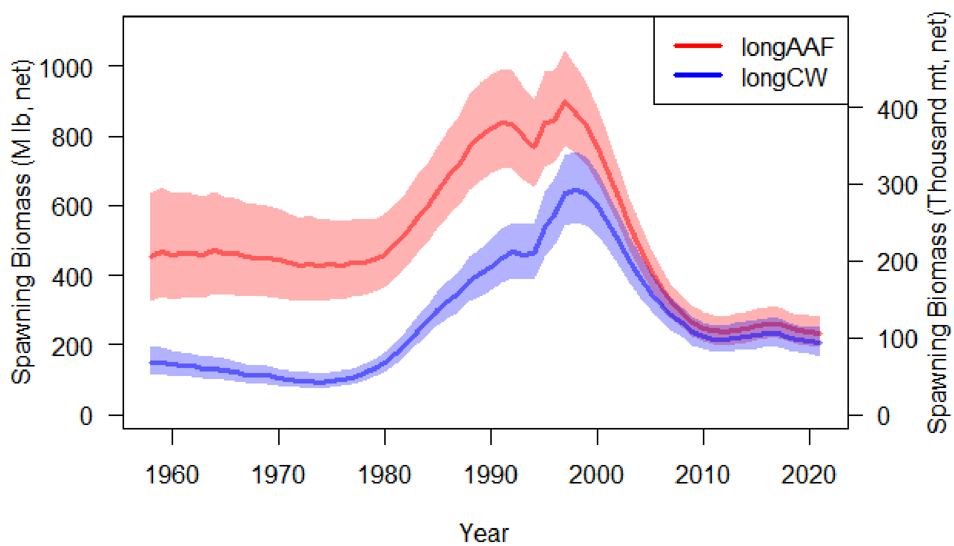

Figure 5. Estimated spawning biomass trajectories from 1958 to 2021 from the 2021 long AAF and long CW stock assessment models (Stewart & Hicks 2022).

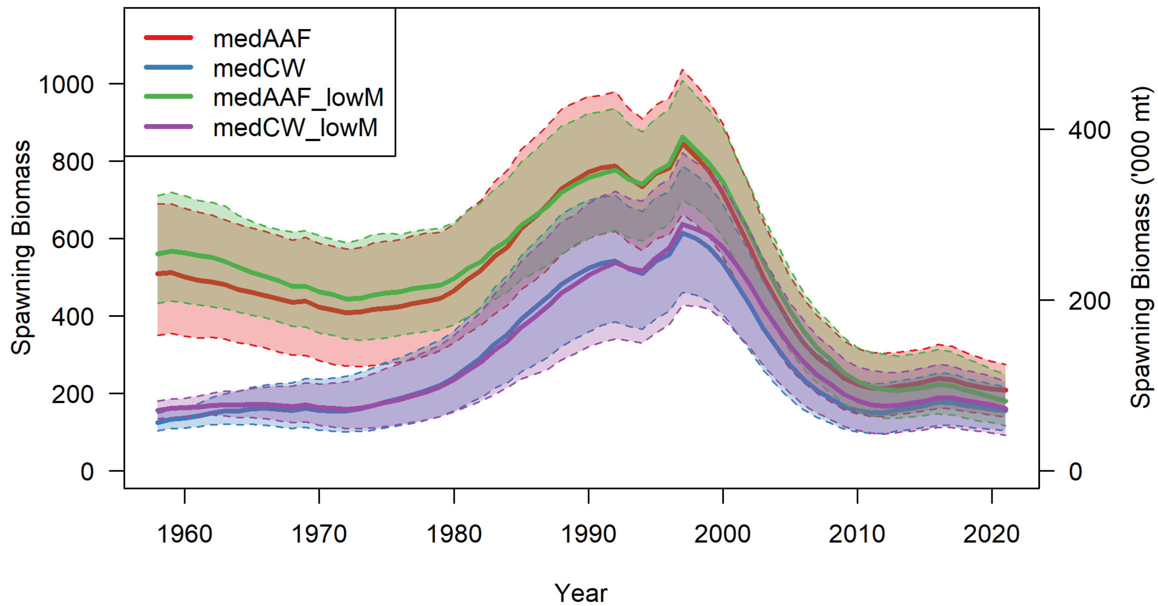

Figure 6. Median, 5th, and 95th quantiles for spawning biomass from the four OM models.

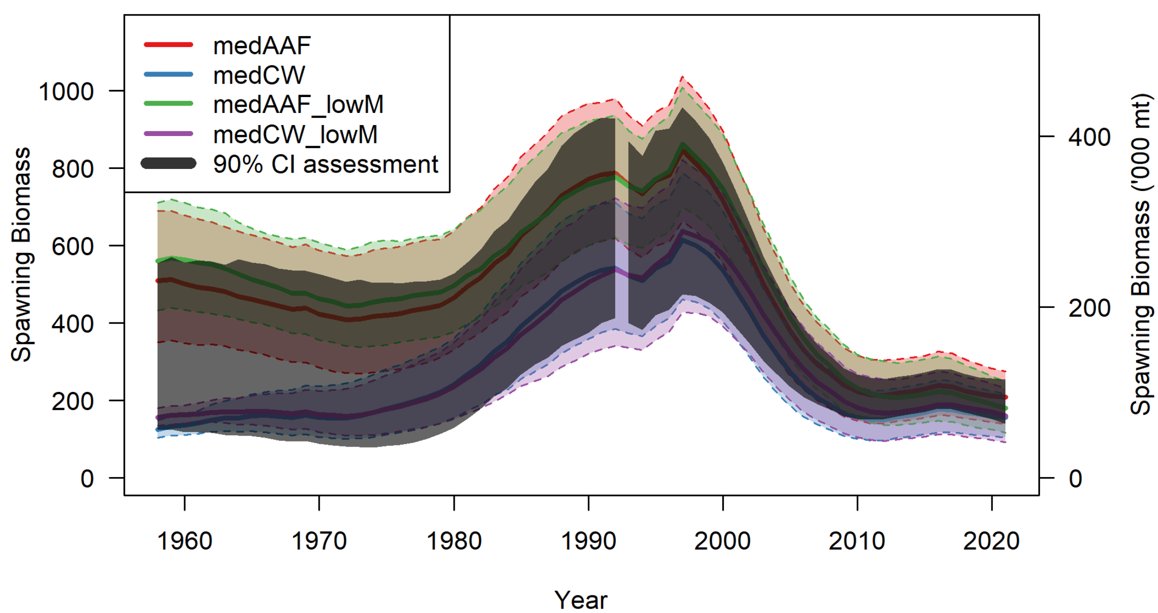

Figure 7. Median, 5th, and 95th quantiles for spawning biomass from the four OM models with the ensemble stock assessment range between the 5th and 95th quantiles shown in grey.

Stock distribution was fit well by both OM models (Figure 8) and showed similar patterns of lack of fit across all models. Specifically, the earliest years in Biological Region 4 were overfit by the OM, and recent years overfit in Biological Region 3 corresponding with a slight underfitting in region 4. All OM models matched closely with the proportion of biomass observed in 2021.

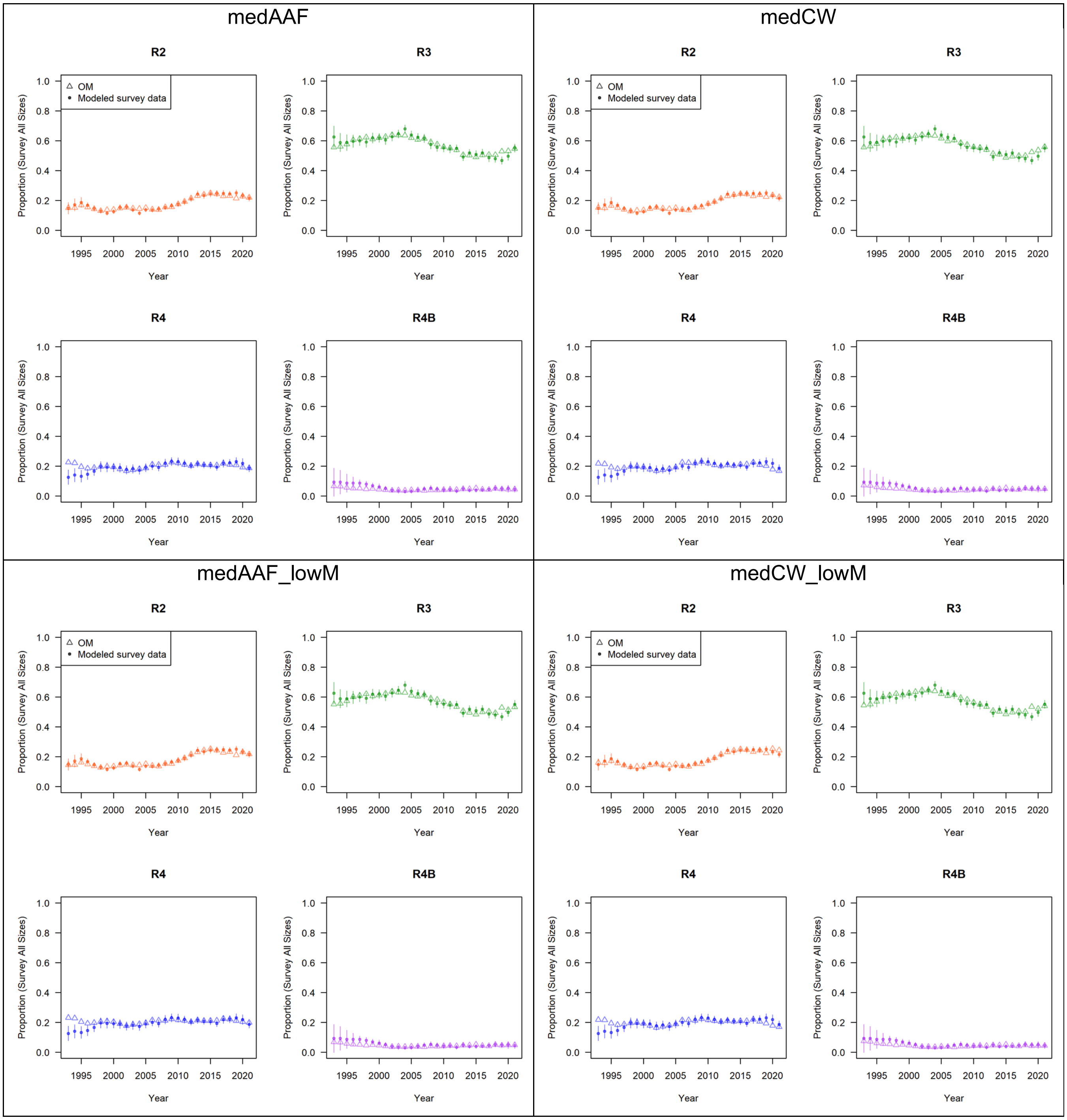

Figure 8. Fits to stock distribution across Biological Regions for each OM model.

The distribution of age-0 recruits showed a high proportion settling in Biological Region 4 in both low and high PDO regimes. The medCW showed a higher proportion of recruits settling in Biological Region 4 in high PDO years, but the medAAF model showed a slightly smaller proportion.

Movement rates between Biological Regions 3 and 2, and Biological Regions 4 and 3 were different between the four OM models (Figure 9). Both models generally showed high movement rates around ages 4 and 5 and slight differences between low and high PDO periods. Movement of fish younger than age 4 was very small from Biological Region 4 to 3 for both models and regimes, but there are few observations of fish younger than age 6 and a number of different movement rates of very young fish in combination with ages 4–6 could achieve similar results.

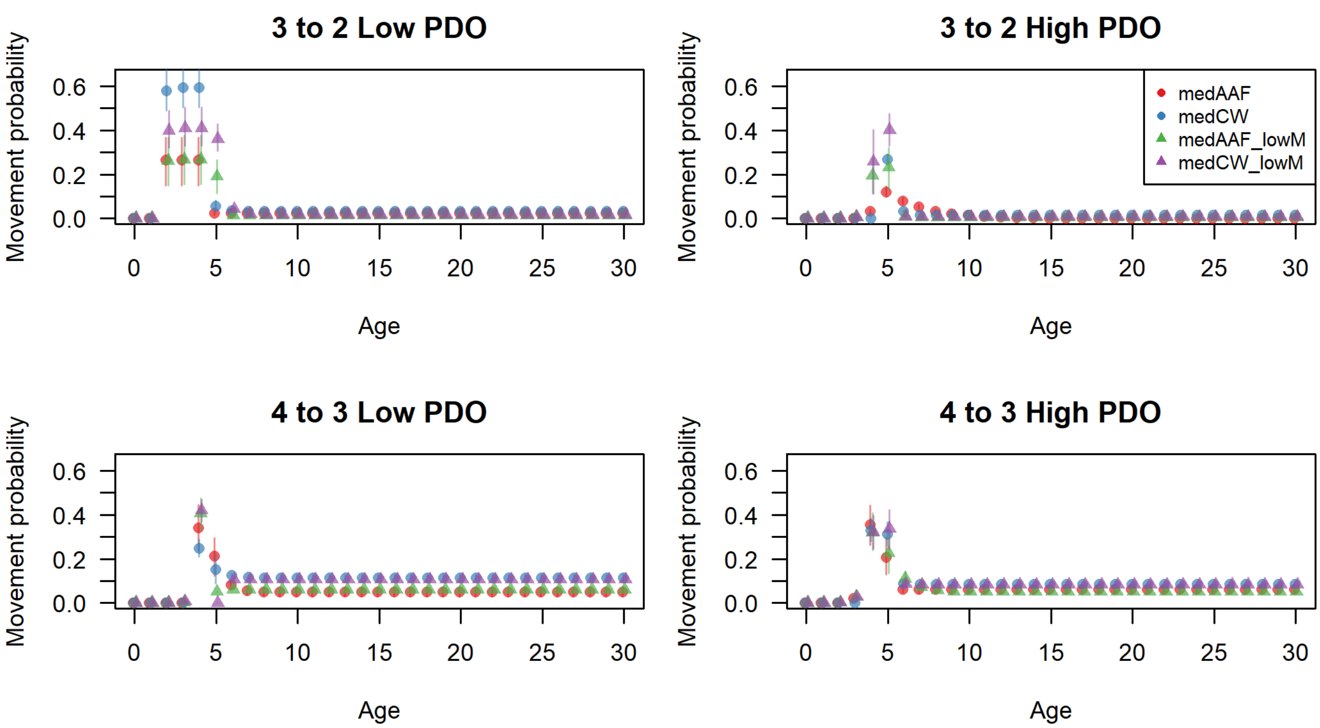

Figure 9. Probability of movement-at-age from Biological Region 3 to region 2 (top) and region 4 to region 3 (bottom) in low PDO (left) and high PDO (right) regimes for the four OM models.

2.2 Projections

The multiple trajectories from the conditioned OM provide replicate time-series of population and fishery processes. These remain fixed and the closed-loop simulation projects forward in time using various management procedures (MPs) and assumptions. The simulated projection of weight-at-age, selectivity/retention deviations, and the environmental regime do not depend on the population dynamics and can be created ahead of time to save time in the simulations, although any of these processes could be dependent on the size of the population, or a certain demographic, and included in the simulation process. Other processes, such as implementation variability, are also simulated during the closed-loop simulations.

2.2.1 Implementation variability and uncertainty

Implementation variability is defined as the deviation of the fishing mortality from the mortality limit determined from an MP. It can be thought of as what actually (or is believed to have) happened compared to the limits that were set. Decision-making variability is the difference between the MP mortality limits and the adopted mortality limits set by the Commission.

Decision-making uncertainty can be applied to the mortality limit specified by the MP ($TCEY_t$) as a multiplier.

$$\widetilde{TCEY}_t = TCEY_t \varepsilon_I$$

where $\widetilde{TCEY}_t$ is the adopted mortality and ε_I is the multiplier. Using observations from 2014 to 2021 of the MP mortality limit determined from the interim management procedure and the adopted mortality limits set by the Commission for that year and IPHC Regulatory Area, the multipliers are shown in Figure 10 (only the years 2014–2019 are plotted for 2A and 2B as those are the years without additional agreements). These years were chosen because they used a relatively consistent management procedure, although explicit use of SPR was added in 2017, additional agreements were added in 2019 and 2020, and the reference SPR changed from 46% to 43% in 2021. Decision-making uncertainty is likely different depending on the management procedure. Additionally, in 2021 and 2022, the adopted coastwide TCEY was equal to the coastwide TCEY specified by the interim management procedure, thus distribution was the only decision-making variability.

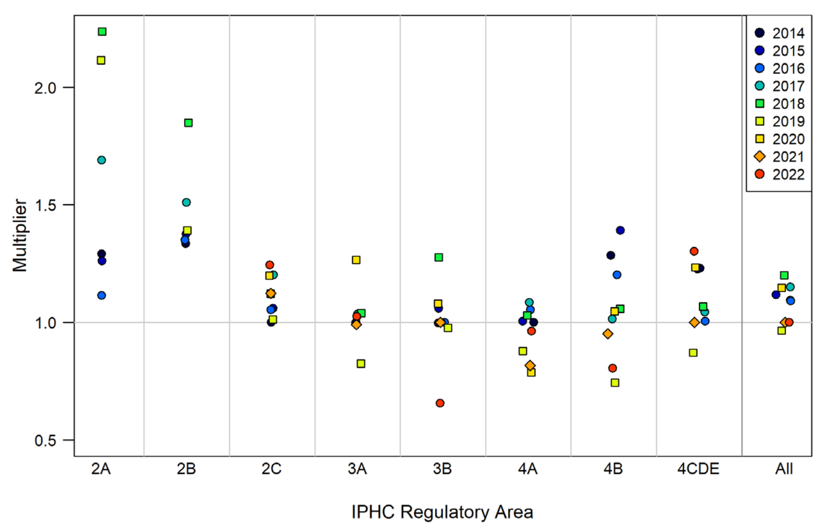

Figure 10. Multipliers for the difference between MP mortality limits and adopted mortality limits from 2014 to 2021. The years 2014-2019 only are plotted for 2A and 2B to show years when no specific agreements for those IPHC Regulatory Areas were in place.

2.2.1.1 Method to simulate decision-making uncertainty

The multiplier to simulate decision-making uncertainty is drawn from a lognormal distribution with correlation between multipliers for each IPHC Regulatory Area. The mean (center) and standard deviation (spread) of that distribution are modified such that the multiplier is closer to a value of one as the TCEY increases between low and high coastwide TCEYs. Using a coastwide low TCEY of 30 Mlbs and a coastwide high TCEY equal to 60 Mlbs (and years with no additional agreements for 2A and 2B), the distribution of simulated multipliers gets closer to 1 as the TCEY increases (Figure 11).

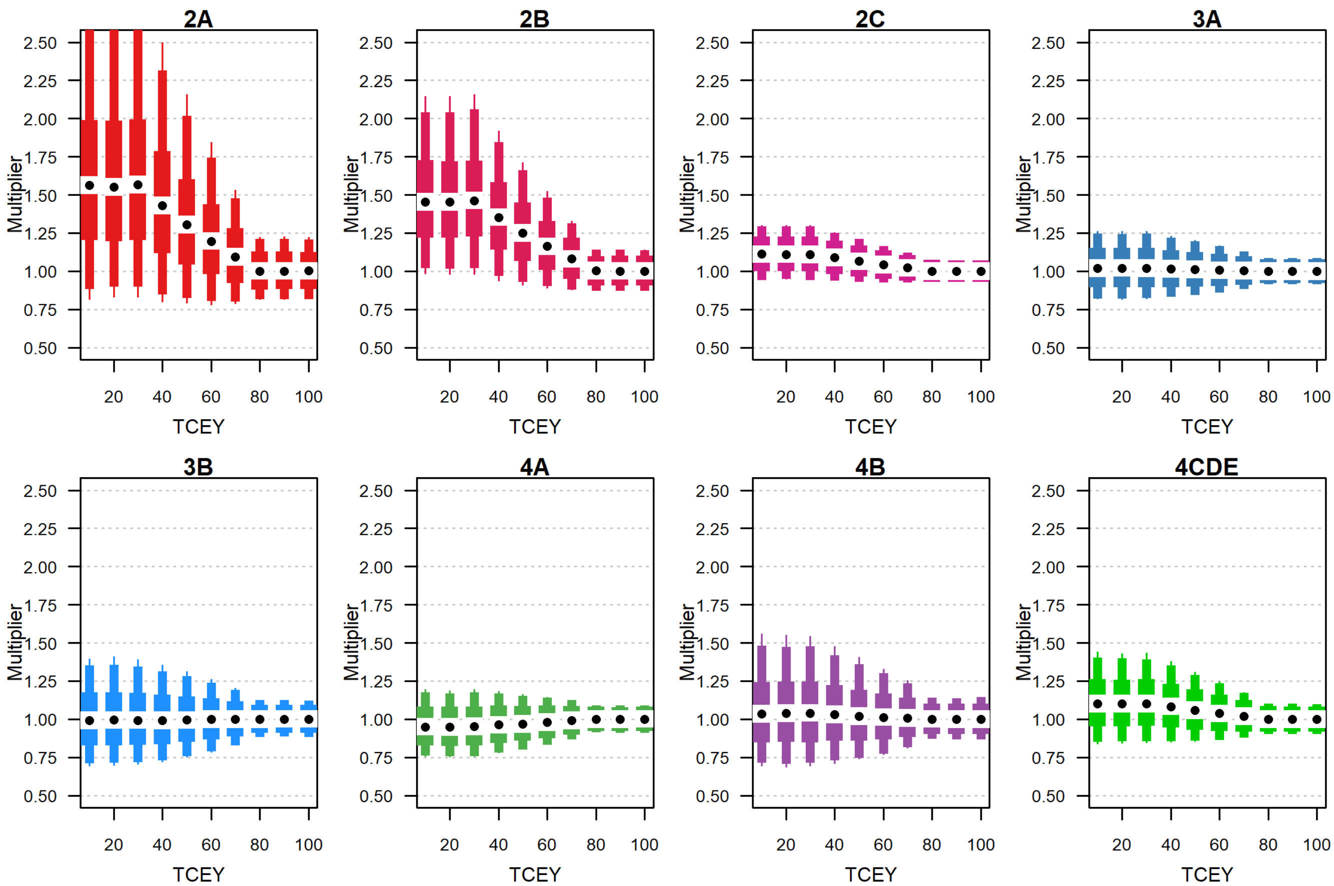

Figure 11. Simulated multipliers for IPHC Regulatory Areas at different values of the coastwide TCEY (without the recent agreements for 2A and 2B). The thickest portion of the vertical bar represents the 25^{th} and 75^{th} percentiles, followed by the 5^{th} and 95^{th} percentiles, and then the 2.5^{th} and 97.5^{th} percentiles.

Each IPHC Regulatory Area has a specific parameterisation to simulate decision-making variability, which is dependent on the specific management procedure. For example, an MP with a specific TCEY for an IPHC Regulatory Area will not have decision-making variability for that area, but other IPHC Regulatory Areas may have increased decision-making variability as a result. Furthermore, two options will be used for decision-making variability:

1. The coastwide TCEY is equal to the coastwide TCEY from the MP, but distribution contains decision-making variability.
2. The coastwide TCEY may deviate from the MP, along with distribution, due to decision-making variability.

Using option 1 at various TCEY values, and assuming 2021 stock distribution, the ranges of simulated TCEYs in each IPHC Regulatory Area are shown in Figure 12.

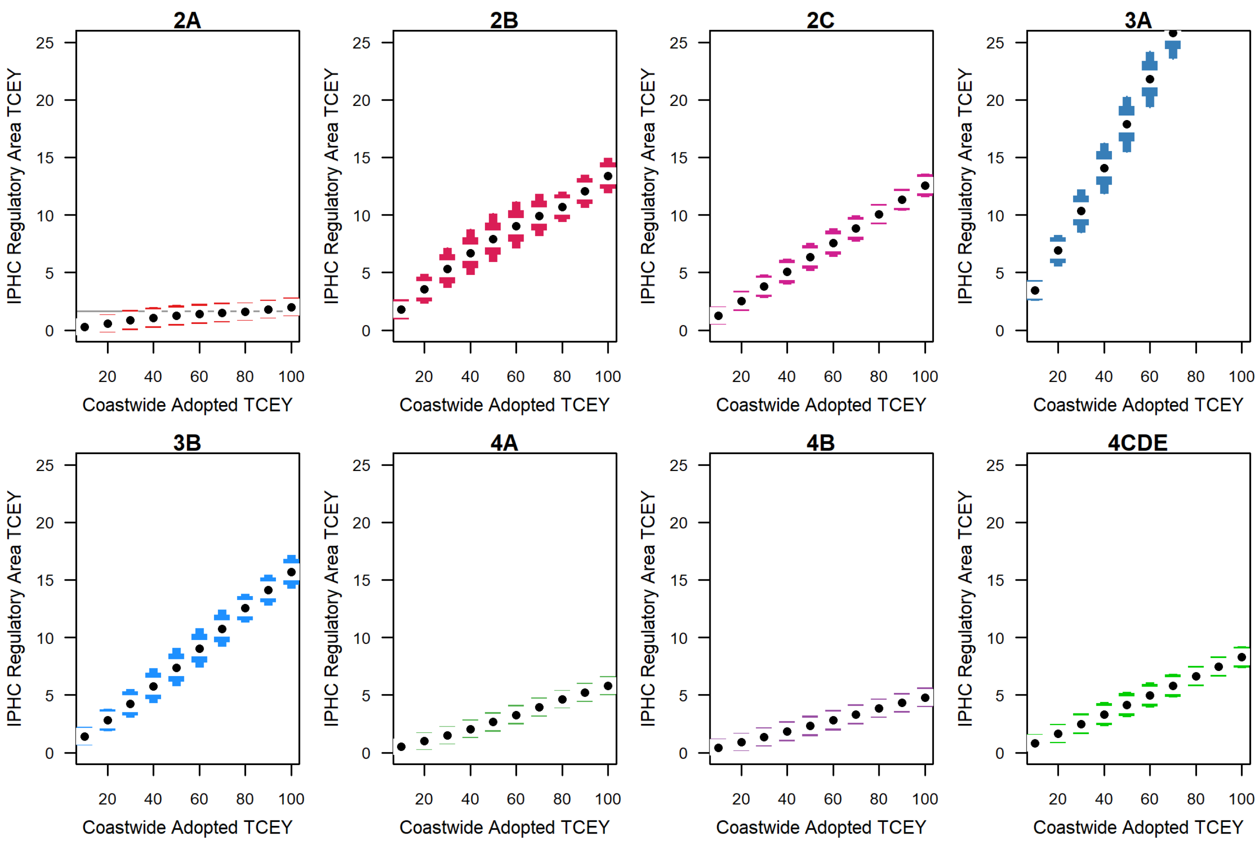

Figure 12. Simulated TCEYs in each IPHC Regulatory Area assuming there is no deviation from the coastwide TCEY (option 1), no additional agreements for 2A and 2B, and 2021 stock distribution.

Actual decision-making variability is likely more complex than these simple methods. In fact, some IPHC Regulatory Areas show a consistent adopted TCEY over a range of MP TCEYs (e.g., 4B in Figure 13). However, the goal of including decision-making uncertainty in the MSE simulations isn't to exactly simulate what the pattern may be in the future, but to identify the effect of decision-making uncertainty and identify MPs that are robust to a plausible amount of uncertainty and illustrate the costs or benefits of reducing decision-making uncertainty. Various modifications may be made to decision-making uncertainty to explore sensitivity to various hypotheses. For example, different offsets depending on the trend in the population or TCEY, as suggested by the SRB (SRB019–Rec.06, para. 35).

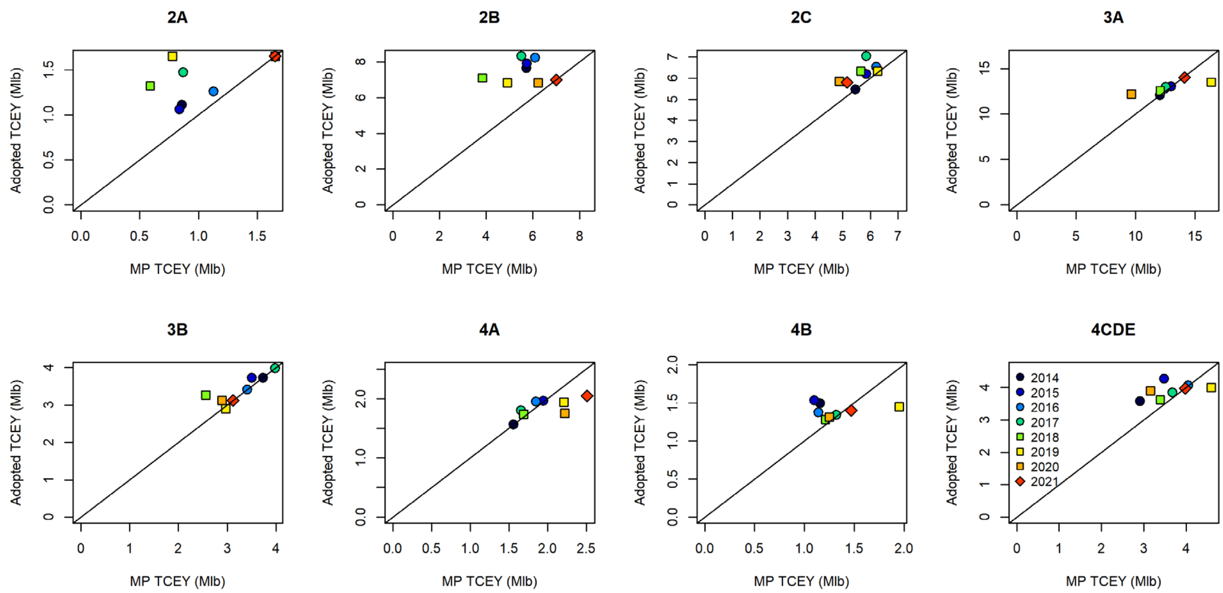

Figure 13. Adopted TCEYs plotted against MP TCEYs for each IPHC Regulatory Area and years 2014 to 2021.

2.2.1.2 Methods to simulate realized and perceived implementation uncertainty

Realized uncertainty is currently implemented in the OM by simulating a range of actual non-directed discard mortality, recreational mortality, and subsistence mortality. These are likely the largest sources of realized variability in the Pacific halibut fisheries, which is relatively small compared to many fisheries.

Perceived uncertainty is currently not simulated in the OM but will be considered as work progresses. Perceived uncertainty includes uncertainty related to sampling and estimation of landings and discards, which can include bias and variability for many reasons. Inclusion of perceived uncertainty in the MSE framework will likely not occur before the 99th Annual Meeting.

2.2.2 Estimation error

Estimation error is the uncertainty in parameters that are estimated for use in a management procedure. For example, relative spawning biomass is used in the 30:20 control rule and is an estimate from the stock assessment. The total mortality given a fixed SPR is also subject to estimation error.

There are three options for examining the effect of estimation error. The first is No Estimation Error, which is useful to understand the intrinsic qualities of a management procedure. The second is Simulated Estimation Error, which simulates the correlated uncertainty in relative spawning biomass and total mortality. This mimics the variability that may arise from a stock assessment, but not may not capture some of the nuances of the estimates from a stock assessment, such as bias and autocorrelation. The third is to run a stock assessment as part of the closed-loop simulation process (Simulated Stock Assessment). This can be time-consuming, especially with a complex ensemble assessment, thus simplifications are often made. Currently, a single simplified model from the Pacific halibut ensemble assessment is implemented in the MSE framework, and is useful for comparison to the simulated estimation error, but is not complete for decision-making purposes.

2.3 Runs and Scenarios

The primary closed-loop simulations consist of integrating the four OM models with equal weight by simulating an equal number of trajectories/projections from each model. Results from the full set of projections are used to calculate the performance metrics for measurable objectives and statistics of interest. Additional scenarios may be evaluated that include different types of implementation error or alternative scenarios of fishery selectivity (e.g. targeting or avoiding small Pacific halibut).

Scenarios that may be useful to examine include the following

- Targeting small Pacific halibut
- Avoiding small Pacific halibut
- Low or high weight-at-age
- Low or high recruitment regime

Specific management procedures being evaluated in 2022 are described in document IPHC-2022-MSAB07-09 along with preliminary results. Complete results will be presented at the 99th IPHC Annual Meeting. The MSE Explorer will be updated as results are obtained (Appendix A).

RECOMMENDATION/S

That the MSAB:

a) **NOTE** paper IPHC-2022-MSAB017-07 describing improvements to the closed-loop simulation framework, methods to include decision-making uncertainty, and possible scenarios to consider.

b) **RECOMMEND** additional improvements or additions to the MSE framework to be done in 2023.

c) **RECOMMEND** additional scenarios for consideration in the future.

REFERENCES

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Seitz, A. C., Farrugia, T. J., Norcross, B. L., Loher, T., & Nielsen, J. L. 2017. Basin-scale reproductive segregation of Pacific halibut (Hippoglossus stenolepis). Fisheries Management and Ecology, 24(4), 339–346.

Stewart, I., and A. Hicks. 2022. Assessment of the Pacific halibut (Hippoglossus stenolepis) stock at the end of 2021. IPHC-2022-SA-01. 16 December 2022. https://www.iphc.int/uploads/pdf/sa/2022/iphc-2022-sa-01.pdf

APPENDICES

Appendix A: Supplementary material

APPENDIX A
SUPPLEMENTARY MATERIAL

In addition to this document, an MSE technical document is available electronically. This is document IPHC-2022-MSE-01 and is available on the IPHC MSE page (https://www.iphc.int/management/science-and-research/management-strategy-evaluation). Additional updates will be made as time allows.

The MSE Explorer will also be updated as additional results.

(http://shiny.westus.cloudapp.azure.com/shiny/sample-apps/MSE-Explorer/).