IPHC Management Strategy Evaluation

PREPARED BY: IPHC SECRETARIAT (A. HICKS & I. STEWART; 21 DECEMBER 2023)

PURPOSE

To provide the Commission with results of the Management Strategy Evaluation (MSE) simulations of size limit and multi-year stock assessment management procedures (MPs), and to request decisions from the Commission on the Operating Model, Objectives, Performance Metrics, and Management Procedures.

EXECUTIVE SUMMARY

This document provides an update on the Commission set Program of Work for 2021–2023. Simulation results for size limits and multi-year stock assessment elements of the SPR-based harvest strategy policy are compared and contrasted across assumptions of estimation error and decision-making variability

The IPHC's MSE Operating Model has been thoroughly reviewed by the SRB and is performing well for evaluating management procedures, noting that further adjustments may be made, at the request of the Commission, to align with the stock assessment (i.e. conditioning to updated stock assessment outputs).

Size limits and multi-year assessments were evaluated independently and compared to an MP with an annual assessment frequency and a 32-inch size limit (MP-A32). Alternative size limits included 26 inches and no size limit (MP-A26 and MP-A0). Biennial and triennial assessment frequencies were evaluated with an empirical rule setting the TCEY in non-assessment years. One of the three empirical rules used FISS observations to adjust the coastwide TCEY and the distribution of the TCEY in non-assessment years (MP-Bb32 and MP-Tb32).

For all management procedures evaluated, the long-term relative spawning biomass passed both spawning biomass objectives for all MPs and was more often above the target for SPR values ranging between 40% and 46%. Removal of a size limit resulted in a 3.7% increase, on average, for the short-term median coastwide TCEY and a 2.7% increase, on average, for the long-term median coastwide TCEY. A majority of that increase occurred when reducing the size limit for directed commercial fisheries to 26 inches. Without a size limit for the directed commercial fishery, landings of O32 fish would likely decline while U32 landings would likely increase, and the trade-off is dependent on population characteristics such as incoming recruitment and size-at-age. Without a size limit for the directed commercial fishery, short-term coastwide directed commercial fishery discard mortality declined by, on average, 78%. For the directed commercial fishery without a size limit to maintain equal value to the fishery with a 32-inch size limit, the price of U32 fish would have to be near one-half the price of O32 fish, on average, and this equal value price ratio would most likely range between zero and one, depending on stock conditions.

A biennial assessment frequency with an empirical rule using FISS observations in non-assessment years showed similar results to an annual assessment. A triennial assessment frequency with an empirical rule using FISS observations in non-assessment years showed a similar short-term median TCEY along with a significant reduction in inter-annual variability of the TCEY. Costs associated with multi-year assessments include 1) lack of detailed management information every year, 2) possibly a loss in long-term yield, and 3) a chance of a smaller stock size. Benefits include 1) reduced inter-annual variability in the TCEY, 2) use of the annual FISS index in a transparent process, 3) more focused assessment research, 4) potential for additional collaboration within the Secretariat, 5) consistency with the three-year cycle of full assessments, and 6) following the precedent of other fisheries commissions.

A summary of the MSE simulation results using four (4) priority performance metrics are shown in Table E1.

Table E1. A summary of the MSE simulation results using four (4) priority performance metrics. The reference fishing intensity, SPR=43%, was used for all MPs. The MP most similar to the current interim harvest strategy is shaded in grey.

MP name	**MP-A0**	**MP-A26**	**MP-A32**	**MP-Bb32**	**MP-Tb32**
Assessment Frequency	**Annual**	**Annual**	**Annual**	**Biennial**	**Triennial**
Size Limit	**0**	**26**	**32**	**32**	**32**
Empirical Rule	**–**	**–**	**–**	**b**	**b**
P(RSB<20%)	PASS	PASS	PASS	PASS	PASS
P(RSB<36%)	0.174	0.174	0.180	0.164	0.197
Median TCEY	60.5	59.9	58.3	58.5	58.3
Median AAV TCEY	17.2%	17.5%	17.8%	17.0%	14.1%

1 INTRODUCTION

MSE is a process to evaluate management procedures, through simulation, to determine which ones meet defined objectives and are robust to uncertainty and variability. This process involves defining objectives, identifying MPs of interest, performing closed-loop simulations, evaluating the results, and finally applying a MP into practice. At IPHC, primary goals and objectives have been defined with the assistance of the Management Strategy Advisory Board (MSAB), MPs of interest have been identified, and a framework has been developed to conduct closed-loop simulations.

An evaluation was completed in 2021 of management procedures relative to the coastwide scale and distribution of the Total Constant Exploitation Yield (TCEY) to IPHC Regulatory Areas for the Pacific halibut fishery using a recently developed MSE framework. 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.

This document provides a review of the defined objectives used in the evaluation, recommendations on refinement, and an update on the Commission set Program of Work tasks in Table 1. Simulation results for size limits and multi-year stock assessment elements of the

SPR-based harvest strategy policy (Figure 1) are compared and contrasted across assumptions of estimation error and decision-making variability.

2 PRIMARY GOALS AND OBJECTIVES

The MSAB has previously suggested four potential goals for evaluating management procedures, and the Commission has identified two of these as primary goals, each one with one or more objectives.

1. Biological Sustainability (also referred to as conservation goal)
   1.1. Keep biomass above a limit to avoid critical stock sizes
2. Optimise directed fishing opportunities (also referred to as fishery goal)
   2.1. Maintain spawning biomass around a level (i.e. a target biomass reference point) that optimises fishing activities
   2.3. Provide directed fishing yield
   2.2. Limit variability in mortality limits

Details of the primary goals and objectives defined by the Commission, along with performance metrics, are shown in Appendix A. The objectives are listed above in an order of importance that should be considered when evaluating management procedures.

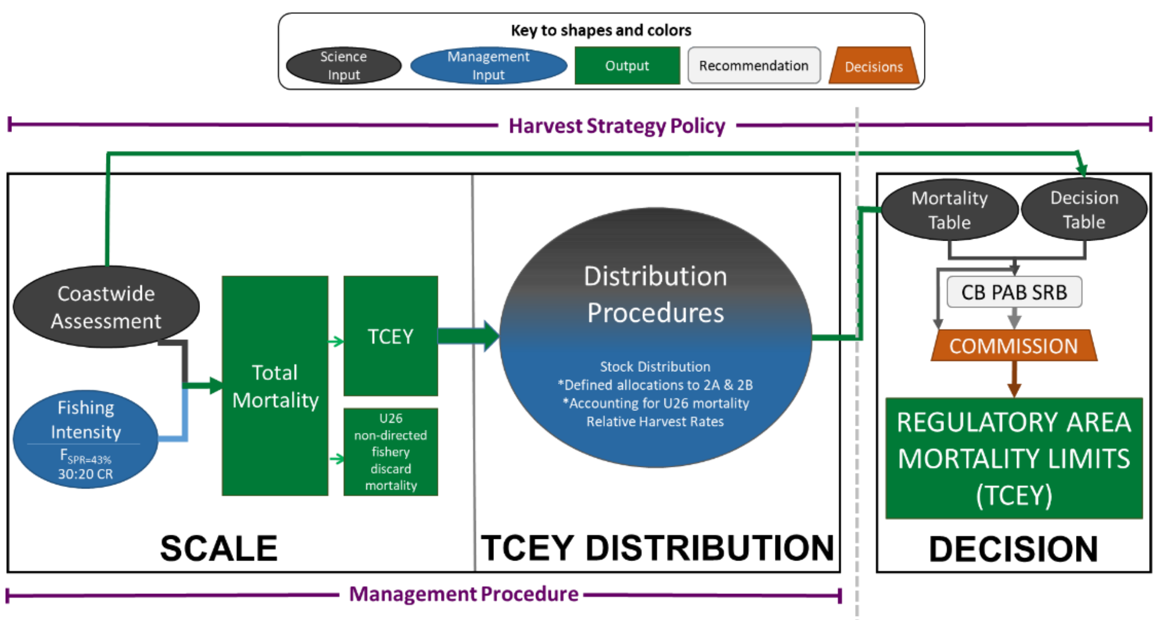

Figure 1. Illustration of the Commission interim IPHC harvest strategy policy (reflecting paragraph ID002 in IPHC-2020-CR-007) showing the coastwide scale and TCEY distribution components that comprise the management procedure. Items with an asterisk are interim agreements that were in place through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

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

The two remaining goals, with undefined objectives are

3. Minimize discard mortality in directed fisheries
4. Minimize discards and discard mortality in non-directed fisheries (bycatch)

Metrics or statistics (both words are used interchangeably) are developed from these objectives. For objectives with defined thresholds and tolerances, performance metrics can be developed. A performance standard is the binary outcome of whether an objective is met and can be determined from the performance metric (e.g. does not exceed the tolerance). Evaluation is performed by examining the metrics associated with the primary objectives, but in many cases additional metrics are useful to understand the trade-offs and important outcomes between management procedures.

2.1 Clarification of a spawning biomass target

The primary objectives have been endorsed by the Commission, but additional clarity on one objective may be useful.

> **IPHC-2022-AM095-R, para 59a.** *The Commission **ENDORSED** the primary objectives and associated performance metrics used to evaluate management procedures in the MSE process (as detailed in paper IPHC-2019-AM095-12).*

> **IPHC-2022-MSAB017-R, para. 28**. *The MSAB **NOTED** that objective 2.1 is stated as a target that has also been interpreted as a threshold and **REQUESTED** clarification from the Commission.*

The development of a spawning biomass target (i.e. a biomass level with a 50% probability of being above or below) was discussed extensively at MSAB013 following the direction of the Commission.

> **AM095-R, para 59c.** *The Commission **RECOMMENDED** the MSAB develop the following additional objective, as well as prioritize this objective in the evaluation of management procedures, for the Commission's consideration.*
>
> *i. A conservation objective that meets a spawning biomass target.*

Four dynamic equilibrium reference points were estimated previously for the Pacific halibut stock: 1) unfished equilibrium dynamic spawning biomass (SB_0), 2) MSY, 3) B_{MSY} as a percentage of SB_0 (RSB_{MSY}), and 4) the equilibrium fishing intensity to achieve MSY using spawning potential ratio (SPR_{MSY}), using three different methods (IPHC-2019-SRB015-11 Rev_1). Estimates of the dynamic equilibrium RSB_{MSY} for Pacific halibut are likely to be in the range of 20% to 30% and SPR_{MSY} to likely be between 30% and 35%. A reasonable RSB_{MSY} proxy, including a precautionary allowance for unexplored sources of uncertainty, would be 30%, and would put a proxy for SB_{MEY} between 36% and 44% given the recommendations of Rayns (2007) and Pascoe et al. (2014).

The objective of maintaining the spawning biomass around a target or above a level that optimises fishing activities was not specifically stated, and objective 2.1 in Appendix A is ambiguous with the general objective and measurable objective potentially in conflict. Below are some insights into the implications of 'around a target' and 'above a level/threshold'.

2.1.1 Around a target

Specifying objective 2.1 in Appendix A as a target implies that a management procedure would be tuned to specifically meet this target with a 50% chance. This means that the expectation is to be above the target spawning biomass half of the time and below the spawning biomass half of the time. How much above and below is not specified. This would typically be accomplished by adjusting the fishing intensity (i.e. SPR) for a specific management procedure until the target is met. If this was a strict performance standard (the probability of 0.5 must be met) it would potentially disregard the trade-offs between the other primary objectives of limiting the variability in mortality limits and provide directed fishing yield. However, other elements introduced into a MP could possibly allow for variability in mortality limits to be minimized, although it would likely result in a complex MP with many elements each aimed at achieving various objectives.

2.1.2 Above a level/threshold

Defining objective 2.1 in Appendix A as a threshold would allow some flexibility in the evaluation. However, this could result in a less clear identification of MPs that meet the objectives, and instead focus the evaluation on identifying trade-offs between objectives. A threshold simply means that the spawning biomass may not drop below the threshold more than 50% of the time (i.e. in half of the simulations) but may remain above the threshold more often. This is similar to the biological sustainability objective 1.1. It would identify MPs with fishing intensities too high to satisfy this objective, but allow for lower fishing intensities that would possibly meet other objectives.

2.1.3 At or above a target

It may seem contradictory to define an objective using the phrase 'above a target', but that may be useful to allow for flexibility in the evaluation of MPs, increase the importance of other objectives, allow for less complex and more transparent MPs, incorporate the precautionary approach, and meet international fisheries guidance as well as ecocertification standards. Furthermore, the concept of a 'target' could be incorporated into the harvest policy in other ways, such as in a definition of overfishing.

Defining a target is common practice in fisheries and is often combined with balancing other objectives. When describing the precautionary approach, FAO states:

> ***FAO (1996) para. 29****. Targets identify the desired outcomes for the fishery. For example, these may take the form of a target fishing mortality, or a specified level of average abundance relative to the unfished state. In some cases, these targets are likely to be identical with those that would be specified for fisheries management, regardless of whether a precautionary approach was to be adopted. In other cases, targets may need to be adjusted to be precautionary, for example, by setting the target fishing mortality lower than FMSY.*

The Canadian Fisheries Act[1], under 'measures to maintain fish stocks', uses the phrase 'at or above' when describing a level necessary for sustainability.

> ***Canadian Fisheries Act, § 6.1 (1)***: *In the management of fisheries, the Minister shall implement measures to maintain major fish stocks at or above the level necessary to promote the sustainability of the stock, taking into account the biology of the fish and the environmental conditions affecting the stock.*

National Standard 1 of the U.S. Magnusson-Stevens Act[2] defines optimal yield (OY) as a value to achieve, on a continuing bases, and that the OY must not exceed MSY. Furthermore, it states to maintain the long-term average biomass near or above Bmsy.

> ***U.S. Magnusson-Stevens Act § 600.310 (b)(2)(i):*** *MSY. The Magnuson-Stevens Act establishes MSY as the basis for fishery management and requires that: The fishing mortality rate does not jeopardize the capacity of a stock or stock complex to produce MSY; the abundance of an overfished stock or stock complex be rebuilt to a level that is capable of producing MSY; and OY not exceed MSY.*

> ***U.S. Magnusson-Stevens Act § 600.310 (b)(2)(ii)****: OY. The determination of OY is a decisional mechanism for resolving the Magnuson-Stevens Act's conservation and management objectives, achieving a fishery management plan's (FMP) objectives, and balancing the various interests that comprise the greatest overall benefits to the Nation. OY is based on MSY as reduced under paragraphs (e)(3)(iii) and (iv) of this section…*

[1] https://laws-lois.justice.gc.ca/PDF/F-14.pdf

[2] https://www.govinfo.gov/content/pkg/CFR-2012-title50-vol12/pdf/CFR-2012-title50-vol12-part600.pdf

> ***U.S. Magnusson-Stevens Act S 600.310 (e)(3)(i)*** *(B) In NS1, use of the phrase ''achieving, on a continuing basis, the optimum yield from each fishery'' means producing, from each stock, stock complex, or fishery: a long-term series of catches such that the average catch is equal to the OY, overfishing is prevented, the long term average biomass is near or above Bmsy, and overfished stocks and stock complexes are rebuilt consistent with timing and other requirements of section 304(e)(4) of the Magnuson-Stevens Act and paragraph (j) of this section.*

Allowing for the spawning biomass to be above the target while accounting for other objectives would still meet ecocertification standards, such as those defined by the Marine Stewardship Council (MSC). The criteria to achieve a score of 100 for stock status in relation to achievement of Maximum Sustainable Yield (MSY), according to the MSC fishery standard V2.01, is "there is a high degree of certainty that the stock has been fluctuating around a level consistent with MSY or has been above this level over recent years." This allows for the principle to be met while also allowing for other objectives.

3 Management Procedures for Evaluation

Two categories of MPs were prioritised in the MSE Program of Work for 2021–2023 (Table 1). One was the investigation of size limits (M.1) and the other was to investigate multi-year stock assessments (i.e. not conducting the stock assessment annually; M.3). Due to improvements in the MSE framework, changes in the OM, and alternative MPs, select additional MP elements investigated previously, such as SPR, may need to be re-evaluated.

3.1 Size limits

Since 1973, the IPHC has restricted the directed commercial fishery for Pacific halibut with a 32 inch (81.3 cm) minimum size limit, although other forms of size limits have been in place since 1940 (Myhre 1973). Many investigations of size limits have been completed since then including IPHC (1960), Clark & Parma (1995), Parma (1999), Valero & Hare (2012), Martell et al. (2015a), Martell et al. (2015b), Stewart & Hicks (2018), and Stewart et al (2021). Most of these analyses have focused on short-term effects or effects on reference points. The novelty of this analysis using the MSE framework was to examine long-term effects of different size limits in relation to defined conservation and fishery objectives. Additionally, long-term changes to the stock and fishery distribution as well as changes in productivity were examined.

The Commission requested that three size limits be investigated: 32 inches, 26 inches, and no size limit.

> **IPHC-2022-AM098-R, para. 61**: *The Commission **RECALLED** SS011-Rec.01 and **REQUESTED** that the current size limit (32 inches), a 26 inch size limit, and no size limit be investigated. to understand the long-term effects of a change in the size limit.*

An important concept to bring into the evaluation of size limits is market considerations. Stewart et al. (2021) used the ratio between the U32 price and O32 price for Pacific halibut to determine what ratio is necessary for the fishery to break even economically. Here, we call that the Equal Value Price Ration (EVPR) which is calculated as

$$\text{EVPR} = \frac{L_{O32,SL} - L_{O32,NSL}}{L_{U32,NSL}}$$

Where L is landings subscripted with the size category (O32 or U32) and the current size limit (*SL*) or a new size limit (*NSL*). The benefit of this calculation is that it does not rely on the current price for Pacific halibut but focuses on the ratio of prices between the two size categories that would result in the commercial fishery having an equal value with the current or a new size limit. Figure 2 describes the meaning of EVPR for three different ranges of values.

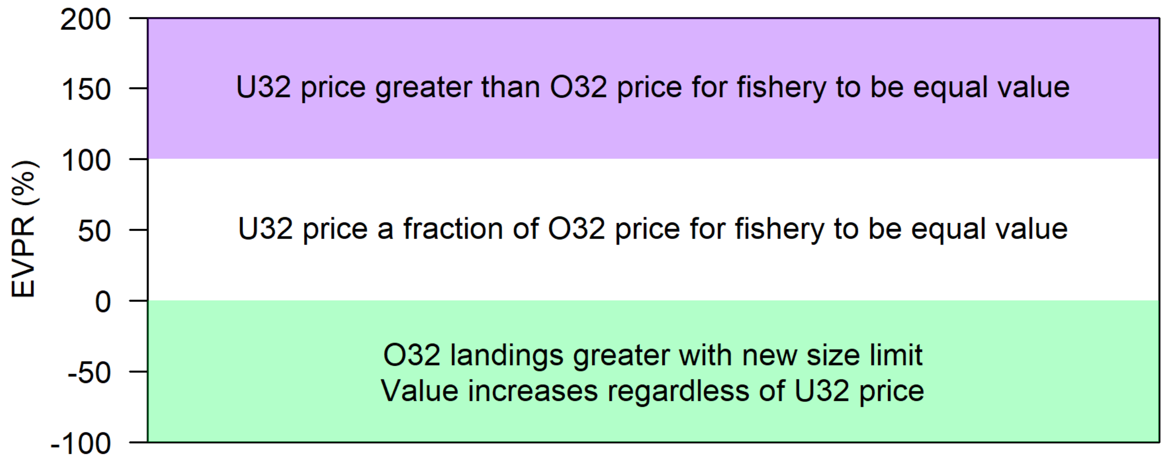

Figure 2. Descriptions of the meaning of EVPR for three different ranges.

The calculation of EVPR does not consider potential changes in the price due to changes in supply or potential savings due to changes in efficiency, and assumes that the prices for O32 and U32 Pacific halibut would change in parallel. A small amount of additional work looking at the impact of supply of the price would provide the value of the fishery in addition to the EVPR, which could be another useful metric for evaluating size limits. It is worth noting that the SRB recently requested a similar product.

> **IPHC-2021-SRB019-R** (para 61): *The SRB* ***REQUESTED*** *further information (e.g. inverse demand curves), to be presented at SRB020, on the regional supply-price relationships for commercial landings, as well as localized importance of the Pacific halibut fishery to communities.*

It is unknown what prices will be for U32 Pacific halibut if a size limit was removed, but the FISS has recently begun selling U32 fish, which may be an indicator for the potential price of small fish. This empirical price ratio was near 88% in 2022 and has been above 80% in recent years (see Table 4 in IPHC-2021-ECON-02-R03).

3.2 Multi-year assessments

Management procedures with multi-year assessments incorporate a process where the stock assessment occurs at intervals longer than annually. The mortality limits in a year with the stock assessment can be determined as in previously defined MPs, but in years without a stock assessment, the mortality limits would need an alternative approach. This may be as simple as maintaining the same mortality limits for each IPHC Regulatory Area in years with no stock assessment, or as complex as invoking an alternative MP that does not require a stock assessment (such as an empirical-based MP relying only on data/observations).

The Commission requested that the Secretariat investigate biennial assessments and potentially longer intervals as time allows.

> **IPHC-2022-AM098-R, para 64**: *The Commission **REQUESTED** that multi-year management procedures include the following concepts:*
>
> > *a) The stock assessment occurs biennially (and possibly triennial if time in 2022 allows) and no changes would occur to the FISS (i.e. remains annual);*
> >
> > *b) The TCEY within IPHC Regulatory Areas for non-assessment years:*
> >
> > > *i. remains the same as defined in the previous assessment year, or*
> > >
> > > *ii. changes within IPHC Regulatory Areas using simple empirical rules, to be developed by the IPHC Secretariat, that incorporate FISS data.*

Furthermore, in 2022, the SRB made a request for triennial assessments.

> **IPHC-2022-SRB021-R, para. 30**. *The SRB **REQUESTED** that the Secretariat examine MPs based on a three-year assessment cycle with annual TCEY changes proportional to changes in the FISS index because (i) this approach would be simpler and more transparent than a model, which has not yet been developed); (ii) the high benefit to cost ratio for multi-year TCEYs; (iii) it matches the current three-year full assessment cycle; and (iv) the general approach has precedents in other fishery commissions (e.g. Southern Bluefin Tuna).*

There are many different empirical rules that could be applied to determine the TCEY in non-assessment years. We identified three empirical rules for determining IPHC Regulatory Area specific TCEYs in non-assessment years, which either use no observations or FISS observations.

a. The same TCEY from the previous year for each IPHC Regulatory Area.
b. Updating the coastwide TCEY proportionally to the change in the coastwide FISS O32 WPUE and updating the distribution of the TCEY using FISS results and the applied distribution procedure.
c. Maintaining the same coastwide TCEY as the previous year but updating the distribution of the TCEY using FISS results and the applied distribution procedure.

Empirical rule (a) does not update the TCEY in IPHC Regulatory Areas, which may deviate from distribution agreements related to a percentage of the coastwide TCEY, if present, due to changes in the distribution of biomass. Empirical rules (b) and (c) both adjust the distribution of the coastwide TCEY and would maintain any agreements related to distribution.

The Commission has realized that there are benefits and costs associated with multi-year assessments. The Commission has asked the SRB to assist the Secretariat in identifying potential costs and benefits of not conducting an annual stock assessment.

> **IPHC-2022-AM098-R, para 63:** *The Commission REQUESTED that the IPHC Secretariat work with the SRB and others as necessary to identify potential costs and benefits of not conducting an annual stock assessment. This will include a prioritized list of work items that could be accomplished in its place.*

The SRB provided some insight at 20th and 21st Meetings of the Scientific Review Boards.

> **IPHC-2022-SRB020-R, para 27**. *The SRB NOTED that assessment research activities (e.g. paras. 23-26) are examples of work that could be done more extensively in non-assessment years within a multi-year assessment schedule. Other work could include investigating optimal sub-sampling designs for ages, sex-ratio, annual assessment methods to use within the MPs, and well as any of the several topics listed under Stock Assessment Research. The quantifiable costs of multi-year assessments could be estimated within the MSE, for example, of potentially lower average yield for longer assessment cycles to achieve the same levels of risk associated with annual assessments.*

A discussion of costs and benefits is presented after examining the simulation results.

3.3 Modelling distribution

The fisheries in the OM are specified by IPHC Regulatory Area because many of the Commission objectives used to evaluate MPs are specific to IPHC Regulatory Areas and the OM is spatially structured by Biological Region. This makes it necessary to distribute the TCEY across the fisheries to appropriately remove biomass from each Biological Region and allow for the calculation of necessary performance metrics. Distribution procedures have been evaluated (Hicks et al. 2021), but a specific MP has not been implemented. Even though distribution procedures are not currently being evaluated and there is no specific agreement on a single distribution procedure, they are part of the MP and need to be included in the simulations. Therefore, the Commission has recommended five different distribution procedures representing a practicable range to provide a robust analysis of size limits and multi-year assessments.

> **IPHC-2022-SS012-R, para 11**: *The Commission* ***RECOMMENDED*** *the following five distribution procedures to be used in the management strategy evaluation of size limits and multi-year assessments, noting that these distribution procedures are for analytical purposes only and are not endorsed by both parties, thus would be reviewed in the future if the Commission wishes to evaluate them for implementation.*
>
> > *a) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3A, relative harvest rates of 0.75 for IPHC Regulatory Areas 3B-4, and no application of the current interim agreements for 2A and 2B;*

b) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3A, relative harvest rates of 0.75 for IPHC Regulatory Areas 3B-4, and current interim agreements for 2A and 2B;

c) Baseline based on recent year O32 FISS results with 1.65 Mlbs to 2A and 20% of the coastwide TCEY to 2B;

d) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3, 4A, and 4CDE, a relative harvest rate of 0.75 for IPHC Regulatory Area 4B, and no agreements for 2A and 2B;

e) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3, 4A, and 4CDE, a relative harvest rate of 0.75 for IPHC Regulatory Area 4B, and current interim agreements for IPHC Regulatory Areas 2A and 2B

Three of the five distribution procedures contain agreements for IPHC Regulatory Areas 2A and 2B (b, c, and e). Decision-making variability for these two areas is set to zero when agreements are in place.

3.4 MP combinations

The simulation time for a single MP may be days, therefore it is useful to identify a minimal set of runs that will provide insight into the performance of each element of the MP of interest. There are six main elements of MPs to evaluate which include the three size limits and three empirical rules for biennial assessments, as presented above, and are combined as shown in Table 2. For each MP, an SPR of 43% was used, with some specific combinations using SPR values of 40% and 46% to further investigate the effects of fishing intensity.

Table 2. Primary MPs to be evaluated. The multi-year assessment specifies the frequency of the stock assessment and the procedure for years without a stock assessment (see Section 3.2).

MP ID	Multi-year assessment	Size Limit (inches)
MP-A32	Annual	32
MP-A26	Annual	26
MP-A0	Annual	0
MP-Ba32	Biennial, empirical rule (a)	32
MP-Bb32	Biennial, empirical rule (b)	32
MP-Bc32	Biennial, empirical rule (c)	32
MP-Tb32	Triennial, empirical rule (b)	32

Additional factors are often useful to investigate to understand how sources of variability affect the outcomes. We examine estimation error (with or without) and decision-making variability (none along with two options) to further examine the specific effects of these sources of variability. Evaluation of the main elements of the MPs under consideration (i.e. size limits and multi-year assessments, Table 2) should be done with estimation error and an appropriate specification of decision-making variability. However, decision-making variability may depend on the MP selected, thus results are available with two decision-making variability options along with no decision-making variability.

4 CLOSED-LOOP SIMULATION FRAMEWORK

The closed-loop framework (Figure 3) 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.

4.1 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.

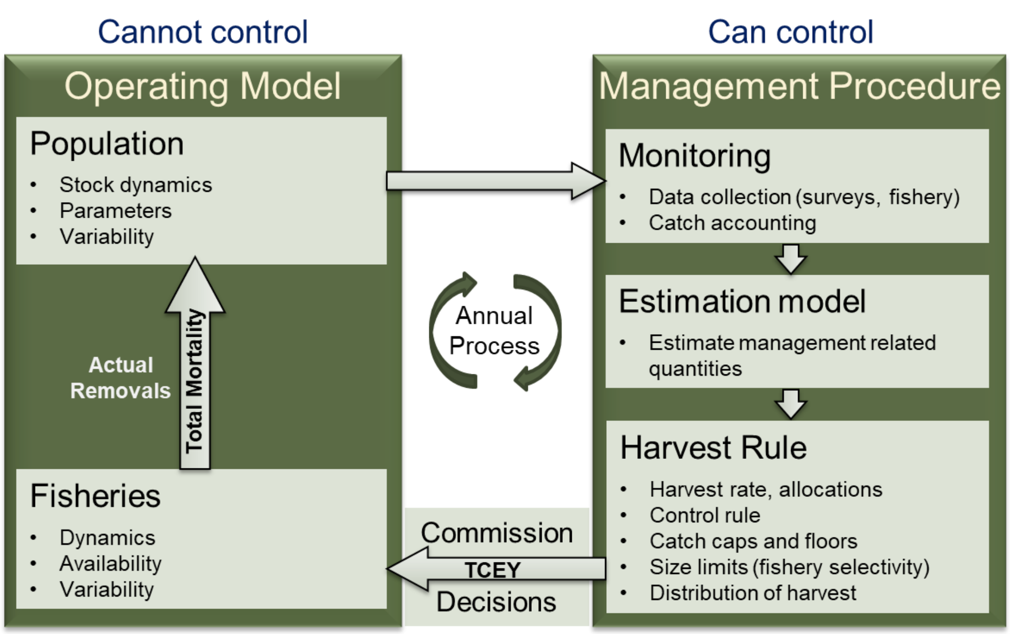

Figure 3. Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

4.1.1 General specifications of the OM

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. Four Biological Regions (Figure 4) were defined with boundaries that matched some of the IPHC Regulatory Area boundaries (see Hicks et al 2020b for more description). Thirty-three fisheries were defined for five general sectors (directed commercial, directed commercial discards, non-directed commercial discard, recreational, and subsistence) consistent with the definitions in the recent IPHC stock assessment. Additionally, there are four modelled surveys, one for each Biological Region

To account for structural uncertainty, as with the ensemble stock assessment (Stewart & Hicks 2022), four individual models were 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 start 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 models were independently conditioned to FISS observations and outputs from ensemble stock assessment.

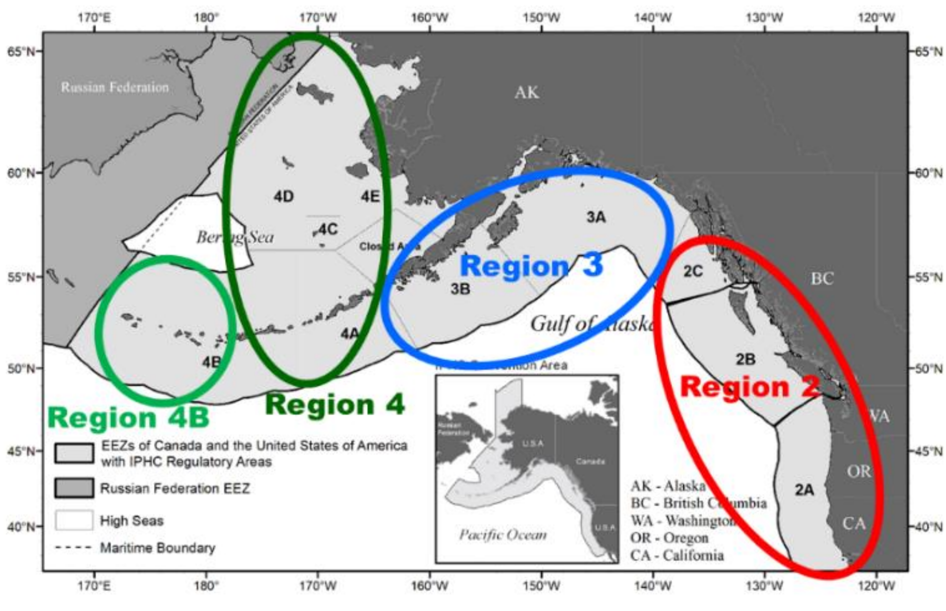

Figure 4. IPHC Regulatory Areas, Biological Regions, and the Pacific halibut geographical range within the territorial waters of Canada and the United States of America.

4.1.2 OM results and outputs

The four OM models generally captured historical trends estimated in spawning biomass as estimated in the ensemble stock assessment. The medCW models fit the lower spawning biomass trend of the long CW assessment model and the medAAF models fit the higher spawning biomass trend of the long AAF assessment model. 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 5).

4.2 Projections

The multiple trajectories from the conditioned OM provide replicate time-series of population and fishery processes and are the starting point for the closed-loop simulation to project forward in time using various management procedures (MPs) and assumptions. Processes such as weight-at-age, selectivity/retention deviations, the environmental regime, recruitment, and implementation variability are simulated during the closed-loop simulations. These processes may or may not depend on the size of the population, or a certain demographic. An example of the projection period is shown in Figure 6.

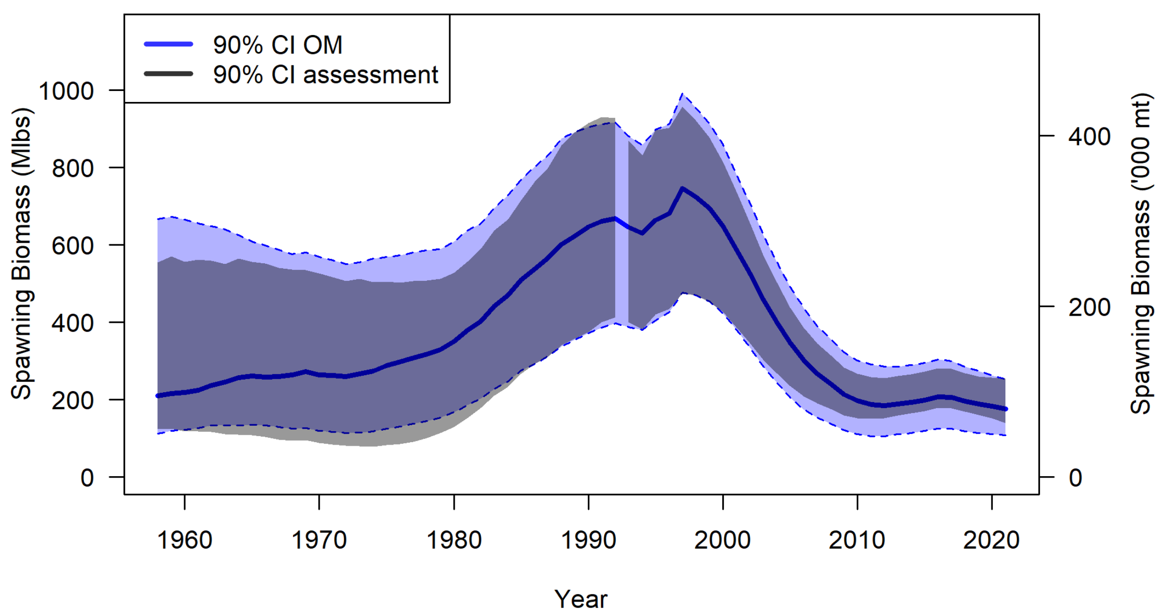

Figure 5. Median, 5th, and 95th quantiles for spawning biomass from the four OM models with the ensemble stock assessment range between the 5th and 95th quantiles shown in grey.

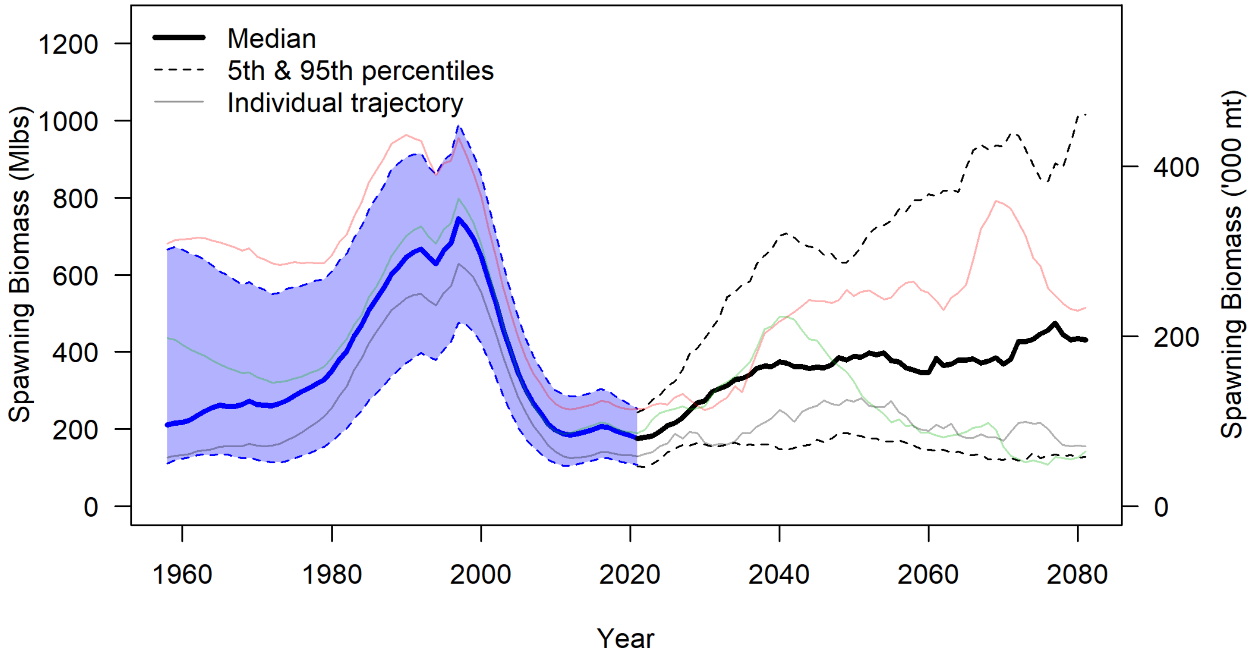

Figure 6. Median, 5th percentile, and 95th percentile of projected spawning biomass when using an SPR of 43%. Three individual trajectories (chosen ad hoc) are shown as thin lines to provide an idea of the variability in one trajectory over the entire period.

4.2.1 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 variability was simulated as a random process that could modify the coastwide TCEY from the MP TCEY and also modify the distribution of the TCEY among IPHC Regulatory Areas. Comparing adopted TCEYs since 2013 to TCEYs from the MP (MP TCEY) to reflect potential variability among IPHC Regulatory Area, two options for decision-making variability were parameterized:

1. The coastwide TCEY is equal to the coastwide TCEY from the MP, but distribution of the TCEY is subjected to decision-making variability.
2. The coastwide TCEY may deviate from the MP, along with distribution, due to decision-making variability. These processes are simulated independently.

Actual decision-making variability may more complex than these simple methods. 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.

4.2.1.1 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 not occur before the 99th Annual Meeting.

4.2.2 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.

Two options for examining the effect of estimation error were simulated. 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.

4.3 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 and statistics of interest. It takes a considerable amount of time to complete simulations for one MP. Therefore, an initial set of MPs and options for estimation error and implementation variability were simulated with 500 replicates (25 for each OM model and distribution procedure). To provide the opportunity to evaluate the primary MPs (MP-A with 3 size limits, MP-Ba, MP-Bb, MP-Bc, and MP-Tb; Table 2) with reduced simulation error and improved accuracy of the differences between them, the number of replicates was increased to 1,100 for the primary MPs without decision-making variability and with option 1 for decision-making variability (i.e. distribution only). That is 55 replicates for a specific OM model and distribution procedure.

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.

Currently, some simulations are available for targeting or avoiding small Pacific halibut. Additional scenarios may be completed before the 99th Annual Meeting.

5 Results and Evaluation

The MPs were integrated across the distribution procedures, resulting in the primary MPs in Table 2, as distribution is considered an uncertainty in this evaluation. However, any interesting differences between distribution procedures may be reported.

Improvement of the methods to evaluate simulation results and present those for decision-making are ongoing. Current tasks specifically include updates to the MSE Explorer tool, providing additional metrics that may be useful alongside metrics associated with the primary objectives, determining new methods to identify best performing management procedures, and providing new types of plots and tables that effectively communicate the results.

The improvements to the MSE framework, including the updated OM, resulted in some different outcomes compared to the previous OM. However, general conclusions were consistent with previous analyses. The additional years at the end of the historical time-series in the OM resulted in immediate optimistic trends in the spawning biomass (Figure 6) due to a possibly large 2012 year class, a positive PDO regime, and increasing trends in weight-at-age. Therefore, short-term results from this analysis are likely more optimistic than previous analyses.

5.1 Size limits

Applying the three size limits resulted in little change to the biological sustainability performance metrics, but short-term fishery sustainability performance metrics showed some improvements when lowering the size limit (Table 3 and Appendix B). Biological Sustainability objectives for each Biological Region were met, except for 4B, which was closer to being met as the size limit decreased. The coastwide TCEY, on average, was 2.7% higher (1.6 Mlbs) with a 26-inch size limit and 3.7% higher (2.1 Mlbs) with no size limit. Annual variability in the TCEY was slightly reduced with lower size limits but above 15%.

The percentage gain in the TCEY is variable across years and is higher in the short-term given starting conditions of the projections (Figure 7) There is a very small probability that the TCEY is less without a size limit across all years. The high percent gain in the short-term is due to starting conditions, which declines as recruitment, weight-at-age, and environmental regimes become more integrated across the range of possible values. Therefore, the gains in yield due to lowering the size limit are likely dependent on the current size-at-age and incoming recruitment. Long-term gains in the TCEY without a size limit were 2.7% (1.7 Mlbs).

The patterns were similar for performance metrics calculated for each IPHC Regulatory Area (Table 4). The median average TCEY in the individual IPHC Regulatory Areas increased between 4.0% and 5.9% except for IPHC Regulatory Area 2A (no change since three of the five distribution procedures had a fixed 1.65 Mlbs). Even though the TCEY in IPHC Regulatory Area 3A showed a modest percent increase without a size limit (4.5%), the absolute increase in the TCEY was over 1 million pounds. Annual variability in the TCEY for each IPHC Regulatory Area showed a slight decrease when removing the size limit but remained above 15% for all areas except 2A.

Table 3. Performance metrics related to primary objectives for size limit MPs with an annual assessment, estimation error and decision-making variability option 1. Biological sustainability metrics are long-term and fishery sustainability are short-term (4–13 years).

MP name	**MP-A0**	**MP-A26**	**MP-A32**
Size Limit	**0**	**26**	**32**
SPR	**0.43**	**0.43**	**0.43**
Replicates	1100	1100	1100
Biological Sustainability			
Median average RSB	38.9%	38.9%	38.8%
P(any RSB_y<20%)	<0.001	<0.001	<0.001
Fishery Sustainability			
P(all RSB<36%)	0.174	0.174	0.180
Median average TCEY	60.5	59.9	58.3
P(any3 change TCEY > 15%)	0.880	0.894	0.906
Median AAV TCEY	17.2%	17.5%	17.8%

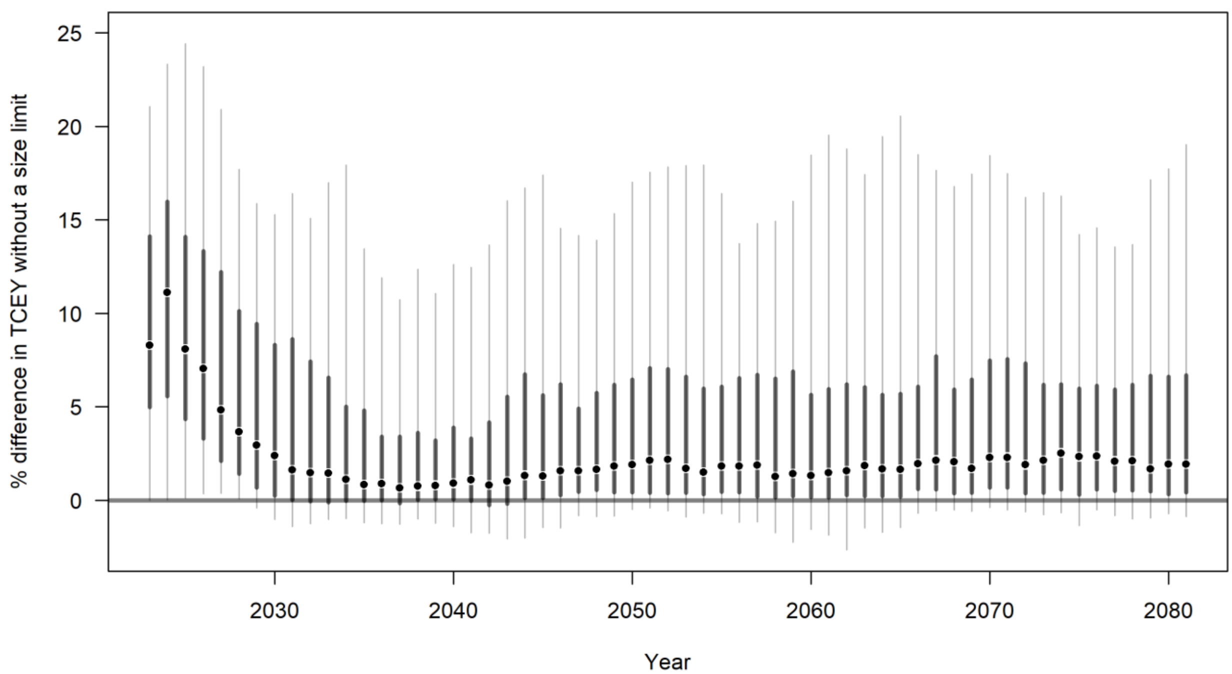

Figure 7. Percent difference in the TCEY without a size limit compared to a 32-inch size limit for each projected year when simulating estimation error and decision-making variability, and using an input SPR equal to 43%. The points are the median, the thin vertical lines connect the 5th and 95th percentiles, and the thick vertical lines connect the 25th and 75th percentiles.

The majority of the gain in median average TCEY and the reduction in annual variability of the TCEY was achieved when lowering the size limit from 32 inches to 26 inches. This is because the directed commercial gear has a low selectivity for Pacific halibut less than 26 inches.

5.1.1 Effects of decision-making variability

Decision-making variability on only the distribution of the TCEY (option1) showed very little difference when compared to results not simulating decision-making variability for all primary metrics except the median average TCEY. Option 2 for decision-making variability (variability on the coastwide TCEY and distribution) typically showed higher values of all primary metrics. However, none of the decision-making variability options changed the relative ranking of the three size limits.

Table 4. Performance metrics related to area-specific primary objectives for size limit MPs with an annual assessment, estimation error and decision-making variability option 1. Fishery sustainability metrics are short-term (4–13 years).

MP name	**MP-A0**	**MP-A26**	**MP-A32**
Size Limit	**0**	**26**	**32**
SPR	**0.43**	**0.43**	**0.43**
Median average TCEY-2A	1.63	1.63	1.62
Median average TCEY-2B	8.86	8.82	8.52
Median average TCEY-2C	6.66	6.6	6.33
Median average TCEY-3A	24.29	24.04	23.24
Median average TCEY-3B	7.42	7.36	7.13
Median average TCEY-4A	3.52	3.48	3.35
Median average TCEY-4CDE	4.06	4.04	3.92
Median average TCEY-4B	2.86	2.82	2.70
P(any3 change TCEY 2A > 15%)	0.254	0.252	0.264
P(any3 change TCEY 2B > 15%)	0.644	0.639	0.679
P(any3 change TCEY 2C > 15%)	0.696	0.711	0.722
P(any3 change TCEY 3A > 15%)	0.738	0.750	0.757
P(any3 change TCEY 3B > 15%)	0.756	0.759	0.777
P(any3 change TCEY 4A > 15%)	0.782	0.778	0.804
P(any3 change TCEY 4CDE > 15%)	0.514	0.527	0.524
P(any3 change TCEY 4B > 15%)	0.771	0.753	0.781
Median AAV TCEY 2A	2.5%	2.6%	2.7%
Median AAV TCEY 2B	16.6%	17.0%	17.4%
Median AAV TCEY 2C	17.8%	17.8%	18.2%
Median AAV TCEY 3A	18.9%	19.1%	19.4%
Median AAV TCEY 3B	19.9%	20.2%	20.7%
Median AAV TCEY 4A	20.0%	20.1%	20.5%
Median AAV TCEY 4CDE	15.0%	15.1%	14.9%
Median AAV TCEY 4B	20.0%	19.8%	20.3%

5.1.2 Effects of fishing intensity (SPR)

Increasing fishing intensity resulted in a higher median TCEY and higher variability in the TCEY. An SPR equal to 40% resulted in the relative spawning biomass to be slightly above the target of 36% in the long-term with a probability of falling below being near 0.42.

The short-term percent gain in the TCEY without a size limit and an input SPR of 40% was greater than the percent gain in the TCEY with an input SPR of 43%. An input SPR of 46% showed a smaller percent gain in the TCEY when eliminating the size limit.

5.1.3 Selectivity scenarios

Two selectivity scenarios were simulated to represent targeting of smaller fish and targeting of larger fish with a size limit of 0 inches. This was implemented by shifting selectivity for the directed commercial fisheries 3 years younger or older. Depending on size-at-age, this could be a significant change in selectivity, thus these scenarios may be extreme cases.

Selecting smaller fish resulted in a lower chance of falling below the target relative spawning biomass, a larger median average TCEY, and lower variability in the TCEY. Selecting larger fish was the opposite with a higher chance of falling below the target relative spawning biomass, a smaller median average TCEY, and higher variability in the TCEY. However, removing the size limit for all of these scenarios resulted in a gain in short-term yield when compared to the current 32-inch size limit assuming recent selectivity.

5.1.4 Other metrics to evaluate size limits

One benefit of lowering or removing the size limit is a decrease in directed commercial discard mortality. Short-term metrics indicate an 78% reduction in the coastwide directed commercial discard mortality (Table 5). Remaining discard mortality would be due to lost gear and regulatory discards. Across IPHC Regulatory Areas, reductions in directed commercial discard mortality would range from 67% to 88%.

Lowering or removing the size limit will likely result in increased yield but with smaller Pacific halibut (U32) in the directed commercial landings. By weight, the directed commercial landings will be composed of a higher percentage of U32 Pacific halibut than the increase in yield (i.e. the weight of O32 directed commercial landings will decrease although the total directed commercial landings increases). Directed commercial landings increased by 4% and 5% for 26-inch and 0-inch size limits, respectively, while the directed commercial landings were composed of 6% and 7% U32 Pacific halibut (Figure 8).

The increase in U32 Pacific halibut in the directed commercial landings may affect the value of the directed commercial fishery if the price for U32 Pacific halibut is less than the price for O32 Pacific halibut. The short-term Equal Value Price Ratio (EVPR) shows a median near 0.5 for both comparisons of no size limit to the current size limit and a 26-inch size limit compared to the current size limit (Figure 9). Most of the distribution of the short-term EVPR was between 0 and 1 although a small proportion was less than 0 (O32 commercial landings increased with a lower size limit) and above 1 (the price of U32 Pacific halibut would have to be greater than the price of O32 Pacific halibut for equal fishery value).

The EVPR varied over years in the projections (Figure 10), with low values in recent years, and an increase in the median to between 0.5 and 1 followed by a long-term median settling near 0.5. As with the potential yield gain, stock conditions, such as the incoming recruitment and size-at-age, are likely driving this variation.

Table 5. Short-term median directed commercial discard mortality (Mlbs, net) for size limit MPs with an annual assessment, estimation error and decision-making variability option 1.

MP name	**MP-A0**	**MP-A26**	**MP-A32**
Size Limit	**0**	**26**	**32**
SPR	**0.43**	**0.43**	**0.43**
Replicates	1100	1100	1100
Median coastwide discard mortality	0.164	0.265	0.755
Median discard mortality 2A	0.004	0.006	0.012
Median discard mortality 2B	0.025	0.038	0.098
Median discard mortality 2C	0.019	0.025	0.058
Median discard mortality 3A	0.054	0.078	0.215
Median discard mortality 3B	0.020	0.045	0.167
Median discard mortality 4A	0.017	0.027	0.090
Median discard mortality 4CDE	0.006	0.011	0.027
Median discard mortality 4B	0.014	0.027	0.076

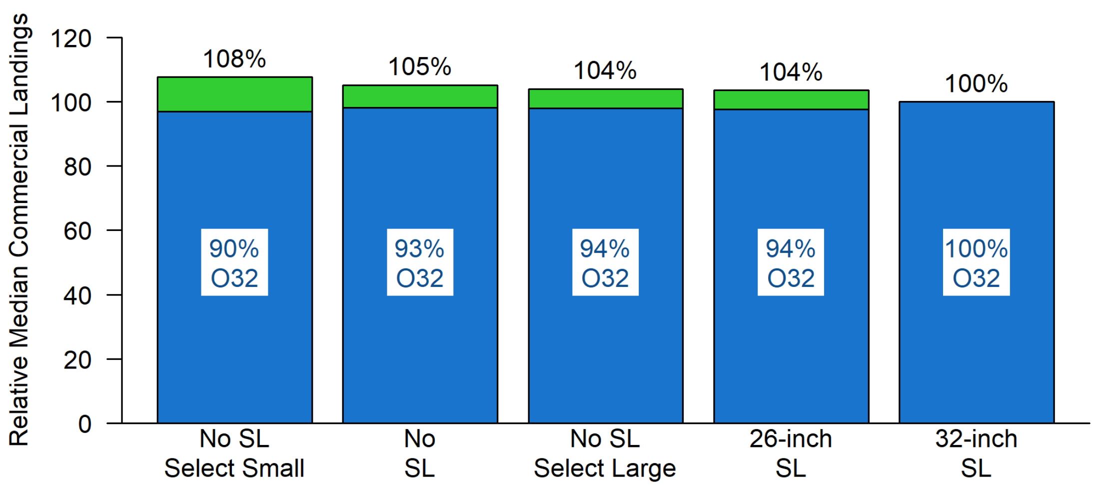

Figure 8. Median directed commercial landings relative to the landings (bar height) with the current size limit (32-inches) for three no size limit scenarios (selecting smaller fish, recent selectivity, and selecting larger fish), a 26-inch size limit, and the current size limit. The percentage of O32 Pacific halibut in the directed commercial landings is shown in blue (bottom) and the percentage of U32 Pacific halibut in the directed commercial landings is shown in green (top).

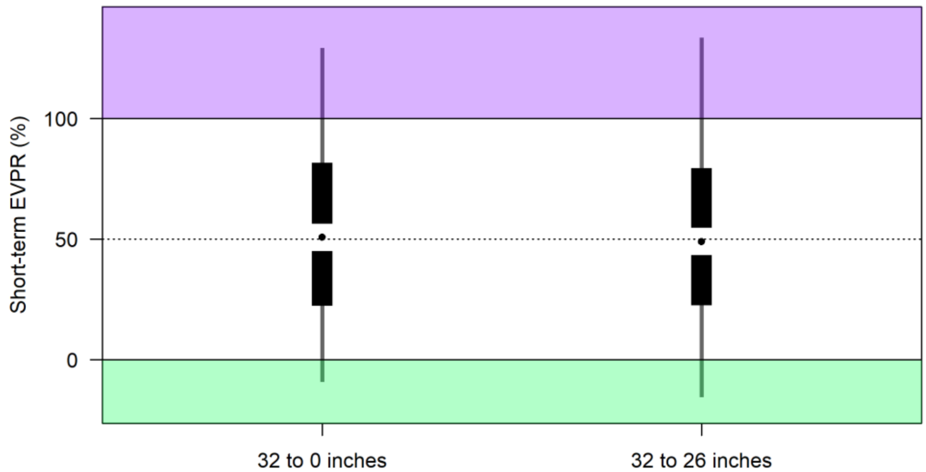

Figure 9. The short-term Equal Value Price Ratio (EVPR) for simulations comparing no size limit to the current size limit (left) and a 26-inch size limit compared to the current size limit (right). The black dot is the median of 1,100 simulations, the thick bar shows the 25th and 75th percentiles, and the thin line shows the 5th and 95th percentiles. Various ranges of values of the EVPR are shaded in colors corresponding to Figure 2.

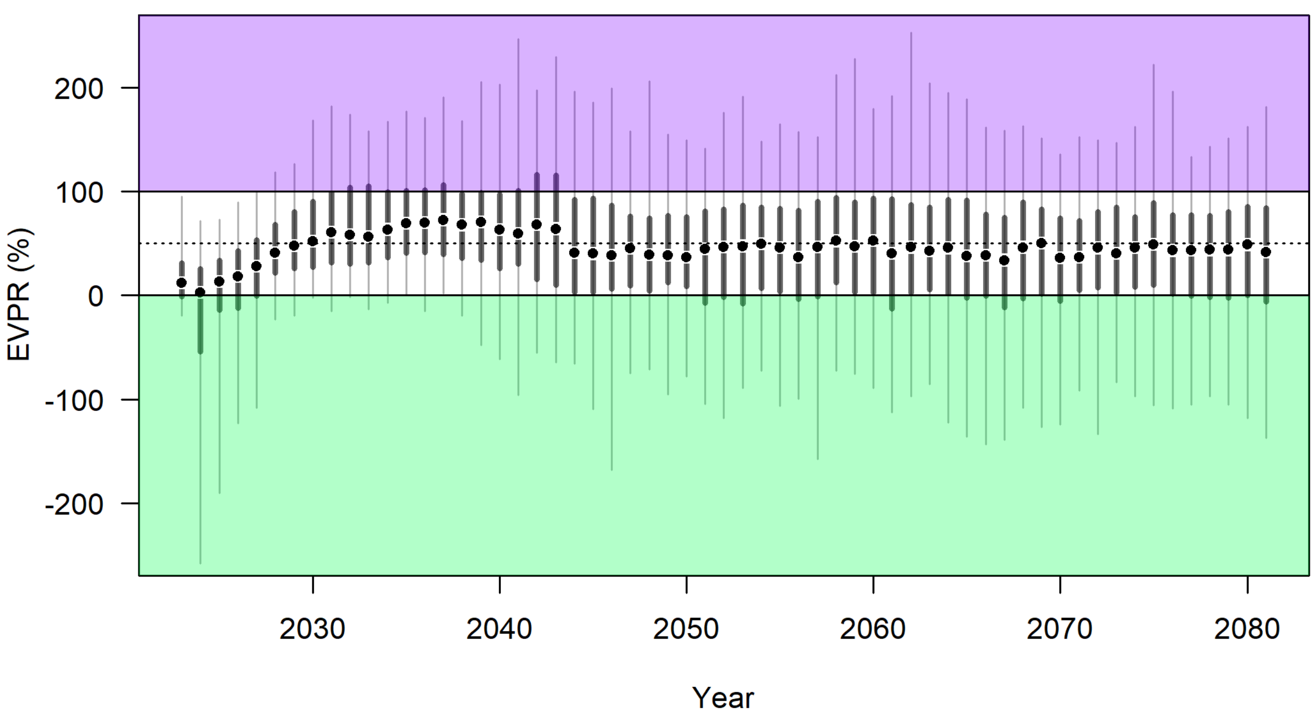

Figure 10. The Equal Value Price Ratio (EVPR) for the directed commercial fishery comparing no size limit to the current size limit for each year for 1,100 simulated projections.

5.2 Multi-year assessments

Simulations of an MP with a biennial assessment frequency were done using three options for non-assessment years: option (a) used the same TCEY in each IPHC Regulatory from the previous assessment year, option (b) updated the coastwide TCEY proportional to the change in the coastwide FISS index and updated distribution using FISS results, and option (c) used a constant coastwide TCEY in non-assessment years but updated distribution using FISS observations. Simulations with a triennial assessment were done using only option (b).

Long-term biological sustainability metrics were very similar across the five MPs and were met with an SPR of 43% (Table 6). The long-term probability that the relative spawning biomass would be less than 36% differed slightly between MPs, with the biennial assessment frequency showing less risk and the triennial frequency showing greater risk than an annual assessment. Differences in the short-term median average TCEY were within 1 million pounds, although the biennial MPs that did not update the coastwide TCEY in non-assessment years (options a & c) were slightly smaller. The annual variability of the TCEY was much less for the biennial assessments using options a and c (which is likely due to the fact that 5 of the 10 years had zero change), slightly less for the biennial assessment with option b, and much less for the triennial assessment frequency with option b. It is not known how much change occurred every other year when the TCEY was able to change, although the probability of a greater than 15% change in the TCEY in three or more years decreased as assessment frequency increased. Long-term fishery sustainability metrics suggested a slightly smaller median average TCEY in the multi-year assessment MPs. The long-term variability in the TCEY was smallest with the triennial assessment frequency, but similar or slightly larger for the biennial assessment frequency (Appendix C).

The patterns in the TCEY across MPs were similar for each IPHC Regulatory Area both in the short-term (Table 7) and the long-term (Appendix C). There were small differences in the median TCEY across IPHC Regulatory Areas, although most were slightly less with multi-year assessments. The variability showed mixed results for the three options with a biennial assessment frequency, but declined significantly with the triennial assessment frequency.

Specifics of the inter-annual changes in the TCEY within the short-term time-period have not been investigated, but one hypothesis for the similar amount of variability of the TCEY for MP-Bb is that the potential change in an assessment or non-assessment year is larger than any single-year change when using an annual assessment frequency. There are no current objectives that would indicate whether a stable 2- or 3-year period with a larger change in the assessment year is preferable to possibly smaller annual changes in the TCEY in non-assessment years.

Table 6. Performance metrics related to primary objectives for annual, biennial, and triennial MPs with a size limit of 32 inches simulated with estimation error and option 1 decision-making variability. Biological sustainability metrics are long-term and fishery sustainability are short-term (4–13 years). In non-assessment years, empirical rules are: a) holds the TCEY constant for each IPHC Regulatory Area, b) adjusts the coastwide TCEY and distribution using most recent FISS results, and c) only adjusts the distribution of the TCEY using most recent FISS results.

MP name	**MP-A32**	**MP-Ba32**	**MP-Bb32**	**MP-Bc32**	**MP-Tb32**
Assessment Frequency	**Annual**	**Biennial**	**Biennial**	**Biennial**	**Triennial**
Size Limit	**32**	**32**	**32**	**32**	**32**
Empirical Rule	**–**	**a**	**b**	**c**	**b**
SPR	**0.43**	**0.43**	**0.43**	**0.43**	**0.43**
Replicates	1100	1100	1100	1100	1100
Biological Sustainability					
Median average RSB	38.8%	38.7%	38.9%	38.7%	39.1%
P(any RSB_y<20%)	<0.001	<0.001	<0.001	<0.001	<0.001
Fishery Sustainability					
P(all RSB<36%)	0.180	0.164	0.164	0.168	0.197
Median average TCEY	58.3	57.8	58.5	57.7	58.3
P(any3 change TCEY > 15%)	0.906	0.682	0.809	0.682	0.628
Median AAV TCEY	17.8%	13.2%	17.0%	13.2%	14.1%

5.2.1 Effects of decision-making variability

Decision-making variability did not change the relative ranking of the MPs. With decision-making variability the median average coastwide TCEY was more similar across all MPs, although differences in the median average TCEY across MPs was very small for all decision-making variability options. Inter-annual variability in the TCEY was slightly reduced with decision-making variability but only for the multi-year MPs (see links in Appendix D).

5.2.2 Effects of fishing intensity (SPR)

A higher fishing intensity (SPR=40%) showed higher long-term probabilities of the relative spawning biomass being below 36%, which were highest in the triennial assessment MP with option (b), but was not greater than 0.50. The TCEY is similar across MPs, although the TCEY from the triennial MP is slightly less in the annual assessment frequency. The variability of the TCEY is higher overall due to higher fishing intensity, and the pattern is similar to that seen with SPR=43%.

Table 7. Short-term fishery-sustainability performance metrics for each IPHC Regulatory Area related to primary objectives for annual, biennial, and triennial MPs with a size limit of 32 inches simulated with estimation error and option 1 decision-making variability.

MP name	**MP-A32**	**MP-Ba32**	**MP-Bb32**	**MP-Bc32**	**MP-Tb32**
Assessment Frequency	**Annual**	**Biennial**	**Biennial**	**Biennial**	**Triennial**
Size Limit	**32**	**32**	**32**	**32**	**32**
Empirical Rule	**–**	**a**	**b**	**c**	**b**
SPR	**0.43**	**0.43**	**0.43**	**0.43**	**0.43**
Replicates	1100	1100	1100	1100	1100
Median average TCEY-2A	1.62	1.60	1.60	1.60	1.60
Median average TCEY-2B	8.52	8.32	8.36	8.29	8.43
Median average TCEY-2C	6.33	6.26	6.39	6.30	6.35
Median average TCEY-3A	23.24	22.90	23.38	23.04	23.39
Median average TCEY-3B	7.13	6.94	7.09	7.04	7.17
Median average TCEY-4A	3.35	3.29	3.39	3.34	3.41
Median average TCEY-4CDE	3.92	3.92	3.94	3.88	3.91
Median average TCEY-4B	2.70	2.72	2.71	2.65	2.72
P(any3 change TCEY 2A > 15%)	0.264	0.207	0.357	0.316	0.288
P(any3 change TCEY 2B > 15%)	0.679	0.383	0.639	0.507	0.432
P(any3 change TCEY 2C > 15%)	0.722	0.419	0.641	0.504	0.434
P(any3 change TCEY 3A > 15%)	0.757	0.456	0.669	0.454	0.447
P(any3 change TCEY 3B > 15%)	0.777	0.486	0.751	0.619	0.526
P(any3 change TCEY 4A > 15%)	0.804	0.458	0.723	0.618	0.496
P(any3 change TCEY 4CDE > 15%)	0.524	0.259	0.430	0.325	0.241
P(any3 change TCEY 4B > 15%)	0.781	0.499	0.709	0.625	0.442
Median AAV TCEY 2A	2.7%	3.8%	4.3%	4.5%	1.9%
Median AAV TCEY 2B	17.4%	13.3%	18.4%	16.7%	15.2%
Median AAV TCEY 2C	18.2%	14.2%	18.2%	16.5%	15.0%
Median AAV TCEY 3A	19.4%	14.8%	19.0%	15.9%	15.3%
Median AAV TCEY 3B	20.7%	15.7%	20.2%	18.0%	16.1%
Median AAV TCEY 4A	20.5%	15.5%	20.8%	19.0%	16.7%
Median AAV TCEY 4CDE	14.9%	11.3%	14.1%	13.2%	11.7%
Median AAV TCEY 4B	20.3%	16.6%	20.5%	19.5%	15.9%

5.2.3 Costs and benefits of multi-year assessments

The Secretariat worked with the SRB to identify costs and benefits of multi-year stock assessments, which are outlined in paragraph 27 from IPHC-2022-SRB020-R and paragraph 30 from IPHC-2022-SRB021-R (see Section 3.2 above). Also incorporating comments from IPHC-2022-MSAB017-R a list of costs and benefits is provided below.

1) Costs include
   a) Detailed management information is not available every year (e.g. stock status),
   b) The TCEY in non-assessment years may not follow stock trends (for options a and c without an empirical rule on coastwide TCEY),
   c) Potentially a small loss in yield (for options a and c with a constant coastwide TCEY across non-assessment years),
   d) Potentially may not meet distribution agreements, if any (only for option a),
   e) A slightly higher chance of a smaller stock size.
2) Benefits include
   a) Reduced inter-annual variability in the TCEY,
   b) Multi-year stability and short-term predictability of the TCEY,
   c) Use of the annual FISS index in a transparent process to determine the TCEY in non-assessment years,
   d) More focused assessment research,
   e) Potential for additional time to collaborate within the Secretariat,
   f) A triennial assessment frequency would be consistent with the current assessment cycle of update and full assessments,
   g) The multi-year approach has precedent at other fisheries commissions

5.3 Additional results anticipated for the 99th IPHC Annual Meeting

Additional results and comparisons may be provided at the 99th Session of the IPHC Annual Meeting (AM099). Elements of interest from MPs examined in previous years may be added. Presentation of the results will likely be improved, and additional performance metrics may also be examined.

6 Next Steps

A secondary set of MPs can be developed based on the performance of the primary set presented above. This may include crossing size limits with biennial assessments, tuning SPR values to best meet objectives, examining different levels of estimation error, incorporating various forms of implementation variability, or examining additional MP elements such as constraints on the inter-annual change in TCEY. This secondary set would not be a full factorial, but instead a specific investigation of relevant factors with the goal to refine the best performing MPs relative to stock and fishery objectives. Other tasks include developing performance metrics for other objectives, such as reducing discard mortality, or specifying and evaluating elements of the Harvest Strategy Policy (e.g. overfishing limit).

An important task for the MSE would be to tune the coastwide specifications to optimise a selected distribution procedure. At a minimum, that would include evaluating SPR values, but may also incorporate investigations of the control rule, size limits, assessment frequency, and constraints on the inter-annual change in TCEY. Furthermore, the MSE may evaluate elements of distribution procedures for future incorporation by the Commission.

7 Scientific Advice

7.1 Clarifying a target objective

Objective 2.1 could be phrased consistently as currently stated under measurable objective to reflect that the objective is met when the relative spawning biomass is above the target (Appendix B). This would mean editing the description under "General Objective" in Appendix B to "Maintain spawning biomass [above] a level that optimi[s]es fishing activities". The Commission may choose to "tune" the SPR value such that the relative spawning biomass is more often closer to the target, while accounting for other objectives.

7.2 Size limits

The removal of a size limit meets or optimises all of the primary objectives, resulting in a 3.7% increase, on average, in the short-term median coastwide TCEY and a 2.7% increase, on average, in the long-term median coastwide TCEY. A majority of that increase occurs when reducing the size limit for directed commercial fisheries to 26 inches. Furthermore, short-term and long-term yield in all IPHC Regulatory Areas increased. Reducing the size limit for the directed commercial fishery would replace some directed commercial landings of O32 Pacific halibut with U32 landings. The magnitude of U32 landings at any point in time is dependent on population characteristics such as incoming recruitment and size-at-age. Over the long term, the price for U32 landings would need to be at least 50% of that for O32 landings to maintain a higher value in the absence of a size limit. Without a size limit for the directed commercial fishery, short-term directed commercial fishery discard mortality would decline by, on average, 78% coastwide and between 67% to 88% across IPHC Regulatory Areas.

7.3 Multi-year Assessments

A biennial assessment frequency with an empirical rule using FISS observations in non-assessment years shows similar performance to an annual assessment. This occurs because the FISS index tracks closely with the stock assessment. A triennial assessment frequency with an empirical rule using FISS observations in non-assessment years shows a slight reduction in the long-term TCEY along with a significant reduction in short-term and long-term inter-annual variability in the TCEY. Costs associated with a triennial assessment using an empirical MP that adjusts the coastwide TCEY and distribution using FISS data include 1) lack of detailed management information (e.g. estimates of SPR, stock status) every year, 2) possibly a loss in long-term yield, and 3) a chance of a smaller stock size. Benefits include 1) reduced inter-annual variability in the TCEY, 2) multi-year stability and short-term predictability of the TCEY, 3) use of the annual FISS index in a transparent process, 4) more focused assessment research, 5) potential of additional time for collaboration within the Secretariat, 6) consistency with the three-year cycle of update and full assessments, and 7) following the precedent of other fisheries commissions.

7.4 Uncertainties not included in these MSE simulations

Relevant uncertainty was captured with the use of four OMs and five distribution procedures. However, it is unknown if the range of the five distribution procedures captures the future distribution procedures that are used. An extreme departure from the five distribution incorporated here may have an unexpected outcome on the results.

7.5 Next Steps

An important task for the MSE would be to tune the coastwide specifications to optimise a selected distribution procedure, or further define the range of potential distribution procedures. At a minimum, that would include evaluating SPR values, but may also incorporate investigations of the control rule, size limits, assessment frequency, and constraints on the inter-annual change in TCEY. Updating the Harvest Strategy Policy document would be useful to identify areas that are complete and items that need additional work, which may be informed by further MSE work.

REFERENCES

Clark, W.G. and A.M. Parma. 1995. Re-evaluation of the 32-inch commercial size limit. International Pacific Halibut Commission Technical Report No. 33. 34 p.

Clark, W. G. and Hare, S. R. 2006. Assessment and management of Pacific halibut: data, methods and policy. International Pacific Halibut Commission Scientific Report 83. 104 p. https://www.iphc.int/uploads/pdf/sr/IPHC-2006-SR083.pdf

Cox, Sean P., and Allen Robert Kronlund. 2008. "Practical stakeholder-driven harvest policies for groundfish fisheries in British Columbia, Canada." *Fisheries Research* 94 (3): 224-237. https://doi.org/10.1016/j.fishres.2008.05.006.

FAO 1996. Precautionary approach to fisheries. *FAO Fish. Tech. Pap.* 350 (2): 210p. https://www.fao.org/3/w3592e/w3592e.pdf

Hare, S. R. 2011. Assessment of the Pacific halibut stock at the end of 2010. International Pacific Halibut Commission Report of Research and Assessment Activities 2010: 85-176.

Hare, S. R. and Clark, W. C. 2008. 2007 IPHC harvest policy analysis: past, present and future considerations. International Pacific Halibut Commission Report of Research and Assessment Activities 2007: 275-296.

Hicks, A, P Carpi, I Stewart, and S Berukoff. 2021. IPHC Management Strategy Evaluation for Pacific halibut (Hippoglossus stenolepis). https://iphc.int/uploads/pdf/am/am097/iphc-2021-am097-11.pdf.

Martell, S., B. Leaman, and I. Stewart. 2015a. Recent developments in the IPHC Management Strategy Evaluation process and size-limit implications. IPHC Report of Assessment and Research Activities 2014. p. 299-312.

Martell, S., I. Stewart, and J. Sullivan. 2015b. Implications of bycatch, discards, and size limits on reference points in the Pacific halibut fishery. In Fisheries bycatch: Global issues and creative solutions. Edited by G.H. Kruse and H.C. An and J. DiCosimo and C.A. Eischens and G. Gislason, S. and D.N. McBride and C.S. Rose and C.E. Siddon. Alaska Sea Grant, University of Alaska Fairbanks.

Myhre, R.J. 1973. Setting the new halibut size limit. Western Fisheries. 85(5): 14IPHC. 1960. Utilization of Pacific halibut stocks: yield per recruitment. IPHC Sci. Rep. No. 28. 52 p.

Parma, A.M. 1991 Performance of alternative harvest rates Int. Pac. Halibut Comm. Report of Commission Activities 1990.

Parma, A.M. 1993. Retrospective catch-at-age analysis of Pacific halibut: implications on assessment of harvesting policies. Pages 247–265 in G. Kruse, D. M. Eggers, R. J. Marasco, C. Pautzke and T. J. Quinn II, eds. Proc. Int'l. Symp. Management Strategies for Exploited Fish Populations. Alaska Sea Grant College Program Report No. AK-SG-93-02. Alaska Sea Grant College Program, Univ. Alaska, Fairbanks, Alaska.

Parma, A.M. 1999. Effects of imposing a maximum size limit in commercial landings. International Pacific Halibut Commission Annual Meeting Handout.

Parma, A.M. 2002. In search of robust harvest rules for Pacific halibut in the face of uncertain assessments and decadal changes in productivity. Bulletin of Marine Science 70: 423-453.

Pascoe, S., Thebaud, O. and Vieira, S. 2014. Estimating proxy economic target reference points in data-poor single-species fisheries. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 6(1): 247-259.

Rayns, N. 2007. The Australian government's harvest strategy policy. ICES Journal of Marine Science 64: 596- 598.

Southward, G.M. 1968. A simulation of management strategies in the Pacific halibut fishery. Report of the International Pacific Halibut Commission Number 47. 70 p. https://www.iphc.int/uploads/pdf/sr/IPHC-1968-SR047.pdf

Stewart, I. and A. Hicks 2018. Evaluation of the IPHC's 32" minimum size limit. IPHC-2018-AM094-14. 1 December 2017. https://www.iphc.int/uploads/pdf/am/2018am/iphc-2018-am094-14.pdf

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

Stewart, I., A. Hicks, B. Hutniczak. 2021. Evaluation of directed commercial fishery size limits in 2020. IPHC-2021-AM097-09. 15 December 2020. https://www.iphc.int/uploads/pdf/am/am097/iphc-2021-am097-09.pdf

Valero, J.L., and S.R. Hare. 2012. Harvest policy considerations for re-evaluating the minimum size limit in the Pacific halibut commercial fishery. 2012 IPHC annual meeting handout. p. 22-58.

APPENDICES

Appendix A: Objectives used by the Commission for the MSE

Appendix B: Results using metrics associated with the primary objectives

Appendix C: Supplementary material

APPENDIX A
OBJECTIVES USED BY THE COMMISSION FOR THE MSE

Table A1. Objectives, evaluated over a simulated ten-year period, reviewed 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	$p_{SB,2} > 5\%$ $p_{SB,3} > 33\%$ $p_{SB,4} > 10\%$ $p_{SB,4B} > 2\%$	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}=36% unfished spawning biomass	Long-term	0.50	$P(SB < SB_{Targ})$
2.2. LIMIT VARIABILITY IN MORTALITY LIMITS	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 B

RESULTS USING METRICS ASSOCIATED WITH THE PRIMARY OBJECTIVES

Table B1. Short-term metrics associated with primary objectives for simulations (1,100 replicates) with simulated estimation error, decision-making variability option 1, and SPR=43%.

	MP	MP-A0	MP-A26	MP-A32	MP-Bb	MP-Tb
Short-term	**Biological Sustainability**					
	P(any RSB_y<20%)	0.005	0.005	0.005	0.005	0.005
	Fishery Sustainability					
	P(all RSB<36%)	0.369	0.372	0.376	0.411	0.403
	Median average TCEY	60.46	59.92	58.33	58.46	58.32
	Median average TCEY-2A	1.63	1.63	1.62	1.60	1.60
	Median average TCEY-2B	8.86	8.82	8.52	8.36	8.43
	Median average TCEY-2C	6.66	6.60	6.33	6.39	6.35
	Median average TCEY-3A	24.29	24.04	23.24	23.38	23.39
	Median average TCEY-3B	7.42	7.36	7.13	7.09	7.17
	Median average TCEY-4A	3.52	3.48	3.35	3.39	3.41
	Median average TCEY-4CDE	4.06	4.04	3.92	3.94	3.91
	Median average TCEY-4B	2.86	2.82	2.70	2.71	2.72
	P(any3 change TCEY > 15%)	0.880	0.894	0.906	0.809	0.628
	P(any3 change TCEY 2A > 15%)	0.254	0.252	0.264	0.357	0.288
	P(any3 change TCEY 2B > 15%)	0.644	0.639	0.679	0.639	0.432
	P(any3 change TCEY 2C > 15%)	0.696	0.711	0.722	0.641	0.434
	P(any3 change TCEY 3A > 15%)	0.738	0.750	0.757	0.669	0.447
	P(any3 change TCEY 3B > 15%)	0.756	0.759	0.777	0.751	0.526
	P(any3 change TCEY 4A > 15%)	0.782	0.778	0.804	0.723	0.496
	P(any3 change TCEY 4CDE > 15%)	0.514	0.527	0.524	0.430	0.241
	P(any3 change TCEY 4B > 15%)	0.771	0.753	0.781	0.709	0.442
	Median AAV TCEY	17.2%	17.5%	17.8%	17.0%	14.1%
	Median AAV TCEY 2A	2.5%	2.6%	2.7%	4.3%	1.9%
	Median AAV TCEY 2B	16.6%	17.0%	17.4%	18.4%	15.2%
	Median AAV TCEY 2C	17.8%	17.8%	18.2%	18.2%	15.0%
	Median AAV TCEY 3A	18.9%	19.1%	19.4%	19.0%	15.3%
	Median AAV TCEY 3B	19.9%	20.2%	20.7%	20.2%	16.1%
	Median AAV TCEY 4A	20.0%	20.1%	20.5%	20.8%	16.7%
	Median AAV TCEY 4CDE	15.0%	15.1%	14.9%	14.1%	11.7%
	Median AAV TCEY 4B	20.0%	19.8%	20.3%	20.5%	15.9%

Table B2. Long-term metrics associated with primary objectives for simulations with simulated estimation error, decision-making variability option 1, and an SPR of 43%.

	MP	MP-A0	MP-A26	MP-A32	MP-Bb	MP-Tb
Long-term	**Biological Sustainability**					
	P(any RSB_y<20%)	<0.001	<0.001	<0.001	<0.001	<0.001
	Fishery Sustainability					
	P(all RSB<36%)	0.174	0.174	0.180	0.164	0.197
	Median average TCEY	63.88	63.53	62.21	61.26	62.95
	Median average TCEY-2A	1.63	1.63	1.62	1.61	1.61
	Median average TCEY-2B	9.32	9.21	9.09	8.83	8.97
	Median average TCEY-2C	7.11	7.07	6.97	6.80	6.93
	Median average TCEY-3A	26.10	26.08	25.69	25.43	26.08
	Median average TCEY-3B	8.00	8.03	7.83	7.81	7.99
	Median average TCEY-4A	3.04	3.02	2.92	2.94	2.94
	Median average TCEY-4CDE	3.46	3.40	3.32	3.44	3.46
	Median average TCEY-4B	2.85	2.82	2.70	2.69	2.66
	P(any3 change TCEY > 15%)	0.855	0.852	0.852	0.781	0.515
	P(any3 change TCEY 2A > 15%)	0.226	0.232	0.245	0.340	0.249
	P(any3 change TCEY 2B > 15%)	0.630	0.637	0.637	0.617	0.385
	P(any3 change TCEY 2C > 15%)	0.693	0.704	0.711	0.636	0.281
	P(any3 change TCEY 3A > 15%)	0.720	0.720	0.715	0.631	0.343
	P(any3 change TCEY 3B > 15%)	0.778	0.778	0.784	0.689	0.423
	P(any3 change TCEY 4A > 15%)	0.785	0.788	0.820	0.766	0.500
	P(any3 change TCEY 4CDE > 15%)	0.484	0.464	0.452	0.390	0.218
	P(any3 change TCEY 4B > 15%)	0.776	0.766	0.776	0.760	0.507
	Median AAV TCEY	15.9%	16.1%	16.3%	15.7%	11.9%
	Median AAV TCEY 2A	1.5%	1.5%	1.6%	1.9%	1.3%
	Median AAV TCEY 2B	15.8%	15.8%	16.1%	17.7%	13.7%
	Median AAV TCEY 2C	16.7%	16.9%	17.0%	17.4%	13.1%
	Median AAV TCEY 3A	16.8%	16.9%	17.2%	17.5%	13.4%
	Median AAV TCEY 3B	18.4%	18.0%	18.5%	18.7%	14.6%
	Median AAV TCEY 4A	18.5%	18.7%	19.2%	19.6%	15.3%
	Median AAV TCEY 4CDE	13.6%	13.6%	13.5%	13.0%	9.0%
	Median AAV TCEY 4B	18.3%	18.3%	18.6%	19.3%	15.7%

APPENDIX C
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 be updated as additional results are produced.

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

Results with 500 simulations, that examine a wider range of options and elements and were presented at MSAB017, are available at

http://shiny.westus.cloudapp.azure.com/shiny/sample-apps/IPHC-MSE-MSAB017/