MSE update on progress in 2024 and development of a revised Harvest Strategy Policy

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PURPOSE

To provide the Scientific Review Board (SRB) with an update on Management Strategy Evaluation (MSE) progress in 2024 and work supporting the development of the IPHC Harvest Strategy Policy (HSP).

1 INTRODUCTION

A 2024 MSE workplan was provided by the Commission through intersession decisions ID003 to ID007 (IPHC Circular 2024-015). This included investigating a new objective, evaluating management procedures (MPs), defining exceptional circumstances, drafting a harvest strategy policy, and investigating different FISS design scenarios. Many of these tasks were developed from past SRB recommendations, including recommendations related to MSE work made at the 24th session of the SRB (IPHC-2024-SRB024-R).

This document reports progress on these recommendations and how they support the development of a harvest strategy policy.

2 HARVEST STRATEGY POLICY

A Harvest Strategy Policy (HSP) provides a framework for applying a science-based approach to setting harvest levels. At the IPHC, this could be specific to the TCEY for each IPHC Regulatory Area throughout the Convention Area, or it could apply to coastwide decisions, leaving specific allocation among areas and sectors to the decision-making process. Currently, the IPHC has not formally adopted a harvest strategy policy but has set harvest levels under an SPR-based framework with elements adopted at multiple Annual Meetings of the IPHC since 2017.

The MSE work and guidance from the MSAB and SRB have been a very important part of developing the HSP. To move towards formally adopting a HSP at the IPHC in the near term, the SRB recommended separating the coastwide TCEY management procedure (MP) from the distribution procedure.

> **IPHC-2023-SRB023-R, para. 30:** *The SRB **RECOMMENDED** that the Commission consider revising the harvest policy to (i) determine coastwide TCEY via a formal management procedure and (ii) negotiate distribution independently (e.g. during annual meetings). Such separated processes are used in other jurisdictions (e.g. most tuna RFMOs, Mid Atlantic Fishery Management Council, AK Sablefish, etc.).*

The coastwide TCEY determined from the MP in the harvest strategy would be an input into the allocation decision-making process.

Therefore, the IPHC HSP can be divided into two components: management procedure and decision-making (Figure 1). The management procedure is an agreed upon method to determine the coastwide TCEY that best meets all conservation and fishery objectives. The MP must be reproducible and include elements such as how to collect data, how often to conduct a stock assessment, and the fishing intensity (i.e. SPR). A harvest strategy extends the MP to encompass objectives and other procedures such as exceptional circumstances. The harvest strategy policy further includes decision-making, where management may deviate from the outputs of the MP to account for other objectives not considered in the harvest strategy. This may be to modify the coastwide TCEY and/or the distribution of the TCEY to account for economic factors or other current conditions. At the IPHC, the policy component occurs at the Annual Meeting of the IPHC where stakeholder input is considered along with scientific information to determine the coastwide mortality limit and allocations to each IPHC Regulatory Area.

The MSE work presented here supports the continued development of the harvest strategy policy.

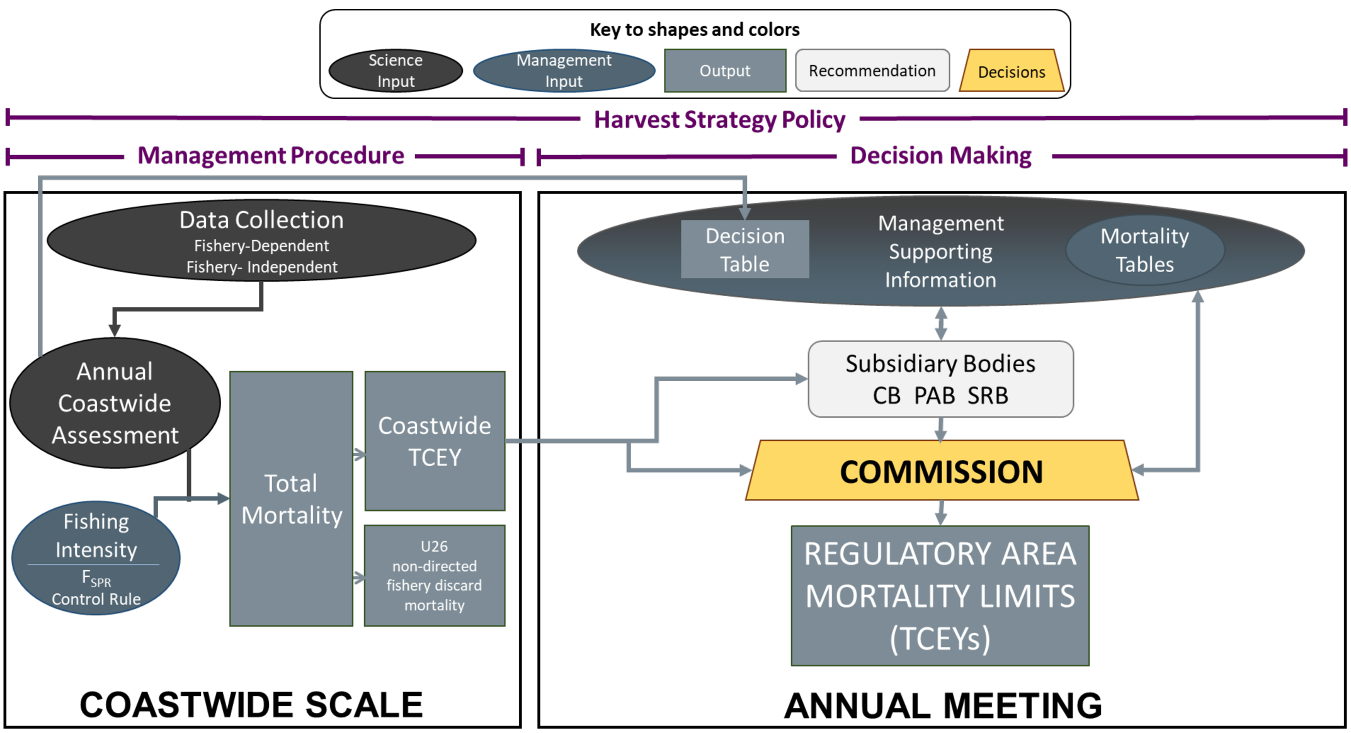

Figure 1. Illustration of the interim harvest strategy policy for the IPHC showing the determination of the coastwide TCEY (the management procedure at the coastwide scale) and the policy component that mainly occurs at the Annual Meeting.

2.1 Exceptional Circumstances

An exceptional circumstance is an event that is beyond the expected range of the MSE. Exceptional circumstances, which trigger specific actions to be taken if one is met, define a process for deviating from an adopted harvest strategy (de Moor, Butterworth, and Johnston 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.

The IPHC Secretariat, with the assistance of the SRB and MSAB, has defined 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). Triggers for an exceptional circumstance have been updated following further discussions with the SRB.

> **IPHC-2024-SRB024-R, para 25**. ***RECALLING*** *paper IPHC-2024-SRB024-03, Appendix A, SRB023-Rec.08 (para. 27), the SRB* ***RECOMMENDED****:*
>
> > *a) removing "exceptional circumstance" item c because the expected timeline of stock assessments and OM updates will automatically revise biological parameters and processes;*
> >
> > *b) removing "exceptional circumstance" item b because:*
> >
> > > *• even though the operating model is an adequate representation of the coastwide dynamics and is useful for development of a coastwide MP, additional work on the regional stock dynamics needs to be done to improve correspondence with regional observations;*
> > >
> > > *• improving estimation of regional stock dynamics is a longer-term project that the Secretariat will continue to work on with input from the SRB;*
> > >
> > > *• as per paragraph 21, the SRB suggests that the annual TCEY distribution should not be included in a MP.*

Therefore, one trigger, using coastwide WPUE or NPUE, for an exceptional circumstance has been defined.

> *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.*

The following actions may take place if an exceptional circumstance is declared.

> *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.

The MSAB was also interested in developing exceptional circumstances using fishery-dependent data.

IPHC-2024-MSAB019-R, para. 53: *The MSAB **NOTED** that the FISS is conducted to measure the population and that it may not be an accurate depiction of the fishery, and that fishery-dependent data may provide insights into fishery concerns that the FISS may not capture.*

IPHC-2024-MSAB019-R, para. 54: *The MSAB **REQUESTED** that the SRB and Secretariat work together to consider different ways to incorporate fishery-dependent data into an exceptional circumstance.*

The MSE simulations predict many types of fishery-dependent data (e.g. WPUE, age-compositions) which may be used to develop additional exceptional circumstances. It will be important to delineate between changes in fishery dependant data that should fall within the scope of the MSE predictions and those that may be caused by management actions not reflective of Pacific halibut stock dynamics (e.g. change in catch rates due to avoidance/targeting of other species). The response in these two cases may be different. Further consideration of exceptional circumstances incorporating fishery-dependent data will continue.

3 Goals and Objectives

The Commission defined four priority coastwide objectives and associated performance metrics for evaluating MSE simulations.

IPHC-2023-AM099-R, para. 76. *The Commission **RECOMMENDED** that for the purpose of a comprehensive and intelligible Harvest Strategy Policy (HSP), four coastwide objectives should be documented within the HSP, in priority order:*

a) Maintain the long-term coastwide female spawning stock biomass above a biomass limit reference point (B20%) at least 95% of the time.

b) Maintain the long-term coastwide female spawning stock biomass at or above a biomass reference point (B36%) 50% or more of the time.

c) Optimise average coastwide TCEY.

d) Limit annual changes in the coastwide TCEY.

IPHC-2023-AM099-R, para. 77. *The Commission **AGREED** that the performance metrics associated with the objectives in Paragraph 76 are:*

a) P(RSB): Probability that the long-term Relative Spawning Biomass (RSB) is less than the Relative Spawning Biomass Limit, failing if the value is greater than 0.05.

b) P(RSB<36%): Probability that the long-term RSB is less than the Relative Spawning Biomass Reference Point, failing if the value is greater than 0.50.

c) Median TCEY: the median of the short-term average TCEY over a ten-year period, where the short-term is 4-14 years in the future.

d) Median AAV TCEY: the average annual variability of the short-term TCEY determined as the average difference in the TCEY over a ten-year period.

These priority objectives and performance metrics come from a larger list of objectives which includes objectives specific to Biological Regions and IPHC Regulatory Areas (Appendix A).

In 2024, the SRB recommended reconsidering two of these objectives.

IPHC-2024-SRB024-R, para 22. *The SRB **RECOMMENDED** that the Commission develop a more specific and quantifiable catch objective to replace Objective c) (from AM099–Rec.02) "Optimize average coastwide TCEY".*

IPHC-2024-SRB024-R, para 23. *The SRB **RECOMMENDED** that the Commission consider revising Objective b) (from AM099–Rec.02) "Maintain the long-term coastwide female spawning stock biomass at or above a biomass reference point (B36%) 50% or more of the time" to utilise a lower percentile than the 50th (median) to reflect concerns associated with the implications of low CPUE for the fishery at the 36% target for relative spawning biomass. A lower percentile better captures the role of uncertainty in this performance measure.*

The 4th ad-hoc meeting of the MSAB met in July to discuss objectives, which is summarized in an informational document for MSAB020 (IPHC-2024-MSAB020-INF01). Some highlights include the following, which will be discussed at MSAB020.

10. A management procedure defined as a reference fishing intensity or more conservative would provide flexibility to the Commission to reduce fishing intensity when short-terms trends are of concern.

12. The objective "optimize yield" may include reducing interannual variability in yield.

13. A new objective may be defined using absolute biomass, commercial catch-rates, or TCEY. However, commercial catch-rates may not be the best option because they are dependent on other factors. TCEY and/or a reference absolute spawning biomass based on what has been observed may be more meaningful, but all have downsides in being a holistic metric. The MSAB should explore these metrics (and possibly FISS WPUE) for use in updating the objectives.

14. Evaluating MPs based on performance of the worst conditions (e.g. low productivity regime) may result in avoiding low stock sizes under any conditions.

15. Objectives, such as avoiding low stock sizes or low catch-rates, may be met by adding elements to the MP, such as reducing fishing intensity when the SB is below a threshold.

17. There is likely a desire to remain above the absolute spawning biomass in 2023 and the tolerance could be 80 or 90%

The 4th ad-hoc meeting of the MSAB discussed the objective "optimize yield" and realized that optimizing yield may include multiple factors such as high yields and low interannual variability. Both of these concepts are important objectives and will be discussed at MSAB020.

Much of the discussion at the 4th ad-hoc meeting of the MSAB centered around understanding the underlying objectives based on recent decisions to reduce the TCEY from the reference TCEY. This is due to a contrast between the stock status being above 36% (a healthy zone) and a continually declining absolute spawning biomass.

Pacific halibut have seen large changes in average weight-at-age and high variability in recruitment, which have changed the stock dynamics considerably. Figure 2 shows the dynamic unfished spawning biomass, the current spawning biomass, and the RSB since 1993. Dynamic unfished spawning biomass is lower than the late 1990's because weight-at-age has decreased considerably, and dynamic unfished spawning biomass has decreased in recent years because of a recent period of low recruitment. The current spawning biomass trajectory (with fishing) has been stable in recent years, resulting in an increasing RSB. Therefore, the Pacific halibut stock is likely to be above the B_{lim} (20%), B_{trigger} (30%), and B_{thresh} (36%) reference points.

However, the coastwide FISS O32 WPUE and coastwide commercial WPUE has been declining in recent years (Figure 3), causing concern about the absolute stock size and fishery catch-rates. The coastwide FISS index of O32 WPUE was at its lowest value observed in the time-series, declining by 3% from the previous year and coastwide commercial WPUE is also at its lowest value in the recent time-series, declining by 10% from the previous year (and likely more as additional logbook information is obtained). In contrast, the stock assessment for 2023 estimates current stock status (42%, Figure 2) above reference levels and a high probability of further decline in spawning biomass at the reference fishing intensity (SPR=43%). The reference coastwide TCEY of 48.9 Mlbs was projected to result in a greater than 70% chance that the spawning biomass in any of the next three years would be less than the spawning biomass in 2023. The long-term average RSB when fishing consistently at an SPR of 43% is estimated to be near 38%.

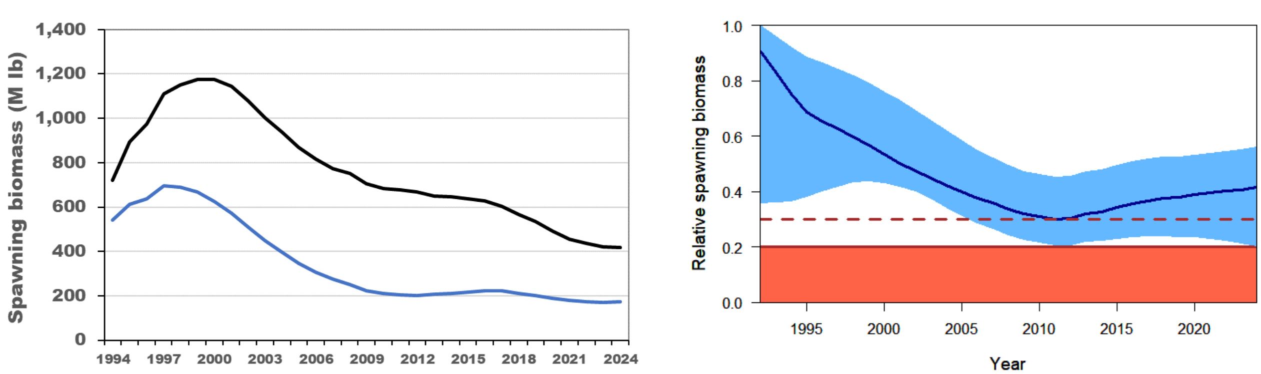

Figure 2. Dynamic unfished spawning biomass (black line) and current spawning biomass (blue line) from the 2023 stock assessment (left) and dynamic relative spawning biomass (right) with an approximate 95% credible interval in light blue and the control rule limit ($B_{20\%}$) and trigger ($B_{30\%}$) in red. Figures from IPHC-2024-SA-01.

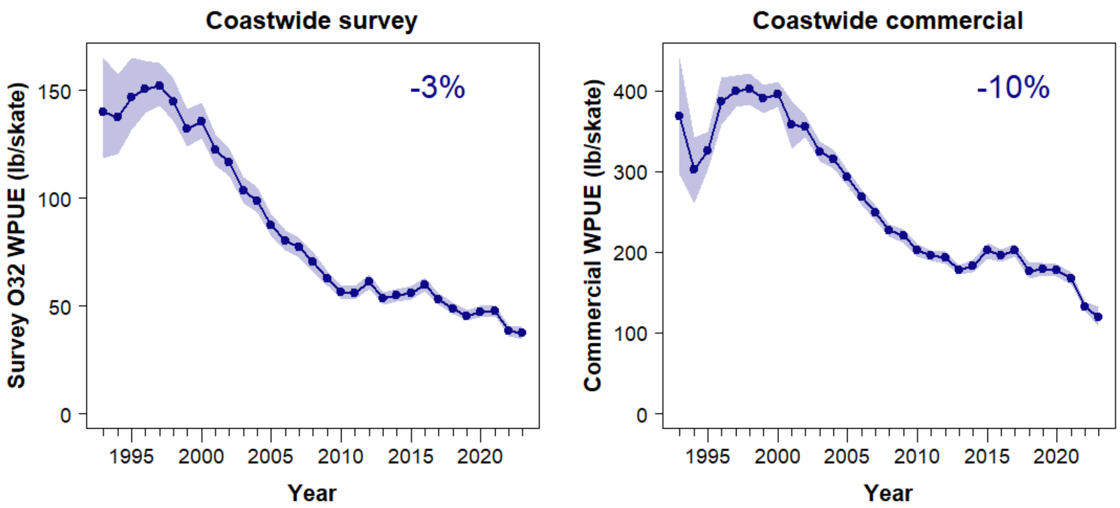

Figure 3. The coastwide FISS O32 WPUE index (left) and coastwide commercial WPUE (right) showing the percent change in the last year (from IPHC-2024-SA-02). Based on past calculations, additional logbooks collected in 2024 will likely further reduce the decline in commercial WPUE to -12%.

Recent Commission decisions (2023 and 2024) have set coastwide TCEYs less than the reference TCEY estimated by the stock assessment and current interim management strategy. Main concerns noted by the Commission include 1) low absolute spawning biomass, 2) low catch-rates in the commercial fishery, 3) high probability of decline in absolute spawning biomass at a fishing mortality above 39 Mlbs, and 4) a large amount of uncertainty in the projections.

The continued departure from the current interim MP and reduction in coastwide TCEY suggests that there may be an additional objective. Related to these concerns, the SRB initially made a recommendation to re-evaluate what they called the target objective (objective b), followed by the recommendation at SRB024 (IPHC-2024-SRB024-R, para 23).

> **IPHC-2023-SRB023-R, para. 25.** *The SRB* ***RECOMMENDED*** *that the Commission re-evaluate the target objective for long-term coastwide female spawning stock biomass given that estimated 2023 female spawning biomass (and associated WPUE), which was well-above the current target B36%, in part triggered harvest rate reductions from the interim harvest policy. Such ad-hoc adjustments limited the value of projections and performance measures from MSE.*

A higher threshold reference point could be achieved with a lower reference fishing intensity or an alternative control rule, such as 40:20. However, instead of updating the $B_{36\%}$ relative spawning biomass objective, it may better reflect recent Commission actions to consider an absolute spawning biomass, or catch-rate, threshold in a new objective.

Clark and Hare (2006) noted that “[t]he Commission’s paramount management objective is to maintain a healthy level of spawning biomass, meaning a level above the historical minimum that last occurred in the mid-1970s.” Thompson (1937) stated the following:

> *In actual practice, capital is accumulated in order that interest may be secured from it, and an accumulated stock of fish may also be profitable. The most obvious gain is the greater economy of effort in obtaining a catch from a larger accumulated stock. […] It not only means less effort, but also less time at sea before the catch is landed. (William F. Thompson, International Fisheries Commission, 1937)*

An objective to maintain the absolute spawning biomass above a threshold may be a useful objective for several reasons. First, the level of spawning biomass likely correlates with catch-rates in the fishery, and a higher spawning biomass would likely result in a more efficient and economically viable fishery. Second, current priority conservation objectives use dynamic relative spawning biomass which may result in a low absolute spawning biomass with a satisfactory stock status. Third, a minimum absolute coastwide spawning biomass may be necessary to ensure successful reproduction (such a level is currently unknown for Pacific halibut). Lastly, an observed reference stock level may have concrete meaning to stakeholders. For example, the recent estimated spawning biomass may be near or below the lowest spawning biomass estimated since the mid-1970's and observed fishery catch rates were historically low in 2022 and 2023.

One way to implement this new objective is to continue the use of a limit reference point for relative spawning biomass ($SB_{20\%}$) and add a fishery biomass limit reference point for which dropping below would result in serious hardships to the fishery. The fishery biomass limit reference point could be defined using an absolute metric in units of spawning biomass, fishery CPUE, FISS WPUE, or some other estimable quantity. A fishery limit reference point differs importantly from a fishing intensity limit, where the former is a threshold used to maintain catch-rates and the latter is a threshold used to indicate the potential for overfishing. A fishery absolute spawning biomass limit may also add extra protection for the stock by further reducing the probability of breaching existing limit and threshold reference points. A new objective related to fishery performance could be phrased as:

> *Maintain the coastwide female spawning stock biomass (or FISS WPUE or fishery catch-rates) above a threshold.*

The metric, the threshold value, and the tolerance for being below that threshold are not obvious choices. Clark and Hare (2006) used the estimated spawning biomass in 1974, which subsequently produced recruitment resulting in an increase in the stock biomass. However, there is a high uncertainty in the estimates of historical absolute spawning biomass before the 1990's. Recent estimates of spawning biomass may be reasonable as they are relevant to concerns of low catch-rates, but it is unknown how and if the stock will quickly recover from this current state.

If an efficient fishery is the objective, then fishery catch-rates may be a reasonable choice for the same reasons listed above for an absolute level of spawning biomass. A subtle difference between catch-rates and spawning biomass are that catch-rates may increase or decrease due to many factors (e.g. improvements in technology, avoidance of non-target species) without a change in spawning biomass.

The discussion of objectives is on the agenda for the 20th Session of the MSAB, where recommendations for updating the objectives will be made to the Commission. The Secretariat will summarize all recommendations from the MSAB and SRB related to these objectives and present them to the Commission at the 100th Interim Meeting of the IPHC and the 101st Annual Meeting of the IPHC.

4 Management Procedures, Methods, and Assumptions

The SRB made a recommendation at SRB023, which coincides with MSAB and Commission recommendations, providing guidance on management procedures (MPs) to evaluate. The investigation of these MPs will support the development of the harvest strategy policy.

> **IPHC-2023-SRB023-R, para. 29.** *The SRB **RECOMMENDED** evaluating fishing intensity and frequency of the stock assessment elements of management procedures and FISS uncertainty scenarios using the MSE framework. MP elements related to constraints on the interannual change in the TCEY and calculation of stock distribution may be evaluated for a subset of the priority management procedures as time allows.*

4.1 MP elements

Elements of MPs that were evaluated included assessment frequency, fishing intensity, and constraints on the interannual change in the TCEY.

4.1.1 Assessment frequency and an empirical management procedure

The frequency of conducting the stock assessment is a priority element of the MP to be investigated. This includes conducting assessments annually (every year), biennially (every second 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 updated.

The mortality limits in a year with a stock assessment can be determined as specified by previous defined MPs (i.e. SPR-based approach), and in years without a stock assessment, the mortality limits would need an alternative approach. There are many different empirical rules that could be applied to determine the coastwide TCEY in non-assessment years and two have been previously identified for evaluation.

a. A multi-year TCEY set constant until a stock assessment is available.
b. Update the coastwide TCEY proportionally to the change in the coastwide FISS O32 WPUE.

Other potential methods to set the TCEY in years without an assessment include, but are not limited to, the following.

c. Update the coastwide TCEY proportionally to the change in the coastwide FISS all-sizes WPUE.
d. Use projected TCEY's from the stock assessment with the reference SPR and control rule. This method is common among other fisheries management organizations.

e. Incorporate commercial fishery catch-rates into the empirical rule.

The MSAB requested collaboration between the Secretariat and the SRB to develop empirical rule options.

> **IPHC-2024-MSAB019-R, para 40:** ***RECALLING*** *paragraph 39 item a) the MSAB* ***REQUESTED*** *the Secretariat and SRB develop empirical rule options using the following possible sources of data:*
>
> *a) A static coastwide TCEY determined from the stock assessment;*
>
> *b) FISS O32 WPUE;*
>
> *c) Incorporation of commercial and FISS age data with FISS O32 WPUE.*

Another option, currently not being considered, is to use a simple statistical model, tuned to meet the objectives, that would determine the coastwide TCEY. Stock assessments would be completed periodically to update the status of the stock and verify that the management procedure is working appropriately.

4.1.2 Constraints

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%. Across those years, the percent change in the adopted coastwide TCEY ranged from -10% to 8% and the coastwide reference TCEY ranged from -21% to 29% (Table 1). This was a period of relatively stable spawning biomass and higher variability is expected when the stock is increasing or decreasing.

Decision-making since 2015 has reduced the interannual variability in the coastwide TCEY, compared to the reference. The adopted TCEYs have a smaller range than the reference TCEYs and tend to cluster around 39 million pounds (Figure 4). 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 1 & Figure 4). 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. Therefore, decision-making variability was modelled as a gaussian random process in the OM with a fixed standard deviation of 7Mlbs.

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 (TCEY increases by one-third of the increase suggested by the unconstrained MP or decreases by one-half of the decrease suggested by the unconstrained MP). The MSAB has requested further investigating constraints on the coastwide TCEY.

Table 1. 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.

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%

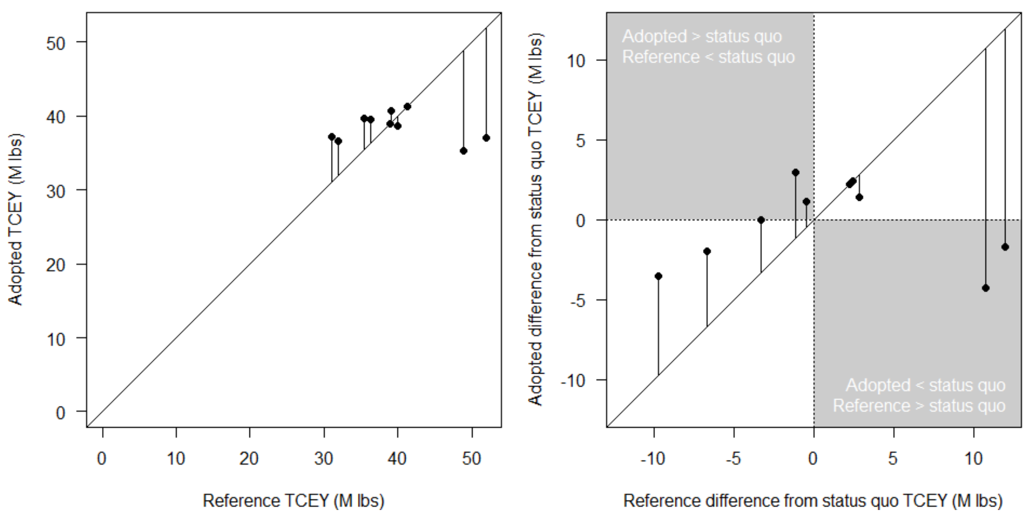

Figure 4. The adopted TCEY vs the reference TCEY (left) and the adopted difference from the status quo TCEY vs the reference difference from the status quo TCEY (right) for the last ten years (2015–2024). The 1:1 line shows when the two are equal. The grey quadrants in the right plot show when the adopted and reference TCEY differences from the status quo are opposite.

Constraints simulated in this round of MSE analyses included the following:

- A maximum 15% change in the coastwide TCEY in either direction from one year to the next.

Additional constraints will be evaluated in the future.

- A maximum 15% change in the coastwide TCEY only when the TCEY is increasing. There is no constraint when the TCEY is decreasing.

- A maximum 20% change in the coastwide TCEY in either direction from one year to the next.

4.1.3 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 distribution of yield across fisheries, SPR is a better indicator of fishing intensity and its effect on the stock than a single *F*. A range of SPR values between 35% and 52% (the interim reference SPR is currently 43%) were investigated.

4.1.4 Distribution of the TCEY

The distribution of the TCEY to IPHC Regulatory Areas is a necessary part of the harvest strategy, but is not a part of the management procedure currently being evaluated. Therefore, the distribution of the TCEY is a source of uncertainty in the MSE simulations. In the past, five distribution procedures spanning a range including recent Commission decisions were integrated into the simulations.

For these simulations, we implemented the approach recommended by the SRB.

> **IPHC-2024-SRB024-R, para 24**. ***NOTING*** *that the Operating Model (OM) requires a distribution of harvest across the IPHC Regulatory Areas even though distribution of the TCEY is not a recommended part of the MP, the SRB* ***RECOMMENDED*** *capturing uncertainty in future TCEY distribution via the approach described in IPHC-2024-SRB024-07, where the TCEY is distributed similar to what is done annually as part of the decision table construction process in the stock assessment.*

We used the observed distribution of the TCEY in recent years to define the simulated percentage of TCEY in each IPHC Regulatory Area. For the last six years, the TCEY in IPHC Regulatory Area 2A has been 1.65 M lbs (Table 2). Over the last twelve years, the adopted TCEY in IPHC Regulatory Area 2B has ranged from 17.1% to 20.8% of the coastwide TCEY with the three most recent years equal to 18.3% and no relationship with the coastwide TCEY (Table 3 and Figure 5). The simulated distribution of the TCEY to IPHC Regulatory Areas 2A and 2B was therefore simply 1.65 Mlbs for 2A and a randomly drawn percentage from a triangle distribution with percentages ranging from 17% to 21% for 2B with the mode of the distribution at 18.3%.

The simulated TCEY in IPHC Regulatory Areas in Alaska was distributed after the TCEY had been distributed to IPHC Regulatory Areas 2A and 2B. A year was randomly sampled, and the observed percentages in only Alaskan areas were used (Table 4).

Table 2. Adopted TCEYs (millions of pounds) for each IPHC Regulatory Area from 2013 to 2024.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
2013	1.11	7.78	5.02	17.07	5.87	2.43	1.93	4.28	45.48
2014	1.11	7.64	5.47	12.05	3.73	1.56	1.49	3.58	36.65
2015	1.06	7.91	6.2	13.00	3.72	1.96	1.53	4.27	39.63
2016	1.26	8.24	6.54	12.75	3.41	1.95	1.37	4.07	39.59
2017	1.47	8.32	7.04	12.96	3.98	1.80	1.34	3.84	40.74
2018	1.32	7.10	6.34	12.54	3.27	1.74	1.28	3.62	37.21
2019	1.65	6.83	6.34	13.5	2.90	1.94	1.45	4.00	38.61
2020	1.65	6.83	5.85	12.2	3.12	1.75	1.31	3.9	36.60
2021	1.65	7.00	5.80	14.00	3.12	2.05	1.40	3.98	39.00
2022	1.65	7.56	5.91	14.55	3.90	2.10	1.45	4.10	41.22
2023	1.65	6.78	5.85	12.08	3.67	1.73	1.36	3.85	36.97
2024	1.65	6.47	5.79	11.36	3.45	1.61	1.25	3.7	35.28

Table 3. Adopted percentage of the coastwide TCEY (millions of pounds) for each IPHC Regulatory Area from 2013 to 2024.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE
2013	2.4%	17.1%	11.0%	37.5%	12.9%	5.3%	4.2%	9.4%
2014	3.0%	20.8%	14.9%	32.9%	10.2%	4.3%	4.1%	9.8%
2015	2.7%	20.0%	15.6%	32.8%	9.4%	4.9%	3.9%	10.8%
2016	3.2%	20.8%	16.5%	32.2%	8.6%	4.9%	3.5%	10.3%
2017	3.6%	20.4%	17.3%	31.8%	9.8%	4.4%	3.3%	9.4%
2018	3.5%	19.1%	17.0%	33.7%	8.8%	4.7%	3.4%	9.7%
2019	4.3%	17.7%	16.4%	35.0%	7.5%	5.0%	3.8%	10.4%
2020	4.5%	18.7%	16.0%	33.3%	8.5%	4.8%	3.6%	10.7%
2021	4.2%	17.9%	14.9%	35.9%	8.0%	5.3%	3.6%	10.2%
2022	4.0%	18.3%	14.3%	35.3%	9.5%	5.1%	3.5%	9.9%
2023	4.5%	18.3%	15.8%	32.7%	9.9%	4.7%	3.7%	10.4%
2024	4.7%	18.3%	16.4%	32.2%	9.8%	4.6%	3.5%	10.5%

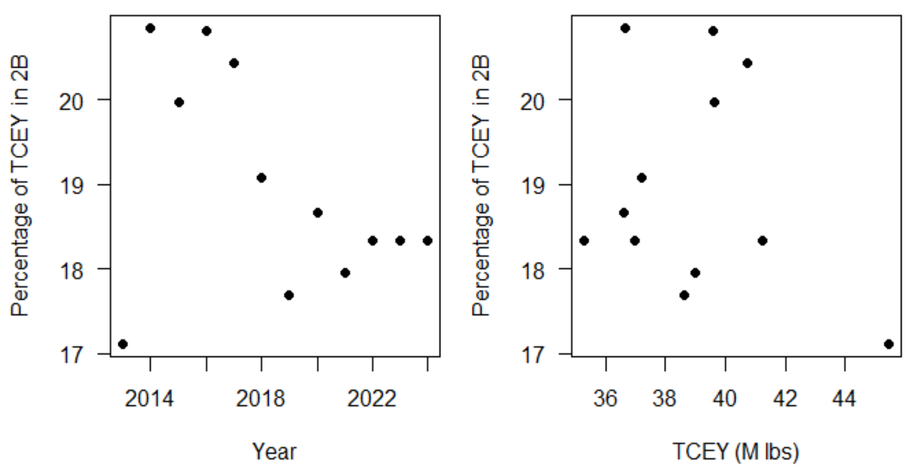

Figure 5. The percentage of the coastwide TCEY in IPHC Regulatory Area 2B plotted against year (left) and the coastwide TCEY (right).

Table 4. Percentage of the adopted TCEY for Alaskan IPHC Regulatory Areas only in each Alaskan IPHC Regulatory Area. IPHC Regulatory Areas 2A and 2B are omitted.

Year	2C	3A	3B	4A	4B	4CDE
2013	13.7%	46.6%	16.0%	6.6%	5.3%	11.7%
2014	19.6%	43.2%	13.4%	5.6%	5.3%	12.8%
2015	20.2%	42.4%	12.1%	6.4%	5.0%	13.9%
2016	21.7%	42.4%	11.3%	6.5%	4.6%	13.5%
2017	22.7%	41.9%	12.9%	5.8%	4.3%	12.4%
2018	22.0%	43.6%	11.4%	6.0%	4.4%	12.6%
2019	21.0%	44.8%	9.6%	6.4%	4.8%	13.3%
2020	20.8%	43.4%	11.1%	6.2%	4.7%	13.9%
2021	19.1%	46.1%	10.3%	6.8%	4.6%	13.1%
2022	18.5%	45.5%	12.2%	6.6%	4.5%	12.8%
2023	20.5%	42.3%	12.9%	6.1%	4.8%	13.5%
2024	21.3%	41.8%	12.7%	5.9%	4.6%	13.6%

4.2 FISS designs

An element of the management procedure that can be evaluated is the collection of data from the FISS. The FISS design was reduced from the proposed scientific designs in 2022, 2023, and 2024 to maintain revenue neutrality and future reductions may be necessary. The SRB made two recommendations to evaluate FISS designs using the MSE framework:

> **IPHC-2024-SRB024-R, para** 35. *The SRB **REQUESTED** that the Secretariat present preliminary (at SRB025) and final (at SRB026) results of MSE runs with different FISS designs to better understand the actual net cost of the survey after accounting for potential reductions in TCEY associated with the increased uncertainty from reduced FISS designs.*

> **IPHC-2024-SRB024-R, para** 43. *The SRB **REQUESTED** that the Secretariat integrate FISS design considerations into the annual MSE workplan and 5-Year Program of Integrated Research and Monitoring to better quantify the value provided by the FISS.*

There are three sources of variability and uncertainty in the simulations, all of which may be affected by the FISS design.

- **FISS uncertainty** affects the estimates of FISS WPUE and NPUE directly. This is used in the empirical rule and affects the stock assessment estimates. It may have some feedback into decision-making variability.
- **Estimation error** is from the stock assessment and is influenced by FISS uncertainty. Estimation error is also influenced by the variability in the population and fishery-dependent data.
- **Decision-making variability** is the variability resulting from decisions made by the Commission to depart from the MP. This could be affected by bias in the FISS and assessment estimates because the Commission may respond similarly based on the trends they perceive (e.g. autocorrelation in the deviations from the MP). It is possible to correlate decision-making with the FISS estimate, but this may mimic a control rule (i.e. element of the MP) and would conflate the estimation error with the decision-making

variability, possibly making performance metrics, such as the probability that the spawning biomass is less than the 2023 spawning biomass, less meaningful. FISS uncertainty is not currently modelled with an effect on decision-making variability.

The MSE framework is capable of examining FISS designs, given the necessary inputs. Projections of estimated uncertainty of FISS O32 WPUE (see document IPHC-2024-SRB024-06) and simulations investigating the outcomes of the stock assessment given different FISS design assumptions (see IPHC-2024-SRB025-06) informed the inputs to the MSE simulations. Unlike the stock assessment simulations, where specific trends in the population are investigated, the MSE simulations have emergent trends influencing uncertainty and bias.

Four FISS designs were simulated, representing increasing observation and assessment error (Table 5). A few simulations assuming no observation error were also included for comparison. The Base FISS design represents an ideal sampling approach with a random selection of stations occurring in all areas. The Base Block FISS design includes sampling in all Biological Regions and IPHC Regulatory Areas each year. It relies on a rotating selection of entire charter regions where individual charter regions are sampled every 1-5 years. The Core FISS design samples charter regions in IPHC Regulatory Areas 2B, 2C, 3A, and 3B every year and other areas are not surveyed. The Reduced Core FISS design samples a subset of higher catch-rate charter regions in areas 2B, 2C, 3A, and 3B. Bias is expected in the Core and Reduced Core FISS designs because some areas are not surveyed. It would not be expected that either of these core designs would be implemented in perpetuity without occasionally surveying other areas.

Table 5. Assumptions of observation and estimation error for four FISS designs.

FISS Design	Frequency	Coastwide WPUE CV	Coastwide WPUE Bias	Assessment Uncertainty	Assessment Bias
Base	Every year	3%	None	15%	None
Base Block	Every year	4%	None	18%	None
Core	2-4 years	6%	Increases annually up to 3%	19%	Increases annually up to 2%
Reduced Core	2-4 years	8%	Increases annually up to 4%	20%	Increases annually up to 2.5%

The Core FISS and Reduced Core FISS designs have additional details in how bias is modelled. Bias is additive depending on the trend in spawning biomass, and is halved when a survey is done on non-core areas. When the spawning biomass is large, the survey is more likely to be revenue neutral increasing the ability to survey non-core areas.

Core FISS design

- Frequency
    - When the spawning biomass is less than the spawning biomass in 2020 other areas are surveyed every 5th year and bias is reduced by one-half.
    - When the spawning biomass is greater than the spawning biomass in 2020 other areas are surveyed every 3rd year and bias is reduced by one-half.
- FISS bias
    - Bias depends on recent 3-year coastwide trend and the number of years without a block design surveying non-core areas:
        - 0-5%: ±0.5% bias added to current bias. Sign chosen randomly.
        - 5-15%: annual increase of 1% bias opposite direction of trend
        - 15-30%: annual increase of 2% bias opposite direction of trend
        - >30%: annual increase of 3% bias opposite direction of trend

- Assessment bias
    - Bias depends on recent 3-year coastwide trend and the number of years without a block design surveying non-core areas:
        - 0-5%: ±0.25% bias added to current bias. Sign chosen randomly.
        - 5-15%: annual increase of 0.5% bias opposite direction of trend
        - 15-30%: annual increase of 1% bias opposite direction of trend
        - >30%: annual increase of 2% bias opposite direction of trend

Reduced Core FISS design

- Frequency
    - When the spawning biomass is less than the spawning biomass in 2020 other areas are surveyed every 5th year and bias is reduced by one-half.
    - When the spawning biomass is greater than the spawning biomass in 2020 other areas are surveyed every 3rd year and bias is reduced by one-half.
- FISS bias
    - Bias depends on recent 3-year coastwide trend and the number of years without a block design surveying non-core areas
        - 0-5%: ±0.5% bias added to current bias. Sign chosen randomly.
        - 5-15%: annual increase of 2% bias opposite direction of trend
        - 15-30%: annual increase of 3% bias opposite direction of trend
        - >30%: annual increase of 4% bias opposite direction of trend
- Assessment bias
    - Bias depends on recent 3-year coastwide trend and the number of years without a block design surveying non-core areas
        - 0-5%: ±0.25% bias added to current bias. Sign chosen randomly.
        - 5-15%: annual increase of 0.75% bias opposite direction of trend
        - 15-30%: annual increase of 1.5% bias opposite direction of trend
        - >30%: annual increase of 2.5% bias opposite direction of trend

The MSE analysis of FISS designs will not capture the stakeholder perception and possible lack of confidence in the FISS as a tool for management. FISS observations have been important for the stock assessment, distribution of the TCEY, general understanding of the trends in each IPHC Regulatory Area, and in negotiations of the coastwide and area-specific TCEYs.

4.3 Depensation

The Pacific halibut population has shown a high amount of variability in spawning biomass over 100 years of commercial fishing, sometimes increasing to high levels quickly after a low period. However, if a population experiences a very low number of spawners, it may have reduced reproductive success. Depensation occurs if the per-capita rate of growth decreases as the density or abundance decreases to low levels (Liermann and Hilborn 2001). In other words, it is inverse density dependence at low population sizes and is also referred to as the Allee effect (Dennis 2002).

There are many mechanisms that may result in depensation (Liermann and Hilborn 2001), such as increased adult mortality observed in Northwest Atlantic cod (*Gadus morhua*) stocks (Kuparinen and Hutchings 2014). It is not known if Pacific halibut may experience depensation, but MSE is a useful tool to examine the effects on the population and management outcomes if depensation was present. The SRB recommended examining the effects of possible depensation in the Pacific halibut stock using the MSE framework.

> **IPHC-2024-SRB024-R, para** 29. *The SRB **NOTED** the analysis of depensation presented in paper IPHC-2024-SRB024-07, and **RECOMMENDED**:*
>
> > *a) fitting a depensatory stock-recruitment model to estimate the depensation parameter value;*
> >
> > *b) operating model stress tests in the MSE with and without depensation across a range of plausible fishing intensities.*

The stock-recruitment elements of the operating model were updated to allow for a depensation parameter following Liermann and Hilborn (1997).

$$R_t = \frac{\alpha S^{\delta}}{\beta^{\delta} + S_t^{\delta}}$$

where R_t is the number of recruits at time t, S_t is the spawning biomass at time t, α is the maximum number of predicted recruits (asymptote), β is the level of spawners that produces $\alpha/2$ recruits, and δ is the depensation parameter. A value greater than 1 for δ indicates depensation. The Pacific halibut stock assessment (and many other stock assessments from around the world) use the steepness parameterization (Mace and Doonan 1998) and use steepness, R_0, and B_0 to calculate the α and β parameters. The derived parameter B_0 is a function of R_0 and other life-history parameters.

$$\alpha = \frac{\left(5^{\delta} - 1\right) R_0 h}{5^{\delta} h - 1}$$

$$\beta^{\delta} = \frac{B_0^{\delta}(1 - h)}{5^{\delta} h - 1}$$

An example Beverton-Holt stock-recruit curve is shown in Figure 6 with these various parameters and concepts labeled.

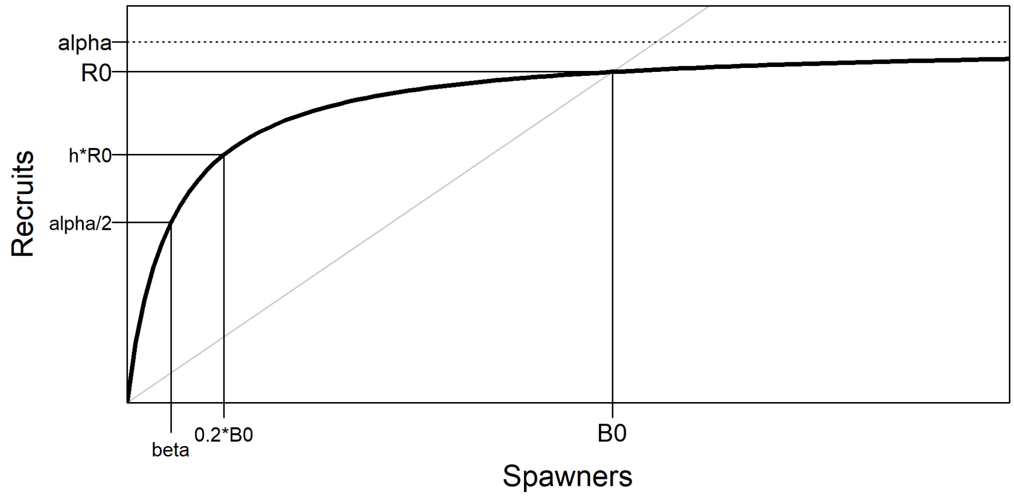

Figure 6. An example Beverton-Holt stock-recruit curve with various parameters and concepts labeled.

Environmental effects may change R_0, which changes the stock-recruit curve. For example, the Pacific halibut stock assessment assumes a steepness of 0.75 and estimates R_0 (and thus B_0) for two different environmental regimes related to periods of low or high Pacific Decadal Oscillation (PDO). Therefore, in each regime, the α and β parameters would be different resulting in different stock-recruit relationships, which should be accounted for in the calculation of recruitment. Figure 7 shows the estimated Beverton-Holt stock-recruit curves for the two regimes within the two 'long' models of the Pacific halibut stock assessment ensemble.

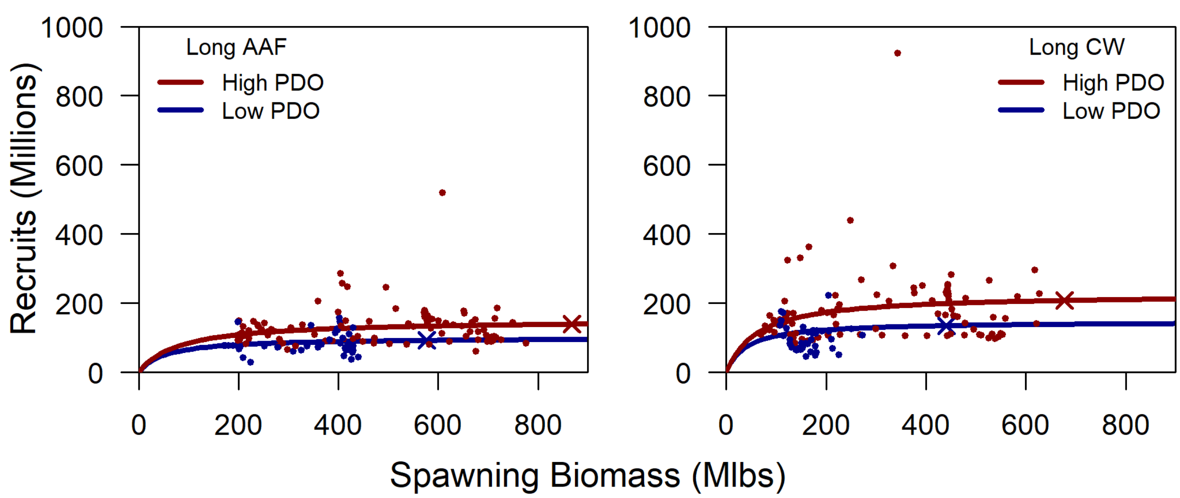

Figure 7. Beverton-Holt stock-recruit curves for two regimes as estimated in the two long models of the stock assessment ensemble. Points are estimated recruits at spawning biomass and the Xs mark the unfished equilibrium R_0 and B_0.

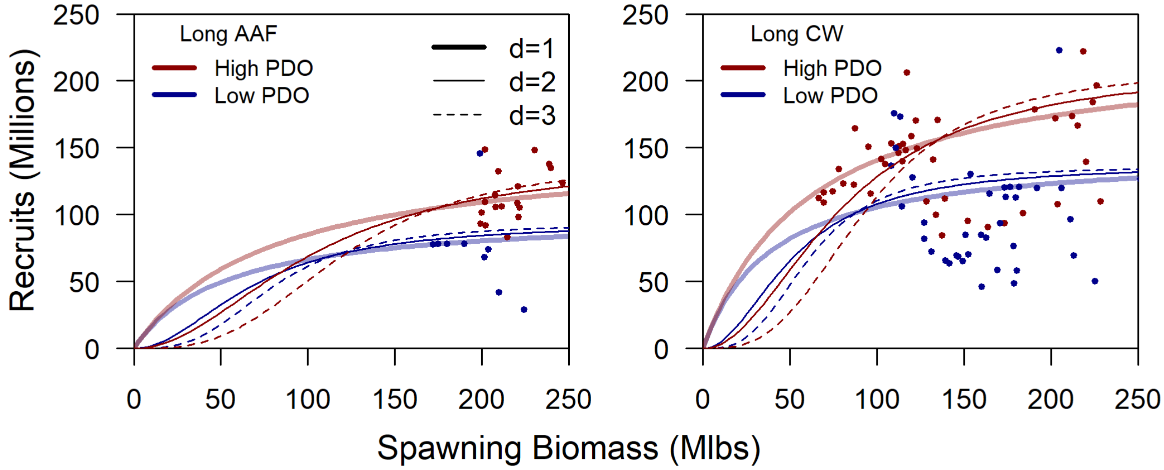

Figure 8. Beverton-Holt stock-recruit curves for the two regimes as estimated in the two long models of the stock assessment ensemble with three different values for depensation. Points are estimated recruits at spawning biomass. Axes have been truncated to focus on the change in the curve at low spawning biomass.

Using the above formulation, depensation with δ at values greater than 1 shows a steepening of the curve at low spawning biomass with a resulting increase in recruits above the curve to meet the consistent R_0.

Estimates of recruitment and estimates of spawning biomass from the two 'long' models in the 2023 stock assessment ensemble were treated as data in a Beverton-Holt stock-recruit model to estimate three parameters, including depensation. The independent and dependent 'observations' (i.e. stock assessment outputs) are both subject to uncertainty, but spawning biomass was treated as a known (i.e. independent) variable in this analysis.

For each long model (LongAAF and LongCW) three analyses were done: 1) all data were combined into a single analysis to estimate the stock-recruit parameters, 2) only recruits and spawning biomass from years with a positive PDO were used, and 3) only recruits and spawning biomass from years with a negative PDO were used. For each analysis, the set of parameters that minimized the lognormal likelihood of observed and predicted recruitment were found using 'optim' in R. A likelihood profile of the depensation parameter determined the 95% confidence interval as the values of δ that produced a likelihood that was 1.92 units away from the minimum.

From the investigation of depensation (results reported below) MSE simulations were done using two levels of depensation, three fishing intensities, and the base block FISS design (Table 6). The average recruitment changed with regime, but the α and β parameters in the stock-recruit relationship were not updated for each recruitment regime (to be consistent with the conditioned OM models). Recruitment was calculated as follows in the OM.

$$R_{s|t} \quad = \quad p_s \times f(B^{sp}_{s=1}) \times e^{(\varepsilon_t - b_t \frac{\sigma_R^2}{2})} \times e^{I_t \gamma} \tag{1}$$

where p_s is the proportion of sex s (0.50), $f(B^{sp}_{s=1})$ is the equilibrium stock-recruit relationship using α and β parameters determined from the low PDO average recruitment and the beginning of the current time-step spawning biomass (superscripts) for females, e^{ε_t} is the annual deviation in recruitment for time-step t, b_t is a bias-correction multiplier for time-step t (Methot and Taylor

2011), and $e^{I_t \gamma}$ is an overall adjustment for changes in recruitment due to regime shifts. Improvements to the stock-recruit modelling with different environmental regimes is expected in the future.

Furthermore, introducing depensation to the operating models changes the stock-recruit function and recruitment deviations without depensation would not necessarily match with recruitment deviations estimated with depensation. Models, however, were not reconditioned by incorporating depensation.

Table 6. Specifications of MSE simulations investigating depensation.

Parameter	**Values**
Depensation (δ)	δ = 1 or 2
SPR	35%, 43%, 52%
FISS design	Base block

The spawning biomass of Pacific halibut is currently at low values and may be at the lowest values observed historically. However, stock status remains above 30% and the spawning biomass of Pacific halibut has likely remained above levels where depensation can be detected, if present. Therefore, parameterizing depensation in the MSE simulations is largely a theoretical exercise to conduct a “stress-test” and show the potential effects if present.

4.4 Summary of MSE simulations

The Base Block FISS design was used to compare other elements of the MPs such as assessment frequency, constraints, and depensation (Table 7). Assessment frequencies of annual, biennial, and triennial were simulated with an empirical rule proportional to FISS O32 WPUE. No constraint was contrasted with a constraint on the coastwide TCEY of 15% in both directions (15% u). A depensation level of 2 was contrasted over three fishing intensities.

Table 7. MSE simulations using the Base Block FISS design and decision-making variability.

Empirical Rule		Proportional to FISS O32			NA	NA	NA
Depensation		None			None	None	δ=2
Constraint		None			15% u/d	15% u	None
Assessment		Annual	Biennial	Triennial	Annual	Annual	Annual
SPR	35						
	40						
	43						
	46						
	49						
	52						

Simulations with the Core and Reduced Core FISS designs were done with only the annual assessment frequency and four levels of fishing intensity from 43% to 52%. Simulations using the Base FISS design and simulations without estimation, observation, and decision-making variability were done only with a fishing intensity of 43%.

5 RESULTS

5.1 Evaluating MP elements

Assessment frequency, different fishing intensities (SPR), and a constraint were simulated assuming a Base Block FISS design with estimation error and decision-making variability. Performance metrics associated with the four priority objectives are shown in Table 8. The probability of being below a relative spawning biomass (RSB) of 36% was similar for each assessment frequency at the same fishing intensity, and an SPR of 40% resulted in an RSB near 36%. The short-term median TCEY was increase and the AAV decreased as the assessment frequency increased; this is opposite of the expected pattern that a greater TCEY results in a higher AAV. The AAV was lowest with the triennial assessment frequency, but was greater than 15% (a past benchmark defined by the MSAB) for all fishing intensities and assessment frequencies. For the annual and biennial assessment frequencies, the AAV was lowest (but above 22%) for a fishing intensity of 46% and increased with lower and higher fishing intensities. This may be a consequence of how decision-making variability was modelled (i.e. constant standard deviation).

Results with no observation error, no estimation error, and no decision-making variability show a slightly higher median TCEY and a much lower AAV (Table 9). Some variability remains in the interannual change in the TCEY due to the annual assessment tracking changes in the population. However, the AAV was near 12% for the biennial and triennial assessment frequencies because the TCEY is proportional to the FISS O32 WPUE which is a different demographic of the population than is tracked using SPR, and when the assessment occurred it resulted in a large correction to maintain the SPR. Using all sizes FISS WPUE may result in a reduced AAV for biennial and triennial assessment frequencies.

Table 8. Performance metrics associated with priority objectives for various fishing intensities (SPR) and an annual, biennial, or triennial assessment with an empirical rule proportional to FISS O32 WPUE used to determine the TCEY in non-assessment years. All simulations assumed the Base Block FISS design, estimation error, and decision-making variability. No constraints are applied to the interannual change in the TCEY. Relative spawning biomass (RSB) performance metrics are long-term and yield based performance metrics (TCEY and AAV) are short-term metrics.

Assessment Frequency	**Annual**				
SPR	**40**	**43**	**46**	**49**	**52**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.4534	0.2466	0.0896	0.0144	0.0012
Median TCEY	64.26	60.11	56.08	52.03	47.87
AAV	25.3%	24.2%	23.5%	23.5%	23.7%
Assessment Frequency	**Biennial**				
SPR	**40**	**43**	**46**	**49**	**52**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.4638	0.2912	0.1294	0.0400	0.0066
Median TCEY	64.96	60.38	56.28	52.27	48.17
AAV	23.3%	22.6%	22.5%	22.8%	23.5%
Assessment Frequency	**Triennial**				
SPR	**40**	**43**	**46**	**49**	**52**

P(RSB<20%)	<0.002	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.4624	0.2634	0.1198	0.0362	0.0036
Median TCEY	64.93	61.00	56.66	52.53	48.63
AAV	18.0%	17.2%	16.7%	16.2%	15.9%

Table 9. Performance metrics associated with priority objectives for an SPR of 43% and an annual, biennial, or triennial assessment with an empirical rule proportional to FISS O32 WPUE used to determine the TCEY in non-assessment years. All simulations assumed **no observation error**, **no estimation error**, and **no decision-making variability**. No constraints are applied to the interannual change in the TCEY. Relative spawning biomass (RSB) performance metrics are long-term and yield based performance metrics (TCEY and AAV) are short-term metrics.

Assessment Frequency	Annual	Biennial	Triennial
P(RSB<20%)	<0.002	<0.002	<0.002
P(RSB<36%)	0.2438	0.2534	0.2652
Median TCEY	60.34	61.08	61.69
AAV	6.2%	11.5%	12.0%

Including a constraint of 15% when the TCEY goes up or down in the MP reduced the AAV, but the AAV remained above 15% with decision-making variability (Table 10). With a constraint, the median TCEY was less, resulting in a smaller probability of the RSB being less than 36%. The 15% constraint resulted in a lower potential range of TCEYs with the 5th percentile of the TCEY as low as 14.7 M lbs (Figure 9).

Table 10. Performance metrics associated with priority objectives for an SPR of 43%, an annual assessment with and without a 15% constraint on the change in the TCEY, and with and without decision-making variability. All simulations assumed the Base Block FISS design. Relative spawning biomass (RSB) performance metrics are long-term and yield based performance metrics (TCEY and AAV) are short-term metrics.

Decision-making variability	No	No	Yes	Yes
Constraint	**None**	**15%**	**None**	**15%**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.2420	0.0564	0.2466	0.0506
Median TCEY	59.92	52.30	60.11	49.51
AAV	20.8%	14.5%	24.2%	16.6%

Overall, the range of SPR values investigated and the three assessment frequencies met the conservation objective and the objective to remain above an RSB of 36% at least 50% of the time. The TCEY increased with higher fishing intensity and was slightly higher with a longer interval between assessments. The interannual variability in the TCEY was greater than 15% but lowest with a triennial assessment frequency. AAV decreased with decreasing fishing intensity when the assessment frequency was every third year.

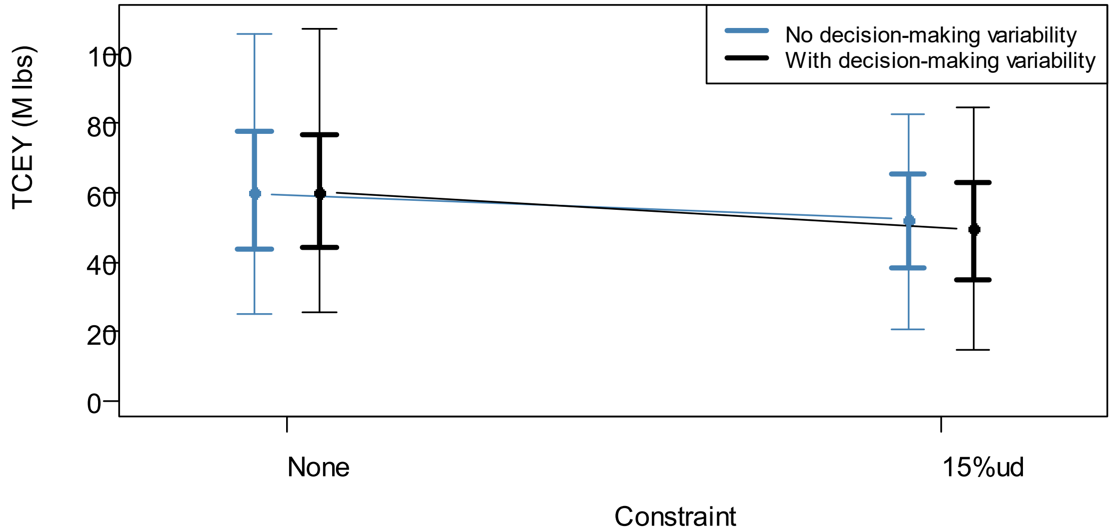

Figure 9. The TCEY (M lbs) for simulations with and without a constraint (15% maximum change up or down) and with and without decision-making variability. All simulations assumed the Base Block FISS design, an annual assessment, and an SPR of 43%. Light whiskers show the 5-95% interval, dark whiskers the 25-75% interval and the dot the median.

5.2 FISS Designs

The three FISS designs were compared across multiple fishing intensities, but with the annual assessment frequency only. Decision-making variability was present in all simulations.

The conservation objective of remaining above an RSB of 20% was met for all fishing intensities and FISS designs (Table 11). The probability that the RSB was less than 36% decreased with the reduced FISS designs, indicating that the population size was slightly larger when the non-core areas were not sampled. This occurred because the median TCEY was less when using the Core FISS design compared to the Base Block FISS design, and was less again when using the Reduced Core FISS design compared to the Core FISS design. The AAV increased with the Core and Reduced Core FISS designs (Figure 10).

With an SPR of 43%, the median TCEY declined by 450,000 lbs moving to the Core FISS design from the Base Block FISS design, and another 450,000 lbs moving to the Reduced Core FISS design. At $6.00/lb, a 450,000 lb drop in the TCEY would equate to a $2.7 million reduction in economic value. A similar drop occurred for an SPR of 52%. This metric includes the long-term, multi-year result where a reduction in the TCEY may provide fish for future years to spawn or be caught at a larger size. This may be why this value is less than the value determined from the stock assessment simulation results reported in document IPHC-2024-SRB025-06. As also discussed in document IPHC-2024-SRB025-06, there is a non-economic value to the FISS in that it is used for decision-making, comparisons, and to have a better understanding of the population trends.

Table 11. Performance metrics associated with priority objectives for various fishing intensities (SPR) and different FISS designs. All simulations assumed an annual assessment and decision-making variability. No constraints were applied to the interannual change in the TCEY. Relative spawning biomass (RSB) performance metrics are long-term and yield based performance metrics (TCEY and AAV) are short-term metrics.

FISS design	**Base Block**			
SPR	**43%**	**46%**	**49%**	**52%**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.2466	0.0896	0.0144	0.0012
Median TCEY	60.11	56.08	52.03	47.87
AAV	24.2%	23.5%	23.5%	23.7%
FISS design	**Core**			
SPR	**43%**	**46%**	**49%**	**52%**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.2308	0.0856	0.0164	0.0010
Median TCEY	59.66	55.30	51.23	47.32
AAV	24.9%	24.0%	24.0%	24.4%
FISS design	**Reduced Core**			
SPR	**43%**	**46%**	**49%**	**52%**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.2256	0.0860	0.0180	0.0012
Median TCEY	59.21	55.10	50.88	47.07
AAV	26.4%	25.5%	25.0%	25.3%

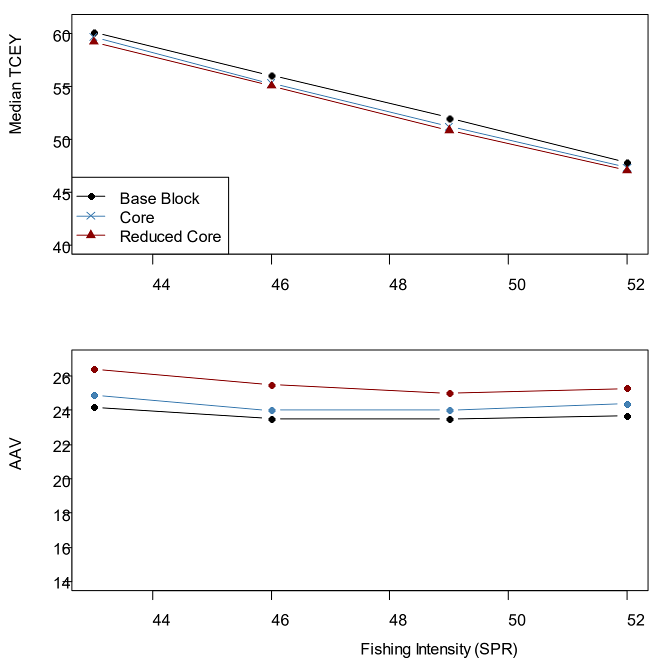

Figure 10. Median TCEY (top) and AAV (bottom) for different fishing intensities (SPR) and FISS designs.

5.3 Depensation Stress Test

The results of estimating the amount of depensation for Pacific halibut are presented first. This is followed by an evaluation of the simulations without depensation and with a depensation level of 2.

5.3.1 Estimates of depensation in the Pacific halibut population

The long areas-as-fleets model (AAF), with all years, showed a nearly linear increase in the number of recruits with increasing spawning biomass (Figure 11). The range of spawning biomass was from 172 Mlbs to 776 Mlbs. The point estimate for depensation was 0.35 and the confidence interval ranged from 0.22 to 1.75 (Table 12). The observations associated with a positive PDO showed depensation with an estimated point value of 4.49 and a 95% confidence interval from 1.35 to 20.85 (Table 12 & Figure 12). Observations associated with a positive PDO showed little difference in likelihood across a wide range of values of δ (Table 12 & Figure 12).

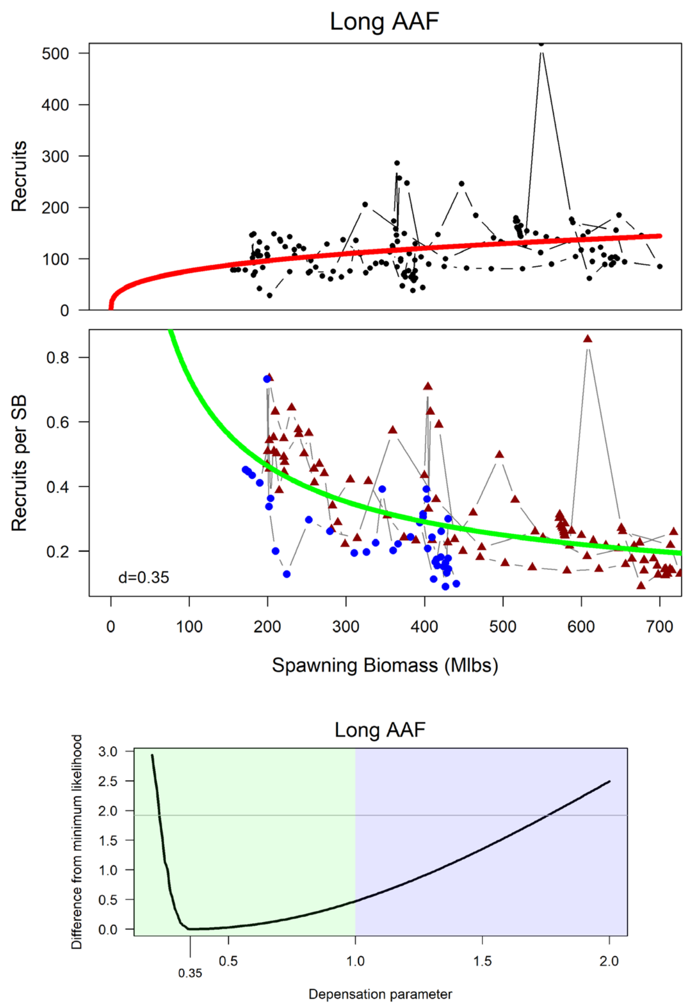

Figure 11. Fitted stock-recruit curve with a depensation parameter when using all observations from the LongAAF model (top plots). The likelihood profile for the depensation parameter with the 95% significance level shown as a dotted horizontal line (bottom plot).

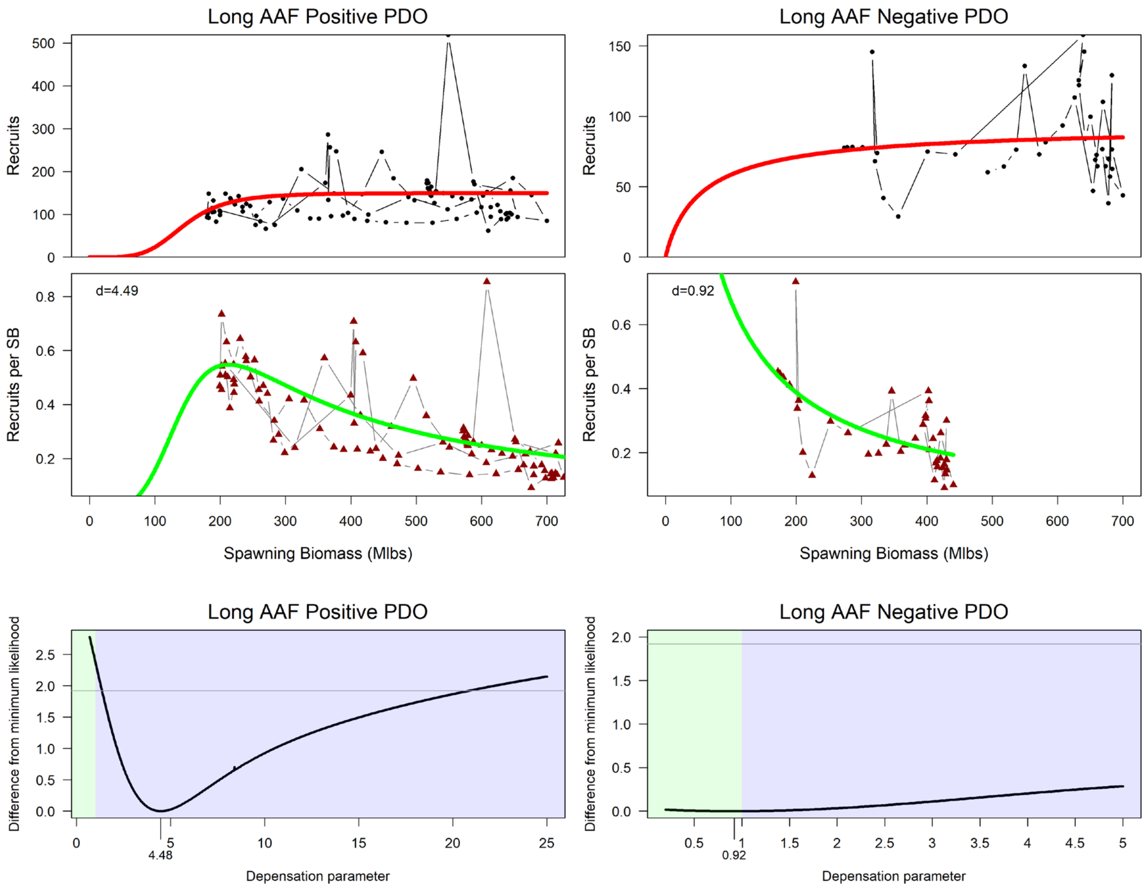

Figure 12. Fitted stock-recruit curve with a depensation parameter when using the high PDO observations (left) or negative PDO (right) observations from the longAAF model (top plots). The likelihood profile for the depensation parameter for the same PDO regimes with the 95% significance level shown as a dotted horizontal line (bottom plots).

Results from the long coastwide model (LongCW) also showed a low estimate of the δ parameter (0.36) when using all of the data (Table 12). However, unlike the longAAF results, the confidence interval for the longCW model with all data did not span 1.0 (Figure 13). Observations from the positive PDO showed potential depensation with a 95% confidence interval for δ ranging from 0.7 to 9.43 (Figure 14). When using only observations associated with the negative PDO, the β parameter was estimated at a negative value. This is not theoretically impossible, and implies less decline in recruits with spawning biomass. However, given this formulation of the Beverton-Holt stock recruit function, a negative β causes NA values when raising it to a non-integer value, and changes the sign when raising it to an even integer value, resulting in a sawtooth pattern in the likelihood profile (see Figure 14). Assuming that δ can only be odd integer values shows a high amount of depensation. This occurs to fit the steep decline in recruitment as low spawning biomass declines (which may be more indicative of a Ricker shaped stock-recruit curve). Regardless, there are few observations at low spawning biomass from a negative PDO phase to inform a stock-recruit-curve, especially with depensation.

Table 12. Estimated depensation parameter for the LongAAF and LongCW model observations combined or separated by PDO regime. The lower and upper 95% confidence interval determined from the likelihood profile is also shown (An NA indicates that the confidence limit could not be determined over the range tested).

Model	Data	Depensation (δ)	Lower	Upper
Long AAF	All	0.35	0.22	1.75
	Positive PDO	4.49	1.35	20.85
	Negative PDO	0.92	NA	NA
Long CW	All	0.36	0.24	0.81
	Positive PDO	2.9	0.70	9.43
	Negative PDO	13	5	29

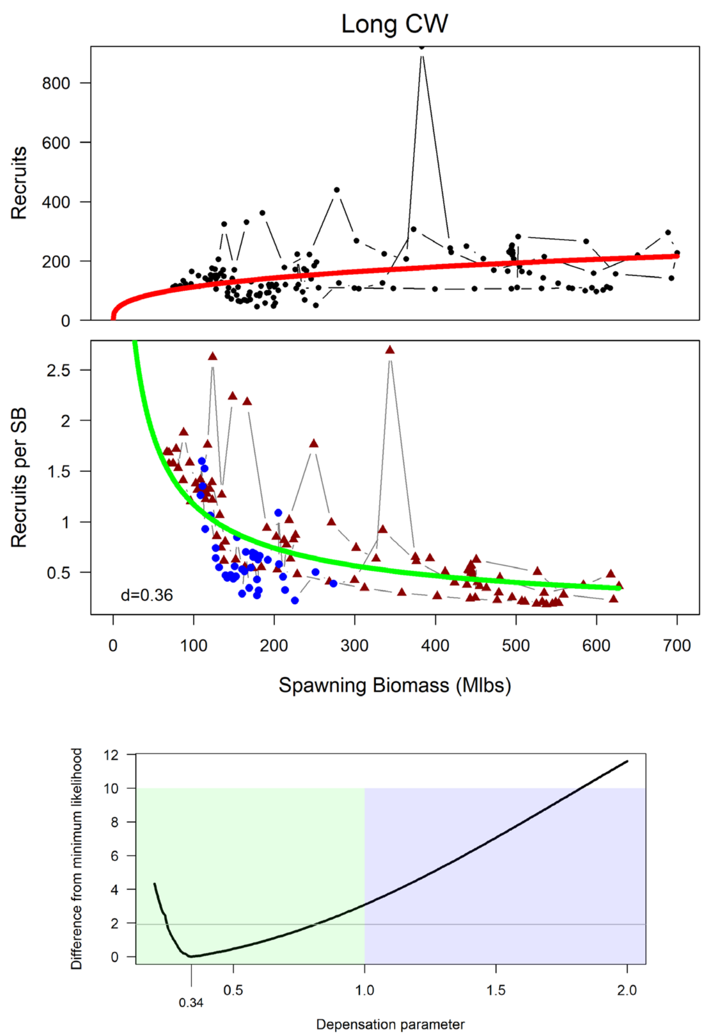

Figure 13. Fitted stock-recruit curve with a depensation parameter when using all observations from the Long CW model (top plots). The likelihood profile for the depensation parameter with the 95% significance level shown as a dotted horizontal line (bottom plot).

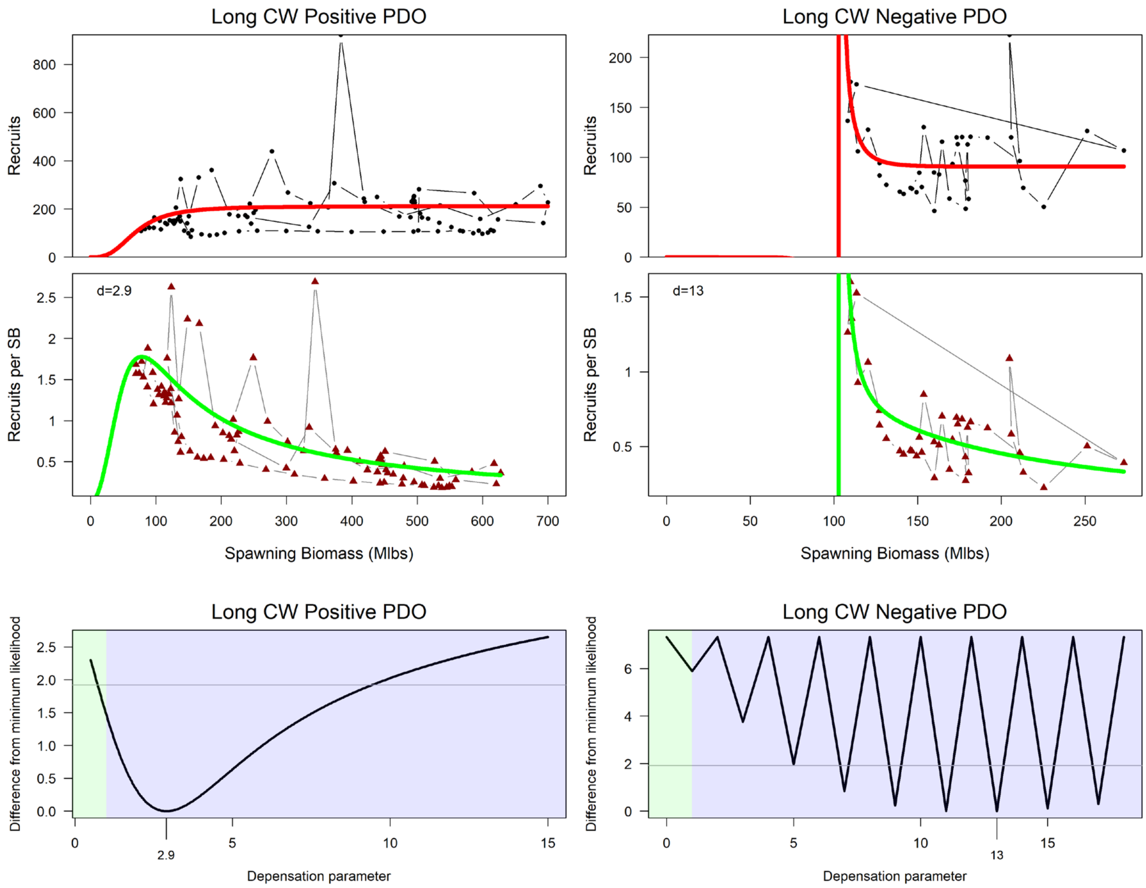

Figure 14. Fitted stock-recruit curve with a depensation parameter when using the high PDO observations (left) or negative PDO (right) observations from the Long CW model (top plots). The likelihood profile for the depensation parameter for the same PDO regimes with the 95% significance level shown as a dotted horizontal line (bottom plots).

From these results, there is not a clear indication of depensation over the observed range of spawning biomass and the value of δ is highly uncertain. Analyzing only recruits from high PDO years showed potential depensation, but was uncertain. Low PDO years had fewer observations, especially at low spawning biomass. The uncertainty in the estimate of depensation is due to variable recruitment and the lack of observations at low spawning biomass.

The purpose of this analysis was to determine a reasonable level of depensation for a stress test using the MSE framework. Given no clear indication of depensation, a value of δ = 2 was chosen. Other values may be reasonable but were not tested at this time. Applying depensation only in a specific environmental regime is also possible but was not attempted here because the OM does not change the stock-recruit function in separate environmental regimes, but simply multiplies recruitment by a factor for the high PDO regime. Future improvements to the OM are expected where tested management outcomes with depensation on specific environmental regimes would be appropriate.

5.3.2 MSE simulations with depensation

Including depensation in the OM (δ = 2) resulted in an undetectable difference in long-term performance metrics for all fishing intensities investigated (SPR = 35%, 43%, and 52%). There are two explanations for no effect due to depensation. First, a control rule reduces the fishing intensity when RSB is less than 30%, and sets directed fishery mortality to zero when below 20%. This results in a realized fishing intensity that may be lower than implied by the input SPR, especially at an SPR of 35% (the long-term median realized SPR was 36% with an input SPR of 35%). Second, this control rule reduces the chance that the spawning biomass falls to a low enough level where depensation becomes a concern.

Depensation	δ=1			δ=2		
SPR	35%	43%	52%	35%	43%	52%
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.7106	0.2466	0.0012	0.7102	0.2462	0.0012
Median TCEY	71.78	66.55	57.81	71.78	66.55	57.81

This does not conclude that depensation does not occur for Pacific halibut. Depensation may exist, especially below spawning biomass levels lower than have been observed. However, if it does exist, the use of a 30:20 control rule and recent levels of fishing intensity seem to avoid these low spawning biomass levels where depensation would have an effect.

6 CONCLUSIONS

Three concepts were evaluated using the MSE: assessment frequency along with harvest control rule elements, FISS designs, and depensation. These simulations show that reducing the fishing intensity (i.e. higher SPR) would achieve a higher spawning biomass, lower interannual variability in the TCEY, and move towards a potential new objective of avoiding low absolute spawning biomass. However, yield would be reduced, on average. Biennial and triennial assessments may improve yield and would lower the interannual variability in the TCEY. This would also allow more time to improve assessment and MSE methods, but at the cost of not providing detailed annual information such as stock status. Reducing the FISS to the core areas, and occasionally surveying non-core areas would reduce yield and increase uncertainty and interannual variability in the TCEY. Finally, depensation is likely not a concern for the Pacific halibut stock, given likely management decisions in the future.

This work supports the development of the harvest strategy policy. Next steps include obtaining support from the SRB to use these results to update the current draft harvest strategy policy (IPHC-2024-SRB025-INF01), work with the MSAB to recommend updated objectives and endorse the MSE simulation results, and then present this work to the Commission along with an updated harvest strategy policy for their endorsement.

Recommendation/s

That the SRB:

1) **NOTE** paper IPHC-2024-SRB025-07 presenting recent MSE work including exceptional circumstances, goals and objectives, evaluating assessment frequency, a constraint and fishing intensity, investigating the effects of reduced FISS designs, and simulating a scenario with depensation.
2) **RECOMMEND** any additional exceptional circumstances using fishery-dependent data.
3) **RECOMMEND** adding a measurable objective related to absolute spawning biomass under the general objective 2.1 "maintain spawning biomass at or above a level that optimizes fishing activities" to be included in the priority Commission objectives after, or in place of, the current biomass threshold objective.
4) **RECOMMEND** further analyses to support the development of the harvest strategy policy.
5) **REQUEST** any further analyses to be provided to the Commission or at SRB026.

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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	$P(p_{SB,R} < p_{SB,R,min})$
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

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

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