# The Effects of Restoration on Salmon Rearing Habitats in the Restoration Reach of the Trinity River at an Index Streamflow, 2009 to 2013.

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## Table of Contents



## List of Tables



## List of Figures

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*Abstract*.— Chinook Salmon (*Oncorhynchus tshawytscha*) and Coho Salmon (*O. kisutch*) populations in the Trinity River are limited by age-0 rearing habitat and are a focus of a large-scale restoration effort. We estimated the effects of restoration on rearing habitat area over a 64-km restoration reach of the Trinity River annually between 2009 and 2013 by systematically sampling 32, 400-m units per year. Rearing habitat areas were mapped at sample units by field measurements of water depth, average flow velocity, and proximity to in-water cover. All data was collected at an index streamflow of 12.7 $m^3s^{-1}$, which is similar to that experienced by a high proportion of the restoration reach during the critical winter and early spring rearing period. Significant differences in rearing habitat area were not detected in most comparisons between years. Two comparisons indicated slight, but statistically significant decreases in rearing habitat area, which were attributed to sampling error and were not likely from true reductions. Paired sample units, surveyed in before and after peak streamflows, identified localized changes in the amount and spatial arrangement of rearing habitat areas. In addition, significant differences were detected in the paired samples; however they indicated both increases and decreases in rearing habitat area. The magnitude of habitat change did not relate to annual peak streamflows, a primary driver in the fluvial processes that were expected to improve habitats. Our results demonstrate that substantial improvements in rearing habitat did not occur at the index streamflow during the study period. The results of this study have led to a reduction in sampling effort for future investigations and an emphasis on detecting change in habitat area over longer time-scales. We suggest the rate and magnitude of habitat improvement from restoration efforts could be increased by revising the current streamflow management to synchronize managed dam releases with tributary streamflow events.

## Introduction

Several noteworthy anthropogenic impacts have degraded riverine habitats in the Trinity River and led to declines in anadromous fish populations. During the historic California Gold Rush and continuing until the 1950's, placer and dredger mining operations delivered excessive amounts of sediments to the river, rearranged the river bed and floodplain, and simplified aquatic habitats (Bailey 2008, AECOM 2013). Mercury waste from the mining operations is still present in the river system and has been detected in aquatic organisms (e.g., May et al. 2005; Bettaso and Goodman 2010; Fuller et al. 2011). More recently, in 1964, construction of Trinity and Lewiston dams and the Clear Creek Tunnel were completed, which enabled export of 70 to 90% of water captured by Trinity dam to the Central Valley (USFWS and Hoopa Valley Tribe 1999). The dams also isolated anadromous fishes from approximately 177 km of upstream habitats, drastically curtailing the upstream limit of their distribution (Locke et al. 2008). Streamflows downstream of the dams were reduced to approximately 4.2 $m^3s^{-1}$and managed to be devoid of natural variation. Elimination of peak geomorphic flows and interruption of sediment and large wood transport regimes simplified the river channel below Lewiston Dam, which resulted in loss of salmonid habitats. The combination of these impacts led to dramatic declines in native fishes, including Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*O. kisutch*), and Rainbow Trout (*O. mykiss*) populations. The Trinity River Flow Evaluation identified the availability of rearing habitat as a primary limiting factor for anadromous salmonid populations downstream of Lewiston Dam (USFWS and Hoopa Valley Tribe 1999).

Since 2000, the Trinity River Restoration Program (TRRP) has been applying large-scale restoration efforts to improve river conditions and restore anadromous fish populations (USDOI 2000). Restoration is focused in a 64 km reach downstream of the lowest dam (Lewiston Dam) where habitat degradation is most pronounced (hereafter referred to as the "restoration reach"). The TRRP applies a host of restoration actions to re-initiate riverine processes and improve aquatic and riparian habitats (USFWS and Hoopa Valley Tribe 1999). Restoration work undertaken by the TRRP includes coarse sediment augmentation, mechanical channel rehabilitation, water year (WY) specific streamflow management, among other actions. Coarse sediment is added annually to reverse the spawning gravel deficit and facilitate fluvial processes. Mechanical channel rehabilitation is implemented to remove riparian berms, and create specific channel features such as point-bars, floodplains, alcoves, and side-channels. Water year-specific streamflow management is intended to facilitate fluvial processes to create and maintain a dynamic and complex channel-form. Streamflow management is used to meet habitat and water temperature needs of anadromous salmonids. The combination of these actions is intended to provide short-term habitat benefits and catalyze fluvial processes that create aquatic and terrestrial habitat over longer time-scales. Initial benefits from restoration are anticipated to be greatest within mechanical channel rehabilitation site boundaries, and long-term improvements are expected to occur throughout the restoration reach (Barinaga 1996; USDOI 2000).

We evaluated if restoration actions have resulted in changes in salmonid rearing habitat area at the restoration reach scale to provide a status update to the TRRP and feedback that may improve application of future restoration efforts. We systematically evaluated changes in rearing habitat areas at sites within the restoration reach since 2009, with sites rotated on a 5-year cycle (Goodman et al. 2012, Alvarez et al. 2013). This report presents results from the first complete 5-year sampling cycle. All rearing habitats were measured at a streamflow release of 12.7 $m^3s^{-1}$ from Lewiston Dam and results pertain directly to those conditions. In this report, we examine hypotheses derived from the Trinity River Flow Evaluation Study (USFWS and Hoopa Valley Tribe 1999) and Integrated Assessment Plan (sub-objective 2.1) (TRRP and ESSA Technologies Ltd. 2009):

1. Restoration efforts create measureable improvements in rearing habitat area over a 5-year period at an index flow;
2. Annual peak streamflows, particularly those greater than 170 $m^3s^{-1}$, will improve rearing habitat with larger improvements stemming from higher magnitude events.

All previous reports on this study have examined changes in rearing habitat at channel rehabilitation sites (Goodman et al. 2012; Alvarez et al. 2013; Alvarez et al. 2015). However, this objective was removed during the internal review process and will be presented in a subsequent report (USFWS in prep.).

## Study Area

The Trinity River is the largest tributary to the Klamath River and is located in northwestern California, USA (Lat. 40.7269, Long. -122.7945; Figure 1). The headwaters are in the Trinity Mountains from which the Trinity River flows 274 km to its confluence with the Klamath River. The Trinity River watershed has a drainage area of 7,679 $km^2$, approximately one quarter of which is upstream of Lewiston Dam (USFWS 1989; USBOR 2009). The restoration reach evaluated in this study extends from Lewiston Dam downstream 64 km to the confluence with the North Fork Trinity River.

## Methods

### Study design

A systematic study design was used to evaluate changes in area of rearing habitat in the restoration reach on a 5-year cycle. Sample sites were 400-m segments of the 142 $m^3s^{-1}$ channel centerline that was estimated with HEC-RAS modeling in 2006 (DWR unpublished data). We selected 400 m sample units as an optimal length for data collection efficiency and compatibility with the sample unit size needs of other disciplines. Sample units were selected with a generalized random tessellation stratified (GRTS) protocol (Stevens and Olsen 2004), providing a spatially balanced (longitudinally) and random sample of the restoration reach.

We implemented a rotating panel revisit design (McDonald 2003) to evaluate status and trends in rearing habitat availability in relation to annual restoration and streamflow events. The rotating panel design was composed of five panels with 16 GRTS sample sites per panel. Two panels (20% of the restoration reach) were sampled each year (Table 1). In each

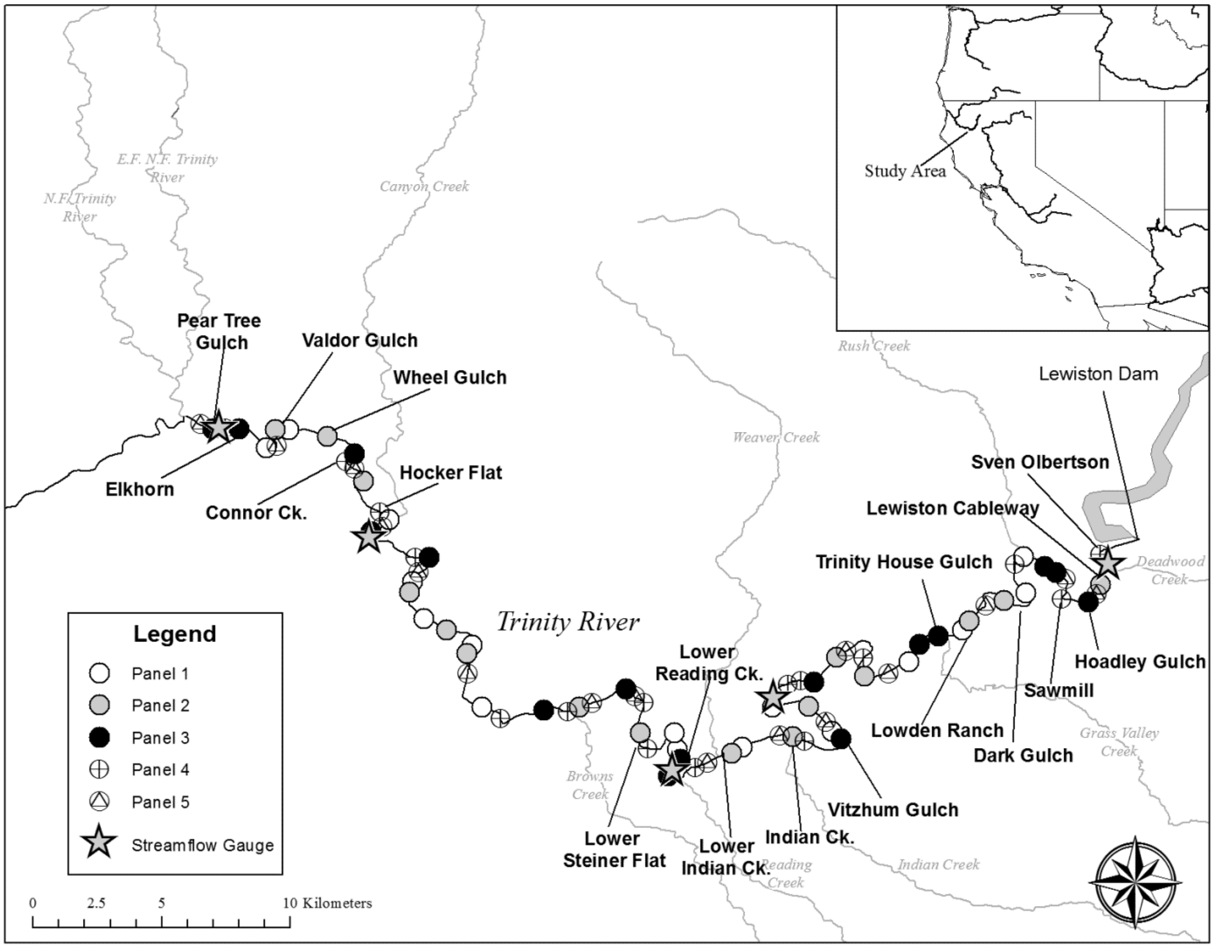



Figure 1. Systemic rearing habitat assessment sample sites on the Trinity River from Lewiston Dam to the confluence with the North Fork Trinity River. Each dot indicates a 400-m sample unit selected using the GRTS protocol. Stars indicate USGS streamflow gauges. Bold labels indicate constructed channel rehabilitation sites included in the sample. Trinity River streamflow is from right to left.

subsequent year, one panel was repeated and one new panel was added until all five panels were sampled. By sampling sites in consecutive years, panel response can be correlated with specific management actions, including peak streamflow releases from Lewiston Dam and construction activities. The first panel was resampled in the studies fifth year, which gave time for sites to experience a range of management actions. The five panels include approximately 50% of the restoration reach length.

## Habitat Surveys

Sites were surveyed during summer baseflow with a planned Lewiston Dam release of 12.7 $m^3s^{-1}$. This streamflow was selected because: (1) it occurs during a time period with little effect from tributary accretions or storm events (consistency during field sampling),

Table 1. The rotating panel revisit sampling design. 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 |

(2) it is similar to streamflows that occur in a high proportion of the restoration reach during the critical winter and early spring rearing period, and (3) it is unlikely to change in the near future due to adult spring-run Chinook Salmon temperature requirements providing consistency in streamflows for future comparisons. Therefore, this measure of habitat provides an index of winter and early spring rearing habitat availability. Variations in streamflow between sample dates occurred at each site due to tributary accretions. Average streamflow during surveys ranged from 12.9 to 14.5 $m^3s^{-1}$ by year. Streamflows were calculated using daily average values from USGS gauges (waterdata.usgs.gov). Differences in streamflow between survey events were always less than the measurement error of USGS gauges and likely had little effect on our results (up to ±15%; Krause 2012).

Rearing habitat was mapped using methods in Goodman et al. (2015), where water depth, mean column velocity, and distance to in-water cover were delineated at specified thresholds (Table 2). Rearing habitat was divided into two developmental phases for each species in their first year of growth (age-0): (1) fry or fish <50 mm FL, and (2) presmolt or fish 50 to 100 mm FL. Rearing habitat was also separated into optimal and total categories. Optimal rearing habitat for Chinook Salmon fry and presmolt included areas that simultaneously met depth, velocity, and cover criteria. Total rearing habitat included areas that met any combination of depth and velocity or cover criteria (including optimal habitat areas). Coho Salmon have shown greater preference for optimal habitat in studies by Goodman et al. (2010) and Alvarez et al. (2015). Therefore, Coho Salmon rearing habitat was limited to optimal areas following Martin et al. (2012). Habitat categories were delineated throughout the wetted area of each study segment (including side or split channels) by ground-based GPS surveys. Off-channel pools that were not connected to the main channel by surface flow were rarely encountered and not surveyed when present. Each habitat measurement was geo-referenced to produce spatially explicit representations of rearing habitat areas. Survey data were processed into ArcGIS polygons and archived in a geodatabase.

Table 2. Habitat categories and their associated 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 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 0.12 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 |

## Restoration Efforts

Streamflow allocations were the primary restoration tools employed by the TRRP over the study period. The Record of Decision defined five WY types for the TRRP that range from critically dry to extremely wet based on annual and historical precipitation (USDOI 2000). Each WY type is associated with a water volume to be released from Lewiston Dam based on annual inflow estimated by the California Department of Water Resources. Each year restoration releases are designed to meet specific objectives, such as achieving salmonid adult and emigration temperature targets, providing salmonid spawning and rearing habitat, initiating channel bed sediment transport and establishing riparian plants in floodplain areas (e.g. TRRP 2013). Streamflows transport bedload particularly, when greater than 170 $m^3s^{-1}$ (GMA 2014), and fluvial processes are expected to create a more complex channel-form and increase rearing habitat area (USFWS and Hoopa Valley Tribe 1999).

Sampling for this study encompassed four peak WY releases ranging from dry to extremely wet. Three WYs had streamflow releases from Lewiston Dam above 170 $m^3s^{-1}$ (Table 3) (TRRP 2013). The largest streamflow during the study period was 348 $m^3s^{-1}$ at Lewiston Dam during the Wet WY in 2011 (USGS gauge # 1152550). This was the third highest streamflow from Lewiston Dam since its construction in 1964 and the largest release prescribed by the TRRP to date. Tributary inflow has an influence on streamflow magnitude, which increases with distance downstream of Lewiston Dam. Streamflows at the downstream extent of the restoration reach (above the N.F. Trinity River confluence), which include tributary accretions, were >170 $m^3s^{-1}$ in all years and ranged from 198 to 368 $m^3s^{-1}$ (USGS gauge # 11526400). The second highest streamflow at the downstream extent of the restoration reach occurred in a dry WY and corresponded with the lowest annual peak releases from Lewiston Dam.

Table 3. Summary of water year types at peak discharges within the restoration reach. Lewiston is at the top of the restoration reach and above the confluence with the North Fork Trinity River (Above NF) is at the bottom which includes tributary accretions. Streamflow is reported in $m^3s^{-1}$.

| WY | Type | Lewiston $Q_{peak}$ | Above NF $Q_{peak}$ |
|---|---|---|---|
| 2010 | Normal | 212 | 226 |
| 2011 | Wet | 348 | 368 |
| 2012 | Normal | 175 | 198 |
| 2013 | Dry | 130 | 265 |

Mechanical channel rehabilitation sites have been constructed annually by the TRRP since 2005 and were expected to provide improvements in rearing habitat area. By 2013, the TRRP had mechanically rehabilitated 18 sites totaling one-third of the restoration reach length (Buffington et al. 2014; TRRP unpublished data). Over the study period, GRTS sample units coincided with segments of 15 channel rehabilitation sites. The sample included sites constructed between 2005 and 2011 with lengths of restored channel ranging from 0.4 to 2.6 km.

**Analysis**

We estimated total and optimal rearing habitat area available in the restoration reach on an annual basis. Annual estimates were calculated by multiplying the mean rearing habitat area of the two panels sampled in a given year by the number of units in the restoration reach (approximately 159.5). Sample error was calculated using a neighborhood variance estimator developed for GRTS sample designs (Stevens and Olsen 2002). The variance estimate incorporated spatial location of sample units into error estimation. Analyses were conducted in R (R Development Core Team 2009) using Spatial Survey Design and Analysis library (spsurvey ver. 2.15.2, Kinkaid and Olsen 2009). We estimated change in habitat area between years with pairwise comparisons between 2009 and future survey years using spsurvey's change analysis function with the Horvitz-Thompson ratio estimator (Diaz-Ramos et al. 1996). All confidence intervals (CI) are 95% level in this report. Several minor improvements have been made to spsurvey and the analysis methods from that used in previous reports resulting in slight reductions in error associated with annual habitat estimates.

We investigated changes in rearing habitat area in association with peak streamflows using two approaches. First, we compared changes in habitat area at sites sampled in sequential years to releases from Lewiston Dam that were prescribed by the TRRP. In this assessment, we compared habitat area at each panel before and after each WY, except in the case of Panel 1, which was sampled before and after four WYs due to the rotating panel schedule. All paired samples failed the Shapiro-Wilk Normality Test (Royston 1995), so we applied the non-parametric Wilcoxon signed rank test for paired samples to determine if changes in habitat area were statistically related to annual peak dam releases. In the second approach, we investigated the effect of sample-site specific annual peak streamflow magnitude on change in habitat area among consecutive years. This analysis incorporates longitudinal variation in peak streamflow magnitude caused by tributary accretions. USGS has five streamflow gauges in the restoration reach, which generally relate to hydrologic reaches that incorporate changes in streamflow from primary tributaries (USGS Gauge #s 11525500, 11525655, 11525854, 11526250, 11526400) (Figure 1). Annual peak streamflows were calculated using the USGS gauges and associated with downstream sample units based on sample year and hydrologic reach. We graphically assessed the data for the effect of site specific annual peak streamflow and change in habitat area. In both approaches, we excluded four sample units that were visited before and after construction of channel rehabilitation sites and one site that was surveyed during construction to focus the analysis on the effects of peak streamflows.

## Results

Measurements of presmolt and fry habitat areas were similar and correlated. Optimal rearing habitat area for presmolt and fry exhibited a Pearson's product-moment correlation ($\rho$) of 0.985 (CI = 0.980 to 0.989) and total rearing habitat area had a $\rho$ of 0.983 (CI = 0.977 to 0.988) (Figure 2). Because of the high correlations, we chose to limit our reporting to only address presmolt habitat area.

### Trends in Habitat Area Estimates

We observed variation in annual estimates of rearing habitat area in the restoration reach, but found no evidence of a consistent trend. Systemic optimal habitat area ranged from 85,605 $m^2$ (CI = 76,309 to 94,902) in 2012 to 138,848 $m^2$ (CI = 108,081 to 169,614) in 2013 (Figure 3; Table 4). Total habitat area ranged from 364,481 $m^2$ (CI = 338,309 to 390,654) in 2010 to 485,073 $m^2$ (CI = 433,158 to 536,988) in 2013. No change was detected in six of the eight pairwise comparisons (Figure 4-5; Table 5). The two significant comparisons indicated a decrease in rearing habitat area. In each survey year, rearing habitat area at sample units had a spatial arrangement with higher habitat values in proximity to Lewiston Dam (Figure 6).

### High Streamflow Releases

We observed changes in habitat area at sites and panels sampled in sequential WYs. Channel features, in particular alluvial bars, shifted in response to high streamflow events, which created variation in spatial arrangement of habitats (Figure 7). However, the highest streamflows did not result in the greatest differences in habitat area. In the case of optimal rearing habitat at sites sampled across WYs, we observed significant increases and decreases in area (Table 6). At panel 2, sampled before and after a normal WY (212 $m^3s^{-1}$ peak at Lewiston Dam) we measured a reduction in rearing habitat at 81% of sites with a median loss of 96 $m^2$ (CI = -174 to -44). In contrast, panel 5 sites were sampled before and after a dry WY (130 $m^3s^{-1}$ peak at Lewiston Dam) and resulted in an increase at 94% of sites

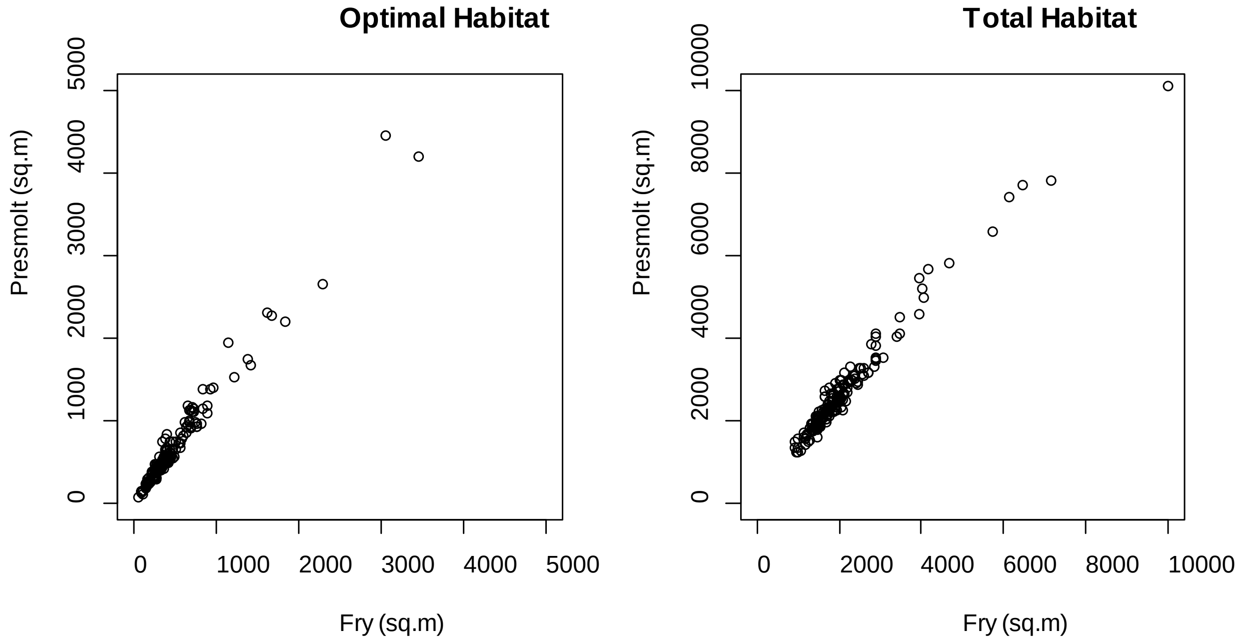



Figure 2. Correlation between fry and presmolt rearing habitat areas. Each dot indicates a GRTS site surveyed for fry and presmolt rearing habitat area.

with a median increase of 186 $m^2$ (CI = 88 to 316). No change was detected at panel 3, sampled before and after a wet WY (348 $m^3s^{-1}$ peak at Lewiston Dam). Rearing habitat increased at panel 1 that was sampled before and after four WYs with a range of WY types from dry to wet with improvements at 68% of sites and a median increase of 143 $m^2$ (CI = 42 to 227). We observed a similar pattern for total habitat at panels sampled before and after WYs. Similarly, we did not find a relationship between increases in habitat area among consecutive years and peak streamflow magnitude experienced at a sample unit (Figure 8). In summary, we failed to identify a relationship between habitat improvement and annual peak streamflow magnitude.

## Discussion

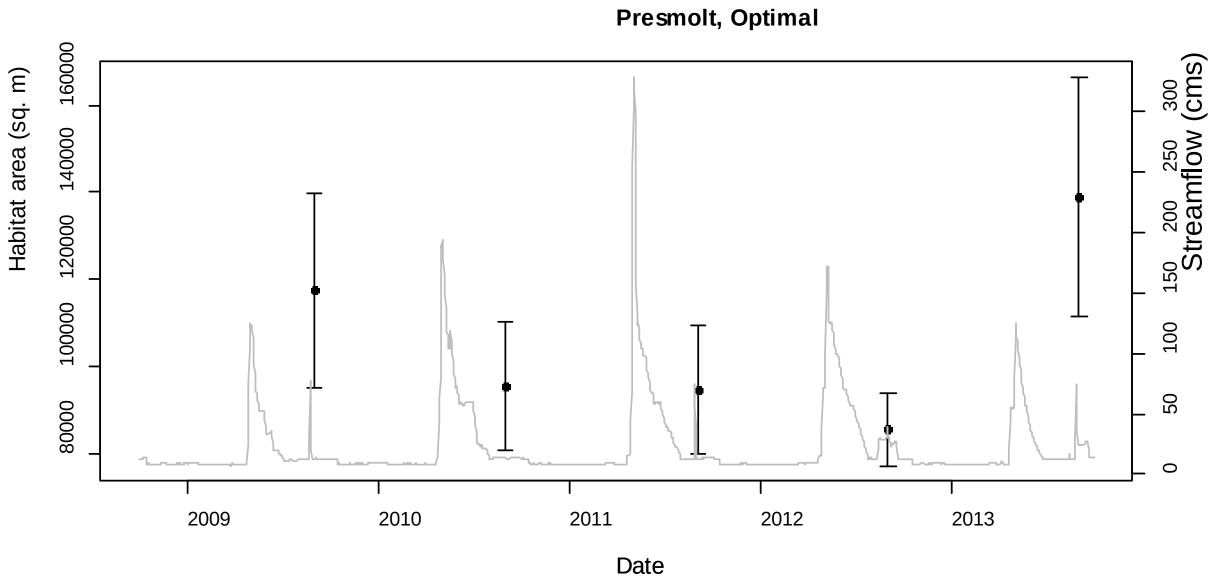
The TRRP is attempting to restore naturally spawning Chinook and Coho Salmon populations to pre-dam levels by increasing rearing habitat area. We collected data over a 5-year period and used it to evaluate effects of management actions that are designed to increase rearing habitat area, including high flow releases from Lewiston Dam. We found little evidence that fish habitat at summer baseflow has increased between 2009 and 2013 at the restoration reach scale. This is due in part to the high variation in habitat area measured between sample units and the short duration between habitat measurements at each site. We also found little evidence that high streamflow releases from Trinity Dam and winter floods generated by tributary inflows increased rearing habitat in the restoration reach over the time-frame evaluated in this study. Under the current TRRP streamflow management, habitat creation from fluvial processes may occur over longer time-scales. However, more rapid improvements may be possible with modifications to the streamflow management approach such as synchronizing dam releases with tributary flood events.

### Trends in Habitat Area Estimates

We found no evidence indicating that rearing habitat areas increased in the restoration reach between 2009 and 2013 at baseflow. Pairwise comparisons indicated only small changes in rearing habitat areas between years with minor reductions in habitat area in two comparisons. During the study period, we found higher levels of among sample unit variation than expected when designing this study. The high level of variation reduced the precision of our restoration reach estimates and reduced our ability to detect change in the sample. In addition, minor reductions in rearing habitat area identified in this study were not likely due to actual differences, but rather artifacts from sampling error in the rotating panel revisit design.

The revisit design introduced a new combination of sample units every year of the study and each year was associated with a unique level of variation. Therefore, annual differences may have been related to panel inclusion (or exclusion) rather than true variation in the amount of rearing habitat area in the restoration reach, which reduces our ability to detect minor change from TRRP efforts. Our results establish the level of variation among sample units within this study design, which will be useful for refining future analyses to detect true system change. Given the high level of inter-panel variation, we recommend reporting on this study at the completion of each cycle of the revisit design. Furthermore, these results have been used to refine and improve the efficiency of the revisit design for future sampling.

These analyses have been used to refine the study design for sampling beyond 2013. We improved the efficiency of the revisit design by reducing sampling across WYs, which was found to be un-informative for evaluating the effects of single high streamflow releases reported in this study. This modification resulted in a one-third reduction in sampling effort. The updated design will cycle through panels between 2014 and 2017 and evaluate changes from multiple high WY releases through paired 5-year comparisons of each panel. We expect this to be a more appropriate time-scale for evaluating change from the process based restoration. However, to our knowledge, no formal hypotheses have been developed by the TRRP regarding the anticipated time-frame for reach level habitat response from restoration efforts. The lack of substantial channel changes in the restoration reach observed in this study is corroborated by other recent studies. Curtis et al. (2015) evaluated geomorphic change in the restoration reach over a 31-year period using aerial photography. Since initiation of the TRRP in 2001, Curtis et al. (2015) observed a 5% increase in active channel area, however this was coupled with a 3% decrease in channel complexity. Furthermore, rates of channel evolution and riparian change were greater before initiation of the TRRP. This result was attributed to the influence of tributary floods on fluvial processes and the relatively dry period that has been experienced since initiation of the TRRP. Although localized channel evolution has occurred since 2001, particularly at channel rehabilitation



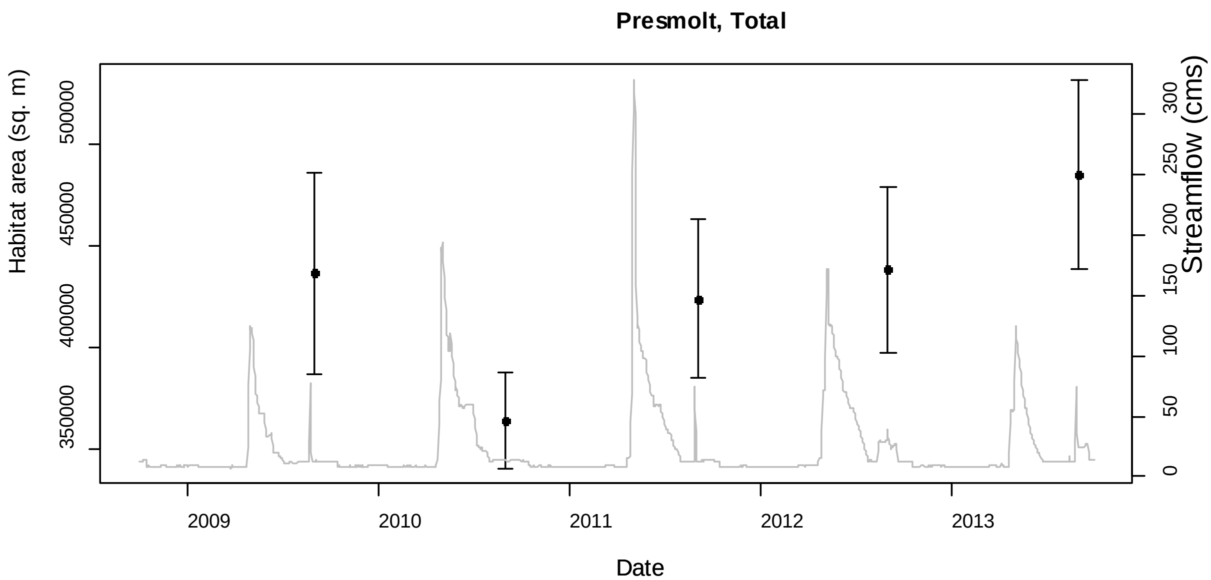




Figure 3. Annual estimates of presmolt rearing habitat area in the Trinity River restoration reach and streamflow. Error bars indicate 95% confidence intervals. Streamflow was measured as daily averages at Lewiston Dam. Year makers indicate the beginning of calendar year. Note habitat area estimates are placed on x-axis in the middle of summer sampling periods but sampling did not occur during periods of elevated summer streamflows observed in all years except 2010.

Table 4. Estimated pairwise difference in mean habitat values between sample years. Negative values (diff. est.) indicate a reduction in habitat area with time, while positive values indicate improvements. Significant differences at α are in bold and occur when confidence bounds do not overlap with 0.

| Yr. comparison | Presmolt Optimal | | | | Presmolt Total | | | |
|---|---|---|---|---|---|---|---|---|
| | Diff. est. | S.E. | LCB | UCB | Diff. est. | S.E. | LCB | UCB |
| 2009 vs 2010 | -138 | 86 | -306 | 29 | **-452** | **176** | **-797** | **-107** |
| 2009 vs 2011 | -144 | 85 | -311 | 24 | -77 | 202 | -473 | 318 |
| 2009 vs 2012 | **-201** | **76** | **-350** | **-51** | 12 | 206 | -393 | 416 |
| 2009 vs 2013 | 133 | 113 | -89 | 355 | 305 | 218 | -122 | 732 |

sites, Curtis et al. (2015) concluded that there is a low potential for geomorphic change from the allowable peak streamflow releases from Lewiston Dam (312 $m^3s^{-1}$).

Data for this assessment was collected at a Lewiston Dam release of 12.7 $m^3s^{-1}$ and the results are directly applicable to that streamflow, but TRRP actions are intended to increase rearing habitat across a range of flows. The index streamflow was selected because it is similar to conditions experienced by a large portion of the restoration reach during the winter rearing period, as well as, providing streamflow stability necessary for the assessment. In addition, the TRRP expected system changes to occur at this streamflow because it is within the range of streamflows (roughly 8.4 to 57 $m^3s^{-1}$) at which habitat is targeted for improvement and therefore may be an indicator for change at other streamflows (TRRP and ESSA 2009). In a hypothetical example, if a segment of river is restored from a simplified and straight channel confined between riparian berms to an alternating bar sequence and a low-sloping floodplain, we expect habitat area to improve at a variety of streamflows. The simplified and unrestored channel would be typified by sparse low quality habitats, particularly at elevated streamflows as depths and water velocities increase. The restored channel will provide a longer meandering channel and a sloping floodplain, providing additional habitat area across a range of streamflows. We expect the restored channel-form to change the sediment and large wood transport regime and, with sufficient peak streamflows, streamflow variation, sediment and wood supplies (added as part of restoration efforts), alluvial bars and large wood jams and other channel features will propagate. The restored channel is expected to be more complex and dynamic while providing higher habitat values at a range of streamflows. However, our rearing habitat index and its relationship to changes at lower and higher streamflows remain untested and should be evaluated in future analyses.

### High Streamflow Releases

High streamflow releases from Lewiston Dam are used by the TRRP to activate a complex suite of fluvial processes anticipated to create a dynamic channel, improve habitat complexity and result in increased rearing habitat area (USFWS and Hoopa Valley Tribe 1999). Higher sediment transport rates are associated with higher peak streamflows

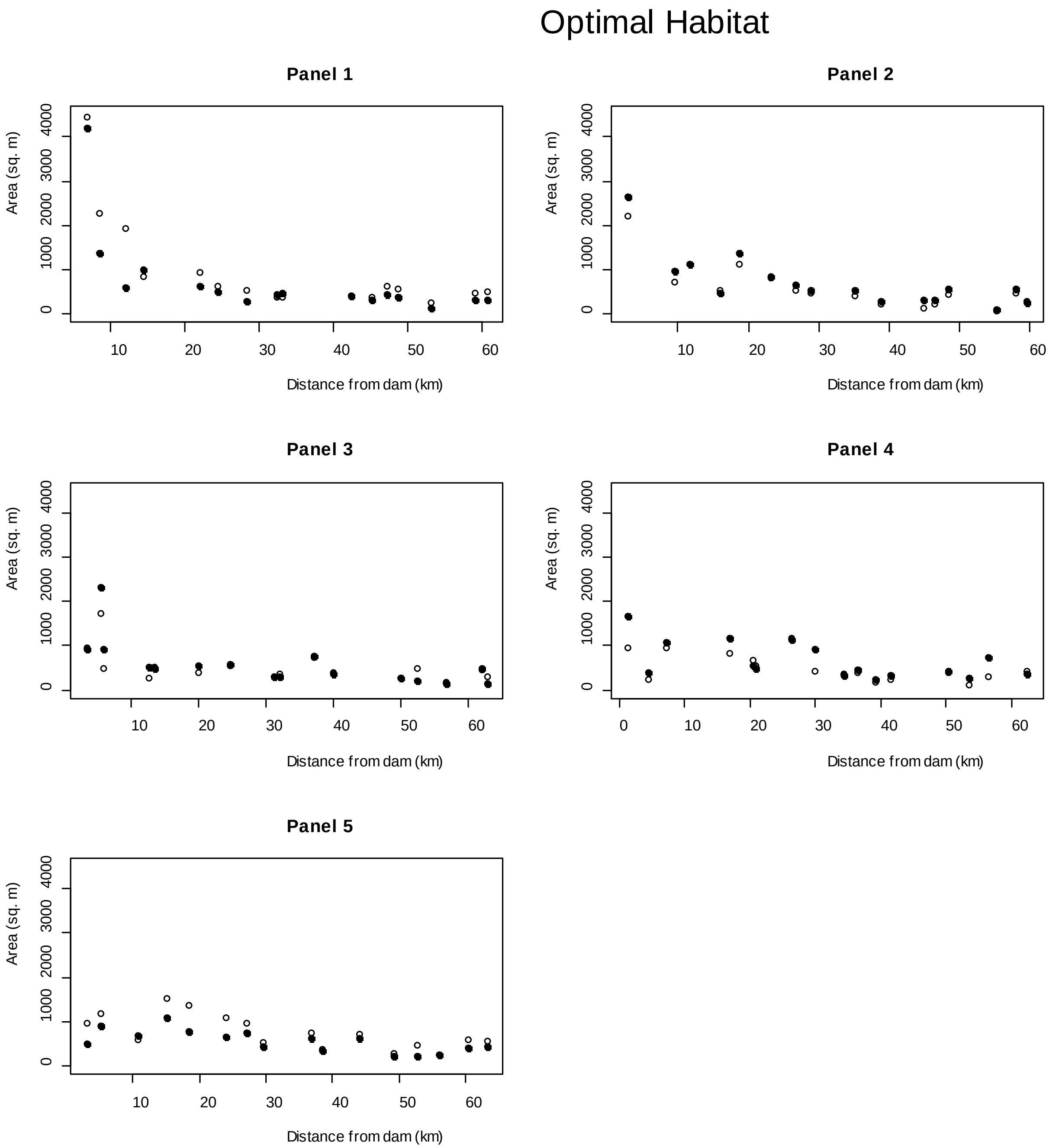



Figure 4. Change in optimal presmolt rearing habitat by panel. Solid circles indicate sample year 1 and empty circles indicate year 2. All samples were taken across water years with: Panel 1 in 2009 and 2013, Panel 2 in 2009 and 2010, Panel 3 in 2010 and 2011, Panel 4 in 2011 and 2012, Panel 5 in 2012 and 2013.

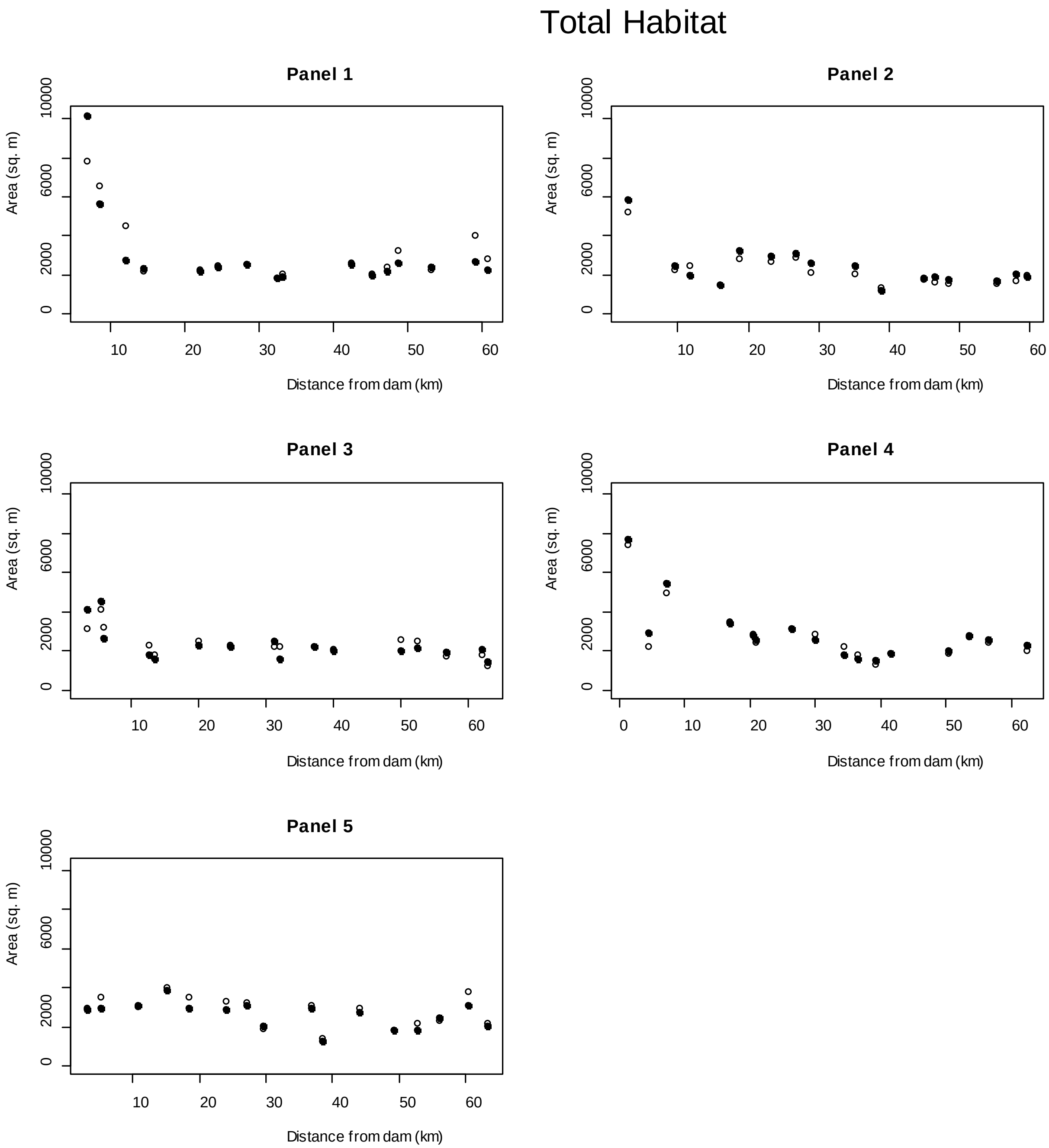



Figure 5. Change in total rearing habitat by panel. Solid circles indicate sample year 1 and empty circles indicate year 2. All samples were taken across water years with: Panel 1 in 2009 and 2013, Panel 2 in 2009 and 2010, Panel 3 in 2010 and 2011, Panel 4 in 2011 and 2012, Panel 5 in 2012 and 2013.

Table 5. Changes in presmolt habitat area across water years at paired sample sites. Tests conducted using a Wilcoxon signed rank test for paired samples at $\alpha = 0.05$. Water year types (WY type) indicate TRRP streamflow release volume allocation and $Q_{peak}$ indicates peak streamflow release from Lewiston Dam in cms. Median differences in habitat area are reported in $m^2$. Percent of sites increased (% Incr.) indicates the percentage of sites within a panel where habitat area increased in the second sample occasion.

| Indicator | Years | WY type | $Q_{Peak}$ | Panel | Median dif. | LCB | UCB | % Incr. |
|---|---|---|---|---|---|---|---|---|
| Optimal | 2009-2010 | Normal | 212 | 2 | **-96** | **-174** | **-44** | 19 |
| | 2010-2011 | Wet | 348 | 3 | -0.12 | -204 | 66 | 44 |
| | 2011-2012 | Normal | 175 | 4 | **-104** | **-271** | **-11** | 31 |
| | 2012-2013 | Dry | 130 | 5 | **186** | **88** | **316** | 94 |
| | 2009-2013 | Dry to Wet | 348 | 1 | **143** | **42** | **227** | 68 |
| Total | 2009-2010 | Normal | 212 | 2 | **-215** | **-356** | **-70** | 19 |
| | 2010-2011 | Wet | 348 | 3 | 7 | -250 | 248 | 44 |
| | 2011-2012 | Normal | 175 | 4 | -67 | -220 | 87 | 38 |
| | 2012-2013 | Dry | 130 | 5 | **188** | **38** | **347** | 81 |
| | 2009-2013 | Dry to Wet | 348 | 1 | 122 | -14 | 489 | 63 |

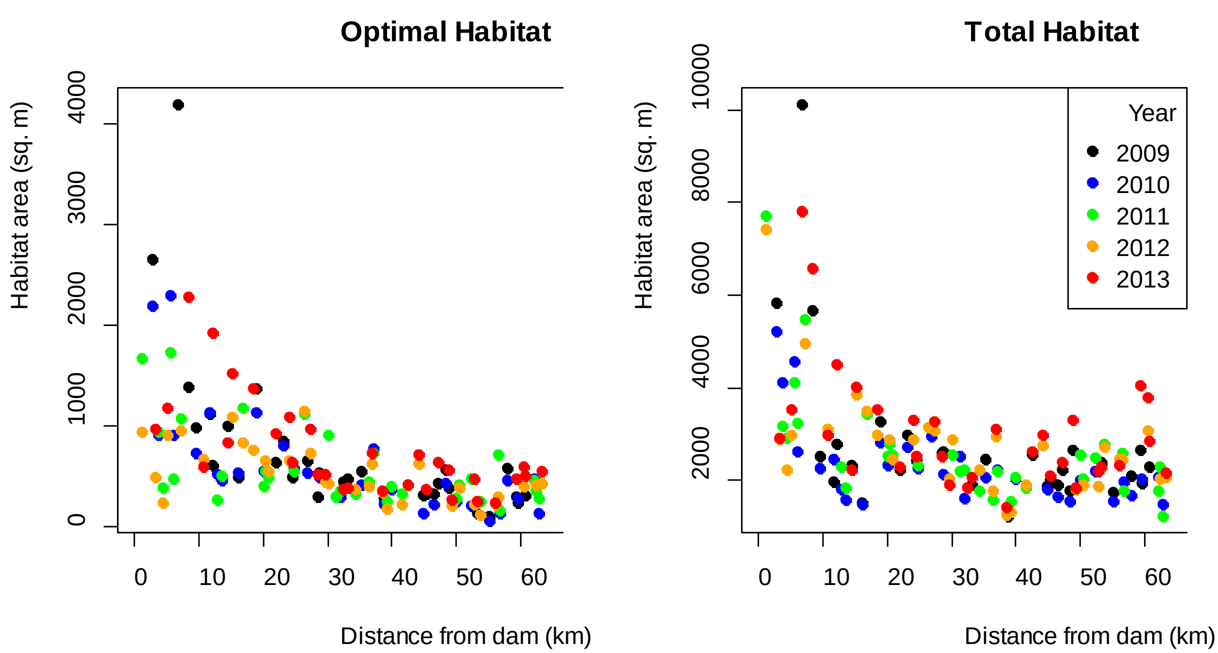



Figure 6. Longitudinal distribution of presmolt habitat area in the restoration reach. Each point indicates the habitat measured at a 400-m sample unit.

(GMA 2014) and are indicative of a general relationship between streamflow magnitude and fluvial processes. In addition, localized changes in the river channel, particularly at alluvial bars, are evident from annual aerial photography (Buffington et al. 2014; Curtis et al. 2015). Therefore, we expected greater improvements in habitat area with higher peak streamflows. However, this was not evident on a restoration reach scale in our dataset.

We evaluated the effect of annual peak streamflows on changes in habitat by comparing habitat area at sample units measured in consecutive years. In our study, localized changes in habitat area and channel-form were observed before and after peak releases. However, we did not observe greater improvements in rearing habitat from higher streamflows across a single water-year. These results suggest that fluvial processes that occurred during the study period may not be related to improvements in low streamflow habitat. Compounding the complexity of this relationship is the influence of tributary streamflow patterns on channel change. In our survey period, the year with the lowest peak release from Lewiston Dam coincided with the second highest peak streamflow at the bottom of the restoration reach (Table 3). However, the lack of concordance between changes in habitat area and peak streamflow magnitude is evident regardless if streamflow is measured at Lewiston Dam or at specific sample units. However, it may be possible that partial duration series of high flow events, such as the number of events above a specific threshold, may be related to changes in habitat area and should be evaluated in future analyses.

Limited data in this study surveyed over a 5-year revisit interval indicated the potential that rearing habitat is improving over longer time-scales. Panel 1 was surveyed in 2009 and 2013, including four peak streamflow releases, and resulted in a significant increase in optimal habitat area. This improvement observed over a longer revisit interval suggests the potential for a positive trend over longer-time scales and that time lags may exist between fluvial processes and habitat response. Future iterations of the rotating panel design will provide more opportunities to evaluate change at longer time-scales and will likely provide more insight on the effect of the high streamflow releases and tributary floods.

### Implications

Refining the restoration approach applied by the TRRP may accelerate fluvial processes that are expected to create a more complex channel and increase rearing habitat area. For example, real-time streamflow management can be applied to mimic dam releases after natural streamflow patterns and some aspects of this approach are currently being implemented at Iron Gate Dam in the Klamath River (Hetrick et al. 2009; Hardy and Shaw 2013). Real-time streamflow management could be used to synchronize dam releases with peak streamflows in downstream tributaries to exponentially increasing the rate of physical processes that are predicted to improve habitat. Under the current streamflow management approach, a single peak release occurs in each WY, however natural streamflow patterns include multiple peak events each year, related to local storms and snowmelt, creating the potential for more than single sediment transport event. Furthermore, the timing of peak releases is currently based on historical averages and often not synchronized with tributary streamflows (Curtis et al. 2015). If dam releases were coupled with tributary flood events,


Figure 7. Oregon Gulch measured before and after a wet water year. Red areas indicate total presmolt habitat area, which increased after a dam release of 348 $m^3s^{-1}s$ in 2011. Habitat improvements were related to changes in a natural bar on the left side of the image. No mechanical rehabilitation work has occurred at this site.

fluvial processes would be further enhanced as peak streamflows would be increased and coupled with sediment delivery from tributaries.

Managing dam releases to mimic inflow to Clair-Engle Reservoir was considered as an alternative during development of the Trinity River Flow Evaluation Study, but was discredited in-part due to the risk of a reduction in salmonid reproductive success from redd scour if high streamflows were released during fall and winter months (USFWS and Hoopa Valley Tribe 1999). However, this risk was evaluated and found to be lower than anticipated due to the preference of salmonids to spawn in habitats with a low probability of scour (May et al. 2009). In addition, the fish fauna of the Trinity River evolved in a system in-which the highest peak streamflows naturally occurred during winter months with a wide range of additional benefits including inundation of floodplain habitats during salmonid rearing periods. Real-time streamflow management would approach a more natural streamflow regime and is in-line with the basic concept of restoring natural processes, which is at the foundation of the TRRP restoration strategy (Poff et al. 1997).

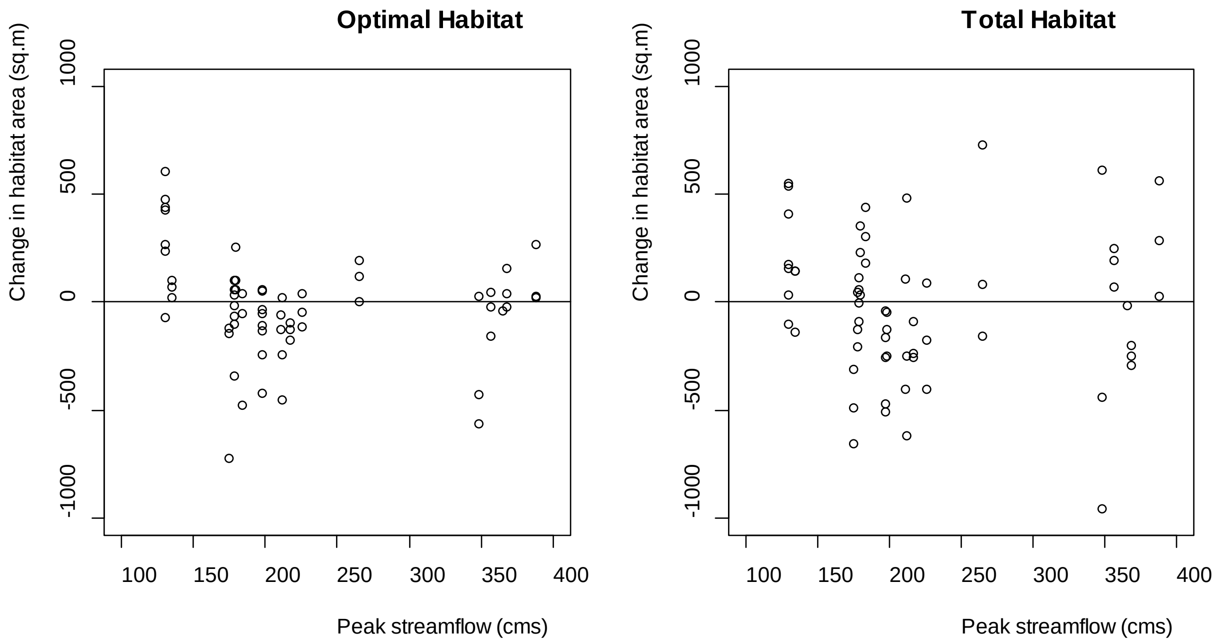



Figure 8. Change in rearing habitat area by site specific peak streamflow. Each dot indicates change at a 400-m sample unit measured in consecutive water years. The horizontal line at 0 indicates no change in habitat area. localized channel evolution has occurred since 2001, particularly at channel rehabilitation sites,

Quantitative habitat restoration goals have not yet been established by the TRRP. It has been suggested that a restored channel form will result in a 200% to 400% increase in rearing habitat area in the restoration reach (USFWS and Hoopa Valley Tribe 1999; Locke et al. 2008; TRRP 2009), which has clearly not been achieved to date at the index streamflow. The goal of a 400% increase in habitat area was introduced in the Flow Evaluation Study as a minimum threshold to detect increases in emigrant Chinook Salmon population size based on sampling approaches applied in the 1990's and therefore may not be an appropriate goal (USFWS and Hoopa Valley Tribe 1999). However, this goal is echoed in the habitat objectives outlined in the Integrated Assessment Plan (TRRP 2009) The Integrated Assessment Plan suggests that TRRP is in the process of revising this goal with more detailed analyses (TRRP 2009), however this has not occurred to date. Recent studies suggest, the 400% increase goal is not feasible given current restoration approaches, the incumbent hydrograph, infrastructure limitations and geomorphic potential (Beechie et al. 2015). The most optimistic scenario evaluated by Beechie et al. (2015), suggests the maximum potential for rearing habitat improvement in the restoration reach will result in an increase of 138% at streamflow evaluated in this study. The restoration scenarios evaluated have not yet included alterations to current streamflow management practices, which may increase the potential for benefits from restoration efforts. The development of updated clear and quantitative restoration goals, assessed with a diverse range of indicators (i.e. temperature, productivity, habitat, streamflow) with associated time-frames, will improve our ability to assess the Trinity River restoration potential and TRRP progress.

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