Memo: Forecasting redd distributions of Winter Run Chinook Salmon (WRCS)

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From CBR/SAFS/UW Seattle, WA 98195

## Background

Historical redd distributions are based on observations of redds in-season. Between 2000 and 2016, 80% of WRCS redds were found within 10 km of Keswick Dam and 94% were within 20 km of Keswick Dam. Historic timing over these years is protracted over a few months. Peak spawning lasts over 1 month mostly in July, and while most spawning is during a 3 month period beginning early May, spawning from April through August has been observed.

For retrospective modeling of Egg-to-Fry development and survival, redds are distributed in time using the temporal resolution of the surveys, and the spatial distribution is constrained to be in a discrete location within each survey reach regardless of the actual distribution within the reach. This means that all the redds within a reach observed on the same day are handled identically. The effect of spatial distribution is largely accommodated by the assigned locations of the reaches and any additional spatial-distribution effects within a reach are very small compared to the temporal variation of temperatures and the reach position in the river. See http://cbr.washington.edu/sacramento/fishmodel/release.Xref.png for details and reach lengths etc.

## Forecasting redds

For prospective analysis and modeling, temperatures can be used to forecast the timing of spawning using the method of Dusek-Jennings & Hendrix (2020). The method is based on a proportional odds logistic regression of the timing distribution based on pre-spawning temperature conditions in April and May. The temporal resolution is 10 days. The parameters for this model are directly from the published calibration.

For modeling the spatial distribution, an analogous method was used (Beer 2021, unpublished) to compute proportional odds of spawning in each reach. The user must specify the total number of redds so they can be allocated to each 10 day period, and to the various reaches.

In practice, the user can choose to:

- Allocate redds to one the upper 3 reaches using *only* the temporal method of Dusek-Jennings & Hendrix (2020).
- Distribute the redds across the upper 3 or 4 reaches using both the temporal and spatial methods (see Figure 1). Note: Selecting a distribution in the upper 3 or 4 reaches does NOT guarantee that they are populated. The lowest ($4^{th}$) reach had very few WRCS redds in recent years. To place redds only in the $4^{th}$ reach or at any other user-selected location(s), the user must use the 'Input or Upload' method.


*Figure 1 Controls for forecasting redds and details of the spatial choices in the drop-down menu of locations.*

The forecasting method can be used with any temperature timeseries. Thus, using historical temperatures, a hindcast of redd distribution can be compared to the observed redd distribution. This is shown in Figure 2.

## Temporal Distribution Methods

The Dusek-Jennings and Hendrix (2020) formulation of the proportional odds logistic regression (POLR) is detailed below. For full details, the reader should consult the published article.

Within the POLR model, the log cumulative logit function defines the probability of an individual spawning at boundary j (day) or earlier, relative to spawning after boundary j (day):

$$L_j = \text{logit}(P(Y_{j,t} \leq j)) = \alpha_j - \beta_{Apr} Apr_t - \beta_{May} May_t$$

The components include the time-boundary specific intercepts: $\alpha_j$, coefficients for the temperature effects: $\beta_{Apr}$ and $\beta_{May}$ and normalized mean monthly temperatures for Apr and May ($Apr_t$ and $May_t$ respectively). Between 2000 and 2016, mean temperature below Keswick Dam (standard deviation in parenthesis) for April is 10.15 °C (sd = 0.70), and for May is 10.53 °C (sd = 0.74).

In the SacPAS Fish Model, when the user selects “Forecast redds”, normalized mean temperatures for April and May are computed and the temporal allocation is made with the logit equation above. The true proportions of the total redds allocated to day *j* is computed as:

$P_j = \exp(L_j) / (1 + \exp(L_j))$ with the parameter values in Table 1. All spawning is constrained to be on one of these 10 days, each 10 days apart. The β parameters have the same sign and warmer temperatures result in later spawning.

*Table 1 Parameter values for computing spawn timing.*

| Parameter | Value | Time group | Day of Year (j) | Date (non-leap year) |
|---|---|---|---|---|
| $\beta_{Apr}$ | 0.08 | | | |
| $\beta_{May}$ | 0.34 | | | |
| $\alpha_1$ | -4.00 | 1 | 135 | May 15 |
| $\alpha_2$ | -3.19 | 2 | 145 | May 25 |
| $\alpha_3$ | -2.50 | 3 | 155 | June 4 |
| $\alpha_4$ | -1.58 | 4 | 165 | June14 |
| $\alpha_5$ | -0.73 | 5 | 175 | June 24 |
| $\alpha_6$ | 0.24 | 6 | 185 | July 4 |
| $\alpha_7$ | 1.40 | 7 | 195 | July 14 |
| $\alpha_8$ | 2.65 | 8 | 205 | July 24 |
| $\alpha_9$ | 4.34 | 9 | 215 | Aug 3 |
| $\alpha_{10}$ | (10) inferred | 10 | 225 | Aug 13 |

## Spatial Distribution Methods

Spatial distribution of fish is computed with an analogous method to the temporal distribution, but the calibration was performed independently. First, the historical observations based on carcass surveys over the years 2003-2019 were divided according to the spawning area reach designations. Four reaches (Upper, Middle, Lower, and Bottom) correspond to (in order from upstream to downstream) 1: “Keswick Dam to ACID dam”, 2: “ACID dam to Hwy 44”, 3: “Hwy 44 to Clear Creek Powerlines”, and 4: “Clear Creek Power lines to Balls Ferry”. Within the POLR model, the log cumulative logit function defines the probability of an individual spawning in reach *k* or upstream in year *t*:

$$L_k = \text{logit}(P(Y_{k,t} \le k))$$
$$= \alpha_k - \beta_N N - \beta_{May} May_t - \beta_{June} June_t - \beta_{MayN} May_t N - \beta_{JuneN} June_t N$$

parameters and fit diagnostics are shown in Table 2. Parameter $\beta_{Apr}$ is negative, so warmer April temperatures will move the distribution upstream.

*Table 2 Parameter values for computing spawn location*

| Coefficients | Value | Std. Error | t-value |
|---|---|---|---|
| $\beta_{normN}$ | 0.36041 | 0.02527 | 14.2605 |
| $\beta_{Jun}$ | 0.23292 | 0.03787 | 6.1507 |
| $\beta_{May}$ | -0.83620 | 0.03189 | -26.2236 |
| $\beta_{normN:Jun}$ | 0.46587 | 0.04753 | 9.8016 |
| $\beta_{normN:May}$ | 0.02865 | 0.04350 | 0.6586 |
| | | | |
| Intercepts: | | | |
| | Value | Std. Error | t-value |
| $\alpha_1$ | -0.2676 | 0.0194 | -13.8231 |
| $\alpha_2$ | 2.7637 | 0.0303 | 91.3004 |
| $\alpha_3$ | 6.9798 | 0.2047 | 34.1007 |
| $\alpha_4$ | 10 (inferred) | | |

The spatial and temporal distributions are considered independently. In practice, the temporal distribution is determined first, then for each day of spawning, the spatial distribution is determined.

## Comparison of survival outcomes

For each historic year, the Fish Model was run with default stage-dependent mortality settings using either the observed redd distribution based on the carcass surveys from the database *or* the forecast redd distribution using the method above. A comparison of the survival outcomes is in Figure 2.

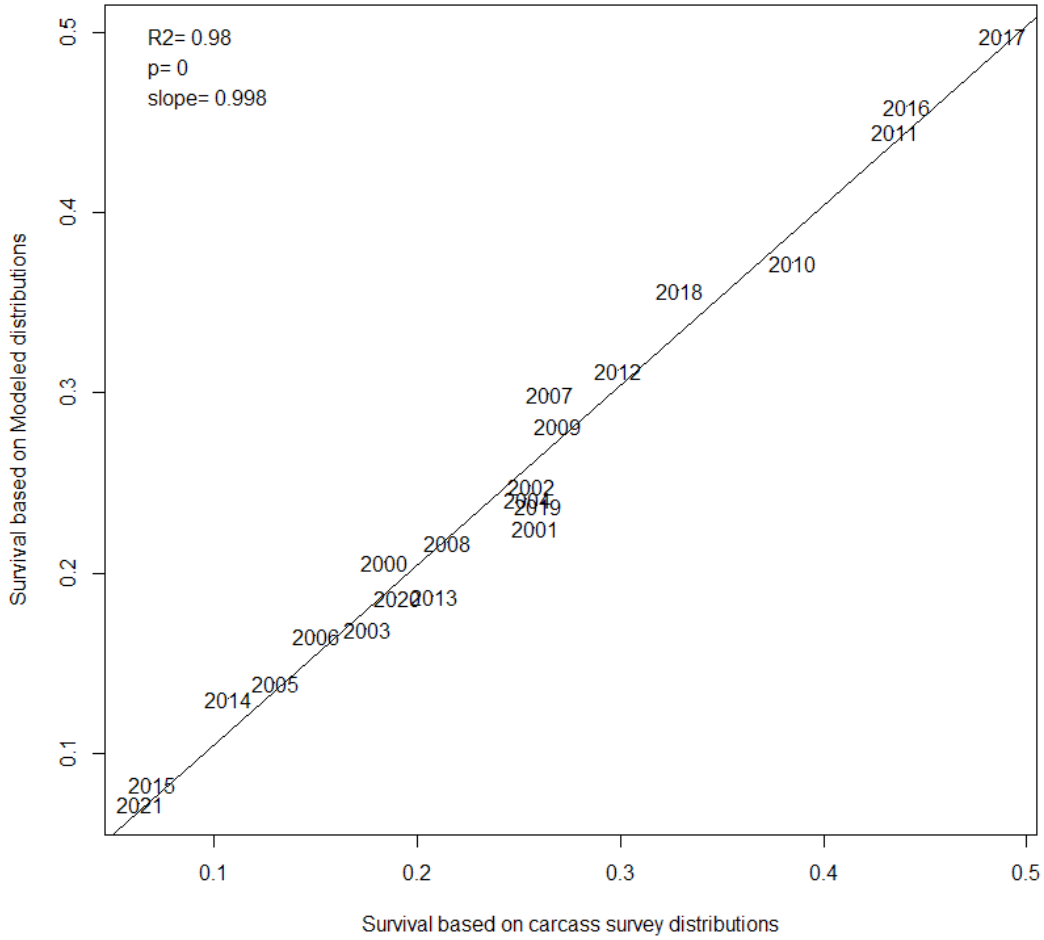


*Figure 2 Comparison of modeled survival using either observed or forecast redd distributions.*

## References

Dusek Jennings, E., & Hendrix, A. N. (2020). Spawn Timing of Winter-Run Chinook Salmon in the Upper Sacramento River. *San Francisco Estuary and Watershed Science*, 18(2). http://dx.doi.org/10.15447///sfews.2020v18iss2art5