Feasibility of Snorkel Surveys for Determining Relative Abundance and Habitat Associations of Juvenile Chinook Salmon on the Mainstem Trinity River, California

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Disclaimers

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Key words: Trinity River, habitat, salmon, juvenile Chinook Salmon, snorkel survey, IHAP.

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Feasibility of Snorkel Surveys for Determining Relative Abundance and Habitat Associations of Juvenile Chinook Salmon on the Mainstem Trinity River, California

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Abstract The Trinity River Restoration Program (TRRP) is restoring salmonid fishery resources by restoring freshwater habitats in the Trinity River, California through physical channel manipulation and restoration of physical processes that create and maintain aquatic habitats. The objective of this study was to assess the feasibility of snorkeling for determining juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) relative abundance in previously mapped physical habitats. This report presents juvenile Chinook Salmon relative abundance data collected during direct observation snorkel surveys conducted January through April 2012 on the upper mainstem Trinity River. We documented and tested the significance of sources of variability of relative abundance estimates including inter-snorkeler, day versus night, intra-day, and intra-week variability. The effects of subsampling were also investigated to inform sampling needs for future studies. We determined that direct observation snorkeling methods are suitable for estimating relative abundance of juvenile Chinook Salmon associated with habitat classifications.

Survey sites were co-located with the TRRP's Integrated Habitat Assessment Project (IHAP) fish habitat mapping sites (400 m sections) that were mapped and classified in summer of 2011. This co-location of habitat mapping and snorkel survey sites allowed the relationship between juvenile Chinook Salmon abundance, habitat quality (a combination of depth, velocity and distance to cover), habitat quantity (percentage of optimal habitat), habitat complexity (total bank length), and space and time to be modelled with a generalized mixed effects model. Time, space, and percent of area mapped as optimal fry habitat were significant explanatory variables in statistical models of juvenile Chinook Salmon relative abundance.

We recommend that future studies focus on a smaller spatial unit for surveys linking juvenile Chinook Salmon relative abundance over the entire range of values of specific habitat categories (depth, velocity, distance to cover). We recommend co-locating sampling sites at 2-D river modelling sites to aid in linking relative abundance to specific habitat categories as well as supporting the development of a salmon production model.

Introduction

The Trinity River Restoration Program (TRRP) is restoring salmonid fishery resources by restoring freshwater habitats in the Trinity River through physical channel manipulation and restoration of physical processes that create and maintain aquatic habitats (USDOI 2000). The TRRP, through the Integrated Assessment Plan (IAP, TRRP and ESSA 2009), identified the need to assess how juvenile salmonid density and abundance responds to changing habitat quantity, quality, and availability as a result of this physical habitat restoration efforts. The Chinook Salmon (*Oncorhynchus tshawytscha)* relative abundance study reported here investigates a method for linking biological responses to changes in physical fish habitat quantity, quality, and availability.

The overarching objective of this study was to assess the feasibility of utilizing a direct observation snorkel survey for determining juvenile Chinook Salmon relative abundance in previously mapped physical habitats. Direct observation snorkel surveys have been shown to be useful as a tool for an underwater census of fish populations (Northcote and Wilkie 1963; Goldstein 1978), and making estimates of fish density, and observing fish behavior (Slaney and Martin 1987; Zubik and Fraley 1988). Estimates of population size have been shown to be valid only if snorkeler counts are precise and accurate (Griffith et al. 1984) even when replicated counts are similar between divers and on repeat dives over time (Slaney and Martin 1987).

This study was designed to collect data on relative abundance rather than estimating population size in the entire reach. The interest was to capture the pattern of relative juvenile Chinook Salmon abundance in relation to habitat over space and through time. This distinction is important as it has bearing on the interpretation of results.

Surveys were conducted from January through April 2012 to encompass the critical rearing period for ocean-type juvenile Chinook Salmon, which emigrate to the ocean in their first year of life and are estimated to make up more than 99% of the juvenile Chinook Salmon that rear in the Trinity River (Pinnix et al. 2013). Timing of the surveys was designed to encompass the period beginning with fry emergence from spawning gravels and the following redistribution of fry and presmolt downstream into naturally occurring and restored habitats. This period is typically characterized by steady and low flows known as winter base-flows because releases from Lewiston Dam are typically static through winter until mid-late April when restoration flows to meet geomorphic and outmigrant temperature objectives are released.

To determine the feasibility of snorkel surveys, effort was largely dedicated to testing sources of variability in relative abundance estimates while the remaining effort was used to collect snorkel survey data to evaluate the relationship between fish density, and habitat quality and availability. These sources of variability included inter-snorkeler,

day-versus-night, intra-day, and intra-week variability. The effects of subsampling river reaches were investigated with intent to inform sampling needs for future studies. In addition, the efficacy of mark-recapture experiments to aid in relative abundance estimation was tested.

This report also presents snorkel survey data collected January through April 2012 on the upper mainstem Trinity River at habitat sites mapped by the Integrated Habitat Assessment Project (IHAP) in the summer of 2011 (Alvarez et al. 2013). This project, in conjunction with the IHAP mapping effort, contributes to the TRRP adaptive management framework by providing feedback to improve management actions.

Objectives

1. Evaluate sources of variation in juvenile (fry and presmolt) Chinook Salmon relative abundance conducted by direct observation snorkel surveys including:
    a. Snorkel count variation (snorkeler effect)
    b. Visibility
    c. Time of day
    d. Day versus Night Effects
2. Determine the relationship between juvenile Chinook Salmon abundance and habitat quantity/quality
3. Determine efficacy of mark-recapture experiments to refine relative abundance estimates
4. Collect detailed snorkel survey data at entire 400 m IHAP sites to determine the effectiveness of subsampling 50 m sections
5. Provide juvenile Chinook Salmon relative abundance data in different habitats for use in a fish production model.

Study Area

The Trinity River is located in northwestern California (Lat. 40.708, Long. -122.808). The headwaters are in the Trinity Mountains from which it flows 274 km (170 mi) to its confluence with the Klamath River. The watershed has a drainage area of 7,679 km^2 (2,965 mi^2), approximately one quarter of which is upstream of Lewiston Dam (USFWS 1989; USBR 2009). The restoration reach and all study sites are located within a 64-km (40 mi) section of the Trinity River between Lewiston Dam and the confluence of the North Fork Trinity River (Figure 1). All sites and gages are referenced in river kilometers (rkms) upstream from the confluence with the Klamath River at Weitchpec, California.

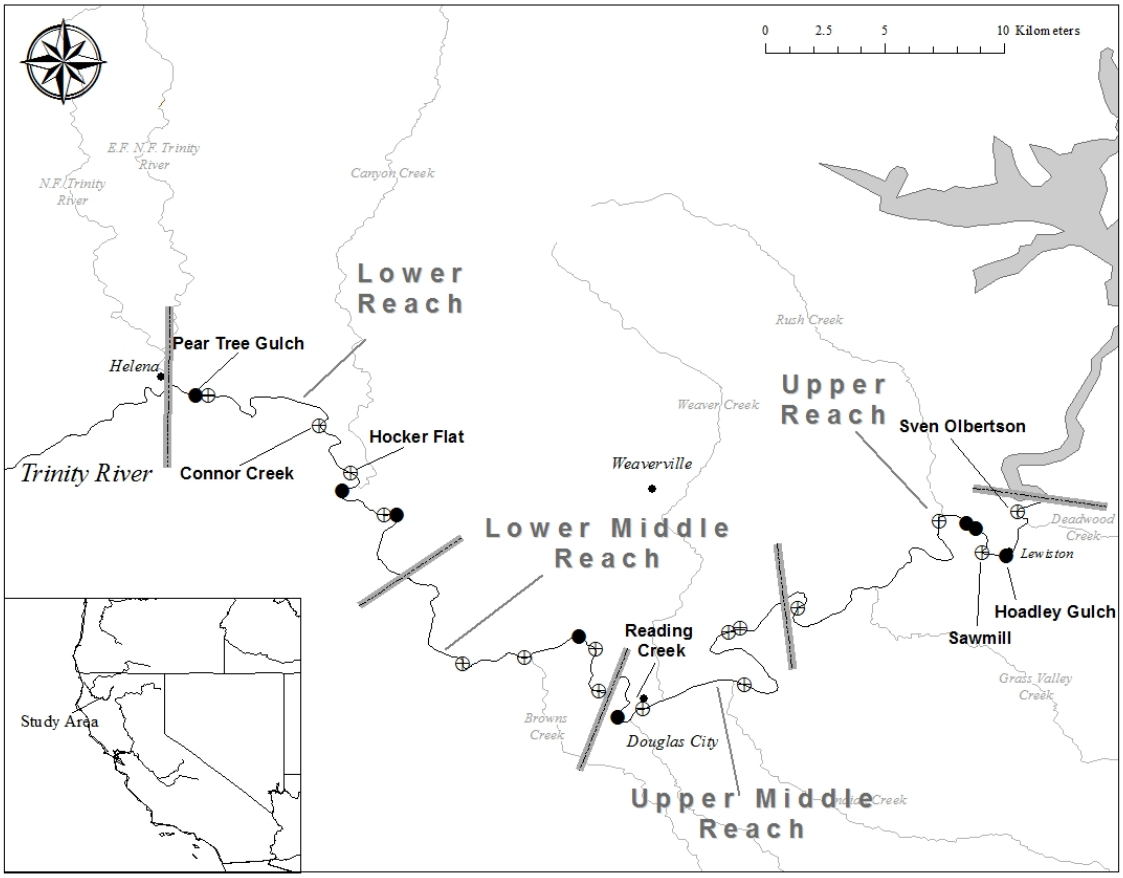

Figure 1. Juvenile Chinook Salmon snorkel survey locations on the Trinity River from Lewiston Dam to the confluence with the North Fork Trinity River. Each dot indicates a 400-m Integrated Habitat Assessment Project sample unit selected using the Generalized Random Tessellation Sampling protocol. Black dots indicate panel 3 and dots with crosses indicate panel 4 sites. Grey labels and lines indicate the designated reaches used in the data analysis. Trinity River streamflow is from right to left.

Methods

This study was conducted by three four-person crews. Each crew consisted of biologists and technicians from the California Department of Fish and Wildlife (CDFW), the Hoopa Valley Tribal Fisheries Department (HVTFD), the Yurok Tribal Fisheries Program (YTFP), and the U.S. Fish and Wildlife Service Arcata Fish and Wildlife Office (USFWS).

Snorkeler Calibration

At the beginning of the study, emphasis was given to train snorkelers and to conduct snorkeler calibration surveys. Training and calibration surveys were performed independently. For training purposes, experienced snorkelers accompanied less

experienced snorkelers and taught them how to identify and enumerate juvenile salmonids.

Calibration surveys were conducted to assess whether the crews, as a group, were producing reasonably similar counts by species and size class. Typical calibration surveys occurred in a side channel where juvenile salmonids were present. The lower and upper ends of the survey sites were blocked with nets (3.175 mm stretch mesh) to reduce movement of fish into and out of the site. Two experienced snorkelers counted fish in the blocked-off section. The section was then sampled by additional crews and repeated until each crew member had snorkeled the section. Counts were then compared by crew leaders and differences noted. This was repeated until counts and fish identification were similar between all snorkelers.

Snorkel Surveys

The overall design for sampling locations is a spatially balanced random design over the 64 km below Lewiston Dam (Figure 1). Snorkel surveys started January 31, 2012 and ended April 19, 2012. Surveys were co-located with groups of sites, known as panels, identified in the IHAP 2010 (Alvarez et al. 2013) revisit design, which includes 32 IHAP sites (panels 3 and 4; 16 sites per panel) chosen by Generalized Random Tessellated Sampling (GRTS). These sites were defined as 400-m (1,312 ft) segments of the 142 cms (5,000 cfs) centerline derived from HEC-RAS modeling in 2006 (TRRP unpublished data). See Alvarez et al. (2013) for further information.

Depending on the assumption to be tested or survey objective, either the entire 400-m IHAP sites were snorkeled with data grouped into 50-m segments, or a subsample of 50-m segments from the 400-m site was snorkeled. Assumption testing for day versus night, intra-day variability, inter-snorkeler variability, and subsampling effectiveness testing was conducted on complete 400-m sections. The remaining snorkel surveys were conducted at subsampled 400-m sites.

Subsampling of sites was done by randomly selecting six 50-m segments, three from each bank; which included all banks of any side channel located within the 50-m section chosen within each 400-m IHAP site. Later in the season (after Feb 19, 2012) an additional 50-m section per bank was added to each subsampled 400-m site resulting in eight randomly selected 50-m sections. Snorkelers felt that an additional 50-m section per bank would capture more of the habitat variability present at the sites. In addition, it was determined that it was not possible to complete two full panels in a given two-week period, so Panel 3 was dropped from surveys after March 1, 2012.

All daytime snorkeling occurred between the hours of 9:00 and 16:30. All nighttime snorkeling occurred between the hours of 17:00 and 5:00. Snorkelers worked in an upstream direction while searching carefully under banks and in cover, such as woody

debris and rock crevices. The snorkel 'lane' or distance from shore in which fish were enumerated was fixed to a width of 2.13 m. Counts of juvenile salmonids by species and size class were recorded. Fish were identified to species and categorized as belonging to one of three size-classes (0-50 mm, 51-100 mm, and >100 mm) by estimating total length. Calibration of length estimates was conducted by each diver at the start of each day by observing fish lures of known size (40 mm, 80 mm, and 120 mm) underwater corresponding to the three size classes. Between snorkeler variability was estimated by snorkeling the same reach two or more times in the same day at least one hour apart to allow fish to resume normal behavior. Snorkelers switched sides for subsequent surveys. Day versus night variability was estimated similarly by snorkeling the same reach twice within the same 24 hour period, once at night and once during the day. This was done at two IHAP sites (rkms 135 and 154) on three different dates (February 1, 15, and 22).

Identification distance, the distance at which individual snorkelers could discern which species he or she observed, was recorded prior to each survey. Small replicas of juvenile salmonids (fish lures with patterns similar to juvenile steelhead and juvenile brown trout) were placed upstream of snorkelers and moved towards them until they could identify the species each lure represented. The distance between the lure and the snorkeler's mask was be measured to the nearest 0.5 m and recorded. If identification distance was less than 1.5 m, no snorkeling occurred.

Trimble Terrasync software and tablet PC's with Trimble Pro XH GPS's were used by crews for identification of survey locations and data entry (Goodman et al. 2010). Data were recorded on tablet computers that allowed counts to be immediately attributed to a line segment of stream bank cover type identified during the snorkeling survey. The crew leader (one per crew) was responsible for identifying and measuring lengths of cover types in the selected survey reach and ensured that snorkel counts were attributed with bank cover types as per the IHAP fish habitat mapping protocol (Goodman et al. 2010). Snorkelers periodically relayed counts to the crew leader as they progressed upstream. At the end of each day/night sampling period, data were backed up on removable flash drives and transferred to a separate laptop computer. At the end of each week, data were uploaded to a network database.

Mark-Recapture

Mark-recapture experiments, to estimate detection probability, were conducted twice during the study; once at the Cemetery Side Channel (rkm 175) and once in the mainstem near Lewiston (rkm 176). Chinook Salmon collected from the Pear Tree Gulch rotary screw trap site (rkm 118; Petros et al. 2013) were anesthetized and batch marked with a colored tattoo (see Methods section in Pinnix and Quinn 2008). Fish were allowed to recover overnight in an in-river live cart. Mortalities and unrecognizable marks were noted and subtracted from the total number marked to calculate total marked fish released. Fish were released at the middle of the reach to be sampled.

On March 7th a 50-m section of Cemetery Side Channel (rkm 175) was isolated by closing off the upper and lower boundaries with a block net (3.175 mm stretch mesh). Care was taken to ensure that there were no gaps underneath or on the sides of net so fish could not escape. Marked fish were then released into the enclosed section of the side channel, which was repeatedly snorkeled by different snorkelers to estimate detection probability. Snorkelers were stationed above and below the netted section to observe whether or not marked fish escaped the netted area.

On April 18th, marked fish were released near Lewiston (rkm 176) into an open section of river with no block nets. In addition to surveying the sampling reach, snorkelers surveyed 100 m of stream bank upstream and 300 m downstream of the sampling reach to determine if marked fish moved out of the survey area.

Data Analyses

Space

Because the number of 400-m sections sampled was relatively low (n = 22), the 64 km restoration reach below Lewiston Dam was broken in to four equal length 16-km reaches to capture the spatial component of variability. The reaches were named Upper (rkm 180-164); Upper-Mid (rkm 164-148 below the dam), Lower-Mid (rkm 148-132), and Lower (rkm 132-116), see Figure 1.

Time

Time was treated as a categorical variable when analyzing the full 400-m sites; the early period spanned from January 31 to February 13 (day of year 31- 44) and the late period spanned from February 14 to March 20 (day of the year 45 - 80). Time was treated as a continuous variable (day of the year) when analyzing the more abundant 50-m subsampled data set.

Habitat Classification

Length of bank was measured during snorkel surveys and was defined as the measured distance of bank between the beginning and ending points of each survey, whether 400-m or 50-m segments. Bank length of cover, was the sum of mapped bank length that fell into vegetation/wood or boulder categories within each survey reach. Percent of area classified as optimal and suitable fry rearing habitat was calculated for each 50-m section based on 2011 IHAP surveys (Martin et al. 2012) within all sites and was used as an explanatory variable in respective snorkel survey sites. Martin et al. (2012) also calculated optimal and suitable rearing habitat for presmolt Chinook Salmon which generally encompasses the respective fry habitat categories, but the fry category was chosen as the bulk of our surveys were conducted during the fry emergence and rearing period.

Response Variable

References to juvenile Chinook Salmon include both size categories, and all analyses were conducted using the snorkeler fish counts (sum of the 0-50 mm, 51-100 mm size categories) as response variables; data for fish larger than 100 mm were not used as these fish were rare. Relative densities were also considered as the response variable for analyses, but not further pursued because: a) densities are computed with relative abundance as the numerator; and b) not dividing the relative abundances by bank length allowed us to explore how the variation in length of bank, and bank length of cover (an index of habitat complexity), related to observed fish counts.

Statistical Modeling

The vast majority of the statistical analyses performed for this report relied on the negative binomial family of generalized linear mixed models, with a log link function (Gotway and Stroup 1997). The unique aspects of these models that make them suitable for use with these data include: a) they are models for counts; b) they allow for flexible variance-to-mean relationships; and c) they allow the inclusion of random effects to account for correlation due to sub-sampling within sites and repeated sampling of locations. These models are very similar to the more traditional generalized linear models that include logistic and Poisson regression, with the added flexibility to account for random effects, and are the best models for non-normal data with random effects (Bolker et al. 2008). Akin to standard linear and generalized linear models, fixed effects (explanatory variables) were used to describe changes in the mean values of the response variable, in this case counts of juvenile Chinook Salmon. The model assumes that:

$$E[\boldsymbol{Y}|\boldsymbol{\delta}] = g^{-1}(\boldsymbol{X\beta} + \boldsymbol{Z\delta})$$
$$Var[\boldsymbol{Y}|\boldsymbol{\delta}] = \boldsymbol{A}^{.5}\boldsymbol{RA}^{.5}$$

where Y is the vector of observed data, X and Z are the design matrices for the fixed and random effects, respectively, β and δ are vectors of fixed and random coefficients, respectively, g() represents the log link function, and A is a diagonal matrix with the variance function of the negative binomial distribution. In addition, it is assumed that the random effects are normally distributed with mean = 0 and covariance matrix G. The software package SAS (SAS Institute 2008) proc glimmix routine was used to estimate parameters via maximum likelihood for this model, and relied on the Laplace method to numerically approximate the marginal distribution.

Snorkeler Variability

To evaluate snorkeler variability, the count (sum of 0-50 mm, 51-100 mm size categories) of Chinook Salmon observed during the first sampling session was subtracted from observed counts during the second sampling session on each day. This allowed an

evaluation of a potential difference in relative abundance between early and later sampling periods within a day.

To explain the observed variation in differences between counts among surveyors, the absolute value of count-differences were modeled as negative binomial random variables. This allowed evaluation of the variance explained by changes in snorkeler declared identification distances, amount of counted fish, and the duration between the two sampling periods within each day. These data were fit using a negative binomial generalized linear model with a log link, and model parameters were estimated using R statistical software (R Development Core Team 2009). This model is similar to the general model described above, but without the random effects component. Significance of model parameters was evaluated using likelihood ratio tests.

Effects of detecting variation in space and time by subsampling IHAP sites

<u>400-m Segment Analysis.</u> The full 400-m segment dataset was used to first test if patterns in relative abundance with space, time, and habitat (bank length of cover and % of site with optimal or suitable fry habitat) existed, and then to evaluate if less than full 400-m sections of the IHAP sites were adept at discovering these patterns. The negative binomial generalized linear mixed model described above was used for both of these purposes. To assess if smaller portions of each 400-m IHAP site were adequate to capture the space, time, and habitat (bank length of cover and % of site with optimal or suitable fry habitat) patterns with relative abundance, all possible combinations of two, four, and six 50-m sections per bank were considered.

<u>Sub-sampled 50-m Analysis.</u> The chosen model from the full 400-m dataset was fit to each 50-m subsample to evaluate if similar patterns emerged for the relationships between relative abundance and location, day of year, and habitat (bank length of cover and % of site with optimal or suitable fry habitat). Next, further variation in relative abundance was evaluated as to whether it could be explained by the amount and cover type of bank lengths per 50-m centerline: for each 50 m of centerline, total bank length, total bank length with cover, and total bank length with vegetation and wood cover were considered. Akaike's information criterion (AIC, Burnham and Anderson 2002) was used to evaluate the inclusion of these terms, and then to evaluate the interactions of the best fitting bank length and cover term with the existing model parameters. Generally, candidate models that are within 2 AIC units of the best fitting model are considered competing models (Burnham and Anderson 2002), and the simplest among the set of competing models is often selected.

Additionally, caution should be applied when comparing p-values and confidence interval widths among the two datasets, as the two data sets (400-m and 50-m) have different time and space ranges. To help facilitate a comparison of the models fit to these data, rather than report on specific values of parameter estimates, predicted counts for

early (day of year 33) and late (day of year 80) periods from each data set were compared.

Day/Night Analysis To evaluate differences in juvenile Chinook Salmon counts between the day and night surveys, the negative binomial generalized linear mixed model was used to mirror a paired t-test.

Results

Mean daily temperature, as measured at USGS Gage #11525530 (rkm 176), averaged 7.9 ^{o}C and generally increased through the study period (Figure 2) with a minimum of 5.8 ^{o}C and a maximum of 10.0 ^{o}C. Mean daily river discharge averaged 758 cfs at USGS Gage #11525854 (rkm 149) and was generally level through the sampling period (Figure 2) with peaks in discharge (maximum of 3010 cfs) in late March due to rain events.

Temporal Distribution of Surveys

Figure 3 displays the temporal distribution of samples by data type. Day of year values are jittered, to help reveal the preponderance of zeros that occur along with the positive counts. Jittering is a technique that adds a negligible amount of variation to the numeric value of each datum to aid in visual displays of data with many common values. The graph shows that the subsampling data extended much later into the season, with around 58% of the subsampling data were collected after the final full 400 m data were collected.

Snorkeler Variability

Figure 4 shows a frequency plot of differences among the early and later counts within a day for snorkeler count data. The average of these differences is 12 (95% CI: -26 to 49), indicating these data provide little evidence of differences in relative abundance due to early or later periods within a day.

The likelihood ratio tests indicated no evidence that variability in snorkeler counts is related to the amount of time in between the counts (p-value = 0.79) or differences in the identification distance between surveys (p-value = 0.77), but strong evidence that the variation in snorkeler counts was related to the amount of fish counted (p-value < 0.0001, Figure 5). This phenomenon is to be expected for count-type data, where the variance is equal to the mean (Poisson distribution) or a function of the mean (over-dispersed Poisson or negative binomial).

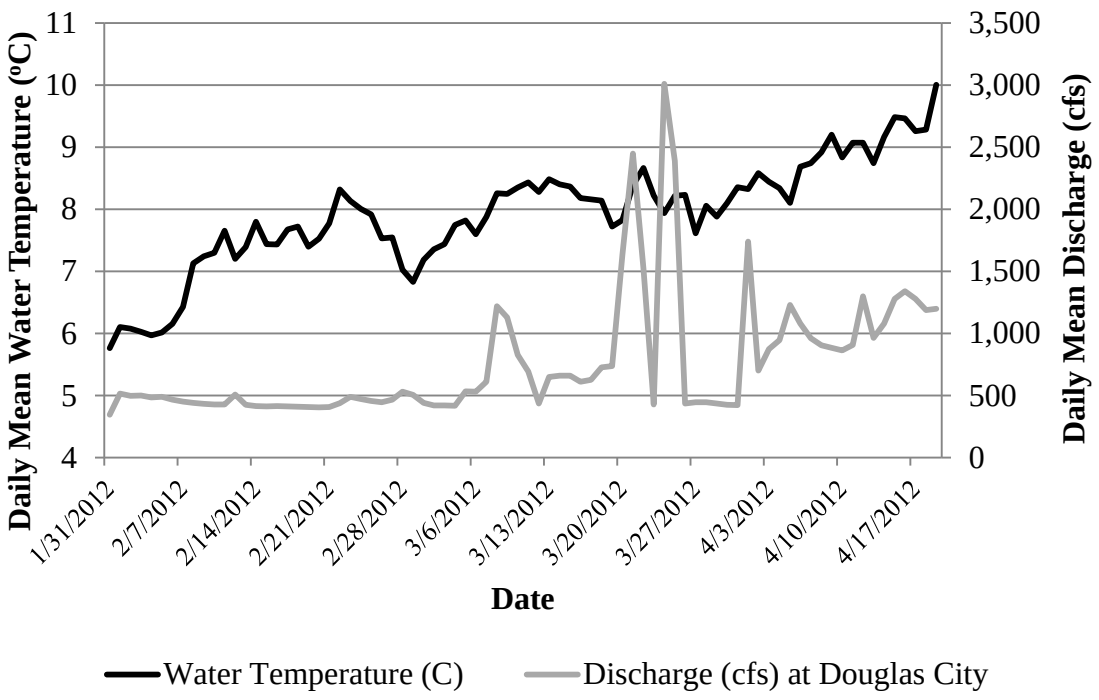

Figure 2. Plot of daily mean water temperature (USGS Gage 11525530 at rkm 176 and Daily mean river discharge (USGS Gage 11525854 at rkm 149) in the mainstem Trinity River during the snorkel surveys for juvenile salmonids, 2012.

Though identification distance difference was not related to differences in counts among snorkelers, there was unexpected variation among snorkelers (Figure 6). In particular, snorkelers 1, 4, 8, and 9 showed low variation in declared identification distances. This could be due to a reduced set of sampling conditions for certain snorkelers (such as a snorkeler that only sampled one day in poor or very good conditions), or could reflect differences among snorkelers in regards to vision or snorkeling comfort.

Full 400-m Data Analysis

Using the 400-m data, it was estimated that the relative abundance of juvenile Chinook Salmon depended on time period, location within the restoration reach, and the percentage of total habitat rated as optimal. For reference, a similar model in which the percentage of habitat rated as *suitable* for Chinook Salmon fry (see Alvarez et al 2013) was also considered, and the AIC value for this model was around 20 AIC units greater than the model using percent *optimal* fry habitat. A difference of 20 units suggests strong support that the model including the percentage of habitat related as *optimal* is the better fitting model. Fixed effects parameter estimates and their tests of significance for this model are presented in Tables 1 and 2.

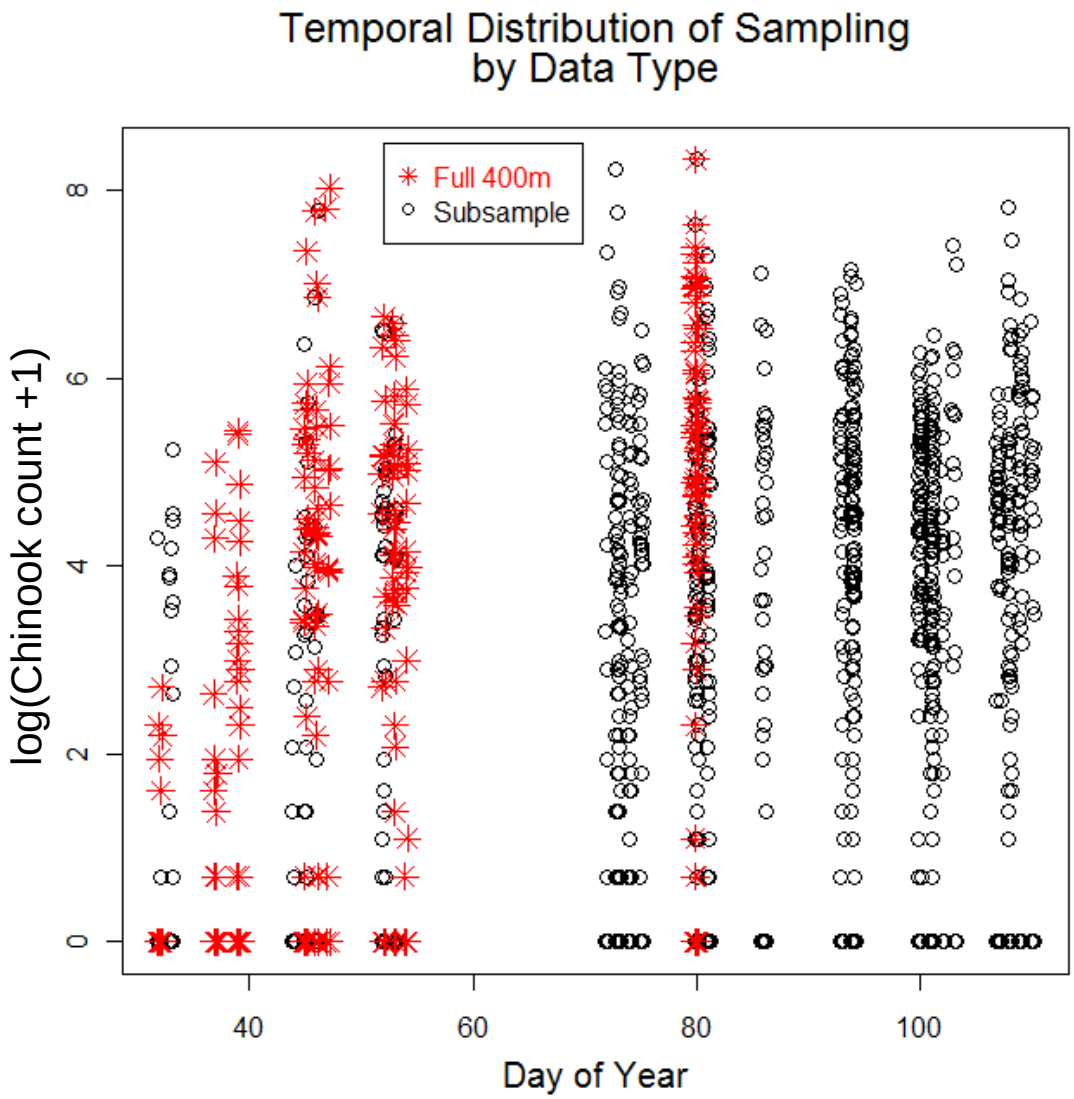

Figure 3. Temporal distribution of sampling for the full 400-m and subsampling data types. Day of year values are jittered to aid in a visual assessment of the number of zeros in the dataset. Chinook Salmon counts are log transformed, after adding 1 to all counts.

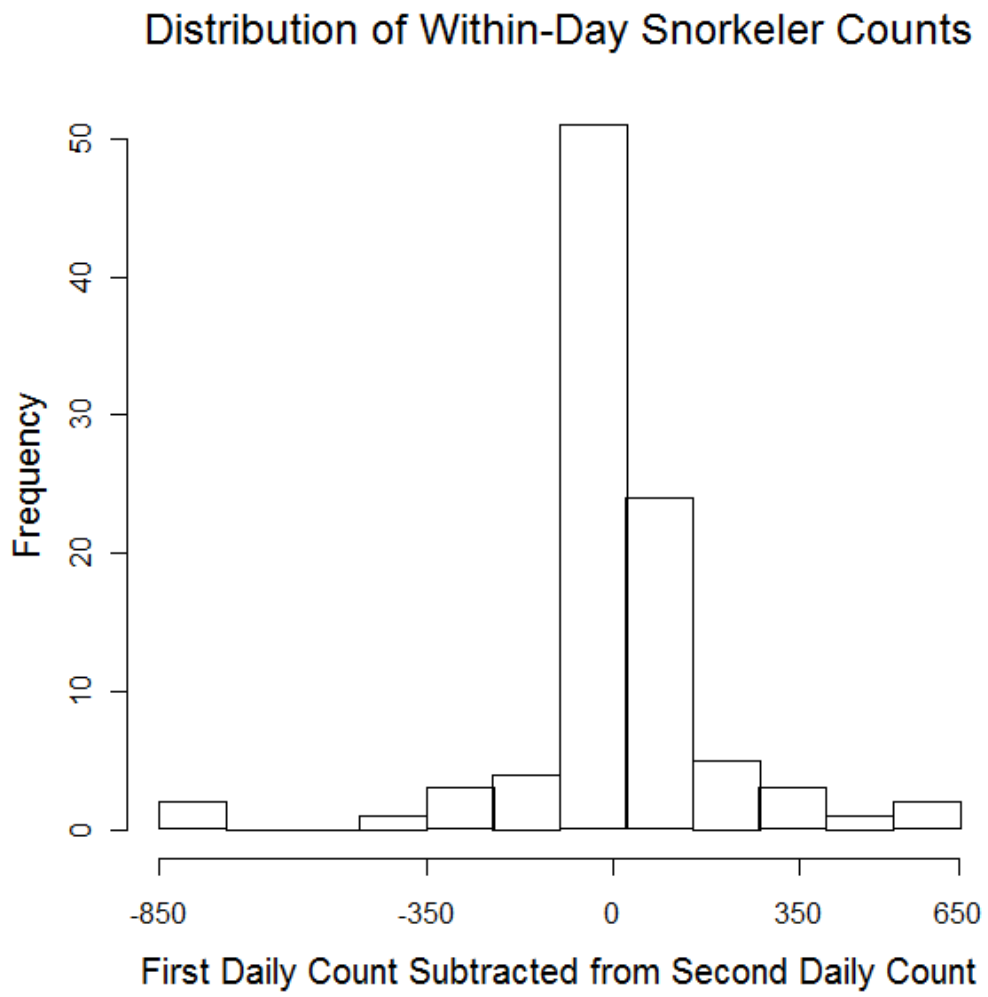

Figure 4. Frequency plot of juvenile Chinook Salmon counts measured during the first sampling sessions of each day subtracted from those collected later in the day, each counted by different snorkelers.

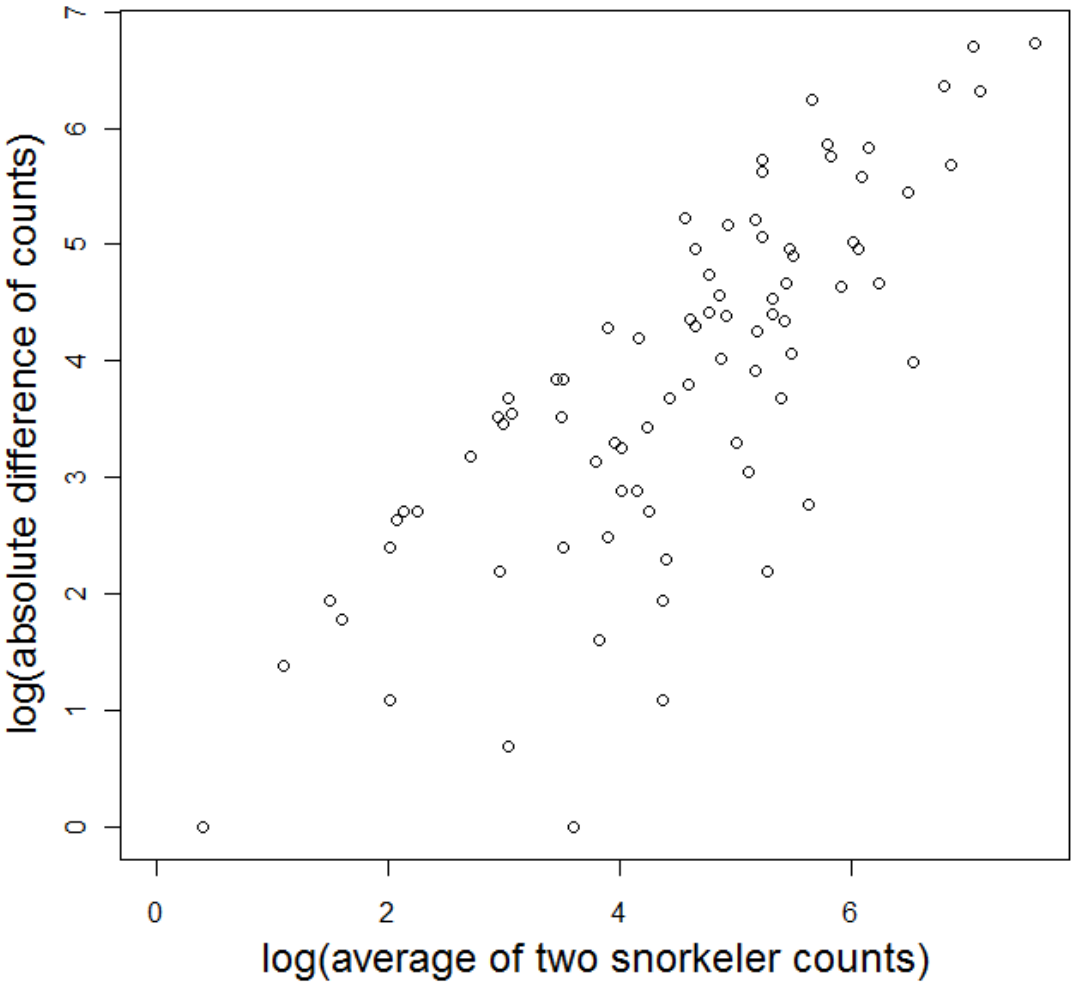

Figure 5. Absolute value of the difference between snorkeler counts plotted as a function of the average of the two counts, both on the log scale.

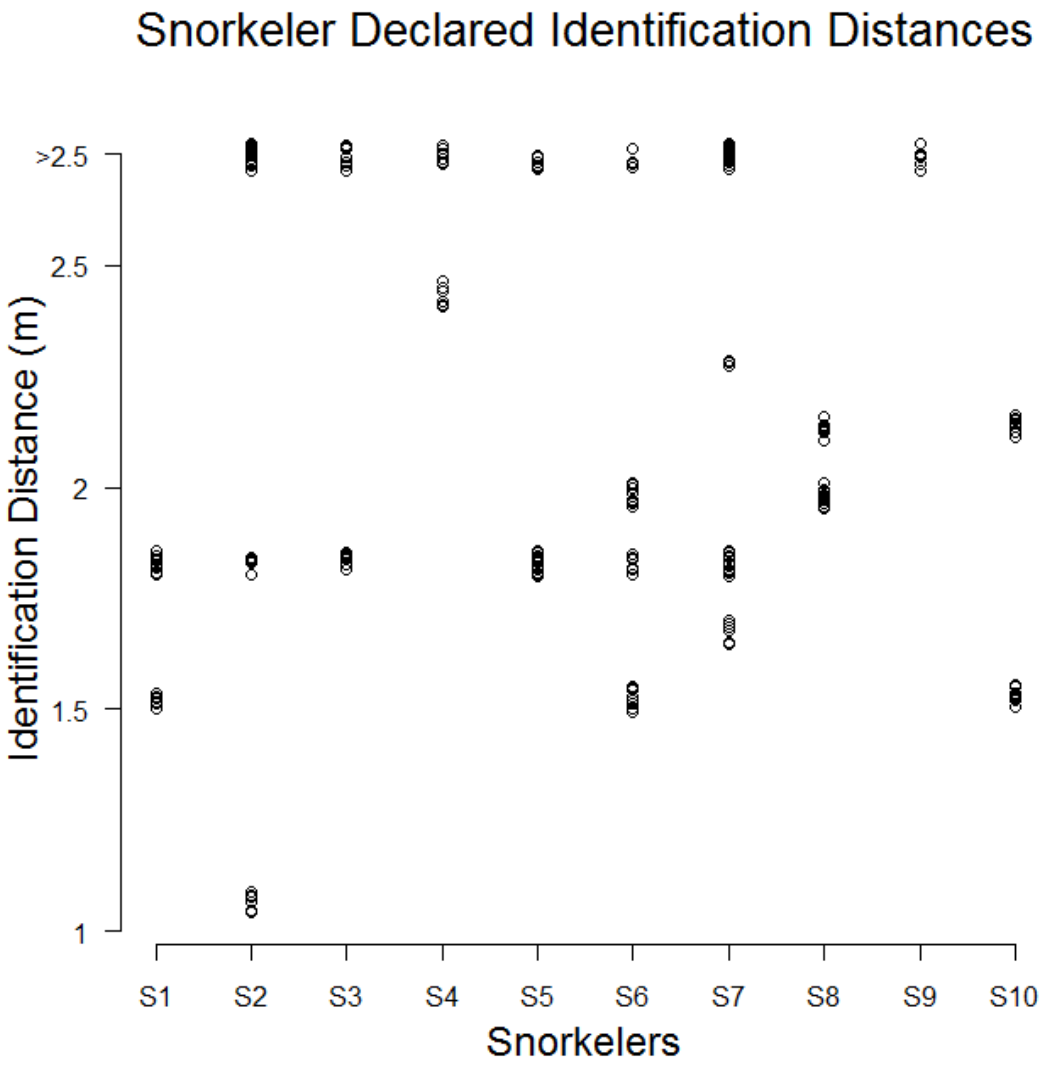

Figure 6. Declared identification distances (m) for 10 snorkelers from the study. Values are jittered in the y-axis direction to reveal multiple declarations of the same distance for each snorkeler.

Table 1. Fixed effects parameter estimates from the fitted model for full 400-m sites.

Solutions for Fixed Effects							
Effect	**space**	**Time period**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Intercept			2.9767	0.7887	6	3.77	0.0092
space	**Upper**		0.6206	0.8494	6	0.73	0.4925
space	**UpperMid**		-0.9116	0.9273	6	-0.98	0.3635
space	**LowerMid**		-0.8348	1.0024	6	-0.83	0.4368
time period		**late**	0.1960	0.7609	6	0.26	0.8053
space*time period	**Upper**	**late**	1.1716	0.9516	6	1.23	0.2643
space*time period	**UpperMid**	**late**	3.7520	0.9770	6	3.84	0.0086
pctFO			-7.1318	15.8380	267	-0.45	0.6529
pctFO*time period		**late**	39.8448	13.1268	267	3.04	0.0026
pctFO*space	**Upper**		-21.1074	13.9485	267	-1.51	0.1314
pctFO*space	**UpperMid**		-38.2327	11.1784	267	-3.42	0.0007
pctFO*space	**LowerMid**		26.6777	23.9409	267	1.11	0.2661

Table 2. F-tests assessing the significance of fixed effects from the fitted model for full 400-m sites.

Type III Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
space	3	6	2.02	0.2128
time	1	6	11.50	0.0147
space*time period	2	6	7.45	0.0237
pctFO	1	267	0.64	0.4258
pctFO*time period	1	267	9.21	0.0026
pctFO*space	3	267	5.86	0.0007

Generally, Tables 1 and 2 can be interpreted as follows: During the early period, there was no evidence that the number of juvenile Chinook Salmon vary in space (p-value = 0.2128) or with the percentage of optimal fry habitat (p-value = 0.4258). There was a time period effect with higher relative abundances (p-value = 0.0147) later in the season. Additionally, there were differences among locations within the restoration reach and time period (p-value = 0.0237), and the percentage of optimal fry habitat and time period was associated with higher counts of juvenile Chinook Salmon (p-value = 0.0026), though this relationship also depends on location within the restoration reach (p-value = 0.0007).

Estimates of average juvenile Chinook Salmon relative abundance reflect these interactive effects (Table 3). There is very little variation among the estimated counts of differing river locations during the early season. Further, not only are estimated counts higher later in the season, but the amount of increase differs by section of the river. In addition, full 400-m site samples were incomplete in the lower-mid section of the restoration reach during the later period of the surveys, and not used in these analyses.

Table 3. Estimated mean number of juvenile Chinook Salmon, with 95% confidence intervals, for each space and time period combination, evaluated at the mean value of the percentage of habitat rated as optimal. Insufficient data existed for Lower-Mid late and so did not enter this analysis.

Estimated Means for Combinations of Space and Time					
space	**time**	**Mean**	**Standard Error Mean**	**Lower Mean**	**Upper Mean**
Upper	**late**	211.63	84.88	79.32	564.69
Upper	**early**	11.05	4.92	3.72	32.82
Upper-Mid	**late**	246.08	99.14	91.82	659.50
Upper-Mid	**early**	3.82	2.33	0.86	16.94
Lower-Mid	**early**	13.35	6.53	4.03	44.17
Lower	**late**	58.68	18.95	26.63	129.30
Lower	**early**	21.17	14.08	4.16	107.77

Subsampling of 400-m Site Analyses

Given the evidence that juvenile Chinook Salmon relative abundance was related to the interactive effects of time period, location along the river, and the percentage of optimal fry habitat, these relationships were evaluated whether they remained statistically significant when sampling less than the full 400-m of each bank (subsamples).

A subsample represented a continuous 50-m section along each bank. For each number of subsamples per bank (2, 4, and 6), the percentage resulting in significant interactions was evaluated (Table 4) using a nominal alpha level of 0.05. Results were found for instances where all three interactions, two out of three, and only one interaction were estimated to be statistically significant. When all three interaction terms are considered, even the modest reduction from the current protocol of eight 50-m segments per bank to six, results in estimating all three interaction terms as significant only around half of the time, and only two samples per bank almost never detects this relationship.

Table 4. Proportions of subsamples for two, four, and six 50-m subsamples per bank, where p-values testing interaction terms were less than or equal to 0.05.

	Samples per Bank		
	2	4	6
Proportion of subsamples with all 3 significant interaction terms	0.02	0.28	0.54
Proportion of subsamples with at least 2 significant interaction terms	0.15	0.64	0.92
Proportion of subsamples with at least 1 significant interaction term	0.54	0.87	1.00

Describing the patterns of juvenile Chinook Salmon in space and time are much more sensitive to lessened sampling effort, as even modest reductions to six 50-m segments per bank drops the proportion of subsamples capturing this variation to nearly 0.50 (Table 5). This contrasts with the interactions of habitat with space and time, which appear more robust to subsampling of IHAP sites (Goodman et al. 2010).

Table 5. Proportions of subsamples for two, four, and six 50-m subsamples per bank, where p-values testing each interaction term were less than or equal to 0.05.

	Samples per Bank		
	2	4	6
Proportion of subsamples with significant space by time interaction term	0.17	0.49	0.56
Proportion of subsamples with significant habitat by time interaction term	0.19	0.53	0.91
Proportion of subsamples with significant habitat by space interaction term	0.36	0.75	0.99

50-m Subsampled Data

The greater range in days of the year that the subsampling data were collected allowed the fitting of a linear trend in juvenile Chinook Salmon relative abundance (Figure 7) with day of year. Additionally, the subsampled data set was much larger, and therefore comparison of p-values between the two datasets (400-m and 50-m) should take this sample size disparity into account.

Fixed effect parameter estimates (Table 6) and tests of significance (Table 7) from the 400-m data model, applied to the 50-m subsampled data, reveal similar patterns to that observed with the 400-m data. The main exception is the lack of evidence for an interaction of day of the year and percent of habitat rated as optimal (p-value = 0.4298). This parameter represents a slope in the subsampled data model, as opposed to a categorical mean for the full 400-m data set. Before fully comparing the predicted counts from each model, the results of assessing the amount of variation explained by bank lengths and amount of cover per 50-m centerline is considered first.

Bank length and cover terms were added to the model to evaluate if they improved the fit of the model to observed juvenile Chinook Salmon counts. Table 8 displays an AIC table for evaluating the inclusions of each term, and indicates that the amount of total cover length per 50-m segment greatly improves the measure of model quality (AIC value improves by around 20 units). When rounded to whole numbers, the AIC values for the amount of vegetation and wood cover per 50-m centerline and the total amount of cover bank length per 50-m centerline are the same. This is not surprising, as the total amount is the length of vegetation and wood cover banks added with the amount of boulder cover. There were many more observations of vegetation and wood cover than boulder cover in the dataset (576 observations to 73), and it is important to note that the total cover length variable is dominated by vegetation and wood cover.

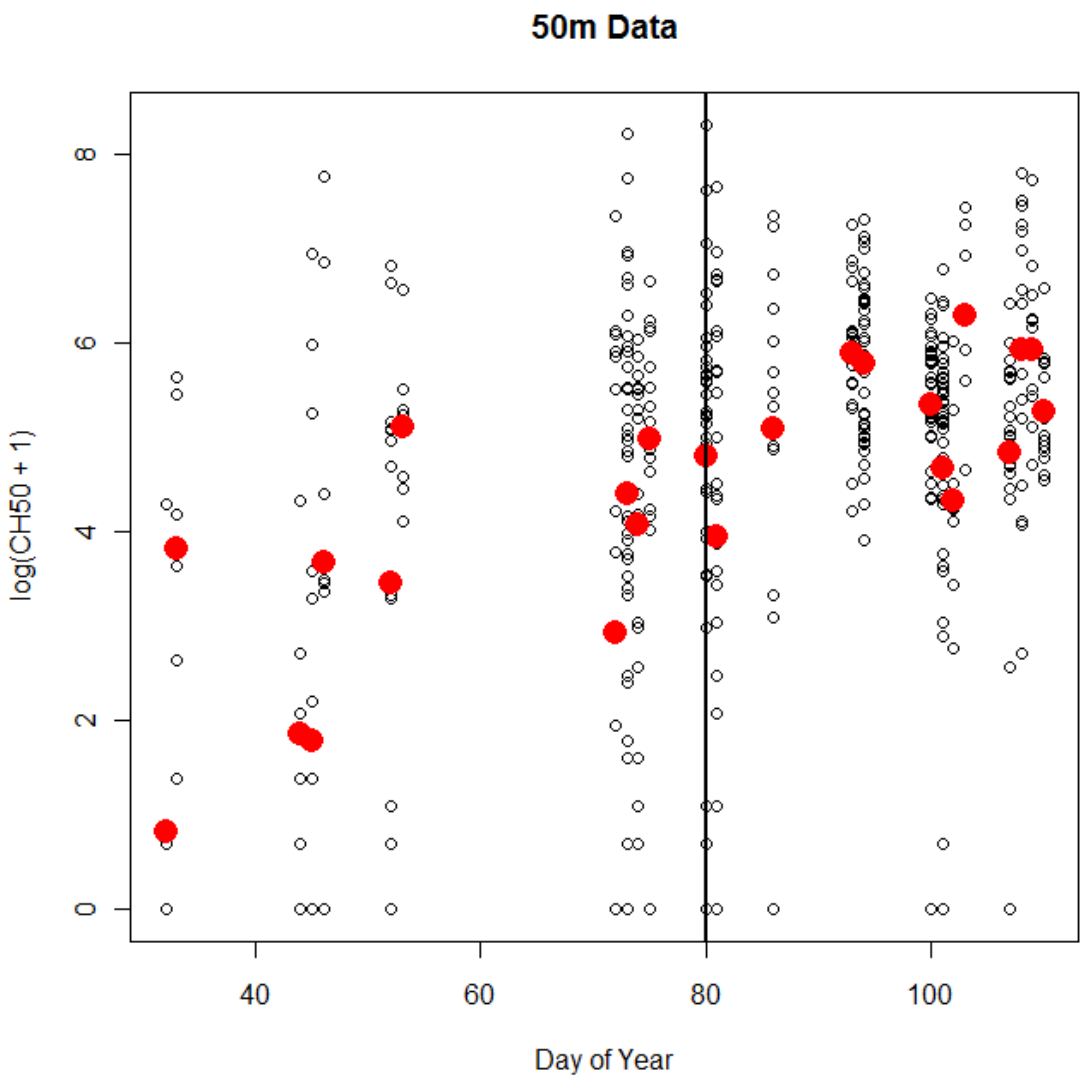

Figure 7. Relationship between average juvenile Chinook Salmon relative abundance and day of year in which sampling occurred. Solid circles represent the average, for each day of year, of the log of juvenile Chinook Salmon counts after adding 1. The vertical bar at day of year 80 represents the last day that the full 400-m data were collected

Table 6. Fixed effects estimates from chosen model for full 400-m section data fit to the 50-m subsampled data. Definition of model terms: space is the categorical variable of location within the restoration reach; pctFO represents the proportional of habitat defined as optimal for Chinook Salmon fry; CL represents the amount of bank length with cover; and D represents the continuous time variable, day of the year. A "*" signifies an interaction between the two variables.

Solutions for Fixed Effects						
Effect	**space**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Intercept		0.8484	0.6208	17	1.37	0.1895
space	**Upper**	0.5096	0.8982	17	0.57	0.5779
space	**UpperMid**	3.6408	0.8909	17	4.09	0.0008
space	**LowerMid**	2.6988	1.6214	17	1.66	0.1143
D		0.04033	0.006816	419	5.92	<.0001
D*space	**Upper**	0.006301	0.009856	419	0.64	0.5230
D*space	**UpperMid**	-0.03068	0.009878	419	-3.11	0.0020
D*space	**LowerMid**	-0.01929	0.01687	419	-1.14	0.2533
pctFO		32.6323	10.5396	419	3.10	0.0021
D*pctFO		-0.07028	0.08892	419	-0.79	0.4298
pctFO*space	**Upper**	-19.4881	8.1966	419	-2.38	0.0179
pctFO*space	**UpperMid**	-25.9022	8.4853	419	-3.05	0.0024
pctFO*space	**LowerMid**	-18.4781	13.6210	419	-1.36	0.1756

Table 7. Tests of significance from chosen model for full 400-m data fit to the subsampled data. Definition of model terms: Space is the categorical variable of location within the restoration reach; pctFO represents the proportional of habitat defined as optimal for Chinook Salmon fry; CL represents the amount of bank length with cover; and D represents the continuous time variable, day of the year. A "*" signifies an interaction between the two variables.

Type III Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Space	3	17	6.96	0.0029
D	1	419	24.34	<.0001
D*space	3	419	5.82	0.0007
pctFO	1	419	3.91	0.0485
D*pctFO	1	419	0.62	0.4298
pctFO*space	3	419	3.13	0.0257

Table 8. AIC values assessing the addition of terms describing the length and cover type of banks per 50-m centerline.

Extra Cover Length Term	AIC	ΔAIC
Total Cover Length	5781	
Veg & Wood Length	5781	
Total Length of Bank	5801	20
None	5802	21

The total cover length term was explored by using AIC to evaluate its interaction with variables previously included in the model (Table 9). The best fitting model included categorical space, day of year, their interaction, the percent of area designated as optimal fry habitat, and both the total cover length and its interaction with day of year. Though the model including an interaction of percent optimal fry habitat with space fit nearly as well (3 AIC units away from best fit), the combination of an extra model term and increasing AIC value suggest a more parsimonious model without the percent optimal fry habitat with space interaction term.

Table 9. Model selection results after including a term to account for the amount of bank length with cover per 50-m of centerline. Definition of model terms: Space is the categorical variable of location within the restoration reach; pctFO represents the proportional of habitat defined as optimal for Chinook Salmon fry; CL represents the amount of bank length with cover; and D represents the continuous time variable, day of the year. A ":" signifies that each term and their interaction are included as fixed effects in the model.

Model Terms	AIC	ΔAIC
Space:D + pctFO + CL:D	5766	
Space:D + pctFO + pctFO:space + CL:D	5769	3
Space:D + pctFO + pctFO:space + pctFO:D + CL:D	5771	5
Space:D + pctFO + pctFO:space + pctFO:D + CL:D + CL:Space	5777	11
Space:D + pctFO + pctFO:space + pctFO:D + CL	5781	15
Space:D + CL:D	5788	22

Finally, the estimated values of juvenile Chinook Salmon counts, both spatially and temporally, were compared from the three models: 1) the parameters estimated from the model chosen for the full 400-m dataset; 2) the parameters estimated from the model chosen for the full 400-m dataset applied to the subsampled dataset; and 3) the parameters estimated from the model selected after adding the amount of bank length with cover to the subsampled data set. The estimated means and confidence intervals are displayed in Figure 8, and are computed at the average values of percent of habitat designated as optimal and amount of bank length with cover, and at day-of-year 33 for the early period and 80 for the later period. The comparison of the estimated means from these models allows assessment, in practical terms, of any substantive differences among them. Again noting the latter two models were fit to a much larger dataset, several patterns are evident. First, the confidence interval widths are generally smaller for the latter two models (some of which is due to the larger sample sizes). The latter two models were fit to the same dataset, and the confidence interval widths for the model including amount of bank length with cover are shorter. Given the AIC results, this is to be expected, the shorter confidence intervals can be attributed to a model that fits the data better. For most time and space combinations, the estimated means among all models are relatively similar. All models reveal the estimated increases in relative abundance later in the season for all spatial groupings, and higher estimated relative abundance in the upper end of the restoration reach.

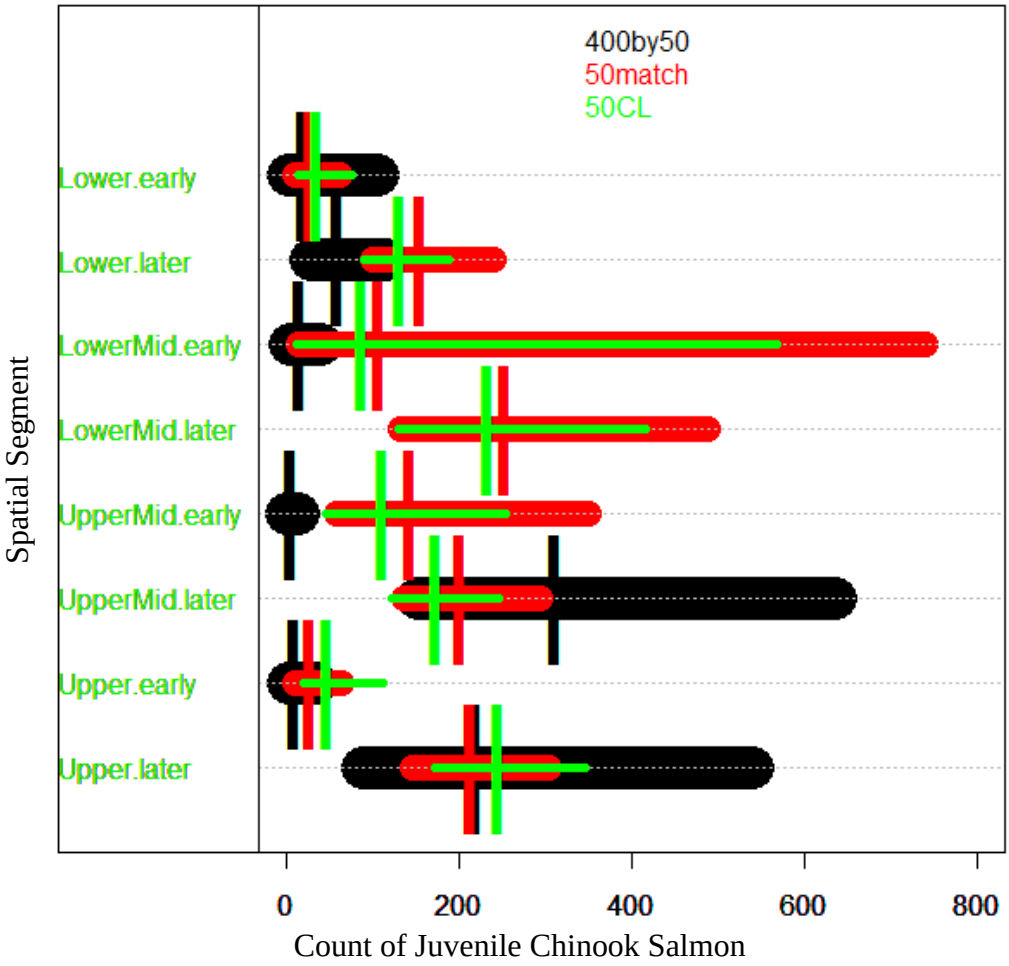

Figure 8. Estimated means and 95% confidence intervals for counts of juvenile Chinook Salmon at early (day of year 33) and late (day of year 80) time periods at the four spatial segments of the restoration reach. Vertical bars represent the estimated mean values, width in the x-axis direction represents the width, and hence the lower and upper endpoints of the 95% confidence intervals. The thickness of the confidence interval bars is only to aid in visual inspection. Black (thickest) bars represent the model fit to the full 400-m dataset, red (middle thickness) represent the same model fit to the subsampled data, and the green (thinnest) bars represent the model that includes the amount of bank length term.

Day vs Night Analysis

There was no evidence to suggest that the relative abundance of juvenile Chinook Salmon differed between day and night surveys (p-value = 0.3668). The estimated day and night means, along with 95% confidence intervals, are provided in Table 10.

Table 10. Estimated means per 50 m section and 95% confidence intervals for relative abundance of juvenile Chinook Salmon.

		n	Mean	95% CI
Chinook Salmon	Day	80	111	(66, 189)
Chinook Salmon	Night	80	84	(51, 138)

Mark Recapture

The mark recapture experiments met with limited success. Photonic marking worked well for marking juvenile Chinook Salmon, and marks were easily identifiable underwater by snorkelers. However, a closed system could not be created using block nets in a side channel even though the bottom of the nets were covered with rocks to prevent the nets from lifting. Marked fish were seen upstream of the upper block net almost immediately after release by snorkelers stationed at the block nets. In the second mark-recapture experiment (mainstem reach with no block nets) snorkelers observed a quick dispersion of marked fish both upstream and downstream of the sample reach, violating the closure assumption needed for mark-recapture expansions. Block netting the mainstem is not possible given the volume of water and width of the river. In both cases, the closure assumption needed for estimating observer efficiency was violated and data were not used for estimating observer efficiency.

Discussion

Feasibility of Direct Observation Snorkel Surveys

The main objective of this study was to determine the feasibility of using direct observation snorkel surveys for monitoring relative abundance of juvenile Chinook Salmon throughout the upper mainstem of the Trinity River from Lewiston Dam to the confluence with the North Fork Trinity River (restoration reach). Snorkeler variability does not mask the variation in abundance longitudinally through the restoration reach and through time. However, it is difficult, if not impossible, using the direct count snorkel methods to estimate total population abundance because of the infeasibility of conducting mark-recapture tests due to violations of the closure assumption. An American Fisheries Society publication (Johnson et al. 2007) of best practices in fisheries science states that for documenting distribution and average density a single pass, no calibration snorkel survey is sufficient, however when estimating relative abundance, a single pass survey *with mark-recapture calibration* is sufficient. In this study a two pass survey with snorkeler calibration, but no mark-recapture calibration, was conducted that adequately documented spatial and temporal differences in relative abundance of juvenile Chinook Salmon throughout the restoration reach of the Trinity River.

Spatial differences in juvenile Chinook Salmon relative abundance were statistically significant at different scales: across the 64-km restoration reach, at the site scale, and at the habitat scale. The level of effort of this study was adequate to capture the differences in abundance through space at these three different scales. Early in the season relatively more fish were observed lower in the system, although the difference between lower and upper means was relatively small (Table 3) compared to the difference later in the season when abundance was higher closer to the dam where density of spawning is higher. The higher abundance lower in the restoration reach early in the season could be due, in part, to the fact that fish are smaller early in the year and have slower swimming speeds resulting in being swept downstream. Another explanation could be that fish emerged from redds lower in the restoration reach earlier due to earlier timing of spawning lower in the restoration reach, although redd surveys (Chamberlain et al. 2012) don't support this assumption. In addition to spatial and temporal differences across the restoration reach, a significantly higher relative abundance of juvenile Chinook Salmon was observed in areas with more bank cover.

Differences in juvenile Chinook Salmon relative abundance were also observed through time. Relative abundance at the start of the season was very low, but as the season progressed relative abundance increased through the end of the sample period (Figure 7). The statistical models found a significant time component as well as a significant time and site interaction, indicating that relative abundance at different sites exhibited different temporal patterns. This is expected since the distribution of Chinook Salmon spawning in the Trinity River is highly concentrated near Lewiston Dam and one would expect that patterns in abundance of juvenile Chinook Salmon would have different temporal patterns at different distances from the dam.

Hillman et al. (1992) suggest that the snorkel survey-based population estimates of juvenile salmonids in water temperature below 10 ^{o}C represent a fraction of the true population. This is due, in part, to behavioral differences (Bjornn 1971) that potentially bias snorkel counts. However, many of these studies were conducted on salmonid species that rear longer in riverine environments and may behave differently than juvenile Chinook Salmon. During the entire survey season, the mean daily temperature never exceeded 10 ^{o}C (Figure 2). The TRRP is interested in documenting juvenile Chinook Salmon habitat use during the critical rearing period of January through April, when water temperatures are typically below 10 ^{o}C. The statistical models had a significant time component affecting relative abundance of juvenile Chinook Salmon. Because time is confounded with temperature (daily mean temperatures increased through time), it is impossible to determine if increases in abundance through time were due to an increase in temperature-dependent detectability. However, it is assumed the modeled increase in abundance is due to a true increase fish numbers due to emergence of Chinook Salmon fry from redds during the survey. Although water temperature was low during the survey, spatial and temporal differences in relative abundance were documented and the

described method gives useful information on juvenile Chinook Salmon habitat associations in these relatively low water temperatures.

Johnson et al. (2007) suggest that conducting nighttime surveys during winter months, when water temperatures are low, improves the detection of juvenile salmonids present in the system. The analysis of day versus night variability showed there was no significant difference in snorkel count estimates of juvenile Chinook Salmon relative abundance between day and night counts. In addition, during the daytime surveys, juvenile Chinook Salmon were observed actively utilizing cover and vegetative habitat, and making feeding forays from their cover positions. During night surveys, juvenile Chinook Salmon seemed inactive and tended to be resting on the bottom outside of cover or vegetative habitats and not actively feeding. We feel comfortable that the methods we employed adequately represent relative abundance of juvenile Chinook Salmon utilizing daytime surveys.

Chinook Salmon Versus Habitat

Both the model fitted to the 400-m site data and the subsampled 50m model had significant differences in abundance between sampled sites within the restoration reach, with higher counts of juvenile Chinook Salmon associated with higher percentages of optimal fry habitat as mapped by the 2011 IHAP sampling. In addition, the subsampled 50-m model including bank length of cover was associated with higher juvenile Chinook Salmon counts. In summary, certain sites in the restoration reach had higher relative abundance of juvenile Chinook Salmon directly related to the amount of optimal Chinook Salmon fry habitat mapped the prior summer, and proportional to the bank length of cover within a site. The sampling protocol, as implemented, supports the relationship between Trinity River juvenile Chinook Salmon physical rearing habitat and the resulting biological response. This serves to validate that areas predicted as optimal habitat will likely have higher relative abundance than nearby areas of less than optimal habitat, and that relative abundance is proportional to the length of bank classified as cover.

Recommendations

Snorkel studies are an appropriate tool for assessing juvenile Chinook Salmon relative abundance on the Trinity River, but careful thought must be given to hypotheses and scale of inference when designing future surveys. We recommend changing the site selection strategy of this project to address specific data needs of IAP assessments such as abundance of juvenile Chinook Salmon at rehabilitation sites, their distribution related to that of spawning location, and importance of feature- and habitat-based measures of quality. Implementation of these future assessments may require deviations from the current GRTS sampling methodology that is used in IHAP mapping. For instance, a

more focused assessment on the effects of site rehabilitation on the relative abundance of juvenile Chinook Salmon would a) require extending the number of sites surveyed beyond the current GRTS design, and b) be greatly improved by several years of pre-construction monitoring at future rehabilitation locations.

We recommend co-locating sampling sites at 2-D river model sites to aid in salmon production model development. In addition, we recommend a study design within the 2-D river model sites that incorporates the parameters that are used to define optimal habitat by the IHAP study, namely 1) depth, 2) velocity, and 3) distance to cover. We recommend a design that balances sample units across the range of these habitat values in order to generate a quantitative relationship between relative abundance of juvenile Chinook Salmon and the habitat characteristics where juvenile Chinook Salmon are both present and absent. This type of data is useful for development of a fish production model, which utilizes a habitat function informed by depth, velocity, and distance to cover, for comparing alternative management actions that might alter the physical structure of the Trinity River. This type of study could be spatially balanced across the restoration reach and conducted through time, which would meet the TRRP objective of characterizing spatial and temporal patterns of juvenile Chinook Salmon abundance over the restoration reach, which is an important step in the process of assessing restoration effectiveness.

Conclusions

Direct observation snorkel surveys are feasible on the mainstem Trinity River for documenting spatial and temporal patterns in relative abundance of juvenile Chinook Salmon. Through assumption testing we have also determined the following:

- Snorkel count variability increased with increases in relative abundance of fish.
- Juvenile Chinook Salmon relative abundance did not significantly change within a day.
- Juvenile Chinook Salmon relative abundance was not related to identification distance.
- Juvenile Chinook Salmon relative abundance was not significantly different between day and night.
- Mark recapture for estimating observer (snorkeler) efficiency is not feasible on the mainstem Trinity River due to inability to meet closure assumptions.
- Subsampling of 400-m sites should utilizing at least six 50 m segments per bank to adequately capture variation in single parameter models, but would require more than six 50-m segments per bank if multi-parameter models are investigated.

This study lays the groundwork for evaluating the relationships between juvenile Chinook Salmon abundance and the habitats necessary to support their critical juvenile rearing period in the upper Trinity River, California. This provides an important tie to future restoration strategies by allowing predictions to be made about effects of potential physical alteration of depth, velocity, and cover attributes in a given river reach on juvenile Chinook Salmon relative abundance.

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Appendices

Appendix 1. Table of sampling effort over space and time. Sites are labeled by reach and river kilometers. Full 400-m sites sampled are indicated by 'O', 50 m subsampling of sites is indicated by 'X'.

	Site	UPPER				UPPER MID						LOWER MID						LOWER				
Date	**rkm**	**179**	**176**	**174**	**173**	**163**	**160**	**159**	**154**	**150**	**149**	**146**	**144**	**143**	**141**	**138**	**130**	**128**	**126**	**124**	**118**	**117**
1/31/2012																		O				
2/1/2012											O							XO				
2/2/2012									X													
2/6/2012		O															O					
2/8/2012				O								O		O								
2/13/2012																						X
2/14/2012			XO														XO					
2/15/2012									XO									O				
2/16/2012									O													
2/21/2012			X														X					
2/22/2012									XO									O				
2/23/2012																						
3/12/2012																	X		X			
3/13/2012		X	X				X	X	X													
3/14/2012					X	X																
3/15/2012												X	X									
3/20/2012			XO			XO	X	XO	XO													
3/21/2012																	X		X	X	X	
3/26/2012						X		X														
4/2/2012		X	X																			
4/3/2012		X	X	X																		
4/9/2012															X	X				X	X	
4/10/2012						X				X		X	X				X		X			
4/11/2012					X																	
4/12/2012			X																			
4/16/2012							X	X	X													
4/17/2012		X				X																
4/18/2012			X																	X		
4/19/2012																	X				X	