Appendix A. Parameterization of the Stage-Structured Model

Paulsen and Fisher (2001) relate parr-to-smolt survival estimates obtained from PIT tagging studies of several Snake River spring and summer Chinook salmon stocks to various indices of land use as well as the Palmer Drought Severity Index (PDSI), an index that combines data on temperature, precipitation and evapotranspiration. Parr-to-smolt survival estimates are from tag release (during summer or fall) to arrival at Lower Granite Dam during out-migration. We consider these data (updated to include survival estimates for 1999 and 2000) for the Bear Valley Creek, Elk Creek, and Sulfur Creek stocks considered earlier; survival rates did not differ significantly among these sites ($P > 0.6$ in a two-way ANOVA with stock and year). Since land use index for these stocks is constant for the years for which survival rates are available (1992-2000), we do not consider land use here. Survival rates appear to be relatively constant for PDSI values above -3 (Figure A1). Values below -3 are considered to indicate "severe drought" (NCDC 1994). Therefore, we modeled the effect of PDSI using a categorical variable, $V_t$, taking the value 1 in severe drought years and 0 otherwise.

We applied the following regression model to the survival rates for these stocks:

$$\log \left( \frac{\gamma_{i,t}}{1-\gamma_{i,t}} \right) = \delta_t + \beta V_t + \epsilon_{i,t}$$  \hspace{1cm} (A1)

where $\delta_t$ measures the effect of year $t$ and $\epsilon_{i,t}$ is an independent random error term for stock $i$ in year $t$. Paulsen and Fisher (2001) found a significant relationship between survival rates and mean length at tagging and mean month of tagging. We choose not to include these variables in the model, allowing the variability due to these factors to be incorporated into variability associated with $\delta_t$ and $\epsilon_{i,t}$. This approach is reasonable if the fish chosen for tagging represent a random sample of parr for these stocks.

Time series of drought indices, $V_t$, were calculated from historical PDSI measurements from 1895 to 2000 that we obtained from the National Oceanic and Atmospheric Administration (NOAA) web site (http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/ftpchapter.html). PDSI values show no time trend, but exhibit a significant degree of autocorrelation. Simulated values
of PDSI for iterating the model were therefore generated using a bootstrap method for time series, the amplitude-adjusted Fourier Transform "surrogate data" method (Theiler et al. 1992ab, as implemented in the R tseries library). Parr-to-smolt survival rates in the model were simulated using the resulting time series of simulated $V_t$ values in conjunction with (A1) (resampling the $\delta$'s and $\varepsilon_{i,t}$'s with replacement to simulate yearly variation). Parameter uncertainty was included by fitting model (A1) to parametric bootstrap data sets formed by resampling the $\varepsilon_{i,t}$'s and adding them to the model predicted values.

We are unaware of any estimates of parr production for the Snake River Chinook populations. However, Petrosky et al. (2001) include a long time series of estimates of smolt per spawner ratios for the Snake River aggregate. We assumed that the number of parr-per-spawner is lognormally distributed and estimated the mean and variance of $\log(\eta_t)$ as follows:

$$E[\log(\eta_t)] = E[\omega_t - \log(\gamma^*_t)] = 6.04$$
$$\text{Var}[\log(\eta_t)] = \text{Var}[\omega_t - \log(\gamma^*_t)] = 0.13$$

where $\omega_t$ is the time series of observed log smolt-per-spawner ratios for smolt years 1992-1999 from Petrosky et al. (2001), and $\log(\gamma^*_t)$ is the time series of mean (across stocks) yearly parr-to-smolt survival rates for smolt years 1992-1999 from Paulsen and Fisher (2001). Parameter uncertainty was included using a parametric bootstrap based on the fitted lognormal distribution.

Levin et al. (2001) related marine survival rates of Snake River Chinook salmon to ocean conditions (using the Oyster Condition Index (OCI) in Willapa Bay as a measure of ocean productivity) and the size of hatchery releases. Smolt-to-adult survival rates are from out-migration past Lower Granite Dam to return at Lower Granite Dam as an adult. We use those data here to model the relationship between smolt-to-adult survival, ocean productivity levels and the size of hatchery releases:

$$\log\left(\frac{V_t}{1-V_t}\right) = \beta_1 R_t + \beta_2 O_t + \beta_3 O_t R_t + \sigma \varepsilon_t$$

where $R_t$ is the number of hatchery fish released (in millions), $O_t$ is an indicator variable = 1 in years of average to good ocean productivity and 0 in years with poor productivity (defined as OCI values $< -1$ as in Levin et al. 2001), and $\varepsilon_t$ is a Gaussian-distributed random error with unit variance. Marine survival rates in the model were generated assuming a constant hatchery release size, simulating Fourier amplitude-adjusted surrogate OCI values (using OCI values from
years 1978-1998) to form new $O_t$ values, and generating new $\varepsilon_t$ values using random normal deviates. Parameter uncertainty was included using a parametric bootstrap of model (A2).

References


Figure A1  PDSI and survival; data sources are given in the text. (a) Plot of logit($\gamma$) versus PDSI. (b) Average PDSI measurement for months July-December for the Central Mountain Region of Idaho from 1895-2000.