Estimation Of Age-0 Chinook And Coho Salmon Rearing Habitat Area Within The Restoration Reach Of The Trinity River At An Index Streamflow - Annual Report 2010.

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August 2012

This study was conducted as part of the Trinity River Restoration Program, with financial support provided by the Bureau of Reclamation and the Arcata Fish and Wildlife Office, U. S. Fish and Wildlife Service.

The Arcata Fish and Wildlife Office Fisheries Program reports its study findings through two publication series. The **Arcata Fisheries Data Series** was established to provide timely dissemination of data to local managers and for inclusion in agency databases. The **Arcata Fisheries Technical Reports** publishes scientific findings from single and multi-year studies that have undergone more extensive peer review and statistical testing. Additionally, some study results are published in a variety of professional fisheries journals.

key words: River Restoration, Trinity River, Fish Habitat, Chinook Salmon, Coho, Salmon

The correct citation for this report is:

Goodman, D.H., J. Alvarez, A. Martin, N.A. Som, and J. Polos. 2012. Estimation of age-0 Chinook and coho salmon rearing habitat area within the restoration reach of the Trinity River at an index streamflow - Annual Report 2010. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TR 2012-17, Arcata, California.

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Abstract. The Trinity River is the focus of a restoration effort designed to improve riverine function and increase anadromous fish populations. Chinook and coho salmon populations are limited by age-0 rearing habitat and are a primary focus of the restoration effort. We evaluated the effects of the restoration effort on Chinook and coho salmon rearing habitat over a 64-km (40 mi) restoration reach in 2009 and 2010. Each year habitat area was measured at 32 randomly selected 400- m study sites and then extrapolated to estimate habitat area for the restoration reach. The objectives of this assessment include: (1) estimation of rearing habitat area in 2010 and comparison to the 2009 estimate, (2) an evaluation of site-specific predictors of habitat area and (3) an assessment of correlation between fry and presmolt habitat area. No significant difference was detected for restoration reach habitat area estimates between 2009 and 2010. However, a significant decrease was detected in all cases when evaluating paired-sites surveyed in 2009 and again in 2010. The mean decrease in habitat area at paired sites ranged from 7% to 19%. The cause of the decrease is not clear and will be evaluated in future assessments. Site-specific predictors were related to habitat area estimates using multiple regression modeling and Akaike’s information criterion. The best fit model for optimal habitat area included bank length and proportion of low slope channel. The best fit model for total habitat area included bank length, bar length, channel rehabilitation construction phase, and proportion of low slope channel. These models may be used by restoration site designers to develop predictions of changes (and prediction of error intervals) in rearing habitat area from channel rehabilitation actions or compare among preferred design alternatives. Finally, despite a high correlation between fry and presmolt habitat area, a significant difference was detected in the slope of linear regression analyses among years. These results indicate the importance of measuring both types of habitat during surveys and information may be lost if the study effort was reduced to a single life stage.

Introduction

Several noteworthy anthropogenic impacts have altered the ecology of the Trinity River. During the California Gold Rush, placer mining operations rearranged the river bed and floodplain of the Trinity River and its tributaries (Bailey 2008). The mine tailings from these operations are still clearly visible within the drainage and affect the geomorphic and biological aspects of the river system (Davis 1966; Fuller et al. 2011). These mining operations also introduced large amounts of elemental mercury into the environment as part of the gold extraction process. Mercury is still found in a variety of organisms that inhabit the restoration reach and has led to a health advisory for Trinity Reservoir (May et al. 2005; Bettaso and Goodman 2010). More recently, the construction of the Trinity River Diversion led to additional impacts. Construction of Trinity and Lewiston dams were completed in 1964 and diverted 70 to 90% of Trinity Basin water to the Central Valley (USFWS and Hoopa Valley Tribe 1999). This led to reduced streamflows year-round, creating a stable environment mostly devoid of natural streamflow variation. In addition, the dams isolated anadromous fishes from historic habitats upstream of the dams. Other impacts from the dams included the interruption of sediment and large wood transport, a change in the riparian community, and a change in the overall size and shape of the Trinity River. The combined anthropogenic impacts have contributed to a system where Chinook and coho salmon populations are remnant of historical levels.

To improve the degraded conditions, Trinity River is the focus of a restoration effort that relies on mechanical actions and riverine processes to increase fish populations (USFWS and Hoopa Valley Tribe 1999). Implementation of this restoration is expected to lead to increased channel complexity and result in systemic increases in salmonid rearing habitat quantity and quality. The historical hydrologic and geomorphic effects of the dams are most pronounced between Lewiston Dam and the North Fork Trinity River. The improvements in salmonid habitat quantity and quality will be most pronounced in this reach (hereafter referred to as the "restoration reach") as well. Chinook and coho salmon populations are limited by the availability of age-0 habitat area (hereafter defined as rearing habitat; USFWS and Hoopa Valley Tribe 1999). The restoration strategy is made up of four components including: (1) mechanical channel rehabilitation, (2) flow management to drive fluvial processes that create and maintain salmonid habitats and provide suitable thermal regimes, (3) coarse sediment augmentation and (4) watershed restoration. Although maximum change in salmonid rearing habitat is anticipated at channel rehabilitation sites, it is hypothesized that the restoration strategy will create effects outside of channel rehabilitation sites, improving habitat throughout the restoration reach (Barinaga 1996; USDOI 2000).

This assessment evaluates the effects that restoration actions have on rearing habitat area within the restoration reach. This study was designed and implemented to address the Integrated Assessment Plan Objective 3.2.1 (Trinity River Restoration

Program [TRRP] and ESSA Technologies Ltd. 2009) and is ranked as a top priority for the TRRP science program. This report focuses on a single assessment that is one component of a broad suite of habitat assessments (California Department of Fish and Game et al. 2010). These assessments are being applied concurrently to evaluate rearing and spawning habitat. Other ongoing evaluations include rehabilitation site assessments, two-dimensional hydrodynamic habitat modeling, and resource selection function development. Reports documenting the results of other components of the project will be provided in separate technical reports.

Rearing habitat is the primary limiting factor of Chinook and coho salmon populations (USFWS and Hoopa Valley Tribe 1999). This assessment does not evaluate differences in rearing habitat across streamflows, but rather focuses evaluating the effects of restoration actions at an index summer streamflow with a dam release of 12.7 cms (450 cfs). This streamflow was selected because: (1) it occurs during a time period with little effect from tributary accretions or storm events, (2) it is similar to streamflows in many areas of the restoration reach during the winter rearing period, and (3) it is unlikely to change in the near future because of its objective to meet adult spring-run Chinook salmon temperature requirements. This measure of habitat provides an index of winter and early spring rearing habitat availability. In the future, this index may be used with ongoing rehabilitation site assessments and two-dimensional hydrodynamic modeling studies to evaluate rearing habitat availability across the range of critical streamflows.

The objectives of this study are:

1. Rearing habitat estimates: estimate rearing habitat area over the restoration reach at the summer index streamflow in 2010 and compare to the 2009 estimate.
2. Correlation of rearing habitat estimates to site-specific predictor variables: evaluate the effect of site-specific predictor variables on habitat availability to evaluate linkages between habitat area and physical features as well as provide information to the channel rehabilitation design processes.
3. Correlation among habitat variables: assess the correlation between fry and presmolt habitat availability at the summer index streamflow to provide insight on the potential for reducing survey effort into the future.

Study Area

The Trinity River is located in northwestern California, USA (Lat. 40.708, Long. -122.808; Figure 1). 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; USBOR 2009). The restoration reach and all study sites are located within 64-km (40 mi) of the Trinity River between Lewiston Dam and the confluence of the North Fork Trinity River.

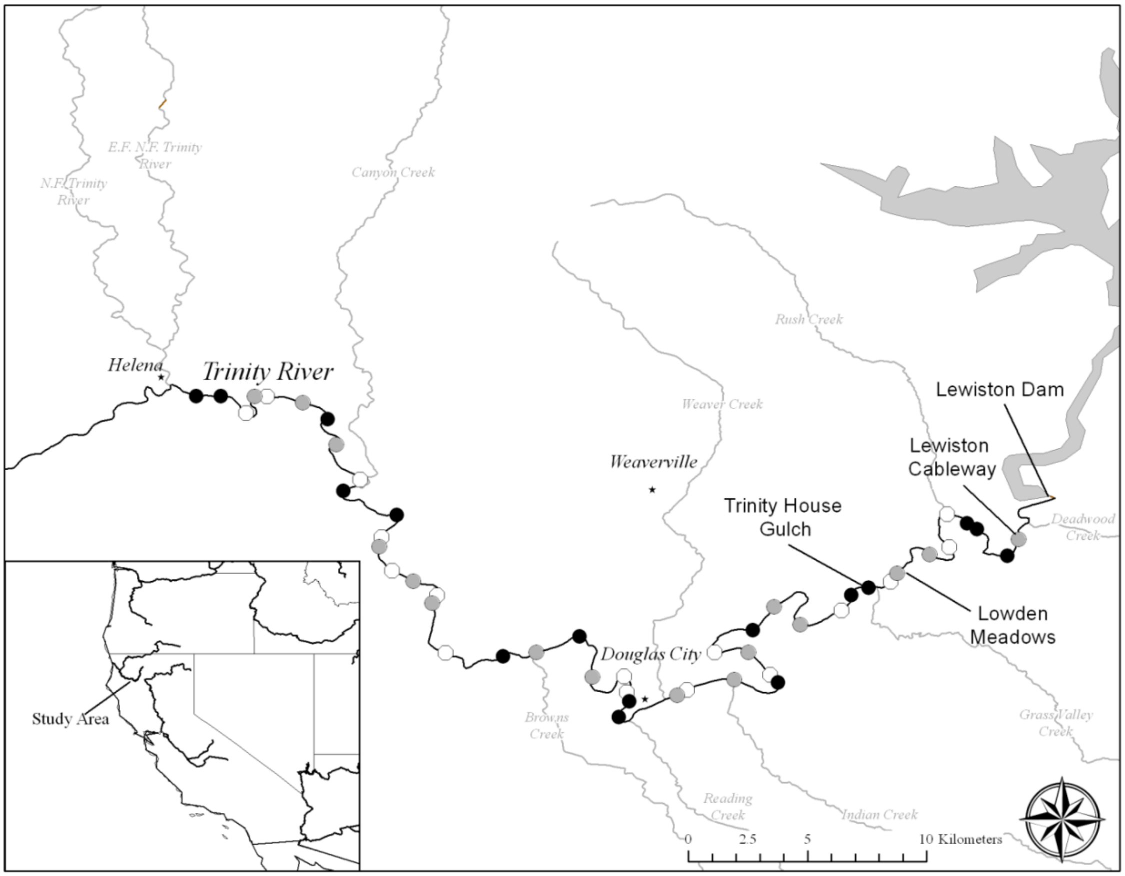


Figure 1. Systemic rearing habitat assessment sample sites on the Trinity River from Lewiston Dam to the confluence with the North Fork Trinity River. Each dot indicates a 400 m sample unit selected using the GRTS protocol. White dots indicate panel 1 sampled in 2009, grey dots indicate panel 2 sampled in 2009 and 2010 and black dots indicate panel 3 sampled in 2010. Trinity River streamflow is from right to left.

Methods

The sampling framework for this study includes: (1) sample site definitions, (2) sample site selection protocol and (3) revisit design. Sample 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). This sample site size was selected based on survey efficiency and recommendations from multidisciplinary planning meetings in anticipation that, if appropriate for specific study objectives, it could be adopted by other disciplines to facilitate in future multi-disciplinary site-specific assessments. The sample universe was defined as the restoration reach, Lewiston Dam to the North Fork Trinity River confluence. Sample units were selected using the generalized random tessellation stratified (GRTS) sample unit selection protocol (Stevens and Olsen 2004). A rotating panel revisit design (McDonald 2003) was developed to evaluate status and trends in rearing habitat availability through time (California Department of Fish and Game et al. 2010). The rotating panel design is composed of five panels with 16 GRTS sample sites per panel. Two panels, or 20% of the restoration reach, are sampled each year (Table 1). In each subsequent year of sampling, one panel is repeated and one new panel is added until all five panels are sampled. In the fifth year the first panel is sampled again and the pattern continues. The five panels make up 50% of the sample universe.

This report represents the second year of the study and in combination with the 2009 data, provides information before and after a single ROD normal water-year streamflow release. The study was initiated in the summer of 2009 and habitat surveys were conducted in panels 1 and 2. The TRRP designated 2010 as a normal water year (www.trrp.net) with releases from Lewiston Dam peaking at 193.71 cms (6,840 cfs; Figure 2). At the downstream extent of the restoration reach streamflows peaked at 218.35 cms (7,710 cfs) due to tributary accretions. After peak streamflows in 2010, habitat surveys were conducted on panels 2 and 3. All surveys were conducted during summer base flows with the Lewiston Dam release of 12.7 cms (450 cfs); however, streamflow variation occurred at each site due to tributary accretions and other factors. Sample units surveyed in 2010 had a mean streamflows of 14.38 cms (508 cfs) with a range of 12.54 to 16.88 cms (443 to 596 cfs) and standard deviation of 0.89 cms (31 cfs). Streamflows were calculated using average daily values from proximal USGS gauges (waterdata.usgs.gov). Differences in surveyed streamflows in all study years were less than the 15% measurement error expected from Trinity River USGS streamflow gauges (Krause 2012).

Rearing habitat mapping was conducted using methods described in Goodman et al. (2010). In summary, habitat parameters of interest (Table 2) were measured and geo-referenced to produce spatially explicit representations of rearing habitat areas within each sample site. Survey data were processed into an ArcGIS polygon shapefile format. Rearing habitat was divided into two developmental phases for each species within their first year of growth (age-0); fry or fish < 50 mm FL and presmolt or fish ≥ 50 mm FL. Optimal Chinook salmon rearing habitat (optimal habitat) for fry and presmolt life stages included areas that simultaneously meet depth, velocity and cover criteria. Total habitat included areas that met any combination of depth and velocity or cover criteria (including optimal habitat areas).

Table 1. The rotating panel revisit sampling design for the rearing habitat assessment on the Trinity River, CA. Each panel is unique (sampling without replacement) and composed of 16 randomly selected spatially balanced sample units.

	Year				
Panel	2009	2010	2011	2012	2013
1	X				X
2	X	X			
3		X	X		
4			X	X	
5				X	X

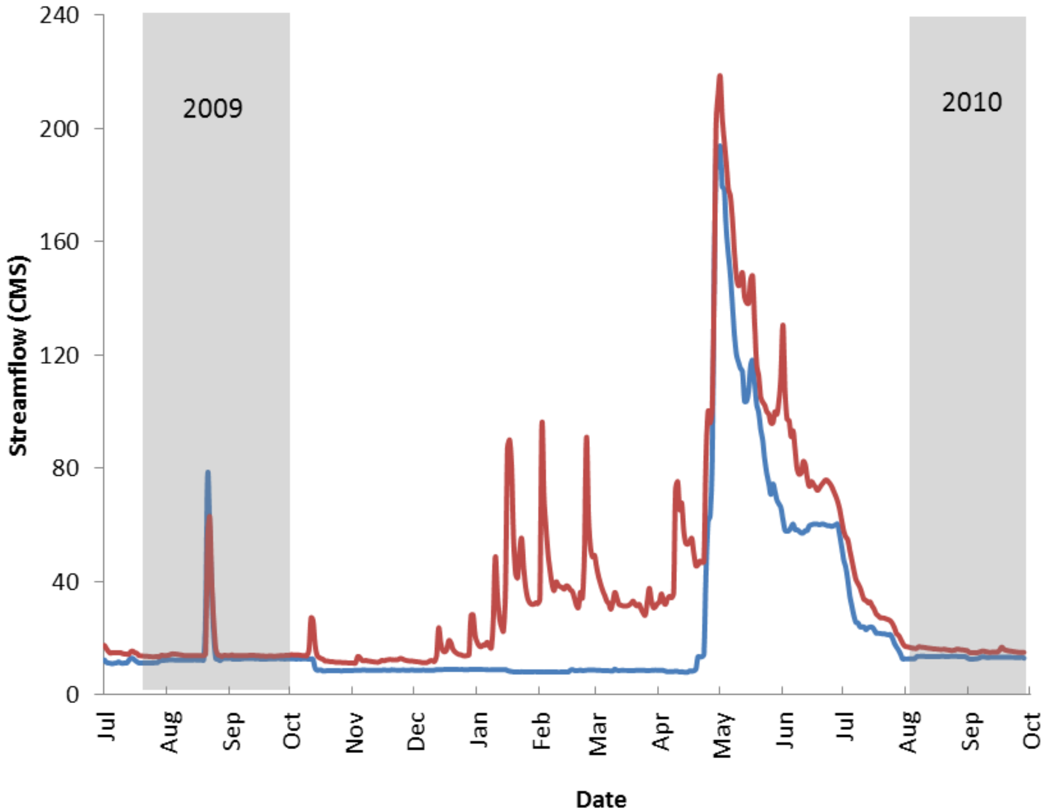


Figure 2. Hydrograph at the upstream and downstream extent of the Trinity River restoration reach during and between the 2009 and 2010 sampling periods. The blue line indicates streamflow measured near the top of the restoration reach just downstream of Lewiston Dam (USGS gauge # 1152550) and the blue line indicates streamflow at the bottom of the restoration reach upstream of the confluence with the North Fork Trinity River (USGS gauge # 11526400). Gray boxes indicate annual survey periods.

Table 2. Habitat categories and their associated habitat criteria for rearing habitat mapping. Chinook salmon total habitat was defined as areas that meet combinations of depth/velocity and cover criteria. Optimal Chinook salmon habitat or coho salmon habitat were defined as areas that simultaneously meet depth, velocity and cover criteria.

Habitat category	Variable	Criteria
Fry (<50 mm)	Depth	>0 to 0.61 m
	Mean column velocity	0 to 0.15 m/sec
	Distance to Cover	0 to 0.61 m
Presmolt ($\geq$50 mm)	Depth	>0 to 1 m
	Mean column velocity	0 to 0.24 m/sec
	Distance to Cover	0 to 0.61 m

Fry and presmolt coho salmon rearing habitat was limited to optimal habitat areas and all other areas were considered unsuitable following Martin et al. (2012).

The definition of fry and presmolt rearing habitat was refined as pertaining only to age-0 fish, rather than relying on a size range as used in Goodman et al. (2010). This refined rearing habitat definition relates more directly to the life stage of interest to the TRRP (USFWS and Hoopa Valley Tribe 1999) and the foundation of habitat suitability data used to derive mapping criteria (Hampton 1997, unpublished data). The habitat suitability data was collected between January and June and therefore habitat area estimates are valid for fish habitat requirements over that time period (Hampton 1997; USFWS and Yurok Tribe unpublished data) given habitat use changes among seasons (Hillman et al. 1989; Bradford and Higgins 2001).

Rearing Habitat Estimates

Rearing habitat area estimates were calculated for each life stage and habitat category. Estimates were calculated by multiplying the mean value of the sample by the number of GRTS sample units in the restoration reach. Sample error was calculated using a neighborhood variance estimator developed for use with GRTS sample designs (Stevens and Olsen 2002). The neighborhood variance estimator incorporates spatial location of GRTS sample units into error estimation. Analyses were conducted in R (R Development Core Team 2009) using Spatial Survey Design and Analysis (spsurvey, Kincaid and Olsen 2009) and displayed using cumulative distribution function plots which display the distribution of habitat quantities and the associated error within the sample. Total estimate comparisons between 2009 and 2010 were conducted using a cumulative distribution function test in spsurvey. Changes in rearing habitat area at panel 2 sites sampled in 2009 and 2010 were evaluated using paired t-tests.

Correlation of Rearing Habitat to Site-specific Predictor Variables

The effects of site-specific predictor variables on habitat quantities were evaluated at GRTS sample units. This analysis builds on a precursor study applied on the Trinity River to analyze data collected in 2009 (unpublished data). The initial step was to develop a set of site-specific predictor variables hypothesized to relate to habitat availability (response variables) and to attribute habitat area estimates with this information. For this analysis habitat availability was defined as total and optimal fry and presmolt habitat. Although there is a wide variety of site-specific variables that may be correlated to habitat area, we selected a small subset based on (1) management importance to the TRRP, (2) considered by the authors to have potential correlations to habitat area and (3) can be measured by remote sense data or through the design process. We hypothesized a direct relationship between the four habitat response variables and five continuous site-specific predictor variables. For construction phase, a categorical variable, we expected higher habitat values associated with constructed sites and more change in these sites across years. Site-specific predictor variables included:

1. Length of wetted edge (bank length): measured with GPS survey techniques concurrent with habitat mapping surveys (Annear et al. 2004; Goodman et. al 2010).
2. Coarse sediment alluvial bar length (bar length): Bar length was estimated from high resolution aerial photography as the adjacent length of the channel centerline (Keen-Zeebert and Curran 2009).
3. Distance from dam: estimated as the mid-point of GRTS sample units using the 142 cms (5,000 cfs) river centerline.
4. Proportion low slope channel (slope): defined as the area of water surface with a slope less than 0.2 degrees. The value of 0.2 degrees is arbitrary and was used to separate low from high water surface slope. Water surface slope was derived from water surface LiDAR returns (Wolpert Inc. 2009). The LiDAR data was then transformed into a triangular irregular network surface or TIN in ArcGIS. A raster analysis was then used to sample slope estimates from the grid at 0.15 m spacing. The raster was then summarized by GRTS sample unit and analyzed as a proportion of water surface within each site with a slope less than 0.2 degrees.
5. Side channel length: measured as side channel centerlines estimated from mapped wetted channel areas within the GRTS site.
6. Channel rehabilitation site phase (construction): a categorical variable coded as construction if TRRP channel rehabilitation actions encompassed greater than 25% of the length of the GRTS sample unit. Otherwise the site was coded as no construction (Table 3).

Multiple regression linear modeling was implemented to test relationships between the four habitat variables (response) and the set of six site-specific predictor variables. Data from panel 1 collected in 2009 (unpublished data) and panels 2 and 3 collected in 2010 were used for this analysis. Data from panel 2 collected in 2009

Table 3. Channel rehabilitation sites within sample units that were constructed at the time of survey. All sites had channel rehabilitation efforts within at least 25% of the sample unit. Lowden Ranch was sampled during channel construction.

Site	Year of Construction	Panel 1	Panel 2	Panel 3
Lewiston Cableway	2008		X	
Hoadley Gulch	2008			X
Dark Gulch	2008	X	X	
Lowden Ranch	2010	X	X	
Vitzhum Gulch	2007			X
Indian Creek	2007		X	
Lower Indian Creek	2007	X	X	
Hocker Flat	2005	X		
Valdor Gulch	2006		X	
Pear Tree Gulch	2006			X

were not used because of a lack of independence of these sites among years. These data were first analyzed for correlation among site-specific predictor variables and response variables using the non-parametric Spearman's rank correlation coefficient ρ (rho). To avoid multi-colinearity, pairs of explanatory variables with correlation values greater than 0.5 were not used concurrently in a single model (Zar 2005). Akaike information criterion (AIC) approach was used to compare candidate multiple regression models for each response variable using AICcmodavg package in R (Burnham and Anderson 2002; Mazerolle 2009). AIC provides a simple and objective way for identification of the best approximating model from a set of candidate models. In this case AICc was used which includes a correction factor for small sample sizes. The same set of candidate models were considered for each of the four habitat response variables.

Correlation among Habitat Variables

To compare the relationship between fry and presmolt habitat area values across years, a comparison of regression lines approach was applied. The equality of intercepts and slopes among years was evaluated using likelihood ratio tests, and the tables and figures presented display the model most supported by these tests. When statistical support for significance of differences was marginal, the figures err on the side of displaying differences among years.

Linear relationships existed for both 2009 and 2010; however, the range of total habitat values differed between the years. There are around ten total habitat 2010 value pairs that are smaller than any observed in 2009. There are two total habitat value pairs in 2009 that exceeded those in 2010, with the largest of these being around 1.67 times the largest 2010 value. Additionally, there is one optimal habitat value pair in 2009 that was nearly 2 times larger than any observed in 2010. Because these values are so much larger than any other in 2009 and 2010, they exhibit extreme influence on the regression coefficient estimates. As such, the comparison of regression lines was carried out twice, with and without each value in their respective analysis.

Results

Rearing Habitat Estimates

Estimates of habitat area were developed for fry and presmolt optimal and total habitat areas (Figure 3; Table 4). No significant differences were detected in cumulative distribution functions between total habitat estimates in 2009 and 2010 for fry ($F = 1.345$, $p = 0.268$) and presmolt ($F = 2.312$, $p = 0.108$). Similarly, no significant differences were detected in cumulative distribution functions of optimal habitat estimates between 2009 and 2010 for fry ($F = 0.914$, $p = 0.406$) and presmolt ($F = 0.387$, $p = 0.681$). The confidence intervals and standard errors for habitat area estimates decreased between 2009 and 2010. Several GRTS sample units with extremely high habitat area values were not sampled in both years because of the rotating panel revisit design and had a strong influence on differences among years.

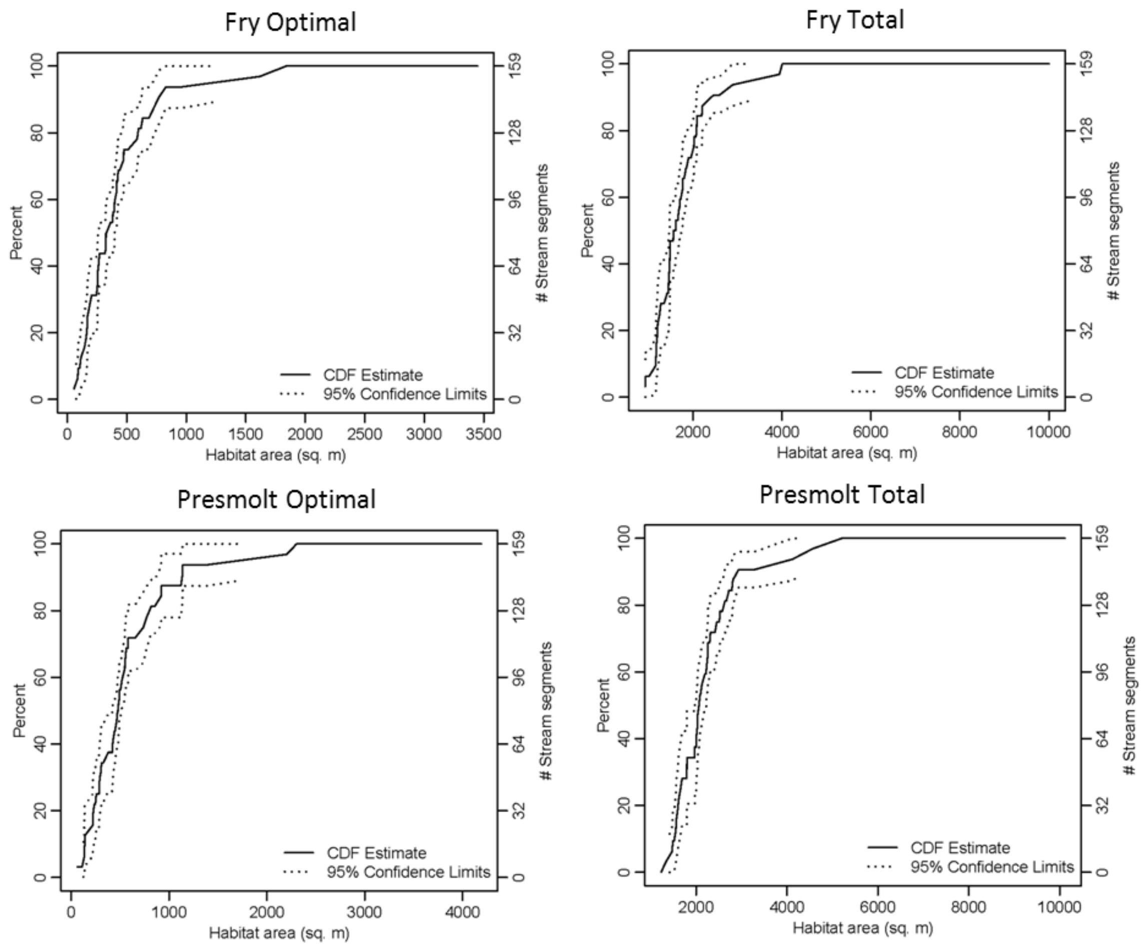


Figure 3. Cumulative distribution functions of fry and presmolt habitat from 32 GRTS sample units from the 2010 Trinity River restoration reach rearing habitat estimate. The primary y-axis corresponds to the percent of the restoration reach estimated to contain the specific quantity of rearing habitat. Alternatively, the secondary y-axis indicates the number of 400 m segments estimated to contain the specific quantity of rearing habitat.

Table 4. Habitat area estimates for the restoration reach of the Trinity River in 2009 and 2010. Habitat values reported in m^2.

		2009				2010			
Life stage	Habitat	Estimate	SE	LCB 95%	UCB 95%	Estimate	SE	LCB 95%	UCB 95%
Fry	Optimal	88,174	10,961	66,690	109,658	69,935	6,430	57,333	82,536
	Total	343,201	29,429	285,521	400,881	282,353	11,094	260,608	304,097
Presmolt	Optimal	117,623	12,724	92,685	142,561	95,540	8,440	78,997	112,082
	Total	436,613	28,413	380,924	492,302	364,482	13,354	338,309	390,654

There were small but significant decreases in habitat area when comparing sites sampled in 2009 and again in 2010 (panel 2). At the 16 resampled sites, 13 GRTS sample units decreased in optimal habitat area and 14 decreased in total habitat area for fry and presmolt habitat. For fry, a significant decrease was detected in optimal habitat area ($t = 2.684$, $df = 15$, $p = 0.017$) with a mean difference of 16% or 86 m^2 (926 ft^2) with a 95% confidence interval (CI) of 23 to 149 m^2 (248 to 1604 ft^2). A significant decrease was also detected for total fry habitat area ($t = 2.684$, $df = 15$, $p = 0.017$) with a mean difference of 8% or 145 m^2 (1561 ft^2) with a 95% CI of 30 - 260 m^2 (323 to 2,799 ft^2). Similarly for presmolt, a significant decrease was detected for optimal habitat area ($t = 3.520$, $df = 15$, $p = 0.0031$) with a mean difference of 15% or 111 m^2 (1,195 ft^2) with a 95% CI of 44 to 179 m^2 (474 to 1,927 ft^2). A significant decrease was also detected for total presmolt habitat area ($t = 2.928$, $df = 15$, $p = 0.010$) with a mean difference of 8% or 200 m^2 (2,153 ft^2) with a 95% CI of 55 to 346 m^2 (592 to 3,724 ft^2). Variation in the difference between 2009 and 2010 habitat area in all cases was related to channel rehabilitation activity status (Figure 4). The sites with channel rehabilitation activities had higher variations than those without. The largest single increase in total habitat area was observed at the Lowden Ranch channel rehabilitation site which was under construction during the 2010 survey. The largest decrease in habitat area in all cases occurred at the Lewiston Cableway channel rehabilitation site, the closest site to Lewiston Dam.

Correlation of Rearing Habitat to Site-specific Predictor Variables

Habitat area variables were related to site-specific predictor variables using multiple regression modeling. To avoid multi-colinearity, parameters with high correlation, such as side channel length and bank length ($\rho = 0.82$), were not included in the same model (Table 5). No other pairwise comparisons among site-specific predictor variables had correlations greater than 0.5. Distance from dam had the strongest correlation to response variables in all cases with higher habitat area associated with units near Lewiston Dam (Table 6). To elucidate the effect of other site-specific predictor variables and better inform modeling objectives, distance from dam was removed from multiple regression modeling. Residual analysis indicated a variance stabilizing transformation was necessary. The regression models detailed below incorporated a log e transformation of the response variables.

Nine models were developed a priori and applied to each of the four habitat area variables (response variables) and then ranked according to AICc values. Congruencies were observed for model comparisons between life stages. For example, AICc rankings among models for optimal habitat were the same for fry and presmolt (Table 7). In both cases the best ranking model included bank length, bar length, channel rehabilitation site phase and proportion of low slope channel (Table 8). However, the simpler model that included just bank length and slope was less than 2 AICc units away from the best ranked model with no difference in parameter significance and only minor differences in parameter estimates. In both the fry and presmolt models, bank length and slope were statistically significant and estimated to be positively associated with transformed response variables. Similarly the rankings among models for total habitat were the same for fry and presmolt (Table 9). The

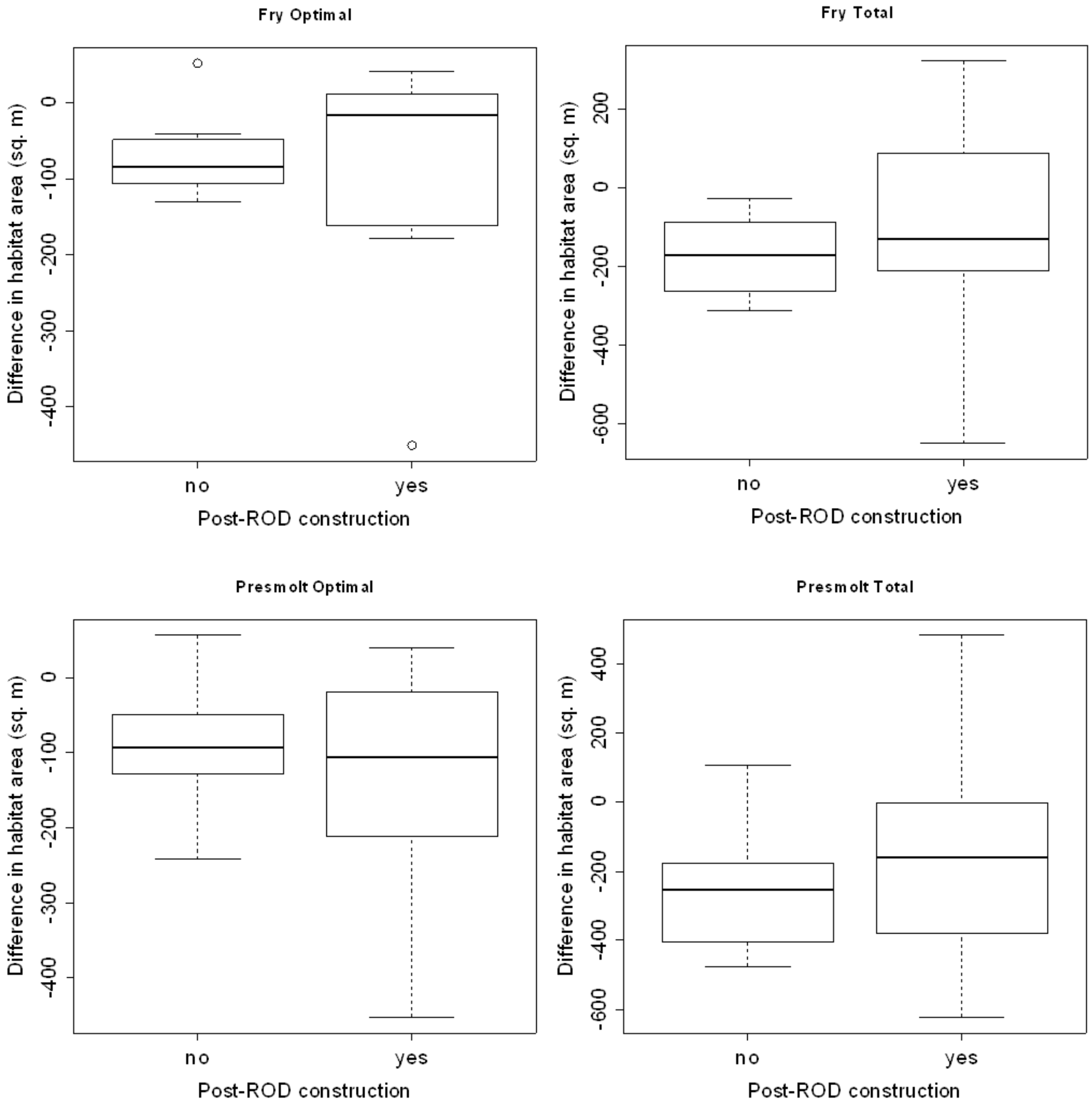


Figure 4. Variation in the difference between 2009 and 2010 estimates of rearing habitat area (m^2) with (yes, n = 7) and without (no, n = 9) post-ROD channel rehabilitation. Difference in habitat area was measured as 2010 area minus 2009 area at paired sites. The following variables are represented in the plot: (1) a horizontal line is drawn at the median observation, (2) the boxes represent the first (Q1) and third quartile (Q3) values, (3) whiskers are defined by the values adjacent to the lowest and highest observations using the following limits (a) lower limit: Q1-1.5*(Q3 - Q1) and b) upper limit: Q3 + 1.5*(Q3 - Q1). Dots indicate values that lie beyond the extremes of the whiskers.

Table 5. Spearman rank correlation coefficients between predictors of rearing habitat availability. Predictors include bank length (bank), alluvial bar length (bar), distance from the dam (dist. dam), proportion of the site that is low slope (slope), and length of side channel (side channel).

	Bank	Bar	Dist. dam	Slope	Side channel
Bank	1	0.27	-0.41	-0.24	0.82
Bar		1	0.22	-0.47	0.18
Dist. dam			1	-0.38	-0.36
Slope				1	-0.17
Side channel					1

best ranked model in this case included just bank length and proportion of low slope channel (Table 10). In the cases of total habitat area, three models had AICc scores within 4 AICc units of the best fitting model. These models all included bank length. In all three models for both life stages bank length was statistically significant and estimated to be positively associated with transformed response variables.

Correlation among Habitat Variables

Comparing the relationship between fry and presmolt habitat values across years indicated that there was generally weak, but inconclusive, evidence of differences in the slope parameters, and very little evidence for differences among the intercepts (Tables 11, Figures 5 – 6). Though there was strong evidence of differences among slopes for total habitat using the entire data (χ^2 = 14.326, df = 1, p = <0.001), removing the extreme and influential pair rendered this test only weakly significant (χ^2 = 2.879, df = 1, p = 0.090). The pattern was similar for optimal habitats, where there was moderate evidence for differences among slopes using the entire data (χ^2 = 6.188, df = 1, p = 0.013), but the evidence weakened when removing the extreme and influential pair (χ^2 = 3.320, df = 1, p = 0.068). In regards to estimated intercept parameters, the evidence of differences among years was much weaker. Though the intercepts across years were estimated to be different using the full data for total habitat (χ^2 = 14.723, df = 1, p = <0.001), there was no evidence of a

Table 6. Spearman rank correlation coefficients between predictor variables and rearing habitat availability. See predictor variable descriptions in Table 3

	Fry		Presmolt	
Predictor	Optimal	Total	Optimal	Total
Dist. dam	-0.82	-0.60	-0.81	-0.50
Bank	0.34	0.50	0.34	0.43
Bar	-0.31	0.14	-0.31	0.18
Slope	0.41	0.10	0.42	0.13
Side channel	0.26	0.45	0.27	0.43

Table 7. Optimal rearing habitat multiple regression model comparisons. The models are listed by habitat covariates with the number of covariates (k), multiple R2, Akaike Information Criterion corrected for small sample sizes (AICc), change in AICc from the best approximating model (ΔAICc), Akaike weights (wi), cumulative model weight (Cum. wi), and log likelihood (LL). Models with the highest wiand the lowest AICc are those that best fit the data. In all cases the response variable was log transformed. See Table 5 for descriptions of model parameters.

Habitat	Model	k	R^2	AICc	ΔAICc	*wi*	Cum. *wi*	LL
Fry optimal	Bank, bar, construction, slope	6	0.55	88.77	0	0.71	0.71	-37.36
	Bank, slope	4	0.48	90.53	1.76	0.29	1	-40.8
	Side channel, slope	4	0.30	104.97	16.2	0	1	-48.02
	Side channel, bar, construction, slope	3	0.33	107.01	18.24	0	1	-50.23
	Bank	6	0.23	107.62	18.85	0	1	-46.78
	Slope	3	0.16	111.14	22.37	0	1	-52.3
	Bar	3	0.08	114.92	26.15	0	1	-54.19
	Side channel	3	0.09	115.29	26.52	0	1	-54.37
	Construction	3	<0.01	119.39	30.62	0	1	-56.42
Presmolt optimal	Bank, bar, construction, slope	6	0.53	89.07	0	0.65	0.65	-37.51
	Bank, slope	4	0.46	90.29	1.23	0.35	1	-40.68
	Side channel, slope	4	0.30	103.31	14.25	0	1	-47.19
	Side channel, bar, construction, slope	6	0.33	105.98	16.91	0	1	-45.96
	Bank	3	0.21	106.52	17.45	0	1	-49.99
	Slope	3	0.16	109.37	20.31	0	1	-51.41
	Bar	3	0.09	113.55	24.48	0	1	-53.5
	Side channel	3	0.09	113.65	24.59	0	1	-53.55
	Construction	3	<0.01	117.9	28.83	0	1	-55.68

Table 8. Parameter estimates of the best approximating fry and presmolt models for optimal rearing habitat area. The fry model had a residual standard error of 0.557 and the presmolt model had 0.559 both with 43 degrees of freedom. For parameter descriptions see Table 3.

Life stage	Parameter	Estimate	Std. Error	t	Pr> |t|
Fry	(Intercept)	3.233	0.455	7.110	< 0.001
	Bank	0.002	0.000	5.850	< 0.001
	Bar	-0.002	0.001	-1.888	0.066
	Construction	-0.273	0.219	-1.248	0.219
	Slope	1.563	0.456	3.425	0.001
Presmolt	(Intercept)	3.646	0.456	7.994	< 0.001
	Bank	0.002	0.000	5.550	< 0.001
	Bar	-0.002	0.001	-1.872	0.068
	Construction	-0.243	0.219	-1.109	0.274
	Slope	1.554	0.458	3.397	0.001

Table 9. Total rearing habitat area multiple linear regression model comparisons. For descriptions of variables see Table 3 caption.

Habitat	Model	k	R^2	AIC_c	ΔAIC_c	w_i	*Cum.* w_i	LL
Fry total	Bank, slope	4	0.41	32.84	0	0.75	0.75	-11.95
	Bank	3	0.34	36.41	3.57	0.13	0.88	-14.93
	Bank, bar, construction, slope	6	0.43	36.5	3.66	0.12	1	-11.22
	Side channel, slope	4	0.21	47.16	14.32	0	1	-19.11
	Side channel	3	0.15	47.84	15.01	0	1	-20.65
	Side channel, bar, construction, slope	6	0.23	50.6	17.77	0	1	-18.28
	Construction	3	0.03	54.56	21.73	0	1	-24.01
	Slope	3	0.03	54.59	21.76	0	1	-24.02
	Bar	3	0.02	55.16	22.32	0	1	-24.31
Presmolt total	Bank, slope	4	0.42	23.19	0	0.66	0.66	-7.13
	Bank	3	0.36	25.4	2.2	0.22	0.88	-9.43
	Bank, bar, construction, slope	6	0.44	26.6	3.41	0.12	1	-6.28
	Side channel	3	0.19	36.68	13.49	0	1	-15.07
	Side channel, slope	4	0.23	36.76	13.57	0	1	-13.91
	Side channel, bar, construction, slope	6	0.27	39.6	16.4	0	1	-12.77
	Construction	3	0.05	44.75	21.56	0	1	-19.1
	Bar	3	0.03	45.63	22.44	0	1	-19.54
	Slope	3	0.01	46.3	23.11	0	1	-19.88

difference when the extreme and influential pair was removed ($\chi^2 = 1.013$, df = 1, p = 0.313). For optimal habitat areas, neither the full or extreme pair reduced data showed any evidence for differences in intercepts ($\chi^2 = 1.448$, df = 1, p = 0.229, $\chi^2 = 2.292$, df = 1, p = 0.130, respectively).

Discussion

Rearing Habitat Estimates

This report is the first evaluation of changes in rearing habitat area at the restoration-reach scale since the implementation of the ROD. There was no change in habitat area estimates across the restoration reach between 2009 and 2010 (P = 0.108 to 0.406). No hypotheses have been made by the TRRP for anticipated

Table 10. Parameter estimates of the best approximating fry and presmolt models for total rearing habitat area. The fry model had a residual standard error of 0.321 and the presmolt model had 0.290 both with 45 degrees of freedom. For parameter descriptions see Table 3.

Life stage	Parameter	Estimate	Std. Error	t	Pr> |t|
Fry	(Intercept)	6.194	0.244	25.386	< 0.001
	Bank	0.001	0.000	5.423	< 0.001
	Slope	0.583	0.239	2.438	0.019
Presmolt	(Intercept)	6.590	0.221	29.861	< 0.001
	Bank	0.001	0.000	5.616	< 0.001
	Slope	0.459	0.216	2.125	0.039

Table 11. Comparisons of the slopes and intercepts of the relationships between fry and presmolt total and optimal habitat across sample years. Tests reference the null hypothesis that slopes or intercepts are equal among years.

Dataset	Intercept			Slope		
	Chisq	df	p	Chisq	df	p
Total Habitat (Full data)	14.723	1	<0.001	14.326	1	<0.001
Total Habitat (w/o extreme value)	1.013	1	0.313	2.879	1	0.090
Optimal Habitat (Full Data)	1.448	1	0.229	6.188	1	0.013
Optimal Habitat (w/o extreme value)	2.292	1	0.130	3.320	1	0.068

changes in habitat area from the combined effects of flow and channel rehabilitation in the restoration reach over a single normal year ROD water year. Therefore, it is not possible to place the results of this assessment into the context of anticipated changes. In the future the TRRP should put effort into developing quantitative predictions of the change in habitat area from restoration actions. However, this study may be used to inform future predictions and hypotheses of system response to restoration actions. In addition, the revisit design for this study is on a 5-year rotating panel and we do not expect to capture the full breadth of changes from restoration at this point.

The standard error of the habitat area estimate decreased between 2009 and 2010, which may be related to the rotating panel revisit design and inclusion of different sample units. The rotating panel introduces different GRTS sample units across years. This design reduces the reliance of a single sample to indicate the status of the restoration reach through time while repeating some samples to improve the ability to evaluate trends. In the case of the 2009 sample, the three GRTS sample units closest to Lewiston Dam had extremely high values for fry and presmolt life stages which increased the standard error of the annual estimate. Only one of the extreme values, the Lewiston Cableway rehabilitation site, was resampled in 2010. Therefore, the 2010 sample had less influence from extreme values resulting in a lower standard error.

Two of the GRTS sites sampled in 2010 were also coincidentally channel rehabilitation sites being built during the survey. Lowden Ranch was sampled in the middle of construction activities with partial alteration of habitat areas within the 12.7 cms (450 cfs) wetted channel. Some of the features intended to increase habitat area were completed, such as an alcove and several large wood habitat structures. However, other features such as a side channel with large wood installations that were designed to increase habitat area (Cardno-Entrix and CH2MHILL 2010; Department of Water Resources 2010) were constructed after mapping was completed. Despite only the partial effect of the rehabilitation effort, Lowden Meadows had the highest gains in habitat area among panel 2 sites. It also was the only site included in the sample that was constructed between the two sampling periods. The other site, Trinity House Gulch, was sampled before construction activities affected any features that would have affected habitat estimates.

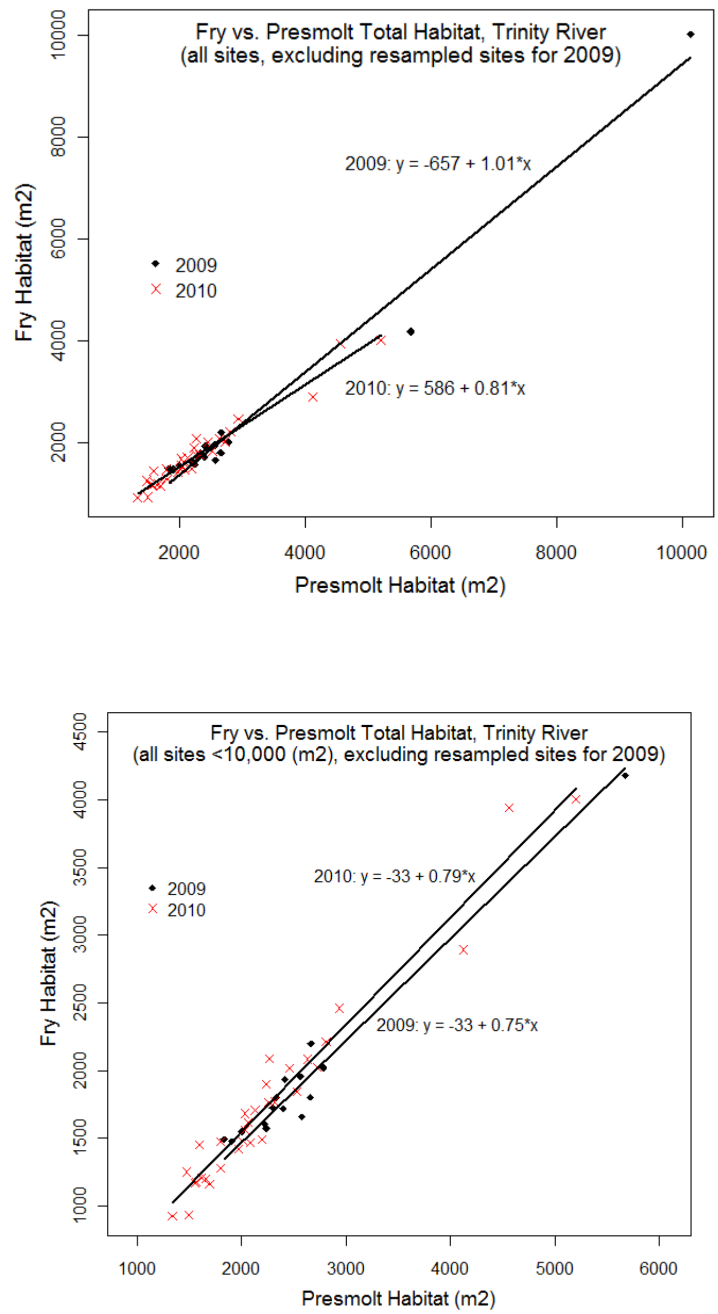
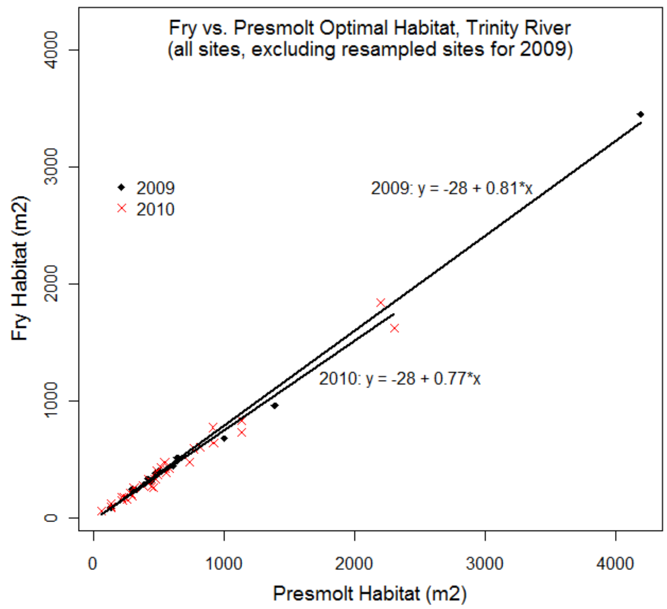


Figure 5. Relationship between fry and presmolt total habitat (m^2) during 2009 (n = 15) and 2010 (n = 32) systemic habitat assessment on the upper Trinity River excluding resampled sites from 2009 sampling. The top figure includes all data and the lower figure excludes sites with habitat areas greater than 10,000 m^2.



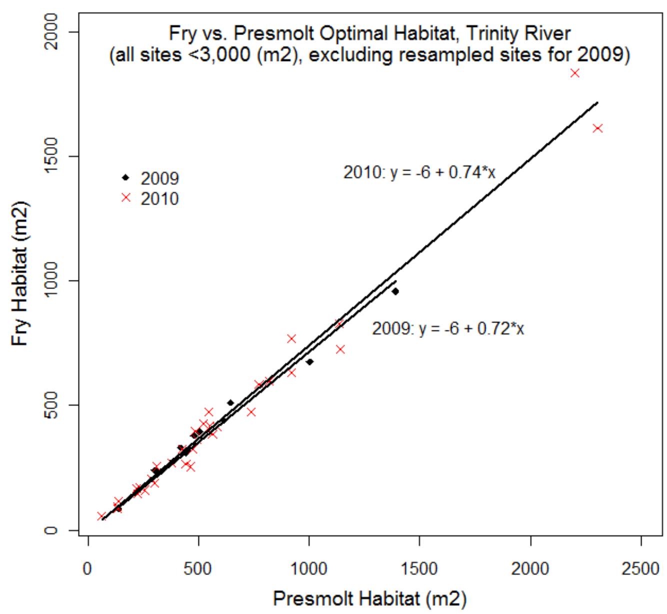


Figure 6. Relationship between fry and presmolt optimal habitat (m^2) during 2009 (n = 15) and 2010 (n = 32) systemic habitat assessment on the upper Trinity River excluding resampled sites from 2009 sampling. The top figure includes all data and the lower figure excludes sites with habitat areas greater than 3,000 m^2.

Therefore, the full benefits of channel rehabilitation actions were not documented in the 2010 survey. Trinity House Gulch is a panel 3 site and will be resampled during the 2011 survey.

An 8% to 16% decrease in habitat area was observed between 2009 and 2010 in panel 2. The cause for the decrease in habitat area is unclear at this time. The decrease may be related to channel rehabilitation sites that were under construction during surveys, geomorphic changes causing reductions in habitat area, natural variation in the system or other factors. We plan to re-evaluate changes at paired sites in 2011 to assess if decreases in habitat area are consistent among years and if so, then what factors are attributing to the declines.

More variation in habitat area occurred between 2009 and 2010 at channel rehabilitation sites than unconstructed sites. This is an anticipated response to the reshaping of the channel associated with channel rehabilitation efforts such as the removal of riparian berms and creation of alluvial features. The largest gain in total habitat occurred from the partial construction of Lowden Ranch as described above. In addition, this site had the second highest increase in optimal habitat area. In contrast, the greatest decreases occurred at the Lewiston Cableway rehabilitation site constructed in 2008. In 2009, the site was evaluated the year after construction. A peak streamflow of 193.71 cms (6,840 cfs) occurred between the 2009 and 2010 surveys, resulting in a readjustment of several constructed and natural features. Channel changes resulted in the reduction in the size of an eddy and alcove which were partially responsible for the observed decrease at the site.

Correlation of Rearing Habitat to Site-specific Predictor Variables

Site-specific predictor variables were related to habitat area and may provide a useful tool in the site design process. Distance from dam had the highest correlation to habitat area. This relationship may be used to prioritize future construction sites. For example, if a program goal is to balance the distribution of rearing habitat area within the restoration reach, then increasing habitat should be prioritized for downstream reaches. Distance from dam was removed before multiple regression modeling analyses were conducted. The multiple regression analyses focus on providing information on the expected habitat response from channel modifications within a selected location or environmental study limit. The equations developed from the multiple regression modeling may be used by site designers to develop quantitative predictions of rearing habitat response from channel rehabilitation efforts. This tool could be used to compare response of site design alternatives in planning processes. Alternatively the equations may be used to develop and test predictions of expected habitat response from actual channel rehabilitation actions. Applying and refining this analysis would be an ideal avenue to further integrate the efforts of the TRRP's design team and science team to maximize the benefits from restoration actions.

Previous evaluations of the effect of site-specific variables on habitat area were conducted in association with (1) the 2009 systemic habitat survey and (2) site-specific channel rehabilitation assessments (unpublished data). The variables in the initial systemic habitat assessment were channel rehabilitation phase (construction), side channel length, bank length, distance from dam and elevation change. Multiple regression modeling was not applied in 2009 due to sample size limitations. In this initial assessment, bank length and distance from dam were correlated to total habitat area and just distance from dam was correlated to optimal habitat area. The component of the study that evaluated correlation of rearing habitat area at sample units to site-specific predictor variables at channel rehabilitation assessments relied on a different set of variables than used in the initial systemic assessment and included radius of curvature, topographic diversity, shear stress diversity, length of wetted edge (bank length) and area of exposed active alluvial deposits (bar area). Of these variables, bank length consistently had a positive correlation with habitat area. No other site-specific predictor variables showed consistent correlations to rearing habitat area at sample units.

Several changes were implemented in the 2010 study of site-specific variables that may be used to predict habitat area. Challenges were identified and discussed about how the slope variable was defined in the 2009 assessment (unpublished data). In summary, slope was coded as the difference in elevation between the upstream and downstream water surface elevation. This definition was problematic for GRTS sample units where the channel was primarily low gradient such as a pool or run, with short areas of large changes in elevation such as a steep riffle. In this case the site may receive a high elevation change despite primarily low slope habitat. This variable was redefined as the proportion of low slope habitat within a sample site to better capture the variable of interest which was amount of low slope channel. This variable was present and significant in all top models and seems to be a good approximation of low slope channel. In addition, bar length was added to the analysis. This variable is of particular importance to the TRRP and is a common feature in many channel rehabilitation designs. This variable was coded as length of bar because of its direct relationship to wetted habitats. In the past, bar area has been suggested as a metric however, this would include large areas of dry channel that would not be expect to relate to in-water conditions. Therefore, bar length is likely a more appropriate metric for this analysis. The larger sample size based on three panels of data facilitated additional analytical approaches to explore relationships among the data, notably multiple regression modeling and AIC model selection.

In the future, we plan to expand the analysis comparing rearing habitat area at sample units to site-specific predictor variables to include additional panels and variables. In 2011, we will have an additional panel of data to include in the analysis that may improve its predictive power and facilitate more sophisticated analytical approaches. Additional site-specific predictor variables should be considered in future assessments, such as channel width and confinement. These variables may be factors that can improve predictions but have not yet been evaluated. In addition, we plan to conduct sensitivity analyses to evaluate if variable definitions affect their correlation to habitat area. For example, additional bar metrics may be considered such as wetted edge associated with alluvial bars that may improve correlation to habitat area. Finally we plan to expand the study to evaluate if the relationships are stable across streamflows. The series of two-dimensional hydrodynamic models that are currently under development will provide a good platform to expand this analysis across streamflows in the future and substantially improve its utility to the TRRP.

Correlation among Habitat Variables

The relationships between fry and presmolt habitat estimates are very strong. However, there were significant differences in the relationships across years for the both optimal habitat and total habitat at $\alpha = 0.10$. While the data point GRTS400-14 for total habitat from the 2009 dataset is much greater than most of the data and is leveraging a shift in the relationships, the strength of the relationship does not suggest that these data should be removed from the dataset as an outlier. This site, encompassing part of the Rush Creek delta, is a unique site with significant complexity which influences the amount of habitat available at the site but does not appear to be out of place with the general relationship observed in the data.

While it may be appropriate to only measure presmolt habitat and use these relationships to estimate fry habitat since they are very strong for both total and optimal habitat, there were some differences between the two years that suggest that sampling of both fry and presmolt habitat should occur in 2011. Additionally, since the river experienced a high geomorphic ROD flow release in 2011, it would be useful to have a full set of fry and presmolt data to evaluate if the changes in the physical condition of the river altered these relationships. A final reason to collect both fry and presmolt habitat data in 2011 is to have a third year of sampling of both fry and presmolt data so that there will be data for future analyses on sampling intensity and repeat design. Currently, there are only 16 sites that are available where repeat sampling occurred. Having both fry and presmolt data for an additional 16 resampled sites should be beneficial, especially after the occurrence of wet water year and geomorphic flows in Spring 2011. In the future more sophisticated analyses of these data should be conducted to ensure that the information needed for this assessment is obtained in the most efficient manner.

Acknowledgements

Many people contributed to the continual success of this project. We would like to thank the field crew for their efforts in collecting the information necessary for this assessment and in particular the efforts of Matt Smith-Caggiano and Oliver Miano from USFWS, Jeremy Alameda, Larry Alameda Jr. and Kyle DeJuilio from the Yurok Tribe and Joel Chase from the Hoopa Valley Tribe. We appreciate the support of Nick Hetrick and Mark Magneson for formatting and report editing. In addition, we would like to thank Tony Olsen and Thomas Kinkaid from USEPA for statistical support and Daniel Jones and Rachel Rodriguez from the Yurok Tribe for database support. Finally, we would like to thank Seth Naman from NOAA and the three other anonymous reviewers for their comments. Their thoughtful reviews resulted in significant improvements to the report.

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