AN ABSTRACT OF THE THESIS OF

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Title: Habitat Selection of Hatchery and Wild Juvenile Salmonids in Eagle Creek Basin, Oregon

Abstract approved:

Carl B. Schreck

To best manage Eagle Creek National Fish Hatchery and minimize any negative impacts that the current hatchery program may be having on Endangered Species Act-listed salmonids in the Eagle Creek Basin, I determined if wild fish are being displaced from preferred habitats by hatchery salmonids *Oncorhynchus* spp. This thesis had two goals. The first goal was to determine the possible effect of hatchery smolts on resident salmonids. I determined the density and distribution of wild juvenile steelhead *O. mykiss* and coho salmon *O. kisutch* in Eagle Creek and North Fork Eagle Creek, Oregon. My first objective was to compare summer rearing densities and distributions of wild salmonids in Eagle Creek, which receives a release of hatchery fish, and North Fork Eagle Creek, which does not receive a release of hatchery fish. Next, I determined if residual hatchery winter steelhead were present in Eagle Creek and/or North Fork Eagle Creek and if so whether or not they have an impact on mesohabitat selection, distribution, and density of wild fish in Eagle Creek basin. By conducting a comprehensive snorkel survey I identified significantly higher densities ($P < 0.05$) of juvenile coho salmon rearing in North Fork Eagle Creek as compared to upper and lower Eagle Creek. Age 0

winter steelhead occurred in significantly higher densities ($P < 0.05$) in upper Eagle Creek compared to lower Eagle Creek and North Fork Eagle Creek. Residual hatchery steelhead were located only in Eagle Creek and found rearing in the same 15 mesohabitat units that contained the estimated majority of wild fish populations. Residual hatchery steelhead comprised 0.9% of the winter steelhead population (1.1% of age 0 winter steelhead and 9.3% of age 1 winter steelhead), and 2.2% of the coho salmon population estimated to be rearing in Eagle Creek. From these data it is unclear if residual hatchery steelhead are affecting densities, distributions, and mesohabitat selection of wild salmonids in the basin. However, while I was unable to detect any direct impacts of residual hatchery fish on the wild population, these results do suggest a significant potential for ecological interaction between hatchery and wild populations.

I began this study with the intention of constructing a statistical model that would explain microhabitat preference of wild salmonids given the presence or absence of residual hatchery winter steelhead. To produce an unbiased model, ideally fish would behave as if there were no observer present (i.e., undisturbed). This is not always the case. Therefore, I addressed a second goal using underwater video to test the prediction that the presence of an in-water observer can elicit a change in fish movement. I analyzed underwater video recordings to document changes in four metrics that can be used to infer a change in fish behavior, which can ultimately result in collection of erroneous microhabitat use data. My four behavior metrics were upstream movement, downstream movement, total movement, and relative abundance of fish in the field-of-view. I detected significant differences in 9 of 10 replicates (ANOVA, $P < 0.05$) in at least one of the four behavior metrics. These results suggest that when attempting to document small-scale microhabitat preference by juvenile salmonids, an in-water observer may alter fish behavior thereby producing erroneous results. I suggest that researchers use caution in making inferences to entire populations when using results of models in which data were collected from only “undisturbed” fish by direct observation.

Habitat Selection of Hatchery and Wild Juvenile Salmonids in Eagle Creek Basin, Oregon

by

William R. Brignon

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CONTRIBUTION OF AUTHORS

Carl B. Schreck, David L. G. Noakes, Howard A. Schaller and Douglas E. Olson assisted with study design and interpretation of the data for Chapters 2 and 3. M. Brian Davis assisted with study design and data collection for Chapter 3.

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CHAPTER 1 : GENERAL INTRODUCTION

The United States Fish and Wildlife Service (USFWS) operates 21 hatchery facilities within the Columbia River Basin. The purpose of these facilities is to mitigate for losses of naturally produced salmonid *Oncorhynchus* spp. populations caused by overharvest, loss of habitat, and construction of the hydropower system (Olson et al. 2004). In 2005 the USFWS appointed a Hatchery Review Team to begin conducting a comprehensive review of federally operated hatcheries in the Columbia River Basin with the intent of better integrating hatchery management strategies with conservation goals that incorporate habitat, harvest, and hydropower needs. Operating USFWS hatcheries with the best available scientific principles will ensure sustainable fisheries into the future and yield the greatest benefit to the conservation of naturally spawning populations of steelhead *O. mykiss* and salmon (USFWS 2007).

The Hatchery Review Team evaluation of Eagle Creek National Fish Hatchery (NFH) was completed in July 2007 (USFWS 2007). The hatchery began operation in 1956 and was funded by the Mitchell Act to provide recreational and commercial fishery opportunities and to mitigate for losses of salmon and steelhead populations caused by the construction of Bonneville Dam. In recent history and up until spring 2008, Eagle Creek NFH released 150,000 juvenile winter steelhead and 500,000 juvenile coho salmon *O. kisutch* into Eagle Creek, Oregon, a tributary to the Clackamas River. Currently these releases have been reduced to 100,000 winter steelhead smolts and 350,000 coho salmon smolts. North Fork Eagle Creek, a major tributary to Eagle Creek, is thought to be the primary producer of the naturally spawning Endangered Species Act (ESA) listed populations of steelhead and salmon in the Eagle Creek Basin (USFWS 2007). Risks associated with ecological interactions between hatchery fish released from Eagle Creek NFH and wild ESA listed species were listed as a major concern of the Hatchery Review Team.

One such risk was the presence of residual hatchery winter steelhead in Eagle Creek and North Fork Eagle Creek. There is a greater potential for negative ecological interactions if hatchery fish do not emigrate quickly (McMichael et al. 2000) and rear in the Eagle Creek Basin throughout the summer months. McMichael et al. (1997) documented reduced growth of wild resident *O. mykiss* rearing in the vicinity of residual hatchery steelhead during summer. Also, residual hatchery steelhead have been shown to migrate over 12 kilometers upstream into areas containing ESA listed fish populations (McMichael and Pearsons 2001), which could have implications for wild fish rearing in the North Fork Eagle Creek.

Very little was known about the juvenile density and distribution of steelhead and salmon in Eagle Creek and North Fork Eagle Creek let alone the impacts the hatchery release have on the juvenile populations in those streams. In Chapter 2, I describe the distribution, density, and population size of residual hatchery winter steelhead, wild winter steelhead and coho salmon in Eagle Creek and North Fork Eagle Creek at a broad habitat scale (i.e., mesohabitat). This allowed me to infer if the hatchery was having large scale effects on the wild fish in the basin. My specific objectives were to: 1) compare summer rearing densities in two similar streams, one stream receives a release of hatchery salmonids and one stream does not receive a release of hatchery salmonids, 2) determine if residual hatchery winter steelhead were present in the Eagle Creek Basin and 3) if so, whether or not they have an impact on mesohabitat selection and distribution of naturally produced salmonids.

The results from Chapter 2 suggested that if residual hatchery winter steelhead were having an impact on wild rearing fish, it might be occurring at a smaller spatial scale (i.e., microhabitat). Therefore, using well known sampling (i.e., snorkel observations) and statistical techniques (i.e., logistic regression modeling), I attempted to describe the explanatory variables influencing the probability of a wild fish occurring given that residual hatchery winter steelhead were in the vicinity. Inconsistencies with fish behavior caused by the presence of the in-water observer, concerns about erroneous data and ultimately, model validity, forced me to abandoned further sampling. I decided that documenting the change in fish behavior as a function of the in-water observer may benefit others who attempt a similar sampling design. Therefore, the objective of Chapter 3 was to determine if the presence of an in-water observer influences fish behavior in terms of movement.

CHAPTER 2 : DENSITY, DISTRUBUTION AND MESOHABITAT SELECTION OF JUVENILE WILD SALMONIDS AND RESIDUAL HATCHERY WINTER STEELHEAD IN EAGLE CREEK AND NORTH FORK EAGLE CREEK, OREGON

Abstract

In order to best manage Eagle Creek National Fish Hatchery and minimize any negative impacts that the current hatchery program may be having on Endangered Species Act listed wild salmonids in the Eagle Creek Basin, it is important to first determine the juvenile density and distribution of wild steelhead *Oncorhynchus mykiss* and coho salmon *O. kisutch* in Eagle Creek and North Fork Eagle Creek, Oregon. My first objective was to compare summer rearing densities and distributions of wild salmonids in Eagle Creek, which receives a release of hatchery fish, and North Fork Eagle Creek, which does not receive a release of hatchery fish. Next, I determined if residual hatchery winter steelhead were present in Eagle Creek and/or North Fork Eagle Creek and, if so, whether or not they have an impact on mesohabitat selection, distribution, and density of wild fish in Eagle Creek basin. By conducting a comprehensive snorkel survey I identified significantly higher densities ($P < 0.05$) of juvenile coho salmon rearing in North Fork Eagle Creek, compared to upper and lower Eagle Creek. I found age 0 winter steelhead in significantly higher densities ($P < 0.05$) in upper Eagle Creek as opposed to lower Eagle Creek and North Fork Eagle Creek. Residual hatchery steelhead were located only in Eagle Creek and were rearing in the same 15 mesohabitat units that contained the estimated majority of wild fish populations. Residual hatchery steelhead comprised 9.3 percent of the age 1 winter steelhead population estimated to be rearing in Eagle Creek. From these data it is unclear if residual hatchery steelhead are affecting densities, distributions, and mesohabitat selection of wild salmonids in the basin. However, while I was unable to detect any

direct impacts of residual hatchery fish on the wild population, these results do suggest a high potential for ecological interaction between hatchery and wild populations.

Introduction

Hatcheries have come under increased scrutiny in the last 20 years with regards to negative ecological interactions between hatchery and natural origin (wild) salmonids. These interactions are thought to be one reason for the current decline in abundance of Pacific salmon *Oncorhynchus* spp. in the Columbia River Basin (Levin et al. 2001; Meffe 1992). Hatcheries in the Pacific Northwest were initially constructed, and are still operated, to compensate for the loss of spawning habitat and degradation of rearing habitat caused by overharvest, logging, irrigation, and construction of the hydropower system (Olson et al. 2004). These hatcheries release millions of juvenile salmonids into river systems where they may interact and compete with wild salmonids, some of which are listed as threatened and endangered under the Endangered Species Act. Understanding interactions that could occur between populations of hatchery and wild salmonids is vital to the management and preservation of Pacific salmon.

Large releases of juvenile hatchery salmonids increase the density of fish in streams at various times of the year, potentially increasing competition for limited resources (Bohlin et al. 2002; Glova 1987; Kennedy and Strange 1986; Kostow and Zhou 2006; Li and Brocksen 1977). Hatchery reared salmonids have the potential to interact with wild salmonids through a variety of mechanisms, including competition for food and habitat (Bachman 1984; Jacobs 1981), predation (Cannamela 1993), spread of disease (Goede 1986; Ratliff 1981) and behavioral disturbances (McMichael et al. 1999). The considerable numbers of hatchery salmonids released, combined with their larger size compared to their wild counterparts, provides them with a competitive advantage over wild salmonids from the same year class (McMichael et al. 2000; Nickelson et al. 1986), as well as later year classes. This places wild fish at a distinct disadvantage at both the community and individual levels.

Hatcheries release certain species of salmon in the spring as presumptive smolts with the intention that they will directly migrate to the ocean, thereby minimizing any negative effects on wild rearing fish. However, this is not always the case. Hatchery releases have lowered densities of wild fish rearing in the vicinity of the hatchery release (Vincent 1987) and in the path of their out-migration (Hillman and Mullan 1989). Predation (Cannamela 1993) and early migration (Hillman and Mullan 1989; McMichael et al. 1999) are just two mechanisms by which hatchery fish lower the density of wild rearing salmonids. Wild fish are typically smaller and less developed than hatchery fish of the same brood year (Nickelson et al. 1986; Rhodes and Quinn 1998). Therefore, wild fish may be more prone to predation and less ready to emigrate at the same time as larger hatchery fish. Wild salmonids have been documented to emigrate early when they join an out-migrating group of hatchery smolts (Hillman and Mullan 1989; McMichael et al. 1999). Hillman and Mullan (1989) reported substantial redistribution in wild spring Chinook salmon *O. tshawytscha* and wild steelhead *O. mykiss* after releases of hatchery spring Chinook salmon in the Wenatchee River, Washington. When wild salmonid abundance is reduced by interactions with spring releases of hatchery fish, valuable rearing habitat is left underutilized throughout the summer months. That in effect lowers the productivity of these streams.

Determining if wild fish are being displaced by the “swamping effect” caused during hatchery releases is important for hatchery managers. McMichael et al. (1999)

documented dominant agonistic behaviors of hatchery steelhead which resulted in wild *O. mykiss* being displaced from preferred habitats. They theorized that the larger size of hatchery steelhead placed the smaller wild fish at a distinct competitive disadvantage. Not all displacement events are due to agonistic behaviors; the same study documented one instance of a wild fish leaving its position to join a group of actively migrating hatchery fish. When hatchery fish displace juvenile wild salmonids, summer rearing densities may be lower in streams that experience a hatchery effect than in streams that do not.

Ecological impacts from releases of hatchery steelhead on populations of wild salmonids are highest when hatchery fish fail to emigrate quickly (McMichael et al. 2000). Delayed migration by hatchery steelhead (i.e. residual hatchery steelhead) and their impacts on wild salmonids have been well documented (e.g., Brostrom 2003; McMichael et al. 1999; McMichael et al. 1997; Viola and Schuck 1995). In the North Fork Teanaway River, a tributary to the Yakima River in Washington, residual hatchery steelhead were shown to reduce the growth of wild resident *O. mykiss* during the summer (McMichael et al. 1997). The same study documented no effect of residual hatchery steelhead on spring Chinook salmon half their size. McMichael et al. (1997) concluded that there was no effect on spring Chinook because this species resides in different habitats in the river, therefore minimizing any competitive effects. This indicates that displacement caused by hatchery fish may have different impacts among species as it does within species (Jacobs 1981).

Eagle Creek, a tributary to the Clackamas River, receives annual releases of winter steelhead and coho salmon *O. kisutch* from Eagle Creek National Fish Hatchery

(NFH). In 2007 the Columbia Basin Hatchery Review Team completed its review of Eagle Creek NFH (USFWS 2007). They listed delayed hatchery fish migration and residual hatchery winter steelhead in Eagle Creek (Kavanagh et al. 2006) as ecological conflicts and risks to Endangered Species Act listed natural populations of winter steelhead in the Clackamas River Basin. Therefore, the objectives of this study are to: 1) compare summer rearing densities in two similar streams, where one stream receives a release of hatchery salmonids and one stream does not receive a release of hatchery salmonids, 2) determine if residual hatchery winter steelhead are present in the Eagle Creek Basin, and 3) if so, whether or not they have an impact on mesohabitat selection and distribution of naturally produced salmonids.

Methods

Study location description

Eagle Creek is located in northwestern Oregon and has a basin that encompasses 57,609 acres. It originates in the Mount Hood National Forest and flows northwest approximately 42.4 kilometers to where it enters the Clackamas River at river kilometer 25.6. There are three major tributaries to Eagle Creek, South Fork Eagle Creek (river kilometer 20.6), Delph Creek (river kilometer 14.4) and North Fork Eagle Creek (river kilometer 10.4). These streams form the drainage for three watersheds, lower Eagle Creek (22,398 acres), upper Eagle Creek (17,315 acres), and North Fork Eagle Creek (17,896 acres). Three natural waterfalls are located within the mainstem of Eagle Creek. The lower one is located at river kilometer 8, the middle one is located at river kilometer 14.9, and the upper one is located at river kilometer 21.8. Eagle Creek and North Fork

Eagle Creek flow through a combination of private and public lands including forests dominated by old growth stands and commercial stands of trees. Tree species include true firs (*Abies* spp.), Douglas fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*). The lower reach is surrounded by agricultural lands and suburban areas. This study included 21.8 river kilometers of Eagle Creek from the mouth to the upper falls and the lower 14.8 river kilometers of North Fork Eagle Creek (Figure 2.1).

Eagle Creek NFH is located approximately at river kilometer 21.3, about 0.5 kilometers below the upper falls on Eagle Creek. The hatchery operates fish ladders located at the lower and middle falls to allow for fish passage and a ladder at the hatchery to collect brood stock and surplus adult hatchery fish. The upper falls acts as an impassible fish barrier. A Smith-Root electric weir (Smith, Root, Inc. Vancouver, Washington) located approximately 3 meters above the hatchery ladder directs fish into the hatchery ponds via the ladder. At the time of this study, Eagle Creek NFH annually released 150,000 winter steelhead smolts and 500,000 coho salmon smolts into Eagle Creek. In 2008 these releases were lowered to 100,000 winter steelhead smolts and 350,000 coho salmon smolts to reduce potential impacts on wild fish. These releases typically occur in the middle of April.

Eagle Creek NFH operates a segregated hatchery program. Hatchery steelhead are an early returning winter steelhead strain and comprise a composite of late run winter steelhead and the original spawning population at the hatchery, which is mixed with earlier returning fish from Big Creek, University of Washington, and Skamania River stocks. Hatchery coho salmon originated from Toutle River and Sandy River parentage.

Additional eyed eggs were subsequently received from Sandy River, Big Creek and Elochoman River early returning stocks, which spawn in October and November (USFWS 2007). In 2003, Oregon Department of Fish and Wildlife (ODFW) began stocking Eagle Creek with 60,000 spring Chinook salmon smolts at river kilometer 12.2. The spring Chinook salmon originated from broodstock spawned at the ODFW Clackamas River Hatchery. Eagle Creek and North Fork Eagle Creek also support naturally reproducing populations of winter steelhead and coho salmon; however it is thought that North Fork Eagle Creek contains the primary habitat where successful natural reproduction occurs in the Eagle Creek basin (USFWS 2007). The Endangered Species Act lists these naturally reproducing populations as Threatened. Cutthroat trout *O. clarki* are also present in the North Fork Eagle Creek and primarily above the upper falls in Eagle Creek. There have been reports of anglers periodically catching cutthroat trout in the lower reaches below the hatchery, however such accounts are rare.

Habitat Survey

Prior to conducting snorkel surveys, I enumerated total area and total number of mesohabitat units (riffles, pools, and glides) in Eagle Creek and North Fork Eagle Creek between June and August 2007. These mesohabitat units make up the sample frame for this study. Traveling upstream, a two-person survey crew classified habitat units using definitions found in Herger et al. (1996) and recorded unit length and width to the nearest 0.5 meters using a laser rangefinder (Nikon Monarch Laser 800). Average and maximum depth to the nearest 0.1 meters were estimated using an incremented wading staff. Surveyed units were sequentially numbered for future identification by the snorkel crew.

Three Hobo Water Temp Pros (Onset Computer Corporation, Bourne, MA.) were secured to the stream bottom (Figure 2.1) and programmed to record the water temperature (ºC) every 4 hours.

Snorkel Survey

A two phase sampling design modified from Hankin and Reeves (1988) was conducted to determine the distribution, estimate the density of juvenile salmonids, verify presence or absence of residual hatchery winter steelhead, and ultimately determine any displacement of wild salmonids that may occur in the presence of residual hatchery winter steelhead in Eagle Creek and North Fork Eagle Creek at the mesohabitat scale. The surveys took place between July 10th and September 14th, 2007 when the creeks were experiencing summer base flows. In the first phase of sampling, habitat units were stratified by type and chosen at random from the sample frame (Appendix A). Two divers then conducted single pass snorkel counts of juvenile salmonids in these units (Figure 2.2). The surveys began at the mouth of Eagle Creek and proceeded upstream past Eagle Creek NFH to the upper falls. North Fork Eagle Creek was sampled from the mouth to the approximate limit of anadromous fish distribution at a point 14.8 river kilometers upstream. Snorkel surveys were only conducted on days when weather conditions permitted a high degree of underwater visibility (i.e., little to no rain on the previous day). A total of three snorkelers in two pairings (W. R. Brignon/J. S. Hogle and W. R. Brignon/T. E. Conder) took part in the surveys. Snorkel crews traveled upstream and followed the protocol described by Thurow (1994). Each snorkeler visually estimated abundance of salmonids by species, age (estimated by size), and origin (hatchery vs. wild, absence or presence of adipose fin). Winter steelhead less than 110mm were considered age 0 fish and fish greater than 110mm were considered age 1 fish (Appendix B). The 110mm length was verified as a reasonable point for age demarcation by conducting a scale analysis of samples collected from fish captured while electrofishing. Any hatchery fish residing in the stream after July 1st were considered residual and identified as being from hatchery origin by the lack of an adipose fin.

In the second phase of sampling, a smaller subset of habitat units was randomly selected (Appendix A) from the sample frame with the overriding condition that there was adequate access in the near proximity to mitigate for equipment and personnel concerns (Figure 2.2). The selection interval for second phase units was approximately 1/10th of the first phase units, as suggested by Dolloff et al. (1993). The upper and lower limits of selected habitat units were block netted to limit immigration and emigration. Observers conducted single pass snorkel counts using identical methodology as in the first phase of sampling. To account for individual snorkeler biases the unit was sampled by both pairs of snorkelers. I then used multiple-pass removal (Zippin 1958) or mark recapture (Engle et al. 2006) to determine the "true" abundance of fish within the selected habitat unit. The multiple-pass depletion was conducted using two Smith-Root backpack electroshockers (Model LR-24, Smith-Root Inc., Vancouver, WA.). Electroshocking passes continued until fish sampled during a pass were less than or equal to 25% of the fish sampled during the previous pass. Captured fish were enumerated by species and age, fork lengths were recorded, and scale samples were collected from a subsample of fish. Multiple-pass depletion electrofishing was conducted on all calibration units with one exception of a pool unit which was considered too deep to accurately conduct electrofishing therefore, a mark-recapture was conducted as described by Engle et al. (2006) to account for snorkeler bias associated with deep pool habitats. Using equations found in Dolloff et al. (1993), calibration ratios were then calculated and applied to first phase diver counts to correct for snorkeler bias. Riffle calibration results are displayed in Appendix C, pool calibration results are displayed Appendix D, and glide calibration results are displayed in Appendix E.

Statistical Analyses

To address my first objective, I divided Eagle Creek into two reaches, upper Eagle Creek and lower Eagle Creek, with the line of demarcation being the confluence with North Fork Eagle Creek, which was considered its own reach. I compared habitat characteristics among the three reaches. Daily water temperatures were compared between reaches using one-way Analysis of Variance (ANOVA). A Student-Newman-Keuls multiple range test was used to compare pairwise differences in water temperature among the three reaches (Zar 1984). I used a 3 x 3 contingency table to test for independence of habitat type by stream reach. Density estimates were compared between stream reaches with a Kruskal-Wallis non-parametric ANOVA. A non-parametric analog to the Student-Newman-Keuls multiple range test was used (Dunn 1964) to test for pairwise differences in density estimates between study reaches. Population estimates with 95% confidence intervals were calculated for all species in each habitat type and stream reach (Dolloff et al. 1993). The percent of the estimated wild fish populations rearing in the same mesohabitat units in which residual hatchery winter steelhead were located are reported. All statistical comparisons were conducted at the $\alpha = 0.05$ significance level using S-PLUS 8.0 (Insightful Corp.).

To describe the factors affecting the density and distribution of wild salmonids and residual hatchery winter steelhead I used an approach promoted by Fletcher et al. (2005). This approach uses two separate statistical models to best describe the data and consists of a three-step process. In the first step I created two sets of data, one data set identifies the presence and absence of a particular species and the other data set identifies the density of a particular species given that the species is present (i.e., the presence data). Second, I constructed two models; a logistic regression model to describe the variables affecting the presence and absence of a species, and a second generalized linear model (GLM) to describe species density given that that species is present. In the final step, the results of both models were used to make inferences regarding which variables best explain the distribution and density of a species. Data collected in North Fork Eagle Creek were not included in these models for two reasons; 1) from preliminary analyses I concluded that including a categorical variable for stream caused the validity of the model fit to be questionable, which suggests that stream specific models describing fish densities would better fit these data than a general model describing fish densities in both streams, and 2) residual hatchery winter steelhead, the focus of this analysis, were only observed in the mainstem of Eagle Creek. A total of six explanatory variables were used to construct both the logistic regression models and the GLMs. These variables are: 1) mesohabitat type (i.e., riffle, pool, glide), 2) distance from the mouth of Eagle Creek (m), 3) age 0 winter steelhead density (fish/m^2), 4) age 1 winter steelhead density (fish/m^2), 5) coho salmon density (fish/m^2), and 6) residual hatchery winter steelhead density (fish/m^2). For each species, the full model contained mesohabitat type and distance from the mouth of Eagle Creek, as well as, the density variables for the three species not being modeled as the dependent variable. A correlation matrix of all continuous variables suggested a potential interaction between age 0 winter steelhead density and distance from the mouth of Eagle Creek (r = 0.60). This interaction term was included in the construction of GLMs describing age 1 winter steelhead density, coho salmon density, and residual hatchery winter steelhead density.

Logistic regression models were constructed to describe the probability of occurrence for coho salmon, age 1 winter steelhead, and residual hatchery winter steelhead. I did not construct a logistic regression model to describe the probability of occurrence for age 0 winter steelhead because they were present all in but two sites and therefore these data lacked the necessary contrast between presence and absence to construct a valid logistic regression model. Generalized linear models were constructed for all species.

Logistic Regression Modeling

Logistic regression models were fit with SAS 9.1 (SAS institute Inc.) using all possible combinations of explanatory variables. Akaike's information criterion (AIC), corrected for small sample bias (AIC_c) and AIC_c weights (w_i) were used for model selection. The AIC_c values were calculated as

$$\text{AIC}_c = -2\ \log_e(L) + 2(K) + \frac{[2K(K+1)]}{(n-K-1)},$$

where $\log_e(L)$ is the log-likelihood, K is the number of model parameters and n is the sample size. The AIC$_c$ weights (w_i) were calculated as

$$w_i = \frac{e^{(-\frac{1}{2}\cdot\Delta i)}}{\sum e^{(-\frac{1}{2}\cdot\Delta i)}},$$

where Δ_i equals the AIC$_c$ of model i minus lowest AIC$_c$ of all possible models. The model with the lowest AIC$_c$ and highest w_i was considered the most parsimonious and models within 2 AIC$_c$ values were considered competing. To account for model selection uncertainty I used multi-model averaging to calculate model-averaged estimates and standard errors of the parameter coefficients for the competing models. In addition, I determined the relative variable importance of the model-averaged variables to give a weight of evidence for the significance of the explanatory variables. Relative variable importance ranges from 0.00 to 1.00, with an increasing relative importance as 1.00 is approached (Burnham and Anderson 2002).

I used the results of the averaged logistic regression model to construct probability plots that display the influence of explanatory variables on a species occurrence. These were calculated with the equation

$$\text{probability of occurence} = \frac{e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k}}{\left(1 + e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k}\right)},$$

where β_0 is the regression intercept, β_k are the regression coefficients of the explanatory variables, and X_k are the explanatory variables (Hosmer and Lemeshow 2000). Plots were constructed for each species and explanatory variable by holding the averaged variable coefficients of the other model parameters constant.

Generalized Linear Modeling

The presence only data (i.e., data associated with a species considering that species is present), for each species best followed a gamma distribution. (Appendix F - Appendix I). These data were then fit to a series of gamma GLMs using all possible combinations of explanatory variables. The model is in the form

$$\text{Log}(\mu) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k,$$

where β_0 is the regression intercept, β_k are the regression coefficients of the explanatory variables, X_k are the explanatory variables, and Log(μ) is the link function for the mean of the gamma distribution describing species density (Lindsey 1997). The shape and scale parameters of the fitted gamma distributions were input into the extract AIC function in SPLUS 8.0 and the resulting AIC values were used to calculate the AIC_c for the model. I used the same model selection processes described for the logistic regression potion of this analysis.

The results of the averaged gamma GLM were used to construct plots that display the influence of explanatory variables on a particular species' density. These were calculated with the equation

$$\text{species density} = e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k},$$

where β_0 is the regression intercept, β_k are the regression coefficients of the explanatory variables, and X_k are the explanatory variables. Plots were constructed for each species and explanatory variable by holding the averaged variable coefficients of the other model parameters constant.

Results

Habitat Survey

The habitat characteristics of North Fork Eagle Creek and upper Eagle Creek are more closely related than those of lower Eagle Creek. Temperature profiles of lower Eagle Creek, upper Eagle Creek, and North Fork Eagle Creek are displayed in Figure 2.3. Temperatures in all reaches were significantly different ($F_{2,1047} = 184.8$; $P < 001$, and Student-Newman-Keuls tests, $P < 0.05$). North Fork Eagle Creek and upper Eagle Creek experience cooler average water temperatures (15.3 and 15.6 ºC, respectively) with lower Eagle Creek experiencing the highest average water temperature (17.4 ºC). Habitat data collected from the three stream reaches are summarized in terms of number of habitat units, length and surface area of the reach occupied by each habitat type (Table 2.1). Chi-square contingency table test suggests that habitat unit composition is independent of stream reach ($\chi^2 = 7.85$, df = 4, $P = 0.097$). On average, lower Eagle Creek is the widest stream reach (17.8 ± 0.69m) followed by upper Eagle Creek (14.6 ± 0.57m) and North Fork Eagle Creek (7.48 ± 0.25m).

Fish Distribution and Density

The highest densities and abundances of age 0 winter steelhead, coho salmon, and residual hatchery winter steelhead were located in the upper reaches of Eagle Creek, upstream of the middle ladder. Fish densities and abundances in North Fork Eagle Creek were more evenly distributed than in Eagle Creek (Figure 2.4 - Figure 2.7). Residual hatchery winter steelhead were first observed in lower Eagle Creek and distributed above the hatchery to the upper falls. Residual hatchery winter steelhead were only observed in mainstem Eagle Creek and not in North Fork Eagle Creek (Figure 2.7). Densities for all species were unevenly distributed throughout the three reaches (Kruskal-Wallis, $P < 0.001$), with the exception of age 1 winter steelhead, which were evenly distributed throughout all reaches (Kruskal-Wallis, $P = 0.40$, Figure 2.8). There was an increasing trend in age 1 winter steelhead density as I traveled upstream in North Fork Eagle Creek (Figure 2.5). Age 0 winter steelhead densities were highest in upper Eagle Creek and lowest in lower Eagle Creek (Figure 2.9). Residual hatchery winter steelhead had the lowest density of all fish with the highest densities found in upper Eagle Creek and the lowest in lower Eagle Creek. No residual hatchery winter steelhead were observed in North Fork Eagle Creek (Figure 2.10). Coho salmon densities were highest in North Fork Eagle Creek and similar in the other two reaches (Figure 2.11).

Population estimates

Population estimates varied among species, reaches and habitat units (Table 2.2). Coho salmon and age 0 winter steelhead populations are estimated to be highest in upper Eagle Creek and North Fork Eagle Creek, whereas population estimates for age 1 winter steelhead were highest in lower Eagle Creek. The estimate of residual hatchery winter steelhead abundance comprised 1.0% of the winter steelhead population (1.1% of age 0 winter steelhead and 9.3% of age 1 winter steelhead), and 2.2% of the coho salmon population estimated to be rearing in Eagle Creek (Appendix J).

Wild Fish Rearing in the Presence of Residual Hatchery Winter Steelhead

Residual hatchery winter steelhead were observed in 15 of the 63 mesohabitat units sampled in Eagle Creek (Figure 2.12). These 15 habitat units were composed of two riffles in lower Eagle Creek and seven pools, three riffles, and three glides in upper

Eagle Creek. The percentage of the estimated population of age 0 winter steelhead, age 1 winter steelhead, and coho salmon rearing in those same 15 units is 55%, 59%, and 55%, respectively.

Factors Influencing the Probability of a Species' Occurrence

Age 0 winter steelhead were located in 61 of the 63 (96.8 %) habitat units sampled in Eagle Creek. The lack of contrast between presence and absence for this species makes it impractical to accurately model the probability of occurrence for this species. However, their presence in 96.8 percent of the units sampled suggests that they have a high probability of occurring anywhere in Eagle Creek regardless of the explanatory variables.

Age 1 winter steelhead were located in 47 of the 63 (74.6%) habitat units sampled in Eagle Creek. Of the 32 models (Appendix K) containing all possible combinations of explanatory variables, four models were within 2 AIC_c values and therefore considered competing (Table 2.3). Model-averaged estimates and standard errors of parameter coefficients for the competing models were calculated along with the relative variable importance of all explanatory variables contained in competing models (Table 2.4). Coho salmon density was included in all four competing models and has a relative variable importance of 1.00. Age 0 winter steelhead density was included in two of the four competing models and has a relative variable importance of 0.46. Less important in explaining the presence of age 1 winter steelhead were the variables for distance from the mouth of Eagle Creek and mesohabitat type, which were each included in one competing model, with a relative variable importance of 0.19 and 0.13, respectively. The probability of age 1 winter steelhead occurring in Eagle Creek increased with distance from the mouth of Eagle Creek, along with an increase in age 0 winter steelhead density and coho salmon density. Riffles had the highest probability of occurrence followed closely by glides and then pools (Figure 2.13).

Coho salmon were located in 48 of the 63 (76.2%) habitat units sampled in Eagle Creek. Three models were within 2 AIC_c values and therefore considered competing (Table 2.3; Appendix K). Model-averaged estimates and standard errors of parameter coefficients for the competing models were calculated along with the relative variable importance of all explanatory variables contained in competing models (Table 2.4). Age 1 winter steelhead density was included in all three competing models with a relative variable importance of 1.00. Distance from the mouth of Eagle Creek and age 0 winter steelhead density were each included in one model with a relative variable importance of 0.24 and 0.22, respectively. There was a higher probability of coho salmon occurrence with an increase in each explanatory variable (Figure 2.14).

Residual hatchery winter steelhead were located in 15 of the 63 (23.8%) habitat units sampled in Eagle Creek. Of the 32 models (Appendix K) containing all possible combinations of explanatory variables, four models were within 2 AIC_c values and therefore are considered competing (Table 2.3). Model-averaged estimates and standard errors of parameter coefficients for the competing models were calculated along with the relative variable importance of all explanatory variables contained in competing models (Table 2.4). Distance from the mouth of Eagle Creek and age 1 winter steelhead density were included in all four competing models and each have a relative variable importance of 1.00. Coho salmon density and age 0 winter steelhead were each included in two competing models and with a relative variable importance of 0.53 and 0.47, respectively. There was a higher probability of residual hatchery winter steelhead with an increase in each explanatory variable (Figure 2.15).

Factors Influencing a Species' Density Given the Presence of that Species

Given that age 0 winter steelhead were present, their density is best explained by three GLMs that were within 2 AIC_c values and therefore considered competing (Table 2.5; Appendix L). Model-averaged estimates and standard errors of parameter coefficients for these models were calculated along with the relative variable importance of all explanatory variables contained in the competing models (Table 2.6). Distance from the mouth of Eagle Creek and coho salmon density were included in all three models and therefore each have a relative variable importance of 1.00. Mesohabitat type was included in two models with a relative variable importance of 0.70. Age 1 winter steelhead density was included in one model and is less important in explaining age 0 winter steelhead density with a relative variable importance of 0.20. Age 0 winter steelhead density was highest in riffles, followed by pools and then glides. There is a positive relationship between age 0 winter steelhead density and distance from the mouth of Eagle Creek, coho salmon density, and age 1 winter steelhead density (Figure 2.16).

Given that age 1 winter steelhead were present, their density is best explained by two GLMs that were within 2 AIC_c values and therefore considered competing (Figure 2.18; Appendix L). Model-averaged estimates and standard errors of parameter coefficients for these models were calculated along with the relative variable importance of all explanatory variables contained in the competing models (Figure 2.19). Age 0 winter steelhead density and mesohabitat type were included in both models and therefore each have a relative variable importance of 1.00. Residual hatchery winter steelhead were included in the most parsimonious model and had a relative variable importance of 0.54. Age 1 winter steelhead density was highest in riffles, followed by glides then pools. There is a positive relationship between age 1 winter steelhead density and both age 0 and residual hatchery winter steelhead densities (Figure 2.17).

Given that coho salmon were present, their density is best explained by one GLM. The difference between this model and the next closest model was 2.24 AIC_c values and therefore not considered a competing model (Figure 2.18; Appendix L). The relative variable importance and estimated parameter coefficients with standard errors for the most parsimonious model are reported (Figure 2.19). Mesohabitat type and age 0 winter steelhead density were included in model. The highest densities of coho salmon were found in riffles, followed by pools and then glides. There is a positive relationship between coho salmon density and age 0 winter steelhead density (Figure 2.18).

Given that residual hatchery winter steelhead were present, their density is best explained by one GLM. The difference between this model and the next closest model was 2.84 AIC_c values and therefore not considered a competing model (Figure 2.18; Appendix L). The relative variable importance and estimated parameter coefficients with standard errors for the most parsimonious model are reported (Table 2.6). Distance from the mouth of Eagle Creek, age 0 winter steelhead density and age 1 winter steelhead density were included in model. There is a positive relationship between residual hatchery winter steelhead density and both distance from the mouth of Eagle Creek and age 1 winter steelhead density. However, there is a negative relationship between residual hatchery winter steelhead density and age 0 winter steelhead density (Figure 2.19).

Discussion

I have visually confirmed the presence of residual hatchery winter steelhead in Eagle Creek, and with a high degree of confidence, their absence in North Fork Eagle Creek. Residual hatchery winter steelhead were found rearing in the presence of Endangered Species Act listed wild salmonids, which suggests a potential for competition. This potential for competition is magnified by the fact that the majority of ages 0 and 1 wild winter steelhead and coho salmon rearing in Eagle Creek were observed in the same 15 mesohabitat units as residual hatchery winter steelhead. Also, it is important to note that the residual hatchery winter steelhead population comprised 0.9% of the winter steelhead population (1.1% of age 0 winter steelhead and 9.3% of age 1 winter steelhead), and 2.2% of the coho salmon population estimated to be rearing in Eagle Creek.

McMichael and Pearsons (2001) documented that residual hatchery steelhead had migrated over 12 kilometers upstream from a release site on the Teanaway River, Wa. into areas containing Endangered Species Act listed fish populations. Considering that North Fork Eagle Creek is thought to be the primary area for successful natural production of Endangered Species Act listed species in the Eagle Creek Basin (USFWS 2007), there was a concern that residual hatchery winter steelhead from Eagle Creek National Fish Hatchery would make a similar migration up the North Fork Eagle Creek. My results suggest that residual hatchery winter steelhead did not migrate up North Fork

Eagle Creek, however similar to McMichael and Pearsons (2001) I did document an upstream migration in Eagle Creek. Due to the impassible upper falls located above the hatchery, fish were only able to migrate upstream less than 0.5 kilometers, a fraction of what McMichael and Pearsons (2001) observed.

As referenced earlier, North Fork Eagle Creek is considered the main site for successful reproduction of winter steelhead (USFWS 2007), therefore it is unexpected that the highest abundance and densities of age 0 winter steelhead were found in upper Eagle Creek. There are many possibilities for this outcome. In their genetic evaluation of ecological interactions between hatchery and wild winter steelhead in Eagle Creek, Matala et al. (2008) found that samples collected from naturally produced juvenile winter steelhead in upper Eagle Creek are most similar to samples collected from Eagle Creek National Fish Hatchery. Therefore, it is possible the high population and density of age 0 winter steelhead estimated in upper Eagle Creek is the product of hatchery fish spawning in the stream. Studies have shown that progeny of hatchery fish who spawn naturally in the stream can be less fit than their wild counterparts (Araki et al. 2007; Ford 2002; Lynch and O'Hely 2001), which translates into lower adult survival. This may be a hint as to why the North Fork Eagle Creek is the primary producer of wild adult steelhead. An additional result of hatchery winter steelhead spawning in upper Eagle Creek may be the lower densities of juvenile coho salmon in upper Eagle Creek. Hayes (1987) documented a large decrease in reproductive success of early spawning trout populations after their redds were superimposed by later spawning individuals. In the Eagle Creek Basin, hatchery coho salmon return to spawn between September and November, followed by wild coho salmon which return from November through

December. Both coho populations (hatchery and wild) are followed by hatchery winter steelhead that return to the basin from December through March and then the wild winter steelhead population which returns from February through June. All coho salmon, regardless of origin, which spawn in the mainstem Eagle Creek will be competing for spawning habitat with the later returning steelhead population and therefore redd superimposition may impact their reproductive success. Incidence of redd superimposition would be higher in the mainstem Eagle Creek because the large number of hatchery winter steelhead returning to the basin rarely stray into the North Fork Eagle Creek (Kavanagh et al. 2006). There is little doubt that habitat availability plays a role in Eagle Creek and North Fork Eagle Creek. It is possible that juvenile rearing habitat in upper Eagle Creek is better suited for age 0 winter steelhead and juvenile rearing habitat in North Fork Eagle Creek is best suited for coho. Most likely there is not one specific explanation, rather a suite of reasons with variable levels of impact that explain the spatial differences in age 0 winter steelhead and coho salmon abundance and densities in Eagle Creek and North Fork Eagle Creek

The probability of coho salmon and age 1 winter steelhead occurring in Eagle Creek was affected by several variables however, residual hatchery winter steelhead was not found to be a factor. The most influential factor describing any one species presence, including the presence of residual hatchery winter steelhead, was the density of other species in the area. As densities increase in Eagle Creek so did the probability of a species' presence. If one species was displacing another, I would expect to see an inverse relationship between the probability of a species occurrence and density of the species used as an explanatory variable. Coho salmon have been shown to displace steelhead from pool mesohabitats to riffle mesohabitats (Hartman 1965). This was not the case in Eagle Creek. All species seemed to prefer similar mesohabitats in the stream and therefore any displacement that would impact the probability of a species being present was not occurring at the mesohabitat scale. Another important factor in describing the probability of a species occurrence was distance from the mouth of Eagle Creek. While the relative importance of this explanatory variable varied among species, there was always a positive relationship describing a species' presence and an increase in the distance from the mouth of Eagle Creek. Most likely this is a function of the adult fish spawning in the cooler water temperatures of upper Eagle Creek and therefore, on a reach scale, juvenile fish were located relatively close to where they hatched. Due to the presence of the large waterfalls located at the middle ladder of Eagle Creek, it is highly unlikely that juvenile fish were able to migrate upstream from lower Eagle Creek into this upper reach.

Given that a species is present, the factors affecting density varied by species with the exception of mesohabitat type. Coho salmon, age 0 winter steelhead and age 1 winter steelhead all exhibited the highest densities in riffle mesohabitats followed by the slower water habitats (i.e., pools and glides). This suggests that given a species is present there is no affect on mesohabitat selection as a function of interspecific or intraspecific competition. Not only does the probability of a species being present increase with the density of other species, but generally speaking, given that a species is present, densities of all species in Eagle Creek either have no relationship or a have a positive relationship. There is one exception to this statement. The GLM used to describe residual hatchery winter steelhead density, given that that species is present, indicates there is a negative relationship with age 0 winter steelhead. This outcome was most likely the result of an influential data point where the highest density (0.19 fish/m ^{2}) of residual hatchery winter steelhead was located in a habitat unit with a relatively low density (0.46 fish/m^2) of age 0 winter steelhead. I removed this data point from the model to assess its influence on the adjusted r^2, which is a measure of the proportion of variability in the data set accounted for by the model. The adjusted r^2 went from 0.61 with the influential data point included in the model to 0.51 without the influential data point in the model. This suggests that the model including the influential data point explains more variability than the model without the influential data point. Also, it should be noted that by removing this data point the model containing age 0 winter steelhead density was no longer considered the most parsimonious model ($\Delta_i = 2.84$). Overall, I feel this influential data point suggests that at higher densities residual hatchery winter steelhead may have an impact on age 0 winter steelhead populations. In the future, I recommend focusing sampling effort in areas with known populations of residual hatchery winter steelhead so it can be determine if there is a distinct relationship between these population densities.

Given my study design, there are four scenarios that could explain my inability to explicitly document a displacement of wild salmonids from preferred mesohabitats by residual hatchery winter steelhead. First, studies suggest that hatchery fish pose a risk of negative hatchery-wild interactions by displacing wild fish (Hillman and Mullan 1989; McMichael et al. 1999; Vincent 1987). It is possible that this is not the case in Eagle Creek. Second, Jonasson et al. (1996) documented the highest densities of residual hatchery steelhead were located near the release site, similar to my study. Also consider, that Vincent (1987) concluded that releases of hatchery fish reduced populations of wild rearing fish in the vicinity of the release site. Therefore, any displacement of wild fish by residual hatchery winter steelhead in Eagle Creek likely would have been seen in the upper reaches near the hatchery. With the majority of both the wild salmonid population and the residual hatchery winter steelhead population located in upper Eagle Creek it is difficult detect a displacement without pre-release data. Due to high spring flows and the associated turbidity I was unable to collect pre-release abundance data on wild fish rearing below the hatchery that would be required for this type of case-control comparison. Third, the studies that document a displacement of wild fish as a function of hatchery fish are conducted shortly after (approx. 1 month or less) the release of the hatchery fish (e.g., Hillman and Mullan 1989; McMichael et al. 1999) when the abundance of hatchery fish is higher than that of the wild fish. It is possible that because I was evaluating a displacement caused by residual hatchery winter steelhead, which have resided in the stream for over 2 months, that any potential large scale displacement occurred closer to the time of release. Lastly, scale may play role in my findings. It is possible that the number of residual hatchery winter steelhead was not large enough to elicit a displacement response or that the elicited response is occurring at a spatial scale smaller than the mesohabitat scale. Regardless, residual hatchery winter steelhead appear to not displace wild ESA listed fish in Eagle Creek and North Fork Eagle Creek at the mesohabitat scale during the time of my study.

Due to potential hybridization and similar phenotypic characteristics (Baker et al. 2002; Brown et al. 2004; Weigel et al. 2002) it is extremely difficult to differentiate juvenile O. *mykiss* from juvenile cutthroat trout, especially during underwater observation. Therefore, the trend of increasing age 1 winter steelhead density in the upper reaches of North Fork Eagle Creek could be a product of species misidentification. Rosenfeld et al. (2000) found that stream width was significant predictor of cutthroat trout presence and were able to predict cutthroat trout presence to a high degree in streams less than 7 meters wide. North Fork Eagle Creek is 7.48 meters wide on average with the smallest widths recorded in upper reaches.

While the data contained in this manuscript are an important component to assessing ecological interactions in the Eagle Creek Basin, it is important to recognize that this is one year of data. In determining what type of impact the hatchery is having on juvenile fish abundance and density a multiyear data set would be ideal and could help explain potential stochastic environmental factors occurring in the basin that can confound the results of a 1 year data set. The uncertainty with the calibration ratios calculated from the correlation between population estimates and diver counts, specifically in riffle habitat units, may have had an effect on the results in the this study. My calibration ratio for coho salmon in riffle habitats was 5.78 fish for each fish I observed. Two calibration units weighed heavily on this ratio. I observed only one coho salmon in these two different riffle calibration units yet my population estimates showed that there were more than 20 coho salmon present in the units. This is most likely a function of the high habitat complexity associated with riffle habits and also suggests that these types of habitats may be more utilized by coho than I expected. Also, population estimates of age 1 winter steelhead in lower Eagle Creek riffle habitats may be inflated due to a data outlier where in one riffle habitat unit 260 fish were estimated to be rearing directly below the North Fork Eagle Creek confluence. This one outlier inflates the lower Eagle Creek age 1 winter steelhead population estimate by more than 2,000 fish, or 40 percent.

Eagle Creek NFH provides an important fishery for commercial, sport and tribal harvest, as well as assisting with tribal reintroduction projects upstream of Bonneville Dam. It is important to maximize these benefits while minimizing the risks to the ESA listed wild populations in Eagle Creek Basin. This study provides a basis of information regarding juvenile population sizes, densities, and rearing distribution in the basin. As a result of limited funding and biological concerns regarding Eagle Creek NFH, the USFWS Hatchery Review Team has recommended that the hatchery lower its release of 150,000 steelhead smolts to 100,000 and the release of coho salmon from 500,000 smolts to 350,000. These lower release numbers were implemented in 2008, one year after I conducted this study. Therefore, I expect that the incidence of residual hatchery winter steelhead would be lower in subsequent years. Sampling effort for any future monitoring and evaluation on the effect of residual hatchery winter steelhead on the wild population should be focused in upper Eagle Creek, where the majority of residual hatchery winter steelhead and wild salmonids are rearing.

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References

Araki, H., W. R. Ardren, E. Olsen, B. Cooper, and M. S. Blouin. 2007. Reproductive success of captive-bred steelhead trout in the wild: Evaluation of three hatchery programs in the Hood River. Conservation Biology 21:181-190.

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113:1-32.

Baker, J., P. Bentzen, and P. Moran. 2002. Molecular markers distinguish coastal cutthroat trout from coastal rainbow trout/steelhead and their hybrids. Transactions of the American Fisheries Society 131:404-417.

Bohlin, T., L. F. Sundstrom, J. I. Johnsson, J. Hojesjo, and J. Pettersson. 2002. Density-dependent growth in brown trout: effects of introducing wild and hatchery fish. Journal of Animal Ecology 71:683-692.

Brostrom, J. K. 2003. Characterize and quantify residual steelhead in the Clearwater River, Idaho, 2002 Annual Report. Bonneville Power Administration, Portland, Oregon.

Brown, L. R., and P. B. Moyle. 1991. Changes in habitat and microhabitat partitioning within an assemblage of stream fishes in response to predation by Sacramento squawfish (*Ptychocheilus grandis*). Canadian Journal of Fisheries and Aquatic Sciences 48:849-856.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer-Verlag, New York, New York.

Cannamela, D. A. 1993. Hatchery steelhead smolt predation of wild and natural juvenile Chinook salmon fry in the Upper Salmon River, Idaho. Idaho Department of Fish and Game, Boise, Idaho.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. United States Forest Service, Southeastern Forest Experimental Station, General Technical Report SE-83, Asheville, North Carolina.

Dunn, O. J. 1964. Multiple comparisons using rank sums. Technometrics 6:241-252.

Engle, R., D. Olson, and J. Lovtang. 2006. Abundance and microhabitat selection of juvenile *Oncorhynchus mykiss* and juvenile Chinook salmon (*O. tshawytscha*) within Shitike Creek, Oregon at varying fish densities and presence or absence of bull trout (*Salvelinus confluentus*), Progress Report 2005. United State Fish and Wildlife Service Columbia River Fisheries Program Office, Vancouver, Washington.

Fletcher, D., D. MacKenzie, and E. Villouta. 2005. Modeling skewed data with many zeros: A simple approach combining ordinary and logistic regression. Environmental and Ecological Statistics 12:45-54.

Ford, M. J. 2002. Selection in captivity during supportive breeding may reduce fitness in the wild. Conservation Biology 16:815-825.

Glova, G. J. 1987. Comparison of allopatric cutthroat trout stocks with those sympatric with coho salmon and sculpins in small streams. Environmental Biology of Fishes 20:275-284.

Goede, R. W. 1986. Management considerations in stocking of diseased or carrier fish. Pages 349-355 *in* R. H. Stroud, editor. Fish culture in fisheries management. American Fisheries Society, Bethesda, Maryland.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). 22:1035-1081.

Hayes, J. W. 1987. Competition for spawning space between brown (*Salmo trutta*) and rainbow trout (*S. gairdneri*) in a lake inlet tributary, New Zealand. Canadian Journal of Fisheries and Aquatic Sciences 44:40-47.

Herger, L. G., W. A. Hubert, and M. K. Young. 1996. Comparison of habitat composition and cutthroat trout abundance at two flows in small mountain streams. North American Journal of Fisheries Management 16:294-301.

Hillman, T. W. and J. W. Mullan. 1989. Effect of hatchery releases on the abundance and behavior of wild juvenile salmonids. Pages 266-281 *in* Summer and winter ecology of juvenile Chinook salmon and steelhead trout in the Wenatchee River, Washington. Don Chapman Inc., Boise, ID.

Hosmer, D. W., and S. Lemeshow. 2000. Applied logistic regression, 2nd edition. Wiley Interscience, New York, New York.

Jacobs, S. E. 1981. Stream utilization and behavior of sympatric and allopatric wild cutthroat trout (*Salmo clarki*) and hatchery coho salmon (*Oncorhynchus kisutch*). Master's thesis. Oregon State University, Corvallis, Oregon.

Jonasson, B. C., R. W. Carmichael, and T. A. Whitesel. 1996. Residual hatchery steelhead characteristics and potential interactions with spring Chinook salmon in northeast Oregon, 1996 Progress Report. Oregon Department of Fish and Wildlife, Salem, Oregon.

Kavanagh, M., D. Olson, B. Brignon, T. Hoffman, D. Dysart, and S. Turner. 2006. Eagle Creek Ecological Interactions: distribution and migration of hatchery and wild steelhead and coho, 2005 Progress Report. United States Fish and Wildlife Service, Vancouver, Washington.

Kennedy, G. J. A., and C. D. Strange. 1986. The effects of intra-and inter-specific competition on the distribution of stocked juvenile Atlantic salmon, *Salmo salar* L., in relation to depth and gradient in an upland trout, *Salmo trutta* L., stream. Journal of Fish Biology 29:199-214.

Kostow, K. E., and S. Zhou. 2006. The effect of an introduced summer steelhead hatchery stock on the productivity of a wild winter steelhead population. Transactions of the American Fisheries Society 135:825-841.

Levin, P. S., R. W. Zabel, and J. G. Williams. 2001. The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon. Proceedings of the Royal Society B: Biological Sciences 268:1153-1158.

Li, H. W., and R. W. Brocksen. 1977. Approaches to the analysis of energetic costs of intraspecific competition for space by rainbow trout (*Salmo gairdneri*). Journal of Fish Biology 11:329-341.

Lindsey, J. K. 1997. Applying Generalized Linear Models. Springer, New York, New York.

Lynch, M., and M. O'Hely. 2001. Captive breeding and the genetic fitness of natural populations. Conservation Genetics 2:363-378.

Matala, A., W. Ardren, D. Olson, M. Kavanagh, B. Brignon and J. Hogle. 2008. Evaluating Natural Productivity and Genetic Interaction between a Segregated Hatchery Stock and a Wild Population of Steelhead Trout (*Oncorhynchus mykiss*) In Eagle Creek, Oregon. 2007 Final Report. United States Fish and Wildlife Service, Vancouver, Washington.

McMichael, G. A., and T. N. Pearsons. 2001. Upstream movement of residual hatchery steelhead into areas containing bull trout and cutthroat trout. North American Journal of Fisheries Management 21:943-946.

McMichael, G. A., T. N. Pearsons, and S. A. Leider. 1999. Behavioral interactions among hatchery-reared steelhead smolts and wild *Oncorhynchus mykiss* in natural streams. North American Journal of Fisheries Management 19:948-956.

McMichael, G. A., T. N. Pearsons, and S. A. Leider. 2000. Minimizing ecological impacts of hatchery-reared juvenile steelhead trout on wild salmonids in a Yakima Basin watershed. Pages 365–380 *in* E. E. Knudsen, C. R. Steward, D. D. MacDonald, J. E. Willams and D. W. Reiser, editors. Sustainable Fisheries Management: Pacific Salmon. Lewis Publishers, New York, New York.

McMichael, G. A., C. S. Sharpe, and T. N. Pearsons. 1997. Effects of residual hatchery-reared steelhead on growth of wild rainbow trout and spring Chinook salmon. Transactions of the American Fisheries Society 126:230-239.

Meffe, G. K. 1992. Techno-arrogance and halfway technologies: Salmon hatcheries on the Pacific Coast of North America. Conservation Biology 6:350-354.

Nickelson, T. E., M. F. Solazzi, S. L. Johnson. 1986. Use of hatchery coho salmon presmolts to rebuild wild populations in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 43:2443-2449.

Olson, D. E., B. Spateholts, M. Paiya, and D. E. Campton. 2004. Salmon hatcheries for the 21st century: A model at Warm Springs National Fish Hatchery. American Fisheries Society Symposium 44:581-598.

Ratliff, D. E. 1981. *Ceratomyxa shasta*: Epizootiology in Chinook salmon of Central Oregon. Transactions of the American Fisheries Society 110:507-513.

Rhodes, J. S., and T. P. Quinn. 1998. Factors affecting the outcome of territorial contests between hatchery and naturally reared coho salmon parr in the laboratory. Journal of Fish Biology 53:1220-1230.

Rosenfeld, J., M. Porter, and E. Parkinson. 2000. Habitat factors affecting the abundance and distribution of juvenile cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 57:766-774.

Thurow, R. F. 1994. Underwater methods for study of salmonids in the Intermountain West. United States Forest Service, Intermountain Research Station, General Technical Report INT-GTR-307, Ogden, Utah.

United States Fish and Wildlife Service, Hatchery Review Team. 2007. Eagle Creek National Fish Hatchery assessments and recommendations, Final Report.

Vincent, E. R. 1987. Effects of stocking catchable-size hatchery rainbow trout on two wild trout species in the Madison River and O'Dell Creek, Montana. North American Journal of Fisheries Management 7:91-105.

Viola, A. E., and M. L. Schuck. 1995. A method to reduce the abundance of residual hatchery steelhead in rivers. North American Journal of Fisheries Management 15:488-493.

Weigel, D. E., J. T. Peterson, and P. Spruell. 2002. A model using phenotypic characteristics to detect introgressive hybridization in wild westslope cutthroat trout and rainbow trout. Transactions of the American Fisheries Society 131:389-403.

Zar, J. H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall, Englewood Cliffs, New Jersey.

Zippin, C. 1958. The removal method of population estimation. Journal of Wildlife Management 22:82-90.

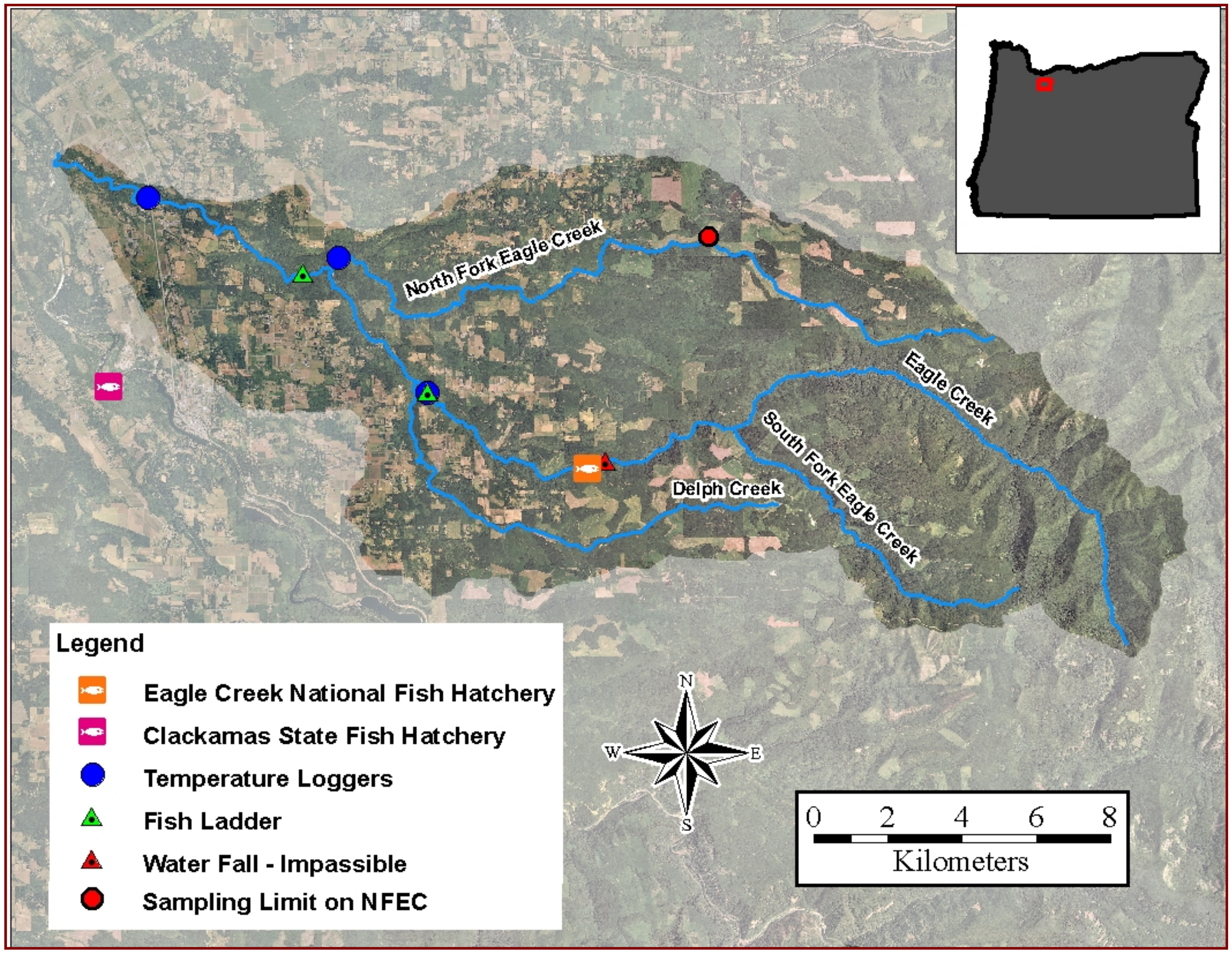


Figure 2.1 Map of Eagle Creek and North Fork Eagle Creek. Locations of hatcheries in the area, temperature loggers, and fish ladders are identified. The upper sampling limit of Eagle Creek is the impassible waterfalls directly above Eagle Creek National Fish Hatchery and the sampling limit on North Fork Eagle Creek is identified.

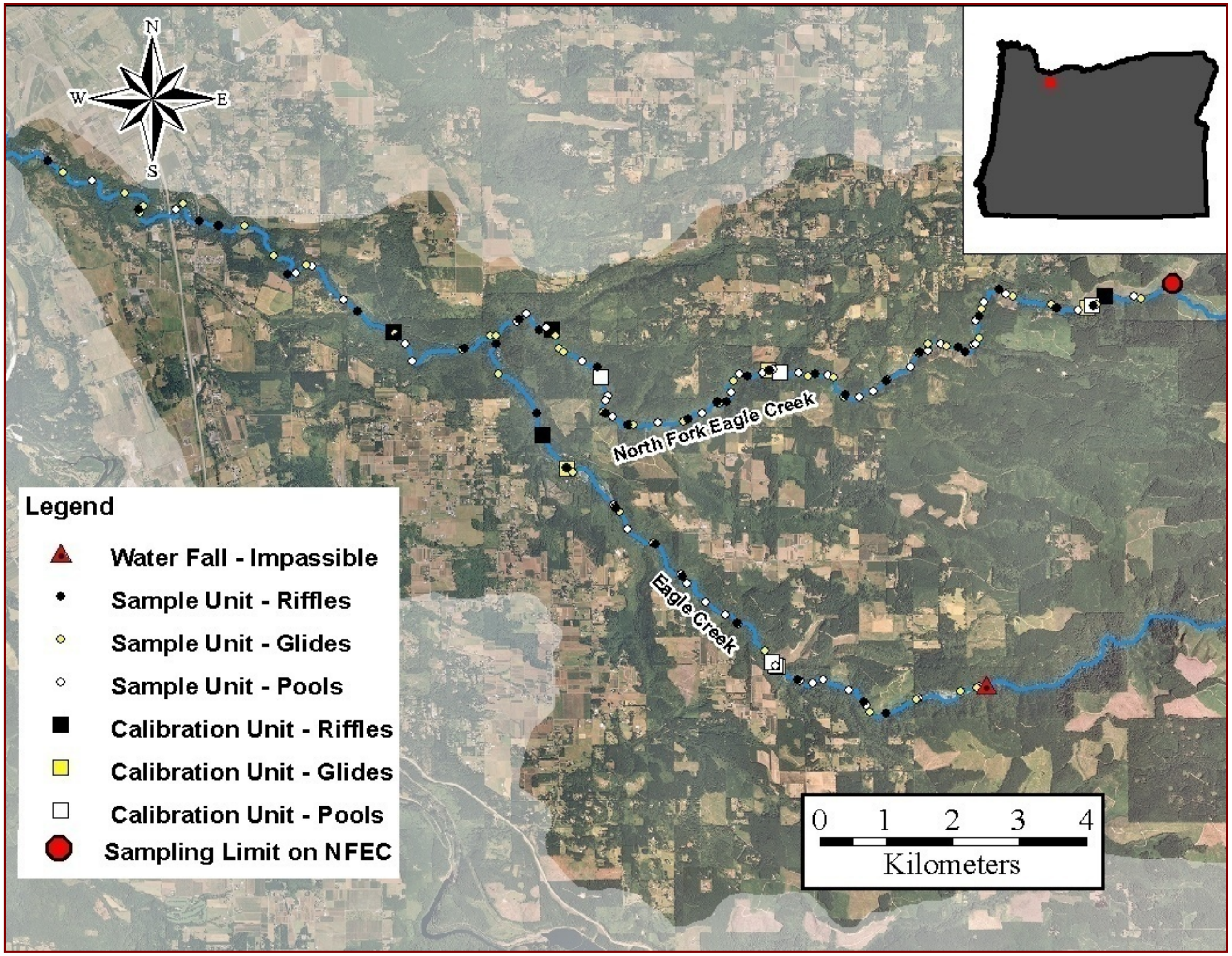
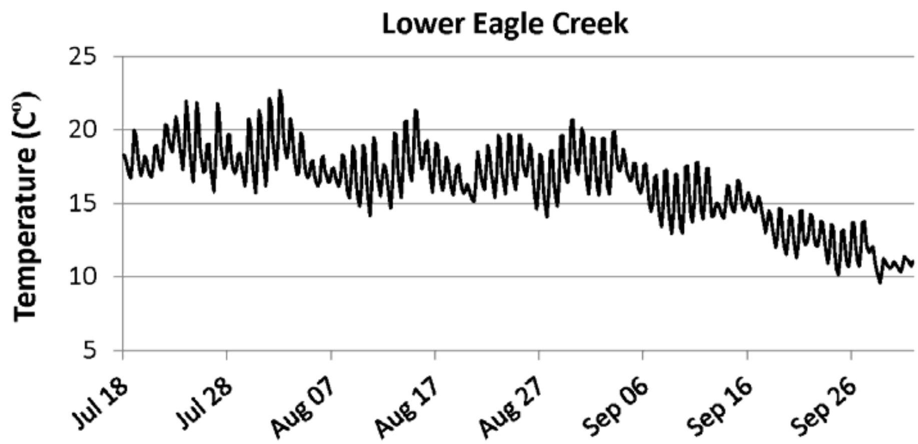
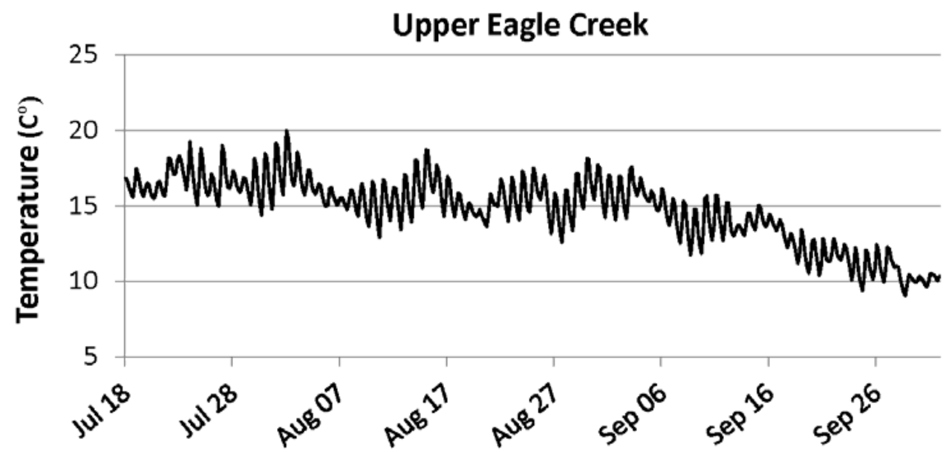


Figure 2.2 Map of mesohabitat units selected for sampling in the 2007 snorkel survey.





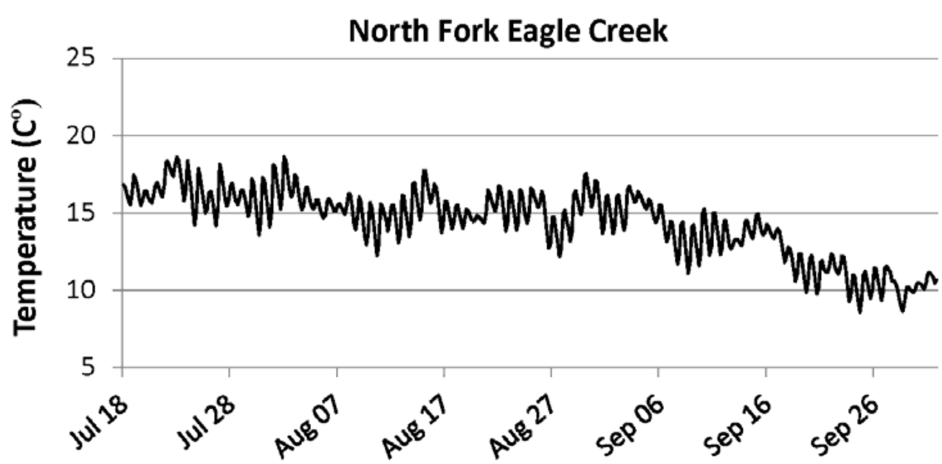


Figure 2.3 Temperature profiles of the three study reaches from July 18th to October 2nd 2007. Snorkel surveys were conducted between July 10th and September 14th 2007.

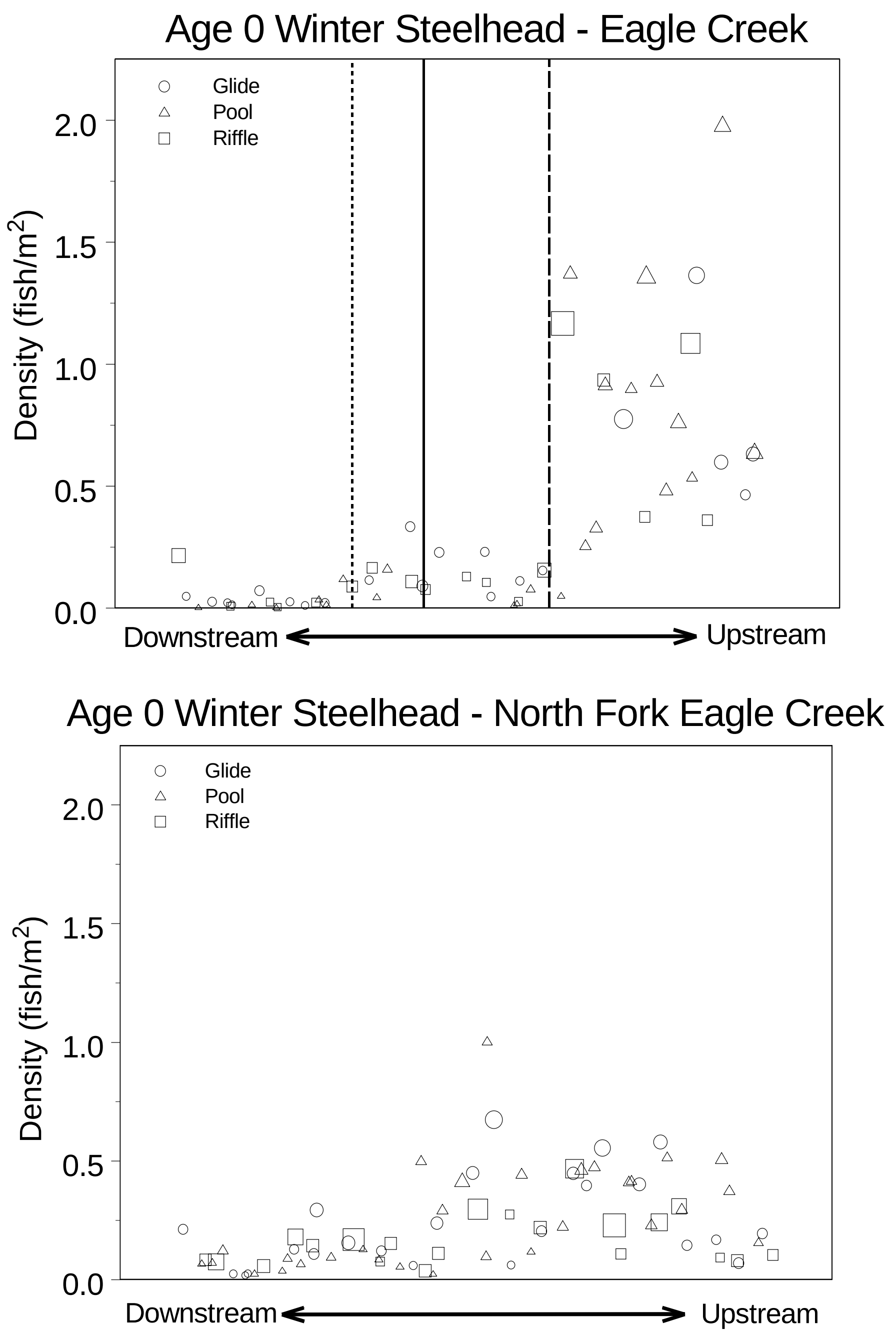


Figure 2.4 Estimated age 0 winter steelhead densities in Eagle Creek and North Fork Eagle Creek. The size of the symbol represents the abundance of fish in the habitat unit relative to other points on the plot. The largest symbol represents 1,085 fish in the Eagle Creek plot and 135 fish in the North Fork Eagle Creek plot. Three points of reference are labeled in the Eagle Creek plot: first detection of residual hatchery winter steelhead (dotted line), the confluence with North Fork Eagle Creek (solid line), and the middle ladder (dashed line).

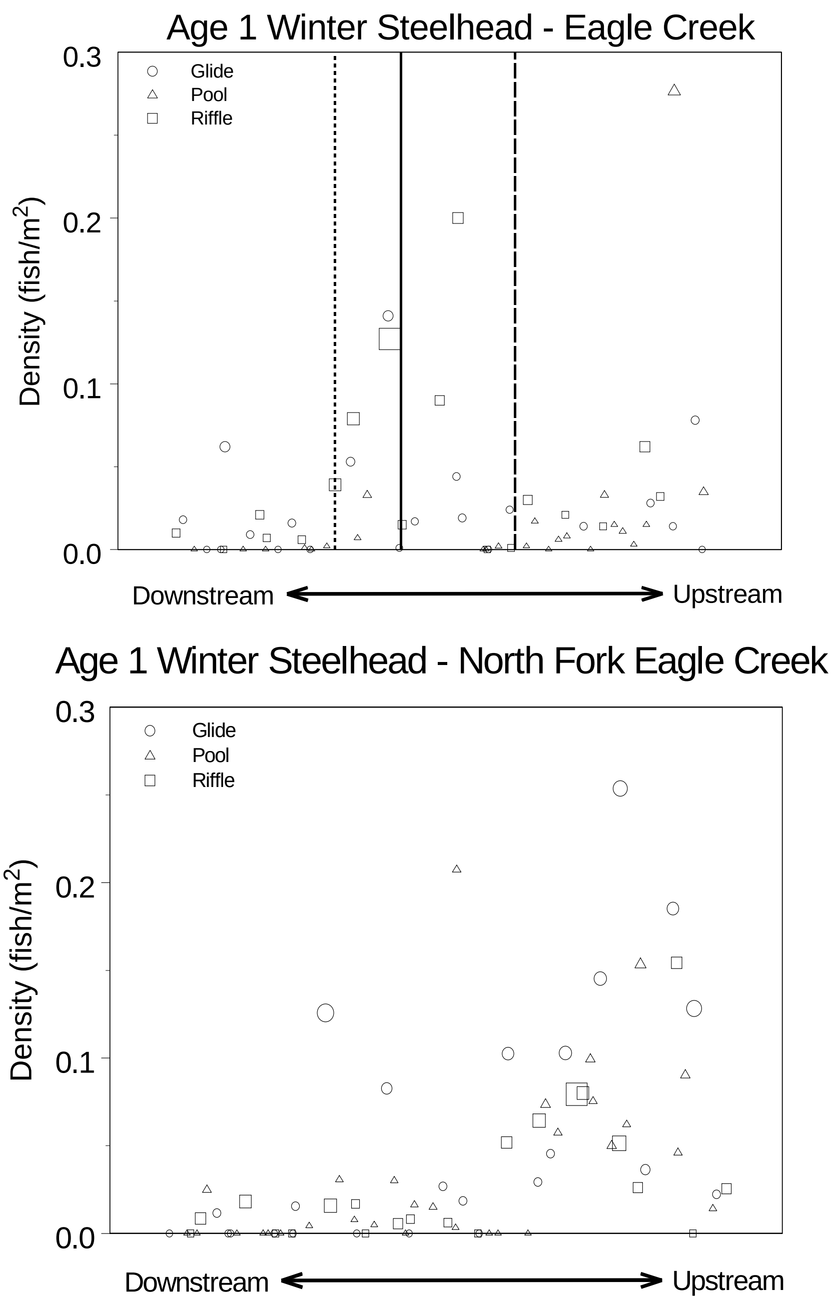


Figure 2.5 Estimated age 1 winter steelhead densities in Eagle Creek and North Fork Eagle Creek. The size of the symbol represents the abundance of fish in the habitat unit relative to other points on the plot. The largest symbol represents 260 fish in the Eagle Creek plot and 43 fish in the North Fork Eagle Creek plot. Three points of reference are labeled in the Eagle Creek plot: first detection of residual hatchery winter steelhead (dotted line), the confluence with North Fork Eagle Creek (solid line), and the middle ladder (dashed line).

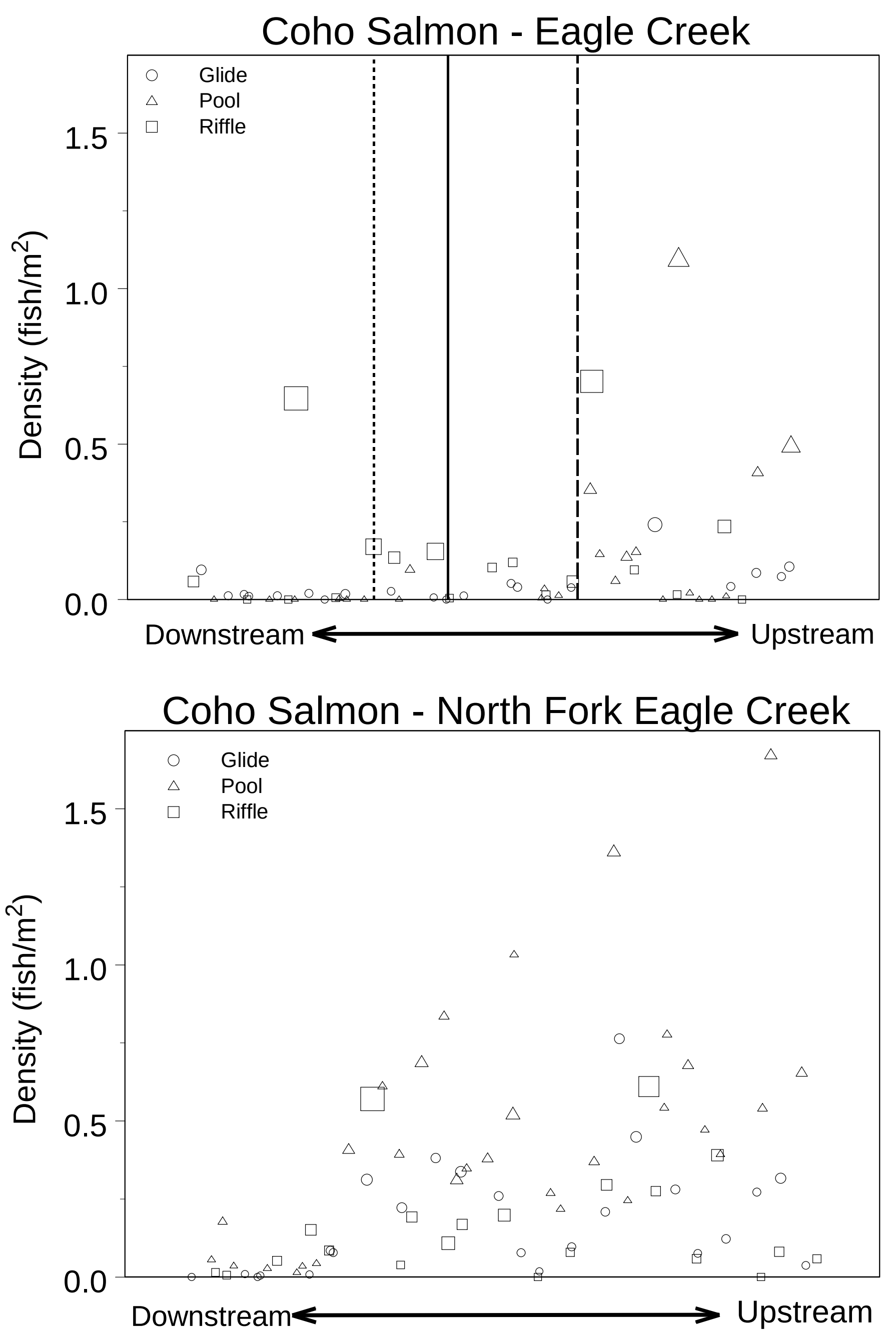


Figure 2.6 Estimated coho salmon densities in Eagle Creek and North Fork Eagle Creek. The size of the symbol represents the abundance of fish in the habitat unit relative to other points on the plot. The largest symbol represents 457 fish in the Eagle Creek plot and 722 fish in the North Fork Eagle Creek plot. Three points of reference are labeled in the Eagle Creek plot: first detection of residual hatchery winter steelhead (dotted line), the confluence with North Fork Eagle Creek (solid line), and the middle ladder (dashed line).

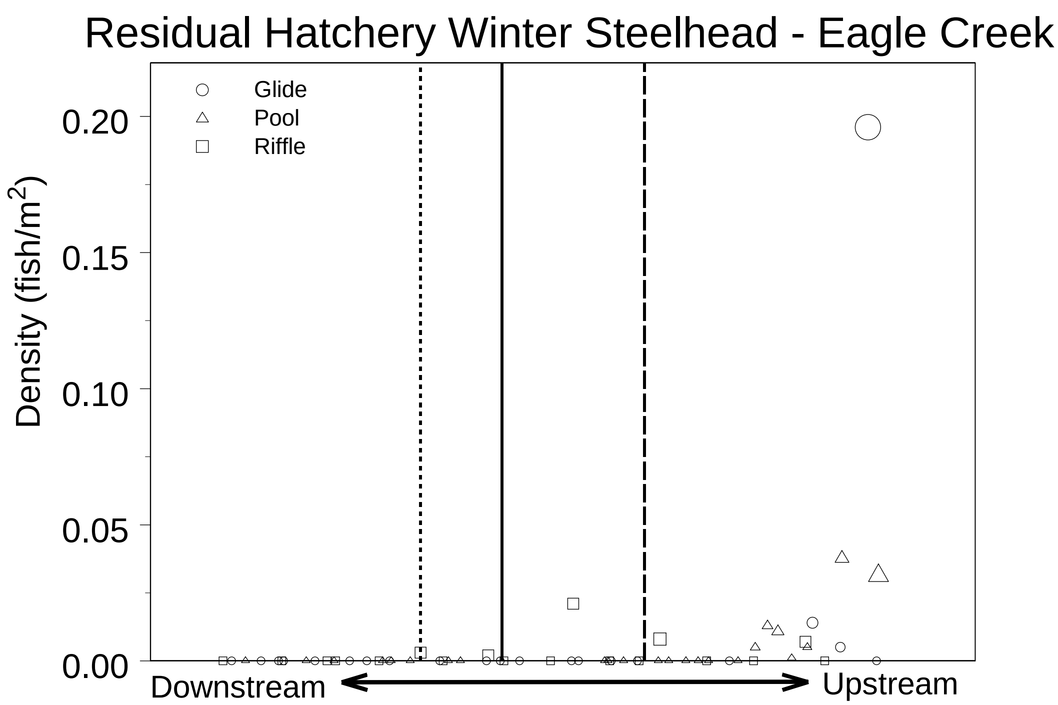


Figure 2.7 Estimated residual hatchery winter steelhead densities in Eagle Creek. Residual hatchery winter steelhead were not observed in North Fork Eagle Creek. The size of the bubble represents the abundance of fish in the habitat unit relative to other points on the plot. The largest symbol represents 50 fish. Three points of reference are labeled in the plot: first detection of residual hatchery winter steelhead (dotted line), the confluence with North Fork Eagle Creek (solid line), and the middle ladder (dashed line).

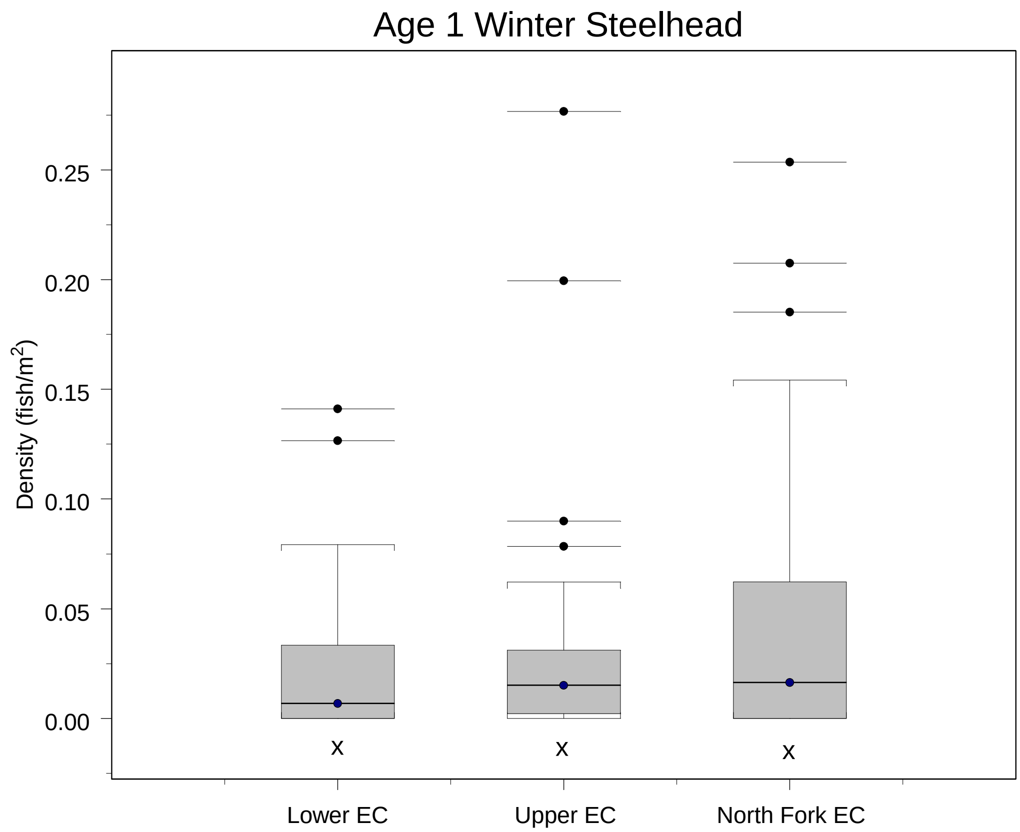


Figure 2.8 Estimated age 1 winter steelhead densities in lower Eagle Creek (EC), upper Eagle Creek, and North Fork Eagle Creek. The ends of each box are the 25th and 75th quartile range and the horizontal line within the box is the median. The whisker ends are all data points that fall within the distance calculated as 1.5 times the interquartile range. A line that lies beyond the whiskers represents an outlier. Non-parametric ANOVA did not detected density differences between stream reaches ($\chi^2 = 1.82$, P = 0.40) therefore, the same letter is used above the x-axis to represent no significant differences (P > 0.05) in pairwise comparisons.

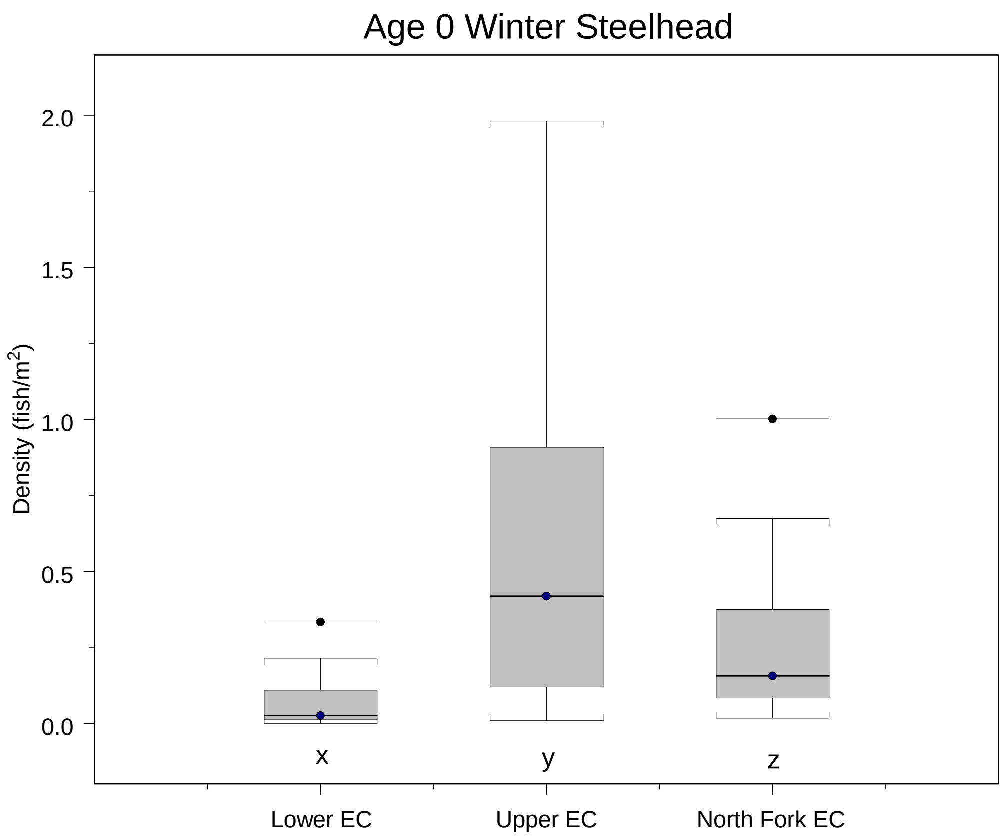


Figure 2.9 Estimated age 0 winter steelhead densities in lower Eagle Creek (EC), upper Eagle Creek, and North Fork Eagle Creek. The ends of each box are the 25th and 75th quartile range and the horizontal line within the box is the median. The whisker ends are all data points that fall within the distance calculated as 1.5 times the interquartile range. A line that lies beyond the whiskers represents an outlier. Non-parametric ANOVA detected density differences between stream reaches ($\chi^2 = 37.1$, $P < 0.001$) and different letters above the x-axis represent significant differences ($P < 0.05$) in pairwise comparisons.

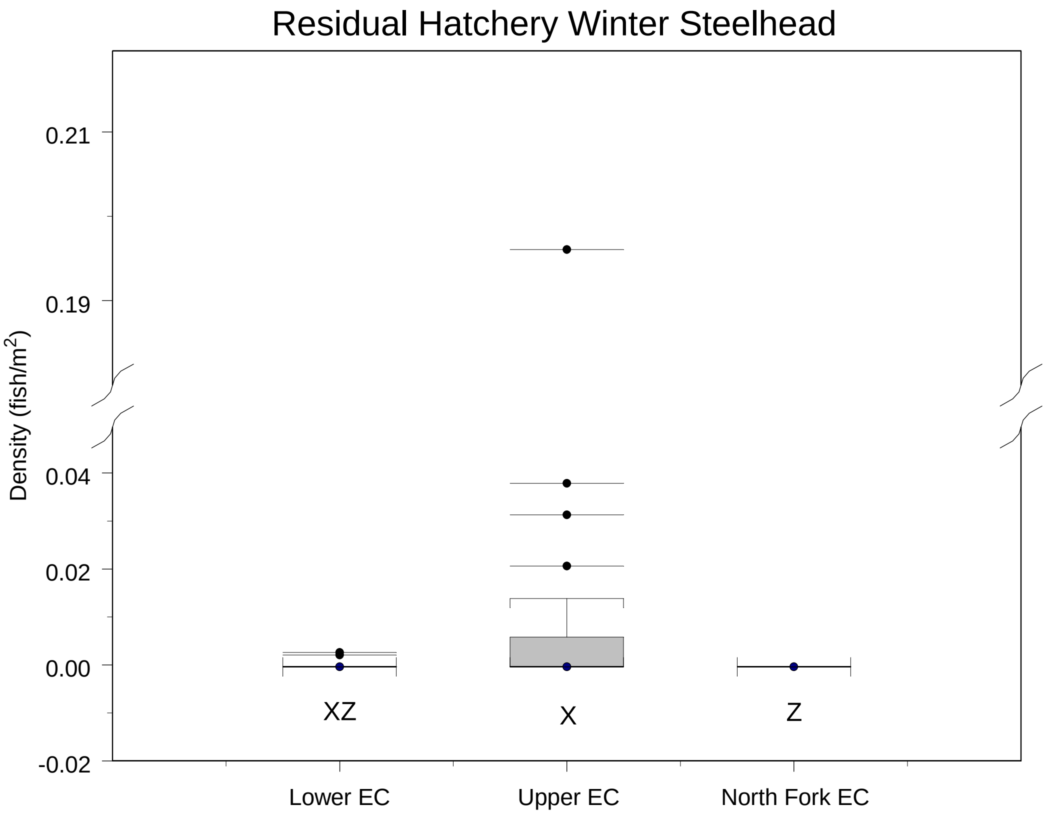


Figure 2.10 Estimated residual hatchery winter steelhead densities in lower Eagle Creek (EC), upper Eagle Creek, and North Fork Eagle Creek. The ends of each box are the 25th and 75th quartile range and the horizontal line within the box is the median. The whisker ends are all data points that fall within the distance calculated as 1.5 times the interquartile range. A line that lies beyond the whiskers represents an outlier. Non-parametric ANOVA detected density differences between stream reaches ($\chi^2 = 33.7$, $P < 0.001$) and different letters above the x-axis represent significant differences ($P < 0.05$) in pairwise comparisons.

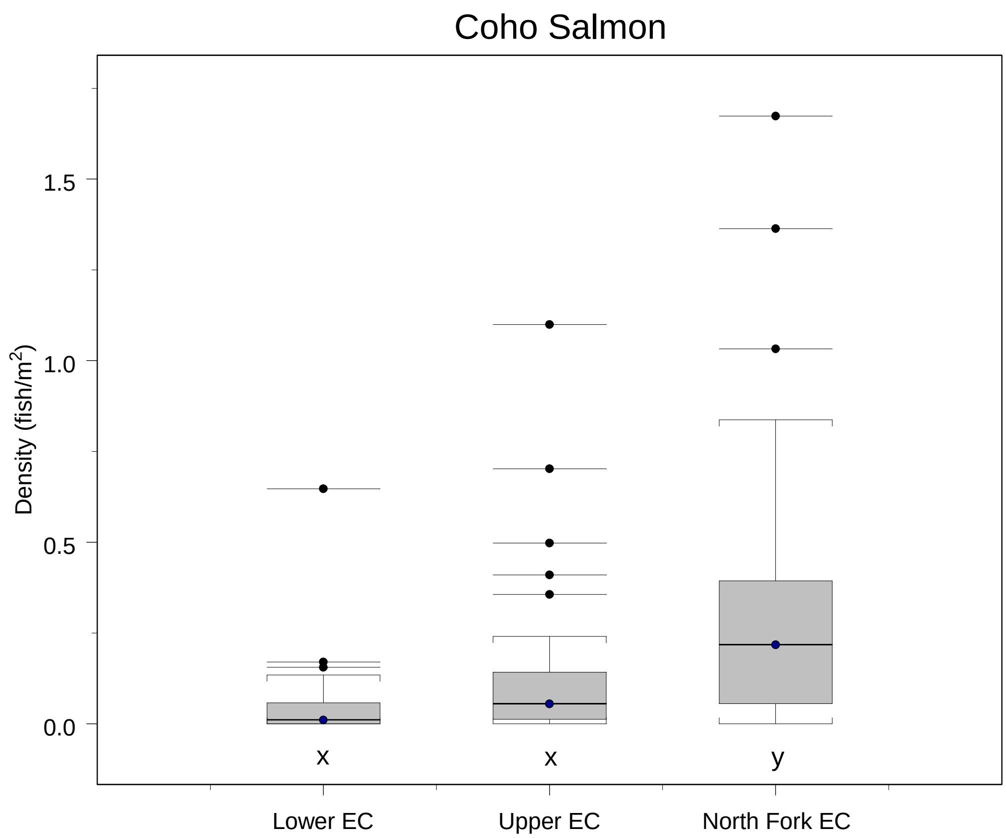


Figure 2.11 Estimated coho salmon densities in lower Eagle Creek (EC), upper Eagle Creek, and North Fork Eagle Creek. The ends of each box are the 25th and 75th quartile range and the horizontal line within the box is the median. The whisker ends are all data points that fall within the distance calculated as 1.5 times the interquartile range. A line that lies beyond the whiskers represents an outlier. Non-parametric ANOVA detected density differences between stream reaches ($\chi^2 = 30.8$, $P < 0.001$) and different letters above the x-axis represent significant differences ($P < 0.05$) in pairwise comparisons.

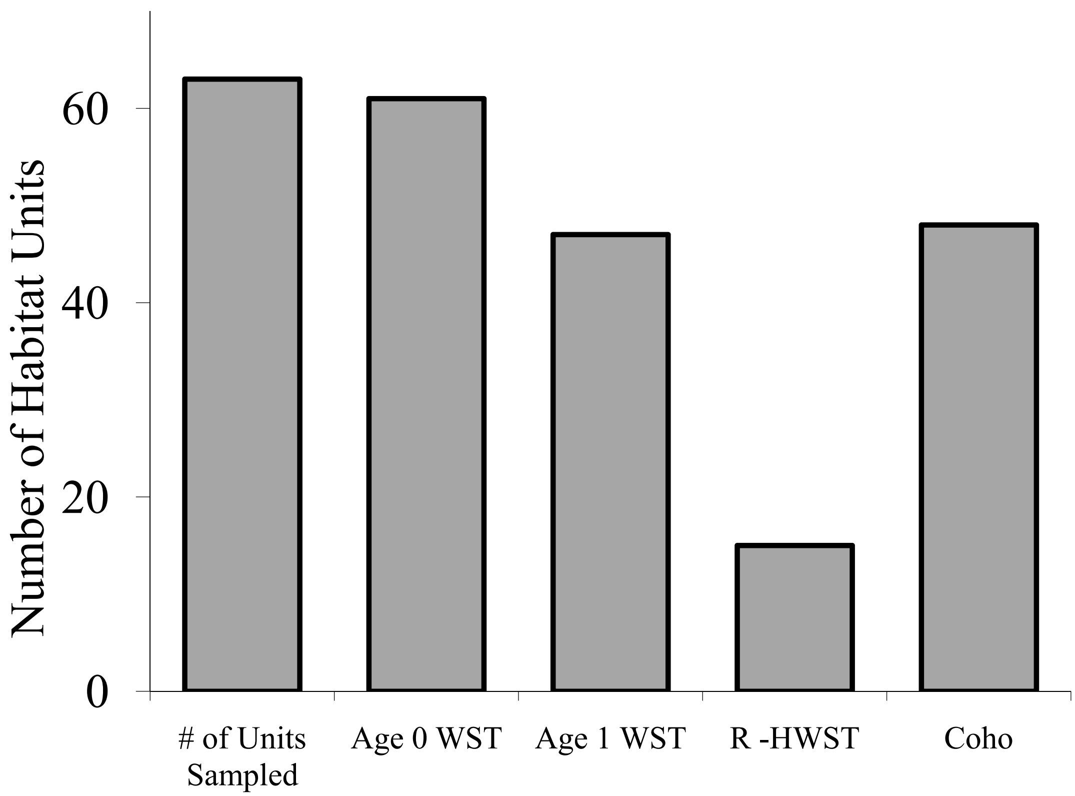


Figure 2.12 Number of sampled mesohabitat units in Eagle Creek where fish species were observed. Winter steelhead is abbreviate WST and residual hatchery winter steelhead is abbreviated R-HWST.

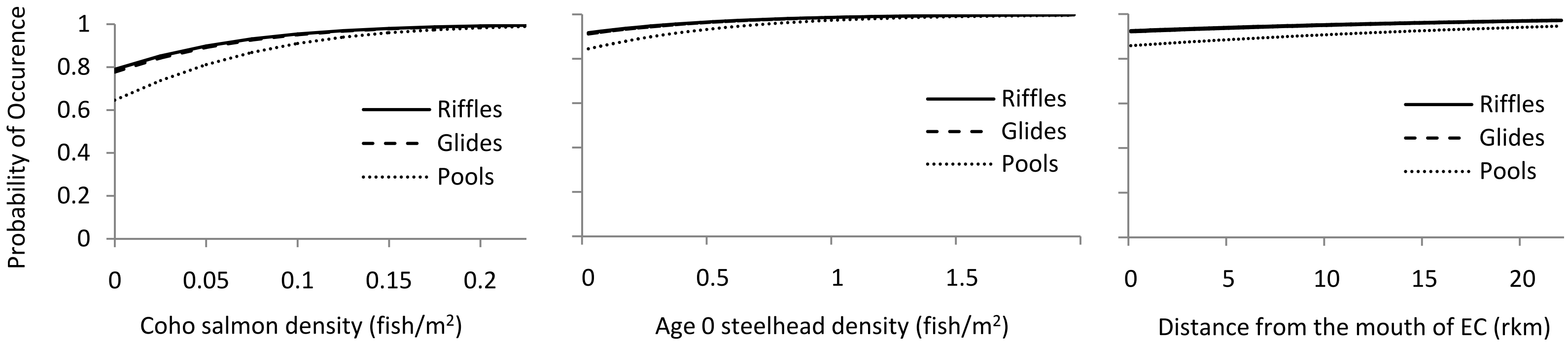


Figure 2.13 Probability of age 1 winter steelhead occurence in Eagle Creek (EC). Plots were constructed with model averaged parameter estimates of competing logistic regression models. The dashed line representing glide habitat is superimposed by the solid line representing riffle habitat.

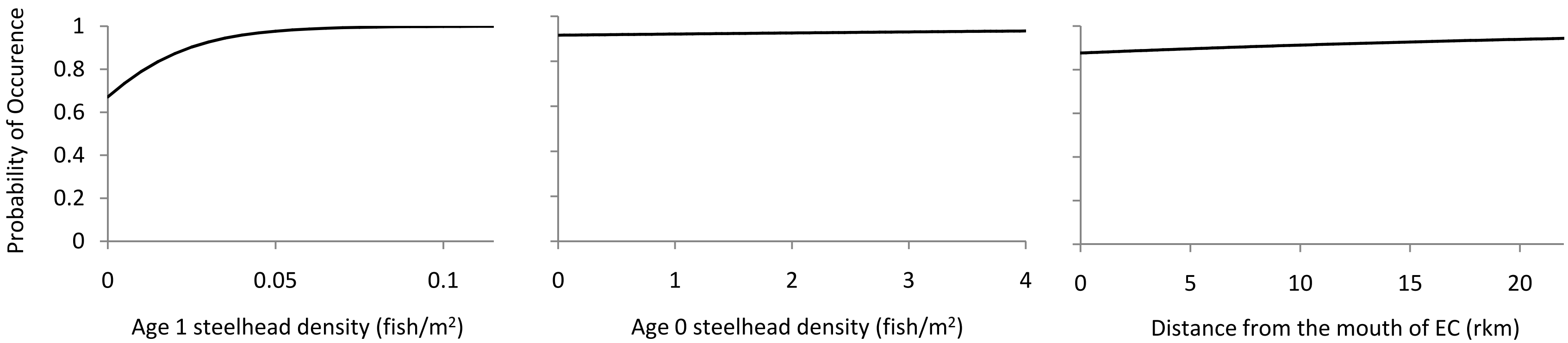


Figure 2.14 Probability of coho salmon occurence in Eagle Creek (EC). Plots were constructed with model averaged parameter estimates of competing logistic regression models.

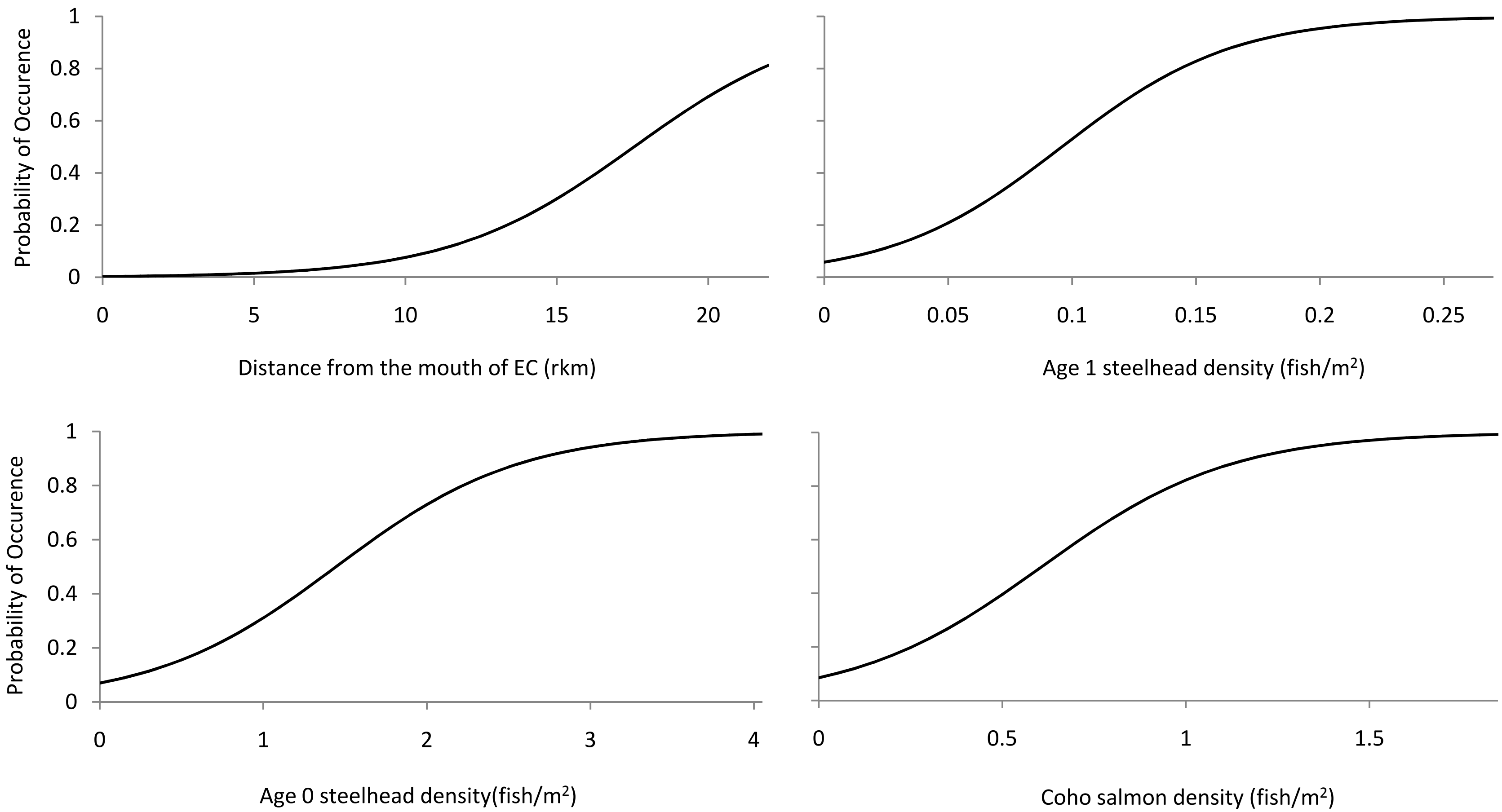


Figure 2.15 Probability of residual hatchery winter steelhead occurence in Eagle Creek (EC). Plots were constructed with model averaged parameter estimates of competing logistic regression models.

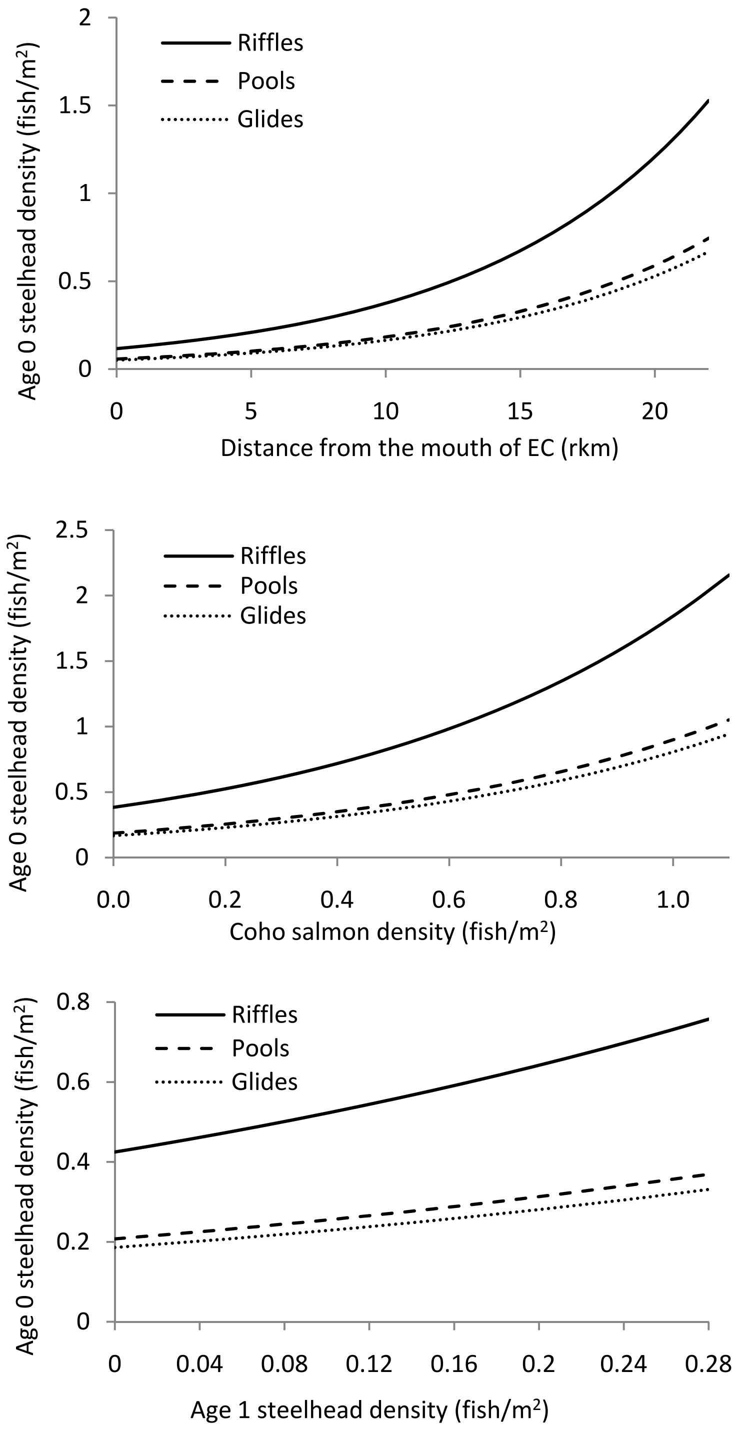


Figure 2.16 Factors influencing age 0 winter steelhead density given their presence. Plots were constructed using model averaged parameter estimates from competing generalized linear models. Eagle Creek is abbreviated EC.

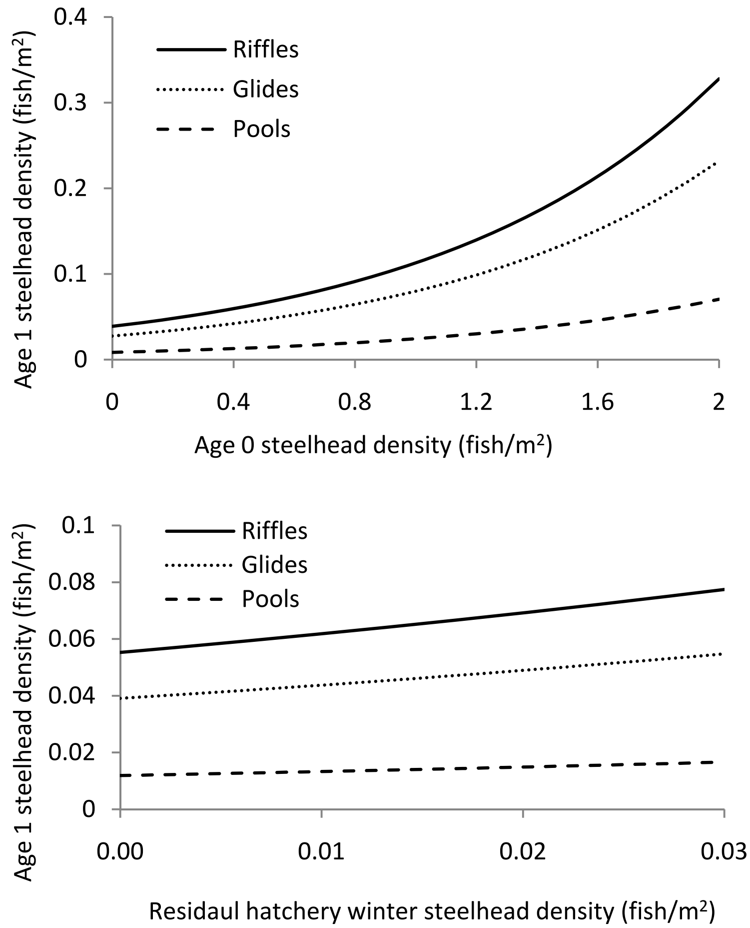


Figure 2.17 Factors influencing age 1 winter steelhead density given their presence. Plots were constructed using model averaged parameter estimates from competing generalized linear models.

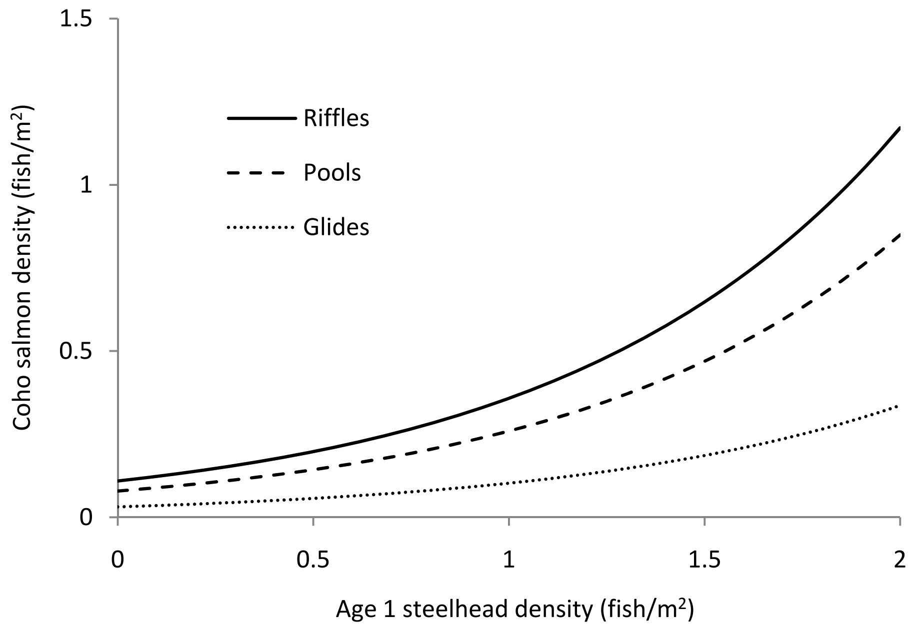


Figure 2.18 Factors influencing coho salmon density given their presence.

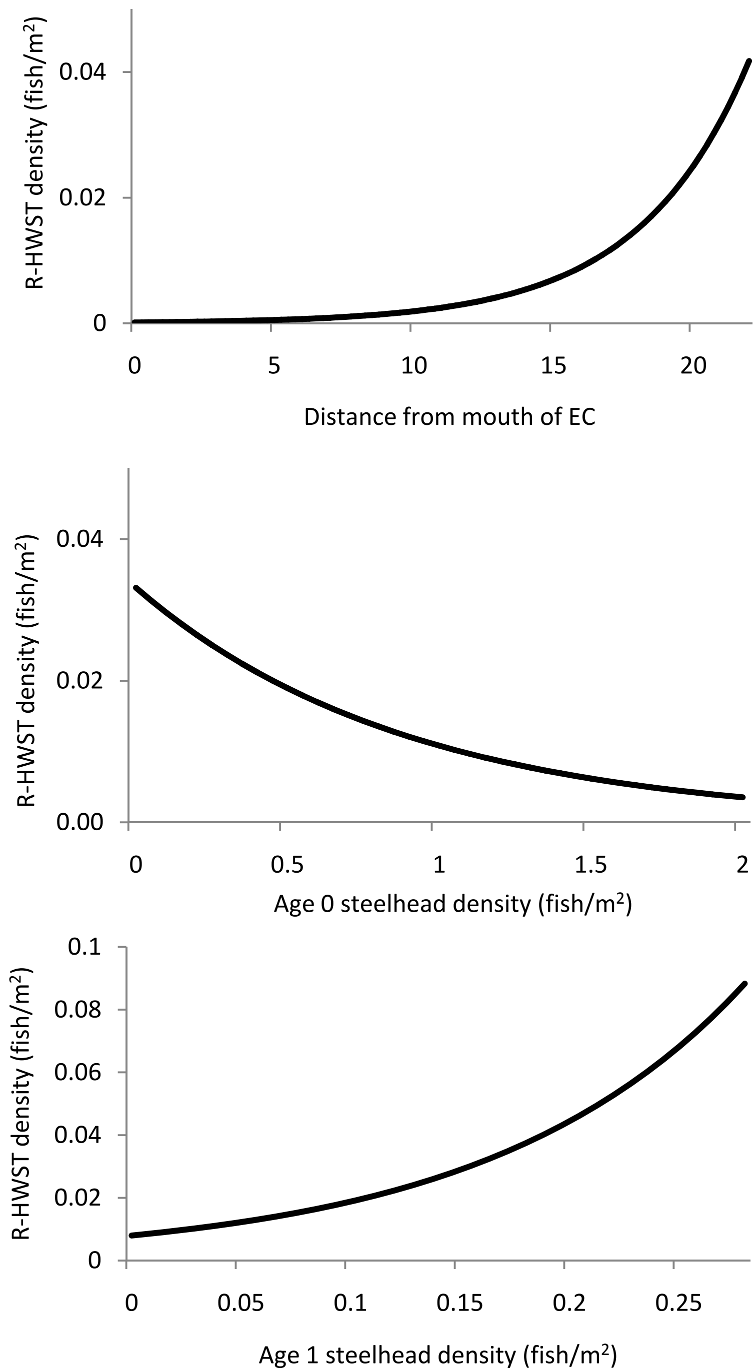


Figure 2.19 Factors influencing residual hatchery winter steelhead (R-HWST) density given their presence. Eagle Creek is abbreviated EC.

Table 2.1 Summary of mesohabitat characteristics of lower Eagle Creek, upper Eagle Creek and North Fork Eagle Creek.

Stream Reach	Riffles	Pools	Glides	Total
Lower Eagle Creek				
Number of Habitat Units	81	31	53	165
% of Total Habitat	49	19	32	100
Length of Habitat Units (m)	5,630	1,380	3,407	10,417
% of Total Stream Length	54	13	33	100
Area of Habitat Units (m^2)	106,997	25,122	60,318	192,437
% of Total Area	56	13	31	100
Upper Eagle Creek				
Number of Habitat Units	106	64	49	219
% of Total Habitat	48	29	23	100
Length of Habitat Units (m)	6,584	2,659	2,214	11,457
% of Total Stream Length	58	23	19	100
Area of Habitat Units (m^2)	107,869	37,417	33,016	178,302
% of Total Area	60	21	19	100
North Fork Eagle Creek				
Number of Habitat Units	212	121	118	451
% of Total Habitat	47	27	26	100
Length of Habitat Units (m)	9,839	2,535	2,474	14,848
% of Total Stream Length	66	17	17	100
Area of Habitat Units (m^2)	77,125	20,399	18,140	115,664
% of Total Area	67	17	16	100

Table 2.2 Population estimates of juvenile fish in lower Eagle Creek (LEC), upper Eagle Creek (UEC), and North Fork Eagle Creek (NFEC) calculated from two phase snorkel surveys conducted during the summer of 2007. Confidence intervals (95%) are reported in parentheses.

Species	Age 0 winter steelhead			Age 1 winter steelhead			Residual Hatchery Winter Steelhead			Coho Salmon		
Habitat Type	LEC	UEC	NFEC	LEC	UEC	NFEC	LEC	UEC	NFEC	LEC	UEC	NFEC
Glides	2,949 (± 2,160)	10,708 (± 2,124)	3,162 (± 3,157)	712 (± 263)	454 (± 250)	677 (± 167)	0	282 (± 250)	0	958 (± 908)	1,975 (± 887)	2,460 (± 1,429)
Pools	948 (± 2,957)	18,421 (± 4,046)	2,581 (± 5,664)	112 (± 49)	637 (± 85)	247 (± 150)	0	215 (± 85)	0	255 (± 762)	6,283 (± 1,079)	5,397 (± 1,582)
Riffles	9,255 (± 885)	30,015 (± 1,318)	10,870 (± 3,080)	4,491 (± 283)	2,030 (± 500)	1,501 (± 1,315)	102 (± 283)	187 (± 500)	0	15,626 (± 784)	11,090 (± 1,215)	14,471 (± 2,940)
Totals	13,152 (± 3,342)	59,143 (± 4,459)	16,613 (± 6,954)	5,315 (± 348)	3,121 (± 508)	2,425 (± 1,254)	102 (± 348)	685 (± 508)	0	16,839 (± 1,267)	19,348 (± 1,697)	22,328 (± 3,486)

Table 2.3 Competing logistic regression models used to describe a species presence and absence in Eagle Creek. Age 0 winter steelhead are not included in this table because they were present in 61 of the 63 habitat units sampled and therefore lacked the appropriate contrast to accurately model the probability of occurrence for this species. Competing models are ranked by Akaike's information criterion weights (w_i) which are calculated using the number of estimated parameters (K), log likelihood ($\log_e L$), Akaike's information criterion (AIC) corrected for small sample size (AIC_c) and the differences in AIC_c (Δ_i). The proportion of variability (adjusted r^2) in the data that is accounted for by the model is reported.

Rank	Model[a]	K	$\log_e L$	AIC	AIC_c	Δ_i	w_i	Adjusted r^2
Age 1 Winter Steelhead								
1	Coho.den	2	-30.17	64.34	64.54	0.00	0.35	0.18
2	Coho.den, Age0.den	3	-29.12	64.23	64.63	0.09	0.33	0.15
3	Coho.den, Age0.den, HABTYPE	5	-27.73	65.46	66.51	1.97	0.13	0.17
4	Coho.den, Dist.EC	3	-29.70	65.40	65.80	1.26	0.19	0.22
Coho Salmon								
1	Age1.den	2	-29.64	63.28	63.48	0.00	0.53	0.14
2	Age1.den, Dist.EC	3	-29.31	64.62	65.03	1.55	0.24	0.15
3	Age1.den, Age0.den	3	-29.41	64.81	65.22	1.74	0.22	0.15
Residual Hatchery Winter Steelhead								
1	Dist.EC, Age1.den, Coho.den	4	-17.24	42.48	43.17	0.00	0.34	0.50
2	Dist.EC, Age1.den, Age0.den	4	-17.42	42.83	43.52	0.35	0.29	0.50
3	Dist.EC, Age1.den	3	-18.94	43.88	44.29	1.12	0.19	0.45
4	Dist.EC, Age1.den, Age0.den, Coho.den	5	-16.71	43.41	44.46	1.29	0.18	0.52

[a] Variable definitions: Dist.EC = distance from the mouth of Eagle Creek (m), HABTYPE = mesohabitat type (riffles, pools, glides), Age0.den = age 0 winter steelhead density (fish/m^2), Age1.den = age 1 winter steelhead density (fish/m^2), Coho.den = coho salmon density (fish/m^2).

Table 2.4 Relative variable importance and estimated model coefficients (± SE) for a model averaged among competing models used to describe the factors influencing the probability of a species occurrence.

Model Variable[a]	Relative Importance	Averaged Coefficient (± SE)
Age 1 Winter Steelhead		
Intercept	na	0.10 (0.47)
Coho.den	1.00	0.000048 (0.000050)
Age0.den	0.46	1.96 (1.45)
Dist.EC	0.19	17.11 (9.32)
HABTYPE (glide)	0.13	-0.07 (0.47)
HABTYPE (pool)	0.13	-0.72 (0.48)
Coho Salmon		
Intercept	na	0.24 (0.48)
Age1.den	1.00	0.000039 (0.000049)
Age0.den	0.22	0.07 (1.03)
Dist.EC	0.24	60.77 (30.89)
Residual Hatchery Winter Steelhead		
Intercept	na	-7.63 (2.40)
Dist.EC	1.00	0.000331 (0.00014)
Age1.den	1.00	1.79 (1.31)
Age0.den	0.47	29.11 (11.83)
Coho.den	0.53	3.91 (3.01)

[a] Variable definitions: Dist.EC = distance from the mouth of Eagle Creek(m), HABTYPE = mesohabitat type (riffles, pools, glides), Age0.den = age 0 winter steelhead density (fish/m^2), Age1.den = age 1 winter steelhead density (fish/m^2), Coho.den = coho salmon density (fish/m^2).

Table 2.5 Competing generalized linear models used to describe the density (fish/m^2) of a species given that the species is present in Eagle Creek. Competing models are ranked by Akaike's information criterion weights (w_i) which are calculated using the number of estimated parameters (K), Akaike's information criterion (AIC) corrected for small sample size (AIC_c) and the differences in AIC_c (Δ_i). The proportion of variability (adjusted r^2) in the data that is accounted for by the model is reported.

Rank	Model[a]	K	AIC	AIC_c	Δ_i	w_i	Adjusted r^2
Age 0 Winter Steelhead							
1	Dist.EC, Coho.den, HABTYPE	5	82.01	83.06	0.00	0.50	0.46
2	Dist.EC, Coho.den	3	83.71	84.11	1.05	0.30	0.42
3	Dist.EC, Coho.den, HABTYPE, Age1.den	6	83.36	84.86	1.79	0.20	0.46
Age 1 Winter Steelhead							
1	Age0.den, HABTYPE, R-HWST.den	5	64.30	65.76	0.00	0.54	0.28
2	Age0.den, HABTYPE	4	65.17	66.12	0.36	0.46	0.24
Coho Salmon							
1	Age0.den, HABTYPE	4	64.77	65.70	0.00	1.00	0.26
Residual Hatchery Winter Steelhead							
1	Dist.EC, Age0.den, Age1.den	4	29.75	33.75	0.00	1.00	0.61

[a] Variable definitions: Dist.EC = distance from the mouth of Eagle Creek (m), HABTYPE = mesohabitat type (riffles, pools, glides), Age0.den = age 0 winter steelhead density (fish/m^2), Age1.den = age 1 winter steelhead density (fish/m^2), Coho.den = coho salmon density (fish/m^2), R-HWST.den = residual hatchery winter steelhead density (fish/m^2).

Table 2.6 Relative variable importance and estimated model coefficients (± SE) for a model averaged among competing models used to describe the factors influencing a species density (fish/m^2) given that the species is present.

Model Variable [a]	Relative Importance	Averaged Coefficient (±SE)
Age 0 Winter Steelhead		
Intercept	na	-3.20 (0.80)
Dist.EC	1.00	0.000117 (0.000052)
Coho.den	1.00	1.57 (1.67)
HABTYPE (pool)	0.70	0.11 (0.46)
HABTYPE (riffle)	0.70	0.83 (0.49)
Age1.den	0.20	2.06 (4.17)
Age 1 Winter Steelhead		
Intercept	na	-3.68 (0.33)
Age0.den	1.00	1.07 (0.40)
HABTYPE (pool)	1.00	-1.19 (0.44)
HABTYPE (riffle)	0.70	0.35 (0.42)
R-HWST.den	0.70	11.23 (6.07)
Coho Salmon		
Intercept	na	-3.46 (0.31)
Age0.den	1.00	1.19 (0.39)
HABTYPE (pool)	1.00	0.93 (0.44)
HABTYPE (riffle)	1.00	1.25 (0.42)
Residual Hatchery Winter Steelhead		
Intercept	na	-8.49 (1.25)
Dist.EC	1.00	0.000256 (0.000077)
Age0.den	1.00	-1.12 (0.62)
Age1.den	1.00	8.59 (3.63)

[a] Variable definitions: Dist.EC = distance from the mouth of Eagle Creek (m), HABTYPE = mesohabitat type (riffles, pools, glides), Age0.den = age 0 winter steelhead density (fish/m^2), Age1.den = age 1 winter steelhead density (fish/m^2), Coho.den = coho salmon density (fish/m^2), R-HWST.den = residual hatchery winter steelhead density (fish/m^2).

CHAPTER 3 : AN IN-WATER OBSERVER CAN AFFECT FISH BEHAVIOR AND BIAS MICROHABITAT USE STUDIES

Abstract

Researchers commonly employ in-water observations as a technique for sampling microhabitat use by juvenile salmonids. Data collected from these surveys are used to construct statistical models that predict microhabitat use and non-use. To produce an unbiased model, ideally fish would behave as if there were no observer present. This is not always the case. I conducted a study using underwater video to test if the presence of an in-water observer can elicit a change in fish behavior. I analyzed underwater video recordings to document changes in four metrics that can be used to infer a change in fish behavior. These changes in fish behavior can result in erroneous microhabitat use data. My four behavior metrics are upstream movement, downstream movement, total movement, and relative abundance of fish in the field-of-view. In 9 of 10 replicates, significant differences (ANOVA, $P < 0.05$) were detected in at least one of the four behavior metrics. These results suggest that when attempting to document small-scale microhabitat preference by juvenile salmonids, an in-water observer may alter fish behavior thereby producing erroneous results. I suggest researchers use caution in making inferences to entire populations when using results of models in which data were collected from only “undisturbed” fish.

Introduction

In-water observations (e.g., snorkel surveys) have a variety of applications and are widely used in fisheries science. Researchers use snorkel surveys to determine fish abundance (e.g., Hankin and Reeves 1988; Schill and Griffith 1984), detect presence or absence (e.g., Peterson et al. 2002; Watson and Hillman 1997), and predict habitat use (e.g., Al-Chokhachy and Budy 2007; Gries and Juanes 1998; Healy and Lonzarich 2000). Studies designed to predict habitat use are conducted at a variety of spatial scales from microhabitat to mesohabitat. Ideally, when conducting habitat use studies, fish behavior as it relates to habitat selection would remain unaffected in the presence of an in-water observer. While conducting research on brown trout *Salmo trutta* and Atlantic salmon *S. salar*, Heggenes et al. (1990) found that they were able to almost touch a fish before eliciting a fright response. Conversely, Peterson et al. (2005) documented both upstream and downstream movements by bull trout *Salvelinus confluentus* during snorkel surveys when an in-water observer approached to within 10 – 20 meters of the fish. Avoidance responses by fish may also vary depending on their size (Grant and Noakes 1987). Depending on the study objectives, displacement of fish caused by an in-water observer could have varying impacts on the study outcome. For example, small scale (i.e., microhabitat) movement or displacement of fish caused by the presence of an in-water observer may have little effect on a study focused at larger spatial scales (i.e., mesohabitat). However, results of habitat use studies at the microhabitat scale may be highly biased by small displacements (i.e. 1 meter) of fish being observed.

Researchers have used various statistical methods to analyze microhabitat use data collected using in-water observations. Such methods have included two-way analysis of variance to determine differences in microhabitat use (e.g., Lohr and West 1992; Moyle and Baltz 1985) and more recently, logistic regression modeling (Hosmer and Lemeshow 2000) to predict microhabitat use (e.g., Al-Chokhachy and Budy 2007; Turgeon and Rodriguez 2005). While researchers differ in the statistical methods used to analyze microhabitat data their methods are similar in that they only collect data from "undisturbed" fish (e.g., Guay et al. 2000; Maki-Petays et al. 2002), which may not be representative of the population as a whole. Inferences from these types of studies may have limited applicability to all fish in the study site and should only appropriately be applied to "undisturbed" fish (Peterson et al. 2005). Gatz et al. (1987) correctly acknowledged that the microhabitat data they collected using electrofishing most likely included "undisturbed" fish and fish that were frightened into refuge habitats.

In addition to biasing microhabitat use studies, a change in fish behavior caused by an in-water observer may bias the results of studies that employ a multiple pass snorkel technique. For example, researchers use multiple pass snorkel surveys, using a method known as bounded counts, described by Routledge (1982), to calculate an estimate of population abundance. This method requires multiple snorkel passes in the same stream section to acquire a point estimate of fish sighted. If the number of visible fish in the study reach changes between snorkel passes as a function of the in-water observer then point estimates from subsequent passes may be biased.

I initially began a study to predict microhabitat selection of juvenile winter steelhead *Oncorhynchus mykiss* and coho salmon *O. kitsch* in the presence of residual hatchery winter steelhead using logistic regression modeling. During snorkel surveys it was obvious that in-water observers were having a large effect on fish behavior, in particular fish movement, and the study was abandoned for fear of collecting erroneous microhabitat use and non-use data. A literature search to determine how snorkel surveys may affect habitat use, movement and behavior of fish was conducted and with the exception of Peterson et al. (2005) I am not aware of any peer-reviewed literature documenting movement of juvenile salmonids during snorkel surveys. Therefore, the objective of this study was to determine if the presence of an in-water observer influences fish behavior in terms of movement.

Methods

Study Location Description

This study was conducted in upper Eagle Creek, Oregon a fourth order stream in the Clackamas River watershed near Portland, Oregon. Eagle Creek originates in the Mount Hood National Forest and is fed primarily by snowmelt. The upper section of Eagle Creek was chosen because previous snorkel surveys suggested that my species of interest, juvenile coho salmon and winter steelhead, would be present. The study was conducted in August and September 2008 when the stream was at base flow and maximum water clarity.

Ten sample sites were selected in upper Eagle Creek based on stream characteristics that would allow for the maximum field-of-view and highest clarity when using underwater video. These characteristics include lack of turbulence, moderate depth (~1 meter), and few obstructions in the field-of-view (i.e., large woody debris and boulders); essentially slow flowing pool habitats were selected. The upstream and downstream limits of a sample site were delineated where changes in stream morphology were such that I would no longer classify the reach as pool habitat. With minimal disturbance to the site (i.e. taking a few steps into the stream and reaching a hand into the water), a Deep Blue Pro Underwater Video Camera (Ocean Systems, Inc., Everett WA) was placed perpendicular to the stream flow, approximately in the middle of the length of the site. The underwater camera was placed on the bottom of the stream, as close to the stream bank as possible in an effort to provide a maximum field-of-view, be totally submerged, and provide a view of the opposite stream bank. A mesh bag filled with stream cobble was attached to the bottom of the camera and acted as ballast to negate any movement caused by stream flow. The underwater camera was powered with a 12 volt deep cycle battery and connected to a Digital Video Camera Recorder (Sony Corporation, Model DCR-TRV27) which allowed me to record and view video in real-time. With the DCR-TRV27 connected to the underwater camera I verified that the field-of-view was clear of any major obstructions and began recording. At each site, immediately after the camera was placed in the stream, 10 minutes of video was recorded prior to the observer entering the stream, however only the 2 minutes of video directly before the observer entered the stream were reviewed and used in the data analysis. Without entering the water, the observer traveled downstream of the camera, until the most downstream limit was reached, approximately 7 meters from the underwater camera. At this point the observer entered the middle of stream with as little disturbance as possible and slowly traveled upstream parallel to the flow, past the underwater camera and exited the stream at the upstream most limit, approximately 5 meters from the camera. The duration of the video taken while the observer was in the stream varied from 60 to 90 seconds, depending on the length of the site. This entire section of video during the in-water observation was reviewed and included in the data analysis. I continued recording video after the observer had left the stream and included these 2 minutes of footage in the video review and subsequent data analysis. Therefore, the video footage used in the data analysis carried in length from 300 to 350 seconds. Before removing the camera from the stream I documented the dimensions of the field-of-view using an incremented wading staff. The maximum distance from the camera lens where I was unable to confidently differentiate fish from other in-water structures was recorded. The maximum width of the field-of-view, site depth, and site width were also recorded. After sampling all 10 sites I archived the videos on digital video discs and then reviewed them.

The three video periods (before, during, and after) and were divided into 5 second intervals and reviewed to document changes in four metrics. These metrics were: upstream movements, downstream movements, total movements, and relative abundance of fish in the field-of-view. For each 5 - second interval I tallied upstream and downstream movements at both sides of the video screen. For example, there are two ways for a movement to be classified as upstream or downstream. A fish traveling upstream and entering the field-of-view and a fish traveling upstream and leaving the field-of-view are both classified as upstream movements. The opposite holds true for downstream movements. Total movements were calculated as the gross number of upstream and downstream movements. The average number of fish visible during a 5 second interval was recorded and considered the relative abundance of fish in the field-of-view. I was unable to confidently differentiate between coho salmon and steelhead in the video recordings; therefore I combined movements and abundance of both species.

Statistical analyses

To detect differences in fish movements and relative abundance of fish in the field-of-view between periods, I analyzed data at each site using a one-way analysis of variance (ANOVA). The null hypotheses were that no significant differences occurred between periods in fish movements or relative abundance of fish in the field-of-view. The chances of having committed a Type II error (β) were calculated for each ANOVA. When ANOVA identified significant differences a Student – Newman – Keuls multiple comparison test was used to determine pair-wise differences between periods (Zar 1984). All statistical conclusions conducted at the $\alpha = 0.05$ significance level using S-PLUS 8.0 (Insightful Corp.).

Results

With Eagle Creek at base flow and no rain events around the time of sampling, the water clarity was high and stayed constant throughout the study. Juvenile coho salmon and winter steelhead were observed at all sample sites. Few fish were present in some sites relative to other sites where larger numbers of fish were available. The 10 sample sites had an average depth of 0.99 m (ranging from 0.60 m to 1.41 m), a mean width of 7.91 m (ranging from 5.1 m to 14.0 m), and water temperature ranged from 10.6

ºC to 12.3 ºC. The camera's field-of-view is best described as a conical shape, projecting from an apex at the camera lens away from the camera to a distance of 3 meters. The maximum diameter at the base of the conical field-of-view was 3 meters at each site. There were significant differences between periods in 9 of 10 sites for at least one metric measured (Table 3.1), however pair-wise differences were only detected in 8 of 10 sites for at least one metric measured.

Upstream Movements

There were significant differences in upstream movements between periods in 7 of 10 sites. Included in these seven sites is one instance where ANOVA identified a significant difference between periods, however this difference was not identified during pair-wise comparisons (Site #7). There were significant differences in three sites where the upstream movements were highest during the in-water observation as compared to before the in-water observation and six instances where the upstream movements were higher after the in-water observation as compared to before the in-water observation. In two sites the upstream movements were higher after the in-water observation than the during the in-water observation (Figure 3.1).

Downstream Movements

There were significant differences in downstream movements between periods in 6 of 10 sites. In all six sites, downstream movements were highest during the in-water observation period as compared to either before or after the in-water observation. In one site the downstream movements were higher after the in-water observations as compared to before the in-water observations (Figure 3.1).

Total Movements

There were significant differences in total movements between periods in 8 of 10 sites. Similar to the results of upstream movements there was one instance where ANOVA identified a significant difference between periods; however this difference was not identified during pair-wise comparisons (Site #7). Total movements were higher during the in-water observation and after the in-water observation as compared to the before the water observation in 5 of 10 sites and 6 of 10 sites, respectively. In one instance total movements were highest after the in-water observation as compared to during the in-water observation and lower in four instances (Figure 3.2).

Relative Abundance of fish in the Field-of-View

There were significant differences in the relative abundance of fish in the field-of-view in 7 of 10 sites. In these seven sites there was a significant difference before the in-water observation period as compared to after the in-water observation period, with four sites showing a higher abundance before the in-water observation and three sites showing a higher abundance after the in-water observation. There were pair-wise differences before the in-water observation period as compared to during the in-water observation period in 5 of 10 sites. At those five sites, relative abundance of fish in the field-of-view was higher before the in-water observation in 2 sites. Five of 10 sites displayed significant differences during the in-water observation period as compared to after the in-water observation period. Of those five sites, the abundance was higher after the in-water observation in four sites. In site #4 there were no fish visible before the in-water observation or during the majority of the in-water observation period, however after the in-water observer passed the underwater camera there was an increase in the abundance of fish in the field-of-view for the remainder of time the observer was in the water, as well as the 2 minute period after the in-water observer exited the stream (Figure 3.3).

Discussion

This study provides evidence that in a stream with high water clarity an in-water observer can influence fish behavior as it relates to movement. This ultimately can affect microhabitat use studies of juvenile coho salmon and winter steelhead. Fish exhibited a downstream movement during the time the observer was in the stream and a subsequent upstream movement after the observer had left the stream. Also, an in-water observer has the potential to either increase or decrease the abundance of fish that are visible in a stream. While the in-water observer caused a significant effect in the majority of my sites, an effect was not documented in all my sites. This suggests there may have been some other environmental and behavioral factors affecting fish movements in addition to the in-water observer.

Factors affecting fish behavior, and ultimately fish movement, are widespread and well documented. Predator avoidance (i.e., fright response) has been observed in various species of trout (Brown and Moyle 1991; Campbell 1998) and Pacific salmon *Oncorhynchus* spp. (Berejikian 1995; Healey and Reinhardt 1995). Conversely, prey species conducting "predator inspections" have been documented in mosquitofish

Gambusia spp. (George 1960), threespine stickleback *Gasterosteus aculeatus* (Godin and Crossman 1994), and minnow shoals *Phoxinus phoxinus* (Magurran 1986). Presence of a predator can also cause distress in fish (Barton 2002) and affect movement and habitat selection (Price and Schreck 2003). To respond to this stressor, fish produce corticotrophin-releasing hormone which has been proven to increase movement in salmon (Clements et al. 2002). If juvenile coho salmon and winter steelhead view an in-water observer as a potential predator, the downstream movements I observed may have been a function of predator avoidance and stress induced locomotion. The upstream movements that occurred after the perceived predator left the stream could be explained as predator inspections or simply a foraging behavior brought on when the in-water observer stirred-up benthic food resources.

After the in-water observer exited the stream there was a significant difference in the abundance of fish in the field-of-view, expressed as either an increase or a decrease depending on the site. This finding has implications for studies utilizing multiple pass snorkel surveys. Not all fish are readily available for visual enumeration during snorkel surveys; some may be utilizing cover or refugia. In instances where the presence of an in-water observer increases the abundance of visible fish, population estimates calculated from subsequent snorkel passes may more closely resemble the true population and therefore reduce the bias of the estimate. On the contrary, if an in-water observer lowers the abundance of visible fish in a site, then subsequent snorkel passes may increase the bias of the population estimate. This is assuming a closed population is sampled, which in my study was not.

The data I collected from site #4 (see Figure 3.3) have interesting implications for studies that attempt to build a predictive model of juvenile salmonid habitat use and non-use. In this one instance the in-water observer turned what would have initially been classified as non-use habitat into use habitat. This suggests that if one is collecting habitat use and non-use data using in-water observations, a multiple pass snorkel design may not be the best approach.

Due to the uncertainty in accurately identifying all fish to species I was unable to detect any potential interspecific differences in movements caused by the in-water observer. It is my belief that the results would have been similar if this study were conducted in streams where these species live in allopatry. However, with the more docile nature of coho salmon as compared to that of steelhead trout one may expect there to be a difference in the magnitude of response. Also, significant differences were not detected in each of the 10 sites. Pairwise significant differences between periods were not found in any comparison of the four metrics measured at sites #6 and #7. These sites also exhibited the fewest number of movements, both upstream and downstream, and the fewest number of fish in the field-of-view. This suggests that changes in movement and abundance of fish in the field-of-view may have a density dependent component.

This study is one example of how underwater video can be utilized to address fisheries related questions. The human eye possesses the ability to see in three dimensions and has a higher visual acuity compared to that of a camera lens. For these reasons, the human eye can see underwater with greater resolution and perception than a camera lens. However, there are also some benefits to utilizing underwater video.

Underwater cameras have less impact on fish behavior than an in-water observer; the video footage can be recorded, archived and reviewed if necessary to verify the findings or add *a posteriori* analyses to the study. Depending on study objectives, utilizing underwater video technology may be a better solution for observing fish in their natural habitat.

I conclude that the presence of an in-water observer can influence juvenile salmonid behavior in terms of movement. Studies that utilize in-water observations to calculate population estimates and evaluate habitat use and selection are essential in managing my fisheries resources. Due to the complexity of underwater habitats, there are biases and limitations associated with all methods used to observe fish in their natural habitat and it is important to acknowledge these limitations. My point is not that microhabitat models constructed using in-water observations are not robust, but rather that researchers should take caution when only collecting data on "undisturbed" fish and acknowledge that any inferences drawn from this type of data cannot appropriately be extrapolated to the entire population.

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References

Al-Chokhachy, R., and P. Budy. 2007. Summer microhabitat use of fluvial bull trout in Eastern Oregon streams. North American Journal of Fisheries Management 27:1068-1081.

Barton, B. A. 2002. Stress in fishes: a diversity of responses with particular reference to changes in circulating corticosteroids. Integrative Comparative Biology 42:517-525.

Berejikian, B. A. 1995. The effects of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry (*Oncorhynchus mykiss*) to avoid a benthic predator. Canadian Journal of Fisheries and Aquatic Sciences 52:2476-2482.

Brown, L. R., and P. B. Moyle. 1991. Changes in habitat and microhabitat partitioning within an assemblage of stream fishes in response to predation by Sacramento squawfish (*Ptychocheilus grandis*). Canadian Journal of Fisheries and Aquatic Sciences 48:849-856.

Campbell, E. A. 1998. Influence of streamflow and predators on habitat choice by trout. Doctoral dissertation. University of California, Davis, California.

Clements, S., C. B. Schreck, D. A. Larsen, and W. W. Dickhoff. 2002. Central administration of corticotropin-releasing hormone stimulates locomotor activity in juvenile Chinook salmon (*Oncorhynchus tshawytscha*). General and Comparative Endocrinology 125:319-327.

Gatz, A. J., M. J. Sale, and J. M. Loar. 1987. Habitat shifts in rainbow trout: competitive influences of brown trout. Oecologia 74:7-19.

George, C. J. W. 1960. Behavioral interactions of the pickerel (*Esox niger* and *Esox americanus*) and the mosquitofish (*Gambusia patruelis*). Doctoral dissertation. Harvard University, Cambridge, Massachusetts.

Godin, J. J., and S. L. Crossman. 1994. Hunger-dependent predator inspection and foraging behaviours in the threespine stickleback (*Gasterosteus aculeatus*) under predation risk. Behavioral Ecology and Sociobiology 34:359-366.

Grant, J. W. A, and D. L. G. Noakes. 1987. Escape behaviour and use of cover by young year brook trout (*Salvelinus fontinalis*). Canadian Journal of Fisheries and Aquatic Sciences 45:1390 – 1396.

Gries, G., and F. Juanes. 1998. Microhabitat use by juvenile Atlantic salmon (*Salmo salar*) sheltering during the day in summer. Canadian Journal of Zoology 76:1441-1449.

Guay, J. C., D. Boisclair, D. Rioux, M. Leclerc, M. Lapointe, and P. Legendre. 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 57:2065-2075.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Healey, M. C., and U. Reinhardt. 1995. Predator avoidance in naive and experienced juvenile Chinook and coho salmon. Canadian Journal of Fisheries and Aquatic Sciences 52:614-622.

Healy, B. D., and D. G. Lonzarich. 2000. Microhabitat use and behavior of overwintering juvenile coho salmon in a Lake Superior tributary. Transactions of the American Fisheries Society 129:866-872.

Heggenes, J., Å. Brabrand, and S. Saltveit. 1990. Comparison of three methods for studies of stream habitat use by young brown trout and Atlantic salmon. Transactions of the American Fisheries Society 119:101-111.

Hosmer, D. W., and S. Lemeshow. 2000. Applied logistic regression, 2nd edition. Wiley Interscience, New York, New York.

Lohr, S. C., and J. L. West. 1992. Microhabitat selection by brook and rainbow trout in a southern Appalachian stream. Transactions of the American Fisheries Society 121:729-736.

Magurran, A. E. 1986. Predator inspection behaviour in minnow shoals: differences between populations and individuals. Behavioral Ecology and Sociobiology 19:267-273.

Maki-Petays, A., A. Huusko, J. Erkinaro, and T. Muotka. 2002. Transferability of habitat suitability criteria of juvenile Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 59:218-228.

Moyle, P. B., and D. M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow determinations. Transactions of the American Fisheries Society 114:695-704.

Peterson, J., J. Dunham, P. Howell, R. Thurow, and S. Bonar. 2002. Protocol for determining bull trout presence. Bull Trout Committee, Western Division, American Fisheries Society, Bethesda, Maryland.

Peterson, J. T., N. P. Banish, and R. F. Thurow. 2005. Are block nets necessary?: Movement of stream-dwelling salmonids in response to three common survey methods. North American Journal of Fisheries Management 25:732-743.

Price, C. S., and C. B. Schreck. 2003. Stress and saltwater-entry behavior of juvenile Chinook salmon (*Oncorhynchus tshawytscha*): conflicts in physiological motivation. Canadian Journal of Fisheries and Aquatic Sciences 60:910-918.

Routledge, R. D. 1982. The method of bounded counts: when does it work? The Journal of Wildlife Management 46:757-761.

Schill, D. J., and J. S. Griffith. 1984. Use of underwater observations to estimate cutthroat trout abundance in the Yellowstone River. North American Journal of Fisheries Management 4:479-487.

Turgeon, K., and M. A. Rodriguez. 2005. Predicting microhabitat selection in juvenile Atlantic salmon *Salmo salar* by the use of logistic regression and classification trees. Freshwater Biology 50:539-551.

Watson, G., and T. W. Hillman. 1997. Factors affecting the distribution and abundance of bull trout: an investigation at hierarchical scales. North American Journal of Fisheries Management 17:237-252.

Zar, J. H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall, Englewood Cliffs, New Jersey.

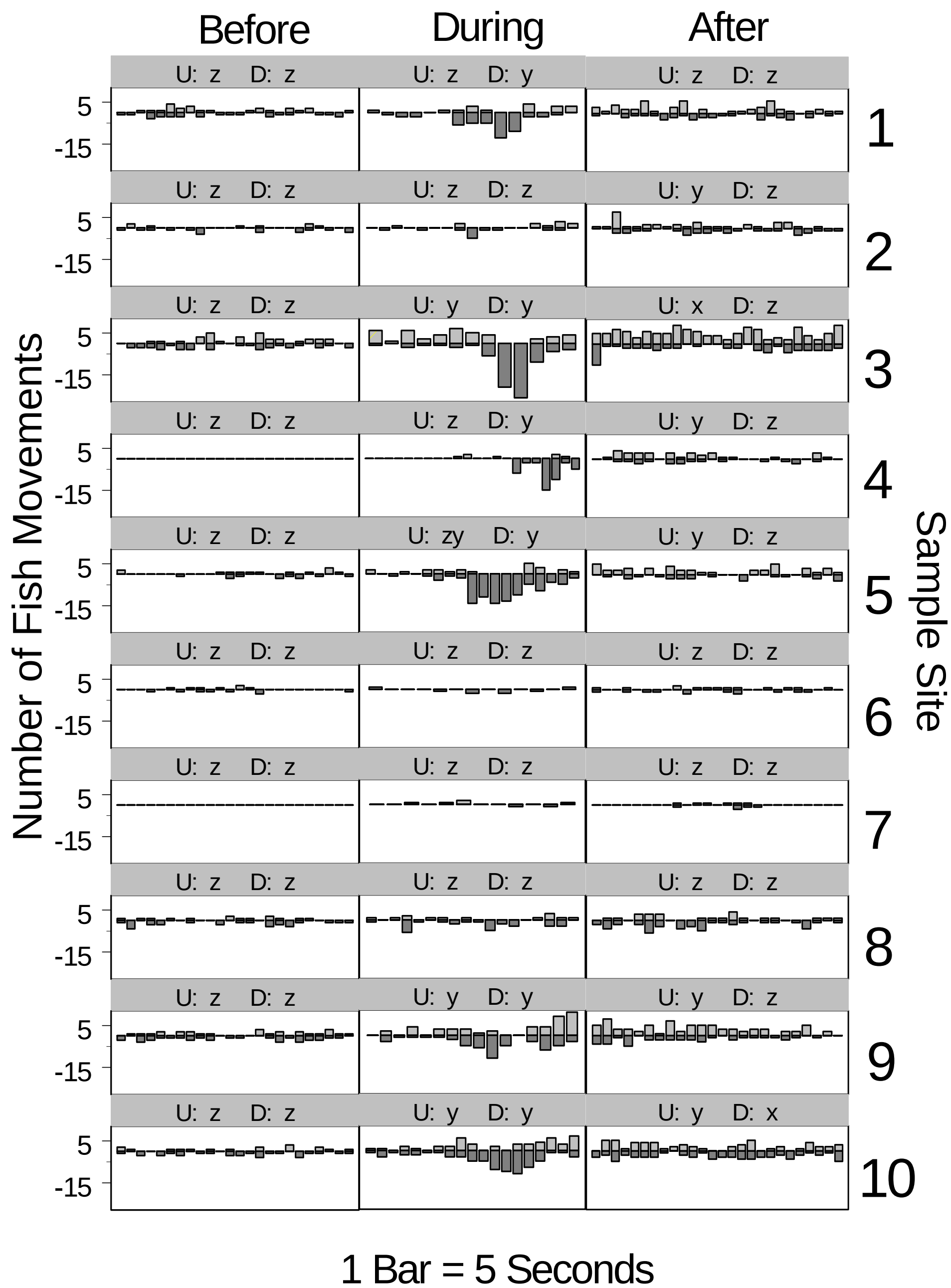


Figure 3.1 Upstream and downstream movements of juvenile coho salmon and winter steelhead for each of the 10 sample sites in Eagle Creek, Oregon. Upstream movements are displayed as positive numbers (light gray bars) and downstream movements are displayed as negative numbers (dark gray bars). Each bar represents a 5 second interval. Within panel strips, lower case letters represent statistically different number of upstream (U:) and downstream (D:) movements between periods as determined by Student-Newman-Keuls tests (P=0.05). The scale of the x-axis is varied to account for varying time duration between sites during the in-water observation period.

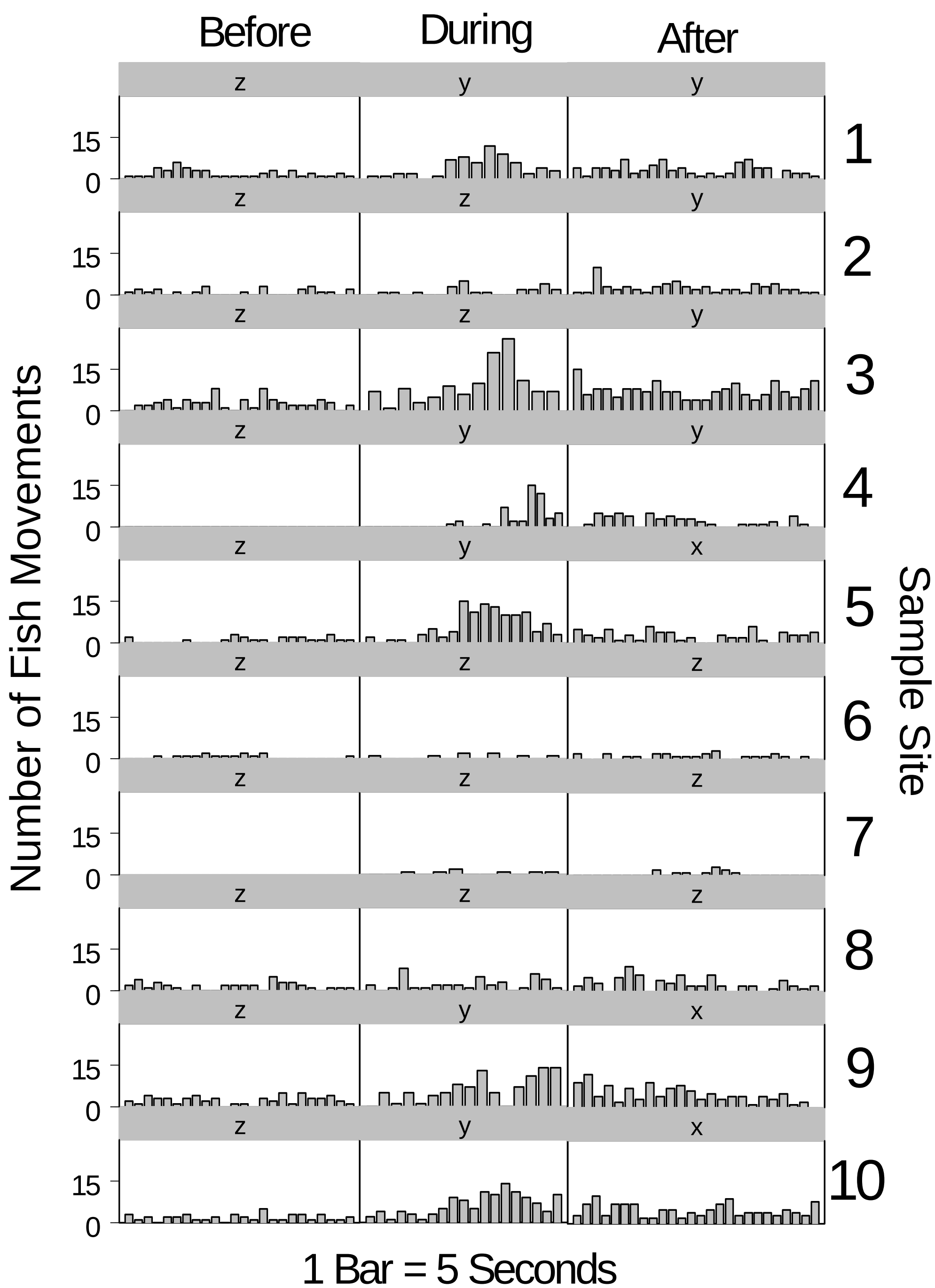


Figure 3.2 Total number of movements of juvenile coho salmon and winter steelhead for each of the 10 sample sites in Eagle Creek, Oregon. Each bar represents a 5 second interval. Within panel strips, lower case letters represent statistically different number of total movements between periods as determined by Student-Newman-Keuls tests (P=0.05). The scale of the x-axis is varied to account for varying time duration in the "during period" between sites.

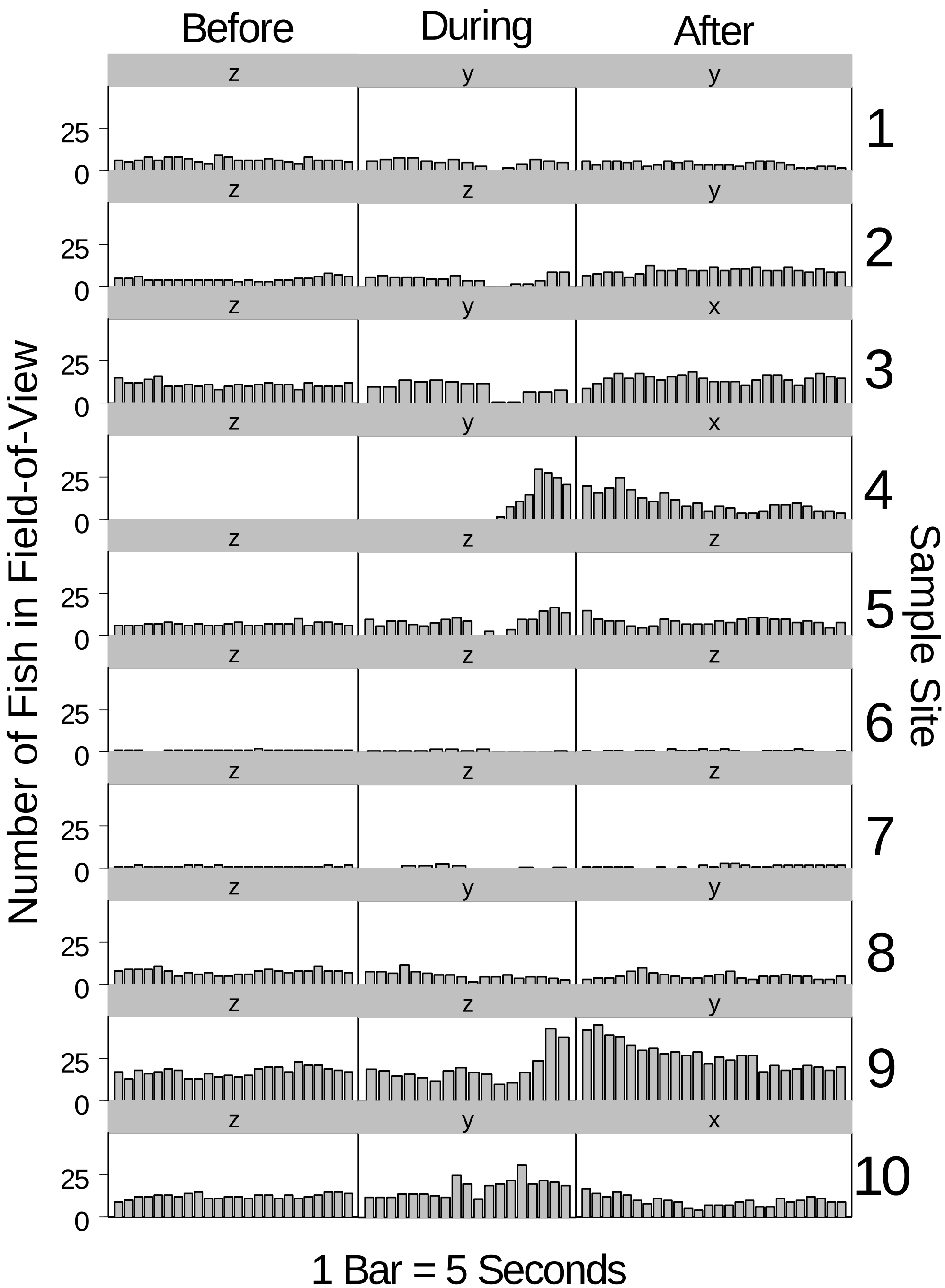


Figure 3.3 Number of juvenile coho salmon and winter steelhead in the field-of-view during sampling for each of the 10 sample sites Eagle Creek, Oregon. Each bar represents a 5 second interval. Within panel strips, lower case letters represent statistically different number of fish in the field-of-view between periods as determined by Student-Newman-Keuls tests (P=0.05). The scale of the x-axis is varied to account for varying time duration in the "during period" between sites.

Table 3.1 Analysis of variance results for comparisons of upstream movements, downstream movements, total movements and relative abundance of fish in the field-of-view for ten sites sampled in Eagle Creek. The probability of committing a type II error (β) is reported.

Upstream Movements

	ANOVA			
Site	$F_{df1, df2}$	df_1, df_2	P - value	β
1	2.97	2, 62	0.059	0.58
2	6.00	2, 63	0.004	0.20
3	23.79	2, 59	< 0.001	0.01
4	15.82	2, 67	< 0.001	0.01
5	5.44	2, 64	0.007	0.27
6	2.28	2, 59	0.112	0.68
7	4.71	2, 58	0.013	0.33
8	1.31	2, 63	0.276	0.75
9	6.53	2, 61	0.003	0.18
10	7.81	2, 66	< 0.001	0.10

Downstream Movements

	ANOVA			
Site	$F_{df1, df2}$	df_1, df_2	P - value	β
1	6.39	2, 62	0.003	0.18
2	1.86	2, 63	0.165	0.77
3	5.57	2, 59	0.006	0.20
4	4.22	2, 67	0.019	0.38
5	15.79	2, 64	< 0.001	0.01
6	0.35	2, 59	0.707	0.80
7	2.00	2, 58	0.144	0.73
8	1.62	2, 63	0.206	0.80
9	7.15	2, 61	0.002	0.13
10	11.17	2, 66	< 0.001	0.02

Total Number of Movements

	ANOVA			
Site	$F_{df1, df2}$	df_1, df_2	P - value	β
1	4.86	2, 62	0.011	0.33
2	7.55	2, 63	0.001	0.10
3	15.56	2, 59	< 0.001	0.01
4	5.63	2, 67	0.005	0.22
5	16.21	2, 64	< 0.001	0.01
6	1.72	2, 59	0.188	0.80
7	4.97	2, 58	0.01	0.33
8	2.29	2, 63	0.11	0.75
9	8.02	2, 61	< 0.001	0.07
10	18.38	2, 66	< 0.001	0.01

Relative Abundance in the Field-of-View

	ANOVA			
Site	$F_{df1, df2}$	df_1, df_2	P - value	B
1	8.79	2, 62	< 0.001	0.06
2	62.14	2, 63	< 0.001	0.01
3	19.25	2, 59	< 0.001	0.01
4	14.43	2, 67	< 0.001	0.01
5	2.61	2, 64	0.081	0.68
6	0.11	2, 59	0.898	0.74
7	1.33	2, 58	0.273	0.75
8	11.18	2, 63	< 0.001	0.02
9	13.89	2, 61	< 0.001	0.01
10	27.4	2, 66	< 0.001	0.01

CHAPTER 4 : GENERAL CONCLUSION

My overall goal was to determine if residual hatchery winter steelhead *Oncorhynchus mykiss* were present in the Eagle Creek Basin and if so, do they influence the distribution and habitat selection of wild salmonids (*Oncorhynchus* spp.). My initial approach was to conduct this study at two scales, mesohabitat and microhabitat. Conducing this study at the mesohabitat scale allowed me to paint a broad, comprehensive picture of how juvenile salmonids, both hatchery and wild, were distributed throughout the basin. By focusing on the microhabitat scale I would be able to identify the specific habitat parameters that impact wild fish presence, however due to a change in fish behavior as a function of my presence in the stream I became concerned that my microhabitat data maybe biased. For this reason I shifted my focus from evaluating microhabitat use to documenting the altered fish behavior as a function of an in-water observer. It was my intention that documenting the change in fish behavior as a function of an in-water observer may assist future researchers when attempting to conduct a similar study.

In Chapter 2, I documented that residual hatchery winter steelhead were present in the mainstem of Eagle Creek and I can say with a high degree of confidence that they were absent in North Fork Eagle Creek during the summer of 2007. The spatial distribution of residual hatchery winter steelhead was skewed, with the highest numbers and densities located in the vicinity of Eagle Creek National Fish Hatchery, a similar distribution to both juvenile coho salmon and age 0 winter steelhead. Also, residual hatchery steelhead comprised 9.3 percent of the total estimated age 1 winter steelhead population rearing in Eagle Creek. I was unable to detect a displacement of wild fish at a large scale (i.e. mesohabitat) as a function of residual hatchery winter steelhead however, with both the hatchery and wild populations rearing in close proximity the potential for completion does exist.

Also, while North Fork Eagle Creek is considered the primary location for successful reproduction of wild winter steelhead (USFWS 2007), the majority of the juvenile populations of both age 0 and age 1 wild winter steelhead were estimated to be rearing in Eagle Creek above the confluence with the North Fork. If my data are representative of the distributions and populations that have reared in the Eagle Creek basin in the past it may suggest that juvenile fish rearing in Eagle Creek experience a lower survival rate than that of juvenile fish rearing in North Fork Eagle Creek. Matala et al. (2008) found that samples collected from naturally produced juvenile winter steelhead in upper Eagle Creek are most similar to samples collected from Eagle Creek National Fish Hatchery. Therefore, the lack of adult steelhead production in mainstem Eagle Creek may be a product of poor survival by the progeny of hatchery fish who spawn in the wild as compared to the progeny of their wild counter parts (Araki et al. 2007; Ford 2002; Lynch and O'Hely 2001).

In Chapter 3, I provided evidence that in a stream with high water clarity an in-water observer can influence fish behavior as it relates to movement, which ultimately can impact microhabitat use studies of juvenile coho salmon *O. kitsch* and winter steelhead. Fish exhibited a downstream movement during the time the observer was in the stream and a subsequent upstream movement after the observer had left the stream.

Also, an in-water observer has the potential to either increase or decrease the abundance of fish that are visible in a stream. While the in-water observer caused a significant effect in the majority of my sites, an effect was not documented in all my sites. This suggests there may have been some other environmental and behavioral factors affecting fish movements in addition to the in-water observer.

BIBLIOGRAPHY

Al-Chokhachy, R., and P. Budy. 2007. Summer microhabitat use of fluvial bull trout in Eastern Oregon streams. North American Journal of Fisheries Management 27:1068-1081.

Araki, H., W. R. Ardren, E. Olsen, B. Cooper, and M. S. Blouin. 2007. Reproductive success of captive-bred steelhead trout in the wild: Evaluation of three hatchery programs in the Hood River. Conservation Biology 21:181-190.

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113:1-32.

Baker, J., P. Bentzen, and P. Moran. 2002. Molecular markers distinguish coastal cutthroat trout from coastal rainbow trout/steelhead and their hybrids. Transactions of the American Fisheries Society 131:404-417.

Barton, B. A. 2002. Stress in fishes: a diversity of responses with particular reference to changes in circulating corticosteroids. Integrative Comparative Biology 42:517-525.

Berejikian, B. A. 1995. The effects of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry (*Oncorhynchus mykiss*) to avoid a benthic predator. Canadian Journal of Fisheries and Aquatic Sciences 52:2476-2482.

Bohlin, T., L. F. Sundstrom, J. I. Johnsson, J. Hojesjo, and J. Pettersson. 2002. Density-dependent growth in brown trout: effects of introducing wild and hatchery fish. Journal of Animal Ecology 71:683-692.

Brostrom, J. K. 2003. Characterize and quantify residual steelhead in the Clearwater River, Idaho, 2002 Annual Report. Bonneville Power Administration, Portland, Oregon.

Brown, L. R., and P. B. Moyle. 1991. Changes in habitat and microhabitat partitioning within an assemblage of stream fishes in response to predation by Sacramento squawfish (*Ptychocheilus grandis*). Canadian Journal of Fisheries and Aquatic Sciences 48:849-856.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer-Verlag, New York, New York.

Campbell, E. A. 1998. Influence of streamflow and predators on habitat choice by trout. Doctoral dissertation. University of California, Davis, California.

Cannamela, D. A. 1993. Hatchery steelhead smolt predation of wild and natural juvenile Chinook salmon fry in the Upper Salmon River, Idaho. Idaho Department of Fish and Game, Boise, Idaho.

Clements, S., C. B. Schreck, D. A. Larsen, and W. W. Dickhoff. 2002. Central administration of corticotropin-releasing hormone stimulates locomotor activity in juvenile Chinook salmon (*Oncorhynchus tshawytscha*). General and Comparative Endocrinology 125:319-327.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. United States Forest Service, Southeastern Forest

Experimental Station, General Technical Report SE-83, Asheville, North Carolina.

Dunn, O. J. 1964. Multiple comparisons using rank sums. Technometrics 6:241-252.

Engle, R., D. Olson, and J. Lovtang. 2006. Abundance and microhabitat selection of juvenile *Oncorhynchus mykiss* and juvenile Chinook salmon (*O. tshawytscha*) within Shitike Creek, Oregon at varying fish densities and presence or absence of bull trout (*Salvelinus confluentus*), Progress Report 2005. United State Fish and Wildlife Service Columbia River Fisheries Program Office, Vancouver, Washington.

Fletcher, D., D. MacKenzie, and E. Villouta. 2005. Modeling skewed data with many zeros: A simple approach combining ordinary and logistic regression. Environmental and Ecological Statistics 12:45-54.

Ford, M. J. 2002. Selection in captivity during supportive breeding may reduce fitness in the wild. Conservation Biology 16:815-825.

Gatz, A. J., M. J. Sale, and J. M. Loar. 1987. Habitat shifts in rainbow trout: competitive influences of brown trout. Oecologia 74:7-19.

George, C. J. W. 1960. Behavioral interactions of the pickerel (*Esox niger* and *Esox americanus*) and the mosquitofish (*Gambusia patruelis*). Doctoral dissertation. Harvard University, Cambridge, Massachusetts.

Glova, G. J. 1987. Comparison of allopatric cutthroat trout stocks with those sympatric with coho salmon and sculpins in small streams. Environmental Biology of Fishes 20:275-284.

Godin, J. J., and S. L. Crossman. 1994. Hunger-dependent predator inspection and foraging behaviours in the threespine stickleback (*Gasterosteus aculeatus*) under predation risk. Behavioral Ecology and Sociobiology 34:359-366.

Goede, R. W. 1986. Management considerations in stocking of diseased or carrier fish. Pages 349-355 *in* R. H. Stroud, editor. Fish culture in fisheries management. American Fisheries Society, Bethesda, Maryland.

Grant, J. W. A, and D. L. G. Noakes. 1987. Escape behaviour and use of cover by young year brook trout (*Salvelinus fontinalis*). Canadian Journal of Fisheries & Aquatic Sciences 45:1390 – 1396.

Gries, G., and F. Juanes. 1998. Microhabitat use by juvenile Atlantic salmon (*Salmo salar*) sheltering during the day in summer. Canadian Journal of Zoology 76:1441-1449.

Guay, J. C., D. Boisclair, D. Rioux, M. Leclerc, M. Lapointe, and P. Legendre. 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 57:2065-2075.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). 22:1035-1081.

Hayes, J. W. 1987. Competition for spawning space between brown (*Salmo trutta*) and rainbow trout (*S. gairdneri*) in a lake inlet tributary, New Zealand. Canadian Journal of Fisheries and Aquatic Sciences 44:40-47.

Healey, M. C., and U. Reinhardt. 1995. Predator avoidance in naive and experienced juvenile Chinook and coho salmon. Canadian Journal of Fisheries and Aquatic Sciences 52:614-622.

Healy, B. D., and D. G. Lonzarich. 2000. Microhabitat use and behavior of overwintering juvenile coho salmon in a Lake Superior tributary. Transactions of the American Fisheries Society 129:866-872.

Heggenes, J., Å. Brabrand, and S. Saltveit. 1990. Comparison of three methods for studies of stream habitat use by young brown trout and Atlantic salmon. Transactions of the American Fisheries Society 119:101-111.

Herger, L. G., W. A. Hubert, and M. K. Young. 1996. Comparison of habitat composition and cutthroat trout abundance at two flows in small mountain streams. North American Journal of Fisheries Management 16:294-301.

Hillman, T. W., and J. W. Mullan. 1989. Effect of hatchery releases on the abundance and behavior of wild juvenile salmonids. Pages 266-281 *in* Summer and winter ecology of juvenile Chinook salmon and steelhead trout in the Wenatchee River, Washington. Don Chapman Inc., Boise, Idaho.

Hosmer, D. W., and S. Lemeshow. 2000. Applied logistic regression, 2nd edition. Wiley Interscience, New York, New York.

Jacobs, S. E. 1981. Stream utilization and behavior of sympatric and allopatric wild cutthroat trout (*Salmo clarki*) and hatchery coho salmon (*Oncorhynchus kisutch*). Master's thesis. Oregon State University, Corvallis, Oregon.

Jonasson, B. C., R. W. Carmichael, and T. A. Whitesel. 1996. Residual hatchery steelhead characteristics and potential interactions with spring Chinook salmon in northeast Oregon, 1996 Progress Report. Oregon Department of Fish and Wildlife, Salem, Oregon.

Kavanagh, M., D. Olson, B. Brignon, T. Hoffman, D. Dysart, and S. Turner. 2006. Eagle Creek Ecological Interactions: distribution and migration of hatchery and wild steelhead and coho, 2005 Progress Report. United States Fish and Wildlife Service, Vancouver, Washington.

Kennedy, G. J. A., and C. D. Strange. 1986. The effects of intra-and inter-specific competition on the distribution of stocked juvenile Atlantic salmon, *Salmo salar* L., in relation to depth and gradient in an upland trout, *Salmo trutta* L., stream. Journal of Fish Biology 29:199-214.

Kostow, K. E., and S. Zhou. 2006. The effect of an introduced summer steelhead hatchery stock on the productivity of a wild winter steelhead population. Transactions of the American Fisheries Society 135:825-841.

Levin, P. S., R. W. Zabel, and J. G. Williams. 2001. The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon. Proceedings of the Royal Society B: Biological Sciences 268:1153-1158.

Li, H. W., and R. W. Brocksen. 1977. Approaches to the analysis of energetic costs of intraspecific competition for space by rainbow trout (*Salmo gairdneri*). Journal of Fish Biology 11:329-341.

Lindsey, J. K. 1997. Applying Generalized Linear Models. Springer, New York, New York.

Lohr, S. C., and J. L. West. 1992. Microhabitat selection by brook and rainbow trout in a southern Appalachian stream. Transactions of the American Fisheries Society 121:729-736.

Lynch, M., and M. O'Hely. 2001. Captive breeding and the genetic fitness of natural populations. Conservation Genetics 2:363-378.

Magurran, A. E. 1986. Predator inspection behaviour in minnow shoals: differences between populations and individuals. Behavioral Ecology and Sociobiology 19:267-273.

Maki-Petays, A., A. Huusko, J. Erkinaro, and T. Muotka. 2002. Transferability of habitat suitability criteria of juvenile Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 59:218-228.

Matala, A., W. Ardren, D. Olson, M. Kavanagh, B. Brignon and J. Hogle. 2008. Evaluating Natural Productivity and Genetic Interaction between a Segregated Hatchery Stock and a Wild Population of Steelhead Trout (*Oncorhynchus mykiss*) In Eagle Creek, Oregon. 2007 Final Report. United States Fish and Wildlife Service, Vancouver, Washington.

McMichael, G. A., and T. N. Pearsons. 2001. Upstream movement of residual hatchery steelhead into areas containing bull trout and cutthroat trout. North American Journal of Fisheries Management 21:943-946.

McMichael, G. A., T. N. Pearsons, and S. A. Leider. 1999. Behavioral interactions among hatchery-reared steelhead smolts and wild *Oncorhynchus mykiss* in natural streams. North American Journal of Fisheries Management 19:948-956.

McMichael, G. A., T. N. Pearsons, and S. A. Leider. 2000. Minimizing ecological impacts of hatchery-reared juvenile steelhead trout on wild salmonids in a Yakima Basin watershed. Pages 365–380 *in* E. E. Knudsen, C. R. Steward, D. D. MacDonald, J. E. Willams and D. W. Reiser, editors. Sustainable Fisheries Management: Pacific Salmon. Lewis Publishers, New York, New York.

McMichael, G. A., C. S. Sharpe, and T. N. Pearsons. 1997. Effects of residual hatchery-reared steelhead on growth of wild rainbow trout and spring Chinook salmon. Transactions of the American Fisheries Society 126:230-239.

Meffe, G. K. 1992. Techno-arrogance and halfway technologies: Salmon hatcheries on the Pacific Coast of North America. Conservation Biology 6:350-354.

Moyle, P. B., and D. M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow determinations. Transactions of the American Fisheries Society 114:695-704.

Nickelson, T. E., M. F. Solazzi, S. L. Johnson. 1986. Use of hatchery coho salmon presmolts to rebuild wild populations in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 43:2443-2449.

Olson, D. E., B. Spateholts, M. Paiya, and D. E. Campton. 2004. Salmon hatcheries for the 21 st century: A model at Warm Springs National Fish Hatchery. American Fisheries Society Symposium 44:581-598.

Peterson, J., J. Dunham, P. Howell, R. Thurow, and S. Bonar. 2002. Protocol for determining bull trout presence. Bull Trout Committee, Western Division, American Fisheries Society, Bethesda, Maryland.

Peterson, J. T., N. P. Banish, and R. F. Thurow. 2005. Are block nets necessary?: Movement of stream-dwelling salmonids in response to three common survey methods. North American Journal of Fisheries Management 25:732-743.

Price, C. S., and C. B. Schreck. 2003. Stress and saltwater-entry behavior of juvenile Chinook salmon (*Oncorhynchus tshawytscha*): conflicts in physiological motivation. Canadian Journal of Fisheries and Aquatic Sciences 60:910-918.

Ratliff, D. E. 1981. *Ceratomyxa shasta*: Epizootiology in Chinook salmon of Central Oregon. Transactions of the American Fisheries Society 110:507-513.

Rhodes, J. S., and T. P. Quinn. 1998. Factors affecting the outcome of territorial contests between hatchery and naturally reared coho salmon parr in the laboratory. Journal of Fish Biology 53:1220-1230.

Rosenfeld, J., M. Porter, and E. Parkinson. 2000. Habitat factors affecting the abundance and distribution of juvenile cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 57:766-774.

Routledge, R. D. 1982. The method of bounded counts: when does it work? The Journal of Wildlife Management 46:757-761.

Schill, D. J., and J. S. Griffith. 1984. Use of underwater observations to estimate cutthroat trout abundance in the Yellowstone River. North American Journal of Fisheries Management 4:479-487.

Thurow, R. F. 1994. Underwater methods for study of salmonids in the Intermountain West. United States Forest Service, Intermountain Research Station, General Technical Report INT-GTR-307, Ogden, Utah.

Turgeon, K., and M. A. Rodriguez. 2005. Predicting microhabitat selection in juvenile Atlantic salmon *Salmo salar* by the use of logistic regression and classification trees. Freshwater Biology 50:539-551.

United States Fish and Wildlife Service, Hatchery Review Team. 2007. Eagle Creek National Fish Hatchery assessments and recommendations, Final Report.

Vincent, E. R. 1987. Effects of stocking catchable-size hatchery rainbow trout on two wild trout species in the Madison River and O'Dell Creek, Montana. North American Journal of Fisheries Management 7:91-105.

Viola, A. E., and M. L. Schuck. 1995. A method to reduce the abundance of residual hatchery steelhead in rivers. North American Journal of Fisheries Management 15:488-493.

Watson, G., and T. W. Hillman. 1997. Factors affecting the distribution and abundance of bull trout: an investigation at hierarchical scales. North American Journal of Fisheries Management 17:237-252.

Weigel, D. E., J. T. Peterson, and P. Spruell. 2002. A model using phenotypic characteristics to detect introgressive hybridization in wild westslope cutthroat trout and rainbow trout. Transactions of the American Fisheries Society 131:389-403.

Zar, J. H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall, Englewood Cliffs, New Jersey.

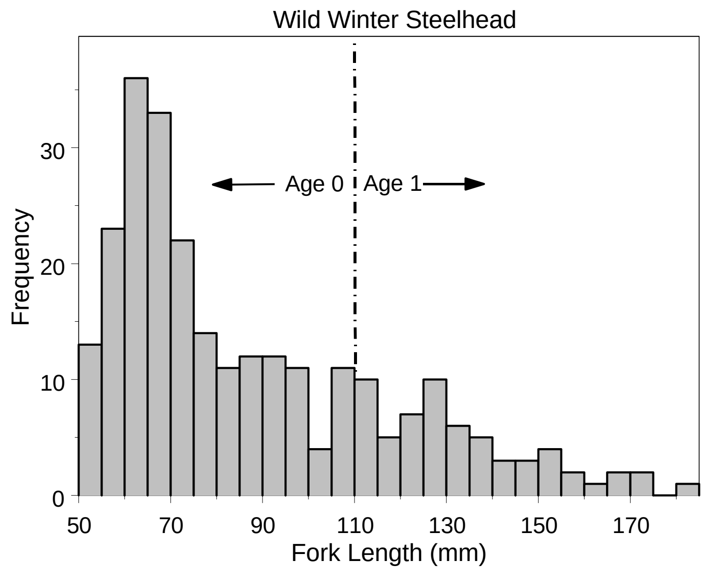
Zippin, C. 1958. The removal method of population estimation. Journal of Wildlife Management 22:82-90.

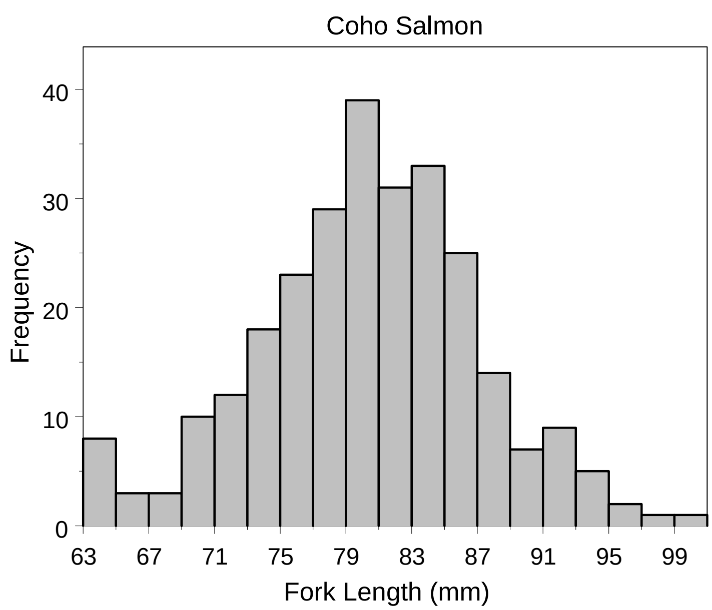
APPENDICIES

Appendix A. Sample frame of available habitat units, number of habitat units selected for first phase snorkel surveys and number of habitat units selected for second phase calibration estimates.

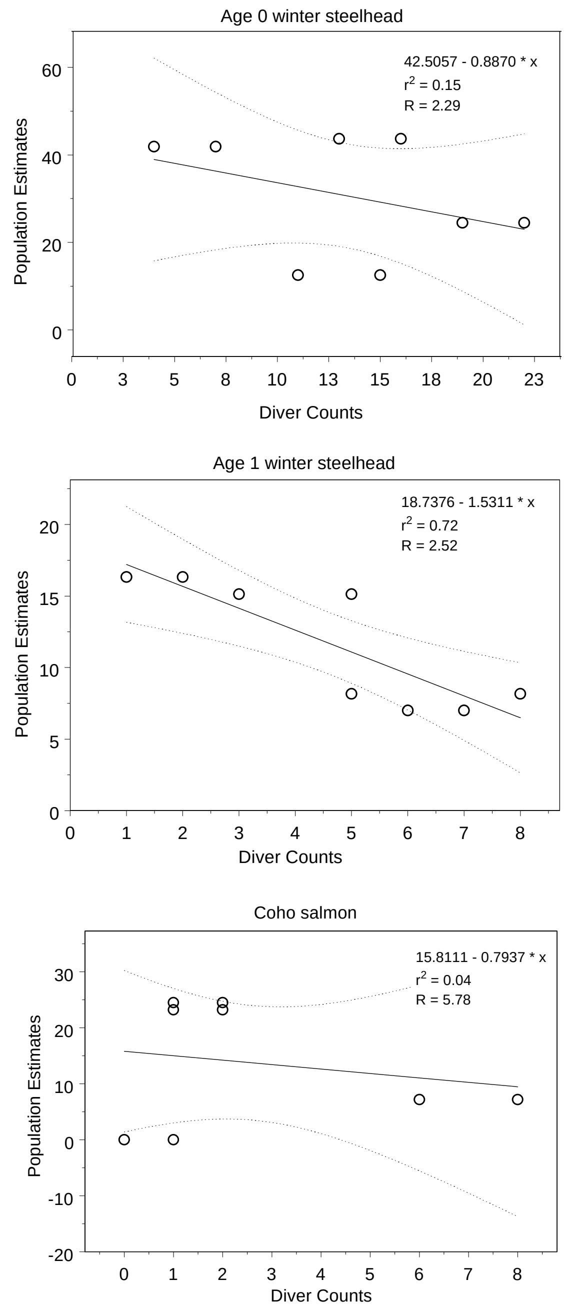
Stream	Riffles[a]	Pools[b]	Glides[c]	Total
Lower Eagle Creek				
Total Number of Units	81	31	53	165
Phase 1 Snorkel Survey	8	8	11	27
Phase 2 Calibration Estimates	1	0	0	1
Upper Eagle Creek				
Total Number of Units	106	64	49	219
Phase 1 Snorkel Survey	10	16	10	36
Phase 2 Calibration Estimates	1	2[d]	2	5
North Fork Eagle Creek				
Total Number of Units	212	121	118	451
Phase 1 Snorkel Survey	21	30	24	75
Phase 2 Calibration Estimates	2	3	2	7

[a] Riffles were sampled at a rate of 1/10
[b] Pools were sampled at a rate of 1/4
[c] Glides were sampled at a rate of 1/5
[d] Second phase calibration estimates were conducted using multiple pass electrofishing with the exception of one pool on Eagle Creek in which a mark-recapture was conducted.

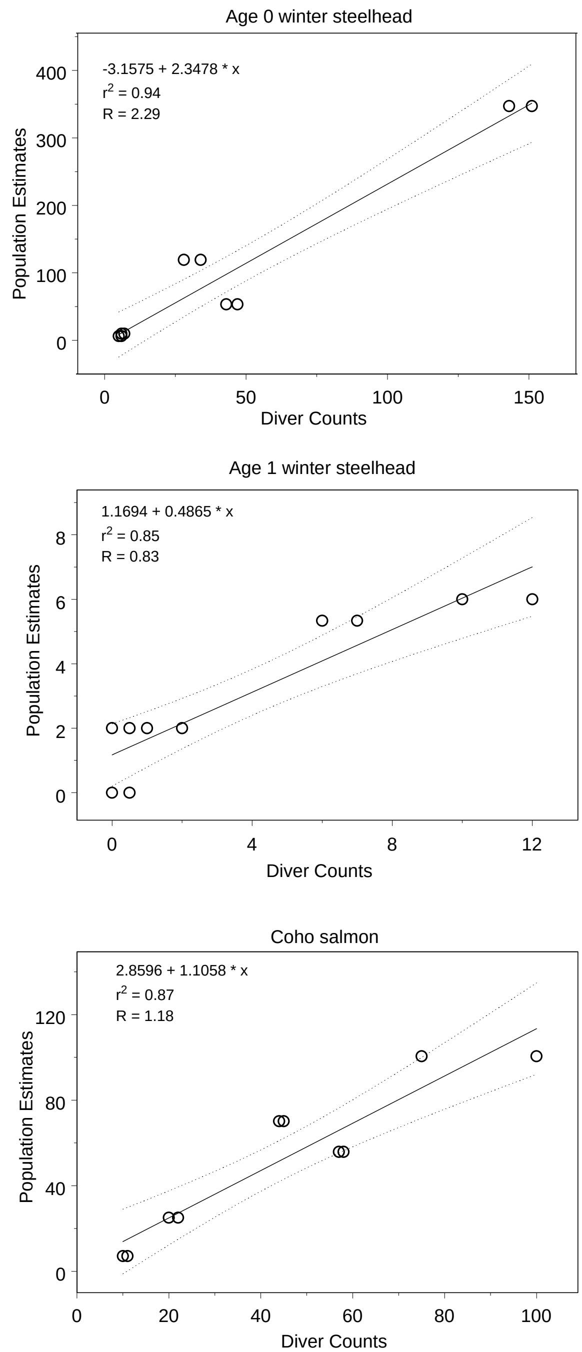




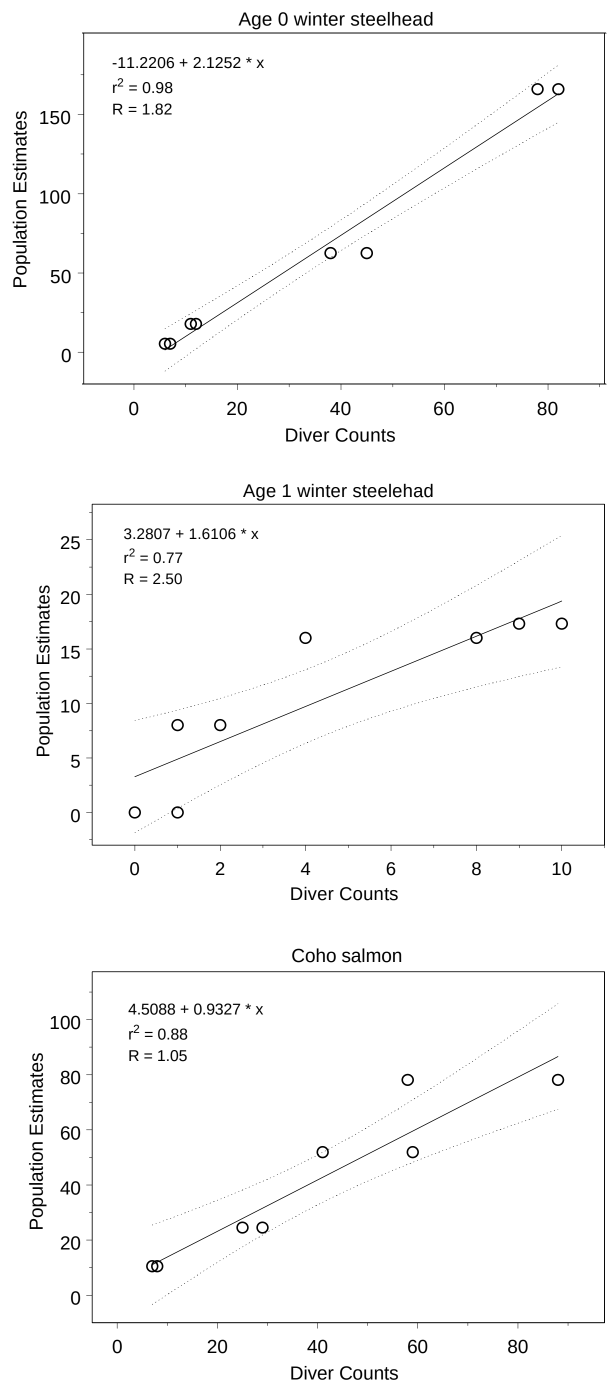
Appendix B. Length-frequency distribution of wild winter steelhead and coho salmon captured from Eagle Creek and North Fork Eagle Creek determined from samples collected by electrofishing. Age 0 and age 1 winter steelhead are separated by a fork length of 110mm which was verified as a reasonable point for demarcation by scale analysis.



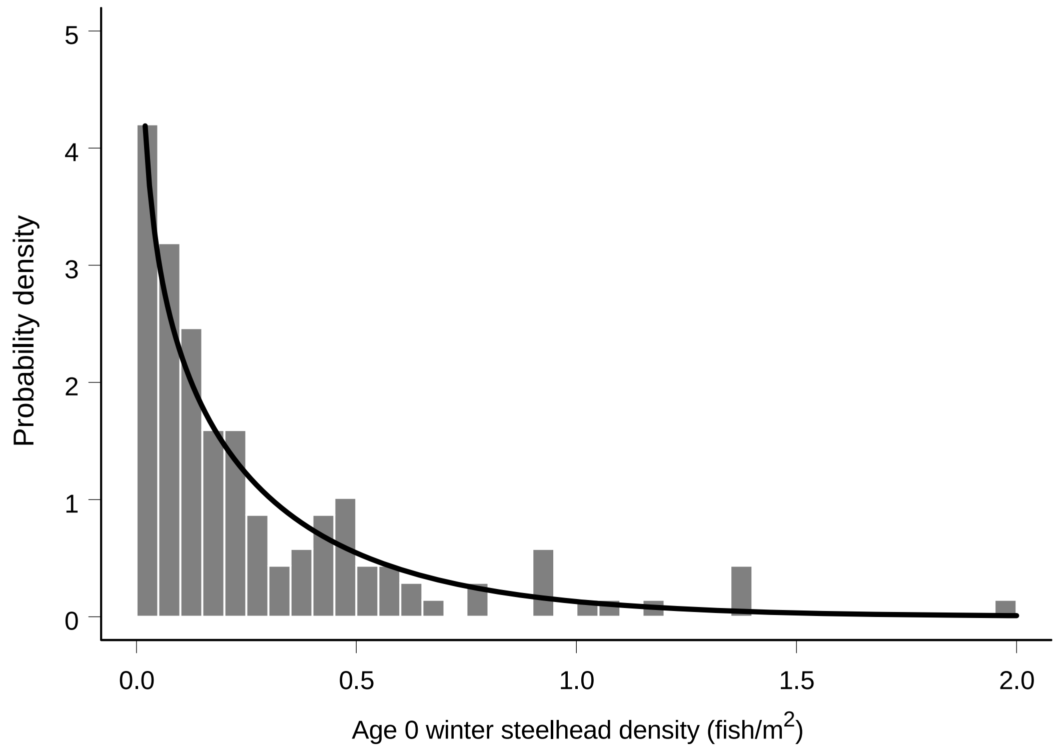
Appendix C. Single pass snorkel counts and “true” population estimates for winter steelhead and coho salmon in riffle habitats. The solid line is the estimated regression of the “true” fish population explained by single pass diver counts. The dotted lines represent the 95% confidence bounds for the estimated mean. The equation for the regression line, correlation coefficient (r^2), and calibration ratio (R) are given for each species.



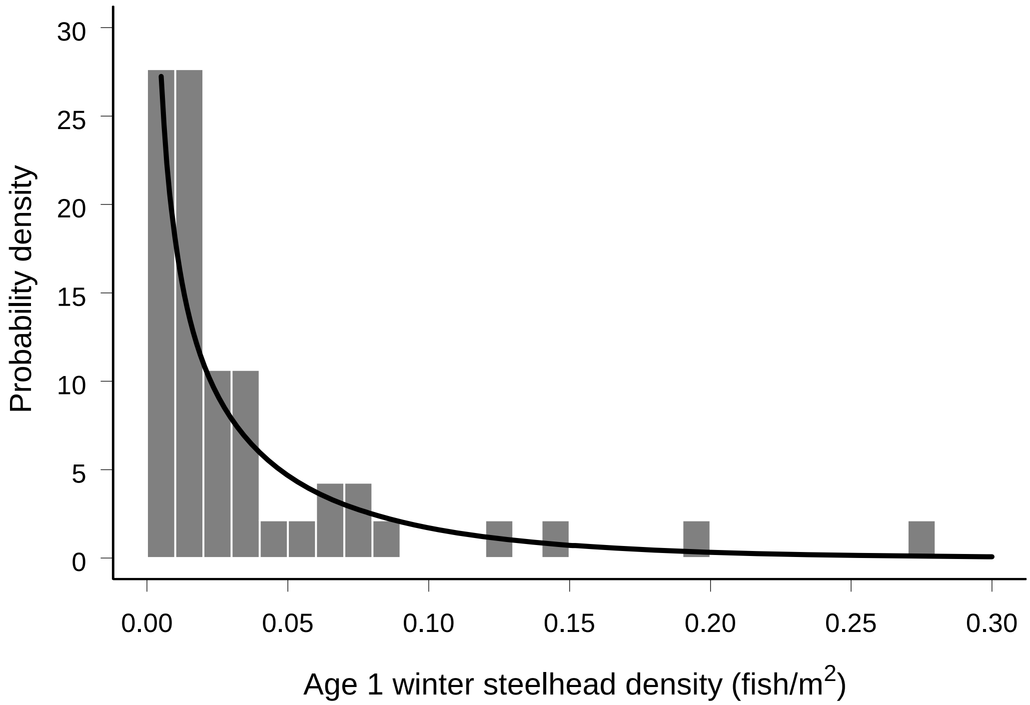
Appendix D. Single pass snorkel counts and "true" population estimates for winter steelhead and coho salmon in pool habitats. The solid line is the estimated regression of the "true" fish population explained by single pass diver counts. The dotted lines represent the 95% confidence bounds for the estimated mean. The equation for the regression line, correlation coefficient (r^2), and calibration ratio (R) are given for each species. To allow for visualization of all data some points are jittered along the x-axis.



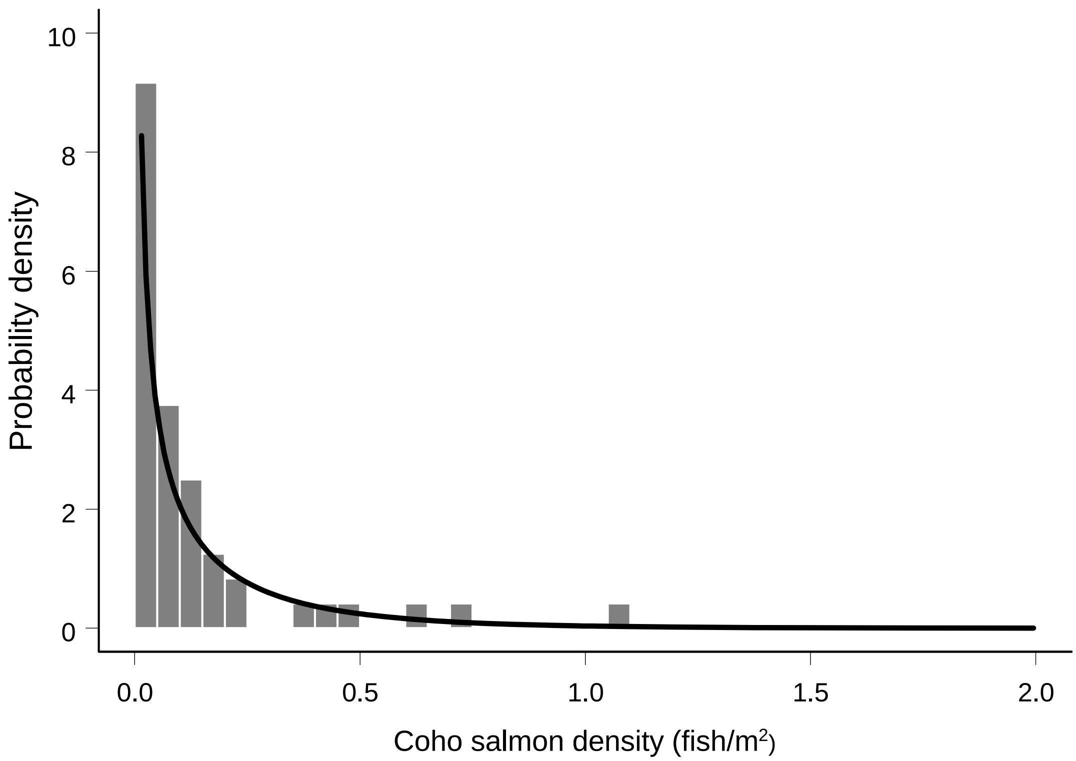
Appendix E. Single pass snorkel counts and "true" population estimates for winter steelhead and coho salmon in glide habitats. The solid line is the estimated regression of the "true" fish population explained by single pass diver counts. The dotted lines represent the 95% confidence bounds for the estimated mean. The equation for the regression line, correlation coefficient (r^2), and calibration ratio (R) are given for each species. To allow for visualization of all data some points are jittered along the x-axis.



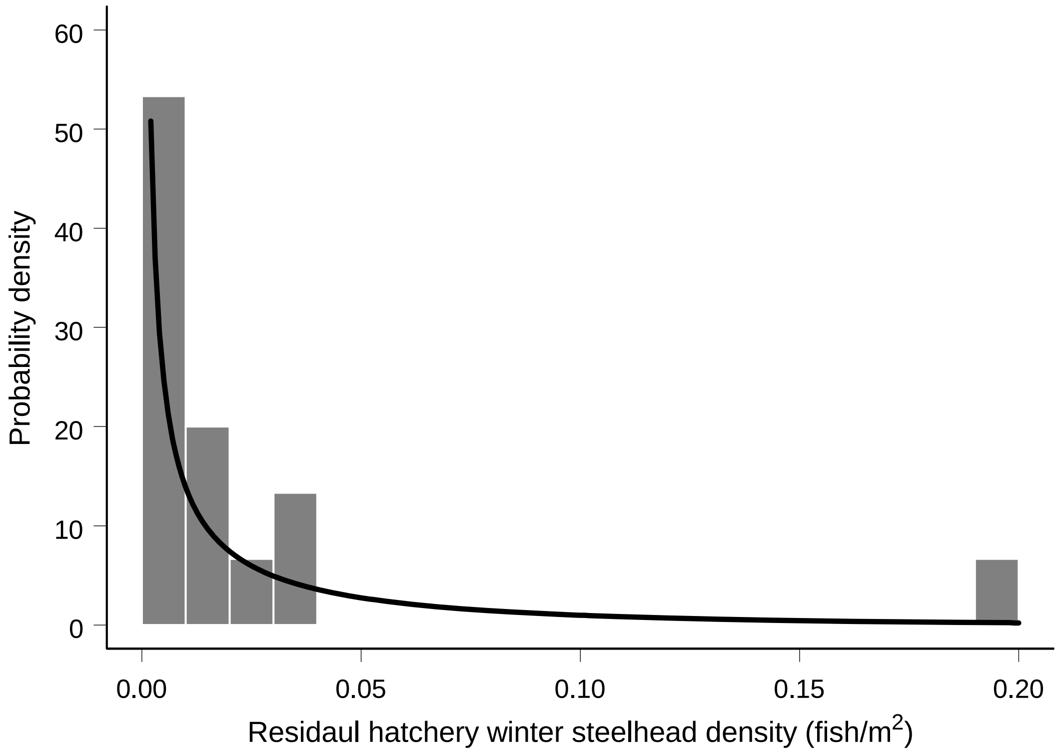
Appendix F. Probability density histogram of estimated age 0 winter steelhead density in Eagle Creek. The black line represents the fitted gamma distribution with scale and shape parameters equal to 0.5777 and 0.5890, respectively.



Appendix G. Probability density histogram of estimated age 1 winter steelhead density in Eagle Creek. The black line represents the fitted gamma distribution with scale and shape parameters equal to 0.0487 and 0.4888, respectively.



Appendix H. Probability density histogram of estimated coho salmon density in Eagle Creek. The black line represents the fitted gamma distribution with scale and shape parameters equal to 0.3369 and 0.4007, respectively.



Appendix I. Probability density histogram of estimated residual hatchery winter steelhead density in Eagle Creek. The black line represents the fitted gamma distribution with scale and shape parameters equal to 0.0989 and 0.2433, respectively.

Appendix J. Percentage of estimated residual hatchery winter steelhead abundance that comprise wild fish populations in Eagle Creek.

Habitat Type	All Winter Steelhead	Age 0 Winter Steelhead	Age 1 Winter steelhead	Coho Salmon
Riffles	1.9	2.1	24.2	9.6
Pools	1.1	1.1	28.7	3.3
Glides	0.6	0.7	4.4	1.1
All	1.0	1.1	9.3	2.2

Appendix K. Logistic regression model selection results used to describe a species presence and absence in Eagle Creek. Age 0 winter steelhead are not included in this table because they were present in 61 of the 63 habitat units sampled and therefore lacked the appropriate contrast to accurately model the probability of occurrence for this species. Competing models are ranked by Akaike's information criterion weights (w_i) which are calculated using the number of estimated parameters (K), log likelihood ($\log_e L$), Akaike's information criterion (AIC) corrected for small sample size (AIC_c) and the differences in AIC_c (Δ_i). Adjusted r^2 values are reported.

Rank	Model [a]	K	$\log_e L$	AIC	AIC_c	Δ_i	w_i	r^2
Age 1 Winter Steelhead								
1	Age0.den,Coho.den	3	-29.11	64.23	64.63	0.09	0.22	0.18
2	Coho.den	2	-30.17	64.34	64.54	0.00	0.23	0.15
3	Dist.EC, Coho.den	3	-29.70	65.40	65.80	1.26	0.12	0.17
4	Age0.den,Coho.den, HABTYPE	5	-27.73	65.46	66.51	1.97	0.09	0.22
5	Dist.EC, Age0.den,Coho.den	4	-29.11	66.22	66.91	2.37	0.07	0.18
6	Coho.den, HABTYPE	4	-29.27	66.53	67.22	2.68	0.06	0.18
7	Dist.EC	2	-31.60	67.20	67.40	2.87	0.06	0.11
8	Dist.EC, Coho.den, HABTYPE	5	-28.50	67.00	68.05	3.51	0.04	0.20
9	Dist.EC, Age0.den,Coho.den, HABTYPE	6	-27.72	67.44	68.94	4.41	0.03	0.22
10	Age0.den, HABTYPE	4	-29.96	67.92	68.61	4.07	0.03	0.16
11	Age0.den	2	-32.28	68.56	68.76	4.22	0.03	0.10
12	Dist.EC, Age0.den, HABTYPE	5	-29.87	69.74	70.79	6.25	0.01	0.16
13	Dist.EC, Age0.den	3	-32.26	70.52	70.92	6.39	0.01	0.10
14	Dist.EC, HABTYPE	4	-31.61	71.22	71.91	7.37	0.01	0.11
15	Intercept Only	1	-35.69	73.38	73.45	8.91	0.00	0.00
16	HABTYPE	3	-34.12	74.24	74.64	10.11	0.00	0.04
17	R-HWST.den	2	The validity of the model fit is questionable [b]					
18	Coho.den, R-HWST.den	3	The validity of the model fit is questionable [b]					
19	Age0.den, R-HWST.den	3	The validity of the model fit is questionable [b]					
20	Dist.EC, R-HWST.den	3	The validity of the model fit is questionable [b]					

Appendix K. Continued…

Rank	Model [a]	K	$\log_e L$	AIC	AIC_c	Δ_i	w_i	r^2
21	Dist.EC, Coho.den, R-HWST.den	4	The validity of the model fit is questionable [b]					
22	Age0.den,Coho.den, R-HWST.den	4	The validity of the model fit is questionable [b]					
23	Dist.EC, Age0.den, R-HWST.den	4	The validity of the model fit is questionable [b]					
24	Coho.den, R-HWST.den, HABTYPE	5	The validity of the model fit is questionable [b]					
25	Age0.den, R-HWST.den, HABTYPE	5	The validity of the model fit is questionable [b]					
26	Dist.EC, R-HWST.den, HABTYPE	5	The validity of the model fit is questionable [b]					
27	Age0.den, Age1.den, Coho.den, R-HWST.den	6	The validity of the model fit is questionable [b]					
28	Dist.EC, Age0.den,Coho.den, R-HWST.den	5	The validity of the model fit is questionable [b]					
29	Dist.EC, Coho.den, R-HWST.den, HABTYPE	6	The validity of the model fit is questionable [b]					
30	Dist.EC, Age0.den, R-HWST.den, HABTYPE	6	The validity of the model fit is questionable [b]					
31	Dist.EC, Age0.den,Coho.den, R-HWST.den, HABTYPE	7	The validity of the model fit is questionable [b]					
32	R-HWST.den, HABTYPE	4	The validity of the model fit is questionable [b]					
Coho Salmon								
1	Age1.den	2	-29.64	63.28	63.48	0.00	0.27	0.14
2	Dist.EC, Age1.den	3	-29.31	64.62	65.03	1.55	0.12	0.15
3	Age0.den, Age1.den	3	-29.41	64.81	65.22	1.74	0.11	0.15
4	Age1.den, R-HWST.den	3	-29.63	65.25	65.66	2.18	0.09	0.14
5	Age1.den, HABTYPE	4	-28.82	65.64	66.33	2.85	0.06	0.17
6	Dist.EC, Age1.den, HABTYPE	5	-28.07	66.15	67.20	3.73	0.04	0.19
7	Dist.EC, Age0.den, Age1.den	4	-29.28	66.56	67.24	3.77	0.04	0.15
8	Dist.EC, Age1.den, R-HWST.den	4	-29.31	66.62	67.31	3.83	0.04	0.15
9	Age0.den, Age1.den, R-HWST.den	4	-29.41	66.81	67.50	4.03	0.04	0.15
10	Age0.den, Age1.den, HABTYPE	5	-28.30	66.60	67.65	4.18	0.03	0.18
11	Age1.den, R-HWST.den, HABTYPE	5	-28.73	67.46	68.52	5.04	0.02	0.17
12	Dist.EC, Age0.den, Age1.den, HABTYPE	6	-27.98	67.96	69.46	5.98	0.01	0.19

Appendix K. Continued…

Rank	Model [a]	K	$\log_e L$	AIC	AIC_c	Δ_i	w_i	r^2
13	Dist.EC, Age0.den, Age1.den, R-HWST.den	5	-29.28	68.55	69.60	6.13	0.01	0.15
14	Dist.EC, Age1.den, R-HWST.den, HABTYPE	6	-28.07	68.14	69.64	6.17	0.01	0.19
15	Age0.den, HABTYPE	4	-30.49	68.99	69.67	6.20	0.01	0.12
16	Dist.EC, HABTYPE	4	-30.59	69.17	69.86	6.38	0.01	0.12
17	Age0.den, Age1.den, R-HWST.den, HABTYPE	6	-28.28	68.56	70.06	6.59	0.01	0.18
18	R-HWST.den, HABTYPE	4	-30.93	69.85	70.54	7.07	0.01	0.18
19	R-HWST.den	2	-33.30	70.60	70.80	7.33	0.01	0.11
20	Age0.den	2	-33.30	70.61	70.81	7.33	0.01	0.04
21	Dist.EC, Age0.den, HABTYPE	5	-30.02	70.03	71.08	7.61	0.01	0.04
22	Age0.den, R-HWST.den, HABTYPE	5	-30.02	70.03	71.08	7.61	0.01	0.13
23	Dist.EC, R-HWST.den, HABTYPE	5	-30.04	70.07	71.12	7.65	0.01	0.13
24	Intercept Only	1	-34.58	71.16	71.22	7.75	0.01	0.13
25	Dist.EC	2	-33.65	71.29	71.49	8.02	0.00	0.00
26	HABTYPE	3	-32.60	71.20	71.61	8.13	0.00	0.03
27	Dist.EC, Age0.den, Age1.den, R-HWST.den, HABTYPE	7	-27.98	69.95	71.99	8.51	0.00	0.06
28	Age0.den, R-HWST.den	3	-32.82	71.63	72.04	8.56	0.00	0.19
29	Dist.EC, R-HWST.den	3	-33.02	72.04	72.45	8.97	0.00	0.05
30	Dist.EC, Age0.den	3	-33.18	72.36	72.76	9.29	0.00	0.05
31	Dist.EC, Age0.den, R-HWST.den, HABTYPE	6	-29.72	71.44	72.94	9.46	0.00	0.04
32	Dist.EC, Age0.den, R-HWST.den	4	-32.77	73.54	74.23	10.76	0.00	0.14
Residual Hatchery Winter Steelhead								
1	Dist.EC, Age1.den, Coho.den	4	-17.24	42.48	43.17	0.00	0.26	0.50
2	Dist.EC, Age0.den, Age1.den	4	-17.41	42.83	43.52	0.35	0.22	0.50
3	Dist.EC, Age1.den	3	-18.94	43.88	44.29	1.12	0.15	0.45
4	Dist.EC, Age0.den, Age1.den, Coho.den	5	-16.70	43.41	44.46	1.29	0.14	0.52

Appendix K. Continued…

Rank	Model [a]	K	$\log_e L$	AIC	AIC_c	Δ_i	w_i	r^2
5	Dist.EC, Age0.den, Age1.den, HABTYPE	6	-16.38	44.75	46.25	3.09	0.06	0.53
6	Dist.EC, Age1.den, Coho.den, HABTYPE	6	-16.43	44.86	46.36	3.20	0.05	0.52
7	Dist.EC, Age1.den, HABTYPE	5	-17.79	45.57	46.62	3.46	0.05	0.49
8	Dist.EC, Age0.den, Age1.den, Coho.den, HABTYPE	7	-15.86	45.71	47.75	4.58	0.03	0.54
9	Age0.den, Age1.den	3	-21.01	48.03	48.43	5.27	0.02	0.39
10	Dist.EC, Coho.den	3	-21.66	49.31	49.72	6.55	0.01	0.37
11	Age0.den, Age1.den, Coho.den	4	-20.53	49.06	49.74	6.58	0.01	0.41
12	Dist.EC, Age0.den, Coho.den	4	-21.19	50.37	51.06	7.90	0.01	0.39
13	Age0.den, Age1.den, HABTYPE	5	-20.41	50.83	51.88	8.71	0.00	0.41
14	Dist.EC	2	-23.99	51.99	52.19	9.02	0.00	0.31
15	Dist.EC, Coho.den, HABTYPE	5	-20.73	51.47	52.52	9.36	0.00	0.40
16	Dist.EC, Age0.den, HABTYPE	5	-20.76	51.52	52.58	9.41	0.00	0.40
17	Dist.EC, Age0.den, Coho.den, HABTYPE	6	-19.99	51.98	53.48	10.32	0.00	0.42
18	Age0.den, Age1.den, Coho.den, HABTYPE	6	-19.99	51.98	53.48	10.32	0.00	0.42
19	Dist.EC, HABTYPE	4	-22.58	53.15	53.84	10.67	0.00	0.42
20	Age0.den	2	-25.43	54.85	55.05	11.89	0.00	0.35
21	Age0.den, Coho.den	3	-24.56	55.12	55.52	12.36	0.00	0.26
22	Age0.den, HABTYPE	4	-24.88	57.76	58.45	15.29	0.00	0.29
23	Age1.den, Coho.den	3	-26.29	58.58	58.98	15.82	0.00	0.28
24	Age0.den, Coho.den, HABTYPE	5	-24.25	58.51	59.56	16.39	0.00	0.24
25	Age1.den, Coho.den, HABTYPE	5	-25.22	60.45	61.50	18.33	0.00	0.30
26	Age1.den	2	-29.52	63.04	63.24	20.08	0.00	0.27
27	Coho.den	2	-30.04	64.08	64.28	21.12	0.00	0.15
28	Age1.den, HABTYPE	4	-27.97	63.93	64.62	21.46	0.00	0.13
29	HABTYPE, Coho.den	4	-29.84	67.67	68.36	25.20	0.00	0.19

Appendix K. Continued…

Rank	Model [a]	K	$\log_e L$	AIC	AIC_c	Δ_i	w_i	r^2
30	Intercept Only	1	-34.58	71.16	71.22	28.06	0.00	0.14
31	HABTYPE	3	-33.74	73.47	73.88	30.71	0.00	0.00
32	Dist.EC, Age0.den	3	-34.58	75.16	75.56	32.40	0.00	0.02

[a] Variable definitions: Dist.EC = distance from the mouth of Eagle Creek (m), HABTYPE = mesohabitat type (riffles, pools, glides), Age0.den = age 0 winter steelhead density (fish/m^2), Age1.den = age 1 winter steelhead density (fish/m^2), Coho.den = coho salmon density (fish/m^2), R-HWST.den = residual hatchery winter steelhead density (fish/m^2).

[b] Due to the lack of contrast between presence of residual hatchery winter steelhead and age 1 winter steelhead it was not possible to properly model the probability of occurrence of age 1 winter steelhead.

Appendix L. Generalized linear model selection results used to describe the density (fish/m^2) of a species given that the species is present in Eagle Creek. Competing models are ranked by Akaike's information criterion weights (w_i) which are calculated using the number of estimated parameters (K), Akaike's information criterion (AIC) corrected for small sample size (AIC_c) and the differences in AIC_c (Δ_i). Adjusted r^2 values are reported.

Rank	Model [a]	K	AIC	AIC_c	Δ_i	w_i	r^2
Age 0 Winter Steelhead							
1	Dist.EC, COS.den, HABTYPE	5	82.01	83.06	0.00	0.27	0.46
2	Dist.EC, COS.den	3	83.71	84.11	1.05	0.16	0.42
3	Dist.EC, COS.den, OM1.den, HABTYPE	6	83.36	84.86	1.79	0.11	0.46
4	Dist.EC, HABTYPE	4	84.59	85.28	2.22	0.09	0.43
5	Dist.EC, COS.den, RWST.den, HABTYPE	6	84.00	85.50	2.44	0.08	0.46
6	Dist.EC, COS.den, OM1.den	4	84.94	85.63	2.57	0.07	0.42
7	Dist.EC, OM1.den, HABTYPE	5	84.92	85.97	2.91	0.06	0.44
8	Dist.EC, COS.den, RWST.den	4	85.70	86.39	3.33	0.05	0.42
9	Dist.EC, COS.den, OM1.den, RWST.den, HABTYPE	7	85.34	87.37	4.31	0.03	0.46
10	Dist.EC, RWST.den, HABTYPE	5	86.55	87.60	4.54	0.03	0.43
11	Dist.EC, COS.den, OM1.den, RWST.den	5	86.91	87.97	4.90	0.02	0.42
12	Dist.EC, OM1.den, RWST.den, HABTYPE	6	86.87	88.37	5.31	0.02	0.44
13	Dist.EC, OM1.den	3	89.85	90.26	7.20	0.01	0.37
14	Dist.EC	2	90.49	90.69	7.63	0.01	0.35
15	Dist.EC, OM1.den, RWST.den	4	91.76	92.45	9.39	0.00	0.37
16	Dist.EC, RWST.den	3	92.41	92.82	9.76	0.00	0.35
17	COS.den, RWST.den	3	118.15	118.56	35.50	0.00	0.16
18	COS.den	2	118.82	119.02	35.95	0.00	0.14
19	COS.den, OM1.den	3	118.95	119.35	36.29	0.00	0.15
20	COS.den, RWST.den, HABTYPE	5	118.90	119.95	36.89	0.00	0.18
21	COS.den, HABTYPE	4	119.43	120.12	37.06	0.00	0.16

Appendix L. Continued…

Rank	Model [a]	K	AIC	AIC_c	Δ_i	w_i	r^2
22	COS.den, OM1.den, RWST.den	4	119.50	120.19	37.12	0.00	0.16
23	COS.den, OM1.den, HABTYPE	5	119.28	120.34	37.27	0.00	0.18
24	HABTYPE, COS.den, OM1.den, RWST.den	6	119.96	121.46	38.40	0.00	0.19
25	OM1.den	2	129.47	129.67	46.61	0.00	0.06
26	OM1.den, HABTYPE	4	128.98	129.67	46.61	0.00	0.09
27	OM1.den, RWST.den, HABTYPE	5	129.47	130.52	47.46	0.00	0.10
28	OM1.den, RWST.den	3	130.15	130.56	47.50	0.00	0.07
29	RWST.den, HABTYPE	4	130.55	131.24	48.17	0.00	0.08
30	RWST.den	2	131.28	131.48	48.41	0.00	0.04
31	HABTYPE	3	133.83	134.24	51.18	0.00	0.04
32	Intercept Only	1	135.23	135.30	52.24	0.00	0.00
Age 1 Winter Steelhead							
1	OM0.den, RWST.den, HABTYPE	5	65.96	67.42	0.00	0.25	0.28
2	OM0.den, HABTYPE	4	66.91	67.86	0.44	0.20	0.24
3	OM0.den, COS.den, RWST.den, HABTYPE	6	67.69	69.79	2.37	0.08	0.28
4	Dist.EC, OM0.den, RWST.den, HABTYPE	6	67.90	70.00	2.58	0.07	0.28
5	COS.den, OM0.den, HABTYPE	5	68.57	70.03	2.61	0.07	0.24
6	Dist*OM0.den, Dist.EC, OM0.den, HABTYPE	6	67.98	70.08	2.66	0.07	0.27
7	Dist.EC, OM0.den, HABTYPE	5	68.66	70.12	2.70	0.06	0.24
8	Dist*OM0.den, Dist.EC, OM0.den, RWST.den, HABTYPE	7	67.95	70.83	3.41	0.05	0.30
9	COS.den, RWST.den, HABTYPE	5	70.83	72.30	4.88	0.02	0.21
10	Dist.EC, COS.den, OM0.den, HABTYPE	6	70.33	72.43	5.01	0.02	0.24
11	Dist.EC, COS.den, OM0.den, RWST.den, HABTYPE	7	69.64	72.52	5.10	0.02	0.28
12	Dist*OM0.den, Dist.EC, COS.den, OM0.den, HABTYPE	7	69.84	72.71	5.29	0.02	0.28
13	HABTYPE, RWST.den	4	71.93	72.89	5.47	0.02	0.17

Appendix L. Continued…

Rank	Model [a]	K	AIC	AIC_c	Δ_i	w_i	r^2
14	Dist*OM0.den, Dist.EC, COS.den, OM0.den, RWST.den, HABTYPE	8	69.81	73.60	6.18	0.01	0.30
15	Dist.EC, RWST.den, HABTYPE	5	72.85	74.31	6.89	0.01	0.19
16	Dist.EC, COS.den, RWST.den, HABTYPE	6	72.22	74.32	6.90	0.01	0.22
17	RWST.den	2	74.38	74.66	7.24	0.01	0.09
18	Dist.EC, COS.den, HABTYPE	5	73.85	75.31	7.89	0.00	0.17
19	OM0.den, RWST.den	3	75.14	75.69	8.27	0.00	0.10
20	COS.den, RWST.den	3	75.44	76.00	8.58	0.00	0.10
21	COS.den, HABTYPE	4	75.29	76.24	8.82	0.00	0.13
22	Dist.EC, RWST.den	3	76.35	76.91	9.49	0.00	0.09
23	Dist.EC, HABTYPE	4	76.03	76.98	9.56	0.00	0.12
24	OM0.den	2	76.85	77.12	9.70	0.00	0.06
25	Dist.EC, OM0.den, RWST.den	4	76.83	77.79	10.37	0.00	0.11
26	COS.den, OM0.den, RWST.den	4	76.97	77.92	10.50	0.00	0.11
27	Dist.EC, COS.den, RWST.den	4	77.43	78.38	10.96	0.00	0.10
28	COS.den	2	78.37	78.65	11.23	0.00	0.04
29	Dist.EC	2	78.62	78.90	11.48	0.00	0.03
30	COS.den, OM0.den	3	78.71	79.27	11.85	0.00	0.06
31	Intercept Only	1	79.21	79.30	11.88	0.00	0.00
32	Dist.EC, OM0.den	3	78.77	79.33	11.91	0.00	0.06
33	Dist*OM0.den, Dist.EC, OM0.den, RWST.den	5	78.14	79.60	12.18	0.00	0.12
34	Dist.EC, COS.den	3	79.48	80.04	12.62	0.00	0.05
35	Dist.EC, COS.den, OM0.den, RWST.den	5	78.68	80.14	12.72	0.00	0.11
36	Dist*OM0.den, Dist.EC, OM0.den	4	79.74	80.69	13.27	0.00	0.07
37	Dist.EC, COS.den, OM0.den	4	80.63	81.58	14.16	0.00	0.06
38	HABTYPE	3	81.24	81.79	14.37	0.00	0.03

Appendix L. Continued…

Rank	Model [a]	K	AIC	AIC_c	Δ_i	w_i	r^2
39	Dist*OM0.den, Dist.EC, COS.den, OM0.den, RWST.den	6	80.02	82.12	14.70	0.00	0.12
40	Dist*OM0.den, Dist.EC, COS.den, OM0.den	5	81.66	83.12	15.70	0.00	0.07
Coho Salmon							
1	OM0.den, HABTYPE	4	66.25	67.18	0.00	0.37	0.33
2	Dist.EC, OM0.den, HABTYPE	5	67.99	69.42	2.24	0.12	0.34
3	OM0.den, OM1.den, HABTYPE	5	68.01	69.43	2.25	0.12	0.34
4	OM0.den, RWST.den, HABTYPE	5	68.05	69.48	2.29	0.12	0.34
5	Dist.EC*OM0.den, Dist.EC, OM0.den, HABTYPE	6	68.60	70.65	3.46	0.07	0.35
6	OM0.den, OM1.den, RWST.den, HABTYPE	6	69.59	71.64	4.46	0.04	0.34
7	Dist.EC, OM0.den, OM1.den, HABTYPE	6	69.69	71.74	4.55	0.04	0.34
8	Dist.EC, OM0.den, RWST.den, HABTYPE	6	69.90	71.95	4.77	0.03	0.34
9	Dist.EC*OM0.den, Dist.EC, OM0.den, OM1.den, HABTYPE	7	70.02	72.82	5.64	0.02	0.36
10	Dist.EC*OM0.den, Dist.EC, OM0.den, RWST.den, HABTYPE	7	70.54	73.34	6.16	0.02	0.35
11	Dist.EC, OM0.den, OM1.den, RWST.den, HABTYPE	7	71.46	74.26	7.07	0.01	0.34
12	Dist.EC, HABTYPE	4	73.36	74.29	7.11	0.01	0.25
13	OM0.den	2	74.23	74.49	7.31	0.01	0.20
14	Dist.EC*OM0.den, Dist.EC, OM0.den, OM1.den, RWST.den, HABTYPE	8	71.82	75.51	8.33	0.01	0.36
15	Dist.EC, OM1.den, HABTYPE	5	75.31	76.74	9.55	0.00	0.25
16	OM0.den, OM1.den	3	76.21	76.75	9.57	0.00	0.20
17	Dist.EC, RWST.den, HABTYPE	5	75.34	76.76	9.58	0.00	0.25
18	OM0.den, RWST.den	3	76.22	76.77	9.58	0.00	0.20
19	Dist.EC, OM0.den	3	76.23	76.77	9.59	0.00	0.20
20	HABTYPE	3	77.87	78.41	11.23	0.00	0.18
21	Dist.EC*OM0.den, Dist.EC, OM0.den	4	77.55	78.48	11.29	0.00	0.20
22	OM0.den, OM1.den, RWST.den	4	78.20	79.13	11.94	0.00	0.20

Appendix L. Continued…

Rank	Model [a]	K	AIC	AIC_c	Δ_i	w_i	r^2
23	Dist.EC, OM0.den, OM1.den	4	78.21	79.14	11.95	0.00	0.20
24	Dist.EC, OM0.den, RWST.den	4	78.22	79.15	11.97	0.00	0.20
25	Dist.EC, OM1.den, RWST.den, HABTYPE	6	77.30	79.35	12.16	0.00	0.25
26	RWST.den, HABTYPE	4	78.96	79.89	12.70	0.00	0.19
27	OM1.den, HABTYPE	4	79.33	80.26	13.08	0.00	0.18
28	Dist.EC*OM0.den, Dist.EC, OM0.den, RWST.den	5	79.53	80.96	13.77	0.00	0.20
29	Dist.EC*OM0.den, Dist.EC, OM0.den, OM1.den	5	79.54	80.97	13.79	0.00	0.20
30	Dist.EC, OM0.den, OM1.den, RWST.den	5	80.20	81.63	14.44	0.00	0.20
31	OM1.den, RWST.den, HABTYPE	5	80.80	82.23	15.04	0.00	0.19
32	Dist.EC*OM0.den, Dist.EC, OM0.den, OM1.den, RWST.den	6	81.52	83.57	16.38	0.00	0.20
33	Dist.EC	2	84.19	84.46	17.27	0.00	0.08
34	Dist.EC, OM1.den	3	85.55	86.10	18.91	0.00	0.09
35	Dist.EC, RWST.den	3	86.15	86.70	19.51	0.00	0.08
36	Dist.EC, OM1.den, RWST.den	4	87.34	88.27	21.09	0.00	0.09
37	Intercept Only	1	89.32	89.40	22.22	0.00	0.00
38	OM1.den	2	89.29	89.56	22.37	0.00	0.02
39	RWST.den	2	90.63	90.90	23.71	0.00	0.01
40	OM1.den, RWST.den	3	91.23	91.78	24.60	0.00	0.02
Residual Hatchery Winter Steelhead							
1	Dist.EC, OM0.den, OM1.den	4	30.64	34.64	0.00	0.47	0.61
2	OM1.den, HABTYPE	4	33.48	37.48	2.84	0.11	0.56
3	Dist.EC, OM1.den, HABTYPE	5	31.05	37.72	3.08	0.10	0.63
4	Dist.EC, OM1.den	3	36.12	38.30	3.66	0.08	0.48
5	Dist.EC*OM0.den, Dist.EC, OM0.den, OM1.den	5	31.90	38.56	3.92	0.07	0.62
6	Dist.EC, COS.den, OM0.den, OM1.den	5	32.52	39.19	4.54	0.05	0.61

Appendix L. Continued…

Rank	Model [a]	K	AIC	AIC_c	Δ_i	w_i	r^2
7	Dist.EC, OM0.den, OM1.den, HABTYPE	6	29.77	40.27	5.62	0.03	0.69
8	Dist.EC, COS.den, OM1.den	4	36.75	40.75	6.11	0.02	0.50
9	COS.den, OM1.den, HABTYPE	5	34.86	41.53	6.89	0.01	0.57
10	OM0.den, OM1.den, HABTYPE	5	35.01	41.67	7.03	0.01	0.57
11	Dist.EC, HABTYPE	4	37.96	41.96	7.32	0.01	0.48
12	HABTYPE	3	40.93	43.11	8.47	0.01	0.39
13	Dist.EC, OM0.den	3	41.28	43.46	8.82	0.01	0.39
14	Dist.EC, COS.den, OM1.den, HABTYPE	6	33.05	43.55	8.91	0.01	0.63
15	Dist.EC*OM0.den, Dist.EC, COS.den, OM0.den, OM1.den	6	33.89	44.39	9.75	0.00	0.62
16	Dist.EC	2	43.52	44.52	9.88	0.00	0.31
17	Dist.EC*OM0.den, Dist.EC, OM0.den	4	41.16	45.16	10.52	0.00	0.42
18	Dist.EC, COS.den	3	43.33	45.52	10.87	0.00	0.35
19	OM0.den, OM1.den, Coho.den, HABTYPE	6	35.44	45.94	11.29	0.00	0.59
20	Dist.EC, OM0.den, HABTYPE	5	39.78	46.44	11.80	0.00	0.48
21	COS.den, HABTYPE	4	42.51	46.51	11.87	0.00	0.40
22	Dist.EC, COS.den, HABTYPE	5	39.94	46.61	11.97	0.00	0.48
23	Dist.EC*OM0.den, Dist.EC, OM0.den, OM1.den, HABTYPE	7	30.69	46.69	12.04	0.00	0.71
24	OM0.den, HABTYPE	4	42.76	46.76	12.12	0.00	0.40
25	Dist.EC, COS.den, OM0.den, OM1.den, HABTYPE	7	30.88	46.88	12.24	0.00	0.71
26	Dist.EC, COS.den, OM0.den	4	43.16	47.16	12.52	0.00	0.39
27	Dist.EC*OM0.den, Dist.EC, OM0.den, HABTYPE	6	37.93	48.43	13.79	0.00	0.55
28	Dist.EC*OM0.den, Dist.EC, COS.den, OM0.den	5	42.88	49.55	14.90	0.00	0.43
29	COS.den, OM0.den, HABTYPE	5	44.50	51.16	16.52	0.00	0.40
30	Dist.EC, COS.den, OM0.den, HABTYPE	6	42.00	52.50	17.86	0.00	0.48
31	Dist.EC*OM0.den, Dist.EC, COS.den, OM0.den, HABTYPE	7	39.46	55.46	20.82	0.00	0.56

Appendix L. Continued…

Rank	Model [a]	K	AIC	AIC_c	Δ_i	w_i	r^2
32	OM0.den, OM1.den	3	53.82	56.00	21.36	0.00	0.17
33	Dist.EC*OM0.den, Dist.EC, COS.den, OM0.den, OM1.den, HABTYPE	8	32.16	56.16	21.52	0.00	0.72
34	OM1.den	2	55.76	56.76	22.12	0.00	0.10
35	COS.den, OM1.den	3	54.84	57.03	22.38	0.00	0.15
36	COS.den, OM0.den, OM1.den	4	55.01	59.01	24.37	0.00	0.18
37	COS.den	2	58.74	59.74	25.10	0.00	0.05
38	Intercept Only	1	59.53	59.84	25.19	0.00	0.00
39	OM0.den	2	61.00	62.00	27.36	0.00	0.01
40	COS.den, OM0.den	3	60.71	62.89	28.25	0.00	0.05

[a] Variable definitions: Dist.EC = distance from the mouth of Eagle Creek (m), HABTYPE = mesohabitat type (riffles, pools, glides), Age0.den = age 0 winter steelhead density (fish/m^2), Age1.den = age 1 winter steelhead density (fish/m^2), Coho.den = coho salmon density (fish/m^2), R-HWST.den = residual hatchery winter steelhead density (fish/m^2).