# Development of the 2024 Pacific halibut (*Hippoglossus stenolepis*) stock assessment

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## PURPOSE

To provide the IPHC's Scientific Review Board (SRB) with a response to recommendations and requests made during SRB023 (IPHC-2023-SRB023-R) and to provide the Commission with an update on progress toward the 2024 stock assessment.

## INTRODUCTION

The International Pacific Halibut Commission (IPHC) conducts an annual coastwide stock assessment of Pacific halibut (*Hippoglossus stenolepis*). The most recent full assessment was completed in 2022 (IPHC-2023-SA01), following updates in 2020 and 2021. The 2023 stock assessment updated the 2022 analysis and all data sources where new information was available but made no structural changes to the methods. Development and supporting analyses arising from the 2023 assessment were reviewed by the IPHC's SRB in June (SRB022; IPHC-2023-SRB022-08, IPHC-2023-SRB022-R) and September 2023 (SRB023; IPHC-2023-SRB023-06, IPHC-2023-SRB023-R).

A summary of the 2023 stock assessment results (IPHC-2024-AM100-10) as well as stock projections and the harvest decision table for 2024 (IPHC-2024-AM100-12) were provided for the IPHC's 100th Annual Meeting (AM100). In addition, the input data files are archived each year on the stock assessment page of the IPHC's website, along with the full assessment (IPHC-2024-SA-01) and data overview (IPHC-2024-SA-02) documents. All previous stock assessments dating back to 1978 are also available at that location.

For 2024, the Secretariat plans to conduct an updated stock assessment, consistent with the schedule for conducting a full assessment and review approximately every three (3) years. Standard data sources and model configurations are expected to remain unchanged.

## TIME-SERIES AND SOFTWARE UPDATES

In order to provide comparability between preliminary results and all subsequent steps working toward the final 2024 stock assessment (the annual bridging analysis), this evaluation began with the final 2023 models. First, each of the four assessment models was extended by one year, including projected 2024 mortality from all sources based on the mortality limits set during AM100 (IPHC-2024-AM100-R). Extending the time-series without adding any new data does not affect the historical time-series' estimates but allows for a simple stepwise evaluation of the effects of adding data (including updating from the projected to actual fishery harvest) and any other changes to the models prior to the final version used for management.

Next, the Stock Synthesis (SS) software was updated from the version used for the 2023 stock assessment (3.30.21) to the most recent release (31 January 2023), 3.30.22.01 (Methot Jr et al. 2024). The changes to the software between these two versions had no effect on the Pacific halibut stock assessment (the results were identical to the final 2023 assessment). However, maintaining a current version (when possible and efficient) reduces the likelihood of compatibility issues with plotting and other auxiliary software and reduces the cumulative transitional burden when future changes are added. No appreciable changes were noted in convergence performance, run times or other technical aspects of the software update.

The IPHC continues to rely on SS for its annual tactical stock assessment modelling. During 2024, Secretariat staff explored the capabilites of R-Template Model Builder (RTMB; Kristensen et al. 2016), via a training course hosted by Fisheries and Oceans Canada. TMB forms the basis of most state-space models currently used for stock assessment (e.g., SAM, WHAM; Nielsen and Berg 2014; Nielsen et al. 2021; Stock and Miller 2021), provides a more efficient Auto-Differentiation (AD) algorithm than Automatic Differentiation Model Builder (ADMB; Fournier et al. 2012) as well as extremely efficient capabilities for modelling random effects and sparse matrices. As the Pacific halibut stock assessment models include time-varying processes (i.e. recruitment, selectivity, and catchability) it would be ideal to treat them as random effects, rather than using the penalized likelihood curently employed. However, current development of stock assessment platforms based on TMB has not included sex-specific dynamics that can accommodate dimorphic growth, but several efforts are underway which may result in a platform that could be applicable to Pacific halibut. The Secretariat will continue to stay informed on these and other modelling efforts (e.g., the U.S. National Oceanic and Atmospheric Administration's Fisheries Integrated Modelling System project) and to review the merits of using a generalized stock assessment platform vs. creating a new application specifically built for Pacific halibut. The Management Strategy Evaluation (MSE) operating model (generally based on the structure of the current stock assesment) has and will continue to refine the Secretariat's understanding of key biological processes and technical modelling needs. The co-development of assessment modelling and the MSE fosters data exploration and structural testing, naturally leading to prioritization of hypotheses and research priorities.

Development of the IPHC's stock assesment is highly dependent on the type of management procedure selected by the Commission. This situation has not changed since the 2023 stock assessment was conducted. The stock assesment analysis conducted each fall in order to provide annual management information is based on the current year's data and must be stable and simple enough to be completed in less than two weeks. If a management procedure based on modelled survey trends, or a multi-year procedure is adopted, it may be uneccesary to conduct annual stock assessments. That type of procedure and timeline could allow for the development of more complex stock assessment ensembles/models (including fully Bayesian analyses), given extended development time between assessments. Therefore, the adoption of a management procedure by the IPHC, developments in the MSE process, and strategic planning for the stock assessment modelling platform should be considered together: the long-term focus should be on selecting the most efficient tools to meet management needs as they continue to evolve.

### PROJECTION OF SELECTIVITY

In the version of the SS software used for 2024, there are a number of new modelling options. Of these, the ability to propagate the process variability in time-varying selectivity parameters into future projections is directly applicable for the Pacific halibut stock assessment. All four assessment models include time-varying selectivity, bias in the maximum likelihood estimates is accounted for by iteratively solved for the variance parameters (Stewart and Hicks 2022). In recent stock assessments an average of the terminal three years of selectivity was used for all projections. Although the annual selectivity estimated in the four models is not highly variable, estimating projection deviations consistent with the variability estimated for the recent time-series provides the same propagation of variance for time-varying selectivity that is used for recruitment variability.

Using the bridging models described above (with the time-series extended to 2025) as a starting point, selectivity deviations were extended through the three-year projection period and the Coefficient of Variation (CV) of the projected spawning biomass and Spawning Potential ratio (SPR) at the end of the projection period were compared with and without this additional source of uncertainty (Table 1). This change made little difference to the estimated variance of the management quantities; this is likely due to the relatively low current exploitation rates and modest variability in selectivity leading to only minor translation of change in fishery selectivity to population estimates over a short-term projection. However, the change is recommended as it comes at no additional computational cost and will ensure that future combinations of models and data will appropriately reflect the uncertainty in fishery selectivity.

**Table 1**. Coefficients of variation (CVs) of estimated spawning biomass and Spawning Potential Ratio (SPR) at the end of a three-year projection of 2024 harvest levels using: 1) average selectivity from 2021-2023 and 2) allowing process error to propagate via projecting selectivity deviations from the terminal year to the end of the projection period for each of the four stock assessment models (CW = coastwide, AAF = Areas-As-Fleets).

| | Spawning biomass | | SPR | |
|---|---|---|---|---|
| Model | Average Selectivity | Projected deviations | Average Selectivity | Projected deviations |
| CW short | 24% | 24% | 9% | 10% |
| CW long | 20% | 20% | 14% | 14% |
| AAF short | 21% | 21% | 16% | 16% |
| AAF long | 17% | 17% | 12% | 12% |

### COMMISSION AND SRB REQUESTS AND RESULTS

There were no requests made by the Commission at AM100 specifically relating to the stock assessment. In 2023, the SRB made the following assessment recommendations and requests during SRB023:

1) SRB023–Rec.03 (para. 20):

   *"The SRB **RECOMMENDED** that the Secretariat investigate approaches (e.g. simulation testing) to estimating uncertainty (or bounding the minimum level of uncertainty) in different assessment outputs: e.g. coastwide and Biological Region spawning stock biomass (see related actions under Section 4.2)."*

2) SRB023–Rec.19 (para. 59):

   *"The SRB **RECOMMENDED** that the Secretariat continue exploring ways of estimating the impacts of different FISS designs and efficiency decisions on stock assessment outputs and fishery performance objectives. The end goal should be to provide a decision support tool*

*that can frame decisions about FISS design in terms of costs and benefits in comparable currencies."*

3) SRB023–Req.07 (para. 60):

*The SRB **REQUESTED** that the Commission NOTE that some longer-term (2025 and beyond) implications of reduced FISS designs are predictable and potentially consequential. For instance, higher FISS CVs will generally result in higher inter-annual variation in TCEY under the current decision-making process. This would occur for two reasons: (1) biomass estimates and projections from the assessment model will have greater uncertainty and therefore greater variability in outputs and (2) ad hoc management adjustments to the interim harvest policy recommendations would be more frequent and/or more variable for greater input uncertainty. The SRB therefore REQUESTED the following analyses for SRB024:*

*a) Assessment of reduced FISS designs (2025-2027) via simulation tests of assessment model outputs (e.g. probability of decline, estimated stock abundance and status, TCEY) under alternative revenue-neutral FISS designs using the existing stock assessment ensemble;*

*b) Mitigation options of reduced FISS designs (short-term and long-term) via MSE simulations of management procedures that deliberately aim to reduce inter-annual variability in TCEY via multi-year TCEYs and (possibly) fixed stock distribution schemes;*

*c) Components (a,b) above would be integrated since (a) will need to inform simulations in (b)."*

4) SRB023–Req.08 (para. 61):

*"The SRB **REQUESTED** that simulations above (para. 60) include:*

*a) a relationship in which the FISS CV is relatively higher at lower stock abundance (i.e. the current CV issue is a function of stock abundance rather than a short-term condition);*

*b) target regulatory area CVs of 15%, 20%, 25%, and 30%;*

*c) coastwide target CV of 15% without controlling specific regulatory area CVs."*

### *Recommendation 1 – General simulation testing*

The SS software has a built in data generating feature that produces a series of randomly generated data sets, matching the original inputs in dimension, using the same distributions and variance as the original data, and centered on the expected values (Methot Jr et al. 2024; Methot and Wetzel 2013). These data sets can then be fit with the original assessment model and provide a 'self-test' of the model's ability to recover the parameter values and management quantities given the structure of the data available and the assumed uncertainty in those data. This approach does not represent a broad simulation test, as the assumptions generating the data match exactly those of the fitted stock assessment. However, the method is a useful check on model performance separated from mismatching assumptions of the population dynamics, data collection or other aspects of the stock assessment.

The secretariat used this tool to test the final 2023 stock assessment, via the creation of 100 bootstrapped data sets for each of the four stock assessment models. Each model was then refit to the bootstrapped data sets and the results compiled and compared to the actual model results from 2023. A range of comparisons were made; however, spawning biomass is reported here as it represents the primary input to management calculations and integrates both the scale and trends recovered by the analysis. The comparisons were made at two levels. First, the distribution of bootstrapped maximum likelihood estimates (MLEs) across the simulations was compared to the actual assessment result and 95% credible interval for each of the four individual models. Second, to represent the actual ensemble approach used to provide management information, each simulation of the four models was integrated using the estimated asymptotic uncertainty and equal weighting. In this comparison the 2.5$^{th}$, 50th, and 97.5$^{th}$ percentiles across all simulations were compared to the same percentiles from the actual 2023 stock assessment. The results are intended to address the question: If the assessment in its current configuration were conducted repeatedly with new data of the same dimension and quality, how similar would the results be to the actual assessment?

Out of the 400 model fits to the bootstrapped data sets, one model failed to reach a minimum negative log-likelihood and estimate a positive definite Hessian matrix. That simulation was excluded from the set of results presented here as it represented only a small fraction of the total experiment. It is possible that rerunning that model from different initial values and/or with different phasing may have produced a reliable solution.

Based on the 99 remaining simulations all four models recovered the historical trend and the general scale of the Pacific halibut population. However, each of the individual stock assessment models showed some bias either for certain historical periods or across the entire time-series. The coastwide long model simulations overestimated the early time-series and slightly underestimated the latter half of the time-series relative to the 2023 stock assessment from which the data were generated (Figure 1). The long Areas-As-Fleets (AAF) model had a similar pattern of simulated to actual spawning biomass, again slightly underestimating the latter half of the time-series (Figure 2). The simulations from the coastwide short time-series model overestimated the spawning biomass (Figure 3), and a similar pattern occurred for the simulations of the short AAF model (Figure 4). The net effect across all four models was a nearly unbiased ensemble result, with the upper credible interval (97.5$^{th}$) slightly higher than that estimated from each of the actual assessment models (Figure 5). The ensemble differed from the base assessment by 2-12% across all years for which there were four model results.

This simulation 'self test' is helpful in understanding the basic performance of the current stock assessment models and indicates another beneficial aspect of using and ensemble of models rather than a single 'best' model to provide management information. Further, this test suggests that it will be important to consider the full ensemble results when simulating and comparing results across potential future Fishery Independent Setline Survey (FISS) designs (See discussion below).

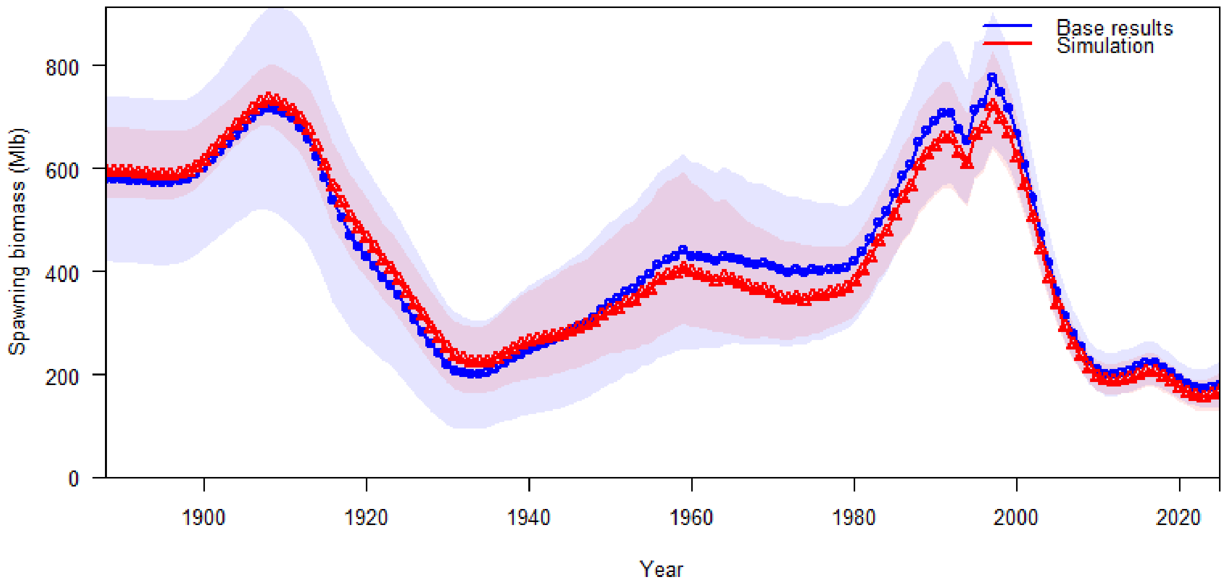


**Figure 1**. Time series of estimated spawning biomass based on the 2023 long coastwide stock assessment model (extended to 2025) and 95% credible intervals (blue series and shaded region) and the distribution of maximum likelihood estimates from 99 bootstrapped data sets (red series; median and 95% interval).

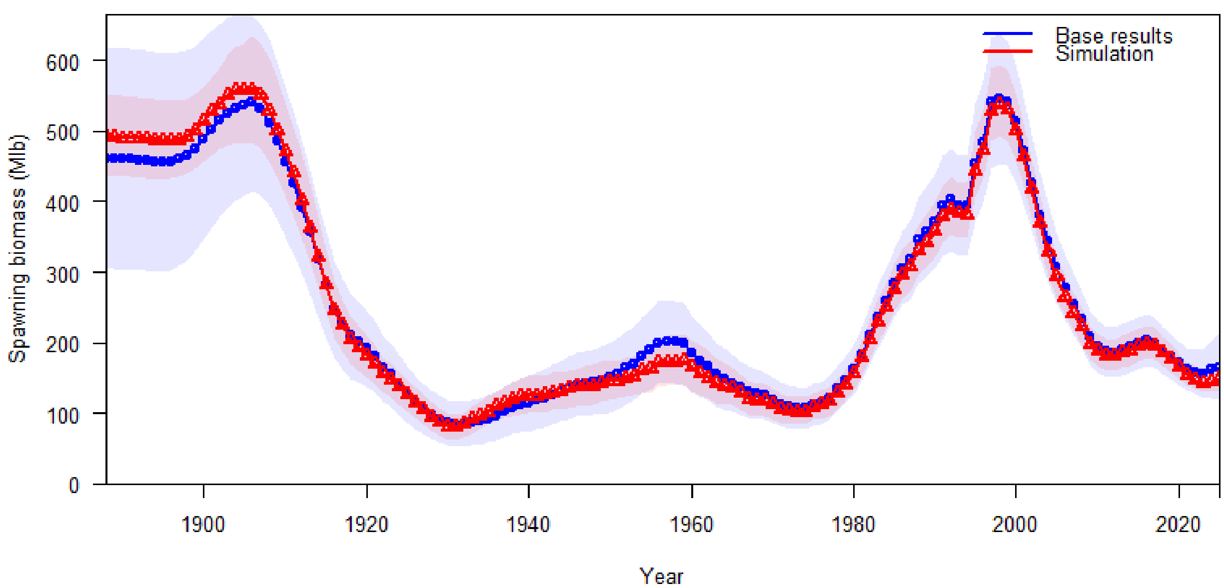


**Figure 2**. Time series of estimated spawning biomass based on the 2023 long Areas-As-Fleets stock assessment model (extended to 2025) and 95% credible intervals (blue series and shaded region) and the distribution of maximum likelihood estimates from 99 bootstrapped data sets (red series; median and 95% interval).

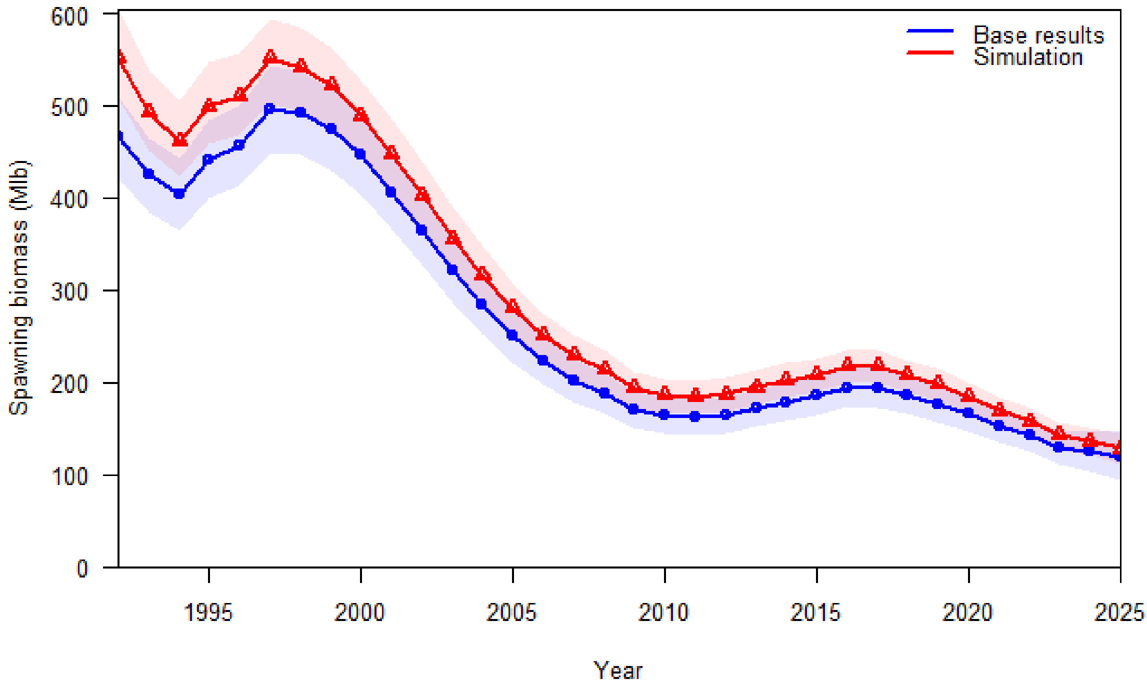


**Figure 3**. Time series of estimated spawning biomass based on the 2023 short coastwide stock assessment model (extended to 2025) and 95% credible intervals (blue series and shaded region) and the distribution of maximum likelihood estimates from 99 bootstrapped data sets (red series; median and 95% interval).

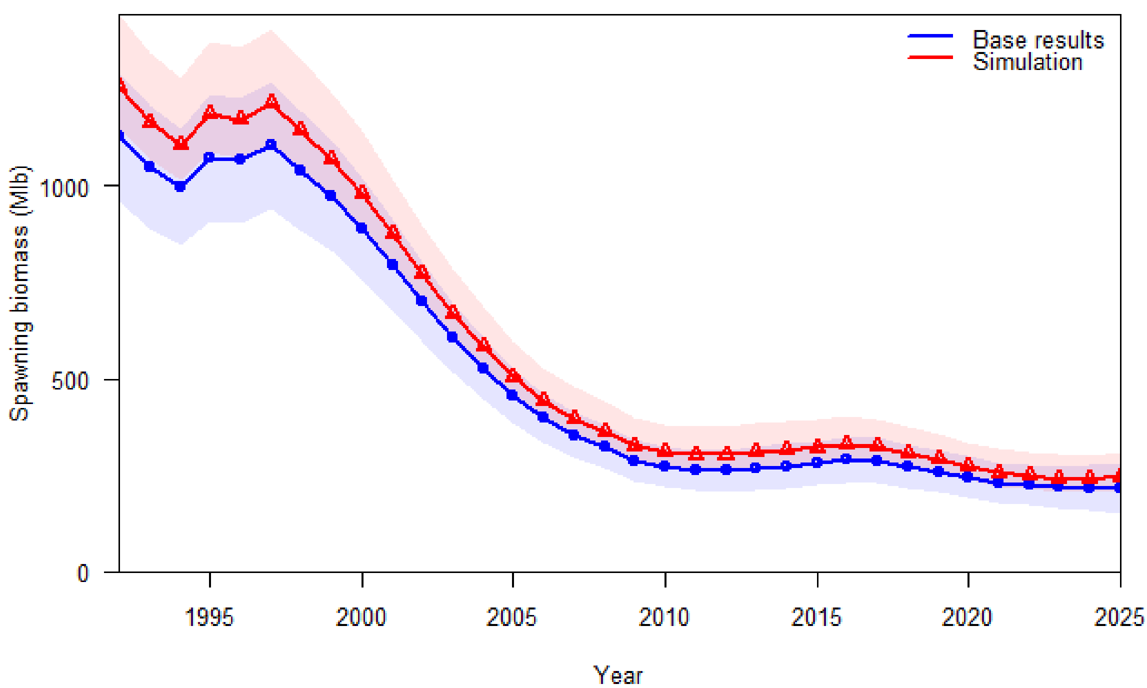


**Figure 4**. Time series of estimated spawning biomass based on the 2023 short Areas-As-Fleets stock assessment model (extended to 2025) and 95% credible intervals (blue series and shaded region) and the distribution of maximum likelihood estimates from 99 bootstrapped data sets (red series; median and 95% interval).

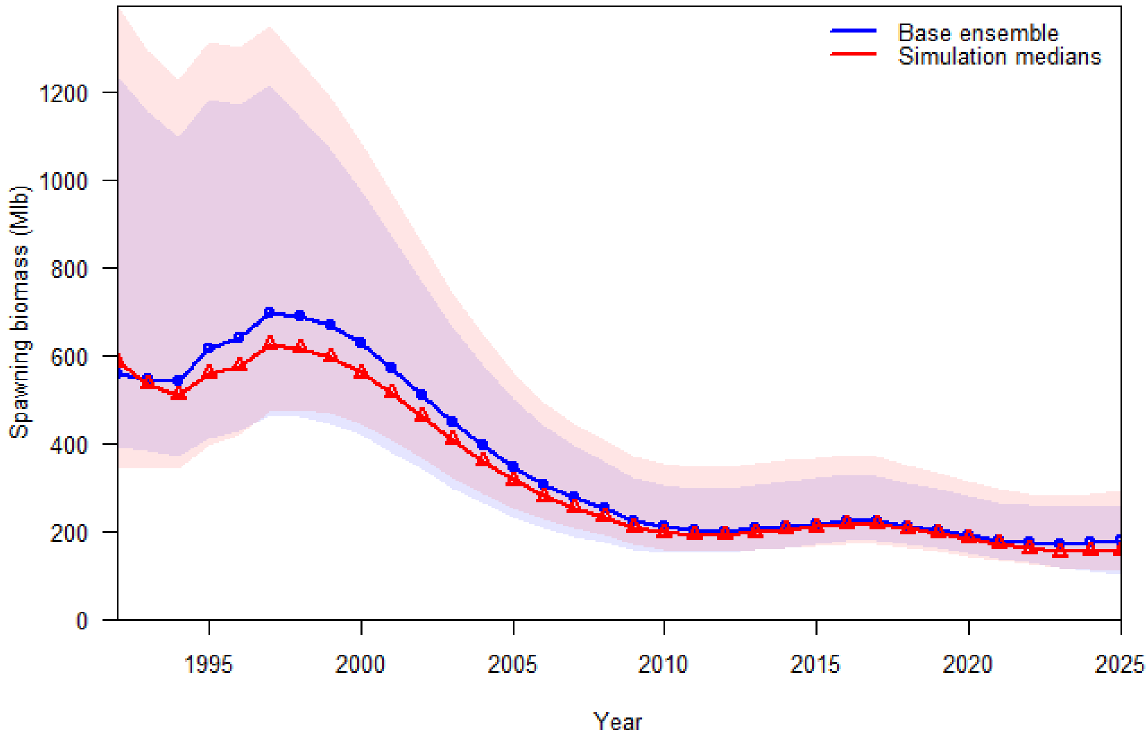


**Figure 5**. Time series of estimated spawning biomass based on the 2023 stock assessment ensemble (extended to 2025) and 95% credible intervals (blue series and shaded region) and the median across 99 bootstrapped data sets of the 2.5th, 50th, and 97.5th percentiles (red series and shaded region).

### *Recommendations 2-4 – Simulation testing of FISS designs*

The remaining SRB023 requests all focus on evaluating how potential future FISS designs may affect the quality of management decision-making. These requests link projections made using the space-time model with stock assessment estimation and overall MSE performance. This analysis will ultimately have three connected phases: 1) projection of the space-time model under different FISS designs to determine the effect of different levels of sampling on the uncertainty (CV) of the index of abundance; 2) fitting stock assessment models to the results from 1 (and including simulated age composition information) with and without bias in the actual population trend to determine the effect on short-term stock assessment estimates; and 3) use of the stock assessment simulation results from 2 to inform MSE scenarios quantifying the overall effect on long-term management performance of alternative FISS designs. The first phase is fully reported for this meeting (IPHC-2024-SRB024-06). An experimental design for phase two is proposed here, for review and discussion.

For 2025 through 2027 the Secretariat has developed three potential FISS designs (IPHC-2024-SRB024-06):

1) A 'base block design' that will ensure good spatial coverage, low CVs and very low potential for multi-year bias due to sampling all survey stations on a frequent basis. This design was developed on request by the Commission to represent a sustainable long-term design if a baseline of constant funding ($1.5M) were provided.
2) A 'core design' that will provide sampling in those areas with the highest biomass at a reduced sampling cost. This design will produce larger CVs than the block design and will

have a high likelihood of biased trends and age compositions due to low abundance and/or high-cost areas going unsampled for multiple consecutive years.

3) A ‘reduced core design’ that provides sampling only in areas that are close to or above revenue positive thresholds. This design will produce larger CVs than the core design and will have a very high likelihood of introducing biased trends and age compositions due to the extremely restricted geographic coverage.

The CV of the terminal year of the FISS index will always be higher than that year’s CV after additional years of data have been collected. For example, the CV for 2025 will have greater uncertainty in 2025 than the index of abundance used for 2025 when the data extend through 2027. Therefore, the projection of each potential design was conducted for each terminal year from 2025 through 2027 (see IPHC-2024-SRB024-06) to allow more accurate evaluation of the degree of uncertainty over 1, 2 and 3 years.

Projections using the space-time model naturally propagate the variance associated with reduced FISS designs; however, because the reduced designs do not represent a random draw from all 1,890 survey stations there is the potential for bias in addition to reduced precision. The degree of potential bias is unknown and will depend on how the design interacts with localized trends and patterns in cohort structure, movement rates, and other factors known to vary interannually. Based on previous summary of changes in different areas of the stock, the Secretariat proposes to use +/- 15% bias in the FISS index over 3 years as a basis for investigating stock assessment performance.

The current stock assessment can be used to simulate new data, given an assumed trend and precision for all data sources. This is achieved via the internal semi-parametric bootstrap used in the ‘self-test reported above.

1) Using the 2024 bridging model, extend the time-series to 2027 assuming constant harvest levels at the projected 2024 mortality for each fishery sector.
2) Fit ‘true’ models to FISS projections that include no trend, a linear 15% positive trend over the next three years, and a linear 15% negative trend over the next three years using the CVs projected for the base block design. Assume all other data sources (fishery CPUE and age composition information) are sampled at the observed rates from 2023.
3) Using the ‘true’ models, bootstrap all of the data (FISS and fishery) in 2025-2027, to create 100 replicate data sets for each of the three trends.

When evaluating alternative or restricted survey designs it is common to consider only the index of abundance (e.g., Anderson et al. 2024); however, the age composition information is also critically important to estimating year-class strengths which can lead to very different management outcomes for the same or similar index trends. The bootstrapping approach described above will naturally produce age composition information that is unbiased, given the true trend in the index.

Once the simulated data sets from the ‘true’ states have been constructed, three experiments will be conducted (Table 2). Each experiment will compare the results from the ‘true’ model with models using data representing either unbiased or biased designs. This experiment therefore produces 9 sets of models to be fit crossing the three designs with three trends (Table 2). Specifically, to explore the effects of increased CVs due to reduced designs, models will be fit to a true projection with no trend and unbiased data for each design. To explore the effects of potential bias, the biased core and reduced core designs will be compared to an unbiased base block design given true trends of +/- 15%. If time permits, a subset of unbiased design reductions will be evaluated over only the period through 2025 to illustrate the effect of a 1-year survey reduction on stock assessment results.

For models fitting to data based on the restricted designs (core and reduced core), the sample sizes for the age composition data will be reduced in proportion to the geographic extent of the scenario (e.g., a reduced core design will include smaller sample sizes than the other two designs and the areas-as-fleets models will have missing data from some biological regions).

**Table 2**. Design matrix for proposed simulations of FISS design effects on the stock assessment.

| 'True' FISS trend | Estimation model | Inference |
|---|---|---|
| No trend | No trend, base block design, 3 years<br>No trend, core design, 1 & 3 years<br>No trend, educed core, 1 & 3 years | Effect of increased CV due to reduced designs |
| +15% over 3 years | +15%, base block design, 3 years<br>No trend, core design, 3 years<br>No trend, reduced core, 3 years | Effect of failing to identify an increasing trend |
| -15% over 3 years | -15%, base block design, 3 years<br>No trend, core design, 3 years<br>No trend, reduced core, 3 years | Effect of failing to identify a decreasing trend |

This approach will provide inference on how a reduced FISS might affect the overall results of the stock assessment ensemble. Specifically, we will be able to address the questions: How does a reduced but unbiased FISS affect the results? How will management information be affected if we fail to detect an increasing trend? How will management information be affected if we fail to detect a decreasing trend? For each of these questions we will compare key management inputs between a correctly specified model (the base block design) and those that are either less precise and/or biased. Results will include a characterization of the bias in: the estimated fishing intensity (SPR), the estimated spawning biomass, and the estimated risk of stock decline. The results of this simulation experiment can then be used to inform estimation model performance in future MSE evaluations in the full closed-loop management system.

Although this simulation experiment will be able to quantify some of the effects of potential FISS designs on potential future management, it will be lacking the most important: stakeholder perception of and confidence in the FISS information. Across years in which a range of FISS designs, from very comprehensive (e.g., 1,558 stations in 2019 and 1,489 stations in 2018) to very small (951 stations in 2020 and 864 stations in 2023) have been completed, it has become very clear that the entire decision-making process relies heavily on the perception of whether the FISS was comprehensive and sufficient to capture coastwide and regional trends. Even large survey designs have often required repeated comparisons with commercial fishery catch rates and age composition information as well as the experiences of harvesters in each of the IPHC Regulatory Areas before a reasonable level of confidence was achieved. Where entire IPHC Regulatory Areas, or entire Biological Regions have gone unsampled, the lack of direct information has affected management allocation decisions and led to stakeholder proposals to freeze mortality limits at or below the previous year's level (Appendix II in IPHC-AM100-INF01-Rev_5). We recognize that stakeholder perception cannot be easily quantified without a specific social science analysis; however, it is nonetheless critically important to the Pacific halibut management process. We suggest that regardless of the quantitative results determined for reduced FISS designs, the long-term goal should be to create a sustainable survey design that meets quantitative objectives (both in the annual process and the full MSE), but also satisfies stakeholder needs and represents a point of stability in the management process rather than a point of concern.

### OTHER TOPICS

Assessment development during 2024 is occurring in parallel with the ongoing histological maturity study and related analyses (IPHC-2024-SRB024-09). As that project produces results, they will be incorporated into the stock assessment as part of the proposed assessment, as sensitivity analyses, or as supporting information in September 2024. It is anticipated that any major revisions to the stock assessment or to the management results inferred from it will be included in the full assessment planned for 2025.

Various other assessment development topics are ongoing; updates on progress will be provided if available in time for SRB023 and SRB024.

### RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2024-SRB024-08 which provides a response to requests from SRB023, and an update on model development for 2024.

b) **REQUEST** any modifications to the proposed FISS design simulations.

c) **REQUEST** any further analyses to be provided at SRB025, 24-26 September 2024.

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