Updates to the Management Strategy Evaluation framework and a review of coastwide management procedures

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PURPOSE

To provide the Management Strategy Advisory Board (MSAB) with an update of changes to the Management Strategy Evaluation (MSE) framework and additional evaluations performed since the 18th Session of the IPHC Management Strategy Advisory Board (MSAB018).

1 BACKGROUND

MSAB018 took place in May 2018 and made a number of requests outlined in IPHC-2023-MSAB018-R. The 22nd and 23rd sessions of the Scientific Review Board (SRB022 and SRB023) and the 99th Session of the IPHC Interim Meeting (IM099) made additional requests for the MSE and harvest strategy work. This document describes work using the MSE framework that has been completed related to some of those requests. The full actions arising from all MSE related requests are available in documents IPHC-2024-MSAB019-04 and IPHC-2024-MSAB019-05.

The IPHC interim harvest strategy policy consists of three components: coastwide scale (the management procedure, MP, determining the coastwide TCEY), TCEY distribution (part of the harvest strategy that distributes the TCEY among IPHC Regulatory Areas), and decision-making (which occurs at the Annual Meeting). An illustration of the harvest strategy policy is shown in Figure 1. Currently, there is no defined distribution procedure and the TCEY distribution is negotiated at the Annual Meeting. Distribution procedures are not currently being evaluated and the MSE process is focused on management procedures related to the coastwide scale. Therefore, distribution procedures are simulated with variability in the MSE simulations to represent this uncertainty in decision-making.

The Commission has endorsed four priority coastwide objectives with associated performance metrics and has recognized other objectives for the evaluation of MPs (Appendix A). These four objectives are listed below in priority order, meaning that if one is not met, subsequent ones need not be considered and the MP is not considered as an option.

a. Maintain the long-term coastwide female spawning stock biomass above a biomass limit reference point ($B_{20\%}$) at least 95% of the time.

b. Maintain the long-term coastwide female spawning stock biomass at or above a biomass threshold reference point ($B_{36\%}$) at least 50% of the time.

c. Optimise average coastwide TCEY.

d. Limit annual changes in the coastwide TCEY.

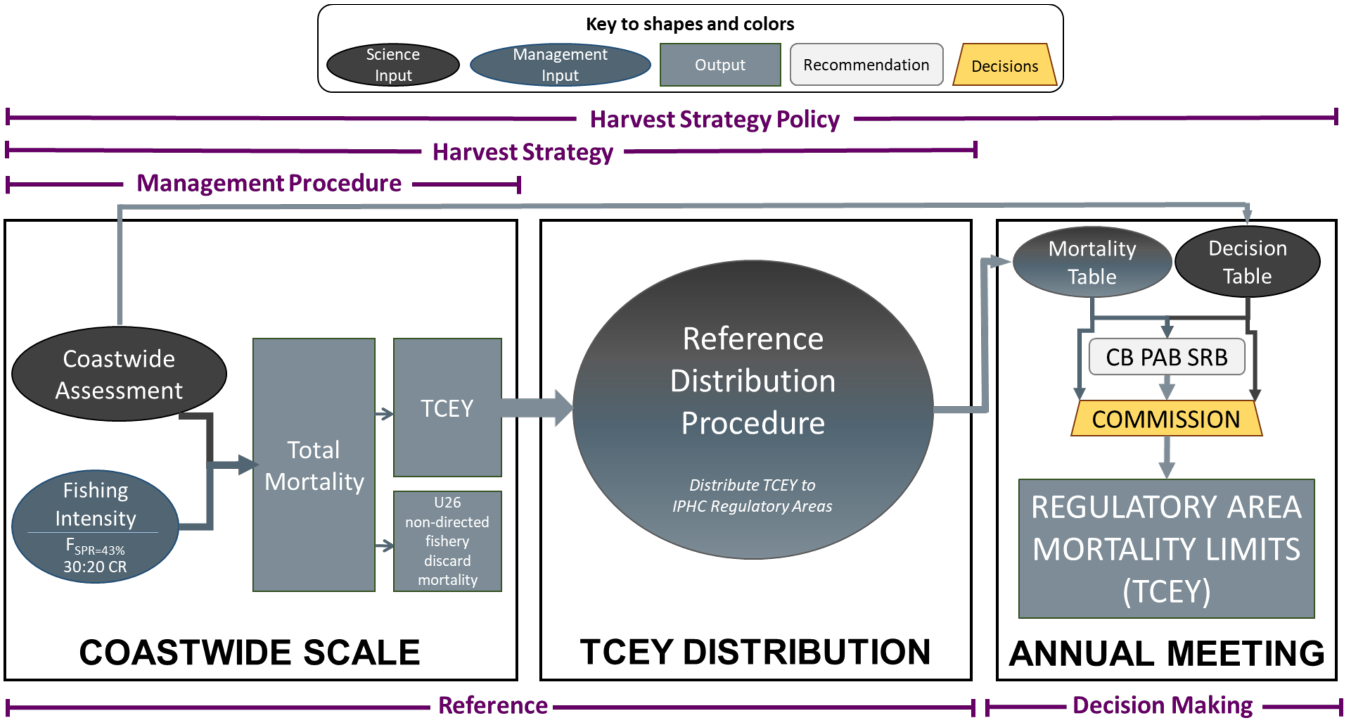

Figure 1. Illustration of the interim harvest strategy policy for the IPHC showing the coastwide scale (management procedure), the TCEY distribution (part of the harvest strategy), and the policy component that mainly occurs at the Annual Meeting.

2 UPDATED MSE OPERATING MODEL

The MSE operating model (OM) is spatially structured with movement of Pacific halibut occurring between Biological Regions (Figure 2). Multiple fishing sectors are modelled within IPHC Regulatory Areas including both landings and discard mortality. Fisheries are specified by IPHC Regulatory Area because many of the Commission objectives used to evaluate management procedures (MPs) are specific to Biological Regions and IPHC Regulatory Areas. Therefore, the simulated TCEY determined from a coastwide MP is distributed among IPHC Regulatory Areas and then sectors within IPHC Regulatory Areas. The OM incorporates four individual models and integrates them into an ensemble to account for structural uncertainty and differing hypotheses about recruitment and distribution.

The IPHC's MSE Operating Model was updated in 2023 to reflect the 2022 stock assessment ensemble and is performing well for evaluating management procedures. The Scientific Review Board (SRB) reviewed the IPHC's MSE Operating Model (OM) for 2023 at the 22nd Session of the SRB (SRB022) and the 23rd Session of the SRB (SRB023) and endorsed the 2023 OM. The SRB recommended updating the operating model following full stock assessments.

> **IPHC-2023-SRB022-R, para. 26:** *The SRB RECOMMENDED that reconditioning the operating model should be limited to situations where the stock assessment has changed significantly. This likely means a three-year schedule for reconditioning the operating model in the year following each full stock assessment.*

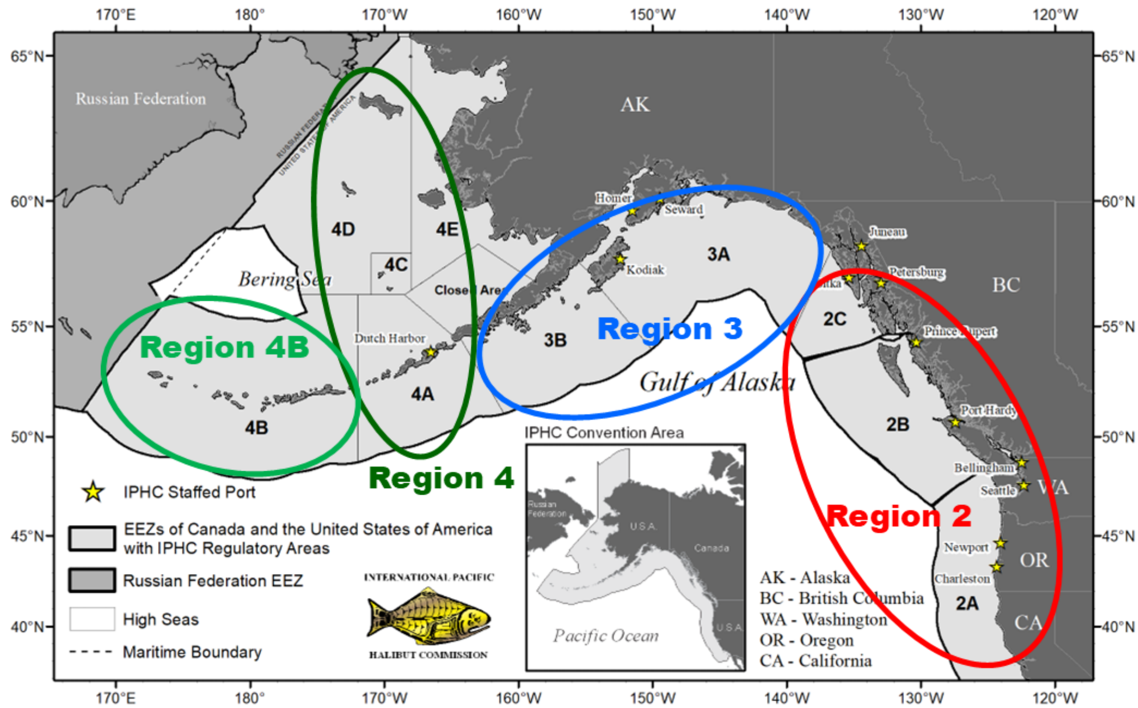

Figure 2. The IPHC convention area with Biological Regions and IPHC Regulatory Areas.

It is expected that this OM will be used until after the next full assessment is completed, but further improvements may be made, as needed or at the request of the Commission.

The estimated historical spawning biomass and projected spawning biomass with no fishing mortality and with fishing intensity equal to a spawning potential ratio (SPR) of 43% from the updated OM are shown in Figure 3. Individual trajectories of spawning biomass are also shown in Figure 3, which show similar increases and decreases with and without fishing. This is because weight-at-age and recruitment are large drivers of spawning biomass while fishing at a constant SPR has a large effect on the overall scale of spawning biomass.

The 2023 OM is consistent with the assumptions used in the 2022 assessment (i.e. three of the four models in the stock assessment ensemble estimated female natural mortality at values greater than 0.18), but includes a wider range of variability in key parameters than the tactical stock assessment. Long-term performance metrics related to spawning biomass and short-term performance metrics for the TCEY from simulations using the 2022 OM and the 2023 OM with the same specifications of an MP (SPR=43%) were similar (Table 1). The short-term median average TCEY was approximately 59 million pounds and the median average annual variability (AAV) for the TCEY changed from 18% to 17%. The probability of the long-term spawning biomass being less than 36% of unfished spawning biomass changed from 0.31 to 0.35. Even though the 2022 stock assessment showed a large increase in the TCEY based on SPR=43% when compared to 2021 stock assessment outputs, the MSE outputs are very similar due to the inclusion of additional uncertainty on natural mortality in both the 2022 and 2023 OMs. Therefore, the relative ranking of management procedures and other MSE results from the 2022 OM remain relevant.

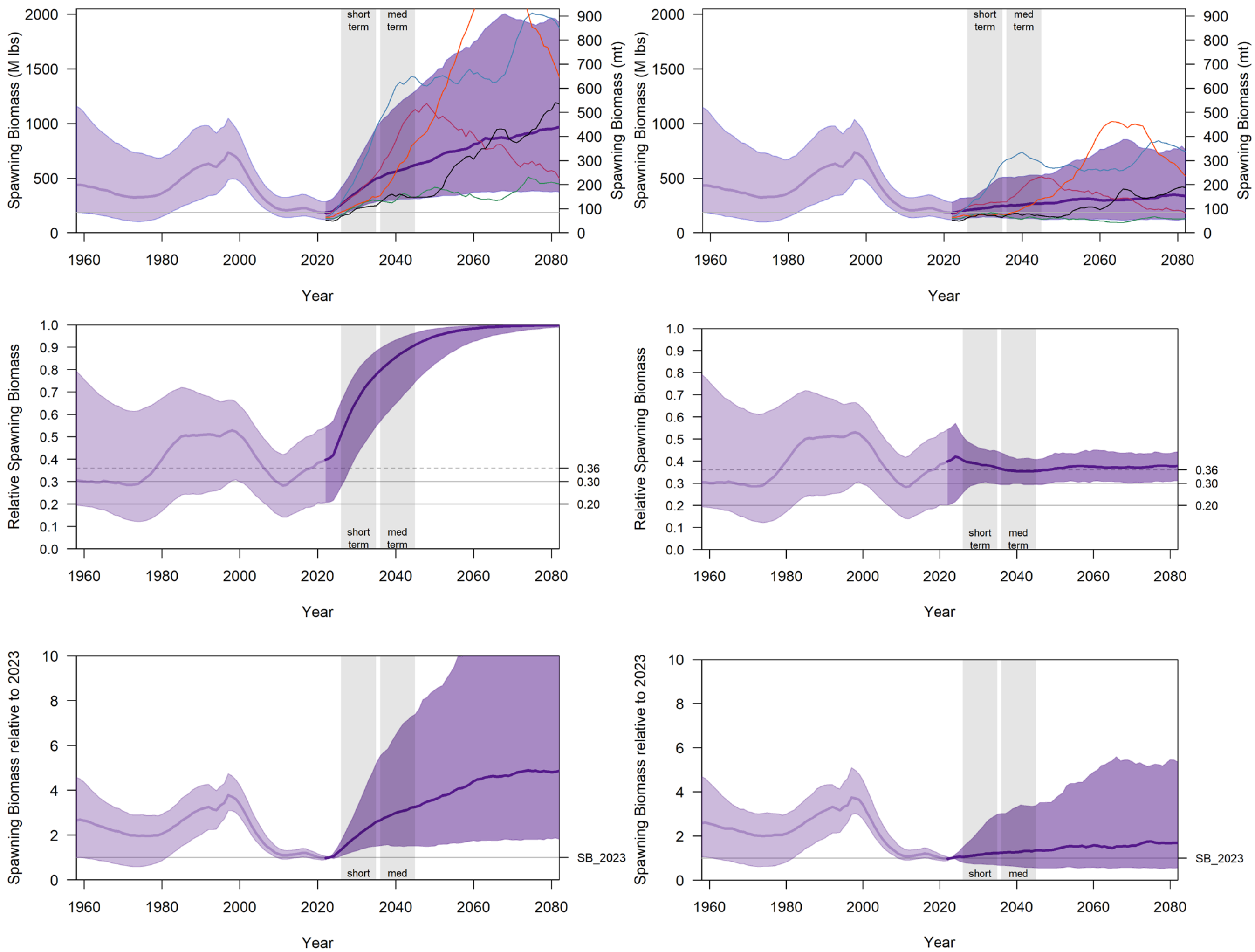

Figure 3. Simulated spawning biomass (top row), relative spawning biomass (middle row), and spawning biomass relative to the spawning biomass in 2023 (bottom row) assuming no fishing mortality (left column) and a fishing intensity equal to an SPR of 43% (right column). The median is shown by the thick dark line and the 5th and 95th percentiles are shown as the shaded polygon (the darker polygon indicates the projected time-period). Individual trajectories of spawning biomass are shown as small lines of different colors. Grey vertical panels indicate the short and medium time-periods used for calculating performance metrics.

Table 1. Performance metrics for the same management procedure simulated with similar assumptions using the 2022 OM and the 2023 OM. The MP uses an SPR=43%, a 30:20 control rule, and an annual assessment.

Period	Performance Metric	2022 OM	2023 OM
Long-term	P(RSB<20%)	PASS	PASS
	P(RSB<36%)	0.31	0.35
Short-term	Median average TCEY	59.0	59.2
	Median AAV TCEY	18.1%	17.0%
	P($SB_{2027\text{-}2036}$ < SB_{2023})	0.17	0.29

One difference between the two OMs is a performance metric related to the 2023 estimate of spawning biomass. In the 2023 OM there is a higher chance that the spawning biomass in 4 to 13 years (short-term) will be less than the 2023 spawning biomass. This is due to the additional data informing the spawning biomass trajectory in recent years.

Specific details of the 2023 OM are available on the IPHC MSE Research Website in the document "Technical Details of the IPHC MSE Framework" (IPHC-2023-MSE-02).

3 Management Procedures (MPs)

The MSAB018 made a request to investigate various elements of management procedures related to coastwide scale and distribution of the TCEY.

> **IPHC-2023-MSAB018-R, para. 29**. *The MSAB REQUESTED that subsequent to an agreement on a distribution procedure by the Commission, the evaluation of annual and multi-year assessments include, but not limited to, the following concepts.*
>
> a) *Annual changes in the TCEY driven by FISS observations in non-assessment years of a multi-year MP;*
> b) *A constraint on the coastwide TCEY to reduce inter-annual variability and the potential for large changes in assessment years of a multi-year. This may be a 10% or 15% constraint, a slow-up fast-down approach, or similar approach;*
> c) *A smoothing element in the distribution procedure to account for uncertainty in the estimates of stock distribution and reduce the variability in area-specific TCEYs. For example, this may include a 3-year rolling average of stock distribution estimates;*
> d) *SPR values ranging from 30% to 56% and alternate trigger reference points in the harvest control rule.*

3.1 Assessment frequency and an empirical management procedure

The frequency of conducting the stock assessment is a priority element of the MP to be investigated (see IPHC-2023-MSAB018-R, para. 29 above). This includes conducting assessments annually (every year), biennially (every 2nd year), or triennially (every third year) to determine the status of the Pacific halibut stock and the coastwide TCEY for that year. In years with no assessment, the coastwide TCEY would be determined using a simpler approach and the estimated status of the stock would not be available. Costs and benefits of a reduced assessment frequency were considered at AM099 in document IPHC-2023-AM099-13 and those pertinent to the coastwide TCEY are repeated here.

Costs include the following.

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 (without an empirical rule on coastwide TCEY).
c) Previous simulations showed a potential small loss in yield when using a constant coastwide TCEY across non-assessment years.

d) Previous simulations showed a higher chance of a smaller stock size.

Benefits include the following.

e) Reduced interannual variability of the coastwide TCEY.

f) Multi-year stability and short-term predictability of the TCEY.

g) Use of the annual FISS index in a transparent process to determine the TCEY in non-assessment years.

h) More focused assessment research.

i) Potential for additional time to collaborate on research supporting the stock assessment within the Secretariat.

j) A triennial assessment frequency would be consistent with the current assessment cycle of update and full assessments.

k) The reduced assessment frequency and use of empirical data approach has precedent at other fisheries commissions.

The mortality limits in a year with a stock assessment can be determined as specified by previous defined MPs (i.e. SPR-based approach). In years without a stock assessment, the mortality limits would need an alternative approach. This may be as simple as setting a constant multi-year TCEY until the next assessment was completed or using empirical observations (e.g. FISS modelled output) to adjust the coastwide TCEY in non-assessment years. There are many different empirical rules that could be applied to determine the coastwide TCEY in non-assessment years and two have been identified for evaluation.

a. The same coastwide TCEY from the previous year until a stock assessment is available.

b. Update the coastwide TCEY proportionally to the change in the coastwide FISS O32 WPUE.

Alternative approaches could be based entirely on the MSE; these would not require the current stock assessment for setting mortality limits in any year, and would use a simpler estimation model that is tuned to achieve the performance desired (i.e. meet primary objectives) or an empirical-based MP as the method for setting annual mortality limits in every year. The stock assessment would be used at a defined interval to verify that management is effective, determine status of the stock, and to potentially tune the MSE OM and existing MP (Cox and Kronlund 2008). This concept was a request of the SRB in 2022:

> **IPHC-2022-SRB020-R, para 20** *The SRB REQUESTED that the MSE not attempt to implement a Stock Synthesis estimation procedure as part of the management procedure and, instead, to integrate a simpler assessment modelling approach into the management procedure via tuning.*

This method is used in other fisheries with well-developed MSE analyses and has the benefit of being relatively simple and not requiring an extensive limit-setting process: the annual MP results from the MSE are applied each year and the process is periodically reviewed. This approach has not yet been evaluated for Pacific halibut and regular occurring stock assessments are assumed to continue in the near future for setting the coastwide TCEY.

3.1.1 Retrospective analysis of an empirical rule

The MSAB018 requested a retrospective analysis of an empirical rule to examine the coastwide TCEYs that would have resulted in the past.

> **IPHC-2023-MSAB018-R, para. 33**: *The MSAB REQUESTED a retrospective analysis of an empirical rule that adjusts the coastwide TCEY proportionally to the change in the coastwide FISS O32 WPUE to compare the coastwide TCEY determined from the assessment to the TCEY determined empirically*.

This retrospective analysis can only be interpreted for each specific year alone because the FISS O32 WPUE would have been different if a different fishing mortality occurred. Therefore, this analysis looks at the empirical coastwide TCEY given what actually occurred in the previous years. The results are on a year-to-year basis and do not represent a forward simulation from a past year.

The coastwide TCEY for year (*y*+1) was determined using the proportional change in the FISS O32 WPUE from year (*y*-1) to year (*y*). In other words, the coastwide TCEY for next year is determined using the recent year coastwide TCEY multiplied by the proportional change in the FISS O32 WPUE from last year to this year. This offset of years occurs because next year's FISS results are available after the fishery occurs.

$$TCEY_{y+1} = TCEY_y \times \frac{WPUE_{O32,y}}{WPUE_{O32,y-1}}$$

A space-time model has been used to estimate the FISS O32 WPUE since 2016. Therefore, the empirical coastwide TCEY can only be determined for 2017 onwards. Estimates of the O32 WPUE are available for years prior to 2016 from the 2016 space-time model, but those estimates are inconsistent with the estimates that would have been available in those prior years without using observations beyond that year in the space-time model. Further, the historical expansion of the FISS design continued through 2019; during this period the understanding of the full stock distribution and abundance in historically unsampled areas was rapidly evolving.

Figure 4 shows the actual adopted TCEYs since 2017 compared to the theoretical empirical TCEY for those same years. The empirical TCEY was similar to the adopted TCEY, but more often slightly below than the adopted TCEY. Because this is not a replay of the time-series with the empirical TCEYs, two or more years of empirical TCEYs cannot be compared. For example, the 2024 empirical TCEY is greater than the 2023 empirical TCEY even though the FISS O32 WPUE decreased slightly. This is because the 2024 empirical TCEY is based on the 2023 adopted TCEY since the population dynamics (and FISS observations) are dependent on the actual fishery removals.

The MSAB018 also requested that new performance metrics be developed for evaluating assessment frequency.

> **IPHC-2023-MSAB019-R, para.** 38. *The MSAB REQUESTED new performance metrics representing the change in the TCEY in non-assessment years and the change in TCEY in assessment years be developed for the evaluation of multi-year assessment MPs*.

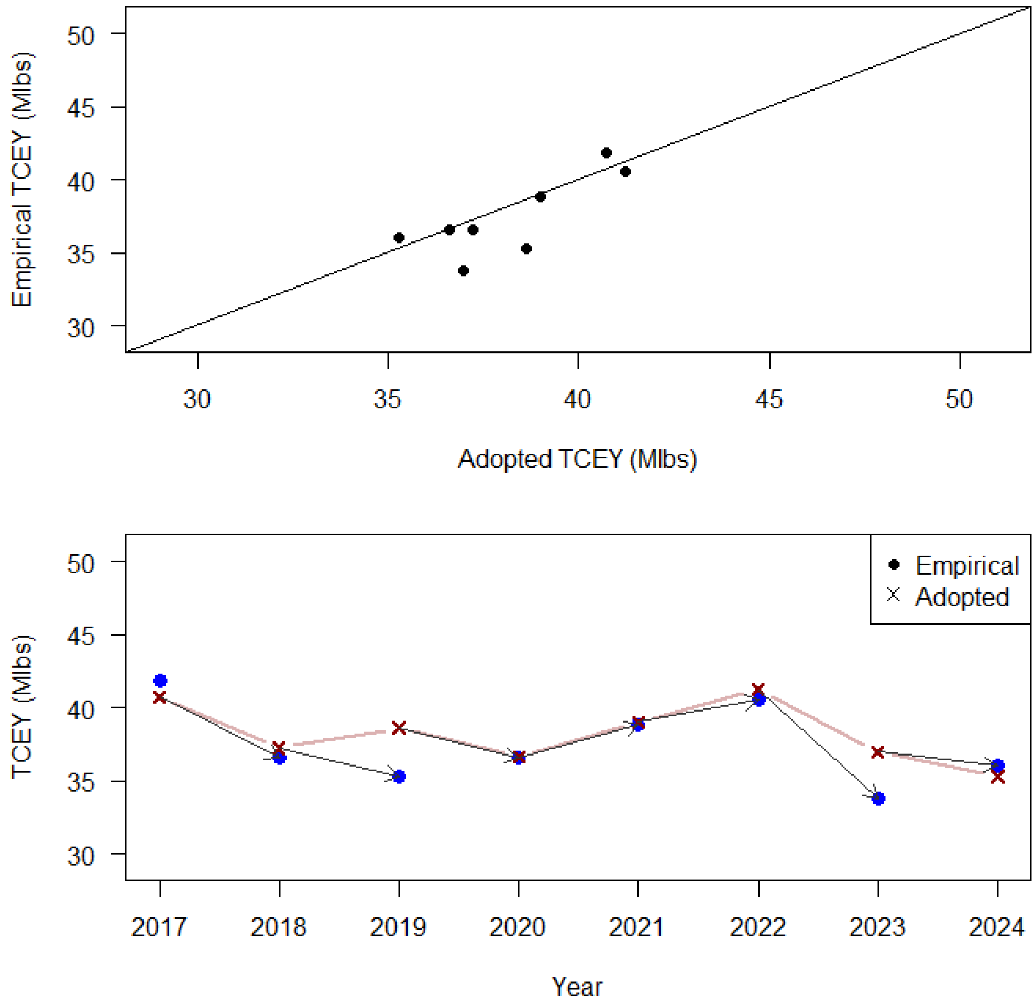

Figure 4. Two comparisons of adopted TCEYs and empirically determined TCEYs for each specific year. The top plot compares the empirical TCEY directly to the actual adopted TCEY. The bottom plot shows the time-series of the adopted and empirical TCEYs, noting that the empirical TCEYs are not a replay from 2017, but are a comparison to the adopted TCEY for each individual year. Arrows shows that the empirical TCEY is based on the previous year's adopted TCEY.

Current performance metrics for the interannual variability in the TCEY include the average annual variation (AAV) and the probability that 3 or more years of a 10-year period have a change in the TCEY greater than 15% from one year to the next. Neither of these metrics measure the potential change every second or third year when using biennial or triennial assessments. This is especially important if the TCEY is held constant during non-assessment years. The current performance metrics, averaged over a 10-year period, regardless of the assessment frequency, are still useful and simply represent the variability over that 10-year period, but an indication of the change in the TCEY when an assessment occurs and when using an empirical rule may be useful when evaluating management procedures.

It is important to consider the objective when developing performance metrics, and sometimes multiple performance metrics may be useful to the evaluation. One consideration here is whether a stable 2-year period with a larger biennial or triennial change is preferable to possibly smaller annual changes in the TCEY. Additional separate metrics are useful to indicate the changes in assessment years and non-assessment years, but if they are not pertinent to the objectives, they can become confusing and superfluous.

3.2 Fishing intensity

The fishing intensity is determined by finding the fishing rate (*F*) that would result in a defined spawning potential ratio (F_{SPR}). Because the fishing rate changes depending on the stock demographics and the distribution of catch across fishery sectors, SPR is a better indicator of fishing intensity and its effect on the stock than *F*. A range of SPR values (interim reference SPR is currently 43%) and possibly alternative trigger reference points (currently 30%) in the harvest control rule may be investigated. This was also recommended by the MSAB (see IPHC-2023-MSAB018-R, para. 29 above). Evaluation of a range of fishing intensities is a high priority and some results are shown in Section 5.2.

3.3 Constraints on the coastwide TCEY

One of the priority objectives (Appendix A) is to limit annual changes in the coastwide TCEY. Due to variability in many different processes (e.g. population, estimation, and decision making) the interannual variability of the TCEY from MSE simulations is typically higher than 15%. Over the past ten years (2015–2024), the interannual variability (average annual variability or AAV) in the adopted coastwide TCEY was 5.4% and the AAV of the reference coastwide TCEY was 14.5%. The percent change in the adopted coastwide TCEY ranged from -10% to 8% across years, and ranged from -21% to 29% for the coastwide reference TCEY across years (Table 2).

Decision-making since 2015 has reduced the interannual variability in the coastwide TCEY, compared to the reference, over the last ten years. The adopted TCEYs have a smaller range than the reference TCEYs and tend to cluster around 39 million pounds (Figure 5). The adopted TCEYs also tend to be closer to the status quo (i.e. the TCEY from the previous year) than the reference TCEYs when the reference TCEY difference from status quo was not near zero (Table 2 & Figure 5). This is akin to saying the change from one year to the next is less for the adopted TCEYs than the reference TCEYs. The spawning biomass has been relatively stable during the last ten years, and it is not known how the recent decision-making process would react to a rapidly increasing or decreasing spawning biomass.

This interannual variability in the coastwide reference TCEY can be reduced by adding a constraint in the MP, mimicking the recent decision-making process. The MSAB has suggested many different constraints including a 15% constraint on the change in the coastwide TCEY from one year to the next, and a slow-up/fast-down approach. The MSAB has requested further investigating constraints on the coastwide TCEY (see IPHC-2023-MSAB018-R, para. 29 above). Evaluating constraints on the coastwide TCEY is a secondary priority.

Table 2. Percent change in the adopted TCEY from the previous year (2015–2024) for each IPHC Regulatory Area and coastwide, and for the coastwide reference TCEY determined from the interim management procedure in place for that year.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Coastwide Adopted	Coastwide Reference
2015	-4.5%	3.5%	13.3%	7.9%	-0.3%	25.6%	2.7%	19.3%	8.1%	6.0%
2016	18.9%	4.2%	5.5%	-1.9%	-8.3%	-0.5%	-10.5%	-4.7%	-0.1%	2.3%
2017	16.7%	1.0%	7.6%	1.6%	16.7%	-7.7%	-2.2%	-5.7%	2.9%	7.7%
2018	-10.2%	-14.7%	-9.9%	-3.2%	-17.8%	-3.3%	-4.5%	-5.7%	-8.7%	-20.7%
2019	25.0%	-3.8%	0.0%	7.7%	-11.3%	11.5%	13.3%	10.5%	3.8%	29.0%
2020	0.0%	0.0%	-7.7%	-9.6%	7.6%	-9.8%	-9.7%	-2.5%	-5.2%	-20.3%
2021	0.0%	2.5%	-0.9%	14.8%	0.0%	17.1%	6.9%	2.1%	6.6%	22.3%
2022	0.0%	8.0%	1.9%	3.9%	25.0%	2.4%	3.6%	3.0%	5.7%	5.7%
2023	0.0%	-10.3%	-1.0%	-17.0%	-5.9%	-17.6%	-6.2%	-6.1%	-10.3%	26.0%
2024	0.0%	-4.6%	-1.0%	-6.0%	-6.0%	-6.9%	-8.1%	-3.9%	-4.6%	-5.9%

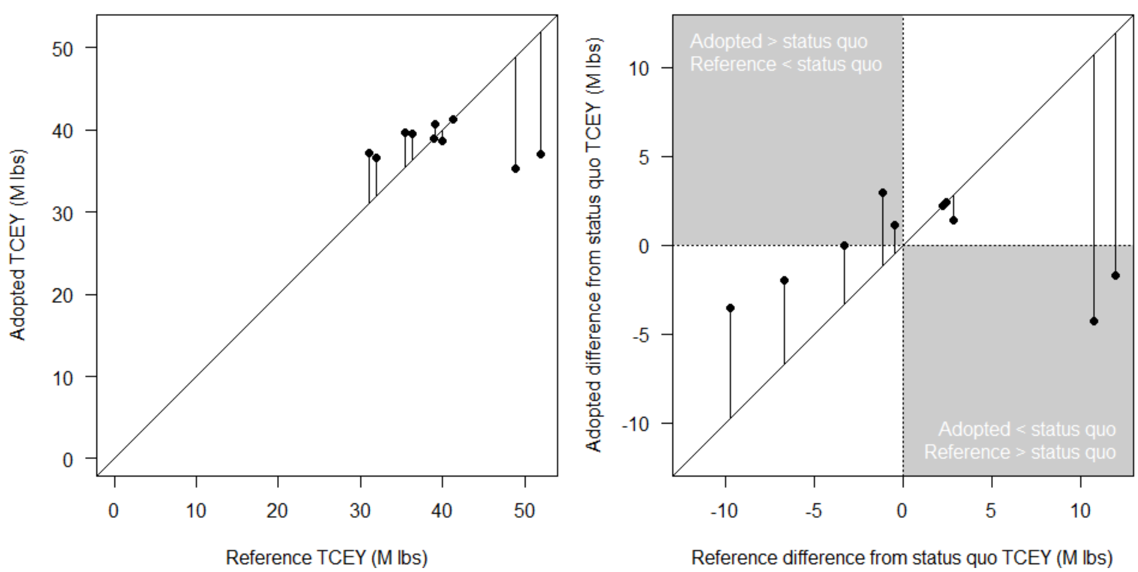

Figure 5. The adopted TCEY vs the reference TCEY (left) and the adopted difference from the status quo TCEY vs the reference difference from the status quo TCEY (right) for the last ten years (2015–2024). The 1:1 line shows when the two are equal. The grey quadrants in the right plot show when the adopted and reference TCEY differences from the status quo are opposite.

4 Exceptional Circumstances

An exceptional circumstance is an event that is beyond the expected range of the MSE evaluation and triggers specific actions that should be taken to re-examine the harvest strategy. Exceptional circumstances, and actions taken if one or more is met, define a process for deviating from an adopted harvest strategy (de Moor et al. 2022). It is important to ensure that the adopted harvest strategy is retained unless there are clear indications that the MSE may not be accurate. The IPHC interim harvest strategy policy (Figure 1) has a decision-making step after the MP, thus the Commission may deviate from an adopted MP as part of the harvest strategy policy. This decision-making variability is included in the MSE simulations.

Defining exceptional circumstances involves defining events that would lead to re-examination of the MSE process to determine if an update to the framework and evaluation of management procedures is necessary. The SRB provided clarity at SRB021 of what an exceptional circumstance is relative to the IPHC process.

> **IPHC-2022-SRB021-R, para 60:** *The SRB **RECOMMENDED** that Exceptional Circumstances be defined to determine whether monitoring information has potentially departed from their expected distributions generated by the MSE. Declaration of Exceptional Circumstances may warrant re-opening and revising the operating models and testing procedures used to justify a particular management procedure.*

This statement indicates that exceptional circumstances should be defined using observations rather than model outputs and should be compared to the distribution generated by the MSE simulations. If the observation(s) are outside of that range, revising the MSE framework and conducting additional simulations should be considered. It is important to have clear definitions for when the agreed upon MP should be re-evaluated.

An exceptional circumstance, in an MSE context, is not usually defined to trigger an action within the management procedure. An example of a trigger within the MP is the 30:20 control rule which defines a reduction in the fishing intensity when stock status is less than 30%.

> **IPHC-2023-AM099-R, para. 88:** ***NOTING*** *paragraph 60 from the 21st Session of the SRB (SRB021), the Commission **REQUESTED** the Secretariat develop a description of options to responding to exceptional circumstances that would trigger a stock assessment in nonassessment years and additional MSE analyses.*

The Secretariat, with the assistance of the SRB and MSAB, is defining exceptional circumstances and the response that would be initiated, as well as potential triggers in a management procedure that would result in a stock assessment being done (if time allows) in a year that would normally not have one scheduled (e.g. in multi-year MPs). For example, an exceptional circumstance would trigger a review of the MSE simulations to determine if the OM can be improved and MPs should be re-evaluated. If a multi-year MP was implemented and an exceptional circumstance occurred in a year without a stock assessment, a stock assessment would be completed as soon as possible along with the re-examination of the MSE. Additionally, the SRB recommended to define a threshold for persistent deviation such that an exceptional circumstance is really an exception rather than a one-year outlier.

> **IPHC-2023-SRB022-R, para 28:** *The SRB **RECOMMENDED** that exceptional circumstance (i) be evaluated annually based on comparisons between the simulation distribution (e.g. a 95% interval) of FISS values from MSE simulations to the realized FISS estimates; and (ii) be clearly distinguished from "unusual conditions". For example, exceptional circumstances should have a high threshold for persistent (i.e. more than a single year) deviation from MSE simulations.*

> **IPHC-2023-SRB022-R (para. 29).** *The SRB **RECOMMENDED** that an initial response to a suspected "exceptional circumstance" should include presentation at the next SRB meeting to establish whether the situation meets the definition of an "exceptional circumstance" and to formulate a response.*

Working with the SRB, the following potential triggers for an exceptional circumstance have been defined.

> **IPHC-2023-SRB023-R, para. 27:** ***RECOGNIZING*** *the spatial variability of environmental factors that influence population dynamics, the SRB **RECOMMENDED** that an exceptional circumstance be defined based on regional as well as stockwide deviations from expectations. For example, an exceptional circumstance could be declared if any of the following are met:*
>
> *a) The coastwide all-sizes FISS WPUE or NPUE from the space-time model falls above the 97.5th percentile or below the 2.5th percentile of the simulated FISS index for two or more consecutive years.*
>
> *b) The observed FISS all-sizes stock distribution for any Biological Region is above the 97.5th percentile or below the 2.5th percentile of the simulated FISS index over a period of 2 or more years.*
>
> *c) Recruitment, weight-at-age, sex ratios, other biological observations, or new research indicating parameters that are outside the 2.5th and 97.5th percentiles of the range used or calculated in the MSE simulations*.

Furthermore, the following actions may take place if an exceptional circumstance is declared.

> **IPHC-2023-SRB023-R, para. 28:** *The SRB **RECOMMENDED** that if an exceptional circumstance occurred the following actions would take place:*
>
> *a) A review of the MSE simulations to determine if the OM can be improved and MPs should be reevaluated.*
>
> *b) If a multi-year MP was implemented and an exceptional circumstance occurred in a year without a stock assessment, a stock assessment would be completed as soon as possible along with the re-examination of the MSE.*
>
> *c) Consult with the SRB and MSAB to identify why the exceptional circumstance occurred, what can be done to resolve it, and determine a set of MPs to evaluate with an updated OM.*
>
> *d) Further consult with the SRB and MSAB after simulations are complete to identify whether a new MP is appropriate.*

If there are other concerns that are not exceptional, i.e. an unexpected event, a stock assessment could be initiated without declaring an exceptional circumstance. However, the time available to prepare, conduct, and review a stock assessment must be taken into account.

> **IPHC-2023-MSAB018-R, para. 32:** *The MSAB NOTED that there are logistical considerations (e.g. data availability, time to fit models) when an assessment is desired in a non-assessment year, especially if a request for an assessment is made between the time the FISS results are available and the Annual Meeting*

The FISS coastwide modelled NPUE was compared to projections from the 2023 OM to determine if an exceptional circumstance has occurred (Figure 6). The current interim reference fishing intensity associated with an SPR of 43% was used because that is the current interim MP and includes decision-making variability to account for departing from that fishing intensity. The 2023 observation from the FISS space-time model is within the 95% prediction interval from the OM, thus an exceptional circumstance has not occurred.

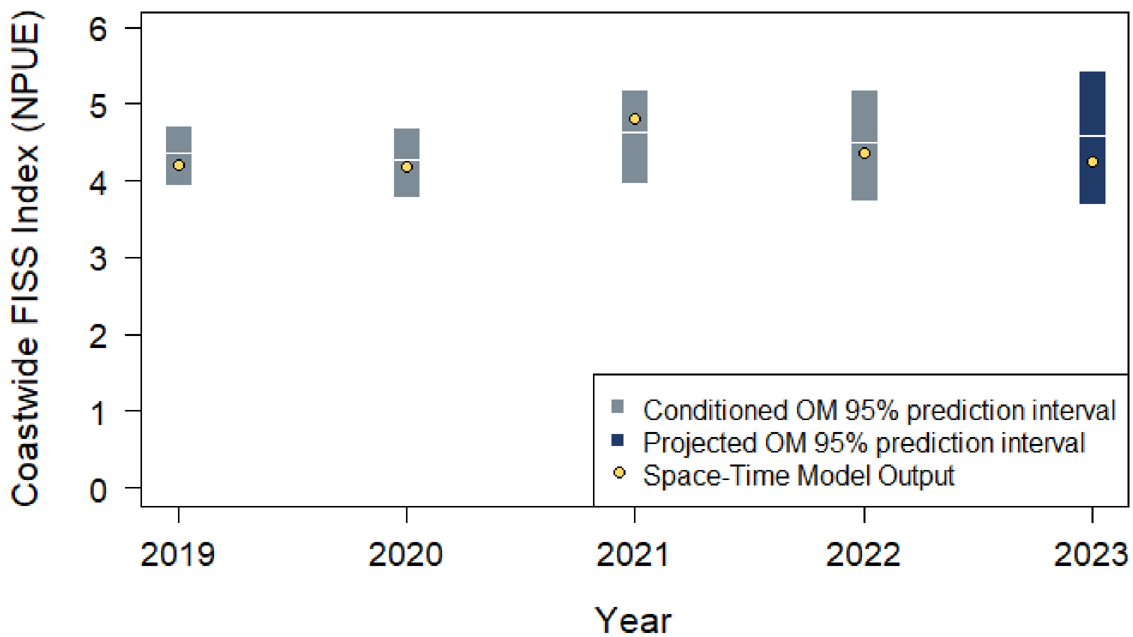

Figure 6. Prediction interval from the 2023 OM projected to 2023 using an SPR of 43, decision-making variability, estimation error, and observation error plotted along with the FISS all-sizes NPUE index from the space-time model (yellow dot). The dark blue box is the 95% prediction interval for all-sizes NPUE from the projected 2023 OM.

5 ADDITIONAL SIMULATIONS SINCE MSAB018

Additional MSE simulations have been conducted since MSAB018 investigating the effects of the environment. Preliminary results for the MP elements described above have been added to the MSE Explorer website and additional results will be added as they become available. Past MSE Explorer websites are available at http://iphcapps.westus2.cloudapp.azure.com/.

5.1 Examining the effect of the environment

Past analyses (IPHC-2019-SRB015-11) showed that, for Pacific halibut, biomass-based reference points, such as MSY and B_0, are affected by a change in environmental regime, but relative reference points, such as relative spawning biomass (RSB) and SPR_{MSY}, are similar across regimes. This indicates that a consistent SPR-based management regime is likely robust across different environmental regimes. Analyses investigating persistent high and low PDO regimes show similar results, and also provide performance metrics specific to the IPHC MSE.

Results of MSE simulations assuming a persistent low or high PDO were initially presented at the 18th Session of the MSAB (MSAB018), the fifth conference for Effects of Climate Change on the Worlds Oceans (ECCWO5), and the PICES 2023 Annual Meeting (PICES-2023). Results were recently updated and showed that fishing and the environment affect the proportion of spawning biomass in each Biological Region in different ways.

The median relative spawning biomass (RSB) when fishing at an SPR equal to 43% was similar for the high and low PDO scenarios (Table 3). However, even though the median was near 38%, there was a higher probability that the RSB was less than 36% for the low PDO scenario. The long-term median TCEY was 22% less for the low PDO scenario and 26% more for the high PDO scenario when compared to the median TCEY for the base simulations that modelled cyclical PDO regime shifts. The median average TCEY for a persistent high PDO was 1.6 times greater than the TCEY for a persistent low PDO. Inter-annual variability in the TCEY was the same for the persistent low and high PDO scenarios, but less than the AAV when PDO regime shifts were modelled because the changing PDO adds additional variability. There were important differences in the variability of the TCEY in each region. Specifically, the TCEY more than doubled (212%) in Biological Region 3 from the low PDO to high PDO, but differences were much smaller in other regions (111% in Biological Region 2, 142% in Biological Region 4 and 118% in Biological Region 4B).

Table 3. Performance metrics related to primary objectives for scenarios with modeled cycles of PDO (both), always low PDO (Low), and always high PDO (High) with an annual assessment, 32-inch size-limit, no decision-making variability, no estimation error, no observation error, and an SPR of 43%. Long-term results are only shown for all performance metrics.

	PDO	**Both**	**Low**	**High**
Long-term metrics	Median RSB	38.8%	37.6%	39.2%
	P(RSB<20%)	<0.001	<0.001	<0.001
	P(RSB<36%)	0.238	0.329	0.157
	Median TCEY (Mlbs)	65.6	51.4	83.0
	Median AAV TCEY	5.2%	4.5%	4.5%
	Median TCEY Region 2 (Mlbs)	20.5	19.1	21.2
	Median TCEY Region 3 (Mlbs)	33.7	23.0	48.7
	Median TCEY Region 4 (Mlbs)	8.1	6.6	9.4
	Median TCEY Region 4B (Mlbs)	2.4	2.2	2.6

The percentage of spawning biomass in each Biological Region is affected by fishing under an SPR-based management procedure (Figure 7). The distribution of spawning biomass across the Biological Regions is also affected by the PDO regime because movement, recruitment distribution, and average recruitment are dependent on the PDO regime. Region 2 shows a reduction in the percentage of spawning biomass with fishing, and the low PDO scenario results in a higher percentage than the persistent high PDO scenario. Region 3 shows a similar percentage of spawning biomass with fishing and a higher percentage of spawning biomass with a high PDO. Region 4 shows a higher percentage of spawning biomass with fishing and is largely unaffected by the PDO regime. Region 4B has a higher percentage of spawning biomass with fishing and a higher spawning biomass for the low PDO scenario.

A range of fishing intensities from SPR=40% to SPR=46% were simulated to determine the response to low or high fishing intensities (Table 4 and Figure 8). The range of fishing intensity had a much smaller effect that the PDO. The percentage of spawning biomass in Biological Region 3 was mostly unresponsive to fishing intensity and the TCEY change was of a similar magnitude to SPR=43%..

Even though we cannot "manage" the PDO regime, it is useful to understand the effects of the PDO regime on the results, allowing for the separation of the effects of fishing from the effects of the environment. For Pacific halibut, the environment sometimes may have a larger effect on the distribution of spawning biomass than fishing does (at a range SPR values from 40% to 46%). These results are dependent upon the full harvest strategy, and different distribution procedures would likely produce different outcomes.

The MSAB018 requested the development of outreach materials related to the results investigating environmental influences and effects of fishing on management outcomes.

> **IPHC-2023-MSAB018-R, para. 21**. *The MSAB REQUESTED that outreach materials be developed that synthesize the effect of the PDO (e.g. via recruitment) on the coastwide and regional stock dynamics and the relative effect of fishing. This may be a pamphlet or poster to be reviewed at a future MSAB meeting.*

A poster was presented at AM100 and is available as document IPHC-2024-MSAB019-INF01.

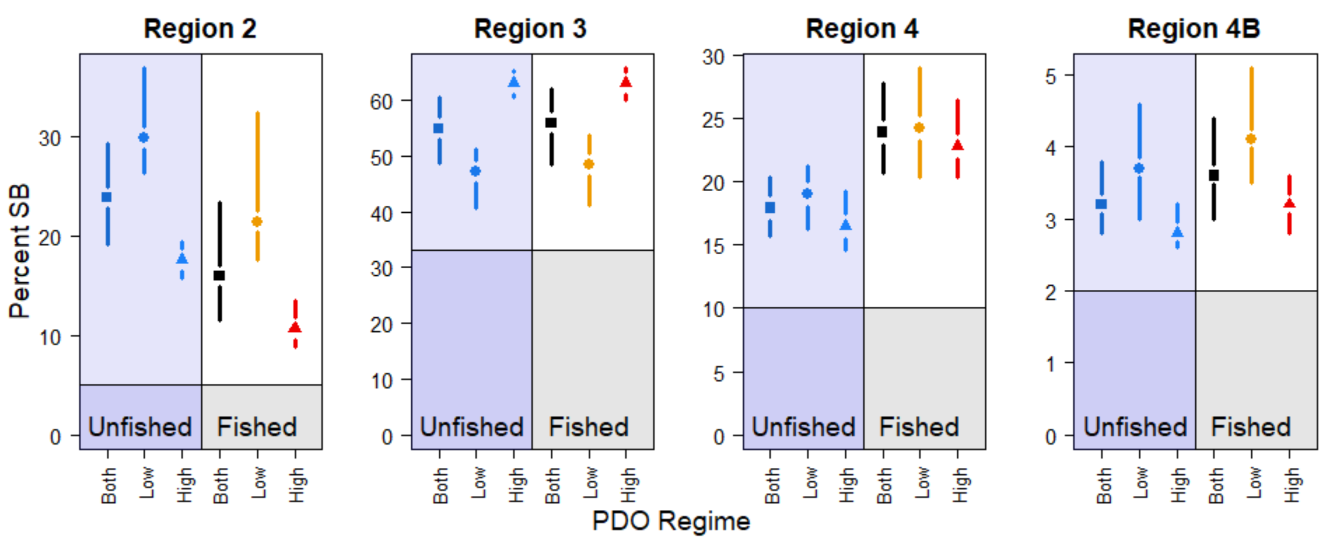

Figure 7. Percentage of spawning biomass in each Biological Region when fished with an SPR of 43% (no estimation error, no observation error, and no implementation error) and when not fished. The PDO is modelled with cyclical low and high periods in "Both", is persistently low in "Low", and is persistently high in "High". The darker shaded area indicates the area below the threshold in the spatial conservation objective (Appendix A).

Table 4. Performance metrics related to primary objectives for scenarios with modeled cycles of PDO (both), always low PDO (Low), and always high PDO (High) with an annual assessment, 32-inch size-limit, no decision-making variability, no estimation error, and no observation error, and SPR values equal to 40% and 46%. Long-term results only are shown for all performance metrics.

	PDO **SPR**	**Both** **0.40**	**Low** **0.40**	**High** **0.40**	**Both** **0.46**	**Low** **0.46**	**High** **0.46**
Long-term metrics	Median RSB	35.7%	34.5%	36.0%	42.0%	40.9%	42.4%
	P(RSB<20%)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	P(RSB<36%)	0.569	0.676	0.501	0.053	0.102	0.024
	Median TCEY (Mlbs)	68.3	53.7	86.8	62.7	49.0	79.0
	Median AAV TCEY	5.3%	4.9%	4.7%	5.1%	4.4%	4.4%
	Median TCEY Region 2 (Mlbs)	21.1	19.6	22.0	19.7	18.4	20.4
	Median TCEY Region 3 (Mlbs)	35.3	24.1	51.0	32.0	22.0	46.5
	Median TCEY Region 4 (Mlbs)	8.6	6.9	9.9	7.7	6.2	8.8
	Median TCEY Region 4B (Mlbs)	2.5	2.3	2.8	2.3	2.1	2.5

5.2 Investigating fishing intensity

Using the 2023 OM, fishing intensity was evaluated using SPR values from 34% to 56% assuming an annual assessment and decision making variability, along with estimation error and observation error that would likely result from rationalized FISS surveys. Performance metrics associated with primary objectives and a performance metric for the probability that the biomass in that time-period will be less than the 2023 spawning biomass are shown in Table 5. Stock assessment frequencies other than annual were not simulated.

All fishing intensities pass the conservation objective to maintain the relative spawning biomass (RSB) above 20% with a probability greater than 95%, which occurs because the 30:20 control rule reduces fishing intensity at RSB less than 30%. As expected, with increasing fishing intensity (decreasing SPR) the long-term RSB has a higher probability of being less than 36% and would be above and below 36% an equal amount of time near an SPR value of 39%. The median short-term TCEY ranged from 44.8 Mlbs to 67.9 Mlbs and the median AAV ranged from 14.7% to 25.7%. An SPR of 52% resulted in a median AAV equal to 15%.

It is often useful to consider performance metrics not associated with the priority objectives. One metric reported in Table 5 is the probability that the biomass in the future (long-term and short-term presented) is less than the spawning biomass in 2023. In the long-term, there is a 1 in 10 chance that the spawning biomass is less than that in 2023 when fishing at a low fishing intensity of SPR=56%. At an SPR of 43% (the current interim reference fishing intensity) the chance is 1 in 5, in the long-term. The short-term shows slightly higher chances because recent recruitment has been low, which will continue to influence the stock size as these low recruitments move through the population age structure.

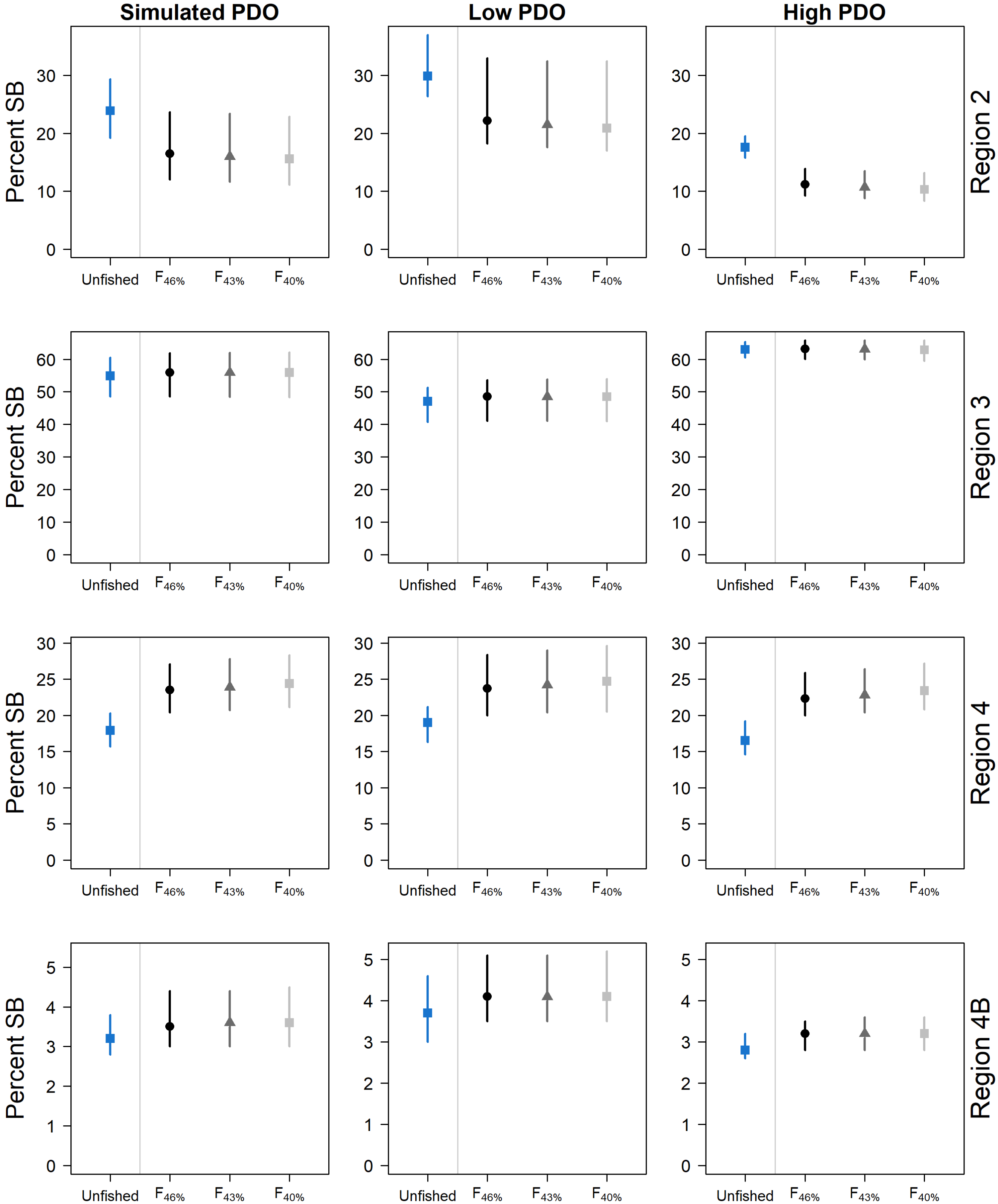

Figure 8. Percent biomass in each Region (rows) for simulated PDO (both low and high regimes), low PDO, and high PDO (columns) at different levels of fishing intensity.

Table 5. Performance metrics related to primary objectives for MSE simulations using different SPR values (i.e. fishing intensity, FI) assuming an annual assessment and decision making variability, along with estimation error and observation error that would likely result from rationalized FISS surveys.

		High Fishing intensity				**SPR**					Low Fishing intensity
Term	**Performance Metric**	**34**	**38**	**40**	**42**	**43**	**44**	**46**	**48**	**52**	**56**
Long	P(RSB<20%)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
	P(RSB<36%)	0.74	0.55	0.46	0.37	0.35	0.31	0.26	0.22	0.17	0.15
Short	Median TCEY	67.9	64.5	62.6	60.4	59.2	58.0	55.7	53.4	49.0	44.8
	Median AAV TCEY	25.7%	20.5%	18.9%	17.5%	17.0%	16.6%	16.0%	15.6%	15.0%	14.7%
Long	P(B<B_{2023})	0.26	0.23	0.22	0.21	0.20	0.19	0.17	0.16	0.12	0.10
Short	P(B<B_{2023})	0.45	0.38	0.34	0.31	0.29	0.28	0.24	0.20	0.15	0.12

Overall, there are trade-offs between amount of yield, variability in yield, and stock size (Figure 9). Yield increases with increasing fishing intensity (lower SPR), but at higher fishing intensities (SPR values less than approximately 40%) the yield relationship begins to show a decreasing slope because the 30:20 control rule is effectively reducing fishing intensity. The control rule decreases the effective fishing intensity and increases the variability in yield. This increase in the interannual variability of yield can be seen with the curvature in the AAV vs yield curve, and the AAV is greater than 19% at SPR values less than 40%. The probability that the RSB is less than 36% increases in a similar non-linear manner as the variability relationship with yield, with a rapid increase in the probability of lower stock size at higher fishing intensity. Interestingly, over the range of fishing intensities examined, the probability that the long-term spawning biomass would be less than the 2023 spawning biomass increases linearly with increasing fishing intensity or yield. In summary, as yield decreases the stock size is larger and variability in yield is smaller, but there are non-linear trends that are important to understand.

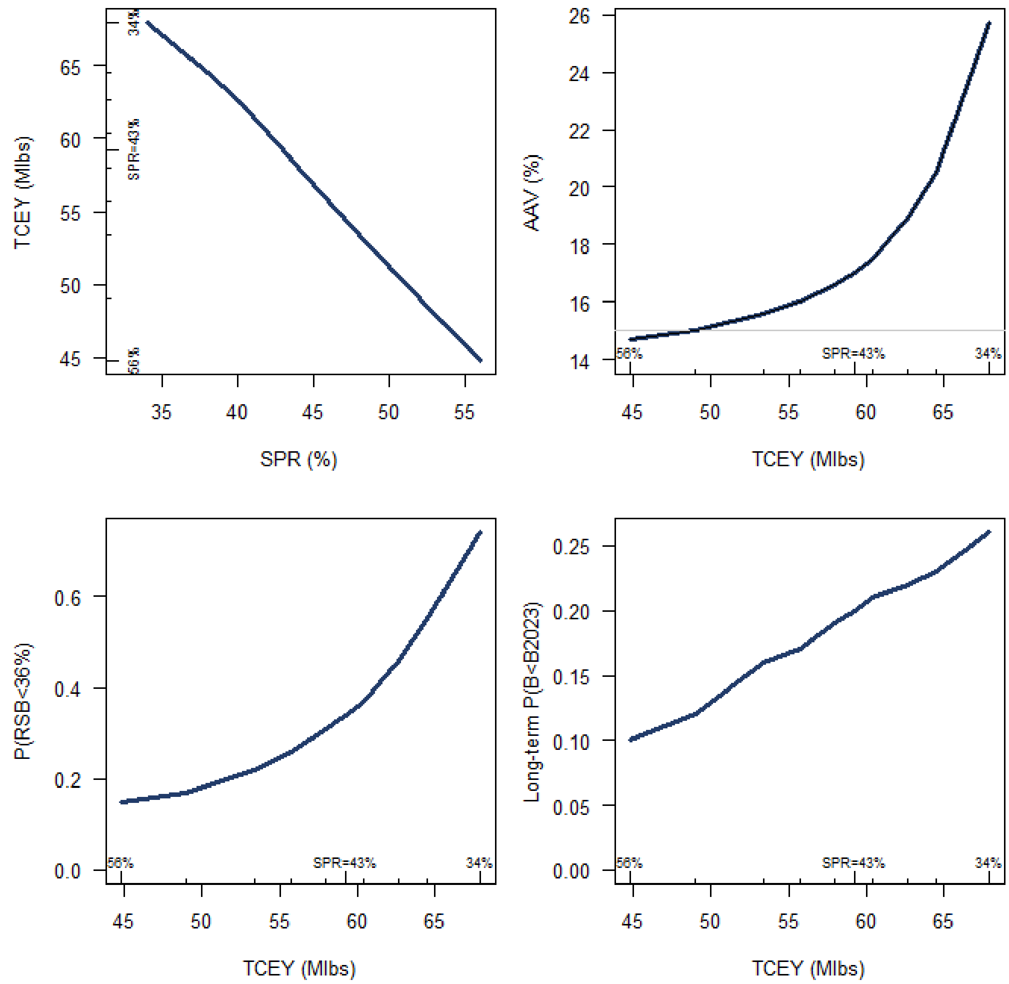

Figure 9. Relationships between TCEY, AAV, and stock size using various performance metrics. Corresponding SPR values are shown along the same axis that the TCEY is plotted.

RECOMMENDATION/S

1) The MSAB **NOTE** paper IPHC-2024-MSAB019-06 presenting recent MSE work including the 2023 operating model, exceptional circumstances, simulations exploring the effects of fishing and the environment, and an evaluation of various levels of fishing intensity.

REFERENCES

Cox, S. P. and Kronlund, A. R. 2008. Practical stakeholder-driven harvest policies for groundfish fisheries in British Columbia, Canada. Fisheries Research 94(3): 224-237.

de Moor, C.L., Butterworth, D., and Johnston, S. 2022. Learning from three decades of Management Strategy Evaluation in South Africa. ICES Journal of Marine Science 79: 1843-1852.

APPENDICES

Appendix A: Primary objectives used by the Commission for the MSE

APPENDIX A
PRIMARY OBJECTIVES USED BY THE COMMISSION FOR THE MSE

Table A1. Primary objectives, evaluated over a simulated ten-year period, accepted by the Commission at the 7th Special Session of the Commission (SS07). Objective 1.1 is a biological sustainability (conservation) objective and objectives 2.1, 2.2, and 2.3 are fishery objectives. Priority objectives are shown in green text.

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 the long-term coastwide female spawning stock biomass above a biomass limit reference point ($B_{20\%}$) at least 95% of the time	*B* < Spawning Biomass Limit (B_{Lim}) B_{Lim}=20% unfished spawning biomass	Long-term	0.05	$P(B < B_{Lim})$ PASS/FAIL Fail if greater than 0.05
	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	$P\left(p_{SB,R} < p_{SB,R,min}\right)$
2.1 MAINTAIN SPAWNING BIOMASS AT OR ABOVE A LEVEL THAT OPTIMIZES FISHING ACTIVITIES	Maintain the long-term coastwide female spawning stock biomass at or above a biomass reference point ($B_{36\%}$) 50% or more of the time	*B*<Spawning Biomass Reference (B_{Thresh}) B_{Thresh}=$B_{36\%}$ unfished spawning biomass	Long-term	0.50	$P(B < B_{Thresh})$ Fail if greater than 0.5
2.2. 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)*
2.3. 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

$$AAV_t = \frac{\sum_{t+1}^{t+9} |TCEY_t - TCEY_{t-1}|}{\sum_t^{t+9} TCEY_t}$$

$$AC_t = \frac{|TCEY_t - TCEY_{t-1}|}{TCEY_{t-1}}$$