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The Effect of Stream Restoration on Preferred Cutthroat Trout Habitat in the Strawberry River, Utah

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THE EFFECT OF STREAM RESTORATION ON PREFERRED CUTTHROAT TROUT HABITAT IN THE STRAWBERRY RIVER, UTAH

by

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ABSTRACT

The Effect of Stream Restoration on Preferred Cutthroat

Trout Habitat in the Strawberry River, Utah

by

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Stream restoration has become a popular management tool for attempting to increase and/or restore fish populations by improving habitat. A section of the Strawberry River, Utah recently underwent a stream restoration project, where the main goals of the project included increasing spawning activity, rearing potential, and resident populations of Bear Lake cutthroat trout *Oncorhynchus clarkia utah*. The impact of the restoration project on cutthroat trout was investigated by first characterizing preferred habitat for different life stages, investigating habitat as a limiting factor in the system, and then assessing the quality of available habitat by comparing restored/unrestored sections of stream and pre-restoration/post-restoration of the same sections of stream.

Results indicated cutthroat trout in the Strawberry River preferred faster water velocities, shallower depths, moderate substrates sizes, and riffle habitat types for spawning. In contrast, juvenile and adult life stages preferred deeper sections of stream, the presence of cover, and pool habitat types. Limiting factor analyses suggested spawner abundance may be limiting in the Strawberry River and maximum daily temperatures during the summer may be the strongest limiting habitat factor for juvenile and resident adult cutthroat trout. Restoration generally appeared to initiate a shift towards more favorable habitat, especially in terms of increasing near-bed velocity and increasing the proportion of preferred substrate sizes for spawning, and increasing the percentage of pools for juvenile and resident adult life stages.

The potential benefits of the restoration remained somewhat ambiguous, a result of relatively small differences observed between study reaches, limited pre-restoration data, high spatial and inter-annual variability within and among control study reaches, and the inherently delayed reaction of ecological responses to physical changes from restoration. However, these issues can be resolved through continued monitoring. Long-term monitoring would allow for the accounting of natural variability to further tease out differences resulting from restoration and differences resulting from natural fluctuations. Additional monitoring would also capture long-term responses, which has the potential to be significant considering the relatively slow response of riparian vegetation to restoration. This study also provides a baseline dataset and template for future long-term monitoring efforts.

(101 pages)

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CHAPTER 1

INTRODUCTION

Degraded habitat ubiquitously threatens a wide range of species and environments (Dobson et al. 1997; Wilcove et al. 1998), and is an especially prominent issue in aquatic ecosystems (Allan and Flecker 1993; Sala et al. 2000; Dudgeon et al. 2005). In effort to address degraded habitat in fluvial ecosystems, a conservatively estimated $1 billion per year was dedicated to stream restoration in the United States between 1990 and 2003 (Bernhardt et al. 2005). The potential for dramatic and relatively immediate physical results generally thought to be associated with stream restoration has made it an attractive tool for managers, whom are often tasked with making significant improvements to a system over a short period of time with minimal resources. Bernhardt et al. (2007) found almost half of all restoration projects were initiated due to the stream system being degraded, with improving in-stream habitat often stated as a primary goal. Despite the significant amount of money and effort committed to stream restoration, there has been limited effectiveness monitoring, particularly in terms of biological responses (Roni et al. 2002; Bernhardt et al. 2005; Miller et al. 2009).

An overwhelming goal of stream restoration is to increase salmonid population abundance and biomass through habitat improvements (NRC 1996). However, food resource availability (e.g., Ensign et al. 1990), climate (e.g., Clarkson and Wilson 1995), competition (e.g., Budy et al. 2007), and habitat (e.g., Bozek and Rahel 1991) are just a few examples of the factors limiting the distribution and abundance of salmonids. In many cases it is a combination of these factors that determine the relative productivity of a fishery. Therefore, the impact of habitat improvement largely hinges on the extent to which habitat was the limiting factor before restoration efforts began (Bond and Lake 2003; Lepori et al. 2005).

The term habitat includes many variables, such as temperature, water velocity, cover (e.g., deep pools, undercut banks, boulders, overhanging vegetation), substrate, and depth. The relative importance of these different variables often changes over the life history of salmonids. For example, spawning activity is strongly correlated with depth, water velocity, and substrate size (Thurow and King 1994; Magee et al. 1996; Knapp and Preisler 1999), while rearing habitat is more strongly correlated with cover (Quiñones and Mulligan 2005; House 1996). Salmonid populations as a whole can suffer if the habitat requirements for all life stages are not met (White and Rahel 2008). The abiotic factors limiting populations can potentially be determined by identifying the habitat requirements of individuals of different life stages (Rosenfeld 2003).

The objectives of this study were to measure the short-term (2-3 year) direct impacts of a stream restoration project on the proportion of suitable habitat for different life stages of Bear Lake cutthroat trout *Oncorhynchus clarkia utah*, as well as the indirect impact on the distribution, size, and biomass of the cutthroat trout population, in the Strawberry River, Utah. However, the response of fish and habitat variables to stream restoration efforts can take many years to become fully realized, especially when restoration is attempting to restore natural processes of a system (Binns 1994; Liermann and Roni 2008). Therefore, this research should also provide a useful dataset and possible template for aiding in future effectiveness monitoring of the Strawberry River Restoration Project.

Strawberry Reservoir is a large (61 km^2), high-elevation (2,317 m) water body in central Utah, established to increase water storage for the southern Wasatch front. However, the reservoir has since become a popular coldwater fishery, receiving year-round fishing pressure (Ward et al. 2008). The three major sport fish in Strawberry Reservoir are Bear Lake cutthroat trout, sterile rainbow trout *Oncorhynchus mykiss*, and kokanee salmon *Oncorhynchus nerka*. The Strawberry River also has a variety of non-game fish, such as mottled sculpin *Cottus bairdi*, mountain suckers *Catostomus platyrhynchus*, Utah sucker *Catostomus ardens*, Utah chub *Gila atraria*, speckled dace *Rhinichthyoss osculus*, and redside shiners *Richardsonius balteatus*.

In 1990, Strawberry Reservoir and its tributaries underwent the largest recorded rotenone treatment to remove undesirable Utah chub (Ward et al. 2008). Bear Lake cutthroat trout were subsequently introduced as the primary biological control on Utah chub populations, establishing them as the main sport fish. Since the treatment, Ward and Robinson (2009) have estimated natural reproduction accounts for 36% of the cutthroat trout population in Strawberry Reservoir, and stocking the remaining 64%. The Utah Division of Wildlife Resources (UDWR) continues to stock cutthroat trout in the Strawberry Reservoir and its tributaries to maintain a population large enough to meet fishing demands and adequately control Utah chub numbers, but would like to maximize the contribution of natural reproduction to the cutthroat trout population.

Until 1990, many of the Strawberry Reservoir tributaries used for spawning and rearing by cutthroat trout were subjected to harmful water management (e.g., dewatering) and land-use practices (e.g., heavy grazing and chemical removal of willows) (U.S. Forest Service 2004; Knight et al. 1995). The management activities resulted in degraded stream systems characterized by high erosion rates, high maximum water temperatures, limited riparian vegetation, and an overall reduction in water and habitat quality throughout reservoir tributaries (U.S. Forest Service 2004). The degradation is problematic because suitable habitat for cutthroat trout generally includes low water temperatures, clear water, high oxygen levels, moderate water velocities, high percentage of cover, limited fine sediment, and a high percentage of pools (Hickman and Raleigh 1982).

The Strawberry River and Indian Creek are the two largest tributaries to Strawberry Reservoir capable of supporting a resident population of cutthroat trout, providing spawning habitat for adfluvial reservoir cutthroat trout, and rearing habitat for juvenile cutthroat trout. Beginning in the mid 1980’s, Indian Creek and the Strawberry River underwent restoration that included the addition of in-stream structures (e.g., juniper cuttings and logs) and riparian revegetation (e.g., willow plantings). Indian Creek has seen an increase in bank stability and the abundance of riparian vegetation since these first restoration efforts, while the response of the Strawberry River has been notably more torpid (U.S. Forest Service 2004). Presently, Indian Creek has significantly more spawning activity, higher fry production, and generally higher resident cutthroat trout populations than the Strawberry River (Knight et al. 1995; Wilson et al. 2004). With the higher cutthroat trout productivity observed in post-restoration Indian Creek, it was believed that a more successful restoration attempt to improve habitat quality on the Strawberry River, by reducing erosion, increasing the amount of riparian cover, and increasing reach-scale heterogeneity, could ultimately lead to higher population viability in the Strawberry River as well.

The UDWR recently completed a second major stream restoration project on the Strawberry River. One of the primary goals of this most recent project was to increase the abundance of naturally reproducing Bear Lake cutthroat trout in Strawberry Reservoir and Strawberry River through in-stream habitat improvements. The UDWR's stream restoration project on the Strawberry River is not uncommon in that it seeks to substantially benefit a fish population by improving habitat quality (Bernhardt et al. 2007).

The Strawberry River restoration plan was based on the popular Rosgen (1994) classification system, where restoration was designed to shift the river into a Rosgen classification characterized by lower width to depth ratios and reduced entrenchment, relative to the pre-restoration Rosgen classification. The restoration specifically involved placing logs cabled to concrete blocks and/or a series of boulders into the stream and bank at a slight angle to divert energy of the flow away from banks and increase local scour in excavated pools below structures. Bank angle was then decreased above and below the structures to promote reconnecting the stream with its natural flood-plain. Coconut fiber was then used in disturbed areas to reduce erosion short-term, and the planting of willows and other riparian vegetation to reduce erosion long-term. The first phase of the UDWR Strawberry River Restoration Project began at the reservoir and ended about 1.5 km upstream. The second phase of the project began in the summer of 2008 and was completed during the summer of 2010. This second phase covered about 5.5 km of stream from Bulls Springs to just above Highway 40, and was the primary focus of this study (Figure 1-1). Monitoring of such a project required an understanding of what constitutes quality habitat, the extent to which habitat may or may not limit the population, and how the restoration has impacted habitat availability.

Field data for this study were collected during 2008, 2009, and 2010 to identify preferred and available habitat for cutthroat trout in the Strawberry River. Data collection occurred at both microhabitat and reach scales. This information and data were then used to better understand the effects of the stream restoration project on the cutthroat trout population in the Strawberry River and Strawberry Reservoir. An observational approach was employed, where undisturbed adults, juveniles, and spawning redds within the stream were visually located, and habitat variables measured to determine preferred habitat (Moyle and Baltz 1985; Knapp et al. 1998; Al-Chokhachy and Budy 2007). Available habitat was then assessed by measuring the same habitat variables throughout different sections of the river. In this thesis I will address the following objectives:

1. Characterize patterns of spawning cutthroat trout habitat use among reaches of the Strawberry River, investigate habitat as a limiting factor, and quantify whether restoration increased the proportion of suitable habitat.

2. Characterize patterns of juvenile and resident adult cutthroat trout habitat use among reaches of the Strawberry River, investigate habitat as a limiting factor, and quantify whether restoration increased the proportion of suitable habitat.
3. Quantify changes in the cutthroat trout distribution, abundance, and length structure for the four study reaches.

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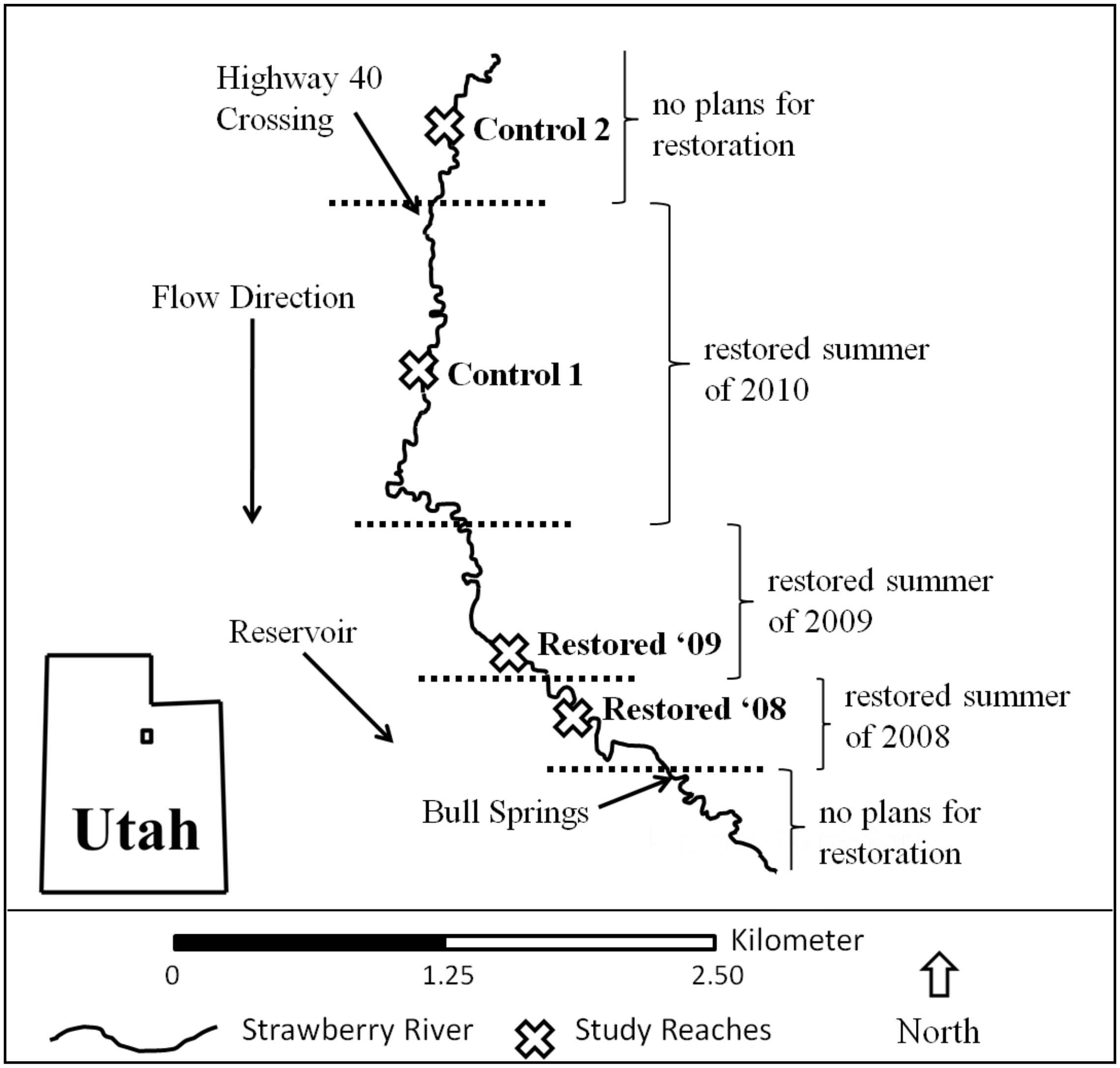

Figure 1-1. Site map of the Strawberry River study area. Dashed lines represent breaks in different years of the restoration project (summers of 2008, 2009, and 2010). The "X's" mark four 500 meter study reaches ("Restored '08," "Restored '09," "Control 1," and "Control 2").

CHAPTER 2

EFFECT OF STREAM RESTORATION ON THE AVAILABILTY OF PREFERRED SPAWNING HABITAT IN THE STRAWBERRY RIVER[1]

Abstract.–Stream restoration has become a popular tool for attempting to increase and/or restore successful spawning activity for fluvial, adfluvial, and anadromous fish populations. A section of the Strawberry River, Utah recently underwent a major stream restoration project, where one of the main goals was to increase successful spawning activity by an adfluvial reservoir population of Bear Lake cutthroat trout *Oncorhynchus clarkia utah*. The impact of the restoration project on cutthroat trout spawning was investigated by first characterizing preferred spawning habitat, and then assessing the quality of available habitat by comparing restored/unrestored sections of stream and pre-restoration/post-restoration of the same sections of stream. Cutthroat trout preferred faster water velocities, shallower depths, moderate substrates sizes, and riffle habitat types for spawning. The restored sections of river tended to have more favorable spawning habitat, based on preference results. However, lack of statistical significance and complicating factors related to spatial and inter-annual variation made it difficult to attribute differences in available habitat between restored and unrestored sections of river to the restoration project. Therefore, the restoration project may have benefited cutthroat trout populations using the Strawberry River for spawning, but results also highlighted the importance of continued long-term monitoring to further tease out the true effect of restoration from natural spatiotemporal variability.

[1]Coauthored by Nicolas R. Braithwaite, Scott W. Miller, and Chris Luecke

Introduction

Deleterious human activities, such as over-grazing, dam construction, and deforestation, have lead to degraded habitat and reduced spawning viability in many fluvial systems (Hicks et al. 1991; Platts 1991). Stream restoration is commonly implemented to remedy degraded in-stream habitat (Bernhardt et al. 2007). Typical restoration methods include gravel addition, placement of in-stream structures, alteration of channel planform (e.g., increase sinuosity of a channelized stream), and alteration of flow regimes on regulated rivers (Mullner and Hubert 1995; House 1996; Propst and Gido 2004; McManamay et al. 2010). While these restoration techniques have become very popular, a paucity of empirical monitoring data exists to determine their true effectiveness (Bernhardt et al. 2005; 2007). Additionally, the potential of stream restoration projects to increase the spawning activity in a stream is directly linked to the degree of spawning habitat limitation of the population before restoration began. Monitoring of a stream restoration project, specifically where the goal is increasing successful spawning activity, should assess what constitutes suitable spawning habitat for that particular system and species, the degree to which habitat was limiting spawning activity before restoration work was done, and the effect of restoration on the abundance and distribution of suitable spawning habitat.

Strawberry Reservoir is one of Utah's most heavily used fisheries, receiving more than a million angler hours annually (Wilson and Ward 2003). After undergoing an unprecedented rotenone treatment in 1990 to remove undesirable Utah chub *Gila atraria*, Bear Lake cutthroat trout *Oncorhynchus clarkia utah* were established in Strawberry

Reservoir and its tributaries as the primary sport fish (Ward et al. 2008). This highly piscivorous species was chosen to keep the Utah chub population from reaching pre-treatment densities. The use of Bear Lake cutthroat trout, along with the implementation of a carefully designed slot limit, has resulted in a cutthroat trout population capable of meeting angler demands and suppressing the Utah chub population (Ward et al. 2008). However, maintaining the balance between effective biological control and angling opportunities, it is necessary for the UDWR to stock Bear Lake cutthroat trout in Strawberry Reservoir. To avoid predation by larger reservoir trout, many of these cutthroat trout are raised to about 200 mm before being stocked, a much higher economic cost to state fish hatcheries than stocking smaller fingerling fish (about 75 mm). This large and necessary stocking effort results in both economic and recreational motivation to increase natural cutthroat trout spawning and recruitment in the tributaries of Strawberry Reservoir.

Many Strawberry Reservoir tributaries were heavily degraded through harmful water management (e.g., dewatering) beginning in the late 1800's and land-use practices (e.g., heavy grazing and chemical removal of willows) during most of the 1900's (U.S. Forest Service 2004; Knight et al. 1995). The majority of these practices ended by the early 1990's, seemingly providing an opportunity to use restoration as a catalyst to restore the degraded tributaries to more closely resemble pre-disturbance conditions and processes. Indian Creek and the Strawberry River, the two most heavily used spawning tributaries, received addition of in-stream structures (e.g., juniper cuttings and logs) and riparian revegetation (e.g., willow plantings). Post-restoration Indian Creek experienced substantial increases in bank stability and riparian vegetation, while the response of the Strawberry River has been limited (U.S. Forest Service 2004). Indian Creek also has significantly more spawning activity than the Strawberry River (Knight et al. 1995). With the improvements observed on Indian Creek, it was believed a more successful restoration attempt to improve habitat quality on the Strawberry River, by reducing erosion, increasing the amount of riparian cover, and increasing reach-scale heterogeneity, might ultimately result in an increase in successful cutthroat trout spawning activity in the river.

In the summer of 2010, the UDWR completed a stream restoration project on the Strawberry River. The restoration plan for the project was based on the popular Rosgen (1994) classification system, and specifically involved placing logs cabled to concrete blocks and/or a series of boulders into the stream and continuing into the stream bank at a slight angle to divert energy from the stream away from banks and increase local scour in excavated pools below structures, decreasing bank angle above and below the structure to promote reconnecting the stream with its natural flood-plain, placing coconut fiber in disturbed areas to reduce erosion short-term, and the planting of willows and other riparian vegetation to reduce erosion long-term. The project had several goals, one of which was to improve spawning opportunities for the cutthroat trout population by improving the quality and abundance of spawning habitat.

The objectives of my study were to identify and characterize what constitutes suitable spawning habitat for cutthroat trout in the Strawberry River, investigate the degree to which cutthroat trout spawning activity in the Strawberry River may be limited by suitable spawning habitat, and to assess the impact of the stream restoration project on suitable spawning habitat in the Strawberry River.

Methods

Study Reaches

Four study reaches were selected to characterize preferred cutthroat trout spawning habitat in the Strawberry River and quantify the efficacy of active restoration to increase the proportion of preferred spawning habitat. The four study reaches were "Restored '08," "Restored '09," "Control 1," and "Control 2" (Figure 2-1). Restored '08 is a true treatment reach, the Restored '09 and Control 1 act as both control and treatment reaches at different points in time, and Control 2 is the only true control reach. All study reaches were 500 m and were selected based on the criteria of: overlapping with already established study reaches by other agencies or investigators (e.g., UDWR electrofishing reaches, Utah State University's Intermountain Center for River Restoration and Rehabilitation (ICRRR) studies), and being geomorphically representative of the restored reach. Control reaches were used to distinguish geomorphic changes resulting from natural climatic and hydrologic fluctuations from restoration effects.

Preferred Spawning Habitat

Cutthroat trout redds in each study reach were marked by one or two individuals walking the streambank(s) and placing a marker in a disturbed area of the stream bed that was consistent with salmonid spawning activity (e.g., a patch of stream bed free of periphyton). Redd marking surveys were conducted after spawning activity had begun and after poor water clarity associated with spring runoff ceased to limit visibility. At each marker, microhabitat variables within 0.5 m^2 were measured and habitat unit (riffle, run, pool, or glide) of the location were noted to determine preferred spawning habitat of the Strawberry Reservoir cutthroat trout population ("use" data). To describe available habitat, the same habitat variables were measured and recorded at 12 equidistant points for 20 equally spaced transects within a randomly selected 200 m of each reach ("availability" data). All redd and transect data were collected immediately after spawning activity was believed to have ended, early July in 2009 and 2010.

Microhabitat variables measured included depth, near-bed flow velocity, and substrate size because previous research has documented the importance of these variables to spawning salmonids (e.g., Thurow and King 1994; Magee et al. 1996; Knapp and Preisler 1999). Depth and flow velocities were measured at the center of each redd. Near-bed velocities were measured using a Marsh-McBirney flowmeter (Flo-Mate Model 2000), with all negative flow velocities entered as 0 in analyses. Redd particle size distributions were estimated by randomly selecting and measuring 100 particles along the intermediate axis in-situ at each redd location. Depth, near-bed velocities, and two particles were also measured at each of the 12 equidistant points within the 20 transects of each reach, for a total of 240 point measurements per 200 m.

Reach-scale measurements included habitat type, average length, and average width of each habitat unit. Habitat type (pool, riffle, run, or glide) was recorded at redd locations and along 200 m of each study reach. Habitat types were qualitatively identified as follows: relatively deep sections of river with slow water velocities were classified as pools, sections with fast water velocities, shallow depths, and turbulent water surfaces were riffles, sections with moderate depth and water velocities were runs, and sections with moderately shallow depths, slow to moderate water velocities, and lack of turbulence in the water surface were glides.

Microhabitat variables of depth, near-bed velocity, and substrate size were characterized as being either “optimal,” “useable,” or “unsuitable” based on the frequency distributions of the microhabitat use data sets (e.g., Thomas and Bovee 1993; Al-Chokhachy and Budy 2007). Optimal refers to the range encompassing the central 50% of use data, useable was between 50% and 94%, and unsuitable refers to the range falling outside of the central 95% distribution of use data. These characterizations were made for each microhabitat variable individually, but also combined to describe multiple microhabitat variables simultaneously. In this composite approach, optimal is a result of all variables being classified as optimal, useable when all variables are classified as useable or a combination of useable and optimal, and unsuitable when one or more variable(s) are classified as unsuitable. Due to temporal variability of available habitat, separate characterizations of optimal, useable, and unsuitable habitat were calculated for each of the two sampling years.

Finally, logistic regression was used to identify the preferred spawning microhabitat of Strawberry River cutthroat trout by assessing the influence of different variables on the odds of observing redd presence (e.g., Cantrell et al. 2005; Al-Chokhachy and Budy 2007). Logistic regression is useful for modeling datasets with a dichotomous response. In this case, the response variable was dummy coded as 0 for availability data and 1 for use data. Depth, near-bed velocity, and substrate size were then included as explanatory microhabitat variables for both the 2009 and 2010 models. In both models, goodness-of-fit was checked using the Hosmer-Lemeshow goodness-of-fit test, multicollinearity was checked using condition indices and variance inflation factors, influential observations were diagnosed using change in the Pearson chi-square and deviance statistics, and a half-normal probability plot with simulated envelope was used to check for outliers (Kutner et al. 2004). Model parameter estimates, odds ratio estimates, and the corresponding *P*-value for each variable were used to provide insight regarding the significance and relative influence of explanatory variables on the odds of redd presence or absence, using a statistical significance threshold of $\alpha = 0.05$. Logistic regression analyses were conducted using Statistical Analysis System (SAS) version 9.2 (PROC LOGISTIC; SAS 2009).

Redd Counts

In the summer of 2010, the number of cutthroat trout redds were enumerated at 450 m intervals in the Strawberry River, from the reservoir upstream to Willow Creek (about 2.7 km above Highway 40). In addition to the 2010 data set, the UDWR provided results from annual redd surveys, dating back to 2000. However, the spatial intervals differed for these surveys, specific reaches included from the reservoir to their fish trapping structure (≈ 1.25 km, depending on the reservoir's water level), the fish trapping structure to Bull Springs (≈ 8.0 km), and Bull Springs to Highway 40 (≈ 4.5 km). The fish trapping structure is an electrical barrier running the width of the river during spawning which diverts fish into a holding pen where the sex, length, and number of fish are recorded, before being released approximately 1.25 km upstream. Redd counts were made by one or two individuals walking the streambank(s) and enumerating each disturbed area of the stream bed that was consistent with salmonid spawning activity. Dates of the redd counts ranged from early-June to mid-July among years. For years there was sufficient data, the proportion of total redds for each year were calculated for the three stream sections used by the UDWR. The 2010 redd count data was also plotted against distance from the reservoir to better understand spatial trends in spawning activity at a more localized scale throughout the Strawberry River. One-way analysis of variance (ANOVA) tests were used to compare mean redd densities between the section of river from the reservoir to the trap and the section above the trap, as well as between restored and unrestored sections (SAS PROC ANOVA, SAS 2009).

Impact of Restoration on Spawning Habitat

The effect of restoration on preferred cutthroat trout spawning habitat in the Strawberry River was assessed primarily through before-after (BA), control-impact (CI), and before-after-control-impact (BACI) type analyses. The BACI style design is ideal as it provides an opportunity for useful comparisons between restored/unrestored reaches, as well as pre-restoration/post-restoration of the same reach, to control for confounding effects of spatiotemporal variability and help determine the effect of an impact (Osenberg et al. 2006). However, in many cases data limited analyses to the simpler BA and CI designs (e.g., only two sampling occasions). In this study, the UDWR's restoration project is the impact.

Due to issues of non-normality and unequal variance, the nonparametric Kruskal-Wallis test was used to test for statistically significant differences in depth, near-bed velocity, and substrate size from availability data among the four study reaches in 2009 and 2010 (SAS PROC NPAR1WAY; SAS 2009). Significant results from the Kruskal-Wallis tests were followed by Tukey's multiple-range tests (threshold $\alpha = 0.05$) on the ranked data to further investigate where differences occurred amongst the study reaches (SAS PROC GLM, SAS 2009) (Neumann and Allen 2007). Data used in Kruskal-Wallis tests consisted of one depth, near-bed velocity, and substrate size measurement from a randomly selected point from each transect, for both 2009 and 2010 sampling occasions. The data was analyzed in this manner to provide an unbiased representation of each transect, without being overwhelmed by the amount of data associated with using all point measurements (e.g., everything becomes significant). One-way ANOVA tests and Tukey's multiple-range comparisons (threshold $\alpha = 0.05$) were used to make comparisons among changes in the microhabitat variables depth, near-bed velocity, and substrate from 2009 to 2010 (SAS PROC ANOVA, SAS 2009). Data used in the one-way ANOVA consisted of the calculated difference between the 2009 and 2010 value of each point, paired in space, allowing for comparison of changes to microhabitat availability across the two sampling years.

Simple chi-squared contingency tables were used to analyze the effects of restoration on qualitatively described preferred spawning habitat (Rogers and White 2007). Data used in chi-squared analyses included the relative proportion of optimal, useable, and unsuitable spawning habitat observed in study reaches and the relative proportion of reach-scale habitat units in different reaches and years.

Results

Preferred Spawning Habitat

Relative to available habitat, cutthroat trout spawning redds in the Strawberry River were characterized by shallower depths, higher water velocities, moderately sized particles, and riffle habitat types. The range of depths and near-bed velocities observed at redds covered a more specific range than the range from transect point measurements (Figure 2-2). Also, the particle size distributions from 2009 and 2010 use and availability data suggested cutthroat trout were selecting for a narrower range of particle sizes than available distributions (Figure 2-3). Riffles appeared to be the preferred reach-scale habitat unit for spawning. Almost 76% of all redds were observed in riffle habitats in 2009 and 84% in 2010, while the remaining redds were either in glide or run habitat types. In terms of length, riffles only accounted for about 43% of available habitat in 2009 and about 38% in 2010.

Optimal, useable, and unsuitable microhabitat characterizations for depth, near-bed velocity, and substrate size also suggested that cutthroat trout were selecting for slightly shallower sections of stream with faster near-bed velocities and moderate substrate sizes (Table 2-1). Ranges of optimal and useable depths and substrate sizes were similar between 2009 and 2010, but with 2010 distributions covering a narrower range than 2009. The near-bed velocity ranges for optimal and useable were narrower and shifted higher in 2010 than 2009.

The results of the 2009 and 2010 logistic regression models suggested that, relative to other available explanatory variable ranges, higher near-bed velocities are significant and most strongly correlated with increased odds of observing a redd, while smaller substrate sizes and shallower depths can also be significantly correlated with increased odds of observing a redd. In the 2009 model, substrate size and near-bed velocity were significant in predicting redd presence or absence, while depth was not statistically significant (Table 2-2). In the 2010 model, depth and near-bed velocity were significant in predicting redd presence or absence, while substrate size was not statistically significant (Table 2-2). While results for depth in 2009 and substrate in 2010 were not statistically significant at the $\alpha = 0.05$ threshold, alpha levels below 0.10 could still suggest ecological significance.

Redd Counts

Generally, the number of redds decreased with distance upstream in 2010 (Figure 2-4). Mean redd densities were significantly higher from the reservoir to the UDWR's fish trapping station than in the rest of the Strawberry River (one-way ANOVA: F = 649.60, df = 1, 35, P = <0.0001). No significant difference in mean redd density occurred in restored sections of stream relative to unrestored sections (one-way ANOVA: F = 0.58, df = 1, 35, P = 0.4501). The mean number of redds per 450 meters below the fish trap was 65.3 (SD = 4.2, N = 3), while the mean number above was 6.3 (SD = 3.8, N = 34). The UDWR's historical data exhibited similar trends, with the highest proportion of redd densities occurring below the fish trap in all years (Figure 2-5). From the UDWR's historical data, the mean number of redds per kilometer from the reservoir to the fish trap was 188.7 (SD = 120.0, N = 5), from the fish trap to Bull Springs was 24.3 (SD = 22.2, N = 5), and from Bull Springs to Highway 40 was 34.3 (SD = 18.8, N = 5).

Impact of Restoration on Spawning Habitat

Mean depths and near-bed velocities were similar across study reaches in 2009, but varied more in 2010. The mean depth of restored study reaches remained relatively constant compared to the two unrestored study reaches, one of which increased in mean depth (Control 1), while the other decreased in mean depth (Control 2) (Table 2-3). Between 2009 and 2010 sampling occasions, the mean near-bed velocity decreased in all but the Restored '09 study reach, and was highest in the two restored study reaches in 2010. Generally, restored study reaches had a more desirable particle size distribution, relative to the particle size distributions observed at redd locations in 2009 and 2010 (Figure 2-5). Restored study reaches also tended to have a lower percentage of fines (defined as < 2 mm) than unrestored reaches, with the notable exception of the Restored '08 study reach in 2009 (Table 2-3).

The only significant differences among the four study reaches were in the ranked 2010 near-bed velocity (Kruskal-Wallis test, $\chi^2 = 14.08$, df = 3, $P = 0.0028$) and substrate size (Kruskal-Wallis test, $\chi^2 = 12.06$, df = 3, $P = 0.0072$). Tukey's multiple-range test indicated that the near-bed velocity differences occurred between the Restored '09 study reach and the two control study reaches (Control 1 and Control 2) and that the substrate size differences occurred between the Restored '09 and Control 1 study reaches. All other comparisons of depth, near-bed velocity, and substrate size amongst study reaches, using the Kruskal-Wallis test, were not significant. Differences between 2009 and 2010 measurements were not significantly different in any of the study reaches for near-bed velocity (one-way ANOVA: $F = 0.61$, df = 3, 76, $P = 0.61$) or substrate size (one-way ANOVA: $F = 0.87$, df = 3, 76, $P = 0.4585$), while they were significantly different for depth (one-way ANOVA: $F = 6.29$, df = 3, 76, $P = 0.0007$). The observed mean decrease in depth between 2009 and 2010 of the Control 1 study reach was significantly different than the observed mean increase in depth between 2009 and 2010 of the Restored ’09 study reach, based on the Tukey’s multiple-range test.

Proportions of optimal, useable, and unsuitable spawning microhabitat tended to be more favorable in restored study reaches, relative to unrestored reaches (Figure 2-6). The difference in proportion of optimal, useable, and unsuitable spawning habitat between restored and unrestored reaches was significant in 2010 near-bed velocities ($\chi^2 = 9.754$, df = 2, $P = 0.008$), but not significant for all other years (2009 and 2010) and microhabitat variables (depth, near-bed velocity, and substrate size). In both 2009 and 2010, restored study reaches had slightly higher percentages of composite (combination of depth, near-bed velocity, and substrate size) optimal and useable spawning habitat and slightly lower percentages of unsuitable spawning habitat than unrestored study reaches. However, these differences were not significant in either 2009 ($\chi^2 = 0.823$, df = 2, $P = 0.667$) or 2010 ($\chi^2 = 1.022$, df = 2, $P = 0.592$). The post-restoration Restored ’09 study reach (2010) had a significantly higher proportion of optimal and useable near-bed velocity relative to pre-restoration ($\chi^2 = 7.342$, df = 2, $P = 0.025$), while proportions of optimal and useable depth ($\chi^2 = 1.353$, df = 2, $P = 0.508$) and substrate ($\chi^2 = 0.547$, df = 2, $P = 0.760$) were not significantly different.

Restored sections of stream tended to have a higher percentage of riffle habitat types than unrestored sections. The mean percentage of riffles (based on proportion of study reach length) for restored study reaches was 43.7% (SD = 16.6, N = 3), while the mean percentage of riffles in unrestored reaches was 34.1% (SD = 7.5, N = 5). However, the relative proportion of riffles to other habitat unit types (pools, runs, and glides) was not significantly different between restored reaches and unrestored reaches ($\chi^2 = 1.947$, df = 1, $P = 0.163$).

Discussion

Preferred Spawning Habitat

Results of preferred spawning habitat analyses indicated that relatively shallow depths, moderate substrate sizes, and faster near-bed velocities were important microhabitat characteristics and that riffles were important reach-scale habitat types in cutthroat trout spawning habitat selection in the Strawberry River. These results are similar to commonly described preferred salmonid spawning habitat characteristics (Hickman and Raleigh 1982; Thurow and King 1994; Magee et al. 1996; Knapp and Preisler 1999). The value of these results to this study is their usefulness in interpreting the observed effects, or lack thereof, of restoration on available spawning habitat for cutthroat trout in the Strawberry River.

Redd Counts

The adfluvial Strawberry Reservoir cutthroat trout population appeared to heavily utilize the first 1 km to 1.5 km of the Strawberry River for spawning, while utilizing the remaining length of the river substantially less. This trend is likely the combined result of three main factors. (1) The Bear Lake strain of Bonneville cutthroat trout evolved in a system where spawning tributaries are relatively short in length and spawning has commonly been observed in only the first kilometer of tributary streams (Burnett 2003). (2) The UDWR fish trap may be acting as a sufficient barrier, keeping a high number of cutthroat trout below the fish trap, rather than continuing upstream. These types of connectivity or barrier issues are believed to limit spawning potential for salmonids by reducing the amount of available spawning habitat (Nehlsen et al. 1991; Sheer and Steel 2006). (3) The UDWR completed a similar stream restoration project in the early 2000's on the section of the Strawberry River from the reservoir to just above the fish trap. This restoration may have resulted in more desirable spawning habitat below the fish trap than above and could be influencing redd densities above and below the fish trap. These three factors, individually and collectively, may explain the acute decrease in redd densities observed above the fish trap.

Redd densities from above the UDWR fish trap to Highway 40 were still moderate to relatively high compared to salmonid redd densities reported in other studies (e.g., Beard and Carline 1991; Wood and Budy 2009). It did not appear that cutthroat trout were selecting for restored sections of stream over unrestored sections. Rather, redd densities appeared to be more closely correlated with distance from the reservoir.

Overall, the spatial distribution and densities of redds observed suggest there may be an opportunity to increase spawning activity in the Strawberry River by increasing the abundance of spawners upstream of the fish trap and through improving spawning habitat quality.

Impact of Restoration on Spawning Habitat

Based on the two years of monitoring presented in this study, it appears that the restoration project may have increased the amount of suitable spawning habitat for cutthroat trout in restored sections of the Strawberry River. In general, restored study reaches had higher near-bed velocities, more favorable particle size distributions (i.e., a higher proportion of particles between 20 and 60 mm), and higher proportions of riffle habitat types than unrestored and pre-restoration study reaches. However, there were several factors acting to limit the amount of causation that can be attributed to the restoration project regarding the significance of observed spawning habitat improvements to the adfluvial Strawberry Reservoir cutthroat trout population:

(1) Often, it was not clear that the improvements to spawning habitat in restored reaches would necessarily be biologically or ecologically relevant. Reducing the percentage of fine sediment is typically considered desirable because it has been negatively correlated with salmonid spawning success (McNeil and Ahnell 1964). The percentage of fine sediment observed in restored reaches was much lower than unrestored reaches in 2010, but even unrestored reaches were still below the important emergence threshold of 30% suggested for salmonids by Kondolf (2000). Therefore, while it appears restoration may lead to a reduction in fine sediment in restored stream sections, it

is not apparent that a reduction will inevitably result in an increase in cutthroat trout spawning success in the Strawberry River.

(2) In some cases, differences between restored/unrestored study reaches and pre-restoration/post-restoration of the same study reach were not statistically significant, implying insufficient evidence that a true difference existed. Additionally, in this type of ecological study, sampling locations and occasions could be viewed more as pseudoreplicates than true replicates, and inadequately consider the influence of temporal and spatial variation (Hurlbert 1984). This is evident in the different climactic conditions experienced in the Strawberry River watershed between 2009 and 2010. Overall, the 2009 year was wetter and cooler, resulting in a higher and more sustained snow-melt runoff event than 2010. This type of discrepancy has the potential to influence differences observed for habitat variables between the two years, but would not be the result of restoration impacts (e.g., the generally shallower depths observed in 2010).

(3) Amplifying the issue of temporal and spatial variation unrelated to the restoration project, is a relatively high level of beaver *Castor canadensis* activity in the Strawberry River. Beaver have been shown to have a significant effect on different physical and ecological habitat characteristics in stream systems (Naiman et al. 1988; Snodgrass and Meffe 1998). For example, the significantly greater change in mean depth observed between the Control 1 and Restored ’09 study reaches was almost certainly driven more by increased depth from beaver activity in the Control 1 study reach than restoration work in the Restored ’09 study reach. However, these inference problems related to spatial and temporal variation can be overcome through long-term monitoring

(ideally both pre and post-restoration or impact) and establishment of a good control reach or reaches, as purposed by Stewart-Oaten et al. (1986).

Conclusion

Based on the findings of this study, there is currently reason for tempered optimism regarding the impact of the UDWR's restoration project on cutthroat trout spawning habitat in the Strawberry River. It will be important to continue monitoring efforts to further tease out the complicating factors of natural variation, as well as to capture the potential long-term responses (e.g., riparian vegetation response). With the need for continued long-term monitoring in mind, perhaps the most important contribution of this study was to create a monitoring protocol and establish a baseline dataset. Ideally, similar monitoring efforts to those described and conducted in this study will be replicated in five and eventually 10-year intervals to more completely assess the true effect of the restoration project.

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Table 2-1. Optimal (central 50% of use data distributions), useable (between 50% and 94% of use data distributions), and unsuitable (outside the central 95% of use data distributions) microhabitat variable ranges for spawning cutthroat trout in the Strawberry River between 2009 and 2010.

	Suitability	Depth (m)	Near-Bed Velocity (m/s)	Particle Size (mm)
2009	Optimal	0.20 - 0.31	0.15 - 0.33	16 - 45
	Useable	0.10 - 0.19 & 0.32 - 0.37	0.07 - 0.14 & 0.34 - 0.66	4 - 15 & 46 - 64
	Unsuitable	< 0.10 & > 0.37	< 0.07 & > 0.66	< 4 & > 64
2010	Optimal	0.18 - 0.21	0.28 - 0.41	22 - 45
	Useable	0.13 - 0.17 & 0.22 - 0.26	0.13 - 0.27 & 0.42 - 0.58	11 - 21 & 46 - 64
	Unsuitable	< 0.13 & > 0.26	< 0.13 & > 0.58	< 11 & > 64

Table 2-2. Parameter estimates, standard errors, odds ratio estimates, and *P*-values for explanatory variables from 2009 and 2010 logistic regression analyses.

	Variable	Parameter Estimate	Standard Error	Odds Ratio Estimate	*P*-value
2009	Intercept	-1.262	0.693		0.069
	Depth (cm)	0.027	0.016	1.027	0.083
	Substrate Size (mm)	-0.079	0.023	0.924	0.0006
	Near-bed Velocity (cm/s)	0.090	0.022	1.095	<0.0001
2010	Intercept	-1.323	0.760		0.084
	Depth (cm)	-0.085	0.041	0.919	0.038
	Substrate Size (mm)	-0.038	0.021	0.963	0.063
	Near-bed Velocity (cm/s)	0.144	0.031	1.155	<0.0001

Table 2-3. Summary statistics for depth, near-bed velocity, and substrate size microhabitat variables. Values were estimated from point measurements within transects. Asterisks denote study reaches in which restoration had occurred before data collection. Restoration occurred between the sampling periods in the Restored '09 study reach.

	Study reach	Depth (m)		Near-bed velocity (m/s)		Substrate size (mm)			
		Mean	SD	Mean	SD	%<2	D_{16}	D_{50}	D_{84}
2009	Restored '08*	0.34	0.21	0.14	0.21	30.9	<2	19.3	49.1
	Restored '09	0.34	0.19	0.12	0.16	16.3	<2	29.7	70.2
	Control 1	0.32	0.21	0.09	0.16	18.1	<2	19.8	63.0
	Control 2	0.32	0.18	0.12	0.22	32.6	<2	13.7	39.4
2010	Restored '08*	0.33	0.19	0.13	0.18	5.8	16.5	38.9	76.9
	Restored '09*	0.31	0.19	0.16	0.15	4.5	14.8	39.6	81.9
	Control 1	0.40	0.25	0.05	0.11	24.0	<2	18.5	63.8
	Control 2	0.26	0.17	0.09	0.17	16.9	<2	30.0	70.1

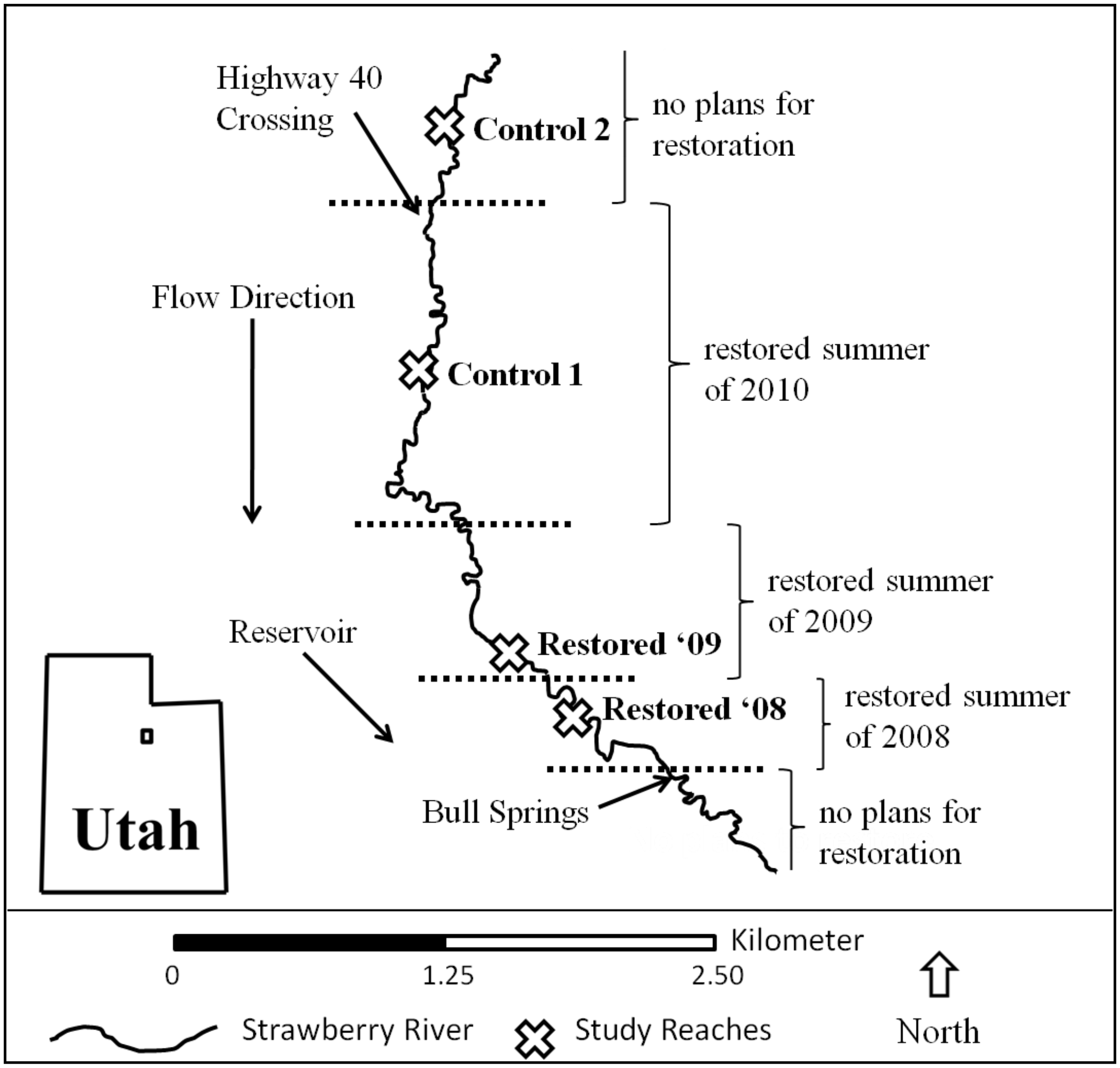

Figure 2-1. Site map of the Strawberry River study area. Dashed lines represent breaks in different years of the restoration project (summers of 2008, 2009, and 2010). The “X’s” mark four 500 meter study reaches (“Restored ’08,” “Restored ’09,” “Control 1,” and “Control 2”).

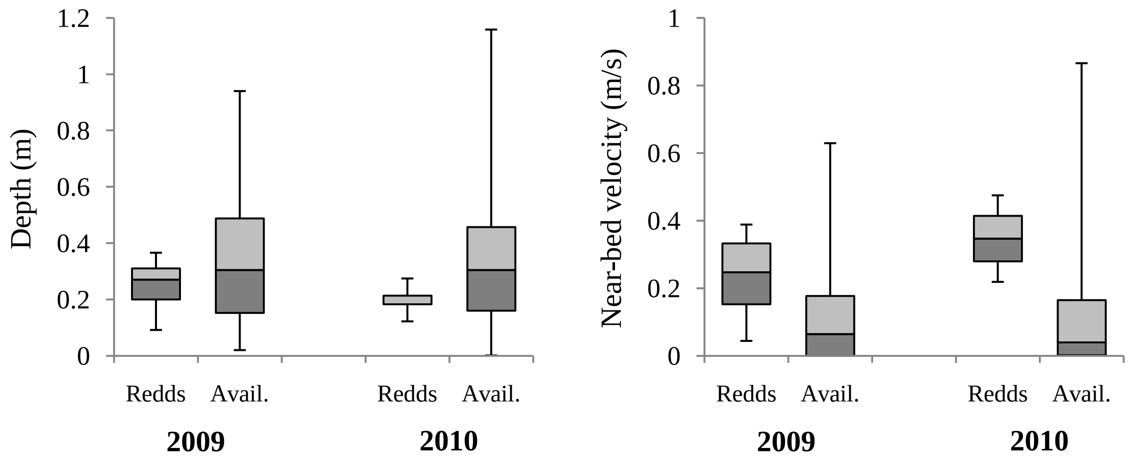

Figure 2-2. Box plots showing the minimum, 3rd quartile, median, 1st quartile, and maximum of depth and near-bed velocity measurements from marked cutthroat trout redd locations ("Redds"), as well as available habitat ("Avail.") from point measurements along transects in 2009 and 2010.

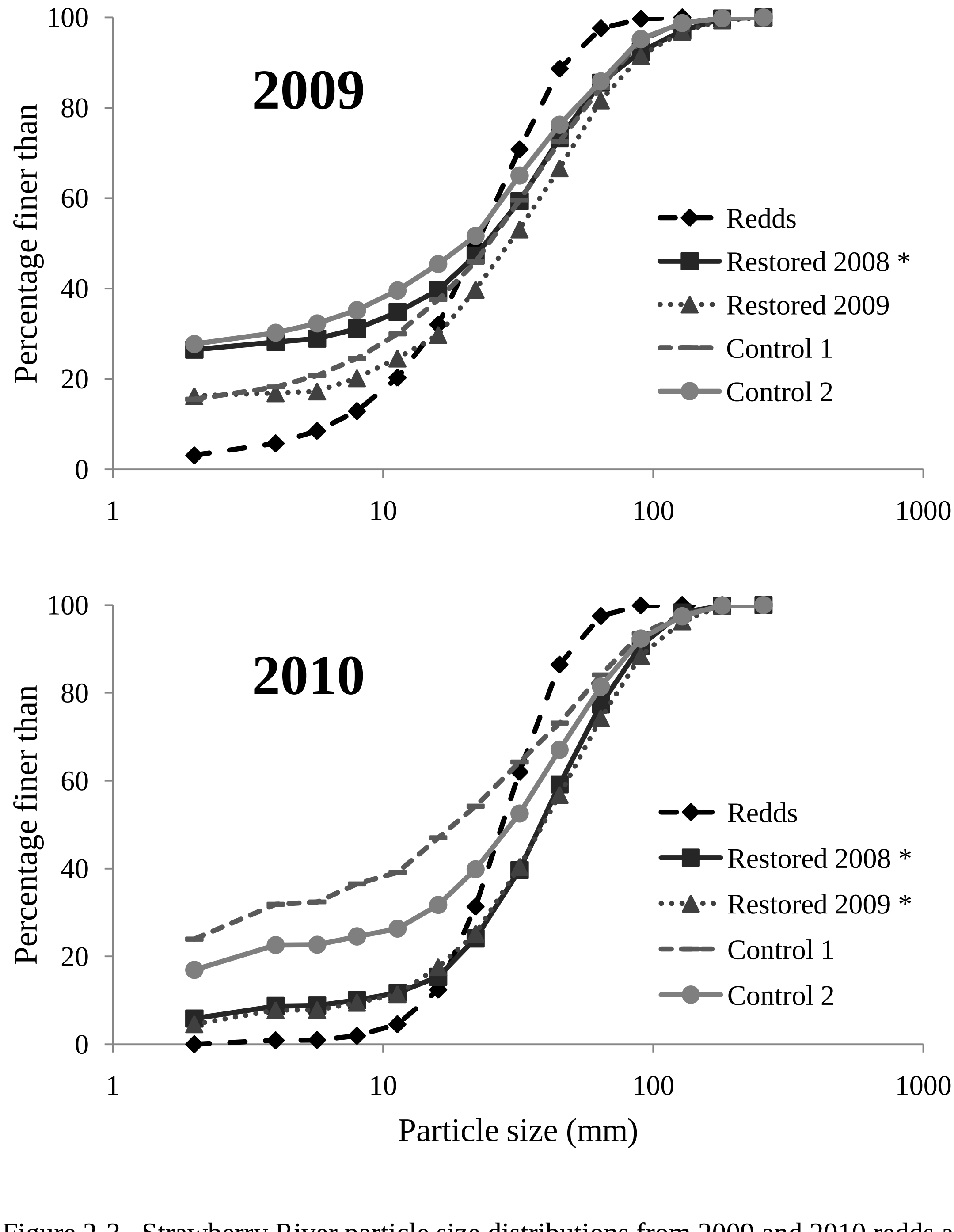

Figure 2-3. Strawberry River particle size distributions from 2009 and 2010 redds and study reaches. Asterisks indicate study reaches that were restored prior to data collection.

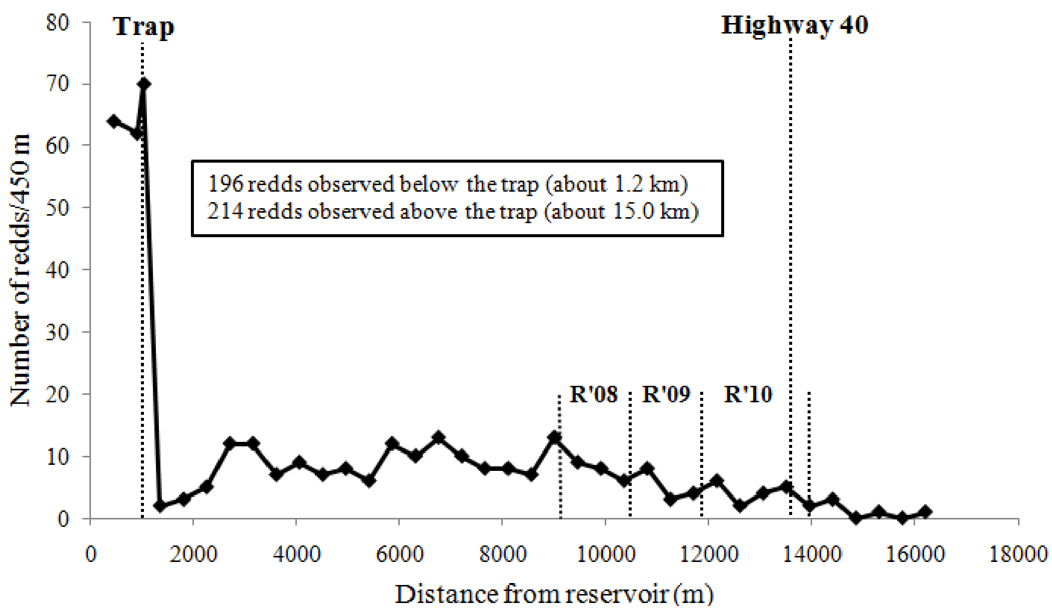

Figure 2-4. 2010 redd count for the Strawberry River (data collected 7/1/2010 – 7/3/2010). "R'08," "R'09," and "R'10" markers refer to when and where those sections of river were restored. Redd counts were conducted before restoration had occurred in the "R'10" section. The "Trap" marker signifies the location of the UDWR fish trapping station.

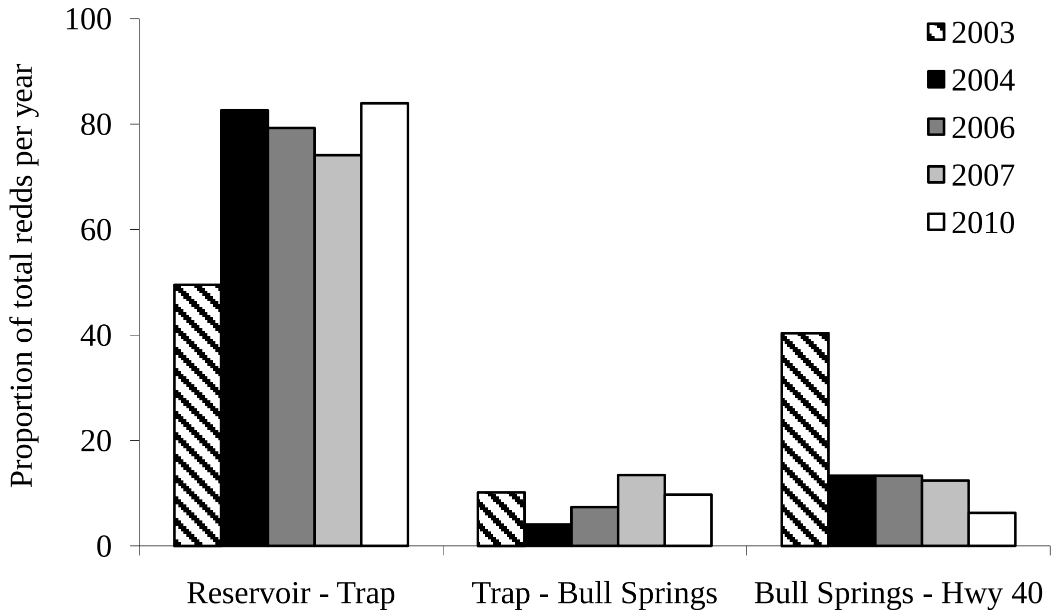

Figure 2-5. Proportion of total redds per year for three major sections of the Strawberry River (e.g., about 50% of redds observed in 2003 occurred between the reservoir and the trap, 10% from the tap to Bull Springs, and 40% from Bull Springs to Highway 40). Years were omitted when redd counts were not conducted in all three reaches.

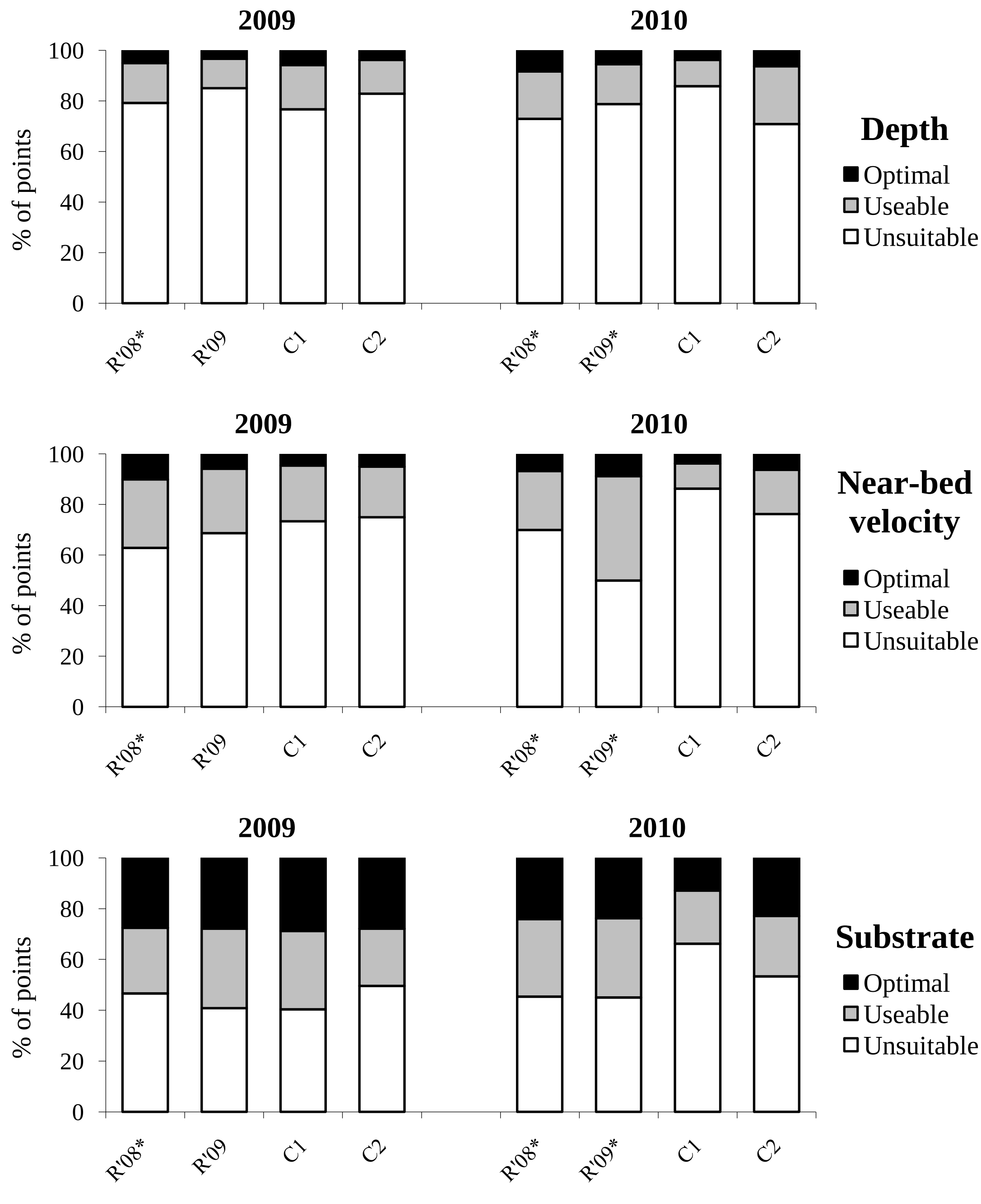

Figure 2-6. Proportion of depth, near-bed velocity, and substrate point measurements classified as optimal (central 50% of use data distributions), useable (between 50% and 94% of use data distributions), and unsuitable (outside the central 95% of use data distributions) for each study reach in 2009 and 2010. Asterisks indicate study reaches that had been restored prior to data collection.

CHAPTER 3

THE EFFECT OF STREAM RESTORATION ON PREFERRED JUVENILE AND ADULT CUTTHROAT TROUT HABITAT IN THE STRAWBERRY RIVER[1]

Abstract – Stream restoration has become a popular management tool for attempting to increase and/or restore fish populations by improving habitat. A section of the Strawberry River, Utah recently underwent a stream restoration project, where two of the main goals were to increase rearing potential and retain larger Bear Lake cutthroat trout *Oncorhynchus clarkia utah* in the river as resident stream fish. The impact of the restoration project on juvenile and resident adult cutthroat trout was primarily investigated by first characterizing preferred cutthroat trout habitat in the Strawberry River, and then assessing the quality of available habitat by comparing restored and unrestored sections of stream and pre-restoration and post-restoration of the same section of stream. Results indicated that adult and juvenile cutthroat trout preferred deeper sections of stream with slightly higher near-bed velocities, moderate substrates sizes, the presence of cover, and pool habitat types. It was difficult to attribute changes in available habitat in restored sections of river to the restoration project due to a limited amount of pre-restoration data, differences between habitat variables in restored/unrestored and pre-restoration/post-restoration study reaches were often small and not statistically significant, and natural temporal and spatial variation among unrestored reaches was high. Long-term monitoring is needed to adequately address issues regarding natural variation and to capture long-term responses to restoration, making it possible to better understand the true effect of restoration on cutthroat trout habitat in the Strawberry River.

[1]Coauthored by Nicolas R. Braithwaite, Scott W. Miller, and Chris Luecke

Introduction

Anthropogenic activities (e.g., over-grazing, dam construction, deforestation, etc.) degrade stream habitat and are a primary culprit in reducing and limiting salmonid populations throughout many fluvial systems (Raymond 1988; Hicks et al. 1991; Platts 1991). Stream restoration is commonly implemented to address the problem of degraded stream habitat (Bernhardt et al. 2007). Restoration methods often attempt to repair and restore habitat through practices such as addition of in-stream structures, alteration of channel planform (e.g., increase sinuosity of a channelized stream), and alteration of flow regimes on regulated rivers (Mullner and Hubert 1995; House 1996; Propst and Gido 2004). Despite the popularity and widespread use of restoration techniques, insufficient monitoring has hindered our ability to determine their true effectiveness (Roni et al. 2002; Bernhardt et al. 2005; Miller et al. 2009). Additionally, the potential of stream restoration projects to enhance fish populations will inherently be linked to how limiting suitable habitat was to the population before restoration began. Therefore, a need currently exists for monitoring of stream restoration projects, including: assessment of what constitutes suitable habitat for that particular system and species, the degree to which habitat was the limiting factor before restoration work was done, and the effect of the restoration on the abundance and distribution of suitable habitat.

Strawberry Reservoir is one of Utah's most heavily used fisheries, receiving more than a million angler hours annually (Wilson and Ward 2003). After completion of the largest recorded rotenone treatment in 1990 to remove undesirable Utah chub *Gila atraria*, Bear Lake cutthroat trout *Oncorhynchus clarkia utah* were established in

Strawberry Reservoir and Strawberry River as the primary sport fish (Ward et al. 2008). The use of Bear Lake cutthroat trout, along with the implementation of a carefully designed slot limit, has resulted in a cutthroat trout population capable of suppressing the Utah chub population (Ward et al. 2008). However, to maintain a population adequate to meet angling demands and control the Utah chub population, it is necessary for the UDWR to stock Bear Lake cutthroat trout in Strawberry Reservoir and the Strawberry River. To avoid predation by the larger reservoir trout, many cutthroat trout are raised to about 200 mm before being stocked, a much higher economic cost to state fish hatcheries than stocking smaller fingerling fish (about 75 mm). This large and necessary stocking effort results in both economic and recreational motivation to increase natural cutthroat trout recruitment in tributaries of Strawberry Reservoir.

Many of the Strawberry Reservoir tributaries were heavily degraded through harmful water use (e.g., dewatering) and land-use practices (e.g., heavy grazing and chemical removal of willows) (Knight et al. 1995; USDA Forest Service 2004). The majority of these practices ended by the early 1990’s, providing an opportunity to use restoration as a catalyst to restore the degraded tributaries to more closely resemble pre-disturbance conditions and processes. Two of the primary goals of early restoration attempts were to increase cutthroat trout recruitment, in order to supplement the reservoir population and to increase the size and number of resident populations of cutthroat trout in the tributaries themselves. Indian Creek and the Strawberry River, the two largest reservoir tributaries, underwent active restoration that included the placement of in-stream structures (e.g., juniper cuttings and logs) and revegetation efforts (e.g., willow plantings). Post-restoration Indian Creek experienced substantial increases in bank stability and riparian vegetation, while the response of the Strawberry River has been notably less significant (USDA Forest Service 2004). Cutthroat trout in Indian Creek have higher fry production, higher fry retention, and generally higher resident populations than the Strawberry River (Knight et al. 1995; Wilson et al. 2004). With the improvements observed on Indian Creek, it was believed that a more successful restoration attempt to improve habitat quality on the Strawberry River, by reducing erosion, increasing the amount of riparian cover, and increasing reach-scale heterogeneity, might ultimately result in an increase in successful recruitment and retaining larger resident cutthroat trout in the river.

In the summer of 2010, the UDWR completed the most recent stream restoration project on the Strawberry River. The restoration plan for the project was based on the popular Rosgen (1994) classification system, and specifically involved placing logs cabled to concrete blocks and/or a series of boulders into the stream and continuing into the stream bank at a slight angle to divert energy from the stream away from banks and increase local scour in excavated pools below structures, decreasing bank angle above and below the structure to promote reconnecting the stream with its natural flood-plain, placing coconut fiber in disturbed areas to reduce erosion short-term, and the planting of willows and other riparian vegetation to reduce erosion long-term. Two main goals of the project were to: (1) increase successful cutthroat trout recruitment by improving the quality and abundance of rearing habitat in the Strawberry River and (2) increase the number of larger resident cutthroat trout in the Strawberry River, also by improving habitat quality.

The objectives of this study were four-fold. First, I examined the cutthroat trout population and size distribution within the Strawberry River. Secondly, I identified and characterized what constituted suitable rearing and resident adult habitat for cutthroat trout in the Strawberry River. Thirdly, I assessed the degree to which habitat may be limiting cutthroat trout in the river. Finally, I assessed the impact of the stream restoration project on the availability of suitable rearing and resident adult habitat.

Methods

Study Reaches

Four study reaches were selected along the upper Strawberry River to characterize the size and distribution of the cutthroat trout population, determine preferred cutthroat trout rearing and resident adult habitat, and quantify the efficacy of active restoration to increase the proportion of suitable rearing and resident adult habitat. The four study reaches were referred to as “Restored ’08,” “Restored ’09,” “Control 1,” and “Control 2” (Figure 3-1). Restored ’08 was a true treatment reach (all data were collected post-restoration), the Restored ’09 and Control 1 acted as both control and treatment reaches at different points in time, and Control 2 was the only true control reach (i.e., no restoration). All study reaches were 500 m and were selected based on the criteria of: overlapping with already established study reaches by other agencies or investigators (e.g., UDWR electrofishing reaches, Utah State University’s Intermountain Center for

River Restoration and Rehabilitation (ICRRR) studies), and being geomorphically representative of the restored reach. Control reaches were used to distinguish geomorphic changes resulting from natural climatic and hydrologic fluctuations from restoration effects.

Population Estimates

Electrofishing surveys were conducted to estimate fish density and size class distributions (i.e., length) of cutthroat trout among the four study reaches. Together, cutthroat trout population size, size distributions, and abundance among reaches, provided a better understanding of the status of resident cutthroat trout populations and their preference for restored or unrestored study reaches. Surveys were conducted in late July and early August in 2009 and 2010 to allow adfluvial spawners an opportunity to return to the reservoir. Block nets were placed across the stream channel at the upstream and downstream boundaries of a 100 m sub-reach, randomly selected within each of the four 500 m study reaches, to ensure a closed population. Each electrofishing survey consisted of three passes of equal effort (i.e. time) with a Smith-Root LR-24 battery powered backpack shocker and three netters capturing and removing cutthroat trout from the population during each pass. Due to the extremely high densities of nongame fish (e.g., mottled sculpin *Cottus bairdi* and redside shiners *Richardsonius balteatus*), only cutthroat trout were targeted for capture. The total number of cutthroat trout captured in each pass, as well as the length and weight of each individual, were recorded.

Cutthroat trout population estimates and corresponding 95% confidence intervals (lower confidence interval bounds were truncated to match the total number of fish captured in cases where the total number captured exceeded the lower confidence interval estimate) for each study reach and year were calculated from electrofishing removal-depletion data using MicroFish version 3.0 (Van Deventer and Platts 1989). One-way ANOVA tests, including study reach as a factor, and Tukey's multiple-comparison tests (threshold $\alpha = 0.05$) were used to determine if the mean lengths of cutthroat trout were significantly different between study reaches in 2009 and 2010 (SAS PROC GLM; SAS 2009).

Habitat Use and Availability

Snorkel surveys, reach-scale, and microhabitat variable measurements were used to determine preferred cutthroat trout rearing and resident adult habitat in the Strawberry River. Snorkel surveys were conducted by two snorkelers beginning at the downstream end of each 500 m reach and slowly moving upstream. Snorkelers called out number and size of all cutthroat trout observed to a recorder on the bank. The recorder then gave the snorkeler a marker to mark the location at which the fish were observed. Cutthroat trout were assigned to one of two size classes: 0-150 mm (juvenile) and >150 mm (adults). At each fish location marker, microhabitat variables within 0.5 m^2 were measured and the habitat unit of the location noted to determine preferred juvenile and adult habitat of the Strawberry River cutthroat trout population. To quantify habitat availability, the same microhabitat variables were measured and habitat unit recorded at 12 equidistant points for 20 equally spaced transects within a randomly selected 200 m of each study reach. All fish location and transect data were collected in late August and early September 2009 and 2010. Similar microhabitat use and availability data were collected in three of the study reaches (Restored ’08, Restored ’09, and Control 1) in 2008 by ICRRR and also included in analyses where applicable.

Microhabitat variables included depth, near-bed flow velocity, substrate size, and cover. Near-bed velocities were measured using a Marsh-McBirney flowmeter (Flo-Mate Model 2000), with all negative flow velocities entered as 0 in analyses. Depth and near-bed velocity were measured at the center of each fish location. The presence of any cover was noted within 0.5 m^2 of marked fish locations. Particle size distributions were estimated by randomly selecting and measuring 10 particles in situ along the intermediate axis within 0.5 m^2 at each fish location. Depth, near-bed velocity, cover, and two particles were measured at each of the 12 equidistant points within the 20 transects of each study reach. However, in 2008 substrate sizes were recorded as visual estimates of the dominant substrate size for a given point or fish location, rather than measurements of individual particles. Cover was classified as: aquatic macrophytes ($\geq$ 100 cm^2), overhanging vegetation (within 1 m of water surface and overhanging by > 0.5 m), undercut bank (> 5 cm deep and > 10 cm long), large woody debris (> 1m in length and at least 10 cm in diameter), boulders (> 125 mm along the intermediate axis), and none (when none of the following criteria were met) (Heitke et al. 2008). Depth was not included as a type of cover because it was already captured by depth measurements.

Reach-scale measurements included the type, average length, and average width of each habitat unit. Habitat type (pool, riffle, run, or glide) was recorded at fish locations and along 200 m of each study reach. Habitat units were qualitatively identified as follows: relatively deep sections of river with slow water velocities were classified as pools, sections with fast water velocities, shallow depths, and turbulent water surfaces were riffles, sections with moderate depth and water velocities were runs, and sections with moderately shallow depths, slow to moderate water velocities, and lack of turbulence in the water surface were glides.

Preferred Habitat

Microhabitat variables of depth, near-bed velocity, and substrate size were characterized as being either “optimal,” “useable,” or “unsuitable” based on the frequency distributions of the microhabitat use data sets (Thomas and Bovee 1993; Al-Chokhachy and Budy 2007). Optimal refers to the range encompassing the central 50% of use data, useable between 50% and 94%, and unsuitable refers to the range falling outside of the central 95% distribution of use data. These characterizations were made for microhabitat variables individually, but also combined to describe multiple microhabitat variables simultaneously. In this composite approach, optimal is a result of all variables being classified as optimal, useable when all variables are classified as useable or a combination of useable and optimal, and unsuitable when one or more variable(s) are classified as unsuitable. Preferred cover was described using a preference ratio, where the cover percentage was observed/available and the relative preference ratio was obtained for all cover types by dividing each individual cover percentage by the highest cover percentage, resulting in a preference ratio ranging from 0 to 1 (e.g., Baltz 1990; Al-Chokhachy and Budy 2007). Due to temporal variability of available habitat, separate characterizations of optimal, useable, and unsuitable habitat and cover preference ratio were calculated for 2008, 2009, and 2010.

Finally, logistic regression was used to identify the preferred rearing and adult resident habitat of Strawberry River cutthroat trout by assessing the influence of different variables on the odds of observing fish presence (e.g., Cantrell et al. 2005; Al-Chokhachy and Budy 2007). Logistic regression is useful for modeling data sets with a dichotomous response. In this case, the response variable was dummy coded as "0" for availability data and "1" for use data. Cover was also dummy coded as "0" for no cover and "1" when any cover type was present. Depth, near-bed velocity, substrate size, and cover were then included as explanatory microhabitat variables in a backward elimination (decision criterion of $\alpha = 0.05$) of non-significant variables. Based on the results of backwards elimination, models were then run with significant explanatory variables for adult and juvenile cutthroat trout in 2008, 2009, and 2010 sampling years. In all models, goodness-of-fit was checked using the Hosmer-Lemeshow goodness-of-fit test, multicollinearity was checked using condition indices and variance inflation factors, influential observations were diagnosed using change in the Pearson Chi-Square and deviance statistics, and a half-normal probability plot with simulated envelope was used to check for outliers (Kutner et al. 2004). Model parameter estimates, standard errors, odds ratio estimates, and the corresponding *P*-value for each variable were used to provide insight regarding the significance and relative influence of explanatory variables on the odds of juvenile and adult presence or absence, using a statistical significance threshold of $\alpha = 0.05$. Logistic regression analyses were conducted using Statistical Analysis System (SAS) version 9.2 (PROC LOGISTIC; SAS 2009).

Habitat as a Limiting Factor

Habitat availability data sets were also used to investigate the degree to which habitat limits juvenile and resident adult cutthroat trout in the Strawberry River. In addition to availability data sets, the UDWR provided temperature data from 2009 and 2010 that was included in limiting factor assessments. The 2009 temperature data were recorded as the average temperature from 70-minute intervals at the UDWR's fish trapping station (about 1.25 km upstream from the reservoir). The 2010 temperature data were recorded as the average temperature from 15-minute intervals at the Highway 40 crossing between the Control 1 and Control 2 study reaches. Ranges of "HSI optimal" habitat were estimated based on cutthroat trout habitat suitability index (HSI) values put forth by Hickman and Raleigh (1982), where a HSI value of 0 is unsuitable and 1 is optimal. The ranges of available habitat in unrestored study reaches were compared to the corresponding HSI optimal ranges, in order to assess whether the restoration has the potential to increase habitat suitability in unrestored sections of the Strawberry River, or if habitat is already near optimal.

Impact of Restoration on Spawning Habitat

The effect of restoration on preferred cutthroat trout rearing and resident adult habitat in the Strawberry River was assessed through before-after (BA), control-impact (CI), and before-after-control-impact (BACI) type analyses. In this study, the UDWR's restoration project is the impact. The BACI style design is ideal because it provides an opportunity for useful comparisons between restored/unrestored reaches and pre-restoration/post-restoration of the same reach, controlling for confounding variables of space and time associated with BA and CI type designs, respectively (Osenberg et al. 2006). However, in many cases data limitations resulted in only BA and CI type analyses being performed.

Due to issues of non-normality and unequal variance, the nonparametric Kruskal-Wallis test was used to test for statistically significant differences in depth, near-bed velocity, and substrate size from availability data among the four study reaches in 2008, 2009, and 2010 (i.e., CI) (SAS PROC NPAR1WAY; SAS 2009). Significant results from the Kruskal-Wallis tests were followed by Tukey's multiple-range comparison tests (threshold $\alpha = 0.05$) on the ranked data to further investigate where differences occurred amongst the study reaches (SAS PROC GLM, SAS 2009) (Neumann and Allen 2007). Data used in Kruskal-Wallis tests consisted of one depth, near-bed velocity, and substrate size measurement from a randomly selected point from each transect, for 2008, 2009, and 2010 sampling occasions. The data was analyzed in this manner to provide an unbiased representation of each transect, without being overwhelmed by the amount of data associated with using all point measurements (e.g., everything becomes significant). Kruskal-Wallis tests and Tukey's multiple-range comparisons (threshold $\alpha = 0.05$) were also used to make comparisons among "differences" in the microhabitat variables of depth, near-bed velocity, and substrate (i.e., BACI) from 2008 to 2009 and from 2009 to 2010 (SAS PROC NPAR1WAY; SAS 2009). Data used in "differences" analyses consisted of the calculated difference between the 2008 and 2009 and 2009 and 2010 value of each point, paired in space, allowing for comparison of changes to microhabitat availability across sampling years.

Simple chi-squared contingency tables were used to analyze the effects of restoration on qualitatively described preferred habitat (Rogers and White 2007). Data used in chi-squared analyses included the relative proportion of optimal, useable, and unsuitable habitat observed in study reaches, the relative proportion of cover among study reaches, and the relative proportion of reach-scale habitat units in different reaches and years.

Results

Population Estimates

Cutthroat trout population estimates were significantly higher in the Control 2 study reach than any of the other study reaches in 2009, while the Restored ’08 and Restored ’09 study reaches had significantly higher populations than the Control 1 and Control 2 study reaches in 2010 (Figure 3-2). The estimated overall cutthroat trout population size range across all four study reaches was moderately higher in 2009 (270 - 319) than 2010 (233 - 248).

The distribution of cutthroat trout length was ecologically similar throughout study reaches and across years, typically following a relatively normal distribution ranging from about 90 mm to 200 mm (Figure 3-3). The mean lengths of cutthroat trout were significantly different statistically among study reaches in 2009 (one-way ANOVA: $F = 6.46$, df = 3, 161, $P = 0.0004$), where the Tukey’s multiple-comparison test revealed the only significant difference to be occurring between the Control 2 ($\bar{x} = 150$ mm) and Restored ’09 ($\bar{x} = 130$ mm) study reaches. The mean lengths of cutthroat trout were also significantly different statistically among study reaches in 2010 (one-way ANOVA: F = 3.55, df = 3, 229, P = 0.0152), where the Tukey's multiple-comparison test revealed the difference to be occurring between the Control 1 ($\bar{x}$ = 149 mm) study reach and the Restored '08 ($\bar{x}$ = 132 mm) and Restored '09 ($\bar{x}$ = 136 mm) study reaches.

Preferred Rearing and Resident Adult Habitat

Relative to available microhabitat, cutthroat trout in the Strawberry River were generally observed using deeper sections of stream, slightly higher near-bed velocities, and modestly larger substrate sizes (Figure 3-4). In 2008, about 22% of cutthroat trout were observed using cover, while cover was present in about 42% of availability data. However, about 46% of observed adult and juvenile cutthroat trout were using cover in 2009 and 31% in 2010, where cover availability was about 31% and 24%, respectively. Pools appeared to be the preferred reach-scale habitat unit for the majority of observed fish. Almost 85% of all cutthroat trout were observed in pool habitat types in 2009, with 65% in pools and 20% in runs in 2010. In terms of length, pools only accounted for about 48% of available habitat in 2009 and about 38% in 2010.

Optimal, useable, and unsuitable microhabitat characterizations for depth, near-bed velocity, and substrate size, also suggested that cutthroat trout in the Strawberry River preferred deep sections of stream with moderate near-bed velocities and modest substrate sizes (Table 3-1). Ranges of optimal, useable, and unsuitable depths, near-bed velocities, and substrate sizes from use data were similar between 2008, 2009, and 2010. Ranges were also similar across juvenile and adult age classes, with one exception being adults selecting for slightly deeper habitat than juveniles. In terms of cover, large woody debris (LWD) was the most preferred cover type for both adult and juvenile cutthroat trout in 2008, 2009, and 2010 (Figure 3-5). After LWD, adults and juveniles appeared to prefer other cover types similarly, with the exception of adults not utilizing boulders as a cover type (Figure 3-5).

The 2008, 2009, and 2010 logistic regression models for predicting adult and juvenile cutthroat trout presence or absence at the microhabitat scale indicated depth and cover were the most significant explanatory variables, with increases in depth appearing to be strongly positively correlated with presence (Table 3-2). Interestingly, cover was negatively correlated with predicting cutthroat trout presence in the 2008 adult and juvenile models, but positively correlated in all other models where it was it was included as an explanatory variable. Near-bed velocity was consistently predicted adult cutthroat trout presence or absence, with increases in velocity correlating with an increase in the odds of adult presence. Generally, substrate size was not a significant explanatory variable because it was only significant in half of the models and the corresponding odds ratio estimates when significant were all near 1.

Habitat as a Limiting Factor

Available depths, substrate sizes, and percentage of cover in unrestored study reaches tended to either overlap or fall slightly below the lower HSI optimal ranges, available near-bed velocities in unrestored study reaches and maximum daily temperatures in June fell mostly within the HSI optimal ranges, and maximum daily temperatures in July and August exceeded the HSI optimal range, almost without exception (Figure 3-6). The maximum average daily temperature exceeded 20^{o}C in 50%

of days during July and August in 2009 and 26% in 2010. Limited data and high inter-annual variability made it difficult to determine if the available percentage of pools in unrestored sections of the Strawberry River fell within or outside the optimal range.

Impact of Restoration on Spawning Habitat

In terms of microhabitat, restored study reaches tended to have a slightly more narrow range of depths and percentages of cover, as well as slightly higher mean near-bed velocities and substrate sizes than unrestored study reaches (Figure 3-7). The differences in mean microhabitat variables and percentage of cover appeared to be relatively consistent across years, with the greatest temporal changes often occurring in unrestored study reaches (e.g., depth in Control 2) (Figure 3-7). The percentage of cover was significantly higher in 2008 in the Restored ’08 and Restored ’09 study reaches than in 2009 (χ^2 = 21.900, df = 1, P < 0.0001) and 2010 (χ^2 = 16.130, df = 1, P < 0.0001) which was primarily driven by higher levels of aquatic macrophytes.

In terms of length, the proportions of reach-scale habitat types in restored study reaches were relatively similar and primarily composed of pools and riffles, while the composition of reach-scale habitat in unrestored study reaches tended to be more variable (Figure 3-8). There was a significantly lower proportion of pools in restored study reaches relative to unrestored study reaches in 2009 (χ^2 = 28.880, df = 1, P < 0.0001), but a significantly higher proportion in 2010 (χ^2 = 11.496, df = 1, P = 0.0007). In terms of total number of habitat units, restored study reaches had a mean of about 41 habitat units per 200 m (SD = 12.55, N = 5), while unrestored study reaches had a mean of 29 (SD = 7.00, N = 3). However, the difference in the mean number of habitat units between restored and unrestored study reaches was not significant (one-way ANOVA: $F = 2.23$, df = 1, 6, $P = 0.1864$).

Generally, comparisons between study reaches for each year of sampling showed that microhabitat characteristics were not significantly different among study reaches, with only near-bed velocity in 2009 being significantly different (Table 3-3). The Tukey's multiple-range comparison showed the significant difference in near-bed velocity in 2009 to be occurring between the Restored '08 and Control 2 study reaches. Comparisons of "differences" between years for study reaches indicated a statistically significant change in depth and near-bed velocity among study reaches between 2009 and 2010 and for depth between 2008 and 2009, while all other "differences" comparisons were not significant (Table 3). Tukey's multiple-range comparisons showed the significant difference in change in depth between 2008 and 2009 occurred between the Restored '09 (decrease in depth) and Control 1 (increase in depth) study reaches, and that depth decreased significantly more in the Control 2 study reach than any of the other study reaches between 2009 and 2010. The significant change in near-bed velocity between 2009 and 2010 occurred between the Control 2 study reach and the Restored '08 and Restored '09 study reaches, based on Tukey's multiple-range comparisons.

The distribution of composite optimal, useable, and unsuitable juvenile and adult cutthroat trout microhabitat tended to vary more by year than among individual study reaches, with the most substantial variation occurring in the Control 2 study reach between 2009 and 2010 (Figure 3-9). The Restored '09 study reach saw a small decline in the proportion of optimal and useable habitat in the year following restoration, while the Control 1 study reach saw a slight increase (Figure 3-9). Overall, the average proportion of composite microhabitat suitability was not significantly different between restored and unrestored study reaches for juveniles (χ^2 = 0.577, df = 2, *P* = 0.749) or adults (χ^2 = 0.223, df = 2, *P* = 0.894).

Discussion

Population Estimates

The distribution of cutthroat trout observed among study reaches and years in the Strawberry River appears to be the result of interplay among restoration, beaver *Castor canadensis* activity, and natural population fluctuations. The addition of instream structures and beaver activity can result in favorable salmonid habitat and often an increase in population abundance (Pollock et al. 2003; Whiteway et al. 2010). The Control 2 study reach had significantly more cutthroat trout and a higher level of beaver activity than any other study reach in 2009, followed by a significant reduction in beaver activity and estimated cutthroat trout population in 2010. Also in 2010, cutthroat trout in the Strawberry River appeared to be selecting more strongly for restored sections of river over unrestored sections. However, the total population estimate for all study reaches was significantly lower in 2010 than in 2009, implying cutthroat trout may be redistributing themselves into restored sections of river, but not increasing in abundance (e.g., Gowan and Fausch 1996). While consistent stocking efforts occurred during this study, it is still important to consider the natural fluctuations of salmonid stream populations that will dampen the inference that can be derived from results, especially given the relatively short duration of monitoring (Platts and Nelson 1988).

There was no evidence that the restoration increased retention of larger resident cutthroat trout or large adfluvial cutthroat trout from Strawberry Reservoir, as cutthroat trout captured during the electrofishing surveys were dominated by relatively small (< 200 mm) resident fish. Additionally, the statistically significant difference observed in mean lengths between several of the study reaches are likely not biologically significant, given the small differences (i.e., less than 20 mm in all cases). Orme (1999) found that fry in Strawberry Reservoir enclosures experienced significantly higher growth and survival rates than fry in tributary enclosures, suggesting the absence of larger cutthroat trout in the Strawberry River may be an inability of the river to compete with Strawberry Reservoir in terms of food production and survival rates.

Preferred Rearing and Resident Adult Habitat

Cutthroat trout in the Strawberry River preferred deeper sections of stream with slightly elevated near-bed velocities, moderate substrate sizes, and the presence of cover at the microhabitat-scale and preferred pools at the reach-scale. These results are similar to commonly described preferred salmonid habitat characteristics (e.g., Hickman and Raleigh 1982; Beecher et al. 2002; Quiñones and Mulligan 2005; Al-Chokhachy and Budy 2007). The value of habitat preference results to this study was their usefulness in interpreting the observed effects, or lack thereof, of restoration on available rearing and resident habitat for cutthroat trout in the Strawberry River.

Habitat as a Limiting Factor

The comparison of habitat availability relative to optimal ranges for cutthroat trout did not establish nor rule out habitat as the limiting factor for the Strawberry River population of cutthroat trout, as most habitat variables measured were either within or just below the lower optimal range. One notable exception was the relatively high maximum daily temperatures observed during July and August in 2009 and 2010. While never exceeding the lethal limit for Bonneville cutthroat trout, it is possible temperatures were high enough to hinder growth during a critical period by increasing metabolic costs and reducing consumption (Johnstone and Rahel 2003).

Impact of Restoration on Spawning Habitat

Based on the short-term monitoring presented in this study, it is difficult to attribute changes to the availability of preferred cutthroat trout habitat in the Strawberry River to the restoration. There were three primary factors acting to limit conclusions and inference:

(1) It was not clear that improvements to cutthroat trout habitat in restored reaches would necessarily be biologically or ecologically relevant because differences between restored/unrestored study reaches and pre-restoration/post-restoration of the same study reach were generally small and not statistically significant.

(2) Sampling locations in this study design were not independent of one another and thus could be viewed more as pseudoreplicates than true replicates (Hurlbert 1984). Issues of temporal and spatial variation were apparent in terms of uneven beaver activity among study reaches and differences in stream discharge among years. Beaver have been

shown to have significant effects on different physical and ecological habitat characteristics in stream systems (Naiman et al. 1988; Snodgrass and Meffe 1998). The potential for high natural variation in habitat variables in the Strawberry River was evident in the substantial changes observed in micro and reach-scale habitat in the Control 2 study reach between 2009 and 2010 sampling occasions. These inference problems related to spatial and temporal variation can be overcome through long-term monitoring (ideally both pre and post-restoration or impact) and establishment of a good control reach or reaches, as purposed by Stewart-Oaten et al. (1986).

(3) The monitoring results presented in this study only span a 0 to 2 year post-restoration period, a considerably limited amount of time to assess the full effect of restoration. Stream restoration projects may be more accurately described as a disturbance immediately following restoration completion, meaning adequate monitoring of a project requires more long-term efforts to fully assess restoration impacts (Kondolf 1995; Klein et al. 2007; Miller et al. 2009). The concept of restoration as a short-term disturbance is especially important regarding the impact revegetation efforts may ultimately have on cutthroat trout habitat in the Strawberry River. Riparian vegetation can have a significant impact on cover, substrate size distribution, and maximum daily stream temperatures through a variety of pathways (Wesche et al. 1987; Gregory 1992; Li et al. 1994), with studies assessing the response of riparian vegetation to a disturbance often measured over many years or even decades (e.g., Platts and Nelson 1985; Green and Kauffman 1995; Shafroth et al. 2002). Therefore, changes to available habitat in

restored reaches of the Strawberry River may not have occurred yet, despite the fact that all active restoration work has been completed.

Conclusion

The current inability to fully assess the impact of the restoration project on cutthroat trout in the Strawberry River should not necessarily be viewed as evidence that the restoration project will not have a significant impact on the availability of preferred cutthroat trout habitat in the Strawberry River. It will be important to continue the monitoring efforts initiated in this study in order to further tease out the complicating factors of variation in time and space, as well as to capture potential long-term responses. With the need for continued long-term monitoring in mind, perhaps the most important contribution of this study was to create a monitoring protocol and establish a baseline data set. Ideally, similar monitoring efforts to those described and conducted in this study will be replicated in five and eventually ten year intervals to more completely assess the true effect of the restoration project.

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Table 3-1. Optimal (central 50% of use data distributions), useable (between 50% and 94% of use data distributions), and unsuitable (outside the central 95% of use data distributions) microhabitat variable ranges for adult and juvenile cutthroat trout in the Strawberry River in 2008, 2009, and 2010.

	Suitability	Depth (m)	Near-bed velocity (m/s)	Substrate size (mm)
		Adults		
2008	Optimal	0.40 - 0.70	0.00 - 0.04	32 - 64
	Useable	0.31 - 0.39 & 0.71 - 0.85	0.05 - 0.23	2 - 31 & 65 - 90
	Unsuitable	< 0.31 & > 0.85	> 0.23	< 2 & > 90
2009	Optimal	0.43 - 0.63	0.00 - 0.20	41 - 67
	Useable	0.28 - 0.42 & 0.64 - 0.82	0.21 - 0.30	16 - 40 & 68 - 84
	Unsuitable	< 0.28 & > 0.82	> 0.30	< 16 & > 84
2010	Optimal	0.41 - 0.62	0.00 - 0.10	34 - 58
	Useable	0.23 - 0.40 & 0.63 - 0.86	0.11 - 0.31	6 - 33 & 59 - 90
	Unsuitable	< 0.23 & > 0.86	> 0.31	< 6 & > 90
		Juveniles		
2008	Optimal	0.29 - 0.48	0.00 - 0.06	22 - 64
	Useable	0.19 - 0.28 & 0.49 - 0.68	0.07 - 0.33	8 - 21 & 65 - 91
	Unsuitable	< 0.19 & > 0.68	> 0.33	< 8 & > 91
2009	Optimal	0.40 - 0.61	0.00 - 0.06	41 - 68
	Useable	0.23 - 0.39 & 0.62 - 0.82	0.07 - 0.24	6 - 40 & 69 - 94
	Unsuitable	< 0.23 & > 0.82	> 0.24	< 6 & > 94
2010	Optimal	0.32 - 0.58	0.00 - 0.09	32 - 62
	Useable	0.16 - 0.31 & 0.59 - 0.75	0.10 - 0.29	7 - 31 & 63 - 90
	Unsuitable	< 0.16 & > 0.75	> 0.29	< 7 & > 90

Table 3-2. Parameter estimates, standard errors, odds ratio estimates, and *P*-values for significant explanatory variables from 2008, 2009, and 2010 logistic regression analyses for Strawberry River juvenile (<150 mm) and adult (>150 mm) cutthroat trout.

	Variable	Parameter estimate	Standard error	Odds ratio estimate	*P*-value
	Adults				
2008	Intercept	-9.619	2.031		<0.0001
	Depth (cm)	0.212	0.042	1.236	<0.0001
	Near-bed velocity (cm/s)	0.072	0.036	1.074	0.0457
	Substrate size (mm)	0.064	0.019	1.066	0.0006
	Cover	-3.182	0.801	0.041	<0.0001
2009	Intercept	-6.72	1.385		<0.0001
	Depth (cm)	0.081	0.020	1.084	<0.0001
	Near-bed velocity (cm/s)	0.092	0.036	1.097	0.0095
	Cover	3.123	0.850	22.720	0.0002
2010	Intercept	-3.631	0.733		<0.0001
	Depth (cm)	0.107	0.016	1.112	<0.0001
	Near-bed velocity (cm/s)	0.103	0.028	1.109	0.0002
	Substrate size (mm)	-0.019	0.007	0.982	0.0107
	Juveniles				
2008	Intercept	-2.660	0.616		<0.0001
	Depth (cm)	0.142	0.023	1.152	<0.0001
	Cover	-0.986	0.426	0.373	0.0206
2009	Intercept	-3.622	0.633		<0.0001
	Depth (cm)	0.063	0.010	1.064	<0.0001
	Substrate size (mm)	0.022	0.008	1.023	0.0055
	Cover	2.862	0.428	17.499	<0.0001
2010	Intercept	-2.974	0.541		<0.0001
	Depth (cm)	0.068	0.012	1.070	<0.0001
	Near-bed velocity (cm/s)	0.093	0.024	1.097	0.0001
	Cover	1.323	0.377	3.753	0.0005

Table 3-3. Results of Kruskal-Wallis tests, testing differences between different microhabitat variables among study reaches in 2008, 2009, and 2010. Differences between 2008-2009 and 2009-2010 measurements of three microhabitat variables shown in the bottom two sections of the table.

Year	Variable	DF	χ^2	*P*-value
2008	Depth	2	2.22	0.3304
	Near-bed velocity	2	2.38	0.3043
	Substrate size	2	1.02	0.5996
2009	Depth	3	6.48	0.0905
	Near-bed velocity	3	9.60	0.0223
	Substrate size	3	1.90	0.5936
2010	Depth	3	2.92	0.4048
	Near-bed velocity	3	5.71	0.1267
	Substrate size	3	7.55	0.0564
2008 - 2009	Depth	2	6.11	0.0471
	Near-bed velocity	2	5.36	0.0686
	Substrate size	2	0.19	0.9099
2009 - 2010	Depth	3	18.18	0.0004
	Near-bed velocity	3	13.96	0.0030
	Substrate size	3	5.30	0.1510

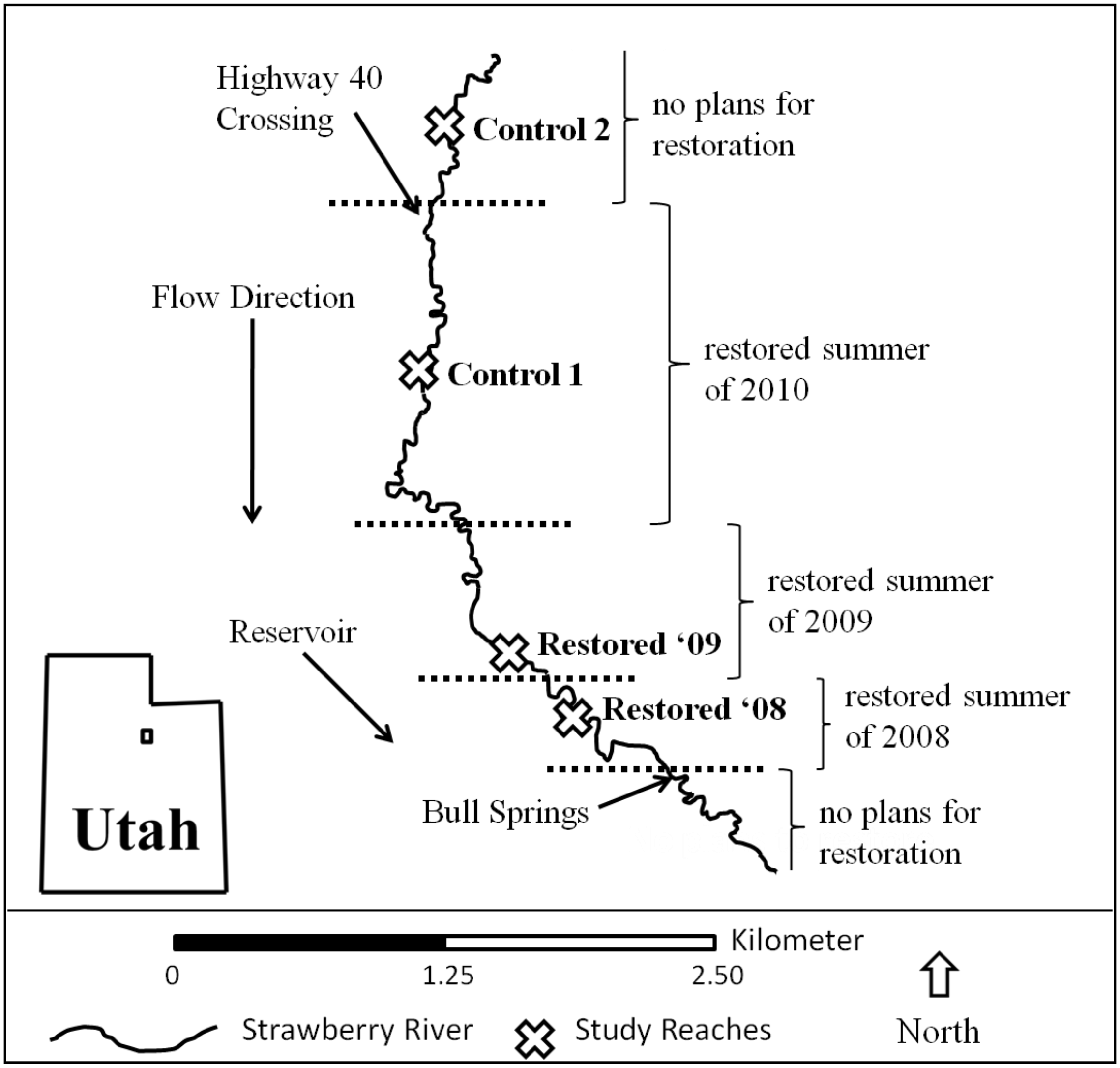

Figure 3-1. Site map of the Strawberry River study area. Dashed lines represent breaks in different years of the restoration project (summers of 2008, 2009, and 2010). The "X's" mark four 500 meter study reaches ("Restored '08," "Restored '09," "Control 1," and "Control 2").

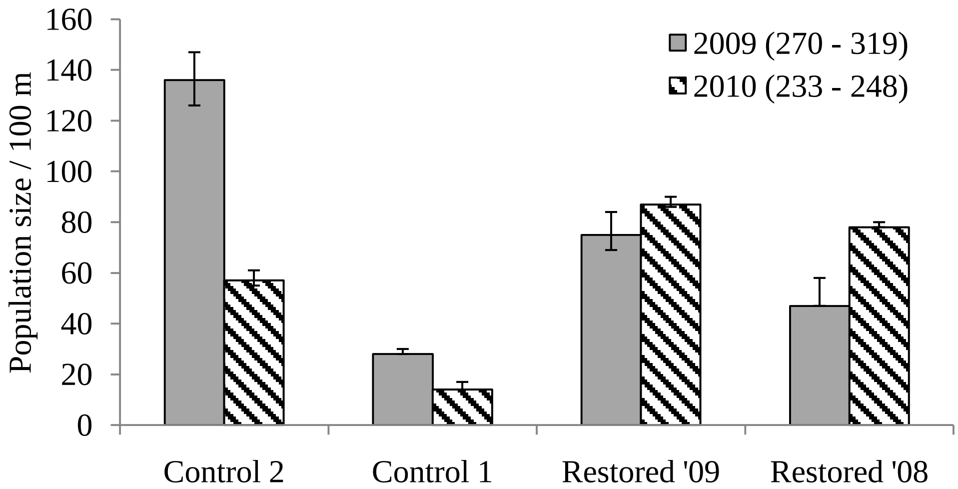

Figure 3-2. Cutthroat trout population estimates per 100 m for each study reach from 2009 and 2010 electrofishing surveys. Error bars represent truncated 95% confidence intervals. Numbers in parenthesis represent the estimated total population range for all four study reaches in 2009 and 2010.

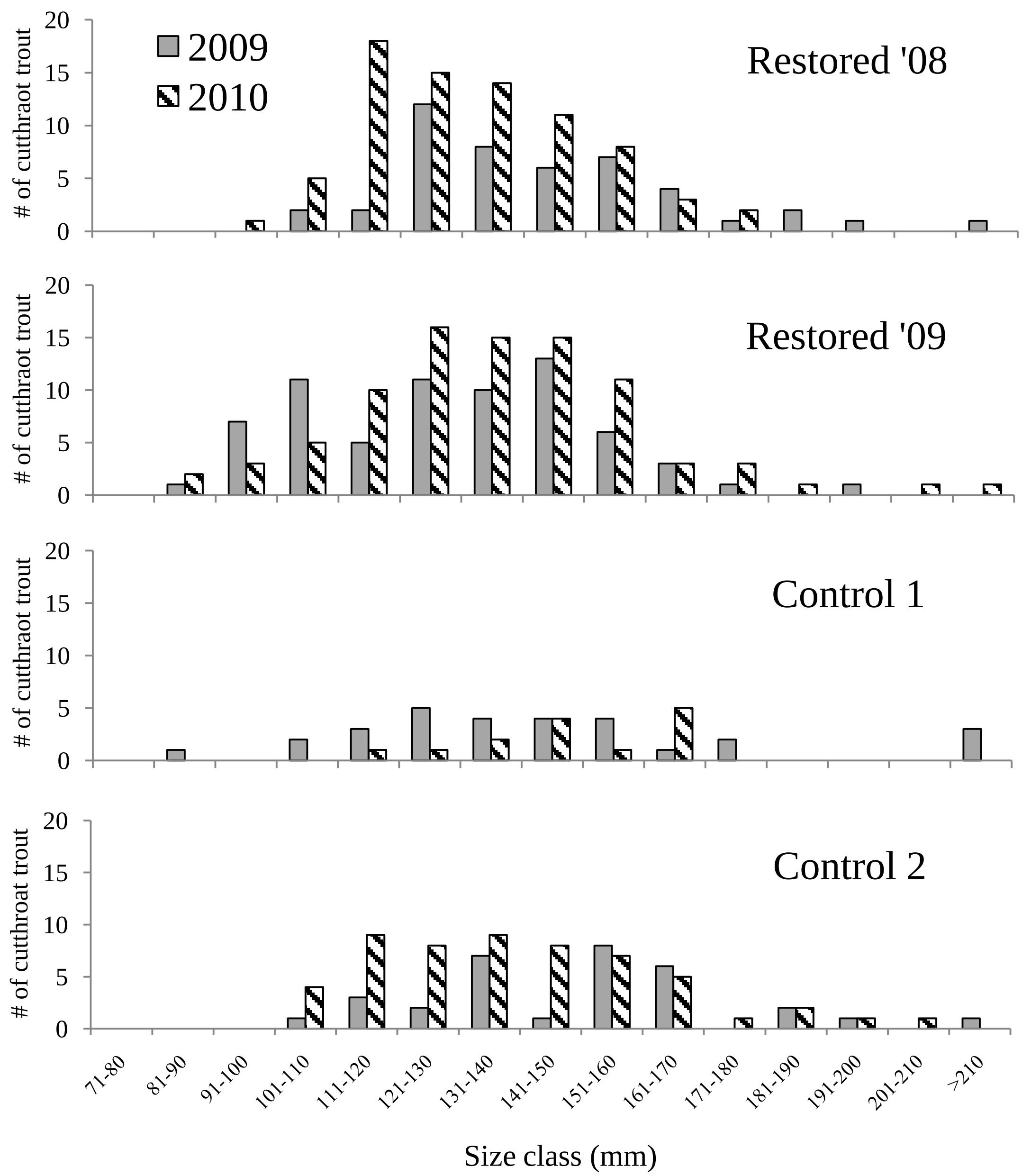

Figure 3-3. Cutthroat trout size class frequency distributions for each of the four study reaches from 2009 and 2010 electrofishing surveys.

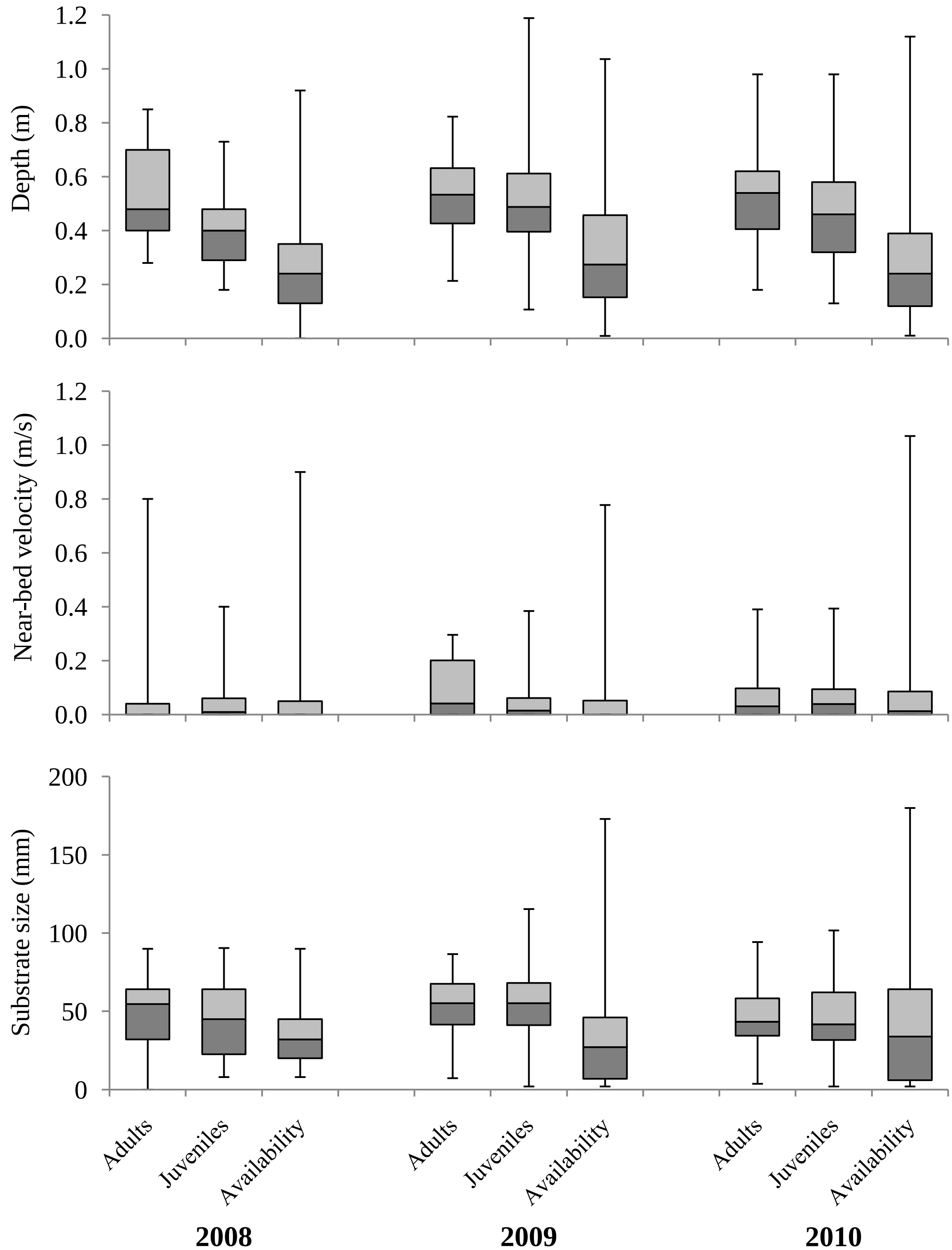

Figure 3-4. Box plots showing the minimum, 1st quartile, median, 3rd quartile, and maximum of three microhabitat variables for adult and juvenile cutthroat trout from marked fish locations, as well as available habitat from point measurements within transects in 2008, 2009, and 2010.

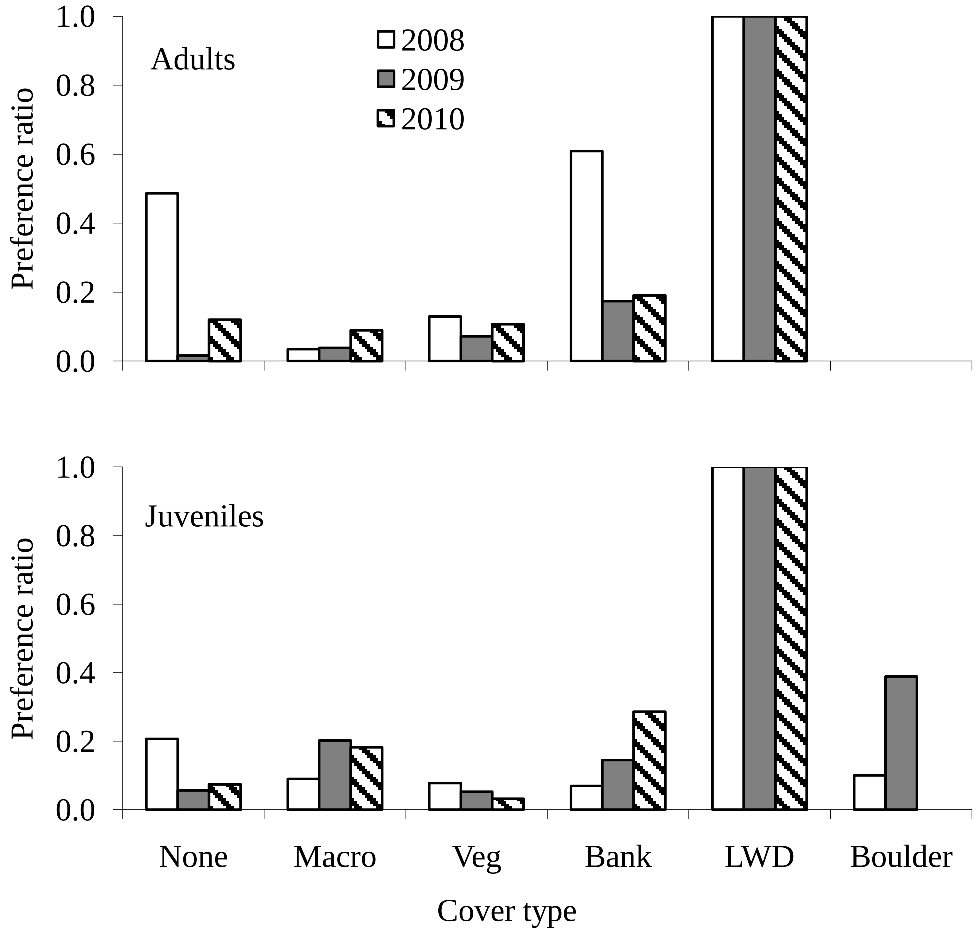

Figure 3-5. Preference ratio of different cover types for adult and juvenile cutthroat in the Strawberry River in 2008, 2009, and 2010. “None” is no cover, “Macro” is aquatic macrophytes, “Veg” is overhanging riparian vegetation, “Bank” is undercut stream bank, “LWD” is large woody debris, and “Boulder” is particles > 125 mm.

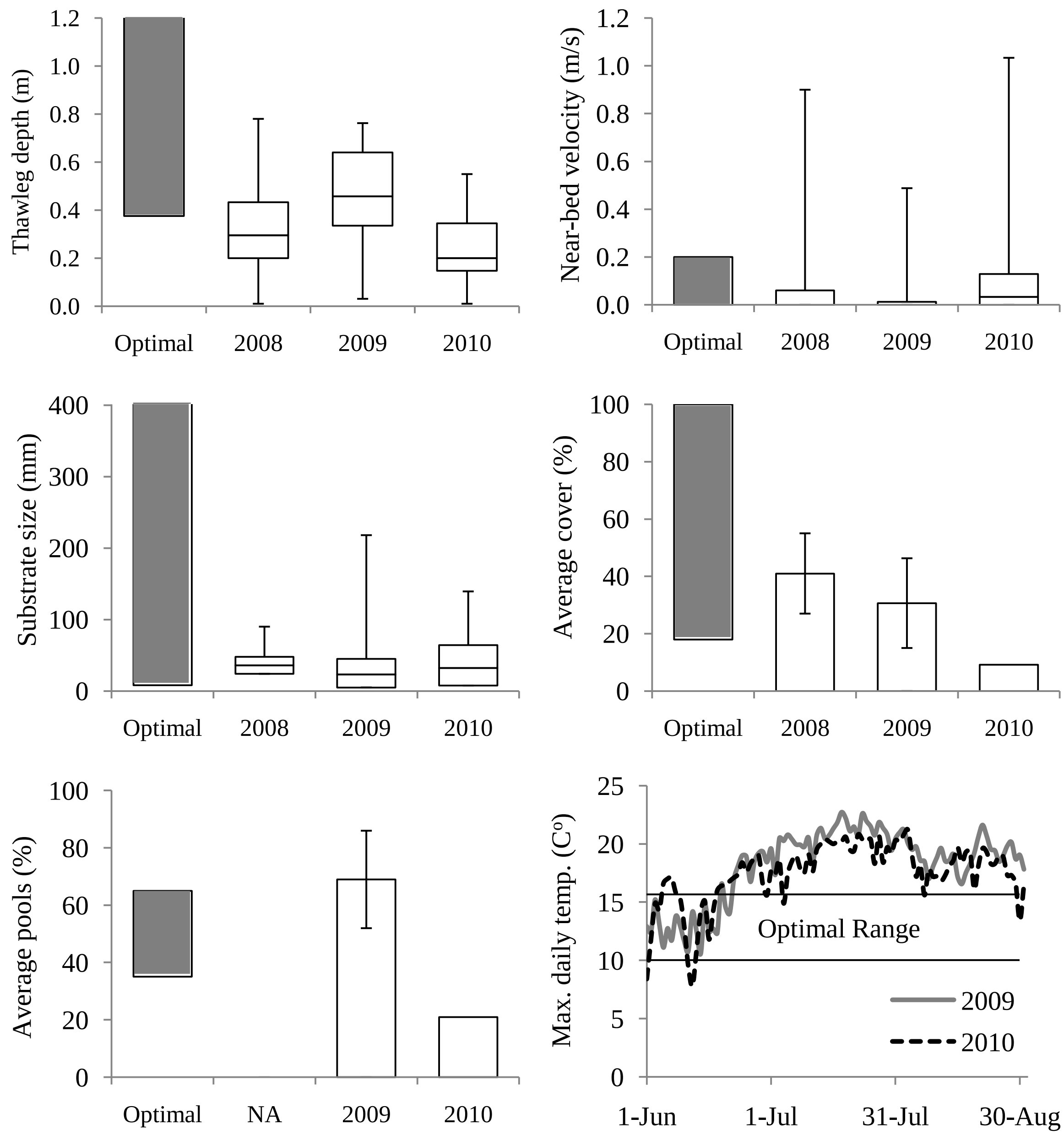

Figure 3-6. Comparison of available habitat ranges observed in 2008, 2009, and 2010 unrestored study reaches and HSI optimal ranges suggested for adult and juvenile cutthroat trout by Hickman and Raleigh (1982). Box plots show the minimum, 1st quartile, median, 3rd quartile, and maximum from availability data. Error bars in cover and pool graphs represent maximum and minimum values. Temperature data were maximum daily temperatures for June to August in 2009 and 2010.

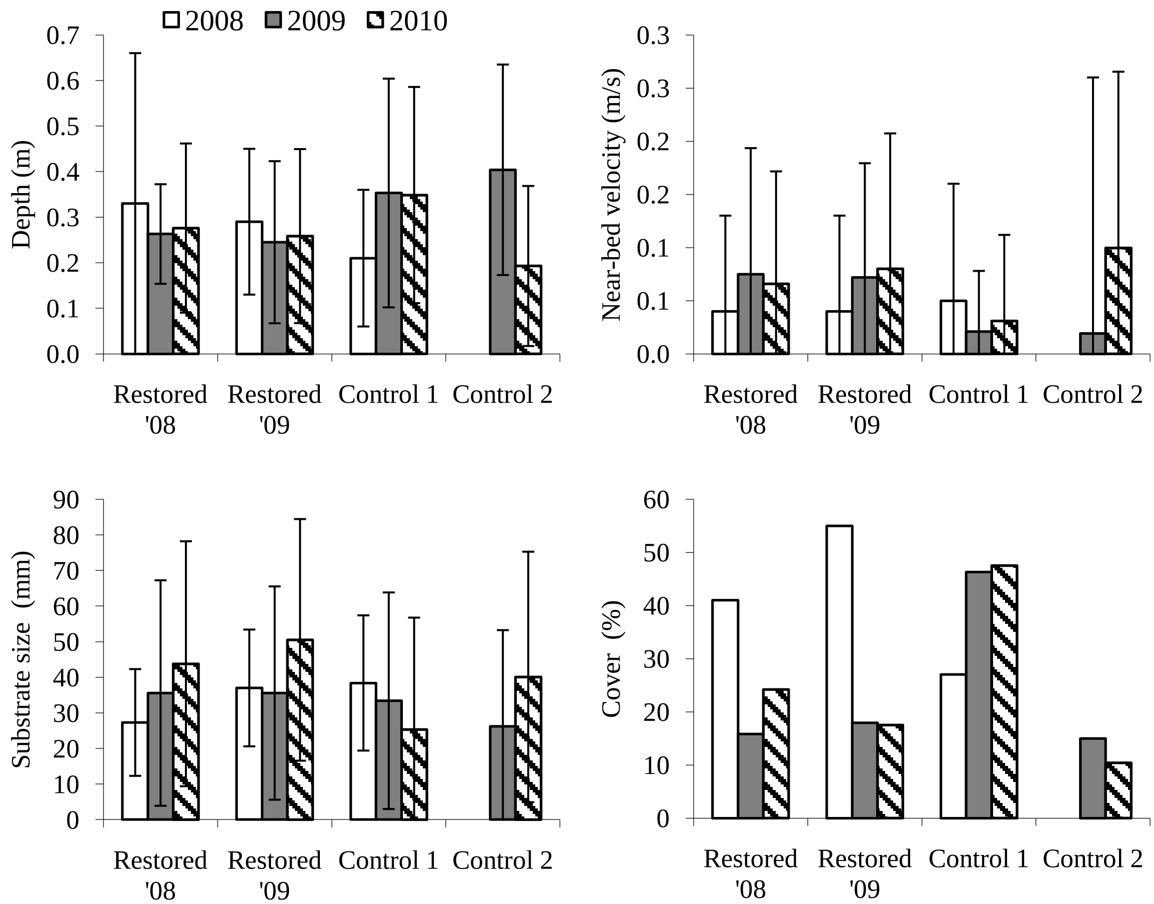

Figure 3-7. Mean depth, near-bed velocity, and substrate size, as well as percentage of cover for each study reach in 2008, 2009, and 2010. Values were estimated from point measurement within transects (*n* = 240, per study reach). Error bars represent one standard deviation. Only the Restored ’08 study reach had been restored in 2008, both Restored ’08 and Restored ’09 study reaches had been restored in 2009, and all study reaches except Control 2 had been restored in 2010.

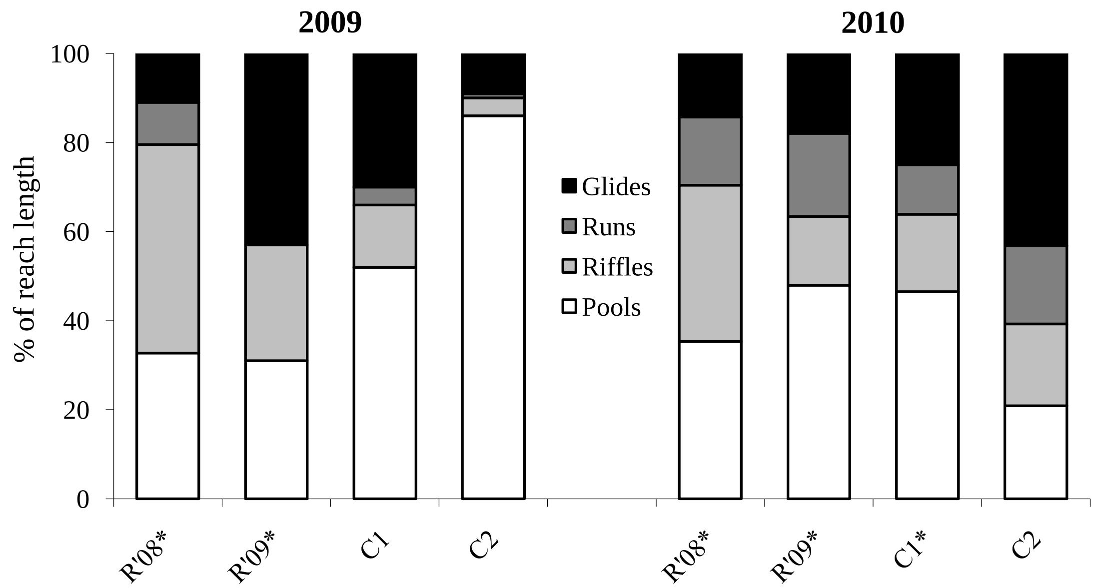

Figure 3-8. Composition of reach-scale habitat units for each study reach in 2009 and 2010. Asterisks indicate study reaches where restoration had occurred before sampling.

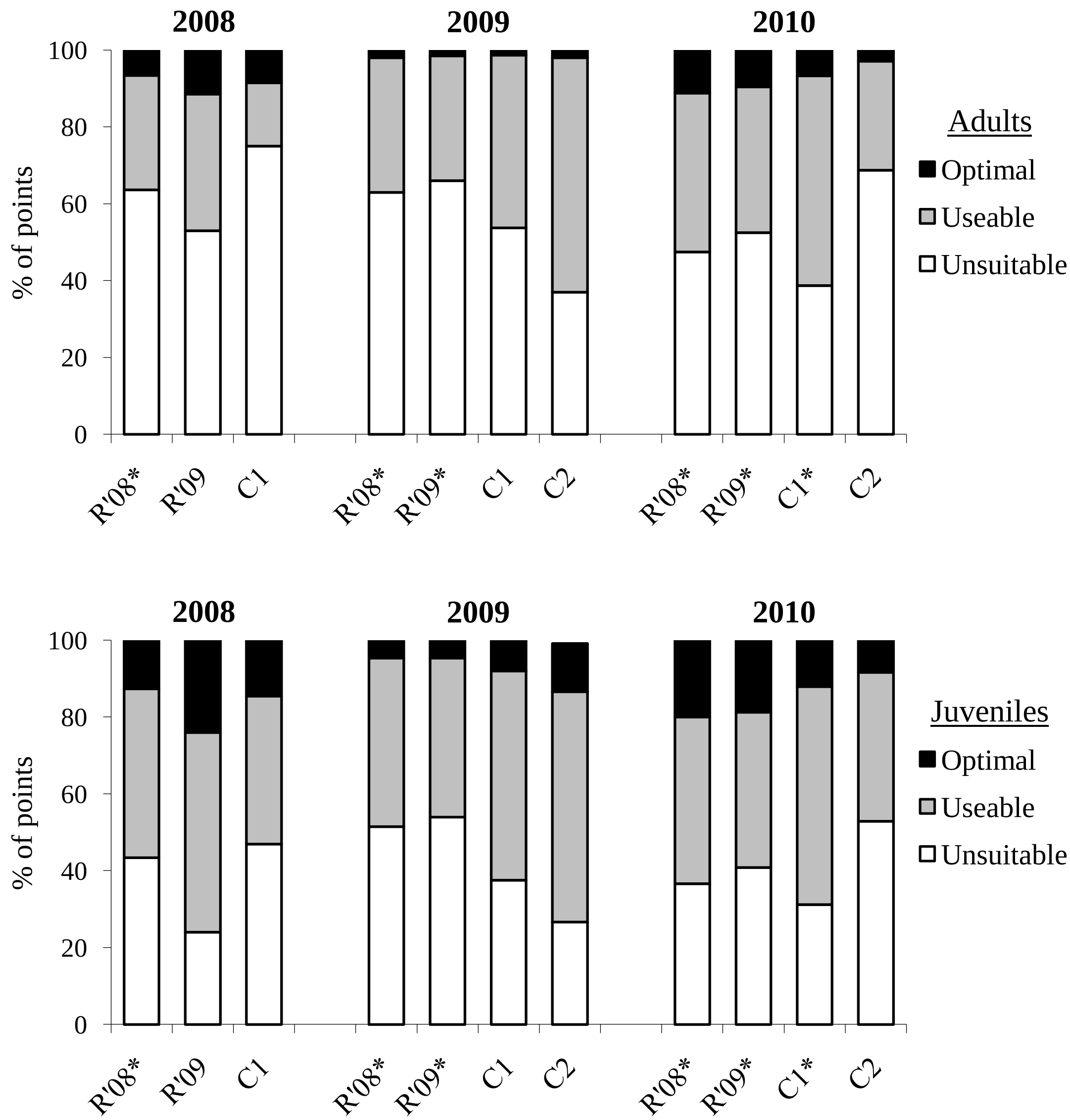

Figure 3-9. Proportion of composite (depth, near-bed velocity, and substrate size) optimal (central 50% of use data distributions), useable (between 50% and 94% of use data distributions), and unsuitable (outside the central 95% of use data distributions) microhabitat for adult and juvenile cutthroat trout in each study reach in 2008, 2009, and 2010. Asterisks indicate study reaches that had been restored prior to data collection.

CHAPTER 4

CONCLUSIONS

This study described preferred spawning, rearing, and resident adult habitat of Bear Lake cutthroat trout *Oncorhynchus clarkia utah* in the Strawberry River, investigated the degree to which habitat may be limiting cutthroat trout in the system, and provided a short-term assessment of the effect of a restoration project on the preferred cutthroat trout habitat in the Strawberry River. Additionally, the length and size distribution of the cutthroat trout population in the Strawberry River was measured. The following is a summary of the major findings of this study.

1) The adfluvial population of Strawberry Reservoir cutthroat trout preferred shallower depths with faster near-bed velocities and moderate substrate sizes in riffle habitat types for spawning. These results are similar to commonly described preferred salmonid spawning habitat characteristics.

2) The number of redds observed in the Strawberry River was significantly higher in the first 1.25 km (reservoir to the UDWR fish trap) than the following 12.5 km (fish trap to the Highway 40 crossing), a trend that is likely a result of the life history strategy specific to the Bear Lake cutthroat trout strain, the potential for the UDWR fish trapping station to act as a barrier, and more desirable spawning habitat from the reservoir to the fish trap.

3) It was unclear if habitat was limiting spawning activity in the Strawberry River. The substantially higher redd densities in the section of river between the reservoir and fish trap and in nearby Indian Creek suggest that spawning activity may be limited more by number of spawners than availability of suitable habitat. However, redd densities

upstream of the fish trap were still relatively high when compared with other salmonid streams.

4) Restored study reaches tended to have slightly higher near-bed velocities, more favorable particle size distributions, and a higher proportion of riffles when compared to pre-restoration and control study reaches, these changes indicated that the restoration may have started a shift toward more favorable spawning habitat in restored sections of the river.

5) Cutthroat trout population estimates were significantly higher in the Control 2 study reach than any other study reach in 2009, and then decreased significantly in 2010, likely due to the effect of beaver dam presence in 2009 and absence in 2010. Population estimates in restored study reaches tended to be higher than unrestored reaches and increased between 2009 and 2010. However, my results suggested that cutthroat trout may have been redistributing themselves into restored sections of river, but not increasing in overall abundance.

6) The length distributions of cutthroat trout captured during electrofishing surveys were not significantly different among study reaches or between years. The larger adfluvial cutthroat trout that entered the Strawberry River for spawning almost exclusively returned to the reservoir after spawning.

7) Adult and juvenile cutthroat trout preferred deeper section of stream with slightly higher near-bed velocities, the presence of cover, and pool habitat types, relative to available habitat. Of these preferences, cutthroat trout presence was most strongly

correlated with increases in depth. These results are similar to commonly described preferred salmonid habitat characteristics.

8) Generally, it is uncertain if habitat was the limiting factor for adult and juvenile cutthroat trout in the Strawberry River, as available habitat ranges for significant habitat variables in unrestored sections of river typically were slightly below or overlapped only with the lower ends of HSI optimal ranges. It is possible factors other than habitat, such as an inability of the river to compete with the reservoir in terms of production, may have been limiting cutthroat trout in the Strawberry River. The maximum daily temperatures observed in July and August were consistently above the HSI optimal range and exceeded 20^{o}C in 50% of days in 2009 and 26% of days in 2010. These summer temperatures may have been high enough to limit growth during a critical period by increasing metabolic costs and reducing consumption.

9) It was difficult to detect an effect of the restoration project on depth and percentage of cover, but abundance of pool habitat types increased as a result of restoration in restored sections of the river.

10) While cutthroat trout in the Strawberry River exhibited clear habitat preferences, these were often not consistent across life stages (e.g., riffles preferred for spawning, while pools were preferred for rearing). These results suggested the population would benefit from a diverse and complex habitat mosaic that can meet the range of habitat requirements of all life stages.

11) Early indications from this short-term monitoring study were that the restoration project tended to increase preferred cutthroat trout habitat and reach-scale heterogeneity

in the Strawberry River. In some cases, ambiguity regarding the impact of restoration was the result of relatively small differences observed between restored/unrestored and pre-restoration/post-restoration study reaches, limited pre-restoration data, high spatial and temporal variability within and among control study reaches, and the inherently delayed reaction of ecological responses to physical or chemical changes from restoration. These issues, which limited inference and conclusions in some portions of the study, can be overcome by continuing monitoring. Long-term monitoring would allow for the accounting of natural spatial and temporal variation to further tease out differences resulting from restoration and differences resulting from climactic, hydrological, and beaver-related fluctuations. Additional monitoring would also capture long-term responses to restoration, which has the potential to be significant considering the relatively slow response of riparian vegetation to the restoration. The sampling locations and protocols (Appendix), as well as the data and results from this study, can be used as a foundation and possible template for future long-term monitoring efforts.

APPENDIX

SAMPLING LOCATIONS AND PROTOCOLS

Habitat Preference

Cutthroat trout redds and fish locations were marked during redd counts and snorkel surveys, as described in Chapters 2 and 3 of this study. The following habitat variables were measured within 0.5 m^2 of markers to determine habitat preferences:

1. Distance from left bank
2. Habitat type (pool, riffle, run, or glide)
3. Depth
4. Velocity (bottom and $6/10^{th}$ water depth)
5. Cover type (within 0.5 m^2 of sampling point)
    a. LWD (> 1m in length and 10 cm in diameter)
    b. Undercut bank (> 5 cm deep and > 10 cm long)
    c. Boulder (> 125 mm)
    d. Overhanging vegetation (within 1 m of water surface and overhanging by > 0.5 m)
    e. Aquatic macrophytes ($\geq$ 100 cm^2)
6. Water temperature
7. pH
8. Conductivity
9. Substrate size
    a. Redd locations: 100 particles were randomly selected from within 0.5 m^2 of the marker.

b. Fish locations: 10 particles were randomly selected from within 0.5 m^2 of the marker.

Microhabitat Availability

Each study reach had 20 transects (as described in Chapters 2 and 3 of this study). The global positioning system (GPS) locations of upstream and downstream boundaries for each study reach, as well as transects within study reaches were recorded (Table AI-1 and Table AI-2). The following habitat variables were measured at each the water's edge of transects to determine microhabitat availability:

1. Wetted width
2. Bank angle
3. Densiometer percentage
4. Reach-scale habitat type (pool, riffle, run, or glide)

There were 12 equidistant points (beginning at the water's edge of the left bank) within the 20 transects of each study reach. The following habitat variables were measured at each point to determine microhabitat availability:

1. Distance from left bank
2. Depth
3. Velocity (bottom and 6/10th water depth)
4. Cover type
    a. LWD (> 1m in length and 10 cm in diameter)
    b. Undercut bank (> 5 cm deep and > 10 cm long)
    c. Boulder (> 125 mm)

   d. Overhanging vegetation (within 1 m of water surface and overhanging by > 0.5 m)
   e. Aquatic macrophytes ($\geq$ 100 cm^2)
5. Water temperature
6. pH
7. Conductivity
8. Substrate size
   a. Two particles were randomly selected and measured along the intermediate axis at each point.

Reach-scale Habitat Availability

There were 12 equidistant points (beginning at the water's edge of the left bank) within 20 transects of each study reach. The following habitat variables were measured at each point:

1. Length of bare or exposed bank (i.e., no vegetation)
2. Length of undercut bank (> 5 cm deep and > 10 cm long)
3. Habitat units (pools, riffles, runs, glides). The following were measured for each individual habitat unit in each study reach:
   a. Length
   b. Average width
   c. Maximum Depth
   d. If pool, then tailout depth was also measured

Electrofishing Surveys

The GPS locations of 100 m electrofishing sub-reaches were recorded for each study reach (Table AI-3). The methods for the electrofishing surveys are described in Chapter 3.

Table AI-1. UTM ’84 GPS locations for the upstream and downstream boundaries for each of the four study reaches.

Reach	Boundary	Zone	Northing	Easting
Restored '08	Upstream	12	4456782	0481279
Restored '08	Downstream	12	4456555	0481428
Restored '09	Upstream	12	4457017	0481006
Restored '09	Downstream	12	4456823	0481131
Control 1	Upstream	12	4458495	0480803
Control 1	Downstream	12	4458175	0480704
Control 2	Upstream	12	4459598	0480962
Control 2	Downstream	12	4459326	0480865

Table AI-2. UTM ’84 GPS locations for each of the 20 transects.

Reach	Transect	Zone	Northing	Easting	Reach	Transect	Zone	Northing	Easting
R08	1	12	4456564.7	481388.7	R09	1	12	4456833.9	481141.3
R08	2	12	4456564.2	481395.5	R09	2	12	4456840.2	481132.1
R08	3	12	4456574.9	481401.5	R09	3	12	4456841.1	481119.6
R08	4	12	4456585.7	481402.3	R09	4	12	4456850.6	481111.9
R08	5	12	4456596.5	481405.9	R09	5	12	4456862.5	481111.1
R08	6	12	4456590.6	481415.3	R09	6	12	4456864.2	481124.1
R08	7	12	4456595.0	481427.3	R09	7	12	4456850.6	481136.0
R08	8	12	4456606.3	481432.6	R09	8	12	4456847.4	481145.0
R08	9	12	4456619.2	481431.9	R09	9	12	4456848.6	481156.2
R08	10	12	4456631.1	481426.5	R09	10	12	4456857.1	481161.1
R08	11	12	4456639.1	481415.4	R09	11	12	4456972.7	481115.5
R08	12	12	4456636.4	481401.9	R09	12	12	4456979.4	481101.7
R08	13	12	4456646.5	481397.5	R09	13	12	4456992.9	481094.8
R08	14	12	4456656.6	481388.4	R09	14	12	4457002.4	481098.8
R08	15	12	4456665.3	481378.2	R09	15	12	4457009.9	481105.1
R08	16	12	4456671.6	481366.2	R09	16	12	4457018.9	481109.3
R08	17	12	4456665.7	481352.7	R09	17	12	4457028.9	481110.6
R08	18	12	4456677.4	481345.4	R09	18	12	4457037.4	481105.6
R08	19	12	4456691.0	481340.6	R09	19	12	4457044.9	481098.9
R08	20	12	4456704.3	481336.8	R09	20	12	4457050.1	481090.9
C1	1	12	4458289.0	480746.6	C2	1	12	4459387.8	480853.4
C1	2	12	4458286.2	480737.7	C2	2	12	4459398.5	480859.0
C1	3	12	4458283.4	480728.0	C2	3	12	4459409.1	480862.6
C1	4	12	4458281.2	480718.2	C2	4	12	4459420.6	480863.5
C1	5	12	4458287.2	480710.7	C2	5	12	4459430.8	480862.1
C1	6	12	4458296.7	480706.5	C2	6	12	4459433.6	480862.4
C1	7	12	4458306.4	480705.2	C2	7	12	4459435.7	480869.5
C1	8	12	4458314.8	480710.7	C2	8	12	4459445.3	480879.8
C1	9	12	4458317.8	480719.9	C2	9	12	4459464.1	480880.6
C1	10	12	4458314.7	480730.4	C2	10	12	4459474.9	480870.3
C1	11	12	4458315.6	480741.8	C2	11	12	4459475.1	480870.7
C1	12	12	4458321.0	480750.8	C2	12	12	4459475.9	480871.4
C1	13	12	4458329.8	480757.7	C2	13	12	4459477.5	480874.9
C1	14	12	4458341.3	480757.9	C2	14	12	4459476.5	480886.6
C1	15	12	4458352.0	480757.3	C2	15	12	4459489.1	480898.5
C1	16	12	4458361.2	480752.7	C2	16	12	4459498.5	480902.1
C1	17	12	4458370.7	480754.1	C2	17	12	4459508.3	480905.9
C1	18	12	4458373.8	480763.6	C2	18	12	4459514.7	480910.2
C1	19	12	4458373.1	480772.8	C2	19	12	4459521.2	480919.7
C1	20	12	4458374.5	480782.9	C2	20	12	4459536.0	480911.8

Table AI-3. UTM ’84 GPS locations of upstream and downstream boundaries for electrofishing sub-reaches.

Reach	Boundary	Zone	Northing	Easting
Restored '08	Upstream	12	4456672	481366
Restored '08	Downstream	12	4456591	481415
Restored '09	Upstream	12	4457050	481091
Restored '09	Downstream	12	4456857	481161
Control 1	Upstream	12	4458371	480754
Control 1	Downstream	12	4458306	480705
Control 2	Upstream	12	4459476	480887
Control 2	Downstream	12	4459421	480863