# Intro

Hatchery is dam mitigation. If less resources could be devoted to hatchery, more could be devoted to habitat restoration, monitoring, research, etc.

# Methods

## Population model

Because juveniles emigrate from their natal stream at different times of year, and therefore survive at different rates to spawning, we modeled four different juvenile life histories representing different modes in the average outmigration. The first three life histories, fry, summer parr, and fall parr, all emigrate from the natal stream at age . These juveniles continue to rear in the lower Wenatchee River until their second spring, at which time they migrate to the marine environment. The number of juveniles in each of these three life histories is best represented as a sigmoidal function of the number of spawners in the previous year. The sigmoid relationship is likely due to a combination of density dependent emigration and survival, where density dependent emigration is the dominant factor at lower spawner densities and density dependent survival becomes more important at higher spawner densities. I chose to represent this relationship with the cumulative density function of a Weibull distribution scaled by a parameter that represents the upper capacity for a given lifestage. The final juvenile life history is fish that remain in the natal stream until , when they go to sea. Their abundance is represented by a Beverton-Holt function of the number of spawners two years previous.

Instead of estimating annual survival and maturation rates between juvenile emigration and adult return, I modeled a single survival rate to adult ruturn for each juvenile life history and an adult age distribution that was conditional on survival. My thinking was that this would be the maximum number of identifiable parameters given that survival and maturation probabilities would be confounded (Buhle et al. 2018). Adults return at ages 3-5. Some number of the returning adults are removed to be used in the conservation hatchery broodstock. Some number of hatchery-origin adults spawn naturally with the natural-origin spawners. Therefore, the population model is,

(1)

The process error for the juvenile abundances corresponding to a given brood year was assumed to be multivariate lognormal with covariance matrix ,

, (2)

allowing for correlation that reflects shared environmental conditions or competition among life histories in a given brood year.

### Survival

The average survival of each juvenile life history was modeled on the logit scale as a function of its average length at emigration. The effect of length, z-scored across life histories, on logit(*s*) was set to 0.18 based on a previous analysis, so the odds of survival increased by 20% with each standard deviation increase in length. The annual process error was shared among all life histories from a brood year and followed an AR1 process,

(3)

(4)

(5)

where was the autocorrelation coefficient. The average lengths(mm) were as follows: fry = 36, summer parr = 64, fall parr = 80, and yearling smolts = 92.

### Adult age proportions

The vector of adult age proportions was shared by the three juvenile life histories that emigrate at age 1, while the smolt juvenile life history had a unique adult age distribution. The additive log ratio (alr) transformed vectors of age proportions for each year were drawn from a multivariate normal AR1 process with autocorrelation coefficient , mean vector and covariance matrix. The multivariate AR1 process included the vectors of age proportions for all life histories for a given brood year *b*, to account for covariance between them.

(6)

(7)

(8)

### Hatchery origin spawners

The number of hatchery-origin spawners was parameterized as a function of the number of natural-origin spawners and the proportion of hatchery origin spawners

(9)

## Likelihood

### Juvenile abundances

The data on the number of juvenile emigrants \_ in each life history are a vector of estimates from a Monte-Carlo simulation using a model that predicts the number of daily emigrants with a Lincoln-Peterson style estimator and then adds emigrants across days (Sorel 559 final project 2018). The data are assumed to be lognormally distributed around the true number of juvenile emigrants, with a unique variance for each year and life history that reflects uncertainty in the estimating model during that period.

(10)

### Spawner age proportions

Two sources of data on adult age proportions were used. The first was from fish that were tagged as juveniles emigrating from the natal stream that were then detected as adults returning to the river. The numbers of fish that emigrated from the natal stream at a given age and returned at each adult age 3, 4 or 5 were assumed to be multinomially distributed.

(11)

The second source of data come from the aging of carcasses recovered on the spawning grounds. The brood year and juvenile life history of each carcass is unknown but can inform the age proportions of adult spawners in a given year, which can be derived from the population model.

(12)

### Spawner abundances and origins

The index of total number of spawners based on redd surveys is assumed to be an unbiased estimate of the true number of spawners with lognormally distributed error. The CV of the spawner abundance survey is assumed to remain constant among years.

(13)

The carcasses that are recovered on the spawning grounds are identified as being of hatchery or natural origin, and therefore inform the proportion of hatchery origin spawners,

. (14)

### Model fitting

The model was developed in Template Model Builder (Kristensen et al. 2016) which uses Laplace approximation of the negative log of the marginal distribution across random variables. The number of wild spawners in the first 5 years cannot be calculated based on previous years, so they were estimated as parameters in the model. The following parameters were treated as random variables: *log*(), *log*(), *logit*(), and *alr*().

## Projection and decision analysis

To inform hatchery management, we projected the population 25 years into the future with different control rules and evaluated performance metrics. The two hatchery management decisions are the number of hatchery-origin adults to allow onto the spawning grounds and the number of natural-origin adults to remove for use in broodstock. A rough control rule was developed in 2013 that designated the minimum acceptable proportionate natural influence (*pNI*) at different levels of adult return, where , *pHOS* is the proportion of hatchery origin spawners on the spawning grounds and pNOB is the proportion of natural-origin adults in the broodstock. For forward simulation, we assumed that the total number of fish in the broodstock was 74. A constant fraction of the return of wild adults *pREM* was taken for broodstock up to the point where that equaled 74 fish, above which only 74 fish were taken. There was a maximum number of hatchery-origin adults allowed to spawn naturally *Hmax* when 0 natural-origin adult returned. From there, the number of hatchery-origin spawners declined linearly as the number of returning natural-origin adults increased up to a point above which no hatchery-origin adults were allowed to spawn naturally *NORcutoff*.

We considered three different control rules. The first was to completely shut down the hatchery program. The second resulted in pNI values that were just above the minimum set by the control rule: with *Hmax*=200, *NORcutoff* = 500, and *pREM* =0.33. Lastly, we simulated a rule with *Hmax*=300, *NORcutoff* = 300, and *pREM* = 0.4. This rule involved allowing more hatchery-origin spawners at low natural-origin abundance but with a lower cutoff for the number of natural-orgin spawners above which *pHOS* = 0. It also allowed for the removal of a higher-proportion of natural-origin spawners for broodstock. We assumed that there was always a sufficient return of hatchery-origin adults to implement the control rule, and did not model the dynamics of the hatchery population.

1,000 simulations were conducted for each scenario and 5 performance metrics were calculated. The probability of quasi extinction was calculated as the proportion of simulations in which the 4-year running mean number of spawners fell below a QET of 50 adults. We also calculated the geometric mean number of spawners across simulation years and took the arithmetic mean across simulations. Finally, we report *pHOS*, *pNOB*, and *pNI*.

# Results

## Model

Rho = 0.24 (0.02, 0.86)

Age comp

Rho = -0.02 (.51,-.55)

Decision table

Discussion

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