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Trend Analysis of Salmon Rearing Habitat Restoration in the Trinity River at Summer Base Streamflow, 2005-2015

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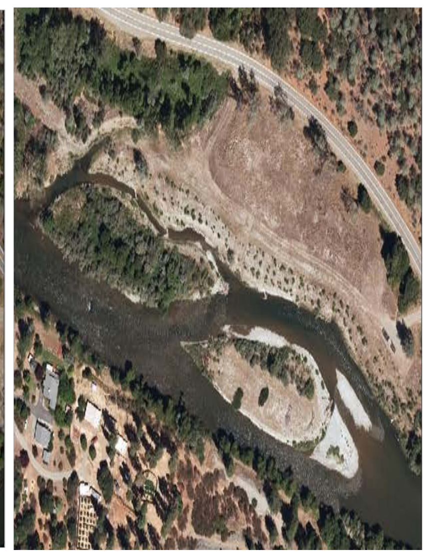

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Trend Analysis of Salmon Rearing Habitat Restoration in the Trinity River at Summer Base Streamflow, 2005-2015

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Abstract.— A goal of the Trinity River Restoration Program is to enhance the production of naturally spawned salmonids by implementing a suite of restoration actions including streamflow management, gravel augmentation and mechanical channel rehabilitation. Short-term monitoring of select channel rehabilitation sites has documented a direct increase in rearing habitat as a result of channel construction activity; however, a companion study failed to detect substantial improvements between 2009 and 2013 at a 64-km restoration reach scale. Here, we analyzed longer term performance of channel rehabilitation sites and the effect of spatiotemporal changes to constructed and natural off channel features to inform the adaptive management process. We assessed the effect of construction, from 2005-2015, at 13 rehabilitation sites surveyed before and after construction. We also developed a sub-sampling protocol to assess trends in the amount of rearing habitat at a total of 22 rehabilitation sites. All data assessed in this report were collected at a Lewiston dam release of 12.7 cms and all analyses were applicable to that streamflow. Rearing habitat increased at 12 of 13 sites after construction. One site, Trinity House Gulch, experienced a 23% decrease in optimal presmolt habitat attributable to fluvial processes that occurred before the first post-construction survey. However, the trend analysis indicated that the level of initial benefit from construction was not sustained over longer time periods at many sites. Ten of 19 sites had less total habitat at the most recent survey than they did at the first survey after construction; 1 of those 10, Hocker Flat, had slightly more optimal habitat. The year of construction does not appear to affect the amount of habitat after construction (n=11 sites) or at the most recent survey (n=19 sites). However, six of seven sites had more habitat at the most recent survey than they did at pre-construction. Kaplan-Meier analysis found evidence that natural off channel features have higher survival than constructed features (Log Rank Test; side channels, p=0.003; alcoves, p=0.062). Trends in rearing habitat that resulted from channel rehabilitation were, in many instances, directly related to the creation and sustainability of off channel features. This analysis provides insight into channel rehabilitation site performance to be used by the Trinity River Restoration Program to refine designs of future restoration projects.

Introduction

The Trinity River Flow Evaluation Final Report identified the availability of age-0 habitat area (herein defined as rearing habitat) as a primary limiting factor for anadromous salmonid populations downstream of Lewiston Dam (USFWS and Hoopa Valley Tribe 1999). The Record of Decision (USDOI 2000) outlined a formal plan for restoring the Trinity River which led to the creation of the Trinity River Restoration Program (TRRP). Restoring juvenile salmonid rearing habitat area in the Trinity River has been an objective of the TRRP since its inception. Declines in anadromous fish populations in the Trinity River are attributed to a suite of anthropogenic influences culminating with the construction of Trinity and Lewiston dams and the Clear Creek Tunnel in 1964. Trinity dam enabled export of 70 to 90% of captured water to be delivered to the Central Valley (USFWS and Hoopa Valley Tribe 1999) and completely blocked access by anadromous fishes to 177 km of upstream habitats, drastically curtailing the upstream limit of their distribution (Moffett and Smith 1950; Locke et al. 2008). Streamflow downstream of the dams was reduced to approximately 4.2 cms (148 cfs) and managed to be devoid of natural variation, eliminating peak geomorphic flows, interrupting sediment and large wood transport and simplifying the river channel below Lewiston Dam. Other negative impacts on the river and its fish populations included mining operations during the historic California Gold Rush and continued until the 1950’s, which delivered large amounts of sediments to the river, rearranged the river bed and floodplain, and simplified aquatic habitats (Bailey 2008, AECOM 2013). 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 TRRP has applied restoration efforts to re-initiate riverine processes, improve aquatic and riparian habitats and restore anadromous fish populations (USDOI 2000). Restoration is focused in a 64 km reach (Figure 1) downstream of the lowest dam (Lewiston Dam) where habitat degradation is most pronounced (hereafter referred to as the “restoration reach”). Restoration work undertaken by the TRRP includes coarse sediment augmentation, mechanical channel rehabilitation including riparian planting and water year specific streamflow management. Coarse sediment is added annually to reverse the spawning gravel deficit created by dam construction and facilitate fluvial processes. Mechanical channel rehabilitation is implemented to remove riparian berms, and create specific channel features such as point-bars, floodplains, side-channels and alcoves. Water year-specific streamflow management requires that the hydrograph below the Lewiston Dam be scaled according to the amount of precipitation expected in the watershed. It is intended to facilitate fluvial processes to create and maintain a dynamic and complex channel-form and to meet habitat and water temperature needs of anadromous salmonids. The combination of these actions is

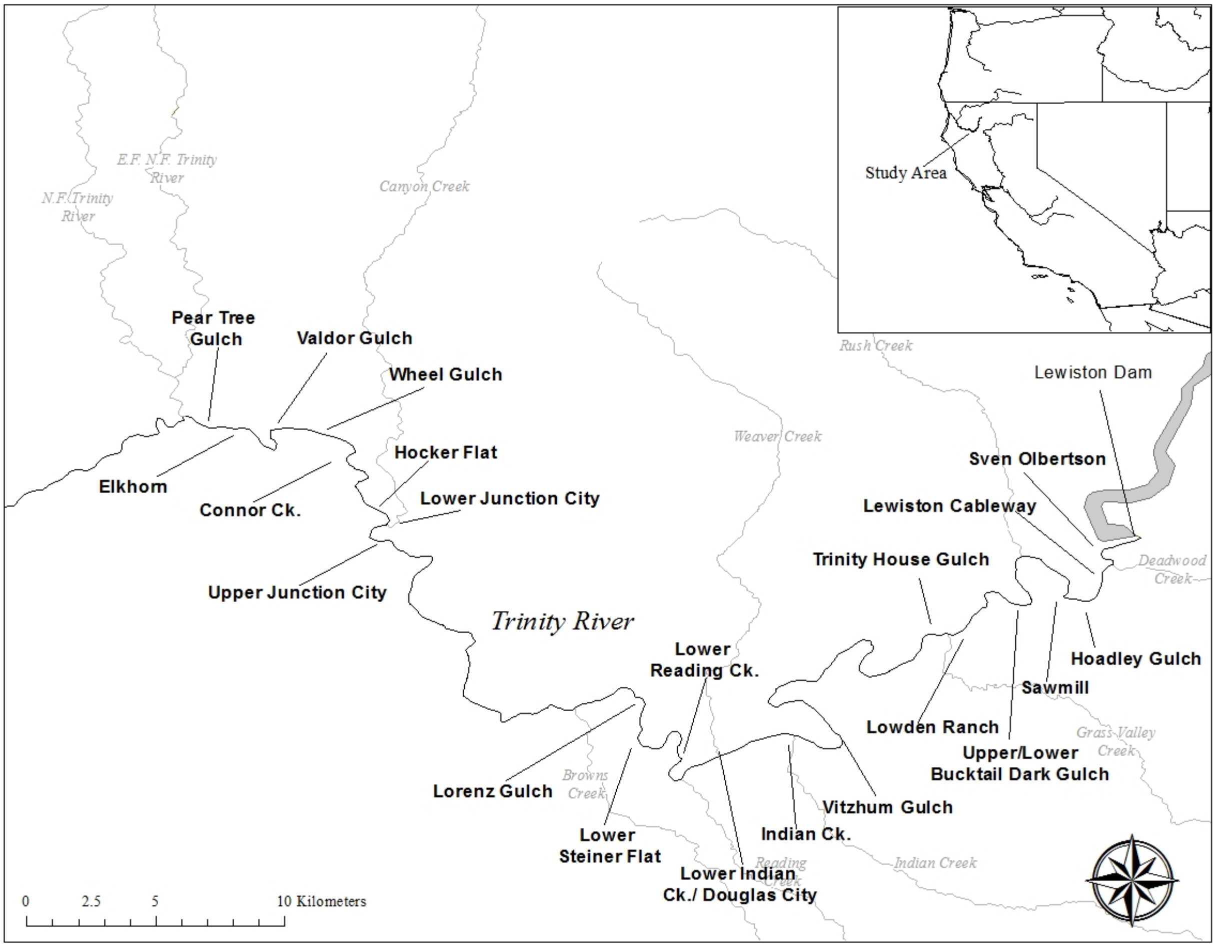

Figure 1. Map of rehabilitation sites on the Trinity River (Lat. 40.7269, Long. -122.7945) from Lewiston Dam to the confluence with the North Fork Trinity River. Streamflow is from right to left. Bold labels indicate channel rehabilitation site names.

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).

Prior to the establishment of the TRRP, the mission of the Trinity River Basin Fish and Wildlife Restoration Program (hereafter referred to as pre-TRRP), initiated in 1985, was to restore anadromous salmonid production by reducing sediment input from large tributaries such as Grass Valley Creek, modernizing the Trinity River fish hatchery, establishing sustainable levels of adult harvest and improving juvenile salmonid habitat (USBOR, 1992; USFWS and Hoopa Valley Tribe 1999). The juvenile habitat improvement projects included the construction of feathered edges and alcoves (USBOR, 1992) and 20 side channels (Glase, 1994; TRRP unpublished data). Two reports documented physical habitat changes and fish use at sites of riparian berm removal and construction of gently sloping point bars and floodplains (USFWS, 1997; Gallagher, S.P., 1999), however, since the establishment of the TRRP, these early restoration efforts have not been evaluated for long-term performance.

As part of the ongoing effectiveness monitoring evaluations by the TRRP, the amount of rearing habitat present at 12.7 cms has been documented throughout the restoration reach (systemic estimate), at rehabilitation sites and at specific feature types following standardized protocols. The systemic estimate, using a random sampling design, identified annual variation in rearing habitat levels but little overall change between 2009 and 2013 (Goodman et al. 2016), which is supported by Curtis et al. (2015) that found a 5% increase in active channel area coupled with a 3% decrease in channel complexity between 1980 and 2011. Previous rehabilitation site-specific estimates have documented the greatest amount of change in habitat levels at rehabilitation sites from construction and much of the improvement has been attributed to the construction of off-channel features such as side channels and alcoves. Improvements associated with other feature types such as floodplains, feathered edges and bars also manifest at discharges above and below the flow assessed here. Most of this change has been evaluated before and after construction (e.g. Goodman et al 2010; Martin et al 2013; Martin, 2016) with a limited number of assessments of long-term (DeJuilio et al 2014) persistence of construction related benefits to rearing habitat. We pooled existing data types to characterize channel rehabilitation site and constructed off-channel feature performance beyond the immediate post-construction phase. We used 10 years (2005-15) of summer rearing habitat data to examine trends in rearing habitat at rehabilitation sites by comparing surveys conducted before and after construction, as well as, any subsequent surveys between one and nine years after construction. This report documents patterns and trends in the amount of rearing habitat available at rehabilitation sites and physical changes to side channels and alcoves over the study period.

The objectives for this report are:

1) Determine the proportion of rehabilitation sites with an increase in rearing habitat from pre-to post-construction.
2) Establish the relationship between time since construction and the difference in the amount of rearing habitat from pre-construction to most recent survey.
3) Establish the relationship between time since construction and the difference in the amount of rearing habitat from the first survey after construction to most recent survey.
4) Determine if construction year affects the amount of rearing habitat present post construction and/or at the time of most recent survey.
5) Analyze the spatiotemporal evolution of off-channel features (natural and constructed side channels and alcoves).

Methods

Study Area

The Trinity River is the largest tributary to the Klamath River and is located in northwestern California, USA (Figure 1). The Trinity River headwaters originate in the Trinity Mountains, the Yolla Bolly Mountains and the Trinity Alps from which it flows approximately 274 km to its confluence with the Klamath River. The Trinity River watershed has a drainage area of 7,679 km2, approximately one quarter of which is upstream of Lewiston Dam (USFWS 1989; USBOR 2009). The channel rehabilitation sites are located in the Trinity River between Lewiston Dam and the confluence with the North Fork Trinity River.

Habitat Surveys

Sites were surveyed during summer base streamflow with a planned Lewiston Dam release of 12.7 cms, hereafter referred to as low flow. This streamflow was selected because: (1) it is the most frequent discharge represented in the rearing habitat data sets that were created specifically to satisfy monitoring requirements identified in the Integrated Assessment Plan (TRRP 2009) for estimating rearing habitat availability at both rehabilitation and systemic scale evaluations, (2) it occurs during a time period with little effect from tributary accretions or storm events (consistency during field sampling), and (3) flow management in the summer months is unlikely to change in the near future due to adult spring-run Chinook Salmon temperature requirements providing consistency for future comparisons.

Rearing habitat was mapped using methods described in Goodman et al. (2015), where depth, velocity, and distance to escape cover were delineated at specified thresholds (Table 1). Cover is defined as wetted woody debris, vegetation or tree roots that could be used for hydraulic refugia, shade or escape from predation. Rearing habitat was divided into two developmental phases for Chinook and Coho salmon within 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 Chinook Salmon rearing habitat for fry and presmolt life stages included areas that simultaneously meet depth, velocity, and cover criteria. Total rearing habitat included areas that meet any combination of depth and velocity or cover criteria (including optimal habitat areas). Validation studies have demonstrated that Coho Salmon are more strongly associated with optimal habitat areas relative to other habitat categories (Goodman et al. 2010; 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. Isolated off-channel pools not connected to surface water of the main channel at low flow were not surveyed. Each habitat measurement was geo-referenced to produce spatially explicit representations of rearing habitat areas.

Data Sources

All data in this analysis were from two rearing habitat geodatabases and aerial photographs of the restoration reach taken every year of our study period by the TRRP. The rehabilitation geodatabase contains all rearing habitat data collected at sites of channel and

Table 1. 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 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/s
	Distance to Cover	0 to 0.61 m
Presmolt (≥50 mm)	Depth	>0 to 1 m
	Mean column velocity	0 to 0.24 m/s
	Distance to Cover	0 to 0.61 m

floodplain rehabilitation projects as part of the overall habitat assessment efforts of the TRRP. These projects are implemented at discrete physical locations within the restoration reach and include the construction of natural riverine features such as floodplains, point bars, forced meanders, mid-channel islands, side channels and alcoves among others. Hereafter, we collectively refer to these features as construction or construction-related. These surveys were typically conducted just prior to and just after construction of rehabilitation sites with some surveys conducted at a range of flows. Only data collected at sites during low flow were included in this analysis. Data collected during the pre- and post-construction surveys at Vitzhum Gulch and Lower Indian Creek, were obtained from Goodman et al. (2010). Those surveys were conducted with habitat survey guild definitions no longer utilized by the TRRP, which did not include an optimal habitat category. Subsequent surveys at these sites were conducted with the currently used survey guilds and are therefore included in the sub-sampling protocol used for the trend analysis described in the Sampling Design section below.

The GRTS (generalized random tessellation stratified) geodatabase contains rearing habitat data collected as part of a study design framework established to develop a systemic estimate of the amount of rearing habitat in the restoration reach on a 5-year cycle (Goodman et al. 2016). Sample sites were defined as 400-m segments of the 142 cms (5,015 cfs) river channel centerline estimated from hydrodynamic modeling in 2006 (DWR unpublished data). Sample units were then selected using the GRTS protocol providing a spatially balanced and random sample of the restoration reach (Stevens and Olsen 2004).

Alcoves and side channels were selected for analysis by visual identification using aerial photographs of the Trinity River from 2005-2015. We defined side channels according to Roni (2005) and alcoves according to Hulse et al. (2002). TRRP and pre-TRRP constructed features were identified using the Design_2D and Historic Projects Points shape files found in TRRP geodatabases (TRRP unpublished data). These two GIS files contain spatial location information about TRRP and historic (pre-TRRP) rehabilitation projects along with supplementary details such as installation date and purpose of specific restoration features.

Sampling Design

For objective one, we compared pre- and post-construction habitat survey data from sites that were surveyed completely (entire site length) or nearly completely (in two cases design changes and time constraints prevented a complete survey). Objectives 2-4 were completed by sub-sampling the two geodatabases. First, we identified rehabilitation sites with segments of overlapping channel rehabilitation and GRTS habitat survey data. The boundaries for these overlapping data were further limited to areas directly adjacent to constructed features. Secondly, the overlapping data within those rehabilitation sites that also contained multiple, spatially distinct GRTS samples were further partitioned along the GRTS sample boundaries. These two steps produced discrete segments of habitat data that partially covered a site and contained all the necessary information (site name, survey year and survey type, habitat area) to ensure correct spatiotemporal comparisons within and between sites. The lengths of these discrete segments were used to normalize the selected habitat data to allow comparisons of habitat area (sq. m) per river distance (m) among sites.

We used a subset of GRTS data to establish the amount of rearing habitat at sites not constructed by the TRRP to be used as a control. To avoid pseudo replication, we removed repeat visits from the dataset, limiting the analysis to the first visit of each GRTS site and then we subset the data to include only sites (n=36) that did not overlap channel rehabilitation sites. These sample units were then used to develop descriptive statistics about the restoration reach that had no channel rehabilitation effort.

For objective five, the spatiotemporal evolution of natural, pre-TRRP constructed and TRRP constructed side channels and natural and TRRP constructed alcoves was assessed by measuring the length (side channels) and surface area (alcoves) of the feature type using aerial photographs in ArcMap. Aerial photographs provide continuous coverage of the restoration reach for the years 2005-2015. A summary of discharges at the upstream and downstream extents of the restoration reach during the aerial photograph surveys can be found in Table 2. The 2009 photographs were taken when the release from Lewiston dam was at 8.5cms (300 cfs) and were therefore excluded from the alcove analysis but not from the side channel analysis because we assumed that surface area, but not length, calculations would be significantly affected by a reduced flow. All spatial analyses were conducted with ArcMap (version 10.3.1).

Analysis

Normalized total and optimal rearing habitat were calculated for fry and presmolt life stages across multiple sites and years. Goodman et al. (2016) found that measurements of optimal rearing habitat area for presmolt and fry exhibited a Pearson's product-moment correlation (ρ) of 0.985 (CI = 0.980 to 0.989) and total rearing habitat area had a ρ of 0.983 (CI = 0.977 to 0.988). For brevity, we limited reporting to presmolt habitat area.

A total of 23 rehabilitation sites were analyzed for this report (Table 3). For objective one, thirteen rehabilitation sites were surveyed completely (n=11) or nearly completely (n=2) before and after construction; percent coverage for Lowden Ranch and Reading Creek was approximately 70% and 64%, respectively. For objective two, seven sites were compared from pre-construction to the most recent survey. For objective three, 19 sites were compared from the first survey after construction to the most recent survey. For objective four, the

Table 2. Summary of discharges at the upstream (Lewiston Dam) and downstream (North Fork Trinity River) extents of the restoration reach for the dates the aerial photograph surveys were conducted. Discharge (Q) is reported in cms. Note that surveys in 2009 were conducted over two days.

Year	Date	Lewiston (Q)	North Fork (Q)
2005	21-Sep	13.6	15.6
2006	25-Jul	11.5	18.6
2007	3-Jul	12.7	14.7
2008	5-Aug	10.4	12.1
2009	15-Apr	8.3	20.2
2009	16-Apr	8.2	19.3
2010	25-Aug	13.6	15.8
2011	16-Aug	12.6	17.0
2012	30-Jul	13.4	16.8
2013	28-Jul	12.7	12.9
2014	9-Jul	13.3	13.3
2015	27-Jul	13.0	12.7

effect of construction on the amount of rearing habitat present at the first survey after construction and the most recent survey was assessed at 11 and 19 sites, respectively.

The sub-sampling design for objectives 2-4 limited our analysis to rearing habitat areas directly adjacent to construction features; Reading Creek rehabilitation site was only included in the analysis for objective one because it did not meet this criterion. The necessity of sampling GRTS data to extend the time frame of analysis for objectives 2-4 resulted in the inclusion of 22 partial rehabilitation sites in the trend analysis. The percent coverage of the 22 sites (Median=39%, range= 8-92%) were calculated from the entire site length. Twelve sites had less than 50% coverage and 10 sites had over 50% coverage.

The construction features adjacent to sampled areas included constructed floodplains designed to interact with a range of flows from 12.7 cms to 170 cms (6,004 cfs), feathered edges, gravel augmentation sites (bars and islands with and without wood placement), wetland expansions, channel expansions, main channel split flows, channel meander bends, re-contoured banks, berm removal, lowered banks, berm notches, side channels and alcoves. The intended benefits associated with some of these features may not be realized at the flow assessed here.

For objective 5, we assessed the spatiotemporal evolution of 109 off-channel features (Table 4). First, we combined natural and constructed feature type data to compare side channel length (n=22) and alcove surface area (n=29) to habitat area using linear regression. This analysis determined the utility of using those two metrics to describe the performance of these two feature types relative to habitat available to juvenile salmonids at low flow. Second, the spatiotemporal evolution of these feature types was addressed by documenting feature life span (number of years contiguous with main stem) and by plotting side channel length and alcove surface area over time. The Kaplan-Meier method with the log rank test was used to calculate and compare natural and TRRP constructed off-channel feature survival rates (Kaplan and Meier, 1958). We define survival as the probability and the rate at which a feature becomes disconnected from the mainstem at 12.7 cms. Survival estimates for off-channel features that became disconnected from the mainstem multiple times were recorded for the last separation event only. Kaplan-Meier analysis accounts for two properties of survival curves: 1) the proportion of features that become disconnected and 2) the rate that a feature becomes disconnected over time.

We identified a subset of off-channel features that were not easily categorized as natural or TRRP constructed. This group was analyzed separately (Table 4) from the survival analysis and includes side channels and alcoves created by river processes that were indirectly affected by construction activities (semi-natural) and pre-TRRP constructed channels that were altered by TRRP construction activities (reconfigured). All pre-TRRP side channels and berm notches constructed at Vitzhum Gulch were also not included in the survival analysis. The thirteen berm notches at Vitzhum Gulch, created by vegetation removal and bank excavation, were designed to allow streamflow behind the berm at 56.6 cms and to provide rearing habitat between 14.2 and 56.6 cms (TRRP, 2008). A third category of constructed alcove (converted side channel), created when a side channel closes on one end, was also described separately. All data analyses were conducted in R (R Development Core Team 2009).

Results

We calculated systemic estimates of normalized total (Median= 5.66 sq.m/m, range = 3.08-25.30 sq. m/m) and optimal (Median=1.21 sq. m/m, range=0.28-10.49 sq. m/m) rearing habitat present in areas of the restoration reach that have not received any rehabilitation effort, which provide a frame of reference for post-construction habitat values.

Objective 1: Determine the proportion of rehabilitation sites with an increase in rearing habitat from pre- to post-construction.

Channel rehabilitation increased rearing habitat availability at construction sites (total presmolt habitat: $t= -5.74$, $df=12$, $p<0.001$; optimal presmolt habitat: $t= -2.57$, $df=10$, $p<0.05$; paired t tests). Increases in either the amount of total (Median=63%, range= 4% to 152%) and/or optimal (Median=64%, range=10% to 379%) presmolt rearing habitat were observed at 12 of thirteen sites as a result of construction (Table 5). The maximum percent increase, observed at Lewiston Cableway, was associated with re-opening a previously constructed (pre-TRRP) side channel. Sites with higher percent gains were not always sites with the lowest pre-construction values. Lowden Ranch saw large percent increases in both habitat types but had intermediate pre-construction values. By contrast, Lower Bucktail Dark Gulch had the second lowest amount of optimal habitat before construction and increased in this category by 156%. Optimal presmolt rearing habitat decreased 23% at Trinity House Gulch after construction. This reduction was associated with alluvial deposition in the upstream section of the site in the mainstem and along the bank on river left just below Grass Valley Creek, which eliminated a large backwater area. Vegetation removal during construction also contributed to optimal habitat reductions. The median and range for total habitat area at pre-construction was 4.26 sq.m/m and 2.83-8.34 sq.m/m, respectively and for post-construction was 6.9 sq.m/m and 3.63-12.25 sq.m/m, respectively. The median and range for optimal habitat area at pre-construction was 1.03 sq.m/m and 0.49-1.92 sq.m/m, respectively and for post-construction was 1.68 sq.m/m and 0.66

Table 3. The channel rehabilitation sites in this analysis including thirteen sites (*) which were surveyed completely before and after construction. Sites are ordered from upstream to downstream and x indicates site and year of habitat survey.

		Survey Year								
Site	Construction Yr.	2007	2008	2009	2010	2011	2012	2013	2014	2015
Sven Olbertson	2008					x	x			
Lewiston Cableway*	2008		x	x	x				x	x
Hoadley Gulch	2008				x	x				x
Sawmill	2009					x	x			
Upper Bucktail Dark Gulch*	2008		x	x				x		
Lower Bucktail Dark Gulch*	2008		x	x	x				x	x
Lowden Ranch*	2010			x	x	x			x	x
Trinity House Gulch*	2010				x	x				x
Vitzhum Gulch*	2007				x	x				x
Indian Creek	2007			x	x				x	x
Lower Indian Creek*	2007			x	x				x	x
Douglas City	2011						x	x		
Reading Creek*	2010			x		x				
Lower Steiner Flat*	2012					x		x	x	x
Lorenz Gulch*	2013							x	x	
Upper Junction City*	2012					x		x		
Lower Junction City*	2014					x				x
Hocker Flat	2005		x	x				x		
Connor Creek	2006					x	x			
Wheel Gulch*	2011				x	x			x	x
Valdor Gulch	2006			x	x				x	x
Elk Horn	2006			x				x		
Pear Tree	2006				x	x				x

Table 4. Sample size and type of analysis for each off-channel feature type. The Kaplan-Meier method with the log rank test was used to calculate and compare natural and TRRP constructed off-channel feature survival rates. A subset of off channel feature types not easily categorized as natural or constructed were analyzed separately. Semi-natural side channels and alcoves were indirectly formed by TRRP construction activities due to physical proximity to areas of floodplain lowering and gravel augmentation, respectively. Converted side channels are alcoves formed when a side channel closes on one end. Reconfigured side channels are pre-TRRP side channels that were altered by TRRP restoration activities.

Analysis	Feature	TRRP	Natural	Pre-TRRP	Semi-natural	Reconfigured
Kaplan-Meier	side channels (sc)	13	25	–	–	–
	alcoves	15	13	–	–	–
Separate	side channels	–	–	7	2	9
	alcoves	–	–	–	5	–
	converted sc	8	–	1	–	–
	Vitzhum notches	11	–	–	–	–

-5.24 sq.m/m, respectively (Figure 2). Lewiston Cableway and Reading Creek sites had the highest and lowest post-construction values for normalized total and optimal presmolt habitat area, respectively (Table 5).

Objective 2: Establish the relationship between time since construction and the difference in the amount of rearing habitat from pre-construction to most recent survey.

Although a majority of sites (6/7) had more rearing habitat at the most recent survey thanthey did at pre-construction (Appendix B, Table B-1), there does not appear to be a clear relationship between this difference and the years since construction (Figure 3). One (Lower Bucktail Dark Gulch) of the seven sites in this analysis had less total presmolt habitat at the most recent survey in 2015 than it did at the pre-construction survey in 2008. Two sites (Lower Bucktail Dark Gulch, Trinity House Gulch) had most recent (2015) survey values for optimal presmolt habitat approaching pre-construction levels. The intervals between the pre-construction and most recent survey for these two sites are seven and five years, respectively.

Objective 3: Establish the relationship between time since construction and the difference in the amount of rearing habitat between the first survey after construction and the most recent survey.

Ten of 19 sites had less total habitat at the most recent survey than they did at the first survey after construction. There does not appear to be a clear relationship between time since construction and the difference in the amount of rearing habitat between the first survey after construction and the most recent survey (Figure 4. Seven of the 19 sites in this analysis had more total and optimal presmolt rearing habitat at the final survey than they did

Table 5. The amount (sq.m), percent change and normalized amount (sq.m/m) of total and optimal presmolt habitat area at thirteen sites surveyed before (pre-con) and after (post-con) construction. Vitzhum Gulch and Lower Indian Creek were not surveyed for optimal habitat.

		Total				Optimal			
Site	Length (m)	Pre-con (sq.m)	Post-con (sq.m)	% Δ	Post-con (sq.m/m)	Pre-con (sq.m)	Post-con (sq.m)	% Δ	Post-con (sq.m/m)
Lewiston Cableway	500	2,433	6,126	152	12.25	547	2,619	379	5.24
Upper Bucktail Dark Gulch	335	2,793	3,558	27	10.62	644	871	35	2.60
Lower Bucktail Dark Gulch	400	1,900	2,694	42	6.74	206	527	156	1.32
Lowden Ranch	1,400	4,029	9,661	140	6.90	1,448	3,592	148	2.57
Trinity House Gulch	600	2,220	3,310	49	5.52	566	437	-23	0.73
Vitzhum Gulch	1,096	4,872	8,348	71	7.62	–	–	–	–
Lower Indian Creek	1,051	3,214	6,920	115	6.58	–	–	–	–
Reading Creek	1,400	3,967	5,088	28	3.63	690	918	33	0.66
Lower Steiner Flat	1,600	4,590	7,476	63	4.67	1,134	2,010	77	1.26
Lorenz Gulch	1,404	5,978	10,491	76	7.47	1,392	3,754	170	2.67
Upper Junction City	904	7,215	7,504	4	8.3	1,397	1,648	18	1.82
Lower Junction City	642	4,036	6,086	51	9.48	805	884	10	1.38
Wheel Gulch	400	1,597	2,649	66	6.62	448	674	50	1.69

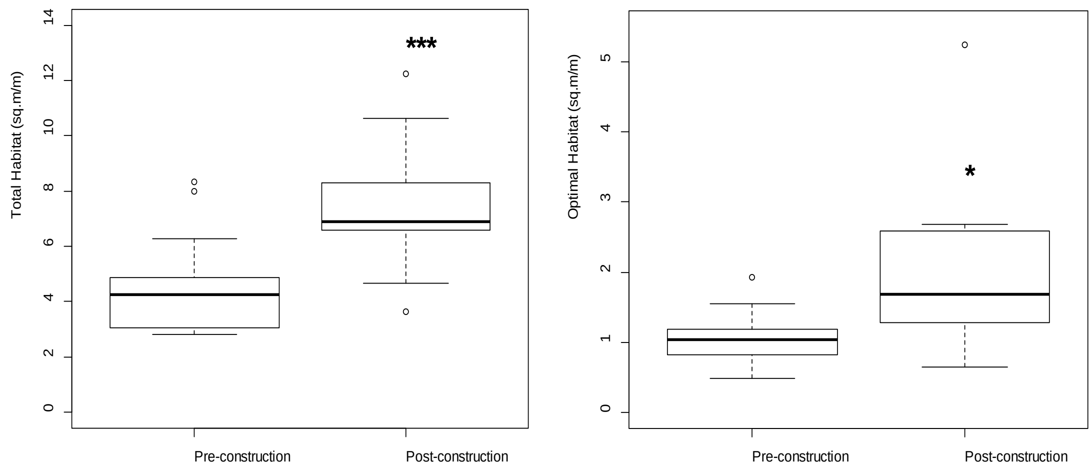

Figure 2. Variation in the amount of total and optimal presmolt habitat area per river meter (sq.m/m) before and after construction. Total habitat panel (left) includes data from 13 complete sites, whereas the Optimal panel (right) includes data for 11 complete sites. Vitzhum Gulch and Lower Indian Creek were not surveyed for Optimal Habitat. Note the plots have different scales. Bold horizontal lines indicate the median, boxes around the median indicate the interquartile range, thin horizontal lines equal 1.5* the interquartile range and open circles indicate outliers. Significant differences are indicated by asterisks (paired t-test, *** p<0.001, * p<0.05).

at the first survey after construction (Appendix B, Table B-2). Two sites (Lowden Ranch and Lower Steiner Flat) had more total but less optimal habitat and one site (Hocker Flat) had less total but more optimal habitat at the final survey than they did at the first survey after construction. The other nine sites had less total and optimal habitat at the most recent survey than they did after construction.

Objective 4: Determine if construction year affects the amount of rearing habitat present post-construction and/or at the time of most recent survey.

The effect of construction year on the amount of total and optimal rearing habitat at the post-construction survey (n=11 sites) was variable (Figure 5). The median values for normalized total and optimal habitat at post-construction (9.55, 1.83) were above the median values for the non-constructed portion (5.66, 1.21) of the restoration reach. Eight of 11 sites had total habitat area values above the median and 10 of 11 sites had optimal habitat area values above the median. (Appendix B, Table B-3). The effect of construction year on the amount of total and optimal rearing habitat at the most recent survey (n=19 sites) was also variable (Figure 6). The median values for normalized total and optimal habitat at the most recent survey (6.46, 1.56) are above the median values for the non-constructed (5.66, 1.21) portion of the restoration reach. Twelve of 19 sites had total habitat area values above the median whereas 11 of 19 sites had optimalhabitat area values above the median. Connor Creek was the only site with a differential response of total and optimal rearing habitat relative to the most recent survey; total habitat area was above and optimal habitat area was below the median (Appendix B, Table B-4). Normalized habitat areas at constructed

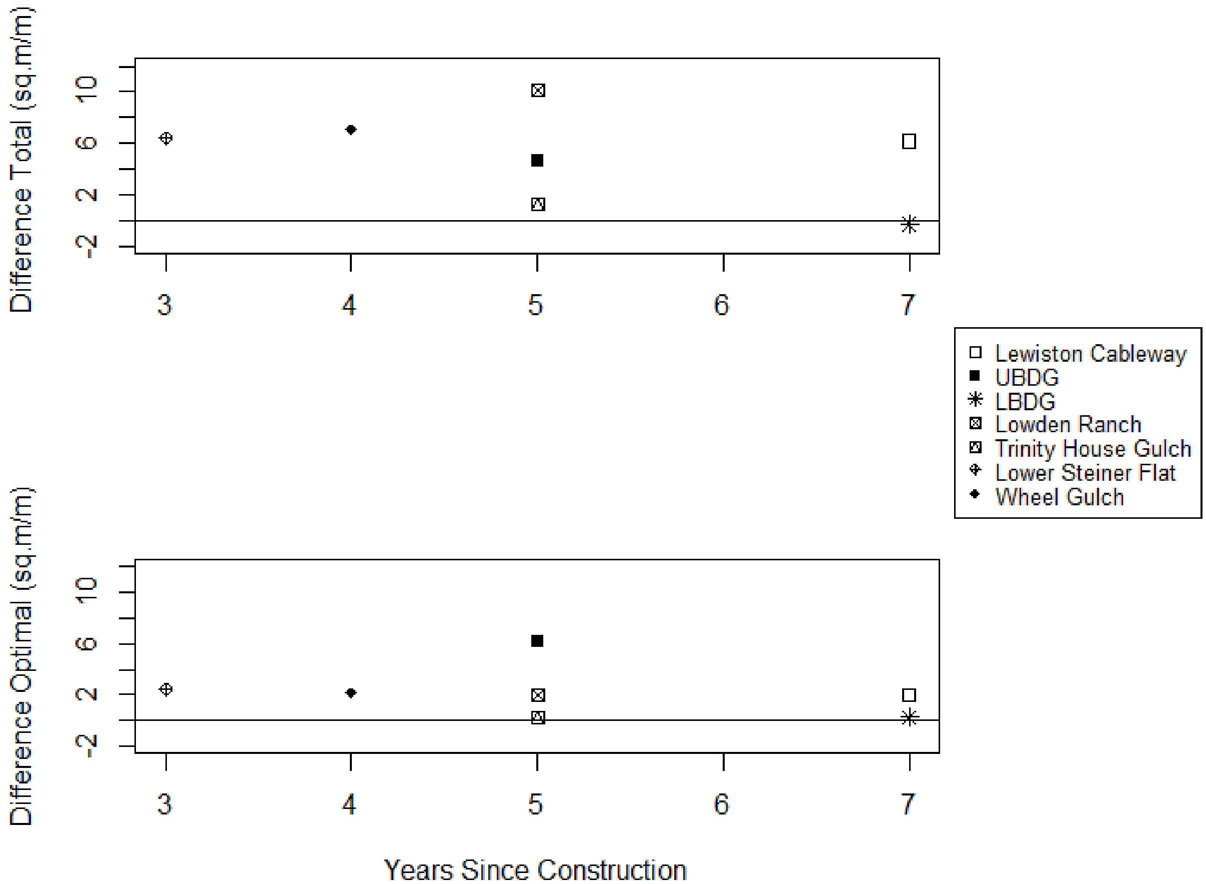

Figure 3. The difference in the amount of total and optimal presmolt habitat area per river meter (sq.m/m) between the pre-construction survey and the most recent survey (n=7 rehabilitation sites). Note that UBDG and LBDG refer to Upper Bucktail Dark Gulch and Lower Bucktail Dark Gulch, respectively.

sites were all within the range of those observed at unconstructed sites with the exception of Lower Bucktail Dark Gulch which was slightly below the range.

Objective 5: Analyze the spatiotemporal evolution of off-channel features (natural and constructed side channels and alcoves).

Regression analyses established the relationship between total rearing habitat and side channel length (n=22, R2=0.57, p<0.001) and alcove surface area (n=29, R2=0.9, p<0.001). The p value indicates that the slope parameter does not equal zero. The equation for side channels was Total Rearing Habitat = 127.85 + 3.06 * Side Channel Length and for alcoves was Total Rearing Habitat = 10.54 + 0.75 * Surface Area. These results indicate that side channel length and alcove surface area are useful proxies for describing the performance of these feature types relative to the habitat provided to juvenile salmonids.

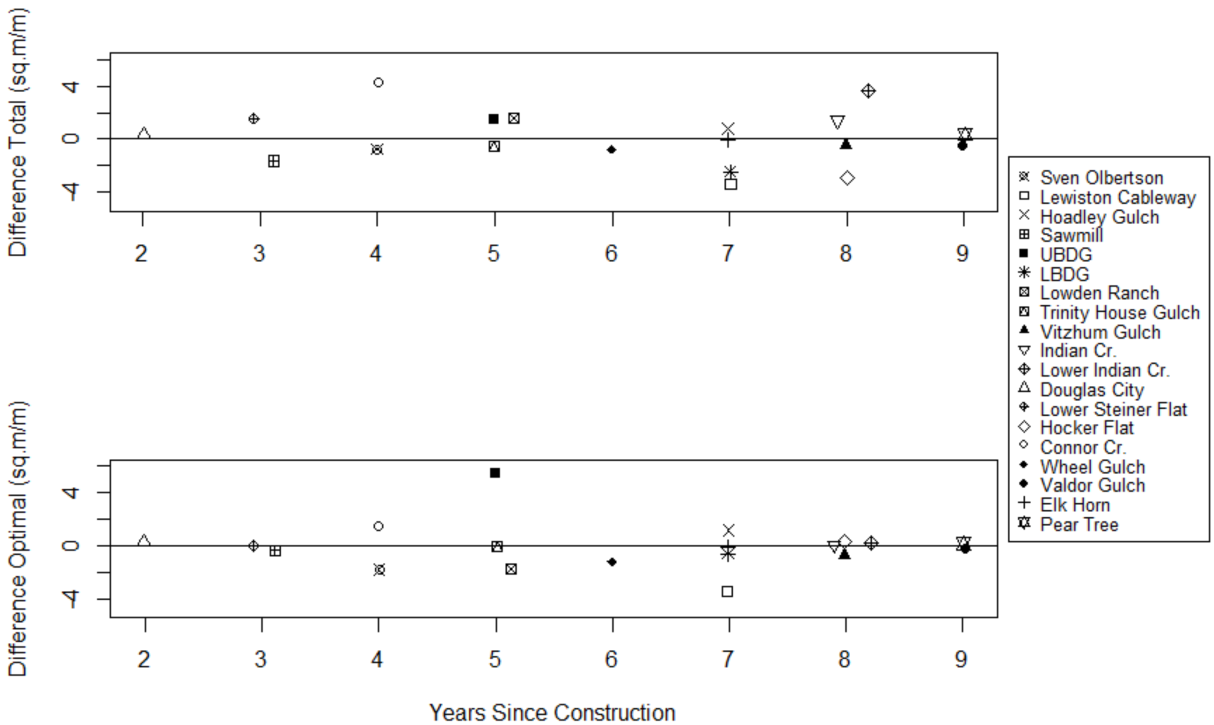

Figure 4. The difference in the amount of total and optimal presmolt habitat area per river meter (sq.m/m) between the first survey after construction and most recent survey (n=19 rehabilitation sites). Note that UBDG and LBDG refer to Upper Bucktail Dark Gulch and Lower Bucktail Dark Gulch, respectively.

Side Channels

We found that natural side channels vary more in length (Appendix B, Figures B-1 and B-2) and have a higher survival (Log Rank Test; p=0.003) than TRRP-constructed side channels (Figure 7) due to a higher likelihood that natural side channels will re-establish connectivity. Twenty-two of 25 (88%) natural side channels and nine of 13 (69%) constructed side channels survived throughout the study period. Two of the three natural side channels that became disconnected from the mainstem re-established connectivity, whereas none of the four constructed side channels that became disconnected re-established connectivity.

One of seven (14%) pre-TRRP constructed side channels permanently closed in 2006, one year into the study period (Appendix B, Figure B-2). Two semi-natural side channels, one at Reading Creek and one at Hocker Flat, formed in 2011 by proximal construction activities and remained connected to the mainstem until the end of the study period. Both were the result of floodplain lowering on the opposite bank that reduced the flow velocity causing sediment deposition, which then split the flow and produced a side channel. The TRRP constructed side channels at Sven Olbertson, Lewiston Cableway, Sawmill, Bucktail Dark Gulch, Lower Steiner Flat and Lorenz Gulch were reconfigured from pre-TRRP constructed

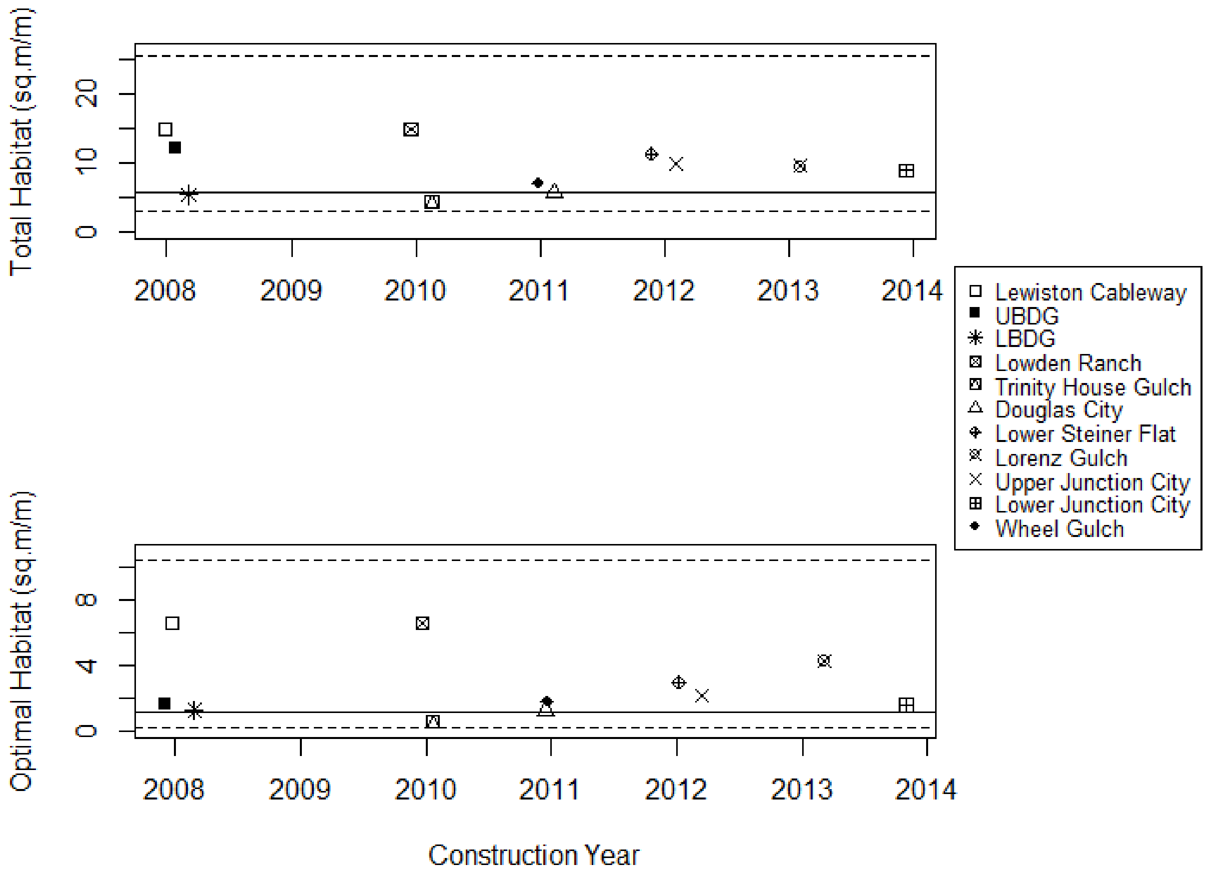

Figure 5. The amount of total and optimal habitat area per river meter (sq.m/m) at the post-construction survey plotted against construction year (n=11 rehabilitation sites). The solid and dashed lines indicate the median and range, respectively, of the systemic estimate of normalized Total and Optimal rearing habitat in areas of the restoration reach that have not received any rehabilitation effort. Note that UBDG and LBDG refer to Upper Bucktail Dark Gulch and Lower Bucktail Dark Gulch, respectively.

channels. Seven of nine (78%) remained connected to the mainstem throughout the study period. Neither of the two that became disconnected from the mainstem re-established connectivity.

Rehabilitation sites with closed or impaired side channels included Sawmill, Lower Bucktail Dark Gulch, Trinity House Gulch, Lower Steiner Flat and Upper Junction City. Hoadley Gulch side channel anabranch closed in 2011 but is not included in the total count of closed side channels because the primary side channel at this site was still functional in 2015. Deadwood Creek side channel is one of the four TRRP constructed side channels that closed permanently and is not associated with a rehabilitation site in this analysis. All of these side channels likely provide habitat at increased discharges and should be evaluated in future

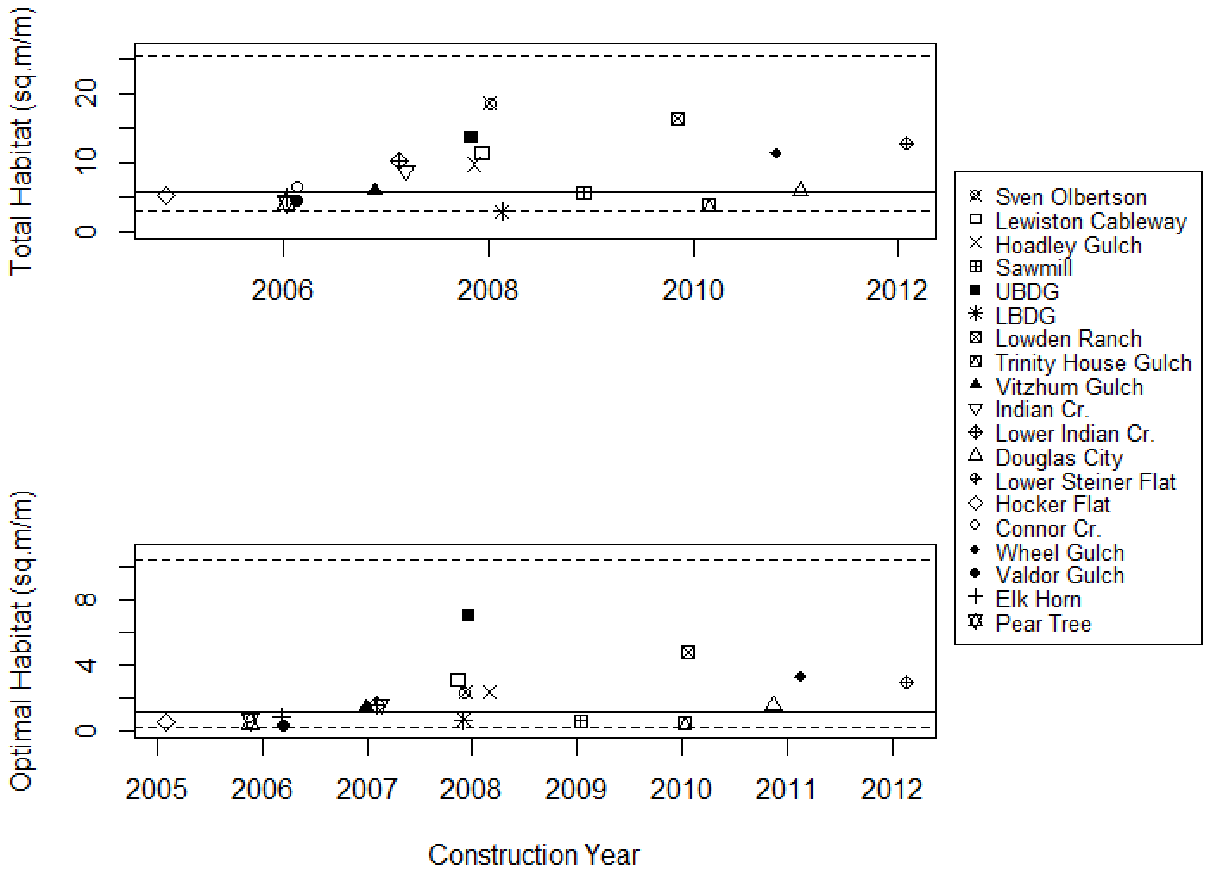

Figure 6. The amount of total and optimal habitat area per river meter (sq.m/m) at the most recent survey plotted against construction year (n=19 rehabilitation sites). The solid and dashed lines indicate the median and range, respectively, of the systemic estimate of normalized Total and Optimal rearing habitat in areas of the restoration reach that have not received any rehabilitation effort. Note that UBDG and LBDG refer to Upper Bucktail Dark Gulch and Lower Bucktail Dark Gulch, respectively.

analyses.

Alcoves

We found that natural alcoves vary more in surface area (Appendix B, Figure B-3) and moderate evidence they have a higher survival than constructed alcoves (Figure 7; Log Rank Test; p=0.062) due to a higher likelihood that natural alcoves will re-establish connectivity. Six of 13 (46%) natural alcoves and nine of 15 (60%) constructed alcoves survived throughout the study period. Four of the 7 natural alcoves that became disconnected from the mainstem re-established connectivity, whereas none of the six constructed alcoves that became disconnected re-established connectivity. Three of eleven

(27%) Vitzhum notches remained connected to the mainstem throughout the study period and only one of 8 (13%) that disconnected from the mainstem re-established connectivity

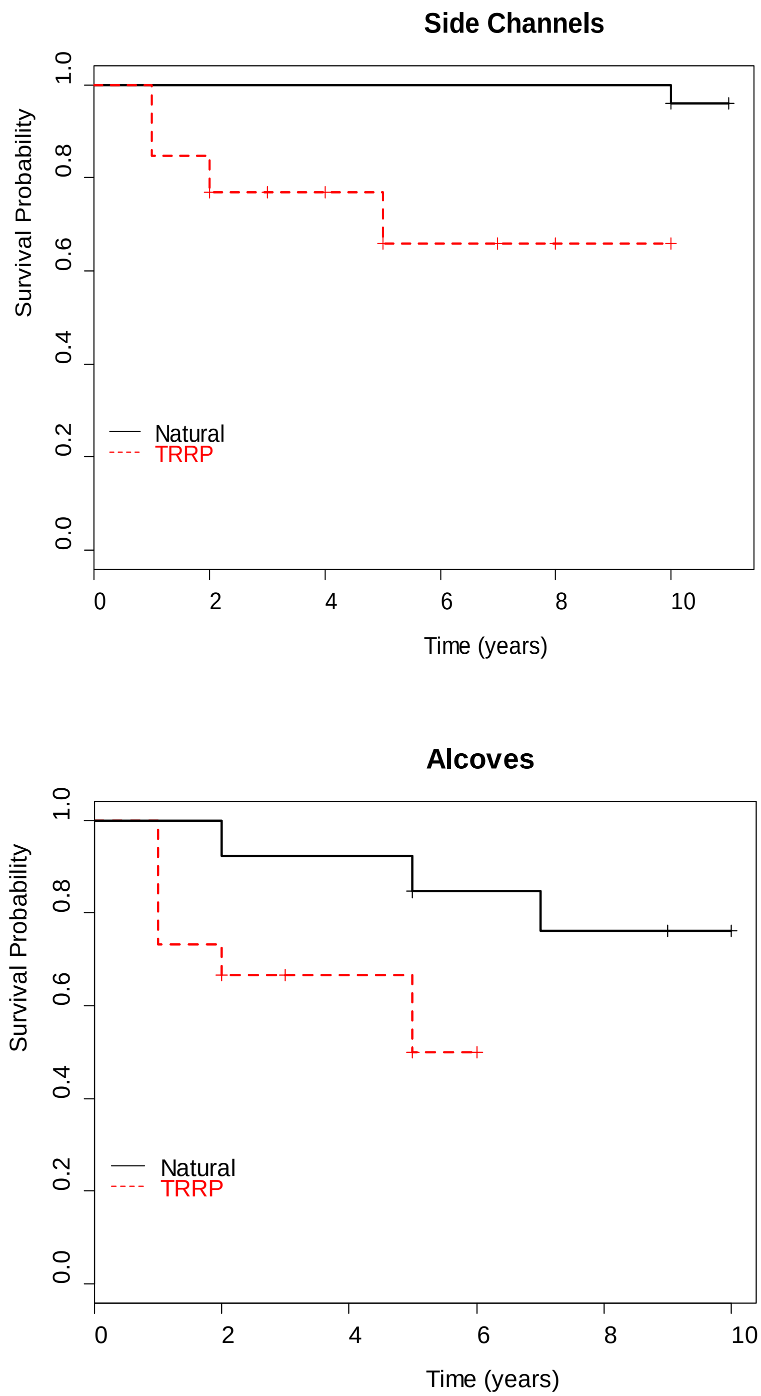

Figure 7. Kaplan-Meier survival curves for natural and TRRP-constructed side channels (upper panel) and alcoves (lower panel) in the restoration reach of the Trinity River, California. Time (years) indicates the amount of time since construction.

(Appendix B, Figure B-3). One of the 5 semi-natural alcoves that formed in proximity to augmented gravel supplies closed permanently after 4 years. None of the converted side channels became disconnected from the mainstem (Appendix B, Figure B-3). Rehabilitation sites with disconnected alcoves included Sawmill, Vitzhum Gulch, Valdor Gulch, Elk Horn and Pear Tree.

Discussion

The information presented in this report is intended to provide feedback to the TRRP on the short-term and long-term performance of channel rehabilitation sites at 12.7 cms to support the adaptive management process. As applied by the TRRP, mechanical channel rehabilitation in conjunction with streamflow management, coarse sediment augmentation and other restoration actions was expected to generate immediate, as well as, long-term improvements in juvenile Chinook and Coho salmon summer rearing habitat. Rehabilitation sites are intended to interact with river features and other restoration actions and fluvial processes to produce a complex and dynamic channel form with habitat benefits extending through time.

We assessed the immediate results of construction at 13 complete rehabilitation sites and explored longer-term trends in the amount of low flow rearing habitat available at 22 sub-sampled rehabilitation sites. We also tracked the spatiotemporal evolution of natural and constructed alcoves and side channels, as well as, the impact these construction features have on the performance of rehabilitation sites. The design and construction of channel rehabilitation sites is one component of the TRRP that is particularly suited to adaptive management and improving designs based on the outcome of previous efforts.

Early mechanical channel rehabilitation projects by the TRRP were relatively modest, focusing on the removal of riparian berms and the creation of point bars. It was theorized that these less invasive efforts would enable fluvial processes to potentiate the development of more complex channel morphology and a more dynamic river in general. Over time rehabilitation projects have become increasingly complex, providing more immediate habitat benefits. These projects, in some cases, have also increasingly been accompanied by detailed design objectives and predictions for site evolution. Many of the sites analyzed here and described below were not developed with specific hypotheses other than general reference to overall program goals such as “increase rearing habitat at a range of streamflows”. However, where appropriate we refer to specific design documentation to provide information about expected versus observed outcomes at rehabilitation sites.

Channel Rehabilitation Site Performance

It is clear from previous rehabilitation site-specific reporting and the analyses presented here that channel construction activities have a dramatic, immediate and almost completely positive short-term influence on the amount of rearing habitat at rehabilitation sites after construction (Goodman et al. 2010; Martin et al. 2013; DeJuilio et al. 2014). We found that 92% (12/13) of sites surveyed before and after construction had more rearing habitat after construction (Table 5). Rearing habitat was improved by many of the wide range of constructed features with constructed alcoves and side channels being a noteworthy source of improvements. Trinity House Gulch was the only site that showed a decrease in rearing habitat in the post-construction survey. The loss of habitat at this site was attributed to deposition of alluvial material in the main channel below Grass Valley Creek after construction and before the first post-construction habitat survey, as well as, vegetation removal during construction (Martin et al. 2013).

The short-term benefits of rehabilitation activities are now well documented; however, knowledge about the performance of these sites over longer time frames is limited. DeJuilio et al. (2014), observed a large increase in rearing habitat at the Sawmill rehabilitation site after construction but found three years later that total and optimal presmolt habitat had decreased (15% and 47%, respectively), after experiencing three high streamflow events over 170 cms. These authors attributed habitat degradation to the closing of a side channel and suggested that future designs include the placement of a hard point (large wood or rock) at side channel entrances to help maintain connectivity to the mainstem by enabling scour. Subsequently, this type of feature was incorporated into channel rehabilitation site designs such as at Lower Steiner Flat (Figure 8), although no formal analysis of their efficacy has been completed. Our sampling design prevented us from reporting on trends in the amount of rearing habitat at the Sawmill rehabilitation site over the entire interval documented in DeJuilio et al. (2014). However, we observed a decrease in total and optimal presmolt habitat from 2011 to 2012 (Appendix A, Figure A-2), which we also attribute to sediment deposition in the Sawmill side channel. Although some initial construction benefits were lost by this side channel closure at Sawmill, the amount of rearing habitat was still higher than pre-construction levels due to sediment aggradation in the mainstem channel, which increased areas of inundation along a lowered floodplain.

Similarly, the loss of low flow rearing habitat after the post-construction survey at other rehabilitation sites can be attributed to side channel closure. For instance, Trinity House Gulch (mentioned above) and Lower Bucktail Dark Gulch suffered habitat losses due to sediment accumulation at side channel entrances. Lower Bucktail Dark Gulch rearing habitat returned to pre-construction levels (Appendix A, Figure A-2) as its constructed side channel began to aggrade with fine sediment (Hoopa Valley et al. 2015) and eventually closed in 2011. Due to this and other factors Lower Bucktail Dark Gulch was reconstructed in 2016.

Channel changes at other rehabilitation sites included the evolution of off-channel features. Lower Steiner Flat included two low flow side channels with alcoves at the downstream end of each, as well as, a separate alcove at the downstream end of a high flow side channel (CH2MHill 2011). The designers correctly predicted that, in the case of aggradation at the upstream low flow side channel, its corresponding alcove would continue to provide habitat benefits. We observed a complex interaction of side channel and alcove evolution that resulted in the aforementioned constructed side channel closing in 2015 (Figure 8), a constructed alcove contracting and growth of a natural side channel. Overall, total rearing habitat increased and optimal habitat decreased between the post-construction survey in 2013 and the most recent survey in 2015 (Appendix A, Figure A-5). During this interval, we documented a steady reduction in the surface area of the constructed alcove in our sub-sample which partly explains the reduction in optimal habitat. Visual inspection of a time series of habitat area maps clearly indicates an increase in total habitat in the natural side channel on river left. Aerial photographs indicate this channel widened between 2014 and 2015 perhaps due to peak streamflow events and associated fluvial processes evidenced by a large pile of woody debris deposited at the head of the vegetated island that bifurcates the flow into the natural side channel.

Changes in the morphology of channel rehabilitation sites after construction were not limited to off-channel habitats. Lewiston Cableway channel rehabilitation site included a series of point bars intended to increase sinuosity and, in conjunction with water year-specific releases and long term gravel augmentation, would sustain a complex dynamic alternating bar morphology (TRRP 2011). Although channel sinuosity increased as a result of construction, it was not maintained through the duration of this study. In the six years between post-construction and the most recent survey, Lewiston Cableway experienced six peak streamflows up to 348 cms (12,290 cfs). Fluvial processes associated with peak flow events led to scour of constructed gravel bars as the channel form reduced in sinuosity and approached the pre-construction configuration. Gravel bar contraction corresponded to a reduction in eddies, changes in the extent of inundation zones, and an associated overall loss in rearing habitat area (Appendix A, Figure A-1).

Sites with an increase in rearing habitat beyond the initial gains from construction include Upper Bucktail Dark Gulch, Lowden Ranch and Wheel Gulch (Appendix A, Figures A-2, A-3 and A-6). Physical changes were clearly evident at Upper Bucktail Dark Gulch as a result of the 2011 spring high flow event. A large gravel bar deposited along the right bank of the mainstem, which increased the water surface elevation at the top of the site increasing areas of inundation along the bar and in the side channel. Re-vegetation efforts during construction along with natural recruitment of vegetation led to the observed increase in optimal habitat, particularly in the side channel. This alluvial deposition and bar expansion, arising from TRRP flow management, has subsequently raised the flood frequency of the constructed side channel and floodplain improving rearing habitat, particularly at higher streamflows (Martin, 2014).

The trajectory of habitat area after construction was variable with increases and decreases over time. At Lowden Ranch and Wheel Gulch, rearing habitat area was either sustained or increased from post-construction in 2011 to 2014 but then diverged in 2015 with total habitat increasing and optimal habitat decreasing (Appendix A, Figures A-3 and A-6). At Lowden Ranch, suitable habitat increased along the periphery of the mainstem but there were also modest gains in suitable habitat in the wetlands expansion area. The entrance to the side channel leading to the wetlands expansion area and the forced meander in the middle section of the site have been maintained by the placement of two point bars, respectively (TRRP 2011). Most of the gains in optimal habitat were due to vegetative growth in the side channel, wetlands expansion and the semi-natural alcove (Table 4) that formed on the downstream end of the constructed gravel bar. Most of the decreases in optimal habitat in 2015 occurred at the downstream end of the site along the left bank due to gravel deposition; however, the natural alcove also became smaller.

Similarly, in Wheel Gulch, the trajectory of total and optimal habitat increased after construction but began to diverge in 2015. Suitable habitat increased along both sides of the mainstem toward the bottom of the site, as well as, along the periphery of the in-channel island and main channel split flow. Gains in optimal habitat occurred in the side channel and alcove primarily due to these features becoming vegetated. These constructed features have performed as predicted (DWR 2010); significant alluvial deposition at the upstream side of the island in either 2014 or 2015 has likely led to the increases seen around the island. The observed reduction in optimal habitat in 2015 was due to a reduction in the surface area of the constructed alcove, a reduction in flow into the constructed side channel and the loss of a large woody debris pile at the side channel entrance visible in 2014 aerial photographs. Reduced flow into the side channel is clearly evident in aerial photograph comparisons from 2014 and 2015 and is the result of sediment deposition that is likely related to flow restriction caused by the sediment accumulation above the in-channel island.

The trend in total and optimal habitat area diverged during a five year interval at Hoadley Gulch and Hocker Flat (Appendix A, Figures A-1 and A-6). At Hoadley Gulch, total habitat decreased from 2010 to 2011 and then increased beyond 2010 levels by the most recent survey in 2015. Optimal habitat initially increased in the first two years and then decreased slightly by 2015. A large portion of the reduction of total habitat and expansion of optimal habitat between 2010 and 2011 at Hoadley Gulch can be attributed to morphological changes to the constructed gravel bar along the right bank near the downstream end of the side channel. As the bar eroded both at the upstream end and in the middle, water velocity increased along the bar and decreased above it. Similar trends in both habitat categories occurred in the side channel as a result of the side channel anabranch closing in 2011. By 2015, areas with cover had been reduced in the side channel anabranch and along the left bank of the mainstem channel presumably by high flows.

At Hocker Flat, total habitat decreased and optimal habitat increased from 2008 to 2013 (Appendix A, Figure A-6). These changes were associated with coarse sediment transport along the constructed floodplain, a natural alcove on the right bank and subtle changes to the edge of the mainstem channel. Total habitat steadily decreased along the left bank as gravel was displaced and in the alcove when flows breached the upstream end of the alcove resulting in higher water velocities. Alternatively, optimal habitats increased as vegetation grew in small patches along the periphery of the mainstem channel and in the alcove.

Off-channel Feature Performance

Numerous studies and the regression analyses presented here have documented the benefit that side channels and alcoves provide to rearing salmonids (Glase 1994, Morley et al. 2005), by increasing edge habitat (Murphy et al. 1989) and providing backwater areas of suitable depth, velocity and cover combinations (Nickelson et al. 1992; Beechie et al. 2005). The second of five major components of the Record of Decision, prepared by the Department of the Interior, includes explicit language expressing the importance of side channels to the overall restoration of the Trinity River (USDOI 2000): “physical channel rehabilitation, including the removal of riparian berms and the establishment of side channel habitat.

Although the benefits have been well documented, many natural and constructed side channels and alcoves are transient in nature; forming and disappearing over short time periods (HVTFD et al. 2011). The evolution of side channels is characterized by a succession of physical states from fully contiguous with the main channel to ephemerally” wetted swales with little to no surface water inputs from the main channel (Cramer 2012). Alcoves form when a mid-river gravel bar enlarges and connects to one side of the riverbank forming a point bar (Hulse et al. 2002) and generally persist for longer periods of time if located near springs or seeps (Solazzi et al. 2000). Other factors to consider that may help extend the low flow connection of constructed features are the presence or absence of large wood or boulders at the entrance to side channels (Lamm et al. 2002; Montgomery and Abbe 2006), location of mainstem hydraulic and/or geomorphic controls, the spatial relationship between the feature and the mainstem thalweg and/or mainstem gradient and coarse sediment load directly upstream.

Survival analysis of natural and constructed side channels and alcoves revealed that natural features are more likely to remain connected to the mainstem. We found strong evidence for a difference in survival between natural and constructed side channels (p=0.003). We also found moderate evidence (p=0.062) that constructed alcove survival is lower than their natural counterparts. The Kaplan-Meier analysis not only accounts for the proportion of disconnected features during the survival interval (2005-2015) but also the rate (how early) that a feature becomes disconnected over time. We only recorded the last separation event during the survival interval, natural features are more dynamic, disconnecting and then reconnecting more often that constructed alcoves (Appendix B, Figures B-1- B-3). Forty percent of constructed alcoves became permanently separated from the mainstem whereas only 23% of natural alcoves became permanently disconnected. This analysis is limited to the survival interval; constructed features could perhaps become reconnected in the future as a result of TRRP management activities. Constructed alcoves at Valdor Gulch, Elk Horn and Pear Tree rehabilitation sites were hypothesized to be scoured episodically by associated high flow channels (TRRP 2011); however, this does not appear to have occurred.

We found differences between side channels constructed before the TRRP and those constructed by the TRRP. Fourteen percent (1/7) of pre-TRRP constructed and 31% (4/13) of the TRRP constructed side channels became permanently closed at one or more ends during the study period. Overall, eighty percent (16/20) of pre-TRRP constructed side channels were still open in 2015, however nine of those were reconfigured by the TRRP after initial construction and were not included in the comparison of pre-TRRP and TRRP constructed side channels. Previous analyses of pre-TRRP side channels identified that channels constructed upstream of Douglas City required much less maintenance to remain functional than those below Douglas city, which was attributed to lower sediment loading upstream of Douglas City (Hampton, 1992; USFWS and Hoopa Valley Tribe 1999). All seven pre-TRRP side channels in this study are upstream of Douglas City and only one, Ambrose Creek, closed. The distribution of side channels (reconfigured, constructed or natural) that have become either permanently or temporarily aggraded relative to this Douglas City dividing line is approximately 50%.

Comparing pre-TRRP and TRRP side channels may be misleading because all of the pre-TRRP features were constructed before the study period (2005-2015) of this analysis and could be the product of a form of “selection” whereby only those best suited for their location-specific hydrological and alluvial conditions still persist. Similarly, 24 of 25 and 9 of 13 natural side channels and alcoves respectively, were formed prior to the study period. Only one side channel and three alcoves have become permanently disconnected suggesting these features have formed in reaches with channel morphology conducive to their persistence. All of these features have experienced the same water year-specific streamflows

Figure 8. Photographs documenting the effect of hard points on fluvial processes at two side channels constructed at Lower Steiner Flat. The upper panel documents a side channel with a constructed large wood jam or hard point soon after construction in 2013 and again in 2016 after scouring streamflow events. The lower panel shows a second side channel soon after construction in 2013 and again the following year documenting closure due to sediment deposition.

during the study period. This variability has made the channel more dynamic; constructed features are presumably still in the process of being sorted out. The TRRP realized in the late 2000's that some of the side channels in this analysis were unable to continually bifurcate flows at all flow levels and utilized that information for subsequent side channel designs. Hierarchical cluster analysis, based on confinement, floodplain width, bankfull width and channel slope, identified five Trinity River reach types with variable likelihoods of secondary channel formation (Beechie et al, 2015). Additional performance analyses and geomorphic assessments of off-channel features could account for their location relative to these reach types to provide an opportunity for improved integration of these features into channel rehabilitation.

We followed the performance of nine alcoves that were formed from closed side channels and noted variable responses over time. In all cases the converted side channels remained connected to the mainstem over the ten year study period (Appendix B, Figure B-4). All but one formed when the upstream entrance became aggraded, eliminating flow into the channel. Ambrose Creek side channel was built in 1989 and did not convert to an alcove until 2005 when the middle section of the side channel became dry. In some, surface area fluctuated over time and ultimately decreased (n=4), some gradually decreased (n=2), one decreased precipitously, one gradually increased and one fluctuated and returned to its original size. The Hoadley side channel anabranch became aggraded by gravel deposition but continues to provide rearing habitat because it has maintained its downstream connection to the larger, primary side channel, which is open on both ends. The fact that all nine converted side channels have remained functional as alcove habitat helps ameliorate the loss of habitat that occurred when the side channel closed.

Conclusions

We have established that TRRP construction activities increase juvenile habitat availability at rehabilitation sites, but less than 50% of the analyzed sites have sustained or increased the amount of low flow rearing habitat gained from construction. Despite these apparent performance issues, 86% (6/7) of sites had more rearing habitat at the most recent survey than they did before being rehabilitated. We have also identified a large amount of variation in the trajectory of rearing habitat levels both within and among sites; there are sites with overall increases, overall decreases and differential trends in total and optimal presmolt habitat across multiple years. These trends have been attributed to various factors including sediment aggradation and degradation, changes to natural and constructed off-channel features, vegetation recruitment and loss and large wood structures and transport. Examples of sites with an increase in total and/or optimal habitat beyond the initial gains from construction include Upper Bucktail Dark Gulch, Lowden Ranch, Lower Steiner Flat and Wheel Gulch and many of these factors were involved at these sites and in some instances produced contradictory results at different times.

In many instances, constructed side channels and alcoves are responsible for a large portion of habitat gained from construction at low flow, but those benefits can be ephemeral if the feature is not placed in the appropriate physical location that facilitates self-maintenance. One example of an appropriate physical location is the natural side channel at the downstream end of the Lower Steiner Flat rehabilitation site, which took shape and evolved prior to and during the water year-specific releases (CH2MHill 2011). The challenge for the TRRP is to not only balance the cost of constructing these features with the potentially short-lived benefit for salmonid production but to also employ the best scientific analyses and design processes possible to construct them in a way that mimics naturally produced features that are sustained by hydrologic and alluvial processes across a range of flows. This is a reflection of the broader challenge facing river restoration programs, namely the balance between initiating riverine processes that may or may not translate into observable improvements and providing immediate, tangible instream biological needs.

A recent global review of stream habitat rehabilitation techniques found that most benefits from instream structures will be short lived (<10 years) unless coupled with riparian planting or other process-based restoration activities that can lead to long-term recovery of deficient processes (Roni et al. 2008). Each rehabilitation site designed by the TRRP includes a re-vegetation plan intended to provide future habitat benefits above the flow assessed in this report. This report did not aim to systematically evaluate the relationship between water year-specific releases and the amount of rearing habitat available at rehabilitation sites over time. However, Goodman et al. 2016 found that the magnitude of habitat change throughout the restoration reach did not relate to annual peak streamflows. It remains to be seen if the current flow regime, in combination with other program activities (channel rehabilitation, sediment augmentation and riparian planting) will be sufficient to generate the kind of self-sustaining conditions necessary for achieving the proximate and ultimate goals of the TRRP, increased juvenile salmonid rearing habitat and increased production of naturally spawned salmonids, respectively. The observations and conclusions in this report are based on low flow measurements; the TRRP is in the process of collecting information to facilitate a complimentary analysis inclusive of a range of streamflows (12.7, 19.8, 33.9 and 56.6 cms/450, 700, 1,200 and 2,000 cfs) to test the hypothesis that rehabilitation sites provide more rearing habitat at flows above 12.7 cms.

Additional future reporting efforts could 1) address the causal mechanisms (i.e. geomorphic analysis) responsible for the trends in habitat at rehabilitation sites, and/or specific feature types and 2) integrate recent advances in understanding of juvenile salmonid habitat relative to production capacity. The habitat mapping criteria for depth, velocity and distance to cover, used to measure rearing habitat described in this report have been utilized for many years, and correlate with juvenile Chinook Salmon habitat selection (Goodman et al. 2015). More recently, the TRRP has focused efforts on the development of a Decision Support System (DSS), which includes a fish population dynamics model (S3: Stream Salmonid Simulator). To support S3 development, an extensive juvenile fish utilization study was conducted that aimed to estimate how physical variables associate with habitat selection, while also accounting for spatial and temporal variation. The methods of data collection and statistical modeling employed in that study allowed the opportunity to estimate small-scale fish densities, and extensions to habitat-unit fish capacities, given estimates of physical variables across discharge values. While the same variables (depth, velocity, distance to cover) were retained in this modeling exercise, their relative contributions to habitat quality (and now, capacity) were not identical to the assumptions of their inclusion in the habitat mapping criteria applied in this report. Draft results of the habitat capacity model suggest that the reduction in rearing habitat observed at intermediate discharges reported in the Trinity River Flow Evaluation Study may not be as limiting to fish production as once thought. The S3 and DSS models will become adaptive management tools for the TRRP in the near future, and therefore methods for assessing and monitoring habitat in the future warrant discussion. Evaluating the potential differences of applying various habitat metrics, and how habitat is defined and measured will inform planning of future studies that, like the analyses described in this report, seek to evaluate TRRP objectives.

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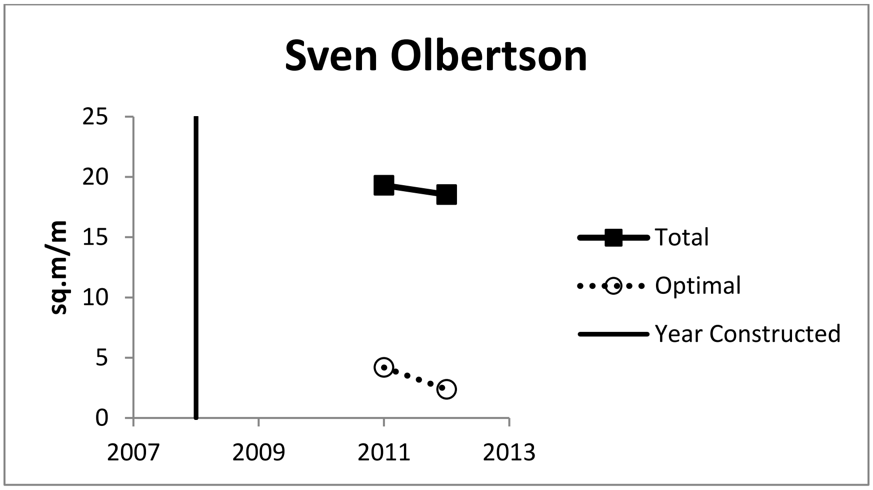
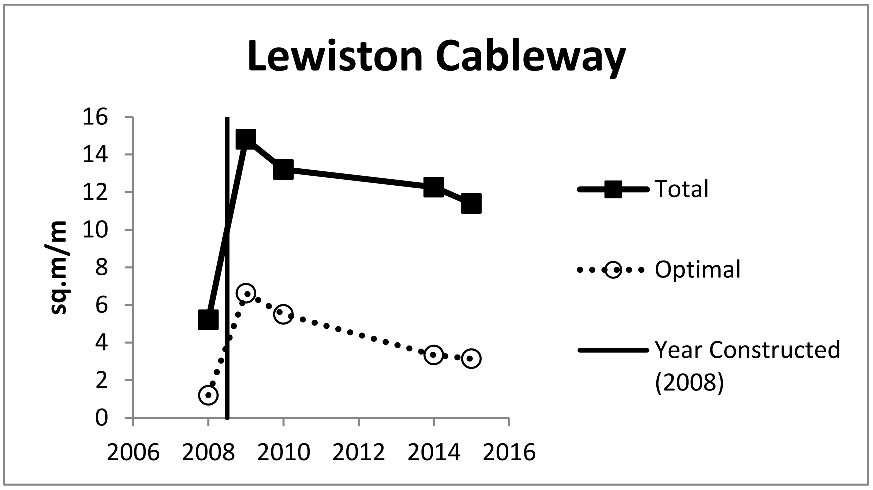
Appendices

Appendix A. Total and optimal habitat area per river meter (sq.m /m) for 22 rehabilitation sites.





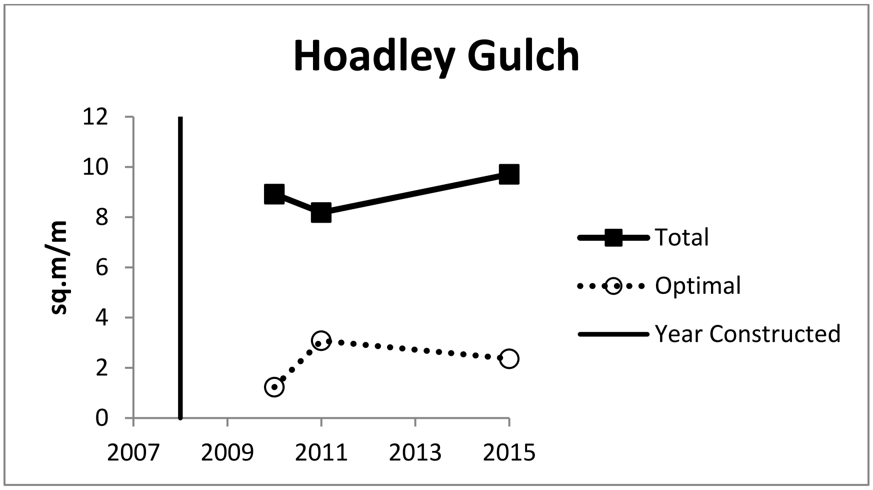
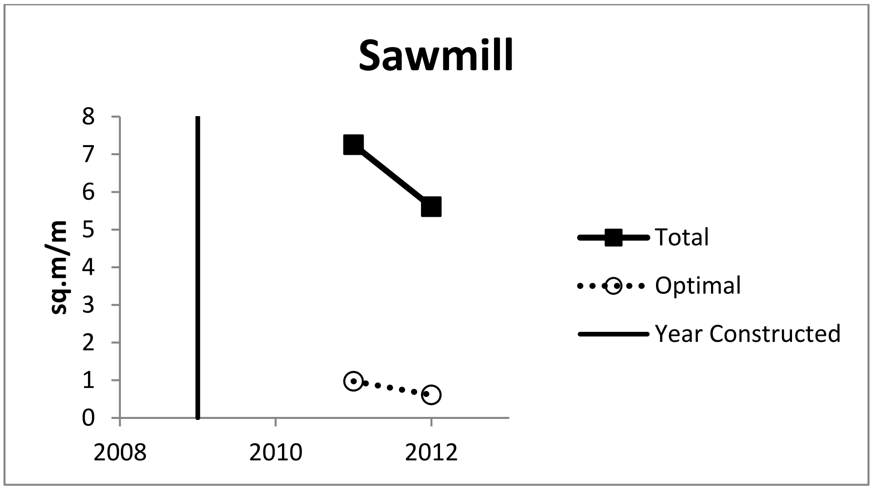
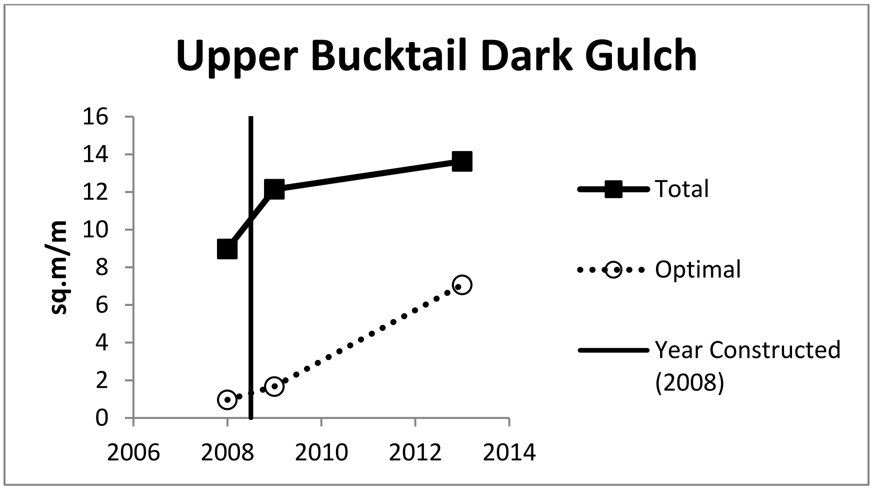


Figure A-1. Total and optimal habitat area per river meter (sq.m /m).





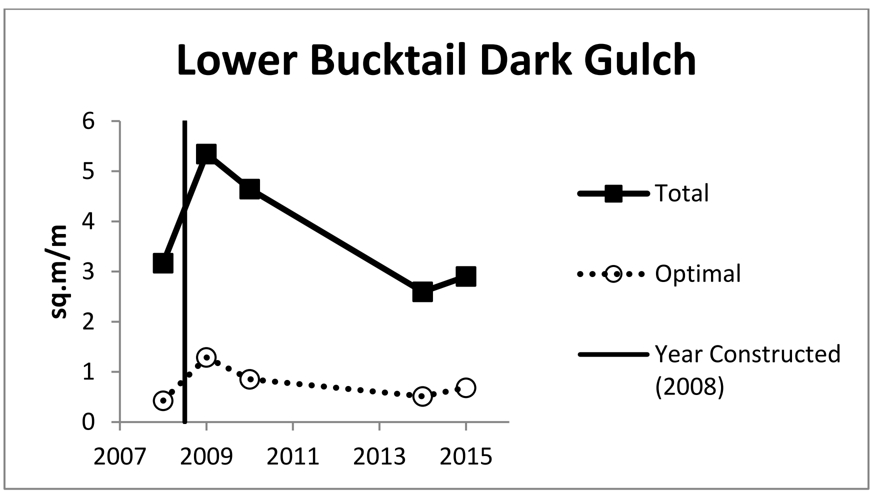


Figure A-2. Total and optimal habitat area per river meter (sq.m /m).

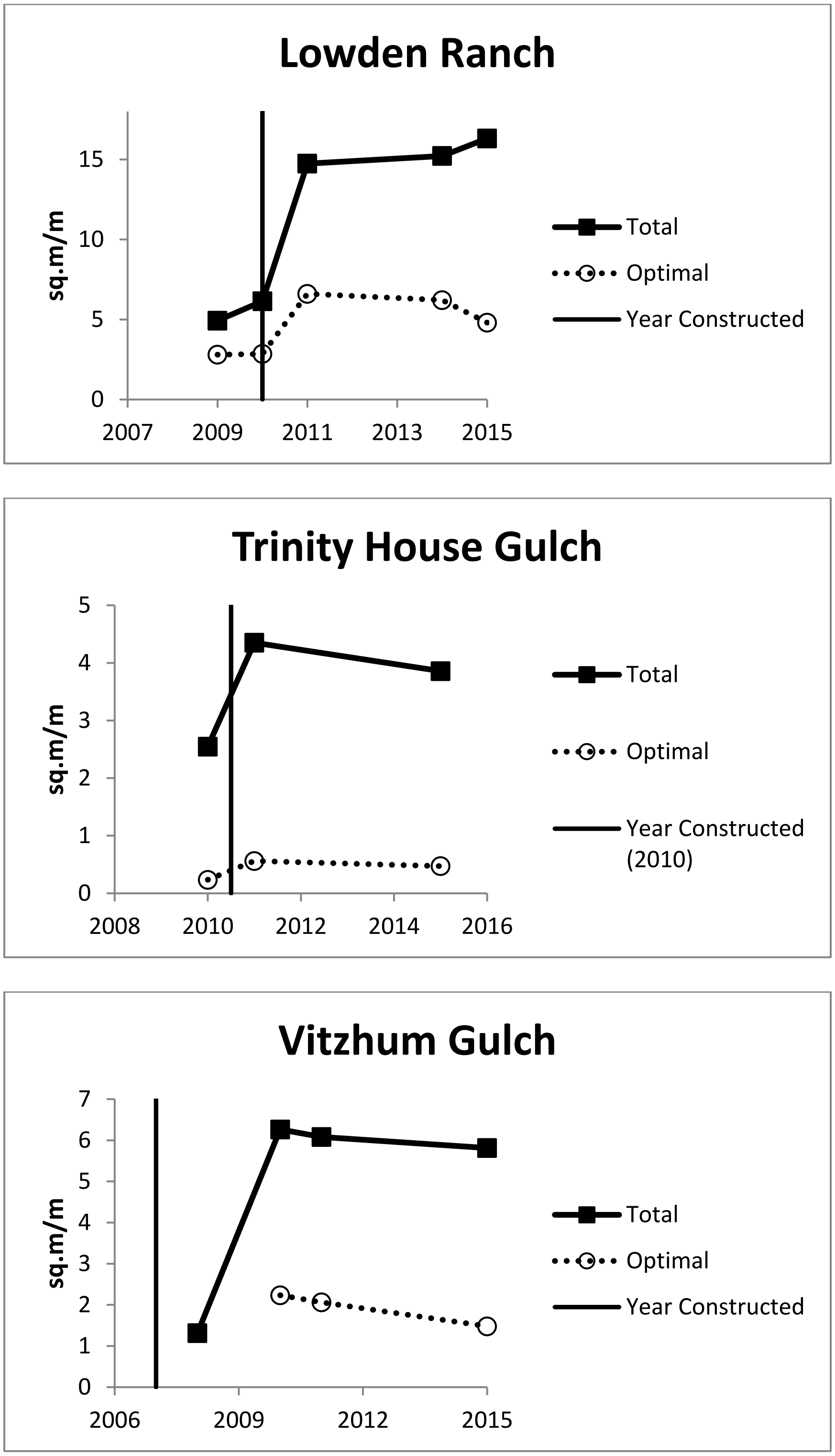
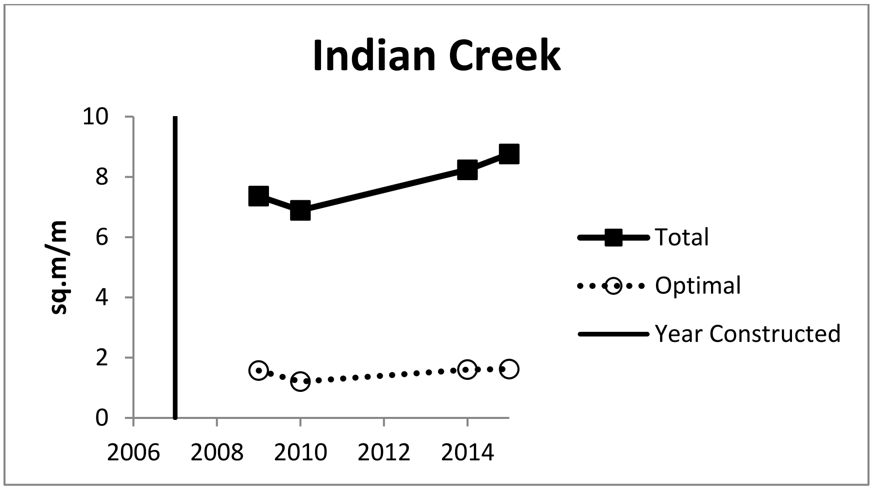
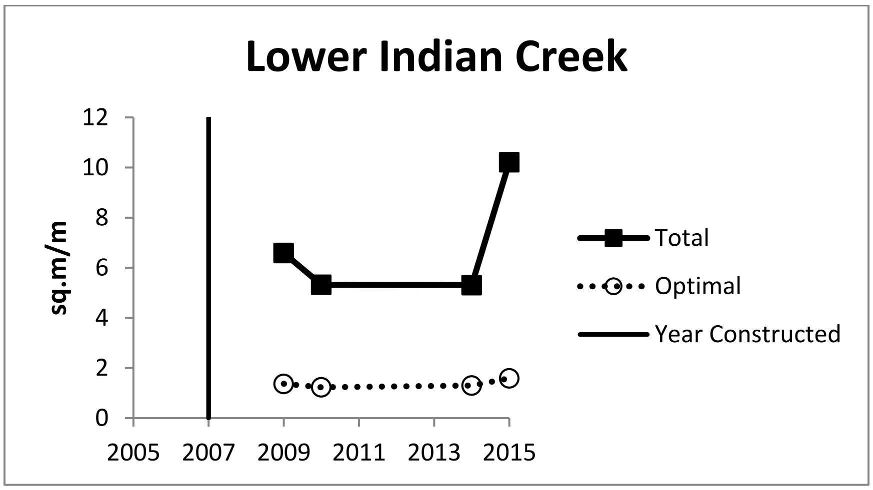


Figure A-3. Total and optimal habitat area per river meter (sq.m /m). Lowden Ranch graph includes data from a survey conducted during construction in 2010.





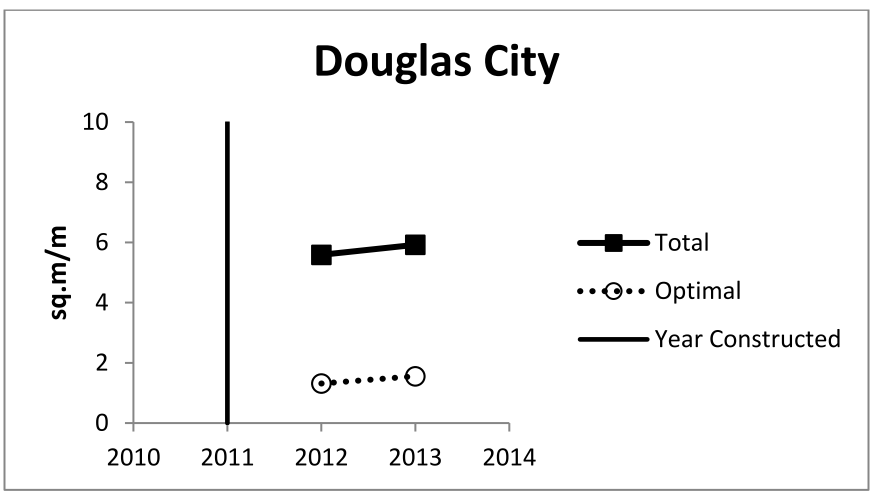
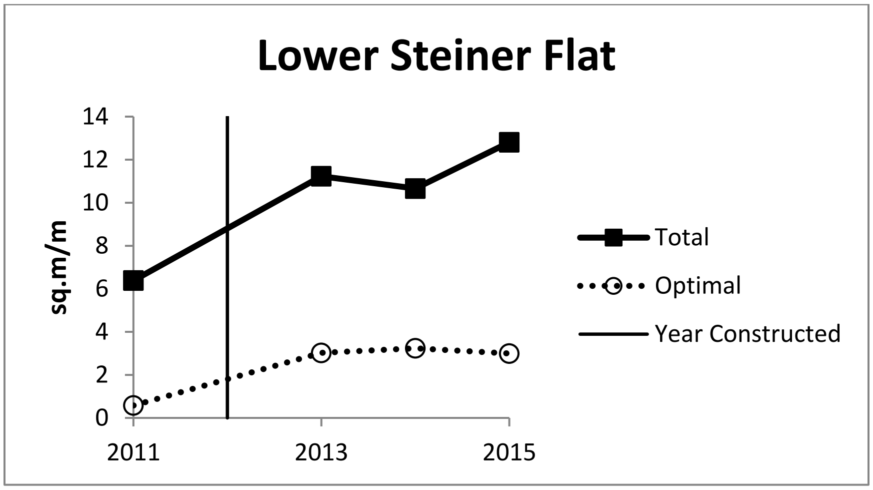
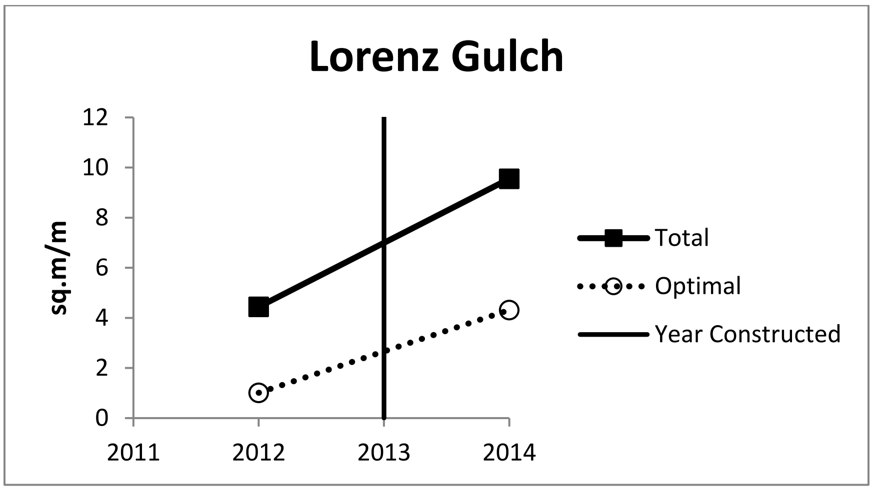


Figure A-4. Total and optimal habitat area per river meter (sq.m /m).





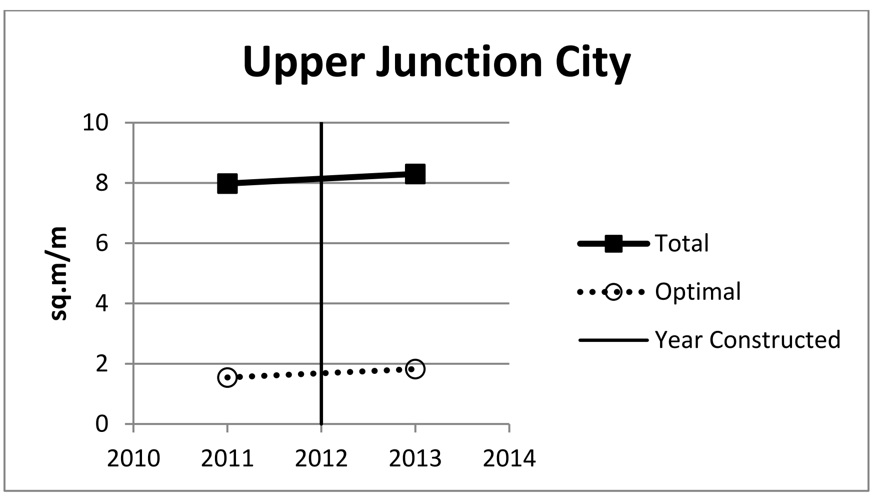


Figure A-5. Total and optimal habitat area per river meter (sq.m /m). The pre-construction survey at Lorenz Gulch was conducted in 2013, however, identical data from a 2012 GRTS survey is depicted to aid visualization.

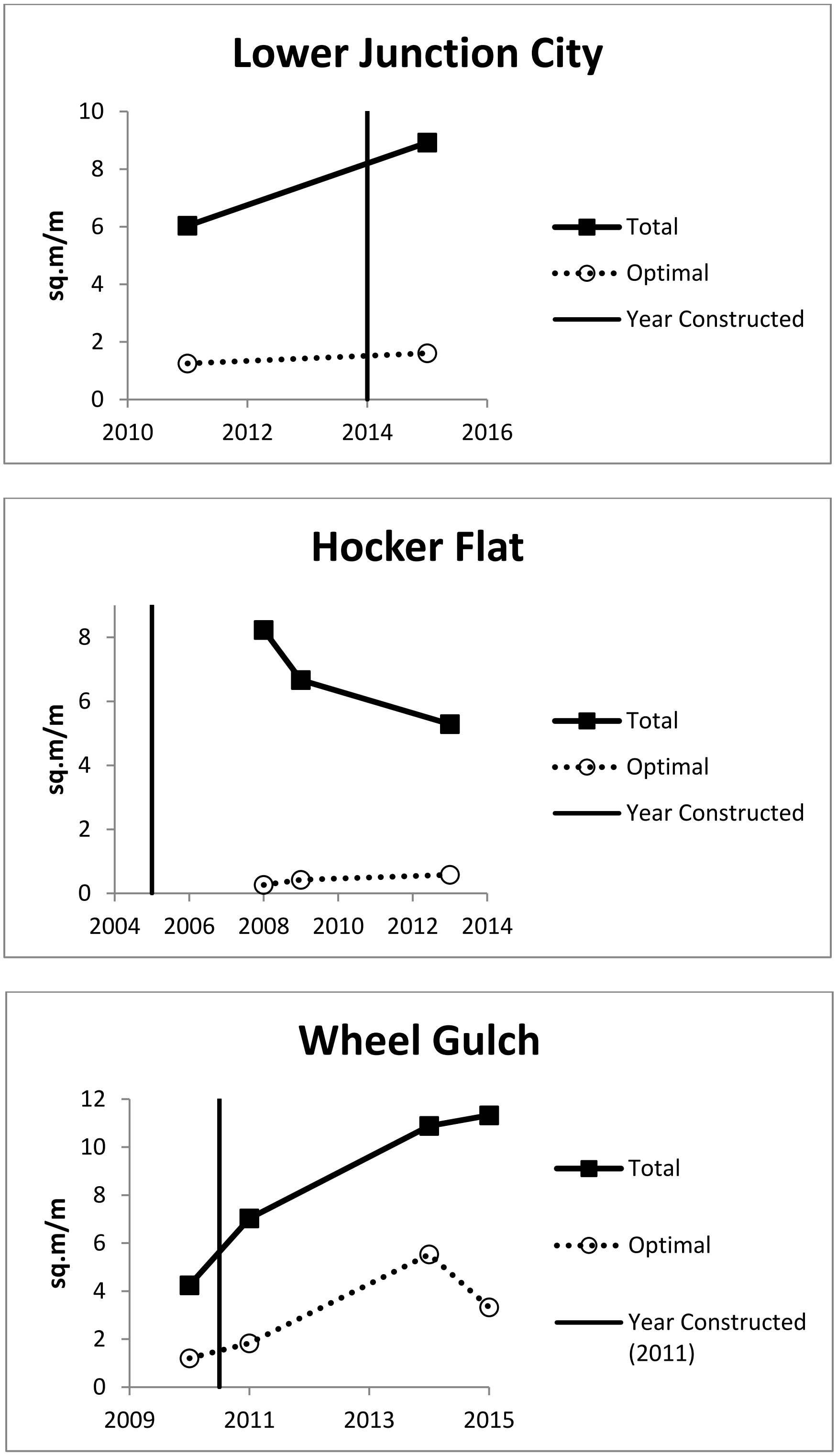


Figure A-6. Total and optimal habitat area per river meter (sq.m /m).

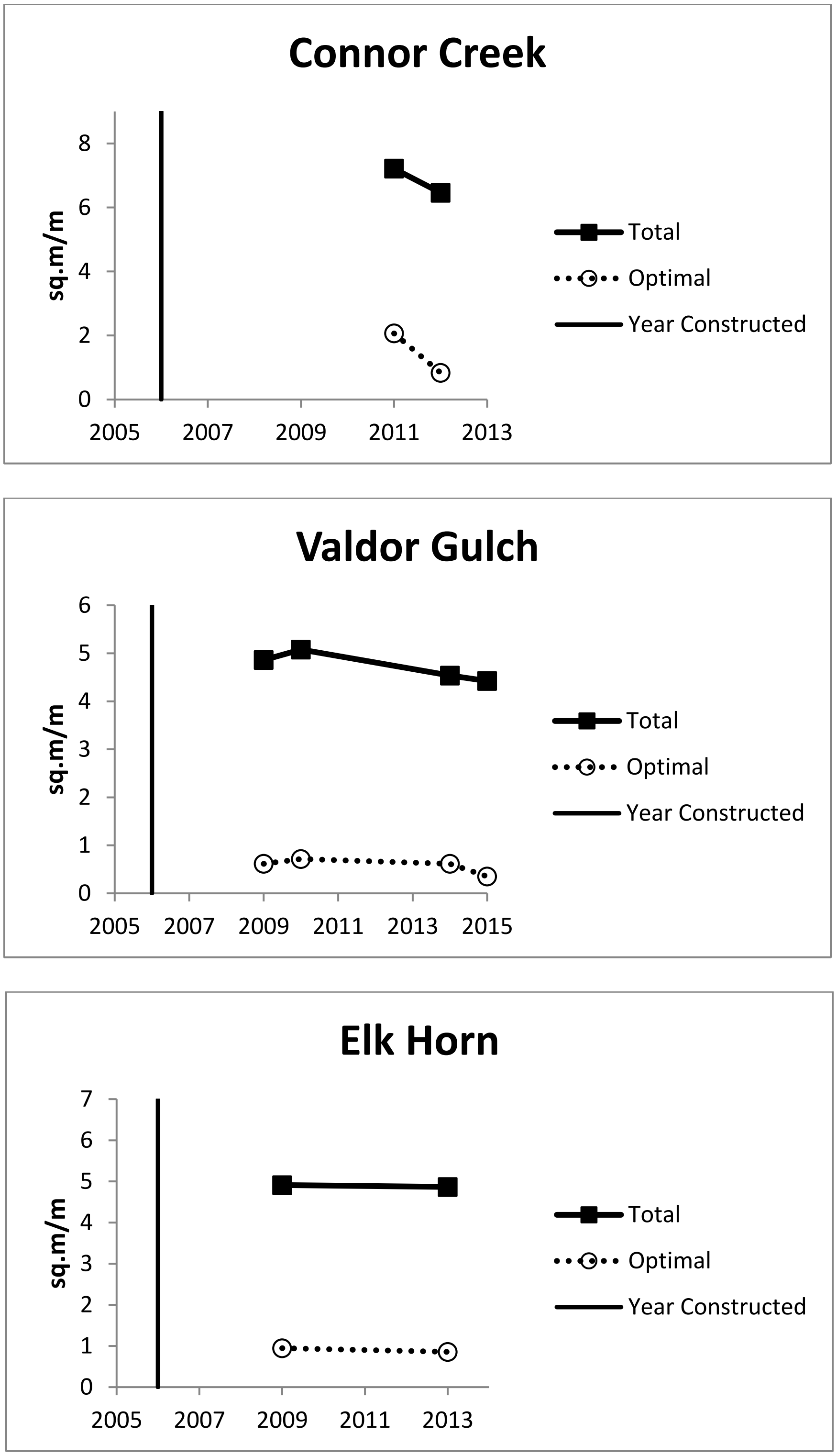


Figure A-7. Total and optimal habitat area per river meter (sq.m /m).

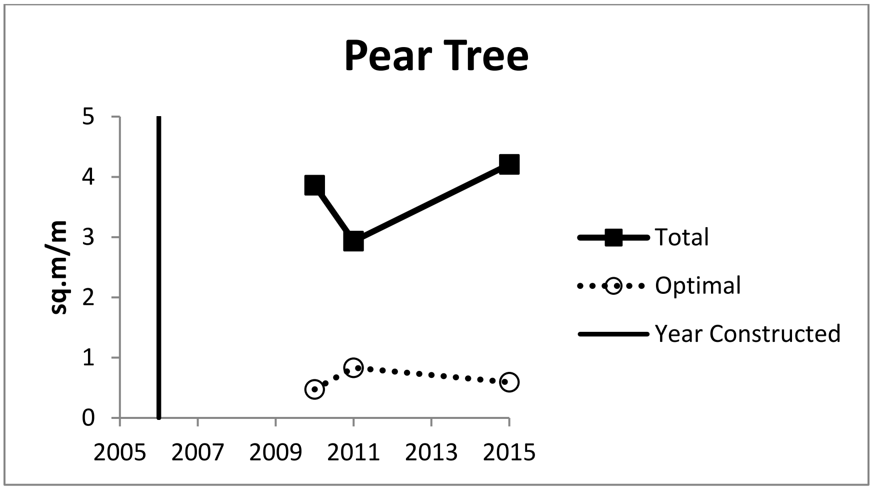


Figure A-8. Total and optimal habitat area per river meter (sq.m /m).

Appendix B. Rehabilitation sites, sample sizes and habitat values for objectives 1-4, and for objective 5, changes to length and surface area of natural and constructed side channels and alcoves, respectively.

Table B-1. Sites (n=7) visualized in Figure 3 to establish the relationship between time since construction and the difference in the amount of normalized (sq.m/m) Total and optimal habitat area between the pre-construction survey and the most recent survey.

Site	Years Since Construction	Difference Total	Difference Optimal
Lewiston Cableway	7	6.182	1.942
Upper Bucktail Dark Gulch	5	4.652	6.111
Lower Bucktail Dark Gulch	7	-0.266	0.258
Lowden Ranch	5	10.177	1.955
Trinity House Gulch	5	1.310	0.237
Lower Steiner Flat	3	6.422	2.418
Wheel Gulch	4	7.080	2.123

Table B-2. Sites (n=19) visualized in Figure 4 to establish the relationship between time since construction and the difference in the amount of normalized (sq.m/m) Total and optimal habitat area between the first survey after construction and the most recent survey.

Site	Years Since Construction	Difference Total	Difference Optimal
Sven Olbertson	4	-0.777	-1.812
Lewiston Cableway	7	-3.411	-3.484
Hoadley Gulch	7	0.790	1.131
Sawmill	3	-1.645	-0.362
Upper Bucktail Dark Gulch	5	1.485	5.404
Lower Bucktail Dark Gulch	7	-2.441	-0.604
Lowden Ranch	5	1.573	-1.802
Trinity House Gulch	5	-0.493	-0.090
Vitzhum Gulch	8	-0.452	-0.754
Indian Creek	8	1.399	0.049
Lower Indian Creek	8	3.626	0.219
Douglas City	2	0.333	0.242
Lower Steiner Flat	3	1.577	-0.028
Hocker Flat	8	-2.943	0.317
Connor Creek	6	-0.751	-1.231
Wheel Gulch	4	4.297	1.498
Valdor Gulch	9	-0.437	-0.264
Elk Horn	7	-0.045	-0.090
Pear Tree	9	0.345	0.119

Table B-3. Sites (n=11) visualized in Figure 5 to determine the effect of construction year on the amount of normalized (sq.m/m) Total and optimal habitat area at the first survey after construction. The systemic estimates of normalized Total (Median=5.66) and Optimal (Median=1.21) rearing habitat present in the non-rehabilitated portion of the restoration reach are provided for comparison.

Site	Year of Construction	Total	Optimal
Lewiston Cableway	2008	14.809	6.626
Upper Bucktail Dark Gulch	2008	12.144	1.669
Lower Bucktail Dark Gulch	2008	5.344	1.289
Lowden Ranch	2010	14.743	6.605
Trinity House Gulch	2010	4.351	0.562
Douglas City	2011	5.590	1.314
Lower Steiner Flat	2012	11.228	3.023
Lorenz Gulch	2013	9.550	4.314
Upper Junction City	2012	9.843	2.197
Lower Junction City	2014	8.919	1.606
Wheel Gulch	2011	7.031	1.830

Table B-4. Sites (n=19) visualized in Figure 6 to determine the effect of construction year on the amount of normalized (sq.m/m) Total and optimal habitat area at the most recent survey. The systemic estimates of normalized Total (Median=5.66) and Optimal (Median=1.21) rearing habitat present in the non-rehabilitated portion of the restoration reach are provided for comparison.

Site	Year of Construction	Total	Optimal
Sven Olbertson	2008	18.530	2.376
Lewiston Cableway	2008	11.398	3.141
Hoadley Gulch	2008	9.708	2.363
Sawmill	2009	5.609	0.612
Upper Bucktail Dark Gulch	2008	13.629	7.073
Lower Bucktail Dark Gulch	2008	2.903	0.685
Lowden Ranch	2010	16.316	4.804
Trinity House Gulch	2010	3.858	0.472
Vitzhum Gulch	2007	5.812	1.480
Indian Creek	2007	8.759	1.621
Lower Indian Creek	2007	10.215	1.587
Douglas City	2011	5.922	1.556
Lower Steiner Flat	2012	12.805	2.995
Hocker Flat	2005	5.287	0.579
Connor Creek	2006	6.461	0.834
Wheel Gulch	2011	11.327	3.328
Valdor Gulch	2006	4.423	0.353
Elk Horn	2006	4.867	0.858
Pear Tree	2006	4.206	0.592

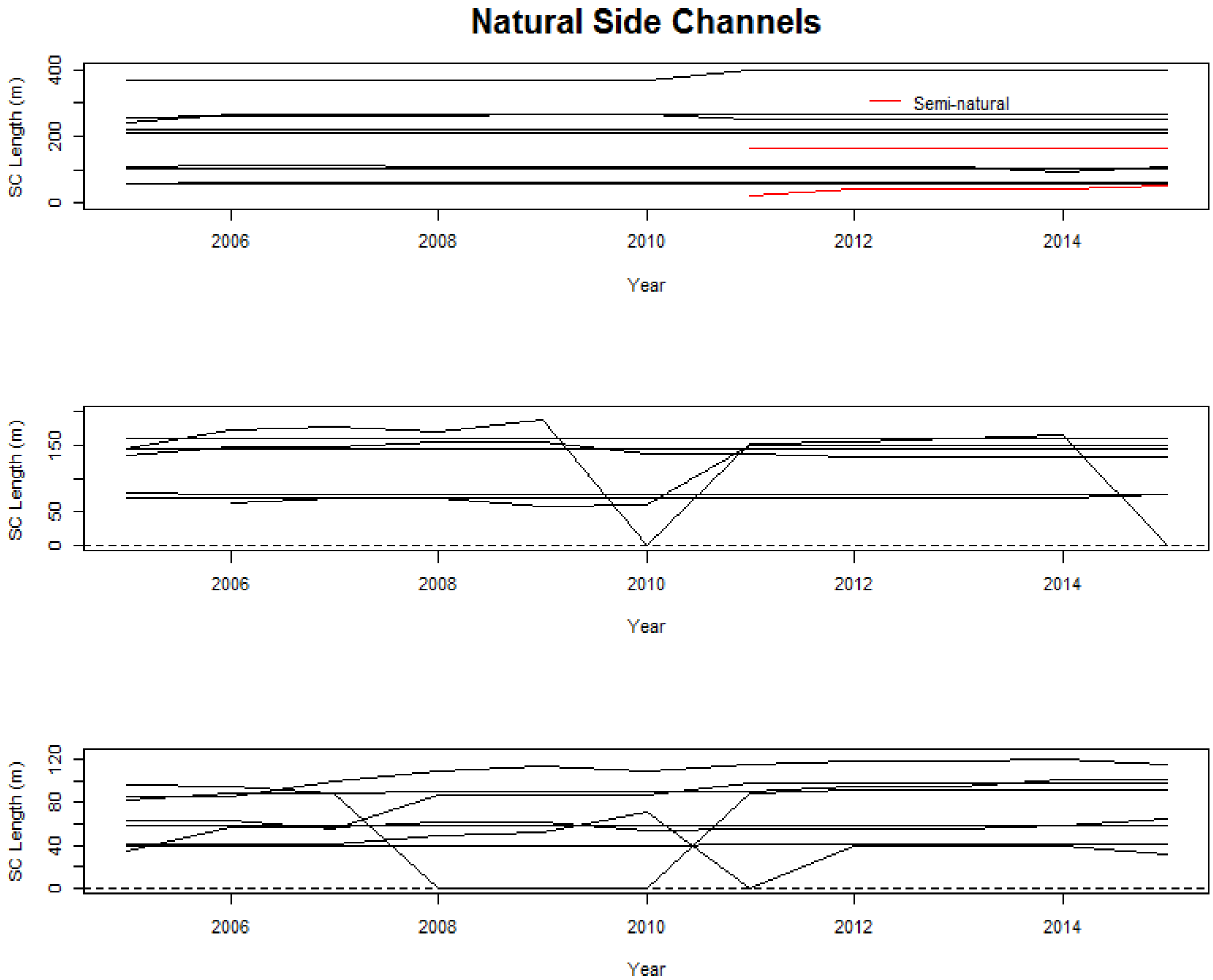


Figure B-1. Length of natural side channels over the study period, 2005-2015. Side channel length is depicted by a line for the years the side channel is either visibly connected (>0) to or temporarily disconnected (= 0) from the mainstem Trinity River over the study period as determined by visual inspection of aerial photographs. Semi-natural side channels created by river processes that were locally affected by construction activities (upper panel) are in red. Note, to aid visualization, natural side channels are displayed in three panels and the y-axes are not scaled the same.

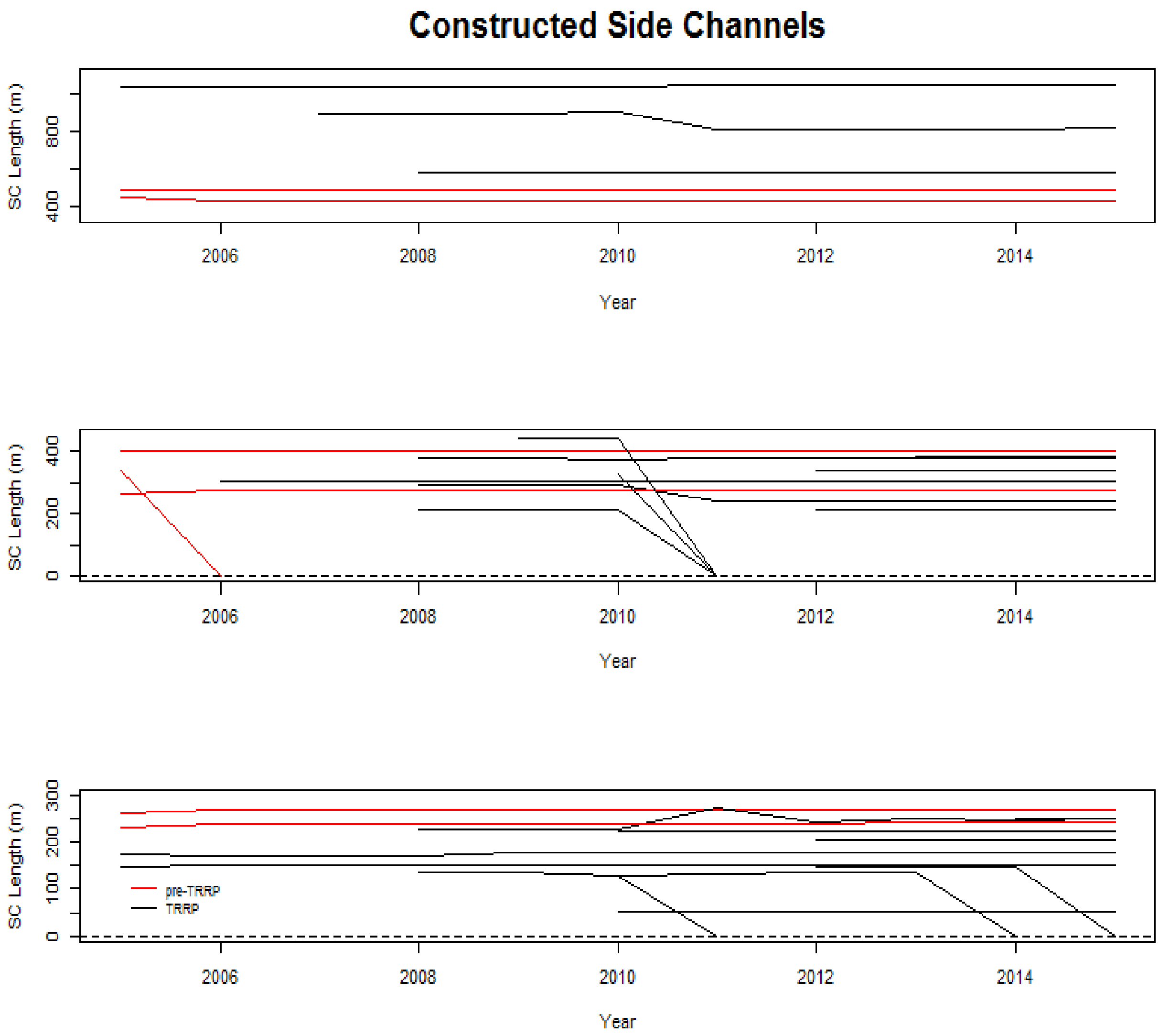


Figure B-2. Length of constructed side channels over the study period, 2005-2015. Side channel length is depicted by a line for the years the side channel is either visibly connected (>0) to or temporarily disconnected (= 0) from the mainstem Trinity River over the study period as determined by visual inspection of aerial photographs. Note, to aid visualization, constructed side channels are displayed in three panels and the y-axes are not scaled the same.

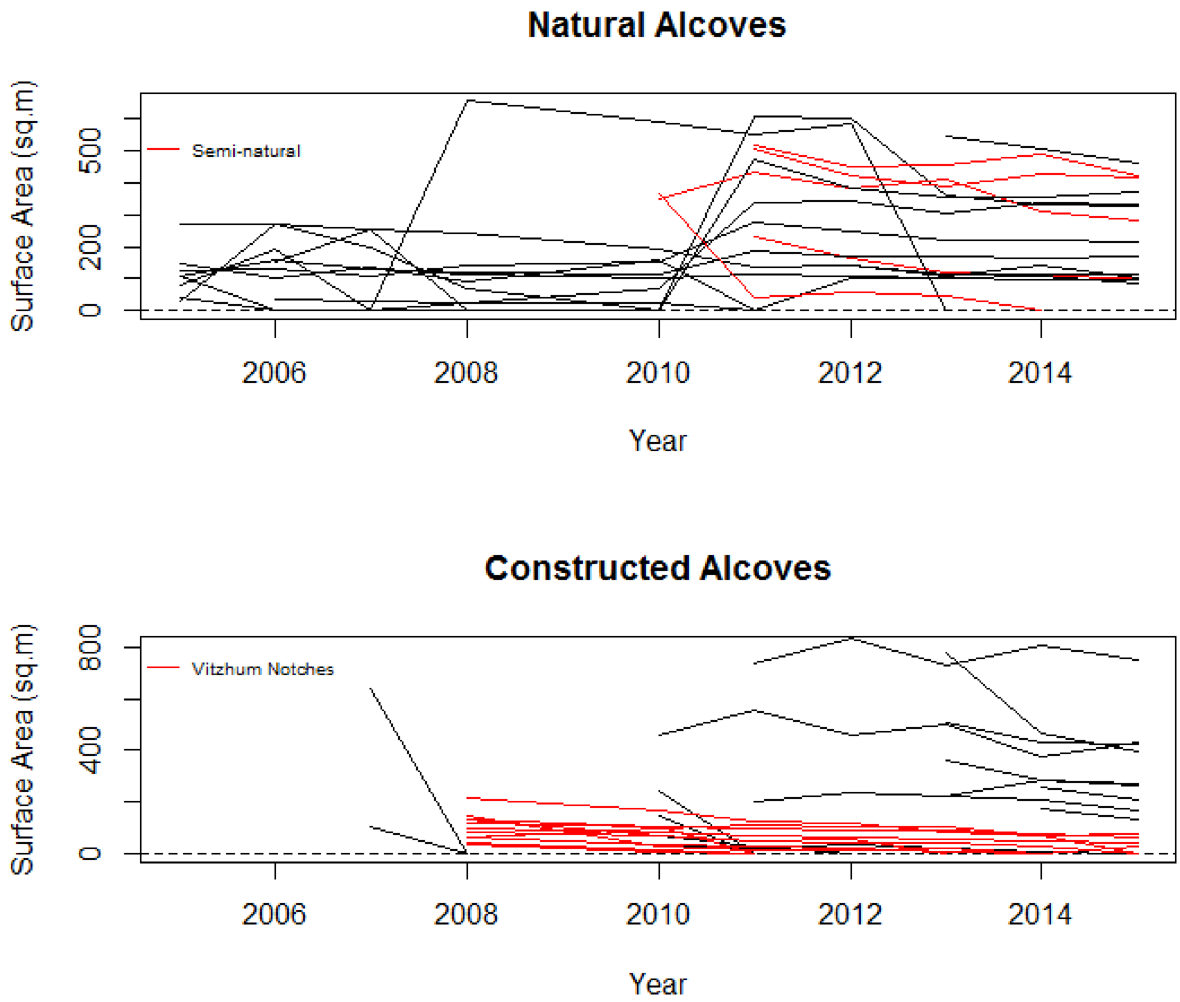


Figure B-3. Surface area of constructed and natural alcoves over the study period, 2005-2015. Alcove surface area is depicted by a line for the years the alcove is visibly connected to the mainstem Trinity River over the study period as determined from visual inspection of aerial photographs. Semi-natural alcoves that formed as a result of gravel augmentation activities (upper panel) and Vitzhum notches (lower panel) are in red. Note the y-axes are not scaled the same to aid visualization.

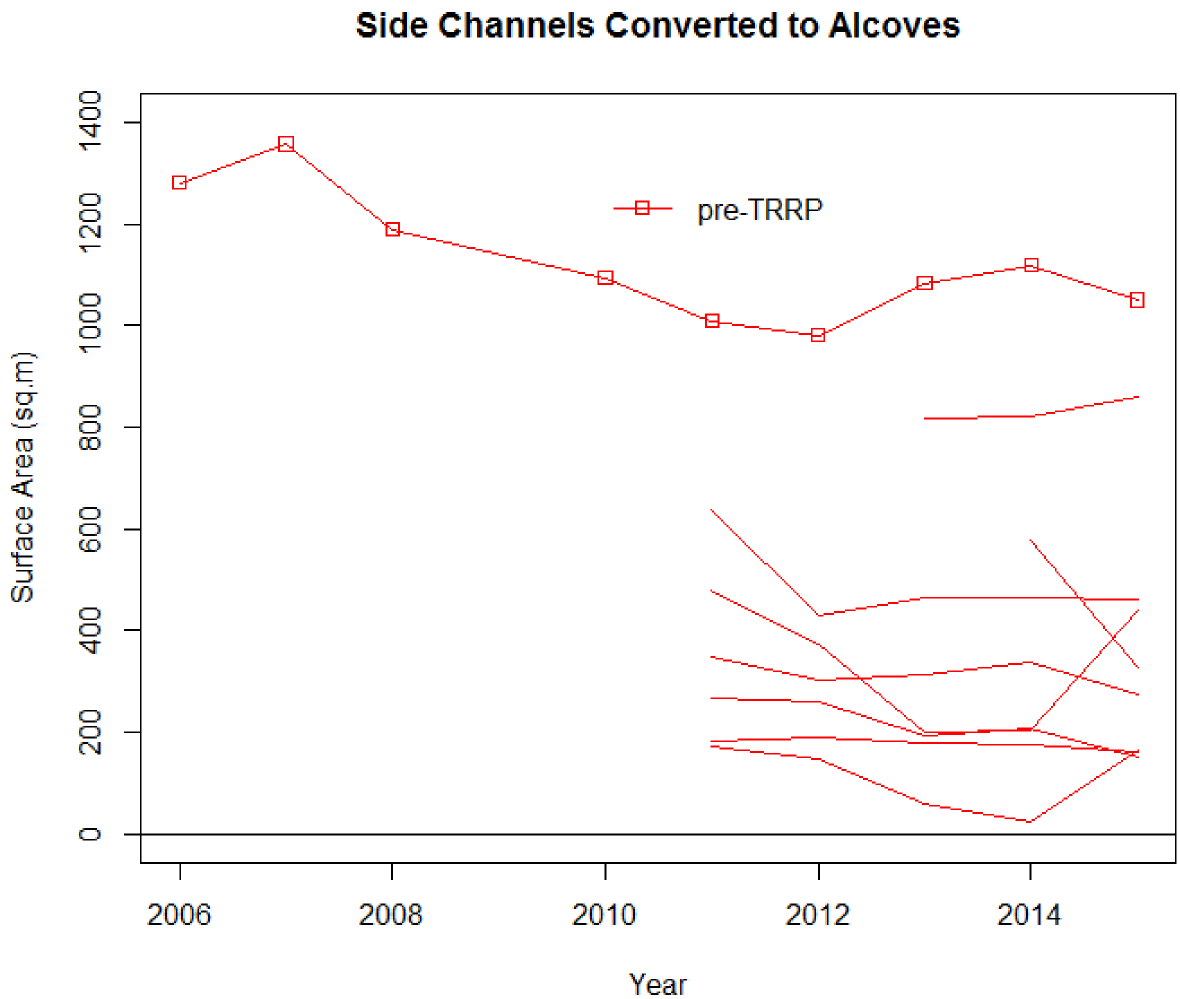


Figure B-4. Surface area of side channels that converted to alcoves over the study period, 2005-2015. Alcove surface area is depicted by a line for the years the alcove is visibly connected to the mainstem Trinity River over the study period as determined from visual inspection of aerial photographs. One converted side channel constructed prior to the TRRP (pre-TRRP) is at the top of the figure.