Modification to the Oregon Production Index Hatchery coho salmon forecast methodology

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Introduction

In October of 2023, members of the Oregon Production Index Technical Team (OPITT) presented a novel methodology (hereafter ARIMA ensemble) for forecasting the Oregon Production Index hatchery coho salmon (OPI-H) to the Science and Statistical Committee (SSC) Salmon Subcommittee and the Salmon Technical Team (STT) at the methodology review meeting. A retrospective performance evaluation of the ARIMA ensemble in forecasting the OPI-H abundance in 2008—2022 showed an approximately 36% mean absolute percent error (MAPE) compared to the 62% MAPE of the methodology that was used at the time. Concurrent with the recommendations to use the ARIMA ensemble from the SSC and STT, the Council approved the ARIMA ensemble for salmon management use beginning in 2024, at the November 2023 Pacific Fishery Management Council meeting. In the first year of implementation, the 2024 ARIMA forecast was 54% of the postseason abundance estimate (403,100 forecast, 742,300 postseason estimate) with an absolute percent error (APE) of 46%. Notably, the APE of the ARIMA model in 2024 was the second lowest relative to the APE of forecasts used in the previous 10 years. During the 2025 OPITT forecast meeting, several concerns were raised regarding the 2025 OPI-H forecast: (1) The lagged by one-year Pacific Decadal Oscillation (lag1_PDO) variable used in the forecasting model was lower for 2025 than for all previous years over which the model was fit and has diverged from a previously correlated relationship with regional sea surface temperature (NOAA, 2023). Furthermore, the lag1_PDO variable had a positive coefficient in the models, which differs from the hypothesized effect pathway involving regional sea surface temperature. (2) The forecast predicted a record low ratio of adults returning in 2025 from the previous year's jack return. (3) The OPI-H forecast was a record low ratio of the Oregon Coast Natural coho forecast, which is developed using a different methodology. The Oregon and Washington Departments of Fish and Wildlife OPITT members evaluated and subsequently proposed a minor change to the ARIMA ensemble approach that address these concerns and yielded additional forecast error reduction (see WDFW & ODFW, 2025 for further explanation of issues).

At the March 2025 Council meeting, the Oregon and Washington Departments of Fish and Wildlife requested Council approval of a minor modification to the approved ARIMA ensemble methodology which considered the concerns raised by the OPITT about the previous forecast methods and reduced remaining forecast error by approximately 15.5% relative to the ARIMA ensemble approach approved in 2023 (WDFW & ODFW, 2025). The forecast produced by the modified procedure (hereafter modified ARIMA ensemble) was adopted by the Council for planning 2025 fisheries. We propose using the modified ARIMA ensemble in future years due to its improved performance.

Methods

The ARIMA ensemble has the following steps to develop forecasts (Leeman et al., 2023):

1. Identify a set of covariates and a minimum and maximum number of covariates to include in each individual model,
2. Fit ARIMA models with all unique combinations of covariates to subsets of the data and make one-step-ahead forecasts,
3. Calculate one-step-ahead performance metrics for unique combinations of covariates across forecast years,
4. Generate performance-weighted ensemble forecasts by taking the weighted-mean of a top-performing subset of models,
5. Evaluate how well forecasts would have performed:
    - if each of the ensemble approaches had been used in the past 15 years
    - if the best performing individual model (based on the prior 15 years of one-step-ahead performance) had been used.
    - if the historical OPI-H models had been used in the past 15 years

The modified ARIMA ensemble methodology that was used in the 2025 forecast and is proposed for use in future management years, utilizes this forecasting methodology reported above and in the 2023 methodology review report with a small modification. This modification is to the equation for calculating forecast performance metrics in step 3. These metrics are then used for selecting a set of the best performing models and calculating model weights in step 4. All other steps are unchanged. In this section, the changes to steps 3 and 4 are explained. MAPE as the performance indicator has been used exclusively to align with the ARIMA ensemble methods adopted by Council in 2023. Code and data for the proposed modified ARIMA ensemble analysis can be found here.

Step 3: Performance evaluation for unique covariate combinations (i.e., individual models)

In the ARIMA ensemble methodology, forecast performance of candidate ARIMA models was assessed with each combination of covariates, i, based on their mean absolute prediction error (MAPE; Equation 1), over the most recent 15 years prior to the year being forecasted. Thus, when forecasting the abundance for the upcoming management year:

Eq. 1. $MAPE_i = \left|\frac{\sum_{t=2010}^{2024}(\hat{y}_{i,t}-y_t)/y_t}{15}\right| * 100,$

where y_t is the postseason estimate of abundance in year t and $\hat{y}_{i,t}$ is a preseason forecast generated with covariate combinations *i*. Each year of performance is given equal weight in the average.

In the modified ARIMA ensemble, absolute errors from more recent years are given greater weight in the MAPE, referred to as weighted MAPE (Wtd_MAPE; Equation 2) and calculated as,

Eq. 2. $Wtd\_MAPE_i = \left|\frac{\sum_{t=2010}^{2024}[(\hat{y}_{i,t}-y_t)/y_t]*\lambda_{t,\alpha}}{\sum_{t=2010}^{2024}\lambda_{t,\alpha}}\right| * 100,$

where $\lambda_{t,\alpha}$ is the weight assigned to the error in year *t* using the annual rate of decay in weight α, which is between 0 and 1,

Eq. 3. $\lambda_{t,\alpha} = (1-\alpha)^{(2024-t)}.$

When $\alpha = 0$, this is equivalent to the traditional MAPE. When $\alpha = 1$, only the performance in year *t* is used, and when $0 < \alpha < 1$ the weight given the error in year *t* is $1-\alpha$ times the weight given to the error in year *t+1*. A performance evaluation of using a range of different α values for weighting was conducted to identify an optimal value to reduce the MAPE. A graphical depiction of the effect of α on the weight applied to a particular year's forecast error in calculating weighted MAPE is shown in Figure 1.

Step 4: Generating ensemble forecasts

Step 4 of the procedure is unchanged from the ARIMA ensemble methodology except that the Wtd_MAPE is used in place of MAPE for model selection and calculating ensemble model weights. Step 4 is critical to the methodology and determining the effects of switching to the use of Wtd_MAPE.

Step 4 can be broken down into two sub-steps. The first step is to screen out all but $M = 10$ of the 1,485 different combinations of covariates, which had lowest Wtd_MAPE. The second step is to generate ensemble forecasts $\hat{y}_t$ by taking a weighted average of the predictions of the 10 selected models,

Eq. 4. $\hat{y}_t = \sum_{i=1}^{M}\omega_i\hat{y}_{i,t},$

where ω_i is the ensemble weight assigned to covariate combination i and $\hat{y}_{i,t}$ is the one-year-ahead forecast for year *t* generated using covariate combination *i*. We calculate ensemble weights as,

$$\text{Eq. 5.} \quad \omega_i = \frac{(p_i)^{-1}}{\sum_{i=1}^{M}(p_i)^{-1}} ,$$

where p_i is the performance metric Wtd_MAPE.

Step 5: Evaluating forecast performance

As a final step, we evaluate the performance of the ensemble forecasts by calculating performance metrics and compared it to the ensemble ARIMA. These performance metrics are informational for comparing alternative methodologies and calibrating expectations for future forecast errors. The performance metrics calculated in this step have no effect on model identification or weighting in development of ensembles because they are for evaluating the performance of the entire methodology (i.e., the final performance of the forecasting approach).

Results

Evaluation of alternative rates of decreasing weight with year

The best forecast performance was achieved with a decay rate (α) of 25% per year in the weights applied to errors when calculating the Wtd_MAPE for model screening and averaging (Figure 2). Weighting with this value of α resulted in a 33.3% average absolute error in the 2010 – 2024 retrospective. The worst performance was achieved with α values ≥ 50%, while the unweighted MAPE (α = 0) had the worst performance among α values < 50%. As such, weights using α = 0.25 were utilized within the modified ARIMA ensemble.

Comparison of performance between the unweighted and weighted methodologies

As noted above, the modified ARIMA ensemble resulted in a 33.3% average absolute error in the 2010 – 2024 retrospective whereas using the ARIMA ensemble resulted in a 39.4% average absolute error, indicating improved performance when using the weighted approach. In many years between 2010 and 2025, the forecasts were similar when using the modified ARIMA ensemble and ARIMA ensemble, indicated by the 15-year equal label (Figure 3). There was no consistent pattern in the differences between the forecasts using the different approaches, with the modified ARIMA ensemble resulting in lower forecasts than the ARIMA ensemble for 2011, 2012, and 2014 and higher forecasts for 2022, 2023, and 2025. In the most recent ten years (2015 to 2024), the modified ARIMA ensemble resulted in a lower APE than the ARIMA ensemble in seven of the years. During the most recent five years, 2020 – 2024, the

MAPE of the modified ARIMA ensemble was 29.4% and ARIMA ensemble approach was 30.6% indicating a small improvement in forecasting.

Comparison of responsiveness between the unweighted and weighted methodologies

One of the benefits of the modified approach is the speed at which it learns; patterns and regime changes are accounted for quicker within this methodology compared to the ARIMA ensemble. The ARIMA ensemble holds the relationships between OPI-H abundance and covariates equal across all years, which may result in failures to quickly pick up regime changes such as the observed change in the Pacific Decadal Oscillation (PDO). The modified ARIMA ensemble allows for the more predictive relationships in recent years to weigh more heavily into the model selection process than past years. By design, the modified ARIMA ensemble can allow for higher influences of more recent covariate relationship changes than the ARIMA ensemble. This is best showcased by the shifting of co-variates within the best performing model (Table 1). These differences between the best model in either approach shows changes in predictive relationships that may be occurring across years.

Discussion

In 2023 the Pacific Fishery Management Council approved a new OPI-H forecast methodology using MAPE-weighted ARIMA ensembles based on their demonstrated forecast error reduction over a 15-year retrospective one-year-ahead evaluation. A minor modification to the ARIMA ensemble methodology for forecasting OPI-H coho abundance that employs exponential weighting to give recent forecasting errors more influence when calculating MAPE of component models for screening and weighted ensemble construction has been evaluated. In laymen's terms, this modification allows for more recent patterns to influence which models are selected. An optimal decay rate for weights to apply to errors, which was 25% per year, has been identified. Applying this weighting reduced the MAPE of the ensemble forecasts in a 15-year retrospective analysis to 33.3% from 39.4% with equal weighting. This finding suggests that, within the 15 years of one-step-ahead ARIMA model errors used for model screening and weight calculation, performance in more recent years is more predictive of performance in the following year than is performance in the more distant past. However, there remains considerable value in considering all 15 years of past performance to some degree, as evidenced by the reduction in ensemble performance when the decay rate in weights was > 50% per year.

In addition to the improved performance exhibited in our retrospective analysis, it seems plausible that more recent errors would contain more information than older errors about model performance the following year. However, there is still clearly a need to spread the weight over multiple years to avoid selection of models that reflect fleeting patterns (a form of overfitting). The modified ARIMA ensemble accounts for possible patterns shifts in environmental covariates while also ensuring that it does not over account for temporary changes. For example, if a covariate like PDO has historically been a good predictor of abundance but in recent years it has been less accurate at predicting abundances, the unmodified approach would be less responsive to this shifting pattern and possibly continue to choose PDO as a good predictor. The modified approach accounts for the more recent shift in PDO while still maintaining covariate relationships with consistently good predictive ability across time. This approach of evaluating the performance of a range of decay rates was designed to find an optimal balance between giving more weight to recent performance and spreading the weight evenly enough to avoid models that only perform well in one or two years.

We conclude that weighting recent errors more heavily in the ARIMA ensemble forecasting methodology may improve future forecast performance. Given the increased adaptability and improved performance of the modified ARIMA ensemble, we recommend the adoption of this methodology for salmon management use continuing in 2026 and beyond.

Figures and Tables

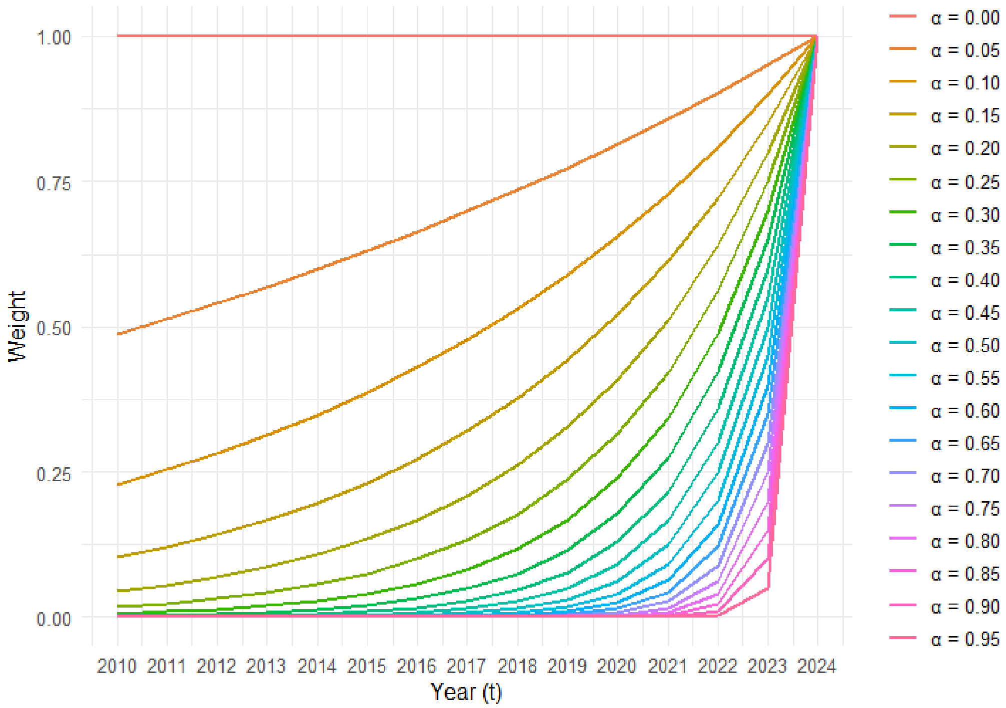

Figure 1. Weights as a function of different values of α in equation 3.

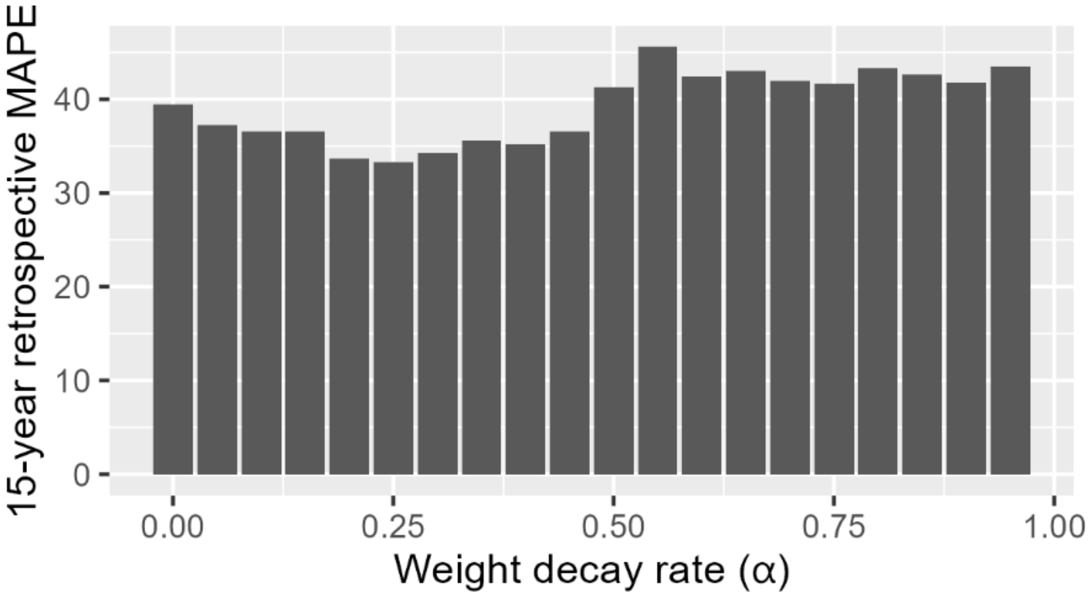

Figure 2. 2010–2024 MAPE of forecasts with different annual rates of decay in weight applied to errors when calculating Wtd_MAPE for model screening and ensemble weighting.

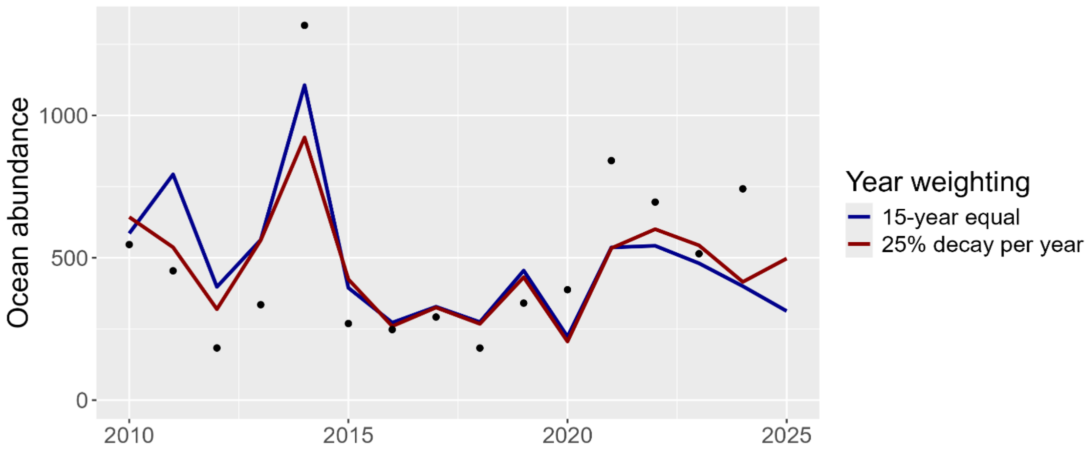

Figure 3. One-year-ahead forecasts (lines) developed with two different implementations of the ARIMA ensemble methodology. The blue line represents an implementation where 15 years of performance are weighted equally in model selection and weighting, and the red line represents the approach where more recent years are weighted higher than older years. The black dots represent the observed abundances.

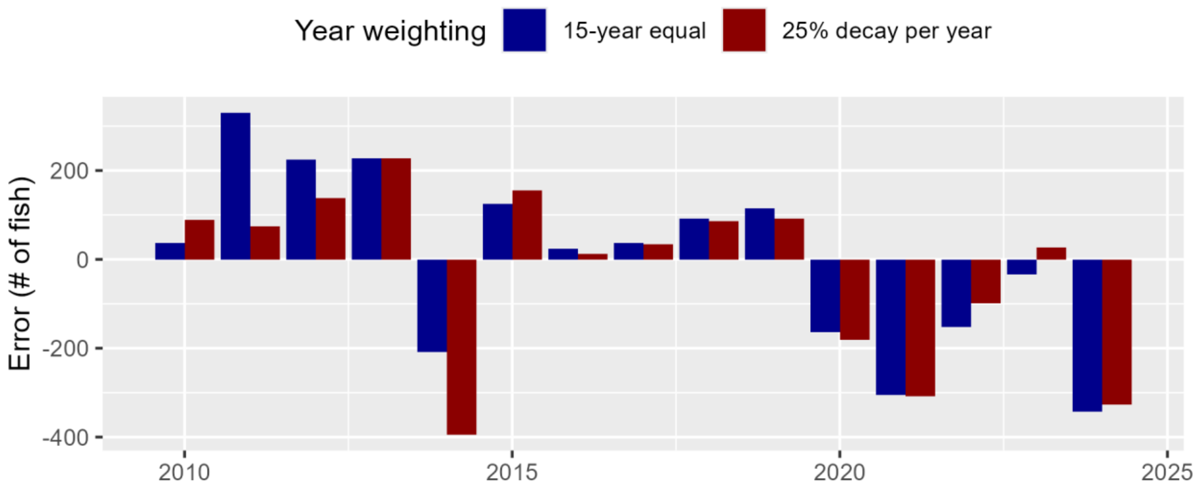

Figure 4. Forecast errors (predicted – observed) from a retrospective analysis of two different implementations of the ARIMA ensemble methodology. The blue bars represent the implementation where 15 years of performance are weighted equally in model selection and weighting, and the red bars represent the approach where more recent years are weighted more heavily than older years.

Table 1. Yearly individual models which performed the best for both the modified ARIMA and ARIMA ensembles. Model covariates: lag1_log_JackOPI = OPI-H jack abundance; year t-1; log-transformed, lag1_log_SmAdj = OPI-H adjusted smolt metric; year t-1; lagged t-1 and log transformed, lag1_NPGO = North Pacific gyre oscillation; year t-1, lag1_PDO = Pacific decadal oscillation; year t-1, MEI.OND = multivariate ENSO Index; Oct., Nov., Dec., PDO.MJJ = Pacific decadal oscillation; May, Jun., Jul., SSH.AMJ = sea surface height; Apr., May, Jun., SST.SMJ = sea surface temperature; Apr., May, Jun., UWI.JAS = upwelling winds index; Jul., Aug., Sep., UWI.SON = upwelling winds index; Sep., Oct., Nov., WSST_A = winter sea surface temperature; average Oct.-Jan..

Year	**modified ARIMA ensemble**	**ARIMA ensemble**
2010	lag1_NPGO + lag1_PDO + UWI.JAS	lag1_log_SmAdj + lag1_NPGO + MEI.OND + UWI.JAS
2011	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + MEI.OND + UWI.SON	lag1_log_SmAdj + lag1_NPGO + lag1_PDO + MEI.OND + UWI.JAS + SST.AMJ
2012	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + PDO.MJJ + UWI.SON	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + PDO.MJJ + UWI.SON
2013	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + MEI.OND	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + PDO.MJJ
2014	lag1_log_JackOPI + lag1_PDO + WSST_A + SST.AMJ + SSH.AMJ	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + PDO.MJJ
2015	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + MEI.OND + UWI.JAS	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A
2016	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + MEI.OND + UWI.JAS	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + UWI.SON
2017	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + SST.AMJ + UWI.SON	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + UWI.SON
2018	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + MEI.OND + SST.AMJ	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A
2019	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + MEI.OND + SST.AMJ	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + UWI.SON
2020	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + MEI.OND + SST.AMJ	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + SST.AMJ + UWI.SON
2021	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + MEI.OND + SST.AMJ	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + SST.AMJ + SSH.AMJ
2022	lag1_log_JackOPI + lag1_NPGO + WSST_A + MEI.OND + SST.AMJ + SSH.AMJ	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + SST.AMJ + UWI.SON
2023	lag1_log_JackOPI + lag1_log_SmAdj + lag1_NPGO + lag1_PDO + WSST_A + UWI.JAS	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + SST.AMJ + UWI.SON
2024	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + UWI.JAS + SST.AMJ	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + SST.AMJ + UWI.SON
2025	lag1_log_JackOPI + lag1_NPGO + MEI.OND	lag1_log_JackOPI + lag1_NPGO + lag1_PDO + WSST_A + SST.AMJ + UWI.SON

References

Leeman et al., 2023. An Evaluation of Preseason Ocean Abundance Forecasts for Oregon Production Area Hatchery Coho Salmon. PFMC November 2023 Council Meeting Briefing Book. Agenda Item D.3, Attachment 1. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

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