An update of the IPHC Secretariat MSE and development of a Harvest Strategy Policy

PREPARED BY: IPHC SECRETARIAT (A. HICKS & I. STEWART; 17 AUGUST 2025)

PURPOSE

To provide the SRB with an update of the IPHC Management Strategy Evaluation (MSE) and the Harvest Strategy Policy (HSP).

1 INTRODUCTION

This document provides responses to recommendations from the 26th Session of the Scientific Review Board (SRB026) and a brief update on progress towards adoption of the Harvest Strategy Policy. The operating models (OMs) in the MSE framework were most recently conditioned using the 2022 stock assessment and will be reconditioned after the 2025 full stock assessment to reflect new understanding of the Pacific halibut population and fishery dynamics. Given that new OMs will be available in 2026, further investigations of Management Procedures (MPs) and other concepts will be done at that time.

2 RECRUITMENT

A recommendation from SRB026 was to incorporate a random walk for recruitment to maintain continuity in recent recruitment trends rather than immediately assuming the mean of the stock-recruit curve.

> **IPHC-2025-SRB026-R, para 24**. *The SRB* ***RECOMMENDED*** *that recruitment projections in the stock assessment and Management Strategy Evaluation (MSE) incorporate a random-walk starting from the most recent reliable recruitment estimate to constrain expected short-term recruitment around recent estimates rather than immediately reverting to the stock-recruitment relationship.*

To begin, an investigation of autocorrelation was conducted. This used the historical estimated recruitment deviations for the four models used in the 2024 ensemble stock assessment (Stewart and Hicks 2024) to examine the autocorrelation of the deviates as well as the deviates of a random walk in recruitment. Finally, an ARIMA model was fit to the recruitment deviations for insight into the autocorrelation.

Each of the four models in the ensemble stock assessment estimates a time-series of recruitment as a deviation from a Beverton-Holt stock-recruit relationship that is dependent on the Pacific Decadal Oscillation (PDO, Mantua et al. (1997)) being low or high. This is characterized by the following equation.

$$R'_0 = R_0 \times e^{I_y \delta} \tag{1}$$

$$R_y = f(B^{sp}_{F,y} | R'_0, B^{sp}_0, h) \times e^{(\varepsilon_y - \frac{\sigma_R^2}{2})} \tag{2}$$

where $f(B^{sp}_{F,y} | R'_0, B^{sp}_0, h)$ is the equilibrium stock-recruit relationship using female spawning biomass in year y with parameters for regime-specific equilibrium unfished mean recruitment (R'_0), equilibrium unfished spawning biomass (B^{sp}_0), and steepness (h). The regime-specific equilibrium unfished mean recruitment is modified by I_y, an indicator for low or high PDO (0 or 1), and δ is the covariate for this environmental relationship defining environment-dependent recruitment regimes. The annual deviation in recruitment, from average, for year y is e^{ε_y}. The deviation is used to indicate variability around the mean recruitment (determined from the stock-recruit relationship incorporating the PDO effects), assumes a normal distribution, and is constrained by a variance parameter (σ_R). Only the two 'long' assessment models estimate an environmental relationship, but all four current MSE models use an environmental relationship.

Recruitment is split into three periods: initial, main, and late. The main period is defined to contain recruitments that are strongly informed by data and centered such that the sum of the deviations equals zero. This ensures that the recruitment over the main period is on average centered on the stock-recruit relationship, thus allowing for the calculation of consistent reference points. Only recruitments in the defined 'main' period are used in this investigation.

Figure 1 shows the estimated recruitment deviates within each period for each stock assessment model. The main period deviates show some short intervals of positive autocorrelation (i.e. 1960s), but also times of negative autocorrelation (e.g. 1990s). The entire main period recruitment deviates show a positive autocorrelation for the first 4-8 lags in the long models, but little autocorrelation in the short models (Figure 2). The long models showed a possible negative autocorrelation at lags greater than 20 years, which may have some relation to the oscillations of the PDO.

The estimated recruitment was converted to a random walk by subtracting the estimated recruitment in year *y-1* from the estimated recruitment in year *y*. These random walk deviations are shown in Figure 3 and it appears that the autocorrelation is reduced in some intervals, such as the 1960s, but these intervals are now characterized by periods of large or periods of small oscillating random walk deviates. This is evident in the calculation of autocorrelation at various lags, showing a significant negative autocorrelation at lag 1 for three of the four models (Figure 4).

ARIMA models were fit to the recruitment deviations (ε_t) to determine the strength and significance of various autoregressive (AR) and random walk processes. An ARIMA model has three integer components, (*p*,*d*,*q*), where *p* indicates the autoregressive (AR) process, *d* indicates the degree of differencing, and *q* indicates a moving average (this last one was not tested). An ARIMA(1,0,0) is an AR(1), and an ARIMA(0,1,0) is a random walk. A number of models were fit with AR processes up to a lag of four, and a difference to a lag of 1 (which is a random walk). The AIC was used to determine the best fit model (Table 1) using the entire main period of estimated recruitment deviations, and the same period for all four models (1992–2016).

The two long models, with the entire main period, showed best fitting models with a 4th order AR process. The 4th order AR process had a weak relationship with the 2nd lag.

$$\text{AAF\_long: } \varepsilon_t = -0.02 + 0.23\varepsilon_{t-1} + 0.07\varepsilon_{t-2} + 0.21\varepsilon_{t-3} + 0.14\varepsilon_{t-4} + \tau_t \quad (3)$$

$$\text{CW\_long: } \varepsilon_t = -0.02 + 0.24\varepsilon_{t-1} + 0.05\varepsilon_{t-2} + 0.21\varepsilon_{t-3} + 0.22\varepsilon_{t-4} + \tau_t \quad (4)$$

The ARIMA model residuals appeared to have less variability than the NULL model, especially in the 1960s (Figure 5).

The ARIMA models were not significantly better than the Null model for the shorter time series of recruitment deviations when comparing AIC. The random walk showed a worse fit and higher AIC than any other model.

Table 1. AIC values for different ARIMA models fitted to the entire main period of each stock assessment model. The short models contained a subset of later years compared to the long models and the AIC for fits to that subset of years is also shown for the long models. Bold values are within two units of the lowest value.

	AAF_long	**CW_long**	**AAF_short**	**CW_short**	**AAF_long**	**CW_long**
Years	1910–2015	1925–2015	1992–2016	1992–2016	1992–2016	1992–2016
(0,0,0)	98.68	94.71	**35.81**	**69.07**	**24.11**	**22.06**
(1,0,0)	85.81	76.81	**36.22**	**70.87**	**25.95**	**23.95**
(2,0,0)	85.04	75.88	38.21	72.01	**25.23**	**22.00**
(3,0,0)	**80.17**	70.24	40.19	73.79	27.16	**23.97**
(4,0,0)	**80.10**	**67.65**	41.80	74.46	29.05	25.54
(0,1,0)	121.70	101.78	43.67	84.11	36.61	35.01

Overall, the estimated recruitment deviations from the assessment models showed some evidence of autocorrelation that may be useful to model. There were short periods of time with positive autocorrelated recruitment deviations, but also periods of time with negatively correlated recruitment deviations. The estimated recruitment deviations for the period from 1992–2016 in all models showed less support for autocorrelation. A random walk appeared to pull the deviated towards zero, but there was little evidence that it would improve the modelling of the recruitment deviations.

Further complicating this analysis is the information content of the data to inform the estimation of recruitment. Sampling variability, ageing error, and missing data may result in short periods of time with autocorrelated recruitment deviations because there is little information to discern a single recruitment event from a period of similar recruitment events. This may explain the patterns observed in the estimates of the recruitment deviations before 1980 (Figure 1).

Linking the PDO to the average recruitment partly addresses the concern from the SRB that recruitment may suddenly increase in the projection period. It is true that recruitment is centered around the stock-recruit curve, but the mean of the stock-recruit curve is adjusted depending on the regime. For example, if the current regime is low, then the recruitments in the near-term projection are also likely to be low. However, if there is a trend of poor recruitment relative to the low regime (e.g. 2006–2011), that may not be captured. The MSE projections simulate the binary PDO covariate using a semi-Markovian process that switches approximately every 10-20 years. Therefore, the near-term projections account for the current regime, which carries forward the trend in average recruitment. Figure 6 shows that the PDO starts low in 2025 for recent MSE simulations and increases to high values (slightly greater than 50%) before oscillating back down and stabilizing to 50%.

This investigation is useful to determine the evidence of autocorrelation, but simulations using the stock assessment and MSE models can indicate the effect that this concern has on management outcomes. The document IPHC-2025-SRB027-07 reports 3-year projections using the stock assessment with different recruitment assumptions. Noting that the regime is currently simulated with correlation in the MSE projections, additional runs were done with the AR(4) process on recruitment deviations from the AAF_long assessment model (Equation 3) where the error (τ_t) had mean zero and a standard deviation equal to σ_R.for that model. Additionally, a simple autocorrelated recruitment series was simulated using Equation 5.

$$\varepsilon_t = \rho\varepsilon_{t-1} + \sqrt{1-\rho^2}\tau_t \tag{5}$$

For these simulations, ρ was equal to 0.5 and τ_t was drawn from a normal distribution with mean equal to zero and a standard deviation equal to σ_R for that model. A comparison of the three methods to simulate future recruitment deviates (uncorrelated, AR(4), and $\rho = 0.5$) indicate slight differences for each method (Figure 7).

Performance metrics associated with the Commission's priority objectives are shown in Table 2 for MSE simulations with no decision-making variability, no observation error, no estimation error, and an SPR of 43%. Not using the additional simulated errors was chosen to focus on the effect of the different methods to model recruitment. The performance metrics for the runs with autocorrelated recruitment are similar to each other, but slightly different than the base scenario with uncorrelated recruitment. With autocorrelated recruitment deviations, there is very little long-term risk of being below 20% relative spawning biomass (RSB) and a slightly greater long-term chance of being below an RSB of 36%. The short-term (4-13 years) performance metrics for the two autocorrelated scenarios show a TCEY that is approximately 2 million pounds less and an increased AAV compared to the base scenario. The short-term performance metrics are similar for the two autocorrelated scenarios. We did not simulate alternative SPR values, but it is likely that they scale similarly across the scenarios. Additionally, with decision-making variability, observation error, and estimation error, the differences may be reduced.

Overall, the three-year stock assessment projections are not significantly affected by the modelling of recruitment because the spawning biomass is not affected by the modelling of near-term recruitments. The MSE results are more likely to be affected by the choice of how recruitment is modelled. There was slight evidence of autocorrelation in the estimated deviates, but that may be a natural result of estimation with ageing error and uncertainty resulting in the appearance of autocorrelation. Simulations with high levels of autocorrelation show small differences in MSE simulations that are unlikely to result in a different selection of a reference management procedure.

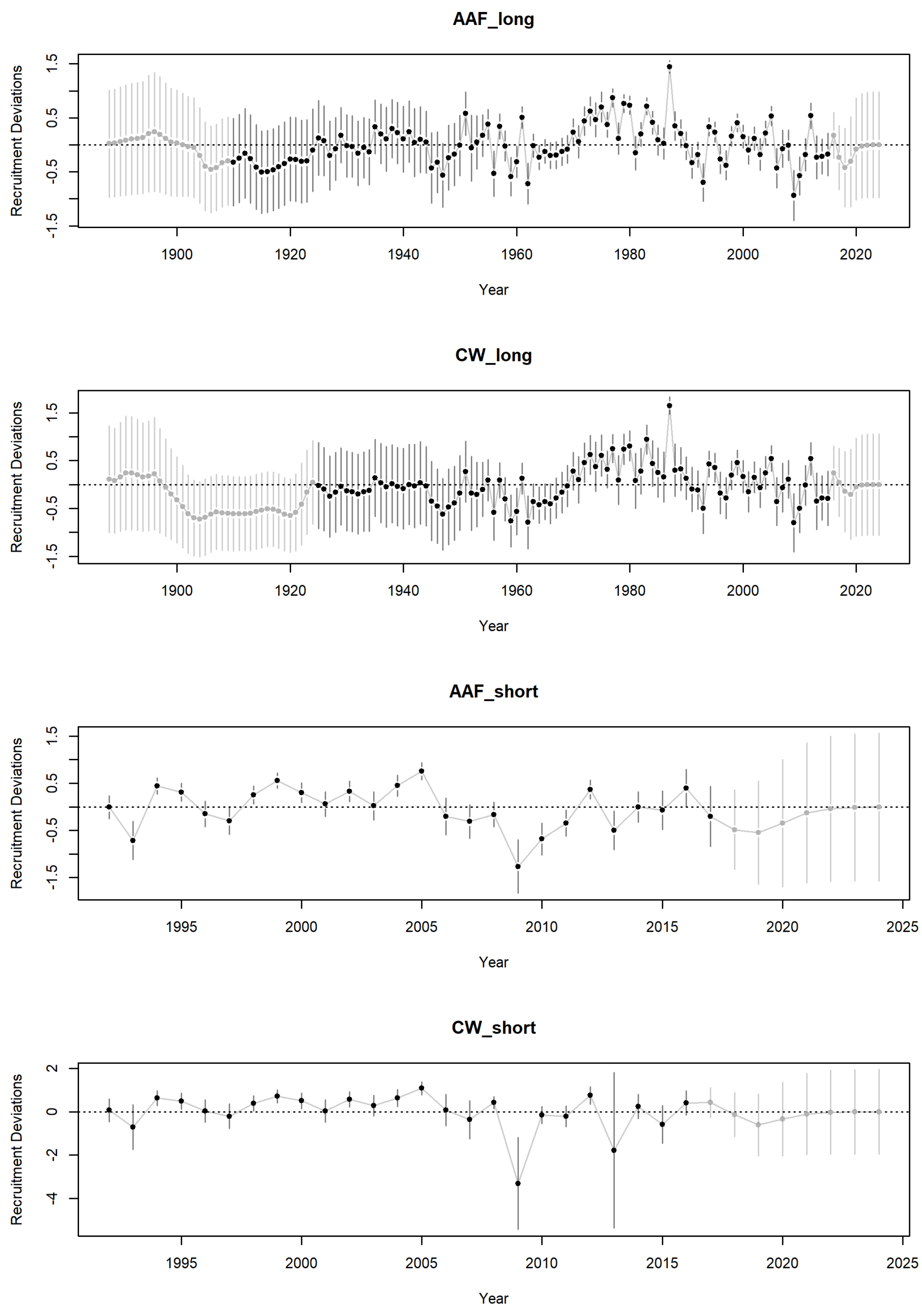

Figure 1. Estimated recruitment deviates from each stock assessment model. Dark points and lines indicate the ‘main’ period.

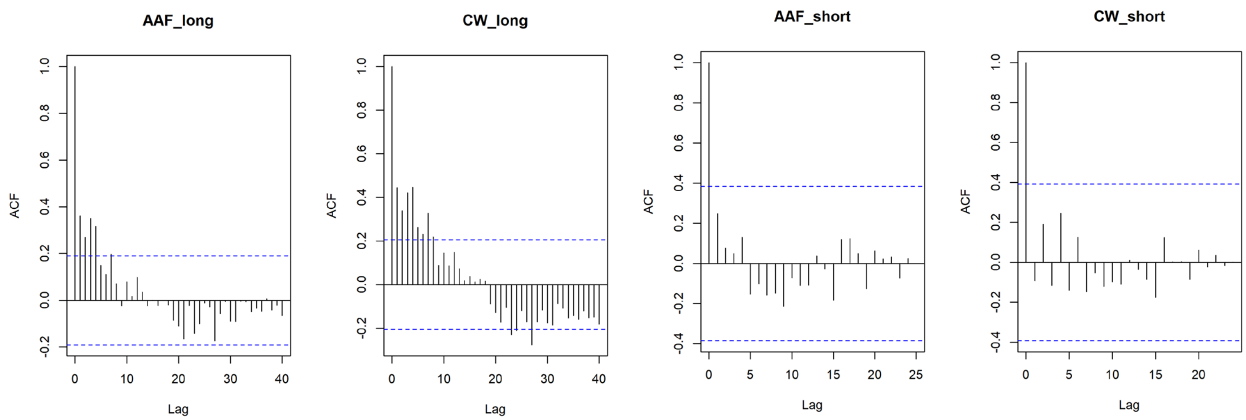

Figure 2. Autocorrelation up to 40 lags for the recruitment deviates from the long models and 25 lags for the short models. Blue horizontal dashed lines are approximate 95% significance levels.

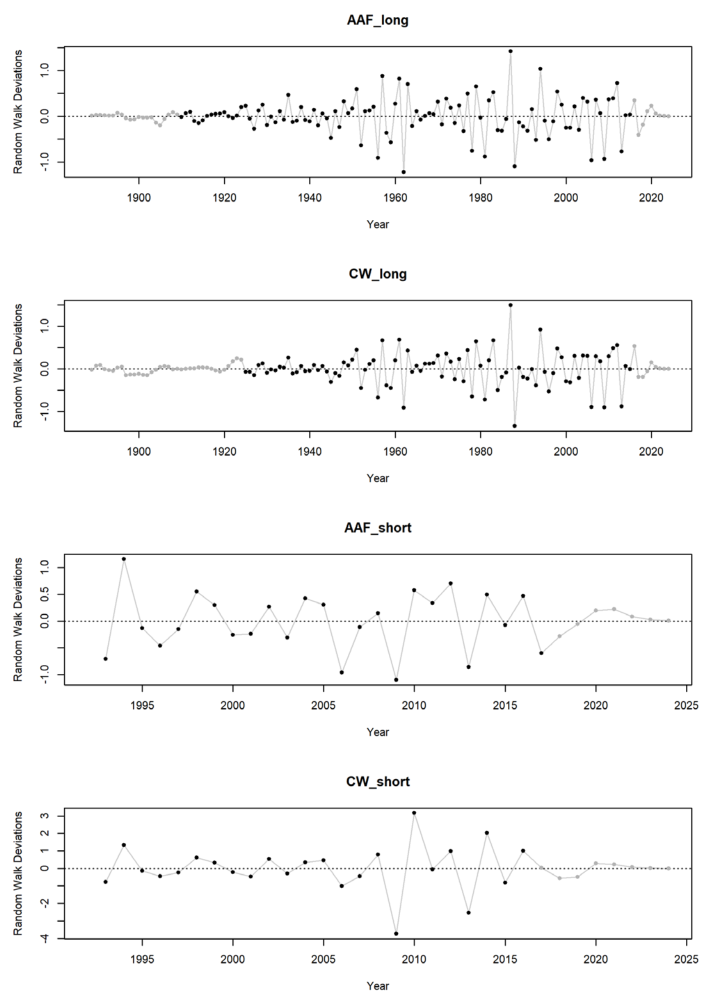

Figure 3. Random walk deviations from each stock assessment model. Dark points and lines indicate the 'main' period.

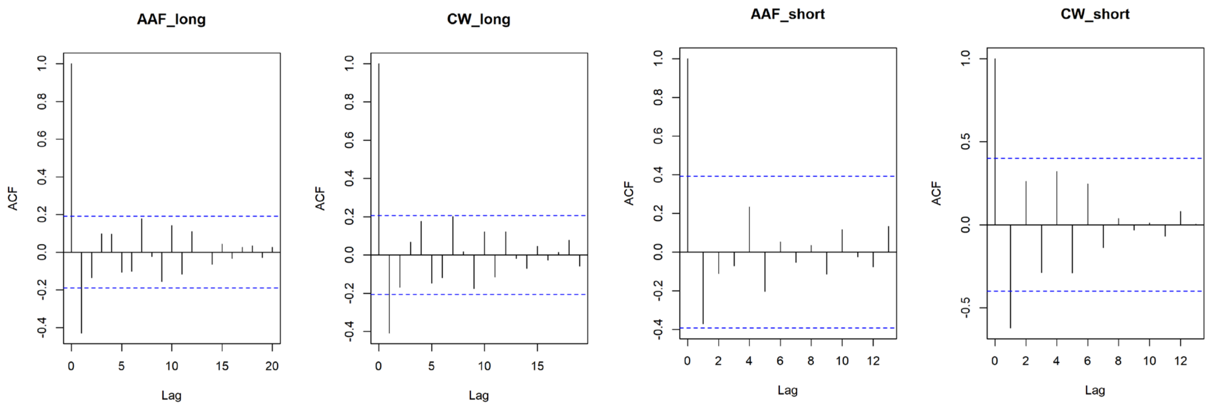

Figure 4. Autocorrelation up to 20 lags for the random walk deviates from the long models and 13 lags for the short models. Blue horizontal dashed lines are approximate 95% significance levels.

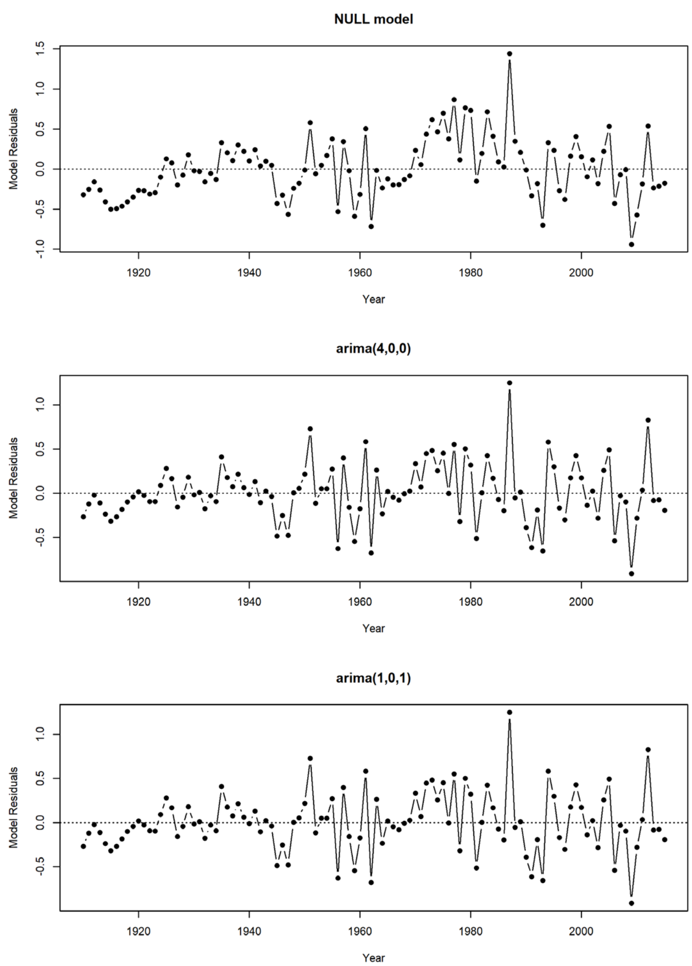

Figure 5. ARIMA model residuals for the NULL, AR(4), and ARIMA(1,0,1) models using the estimated recruitment deviations from the AAF_long assessment model.

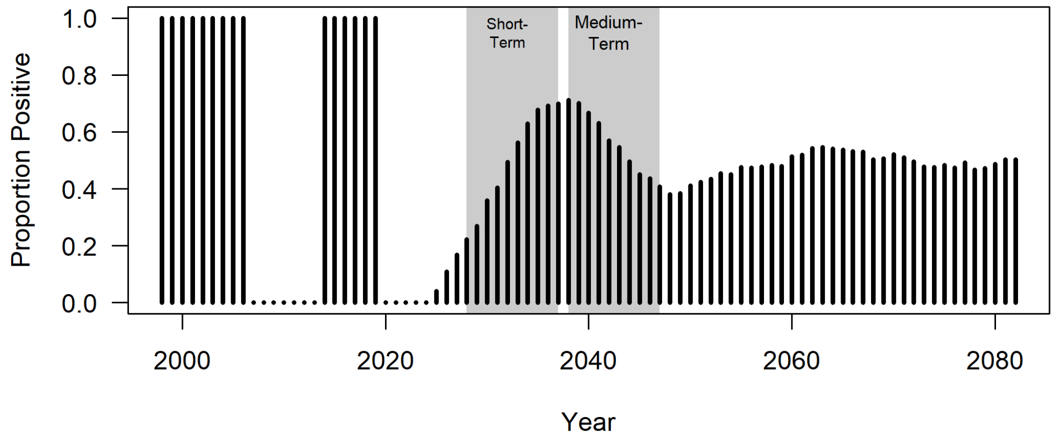

Figure 6. Proportion of simulations where the PDO was positive from 2025 MSE runs. Prior to 2025 the PDO was fixed at high or low determined from historical observations.

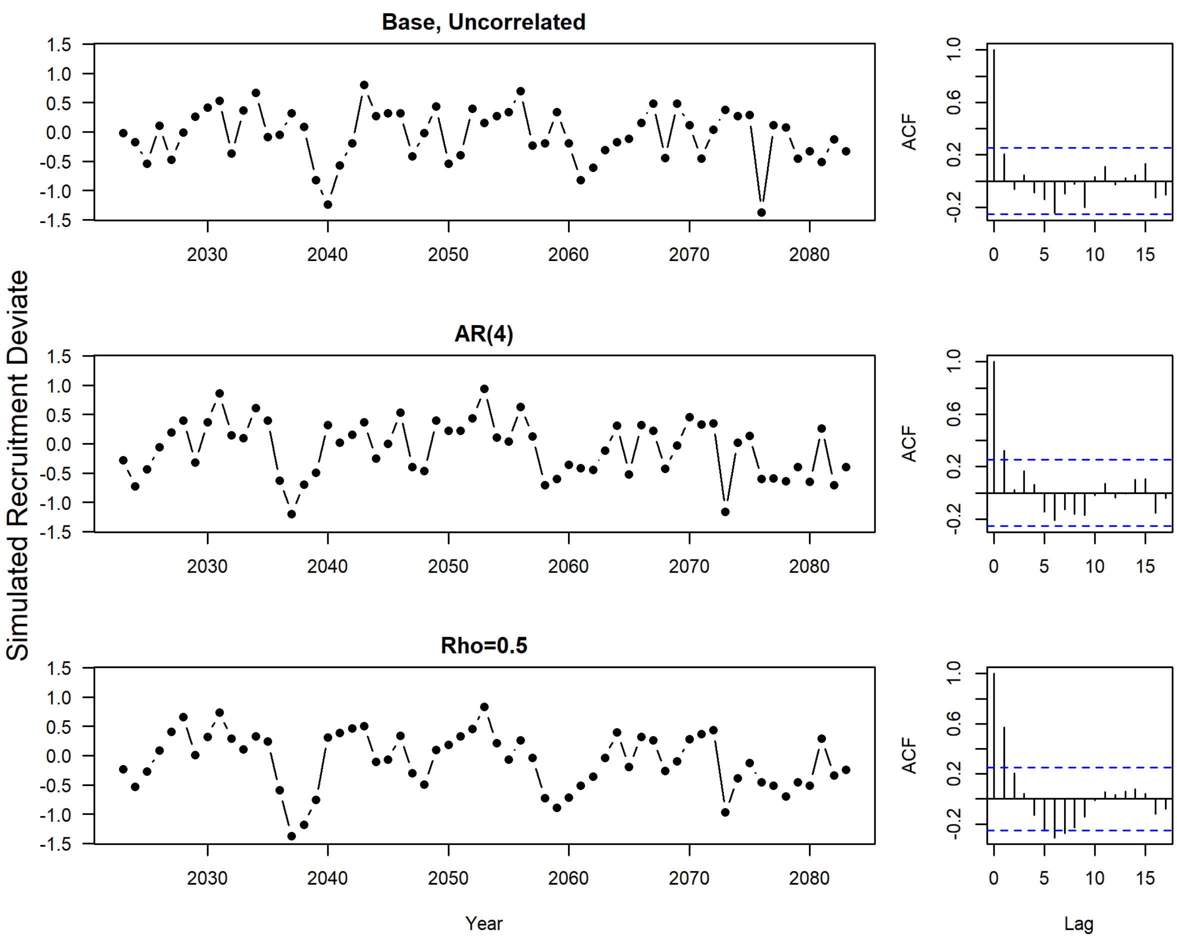

Figure 7. Simulated recruitment deviates using three methods. An example of one simulation for 60 years is show in the left column and the autocorrelation at different lags is show on the right.

Table 2. Performance metrics for MSE simulations with three options for recruitment variability assuming no decision-making variability, no observation error, and no estimation error. An SPR of 43% was used for all scenarios.

Recruitment Deviates	Uncorrelated	AR(4)	$\rho = 0.5$
P(RSB<20%)	<0.001	<0.001	<0.001
P(RSB<36%)	0.24	0.28	0.28
Median TCEY	53.8	51.8	51.6
AAV	10.8%	11.9%	12.0%

3 Definitions of Overfished and Depleted

A definition of overfished has been in the draft Harvest Strategy Policy (HSP) since its inception and reflects the effect of fishing on the stock by using dynamic unfished spawning biomass. Following review of HSPs from other countries, the SRB recommended considering an additional reference point called ‘Depleted’ that reflects the size of the stock relative to fishing and stock productivity.

> IPHC-2025-SRB026-R**, para. 30**: ***NOTING*** *that “Overfished” implies that fishing was the cause of a current biomass state while the term “Depleted” is agnostic about the cause of low biomass, the SRB* ***RECOMMENDED*** *that the Secretariat consider defining “Overfished” relative to a dynamic reference point that incorporates productivity change while “Depleted” should refer to an absolute biomass reference point.*
>
> IPHC-2025-SRB026-R**, para. 31**. *The SRB* ***RECOMMENDED*** *that the Secretariat/Commission adopt an absolute biomass limit defining “Depleted” to avoid low biomass levels where stock dynamics are poorly understood such that recovery projections would be unreliable.*

Both “Overfished” and “Depleted” are important reference points to include in an HSP. A stock may be “Depleted” without being “Overfished” due to environmental conditions or may be “Overfished” without being “Depleted” due to high fishing rates. Continued high fishing rates when a stock is “Overfished” would likely lead to a “Depleted” stock. The priority objectives in the IPHC HSP already contain a reference point to determine “Overfished”. This is $RSB_{20\%}$ in the first objective, using a dynamic relative spawning biomass, and the Secretariat recommends retaining the definition for “Overfished” that is currently in the draft HSP.

> **Overfished**: when the estimated probability that coastwide female relative spawning stock biomass is below the limit reference point ($RSB_{20\%}$) is greater than 50%.

The SRB also recommended including a reference point based on an absolute spawning biomass to determine if the stock is “Depleted,” a level where recovery projections may be unreliable due to uncertain stock dynamics. This implies a spawning biomass below the lowest level observed from which the population is known to have recovered. The Secretariat has currently identified two possible approaches to identify an appropriate absolute spawning biomass reference point.

First, the Secretariat has suggested using the lowest spawning biomass observed in the estimated time series from the ensemble stock assessment, which is 2024 based on the most recent stock assessment. The estimated spawning biomass in the 1970s is highly uncertain and may have been at similar levels seen in recent years. However, given that recent levels are known to be low with a much greater certainty, the Secretariat suggests using the 2023 or 2024 spawning biomass as this absolute reference point. The advantage of choosing a year (or the lowest estimated spawning biomass within a range of years) to define the absolute reference point is that it scales to changes in the stock assessment due to updates to data and new assumptions, accounting for uncertainty. However, it has not been seen how quickly the population may recover from this recent low period of spawning biomass.

Alternatively, simulation (via the MSE framework) could be used to identify an absolute spawning biomass reference point outside of the range of observed stock sizes where the chance of recovery is low. To explore this, we simulate the population forward at a high fishing rate for 40 years under a worst-case scenario, assuming low weight-at-age, low PDO (defining poor recruitment and alternative movement), and a depensation parameter in the stock-recruit curve equal to 5. After 40 years, fishing stops, except for 3 million pounds representing a small amount of bycatch and subsistence fishing, and the population is simulated forward another 50 years. A bifurcation point in the spawning biomass where trajectories either recover or stabilize and those that continue to decline is then estimated. The details of this approach are outlined below.

3.1 Low productivity scenarios

The low productivity scenarios are defined by low weight-at-age and a low PDO (i.e. low average recruitment and different movement patterns compared to a high PDO) resulting in a lower coastwide spawning biomass. Results of simulations comparing productivity regimes are provided in Section 3 of IPHC-2025-SRB026-08.

3.2 Determining depensation

Depensation occurs if the per-capita rate of growth decreases as the density or abundance decreases to low levels (Liermann and Hilborn 2001) and is also referred to as the Allee effect (Dennis 2002). In other words, it is inverse density dependence at low population sizes where there is reduced reproductive success. Example stock-recruit curves with different depensation parameters are shown in Figure 8.

An analysis of depensation is presented in IPHC-2024-SRB025-07. A parameter for depensation was estimated using the estimated recruitment and spawning biomass from each stock assessment model for all years in the ‘main’ period, as well as for negative and positive PDO years separately. The estimated depensation parameter (d) ranged from 0.35 to 4.49. A value of 5 was used for these simulations as a worst-case scenario and shows a strong reduction in recruitment at low spawning biomass (Figure 8).

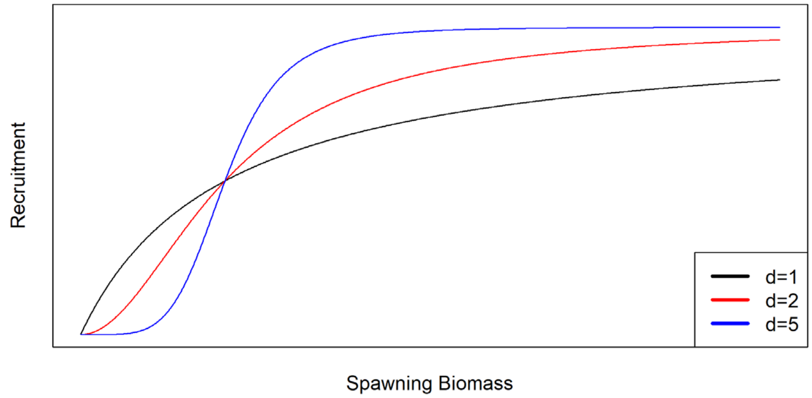

Figure 8. Three example stock-recruit curves with different depensation parameters and the same α and β parameters. When d=1, the curve is a Beverton-Holt stock-recruit curve.

3.3 Simulation results

After 40 years of fishing at a high intensity, fishing is stopped in the simulations and the probability of recovery is determined by defining a trajectory as "recovered" if it stabilized or increased to a greater spawning biomass after 50 years without fishing. Boxplots showing the spawning biomass for trajectories that recovered (Increase) and those that did not recover (Decline) are shown in Figure 9. Nearly all trajectories with a spawning biomass greater than 70 M lbs recovered and no trajectories recovered when starting at a spawning biomass less than 40 M lbs (Figure 10). A high proportion of the trajectories (greater than 50%) in the worst-case scenario recovered when above a spawning biomass near 70 M lbs, which may be a suitable proxy absolute spawning biomass for defining Depleted. Alternatively, 90 M lbs could be used as a proxy for Depleted because that is the spawning biomass where all trajectories recovered once fishing stopped.

Therefore, Depleted could be defined as follows.

> **Depleted**: when the coastwide female spawning stock biomass is estimated to be below a spawning biomass of 70 million pounds with a probability of 50% or higher.

The threshold (70 M lbs) and/or the tolerance (50%) can be modified to reflect an appropriate risk level.

The concept of these two reference points, Overfished and Depleted, is shown in Figure 11 with the Depleted threshold defined at 70 M lbs. Overfished is currently defined as 20% of unfished spawning biomass and changes over time when calculated as an absolute spawning biomass, depending on current stock conditions. In terms of relative spawning biomass, the overfished threshold is constant (20%) and the Depleted threshold varies (Figure 11).

Defining both "Overfished" and "Depleted" reference points in the IPHC HSP would highlight the differences between natural fluctuations in the population due to extrinsic forces such as the environment, and the changes in the population controlled through fishing. Certification agencies could then better determine if these changes are a result of management and be certain that low population sizes are avoided. The Commission will need to consider what response would be taken when a 'Depleted' condition is approached.

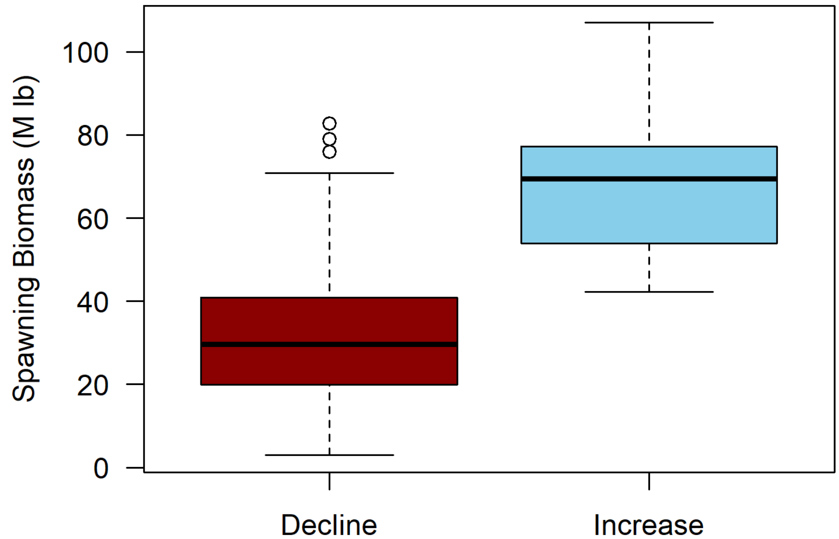

Figure 9. Boxplots of the spawning biomass for trajectories that recovered (Increase) and those that did not recover (Decline).

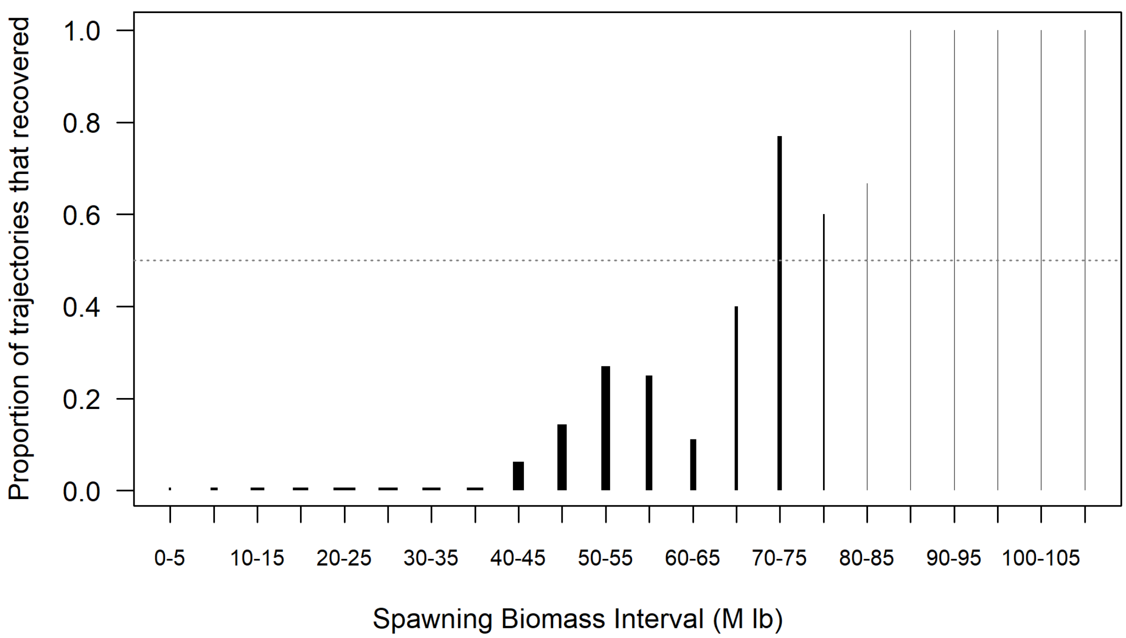

Figure 10. Proportion of trajectories that recovered at various intervals of spawning biomass in 2062 at the start of no fishing. The width of the line indicates the number of trajectories within each interval used to calculate the proportion.

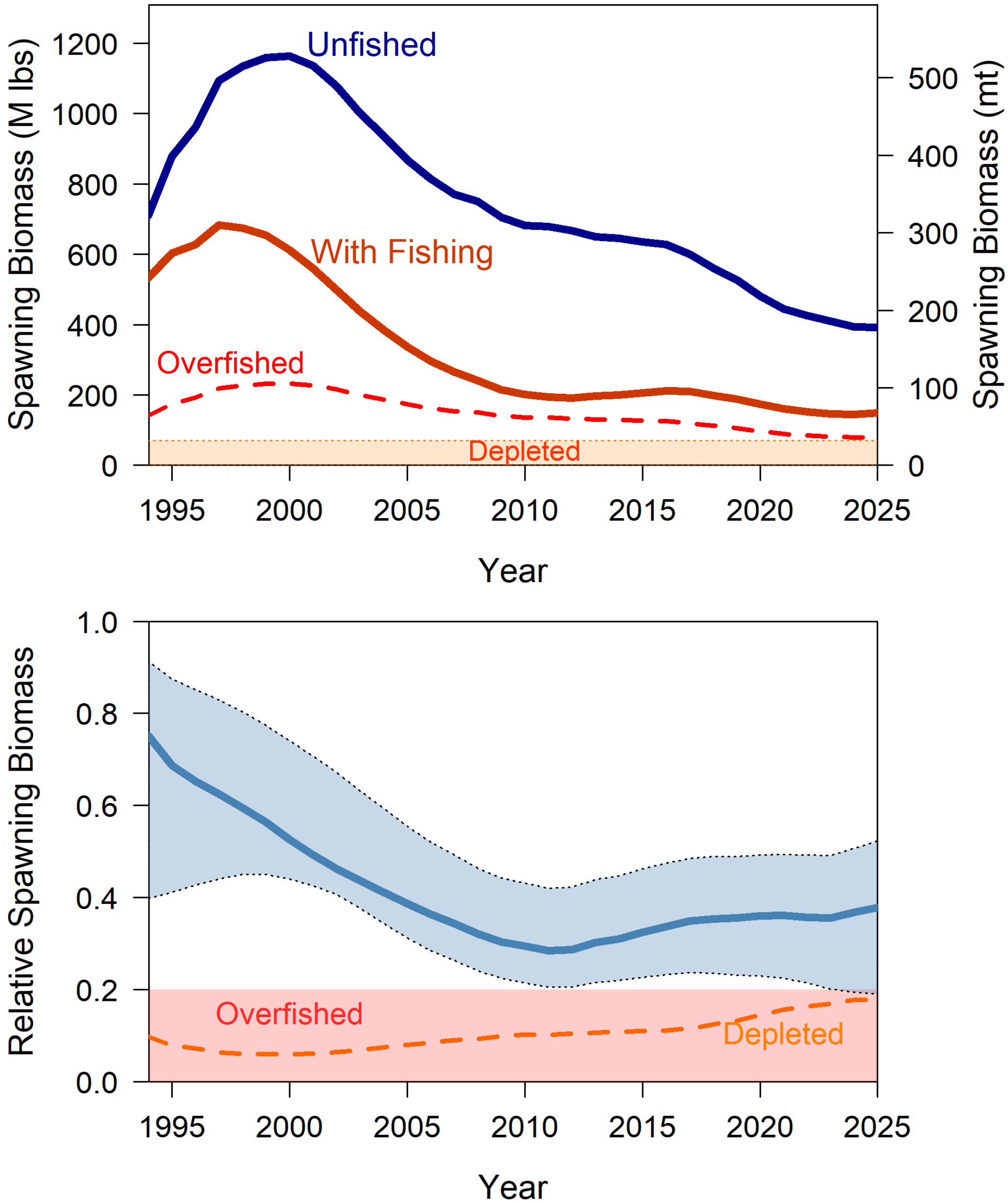

Figure 11. Estimated spawning biomass (top) if fishing had not occurred (unfished) and estimated spawning biomass from the 2024 ensemble stock assessment (with fishing). The Overfished threshold of 20% of unfished spawning biomass is shown as a dashed line. An example 'Depleted' threshold is shown as a straight horizontal line, assuming that it is defined as a constant absolute spawning biomass at 70 M lb. The relative spawning biomass ("with fishing" divided by "unfished") is shown on the bottom plot with a 95% credible interval (accounting for the covariance in the biomass estimated with and without fishing). The Overfished threshold is shown at 20%. The example Depleted value of 70 M lbs is shown as an orange dashed line.

4 DEFINITION OF OVERFISHING

A preliminary definition of overfishing was presented to the Commission at SRB026, resulting in the following recommendations.

> IPHC-2025-SRB026-R, **para. 33**. *The SRB **RECOMMENDED** that the Secretariat evaluate via simulation the ability to detect overfishing (based on the proposed definition) under scenarios of reduced assessment performance when defining "Overfishing" based on probabilities of stock status.*

> IPHC-2025-SRB026-R, **para. 34**. *The SRB **RECOMMENDED** that the Secretariat consider and justify alternative timelines to the three-year rebuilding period specified in the proposed definition of "overfishing" since a three-year period is probably unrealistic for rebuilding timelines*

The definition of "Overfishing" was incomplete in previous drafts of the HSP. Using the concept that "Overfishing" would lead to an "Overfished" state, the Secretariat proposes the following definition for "Overfishing".

> **Overfishing**: where the stock is subject to a level of fishing that would move it to an overfished state with a greater than 50% probability within three (3) years at a constant mortality (measured in biomass) or prevent it from rebuilding to a 'not overfished' state within the required timeframe and specifications of a rebuilding plan.

The benefits of this definition are (1) it is consistent with the decision table and the decision table could easily be used to define the overfishing level, (2) it provides flexibility to the Commission to allow high fishing rates if the stock is large and the Commission would prefer to fish down the stock to achieve optimum yield, (3) it is consistent with a rebuilding plan, and (4) a constant mortality spread over three years ensures that one year is not excessive.

Given this new definition, the recommendation in paragraph 34 of IPHC-2025-SRB026-R to justify alternative timelines to the three-year rebuilding period are now moot. It is consistent with the HSP to include the specifications of the rebuilding plan in the definition of overfishing. Maintaining a three-year period if above the overfished threshold and not in a rebuilding plan remains consistent with the decision table.

The simulations recommended in paragraph 33 will be completed following the reconditioning of the OM in early 2026, and will be presented at the 28th Session of the Scientific Review Board (SRB028).

5 HARVEST STRATEGY POLICY (HSP)

Workshops with Commissioners occurred in April and August 2025 to discuss potential changes to the draft HSP and how to move it forward for adoption. The next steps are for the Commission to review the edits from these workshops, possibly hold another work session, consider a new draft at the Work Meeting, and then move the HSP forward for adoption at the next Interim Meeting or Annual Meeting.

RECOMMENDATION/S

That the SRB:

1) **NOTE** paper IPHC-2025-SRB027-08 which details investigations of autocorrelation in recruitment, definitions of Overfished and Depleted, a definition of Overfishing, and a brief update on the Harvest Strategy Policy.
2) **REQUEST** any topics to add to the 2025-2026 MSE Program of Work.

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