Scientific and Statistical Committee
Salmon Subcommittee Report on the Salmon Methodology Review

Pacific Fishery Management Council
Online Meeting

October 11, 2023

The Scientific and Statistical Committee's (SSC) Salmon Subcommittee (SSC-SS) met with the Salmon Technical Team (STT) on October 11, 2023, for an online Salmon Methodology Review, which covered three review topics (Sacramento River Winter Chinook Forecast Review, Oregon Production Index – Hatchery Forecast Review, and a change to South of Falcon Fisheries modeling in the Chinook Fishery Regulation Assessment Model [FRAM]) and a presentation on updates to the FRAM documentation.

Sacramento River Winter Chinook Forecast Review

Sacramento River Winter Chinook salmon (SRWC) are listed under the Endangered Species Act, and ocean harvest-related mortality of this population has been managed via fisheries regulation of mixed-stock fisheries in California with the aim of keeping fisheries from unacceptably increasing the risk of extinction for SRWC. Since 2012, the Pacific Fishery Management Council (PFMC) has used a harvest control rule for SRWC that specifies the maximum allowable age-3 harvest impact rate. In 2018, after SSC review (Agenda Item D.2.a Supp SSC Rpt November 2016), the PFMC modified the harvest control rule to use the forecast age-3 SRWC abundance to determine the allowable impact rate.

Currently the model used to perform the annual forecast (*Base*) uses natural-origin female spawners, a Juvenile Production Index (JPI), and a stream temperature index to forecast SWRC abundance (O'Farrell et al. 2016; Agenda Item D.2 Attachment 1 Nov 2016). While this forecast has been used since 2018, the forecast was developed using a relatively short time-series of data and produces forecasts with considerable uncertainty, and motivates method development to improve forecast performance. This review used additional years of observations and associated covariate data accrued since the initial model development to re-evaluate forecasting models.

Tanya Rogers (SWFSC) presented an evaluation of several preseason abundance forecasts methods for SRWC, including a model with an egg-to-fry survival covariate. Michael O'Farrell (SWFSC, STT) was also available to answer questions. The analysts compared the performance of different models to forecast SRWC spawner abundance (SRWC age-3 escapement absent fishing estimated from spawner surveys and coded-wire tag recoveries) including the *Base* model and an extension of the *Base* model that included the egg-to-fry covariate (empirically measured egg-to-fry survival rate; *ETF* model). Both the *Base* and *ETF* models were considered by O'Farrell et al. (2016) and are described in greater detail there.

In addition to *Base* and *ETF* models, the analysts considered a range of Gaussian Process (GP) models to forecast SRWC spawner abundance. GP models are a non-parametric class of models that allow for flexible functional forms among covariates and between the covariates and the response variable; observations inform the model form. They compared the forecast performance of models including all possible combinations of four covariates (included with appropriate time-lags and transformations): the empirical egg-to-fry survival rate, total number of female spawners, number of hatchery pre-smolts released, and an index of river temperature (degree days above 12 °C between May 15 and October 31 at Clear Creek Gage). All covariates were transformed, centered, and standardized before inclusion in the GP models. For all models, performance was measured using leave-future-out cross validation. For this cross-validation, a one-year ahead forecast was made using data through year *t*, compared to the observed abundance in year *t*+1, and then the model estimates were updated using observations through year *t+1* to produce forecasts in year *t+2*, and so on. The analysts report 9 different measures of forecast accuracy including mean error (ME), two measures of root mean square error (RMSE; natural- and log-scale), mean percent error (MPE), mean absolute percent error (MAPE), median log accuracy ratio (MLAR), two measures of proportion of variance explained (R^2 ; natural- and log-scale), and Pearson correlation coefficient (r). The SSC-SS appreciates the thoroughness of the forecast metrics, and requests that the analysts identify their preferred metric(s) of forecast performance that should be followed to identify the best models.

Both the *Base* and *ETF* models produced highly uncertain forecasts models that, on average, produced forecasts that were less accurate than simply using the long-term average spawner abundance (i.e. had negative R^2 values). This was true using both the median and modal forecast for *Base* and *ETF*. However, the *ETF* model was the only model considered that appeared to forecast the very low spawner abundance observed between 2015 and 2017. In contrast, six of the considered GP models made forecasts more accurate than the average spawner abundance. All of the best performing GP models included the river temperature and the number of female spawners three-years prior as explanatory covariates. The two best performing GP models (as identified by the analysts) were considered in more detail and included: 1) river temperature and number of female spawners (*GP-1*) and 2) river temperature, number of female spawners, and number of hatchery releases (*GP-2*). Note that neither of the two best fitting models include the egg-to-fry covariate. The JPI covariate was not considered for inclusion.

GP-1 and *GP-2* produce very similar forecasts and as a result have similar metrics of forecast performance, though GP-2 has slightly better performance by most metrics over the most recent years considered (2015-2022). GP-2 typically had less error when measured as numbers of fish, while GP-1 typically had less error when measured as a proportion or percentage. However, there remain some patterns in the forecast that suggest further evaluation of forecasting methodologies (including exploration of additional covariates) is warranted. For example, GP-1 under-forecasted spawner abundance in 5 of the last 5 years, even though forecast errors were relatively small (GP-2 model under-forecasted in 4 of 5 recent years).

The SSC-SS identified a set of additional analyses that would be informative for evaluating the management consequences of forecast errors. Because the SRWC forecast is used directly in harvest management to regulate allowable impact rates, different types of forecast error can have distinct downstream consequences. For example, a high forecast when true abundance is low, will potentially allow for higher than intended impact rates for an endangered population. Conversely, a low forecast when actual abundance is high will result in a lower than intended SRWC impact rate, potentially restricting harvest and foregoing catch of more abundant stocks. The SSC-SS requests an analysis documenting how forecasts from the *Base, ETF, GP-1,* and *GP-2* models would have interacted with the SRWC harvest control rule to affect desired impact rates. In particular, the SSC-SS is interested in understanding the direction and magnitude of impact rate error that would have occurred when using the four different forecast methods over return years 2015-2022 (or through 2023 once a 2023 estimate is available).

The SSC-SS recommends using one of the GP models in harvest management starting in 2024. While the forecasts are imperfect, they are superior to both the *Base* and *ETF* models currently considered in forecasting abundance. However, the *ETF* is the only model that reasonably forecast the years of very low abundance (return year 2016 had a postseason estimate of only 865, while GP-1 forecasted over 3,000 for that year and GP-2 forecasted 2,883), so if the Council would like to pursue a precautionary approach for this endangered species, the *ETF* model is worth consideration.

The SSC-SS recommends that the forecast methods for SRWC be revisited periodically (3-5 years) to re-assess their performance. The SSC-SS identified several additional factors that may warrant inclusion in future forecast models including separating the contribution of hatchery- and natural-origin spawners, the juvenile production index, explicit measure of annual variation in the age-structure of spawners, as well as other environmental covariates. The location and abundance of hatchery releases for SRWC have changed substantially over the last decade, suggesting that covariates reflecting hatchery practices may be worth additional consideration in the near future. The SSC-SS thanks Tanya Rogers and Michael O'Farrell for the presentation and analysis.

The SSC-SS requested that the analysts provide a supplemental report that:

1. Calculates a targeted suite of performance metrics identified by the analysts for comparisons of the control rule outputs as applied to the postseason estimates or each of the primary forecast alternatives considered.

2. Repeats the main analyses for forecast performance, and the supplemental analyses of control rule error, when both the training data and postseason estimates used for evaluating model performance are based on year-specific estimates of age structure rather than the average age structure across years.

If these supplemental results are available in time, they should help inform the recommendations of the full SSC on SRWC forecasting.

Oregon Production Index- Hatchery Forecast Review

The SSC-SS reviewed "An evaluation of preseason ocean abundance forecasts for Oregon Production Area hatchery Coho Salmon" and had the opportunity to ask questions of Cassie Leeman (ODFW, STT) and her coauthors, Shannon Conley, Mark Sorel and Thomas Buehrens (all from WDFW). The Oregon Production Index Technical Team (OPITT) annually produces a forecast of natural-origin Coho salmon from the Columbia River Basin and hatchery Coho salmon production from Leadbetter Point, WA, to the California/Mexico border, which is called the Oregon Production Index-Hatchery (OPI-H) forecast. Since 2015, the current multivariate linear regression model that uses jack returns and delayed smolt release estimates has over-predicted the post-season abundance estimate in all but one year. The OPI-H is the largest component of PFMC-area ocean coho fisheries, hence an accurate forecast of its abundance is desirable as over-forecasting could have negative impacts on other Council managed coho stocks (including stocks currently under rebuilding plans) and under-forecasting could unnecessarily constrain fisheries. In response to concerns about the possible fisheries management consequences of over-forecasting, Leeman and co-authors explored alternate forecast models and recommended a new approach, a MAPE (mean absolute percent error)-weighted ARIMA-based (autoregressive integrated moving average) ensemble forecast, for use starting in 2024.

Leeman and co-authors chose to explore a methodology of weighted ensemble forecasts of ARIMA models with unique combinations of covariates that had the best performance metrics in one-step-ahead forecasts. Jack returns, delayed smolt release, and nine environmental covariates were considered for use in forecasting, with a minimum of zero and a maximum of six covariates used per model. The ARIMA models were fit with each combination of covariates to post-season ocean abundance estimates for 1970 through the 2007 for the 2008 forecast, through 2008 for the 2009 forecast, and so on. Forecast performance of each model for the most recent 15 years was assessed with the mean absolute percent error (MAPE), root mean square error (RMSE), and median symmetric accuracy (MSA). Ensemble forecasts were made using the weighted mean of the 10 models for each year with the lowest MAPE, RMSE, and MSA by normalizing the inverse of the performance metric for each model, and using a Markov chain Monte Carlo (MCMC) stacking weight. The performances of these weighted ensemble forecasts were compared to the current OPI-H forecast method and to the single best individual covariate combination as measured by MAPE. The current OPI-H model was the worst performing model. The MAPE-weighted ensemble performed the best, though there was little difference among the ensemble models. The MAPE weighted ensemble model is recommended by the authors.

The SSC-SS agrees that the MAPE weighted ensemble forecast model is an improvement over the current methodology, and supports its use in 2024. The SSC-SS suggests that the model structure and covariates of the top 10 models, and their assigned weights, be reported annually. The SSC-SS has concerns that the MAPE-weighted ensemble, while an improvement from the current model, still over-predicts abundance in nine of the past 15 years. Assessing model performance based on errors in number of fish rather than proportional errors may be more appropriate given the main use of this forecast in the Council process is setting quotas in numbers of fish, and consideration should be given to performance metrics that directly consider the magnitude and direction of bias. While the MAPE-weighted ensemble output includes prediction intervals, the Coho Fishery Regulation Assessment Model (Coho FRAM) does not incorporate uncertainty and OPI-H Coho salmon constitute a significant portion of many Council-managed fisheries. The SSC-SS recommends forecasting the natural and hatchery component of the OPI-H separately and exploring the possibility of forecasting the various components of the OPI-H separately and aggregating these forecasts as needed for Council use. Including new environmental covariates, including freshwater indices, for the model selection could be explored.

South of Falcon Fisheries in Chinook FRAM and FRAM Technical Detail Documentation

Derek Dapp (WDFW) provided an overview of updates and additions to the FRAM documentation that have occurred since the 2022 Salmon Methodology review. The current FRAM online material documents parts of FRAM (with the eventual goal of documenting all of the model), including structural and design changes since 2007, and provides a more detailed description of its procedures and algorithms than previous iterations of the FRAM documentation.

A comprehensive effort to provide documentation for the FRAM began in 2019. Updates and improvements to the documentation for this year focused on calibration methods: the process used to develop the Chinook FRAM base period. The SSC-SS appreciates the efforts made thus far to provide clear and comprehensive documentation for the FRAM and recommends that documentation of existing methodologies be completed as soon as possible. As a living document, material on the FRAM website can be updated regularly and new topics added. The SSC-SS finds the online FRAM user's manual and overview of the documentation to be well organized and user friendly and do not require further review. However, future review of changes to FRAM algorithms or portions of FRAM that have not been previously reviewed (e.g., Backward FRAM) will require completed documentation of all the underlying concepts and algorithms.

Jon Carey (NMFS) presented a new method to calculate Chinook FRAM preseason fishery scalars for south of Cape Falcon fisheries. Fishery scalars are used to project catch for fisheries that are managed as seasons and have no external estimates of projected total catch. This is the case for Council-managed fisheries that occur south of Cape Falcon, Oregon (SOF). Previously, fishery scalars were produced by dividing projected effort by base period effort. The updated method changes the calculation of the scalar by multiplying the projected effort over reference period effort by the average of the fishery scalars in the reference period. The reference period may be the base period, but can be a different set of years.

The new scalar improves the agreement between projected catch and observed historical catch and so the SSC-SS supports its use. The SSC-SS recommends that scalars used to project catch in other fisheries, including those in coho FRAM, be evaluated to see if they can be similarly improved.

Appendix 1

SSC Salmon Subcommittee Members Present

Dr. John Budrick, California Department of Fish and Wildlife, San Carlos, CA
Mr. Alan Byrne (SSC Salmon Subcommittee Chair), Idaho Department of Fish and Game, Boise, ID

Dr. Owen Hamel, National Marine Fisheries Service Northwest Fisheries Science Center, Seattle, WA
Dr. Galen Johnson, Northwest Indian Fisheries Commission, Olympia, WA
Dr. Tommy Moore, Northwest Indian Fisheries Commission, Olympia, WA
Dr. William Satterthwaite, National Marine Fisheries Service Southwest Fisheries Science Center, Santa Cruz, CA
Dr. Jason Schaffler, Muckleshoot Indian Tribe, Auburn, WA
Dr. Ole Shelton, National Marine Fisheries Service Northwest Fisheries Science Center, Seattle, WA
Dr. Cameron Speir, National Marine Fisheries Service Southwest Fisheries Science Center, Santa Cruz, CA
Dr. Tien-Shui Tsou, Washington Department of Fish and Wildlife, Olympia, WA

PFMC
10/26/23