Lewis River Case Study Final Report

A decision-support tool for assessing watershed-scale habitat recovery strategies for ESA-listed salmonids

Appendix K: Functional Relationships

May 2007

Introduction

A literature review was used to develop empirically based functional relationships between key habitat characteristics and fish abundance or survival at various life stages. Relationships were used in the Lewis River Case Study (Lewis River Case Study Final Report) to understand the impact of fine sediments on juvenile salmonids, both in the FishEye Model (Appendix J) and as their own habitat evaluation model. These functional relationships can be used to estimate the effects of changes in habitat conditions on juvenile survival for particular species. This method of estimating restoration effects on fish populations is the least complex method we could develop. It has clear limitations in that effects on multiple habitat conditions are not linked and there is no life-cycle model incorporated. The strength of this approach is that it is based solely on empirical data. Comparing the restoration priorities between this limited but simple and transparent method to restoration prioritization results from a complex model such as EDT will help identify strengths and limitations of the two approaches as well as to indicate knowledge gaps. Restoration actions that change habitat in a way that is estimated to have a strong fish response using both methods might be rated particularly high.

Methods

Five measures of substrate composition were used in the studies of the relationship between sediment and egg survival included in this analysis: percent fines less than 0.85 mm, percent fines less than 3.3 mm, percent fines less than 4.7 mm, percent fines less than 6.4 mm and the geometric mean of particle size. The actual sieve size used in the various studies varied somewhat but within a size class all were within 0.2 mm of each other. The sediment model that will be used to estimate the changes in sediment resulting from the implementation of the various scenarios used the sediment size classes from Table A-3. The closest correspondence to the sediment sizes in the literature was percent fines < 0.85mm, hence only the relationships developed for that size class will be presented here.

Statistical Analysis

Logistic regression models that included sediment as a covariate were fit to the data from all appropriate studies located in the literature search. In this model, each egg has a specific probability of hatching, with this probability depending on sediment composition. Further, each trial in an experiment or each redd is a binomial experiment with N trials, where N is the number of eggs in the redd. Thus, we model the probability of hatching, and from this derive the proportion of eggs expected to hatch. In most of the studies used here, the number of eggs planted, or the estimated eggs produced by each female were given. In those studies without this information, the average fecundity from other studies with that species was used. In a few of the studies used here, the data given were means of 2-6 trials. These data were weighted to reflect the fact that there is less variability associated with means than with individual values.

An initial fitting of logistic regression models to the individual studies used here indicated that nearly all of the data are over-dispersed; the observed variation exceeds that expected under a binomial model, and therefore quasi-likelihood procedures were used to fit models to these data (McCullagh & Nelder 1989). Williams' method (Williams 1982) was used to estimate the overdispersion parameter, which is subsequently used to adjust the standard errors of the regression parameter estimates.

The first stage of modeling checked whether the slope of the relationship between percent fines and survival differed. A common slope model was then fit to the data and used to estimate the change in the odds of survival when the percentage of fines in the substrate changes. We needed an estimate of the intercept in order to estimate survival or the change in survival. If there was more than one intercept for a given species, a weighted average of the intercepts was calculated with the slope held constant at the value determined in the previous step. The slope and intercept were used to estimate the change in mean survival resulting from the various scenarios evaluated under this study.

We used a bootstrap procedure (Efron and Gong 1983) to estimate the covariance matrix for the slope and intercept. A bootstrap sample was drawn from each of the groups having a common slope. We fit a parallel lines model to the bootstrap sample and used the slope of the lines as an offset in a subsequent model to estimate the intercept. We repeated this 5000 times, and then used results to estimate the variances of the intercept and slope, and the covariance between them. These estimates were then used to construct 95% Wald confidence intervals for the estimated mean survival.

Results

Egg-to-fry Survival vs. Percent fines < 0.85 mm

The studies utilizing percent fines less than 0.85 mm as the sediment metric included experiments and field studies with four salmon species: chinook, coho and chum salmon and steelhead. Only one paper reported results of an experiment with chum salmon (Hall 1986). There was convincing evidence for a negative relationship between sediment and survival ($p < 0.001$), even though there is considerable overdispersion (deviance=17.22 on 4 df, $p < 0.002$). The modeled relationship is:

$$\text{logit(survival)} = \underset{(0.316)}{0.144} - \underset{(0.029)}{0.146}\text{*fines}$$

Among the papers reporting results from chinook (Bennett et al 2003, Tappel & Bjornn 1983, Hall 1986, Reiser & White 1988, Reiser & White 1990), survival was monitored from the green egg stage in three and from the eyed egg stage in two (Table K-1). Reiser and White (1990) conducted experiments on both, but because the relationship between survival and sediment was not significant for the eyed egg data ($p>0.11$), these data were not included in further analyses. Within each of these groups, the slope of the regression line was not different in the various studies ($p>0.56$ for eyed egg survival; $p > 0.75$ for green egg survival). The intercept did differ among the studies of eyed egg survival ($p<0.006$). Within the studies of green egg survival, two (Bennet et al. 2003 and Reiser and White 1988) were not statistically different ($p< 0.13$), but the third did have a different intercept ($p< 0.0001$).

Table K-1. Chinook salmon and steelhead studies evaluated, including the life stage at which monitoring began, sediment metric and whether the study was conducted in an artificial (lab) or natural (field) environment.

Species	Life Stage	Sediment Metric	Source	Type
chinook	green egg-to-fry	% fines < 0.84mm	Reiser & White 1988	lab
chinook	green egg-to-fry	% fines < 0.84mm	Reiser & White 1990	lab
chinook	green egg-to-fry	% fines < 0.85mm	Bennett et al. 2003	lab
chinook	eyed egg-to-fry	% fines < 0.84mm	Reiser & White 1990	lab
chinook	eyed egg-to-fry	% fines <0.8mm	Hall 1986	lab
chinook	eyed egg-to-fry	% fines < 0.85mm	Tappel & Bjornn 1983	lab
steelhead	eyed egg to yolk absorption	% fines < 0.841mm	Cederholm & Lestelle 1974	field
steelhead	eyed egg-to-fry	% fines < .85mm	Tappel & Bjornn 1983	lab

For the steelhead data (Table K-1), there was no linear relationship in the Cederholm and Lestelle (1974) data ($p > 0.62$). The Tappel and Bjornn (1983) steelhead data monitored survival from the eyed egg stage, and there was no evidence that steelhead survival differed from chinook survival in those data ($p > 0.17$). Thus, the steelhead data were combined with the eyed chinook data. Within these studies, there was no evidence that the slope of the relationship was different among the studies ($p > 0.78$), but the intercept was different in the Hall data ($p < 0.007$).

These results suggest a model for chinook and steelhead survival that adjusts survival depending on the egg stage at which monitoring begins. Since there were no studies found that monitored steelhead survival from the green egg stage, it could not be determined whether steelhead and chinook survival would be the same from the green egg stage. The survival data for each life stage were combined and a single model was fit to estimate the slope of the relationship, although survival from the eyed egg stage was not included in the final functional relationships or the Lewis River DSS.

In these models, the estimated odds of emergence from the green egg stage decreases by 12.1% for each 1% increase in fine sediment (95% Wald confidence interval 8.9% to 15.1%) and the estimated odds for eyed eggs decreases by 25.5% for each 1% increase in fine sediment (95% Wald confidence interval 21.5% to 29.3%).

The final functional relationship models for chinook salmon and steelhead are:

$$\text{green egg survival (Chinook): logit(survival)} = \underset{(0.154)}{0.237} - \underset{(0.018)}{0.129}\text{*fines}$$

$$\text{eyed egg survival (Chinook \& Steelhead): logit(survival)} = \underset{(0.266)}{3.54} - \underset{(0.027)}{0.294}\text{*fines}$$

Plots of these relationships and 95% confidence intervals for estimated mean survival are included below (Figure K-1 and Figure K-2).

Four coho studies were analyzed (Hall and Lantz 1969, Cederholm and Salo 1979, Tagart 1984, and Hall 1986; see Table K-2). Each of these studies except Hall's monitored survival from green eggs, the latter monitored from the eyed egg stage. There was no evidence that the slope of the relationship between survival and sediment differed in the two groups ($p > 0.28$), so egg stage was not considered a factor in subsequent analyses. There was moderate evidence suggesting that the slope of the relationship differed among the four studies ($p < 0.05$), however pairwise comparisons did not find any differences so a common slope was assumed for the four data sets.

There is at best moderate evidence that the intercept differed between the data of Cederholm & Salo, Hall, and Tagart ($p > 0.05$), but convincing evidence that the intercept differs in the Hall and Lantz data ($p < 0.0001$). In this model, the odds of coho survival is estimated to decrease 13.3% for every 1% increase in the percentage of fine sediment (95% Wald confidence interval: 9.6% to 16.9%).

Table K-2. Coho salmon evaluated, including the life stage at which monitoring began, sediment metric and whether the study was conducted in an artificial (lab) or natural (field) environment.

Species	Egg Stage	Sediment Metric	Source	Type
coho	egg-to-fry	% fines < 0.83mm	Hall & Lantz 1969	field
coho	eyed egg-to-fry	% fines <0.8mm	Hall 1986	lab
coho	green egg-to-fry	% fines < 0.85mm	Cederholm & Salo 1979	lab
coho	egg-to-fry	% fines < 0.85mm	Tagart 1984	field

The final functional relationship model for coho salmon is:

$$\text{logit(survival)} = \underset{(0.329)}{1.72} - \underset{(0.021)}{0.143}\text{*fines}$$

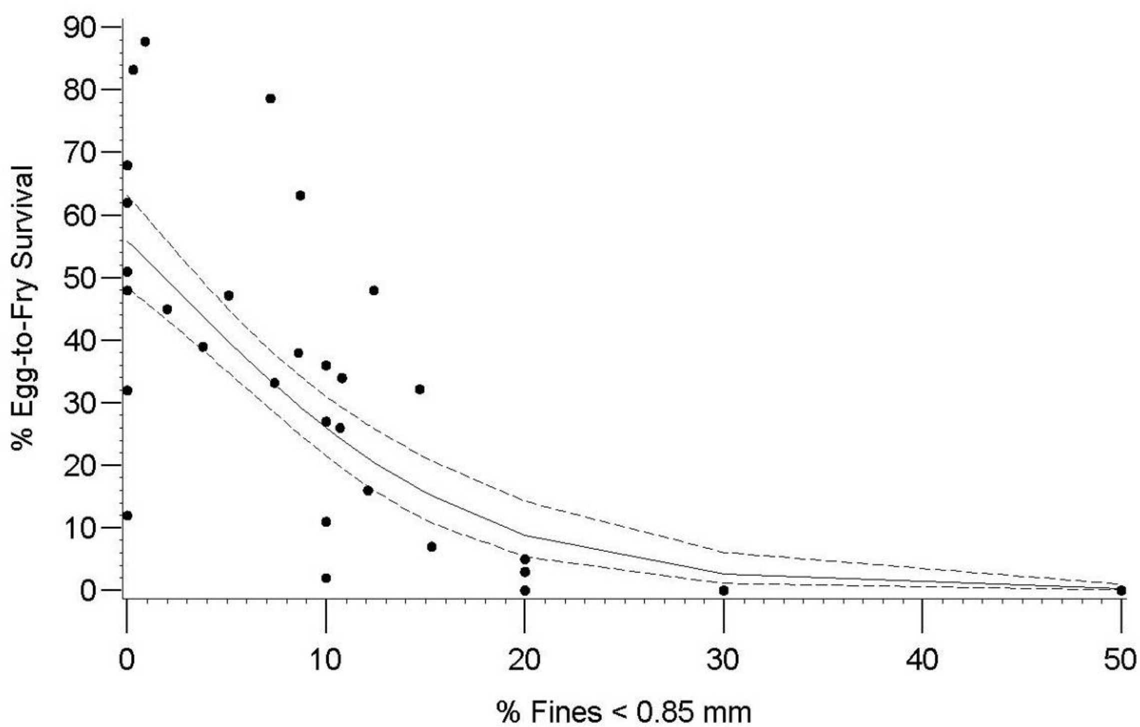

Figure K-1. Relationship between green egg-to-fry survival of chinook salmon and the percentage of fine sediment. The points are from studies used to estimate the relationship. The solid line is the estimated mean survival; the dashed lines are 95% confidence intervals for the mean.

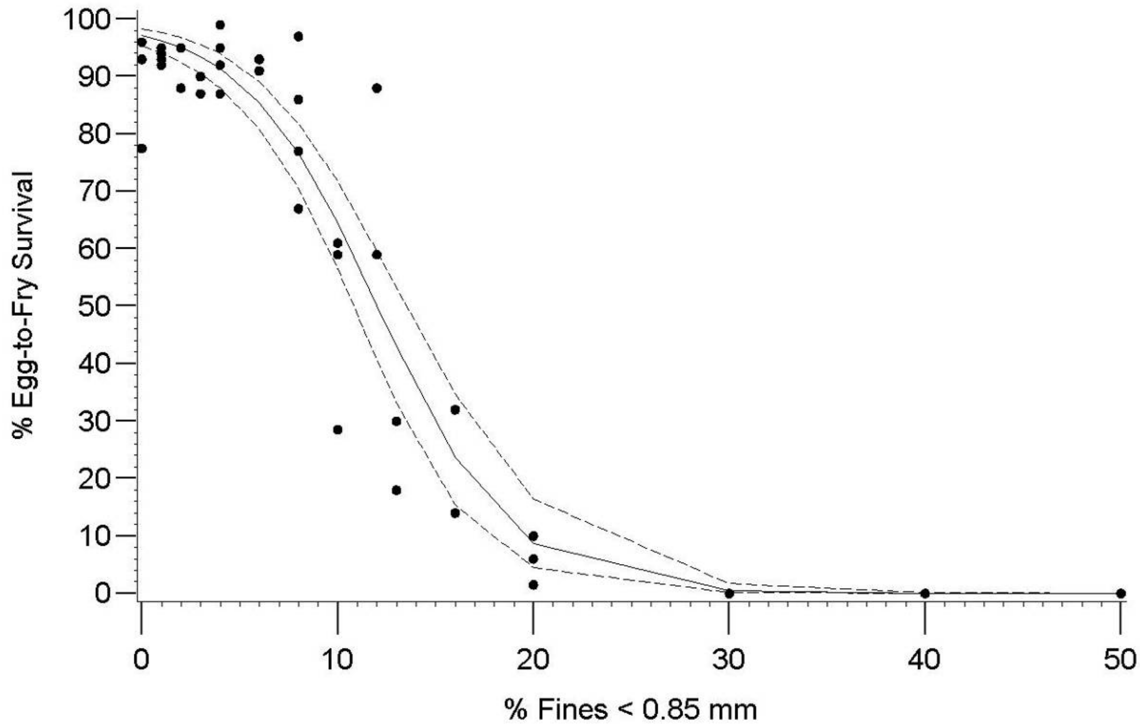

Figure K-2. Relationship between eyed egg-to-fry survival of chinook salmon and steelhead and the percentage of fine sediment. The points are from studies used to estimate the relationship. The solid line is the estimated mean survival; the dashed lines are 95% confidence intervals for the mean.

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