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Large Wood Placement At Channel Rehabilitation Sites By The Trinity River Restoration Program, 2005-2016

Josh Boyce and Damon H. Goodman

U.S. Fish and Wildlife Service
Arcata Fish and Wildlife Office
1655 Heindon Road
Arcata, CA 95521
(707) 822-7201

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Josh Boyce, Damon H. Goodman

U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office
1655 Heindon Road; Arcata, California

Abstract.— The Trinity River Restoration Program implements large wood augmentation as part of a broader restoration strategy to restore ecological processes and increase the production of naturally-spawned anadromous fishes. Restoration efforts are implemented under an adaptive management framework whereby monitoring data are used to test restoration hypotheses to help inform subsequent restoration implementation decisions. Here, we summarize large wood placement at 27 rehabilitation sites immediately after construction from 2005-2016 to assist with the development of a large wood management strategy for the program and provide feedback for the adaptive management process. A total of 7,591 large wood pieces and 1,919 large wood structures have been placed in the restoration reach since 2006. Fifty-nine percent of those LW pieces were incorporated into weirs, deflectors and constructed wood jams. We found that the number of large wood pieces and the number of constructed wood jams per river kilometer placed during construction of rehabilitation sites have increased over our monitoring period. However, the level of complexity of constructed wood jams, as estimated by the number of LW pieces per structure, was variable. We also found that over 80% of the large wood pieces and structures are placed in off-channel areas such as high and low flow side channels and 60% are located within the bankfull channel and are inundated at streamflows at or below 14.2 cms (500 cfs). At eight of 27 sites, rehabilitation site design reports include specific LW placement objectives that were met over 75% of the time during construction. However, we could not identify specific LW design objectives for the other 19 sites. The increased use of large wood in channel rehabilitation likely reflects the growing awareness and demonstrated utility of large wood augmentation and off-channel habitat creation as means to improve restoration of riverine ecosystems and fish production immediately after construction. The database we accessed to summarize large wood placement at rehabilitation sites contains data from multiple re-visit surveys, which will be leveraged in future efforts to assess inter-annual large wood dynamics, longevity of wood installations and provide additional information to facilitate improvements in future restoration efforts.

Introduction

The Trinity River valley has been severely altered by anthropogenic activities, which started in the early- to mid-19th century with beaver extirpation by the Hudson Bay Company of Canada (Litton, 2003) as well as upland and riparian timber harvest and hydraulic and placer mining (Bailey 2008, AECOM 2013). Trapping of beaver drastically changed the hydrology of the mainstem Trinity and its tributaries by eliminating the benefits associated with beaver dam construction such as slowing water and sediment transport, floodplain expansion and enhancement of the diversity of plant communities in the riparian zone. Mining activities resulted in the removal of forest canopy on the hillsides and floodplains but also led to direct removal of live and dead trees (large wood or LW) from the active river channel. Mining also introduced large amounts of sediment both in the riparian zone and directly into the river channel (Krause 2010). The resultant dredge piles of gravel-boulder in the riparian zone have restricted production of many tree species that are critical to maintaining equilibrium between recruitment and depletion of LW. By the middle of the 20th century construction of the Trinity River Division (TRD) of the Central Valley Project (CVP) not only blocked access by anadromous salmonids to 177 km of upstream habitats (Moffett and Smith 1950; Locke et al. 2008) but also completely interrupted sediment and LW contributions from upstream. Additionally, the dams eliminated peak geomorphic flows and reduced flow variability which drastically altered the morphology of the river channel (Evans 1979; Frederiksen and Kamine 1980) and reduced hydraulic recruitment of LW. More recently timber extraction, floodplain development and riparian firewood collection have contributed to the lack of natural LW inputs along the Trinity River corridor (Cardno Entrix and CH2MHill 2011).

The Record of Decision (ROD) (USDOI 2000) outlined a formal plan for restoring the Trinity River which led to the creation of the Trinity River Restoration Program (TRRP). The TRRP incorporated many of the recommendations of the Trinity River Flow Evaluation Final Report (TRFEFR), which identified the necessary restoration actions to re-initiate riverine processes, improve aquatic and riparian habitats and restore anadromous fish populations (USFWS and Hoopa Valley Tribe 1999; USDOI 2000). Restoration efforts are focused in a 64 km reach (hereafter referred to as the “restoration reach”) downstream of the lowest dam (Lewiston Dam) where habitat degradation is most pronounced. Restoration work undertaken by the TRRP includes coarse sediment augmentation, water year (WY) specific streamflow management and mechanical channel rehabilitation including riparian planting. Coarse sediment is added annually to reverse the spawning gravel deficit created by dam construction and to facilitate fluvial processes. Water year-specific streamflow management, in which Lewiston Dam discharges are scaled to the amount of precipitation expected in the watershed, 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. Mechanical channel rehabilitation includes riparian berm removal, the construction of specific features such as point-bars, floodplains and off channel habitats and, increasingly, LW augmentation.

Large wood is an integral component of fluvial systems (Naiman et al. 2002; USBR and ERDC, 2016) providing ecological services including the retention of organic matter and enhancement of nutrient loading (Bilby 1981; Flores et al 2011) and providing areas that increase primary and secondary productivity (Benke et al 1985; Coe et al 2009; Lester et al

2009). LW also provides geomorphological services by creating alluvial reaches in channels that are predominantly bedrock (Montgomery et al 1996), affecting sediment storage (Bilby and Ward 1989) and pool formation (Abbe and Montgomery 1996; Beechie and Sibley 1997) that result in physical changes to aquatic and terrestrial habitats (Roni et al. 2015). Perhaps the most controversial aspect of the function of LW is the biological effectiveness of LW structures for directly increasing fish production (Roni et al 2015). These authors report that comprehensive reviews and meta-analyses (Thompson 2006; Stewart et al 2009) of published LW studies have produced varying conclusions for the direct effect of LW placement on fish biomass and abundance, with the most conclusive evidence cited for salmonids (Whiteway et al 2010). In the Trinity and Klamath rivers, juvenile salmonids prefer high quality habitat, which include areas with LW as escape cover (e.g. Goodman et al 2015). These preferences have been incorporated into physical habitat simulation models to refine instream flow assessments used in the management of river restoration programs (Hardy et al 2006). Although there are debates about specific aspects of the function of LW, the more general and beneficial influence of LW in river ecosystems has been documented. This is reflected by the increased implementation of LW augmentation practices in river restoration programs (Abbe et al 2003; USBR and ERDC 2016) including the TRRP.

The TRFEFR and ROD did not address the issue of LW augmentation and no specific recommendations were formulated as the TRRP was developed and initiated. It was not until 2011, approximately six years after the first rehabilitation sites were completed, that any formal Trinity River-specific LW recommendations were established. The TRRP requested a formal analysis of current and historic LW conditions in the Trinity River that was then used to make recommendations for the integration of LW placement into rehabilitation site designs and overall target levels for the restoration reach (Hoopa Valley Tribe et al 2011; Cardno Entrix and CH2MHill 2011). These recommendations and decisions made by rehabilitation site designers for the increased implementation of LW augmentation account for both impacts to infrastructure (USFWS et al 2000; USDOI 2000) as well as the understanding that the restoration program seeks to restore the Trinity River channel, floodplain and terraces at a reduced scale relative to pre-dam conditions. Despite these constraints, the TRRP has increased investment in LW augmentation over time.

In the absence of dam removal and restoration of the historic flow regime, the investment of resources into the placement and monitoring of LW by the TRRP is justified and as such, a long-term strategy for managing these efforts is warranted. This report informs the development of a formal LW management strategy for the TRRP and will be useful for the development of a LW budget for the restoration reach of the Trinity River. This baseline information will assist the TRRP in understanding the many processes that affect the quantity, longevity, recruitment, deposition and transport of LW within the restoration reach. Furthermore, these data will be used to estimate the short and long-term LW target levels for riparian vegetation and LW augmentation efforts of the TRRP.

The goal of this report is to summarize TRRP large wood augmentation efforts to date. More specifically, the objectives are to:

1) Summarize the number and size distribution of LW pieces and compare to LW recommendations developed for the TRRP.

2) Summarize the number and type of installed LW structures.

3) Summarize the location of LW pieces and constructed wood jams relative to channel location and streamflow inundation, and

4) Compare LW installation objectives described in rehabilitation site design reports to as-built conditions after construction.

Methods

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 Trinity River headwaters originate in the Trinity Mountains, the Yolla Bolly Mountains and the Trinity Alps from which 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 (1,860 km2) of which is upstream of Lewiston Dam (USFWS 1989; USBR 2009). We estimated a total

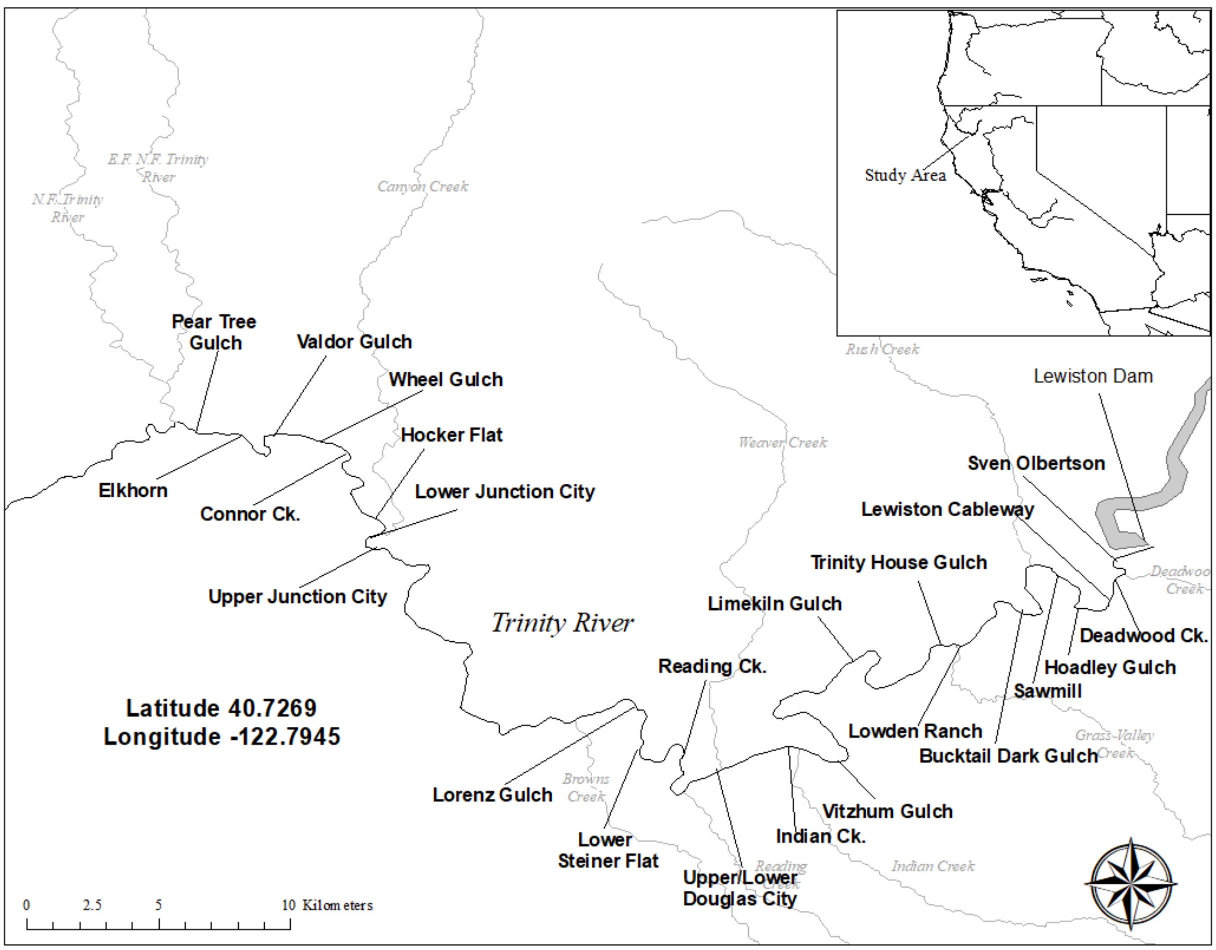

Figure 1. Map of rehabilitation sites on the Trinity River from Lewiston Dam to the confluence with the North Fork Trinity River. Streamflow is from right to left. Bold labels indicate channel rehabilitation site names.

of 1,300 km^2 of forested terrain above Lewiston Dam and approximately 46 km^2 of forested terrain within 100 m of streams 2nd order or greater in size (USGS 2011) providing additional evidence of dam related reduction in LW inputs to the restoration reach. Large wood from these areas that deposits in Trinity Reservoir either becomes submerged on the bottom, becomes stranded on the banks during reservoir draw down or is physically removed (P. Zedonis, USBR, personal communication, April, 2018.)

TRRP channel rehabilitation sites are located in the restoration reach of the Trinity River between Lewiston Dam and the confluence with the North Fork Trinity River. The channel rehabilitation plan is divided into two phases. Phase I, completed in 2010, included construction of 14 sites; Phase II is currently underway with nine sites completed to date. The summary presented here includes 27 sites (Table 1), which vary in length (median=0.7 km, range=0.1-2.5 km) and complexity with some only including lowered floodplains while others include main channel meanders, skeletal bars, mid-channel islands, side channels, alcoves and LW structures.

Large Wood Surveys

Large wood surveys were conducted within TRRP rehabilitation site boundaries from 2006-2016. The surveys were conducted at variable times throughout the year with most completed between January and March of the year following the completion of rehabilitation site construction. No LW was placed by the TRRP at Hocker Flat which was constructed in 2005. We have included Hocker Flat in several analyses to indicate the lack of LW placements, although no formal survey was conducted. All LW pieces and structures were georeferenced with mapping grade GPS, photographed and attributed with information about physical structure and location within the floodplain. For this analysis, we coded each wood structure into counts of wood by size, structure configuration or category, channel location and streamflow inundation threshold.

Individual LW pieces were categorized into three size classes (Keller and Swanson 1979) according to overall length and diameter at breast height (dbh), however, it should be noted that at some rehabilitation sites there was inherent error attempting to estimate the length and/or diameter of partially buried LW pieces after construction:

Class I: 20-30 cm dbh and 2-4 m length

Class II: 30-70 cm dbh or >20 cm dbh AND 4-10 m length

Class III: >70 cm dbh or >20 cm dbh and 10m length

Large wood structures were categorized as V weirs, log weirs, log deflectors, wildlife, “other” and constructed wood jams (CWJ). V weirs were defined as two logs in a V-formation, spanning the channel with no space at the vertex and oriented either upstream or downstream (Anderson et al 1984; House and Boehne 1985). Log weirs were defined as one or more anchored, embedded logs spanning the channel with negligible underflow and oriented perpendicular or diagonal to the direction of flow forming a sill dam (Crispin et al 1993). Log deflectors were defined as one or more logs anchored on the bank at a 45-135

Table 1. The channel rehabilitation sites surveyed for LW. Sites are ordered chronologically by year of construction and x indicates site and year of survey.

Site	Year of Construction	Survey Year											
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Hocker Flat	2005												
Connor Creek	2006	x	x	x		x		x			x	x	
Valdor Gulch	2006	x	x	x		x		x			x	x	
Elk Horn	2006	x	x	x		x		x			x	x	
Pear Tree Gulch	2006	x	x	x		x		x			x	x	
Vitzhum Gulch	2007		x	x		x	x	x					x
Indian Creek	2007		x	x		x		x					x
Indian Creek Side Channel	2007		x	x	x	x	x	x				x	x
Sven Olbertson	2008				x	x	x	x					
Deadwood Creek	2008				x	x	x	x					
Lewiston Cableway	2008				x	x	x	x					
Hoadley Gulch	2008				x	x	x	x					
Dark Gulch	2008				x	x	x	x					x
Bucktail Side Channel	2008				x	x	x	x					x
Sawmill	2009				x		x	x					
Lowden Ranch	2010						x	x					
Trinity House Gulch	2010						x	x					
Reading Creek	2010						x	x					
Wheel Gulch	2011							x			x		
Lower Steiner Flat	2012								x		x		
Upper Junction City	2012								x				
Lower Douglas City	2013									x	x		x
Lorenz Gulch	2013									x			
Lower Junction City	2014										x	x	
Limekiln Gulch	2015											x	x
Upper Douglas City	2015											x	x
Bucktail	2016												x

degree angle either singly or in pairs (Allan and Lowe 1997). The wildlife category includes any LW on a terrace near the peak flood zone. The "other" category was a catch-all for any placed LW that did not meet the criteria for any other category.

The classification of a constructed LW feature as a CWJ included the consideration of several sources of information including the number and size class category of the wood pieces in the feature. We used photographs taken in the field to visually estimate the apparent complexity of the arrangement of LW pieces in the CWJ and the degree to which they were anchored together or to the bank with gravel, boulders or live trees. We screened all CWJ's with less than six total LW pieces with this classification process, which resulted in the re-classification of structures erroneously designated as CWJ's. Also, we used the term CWJ to encompass LW features that have been referred to as engineered log jams, bar apex jams, meander jams, flow deflection jams and floodplain jams (HVTFD et al 2011), and wood habitat structures (Cardno Entrix and CH2MHill 2011). We also incorporated elements of term definitions including large organic debris, jam, and stabile debris found in Armantrout 1998.

There were four channel location categories for LW pieces and structures:

Mainstem: LW placed completely in mainstem, not physically contiguous with side channel

Side Channel: LW placed inside or within 15 meters of side channel entrance or exit

High Flow Channel: LW placed inside or within 15 meters of high flow channel entrance or exit

NA: LW located beyond floodplain, on terrace

Wood placements were categorized based on the streamflow required to inundate it:

B: "base flow", LW is wetted between 8.5-14.2 cms (300-500 cfs)

AB: "above base flow", any LW wetted above 14.2 cms (500 cfs)

Analysis

Data selected for this analysis were limited to those inside or within 10 m of constructed features depicted in the Design_2D shapefile found in the TRRP as-built geodatabase (TRRP unpublished data). In a few cases, LW placed by the TRRP fell outside of the 10 m buffer, these additional data points were included in the analyses. We assumed wood counted in the first survey after construction was a TRRP installation and any wood that was naturally recruited was negligible for the purpose of these analyses. The length of each rehabilitation site was obtained from either the TRRP website (www.trrp.net) or calculated from the 142 cms (5,015 cfs) river channel centerline estimated from hydrodynamic modeling in 2006 (DWR unpublished data). Site lengths were used to calculate the number of LW elements per river kilometer, a metric used to compare effort among rehabilitation sites and to the Trinity-specific LW loading recommendation (Cardno-Entrix and CHM2Hill 2011). All data analyses were conducted in R (R Development Core Team 2009).

We conducted a comprehensive review of rehabilitation site design reports to compare LW installation objectives to as-built conditions after construction. Final design reports were available for Bucktail (HVTFD et al 2015), Limekiln Gulch (USFWS et al 2014), Vitzhum Gulch (TRRP, 2008), Douglas City (HVTFD et al 2013), Lower Steiner Flat (CH2MHill 2011), Upper Junction City (Chamberlain et al 2012), Lower Junction City (USFWS et al 2014) and Wheel Gulch (DWR 2010). A 50% design report was available for Lorenz Gulch (Draft Technical Report-unpublished). Phase I Design Summary Fact Sheets (TRRP 2011), which briefly describe design objectives for sites without a formal design report, were available for Sven Olbertson, Lewiston Cableway, Deadwood Creek, Hoadley Gulch, Sawmill Gulch, Dark Gulch, Lowden Ranch, Indian Creek, Reading Creek, Trinity House Gulch, Hocker Flat, Connor Creek, Valdor Gulch, Elkhorn and Pear Tree Gulch.

The channel rehabilitation features adjacent to LW installations included the following: areas of clearing and grubbing, constructed floodplains designed to interact with a range of streamflows from 12.7 cms to 170 cms (450 to 6,004 cfs), feathered edges, gravel augmentation sites (bars and islands with wood placement), anastomosing channels, wetland enhancements, tributary enhancements, drainage improvement, channel expansions, main channel split flows, channel meander bends, re-contoured banks, berm removal, lowered banks, berm notches, low flow/high flow side channels and alcoves.

Results

Objective 1: Summarize the number and size distribution of LW pieces and compare to LW recommendations developed for the TRRP.

A LW inventory was created from 2005-2016 for each rehabilitation site constructed by the TRRP with the exception of Hocker Flat, which did not include LW installations (Table 1). The total number of LW pieces placed per river kilometer at each rehabilitation site is displayed in Figure 2A and indicates a general increasing trend from 2006 (median=39, range=16-72) to 2016 (n=522). The longitudinal distribution of these data within the restoration reach are displayed from upstream to downstream for comparison (Figure 2B). One site (Bucktail) met the range (500-600 pieces LW/rkm) of LW loading recommended for the Trinity River by Cardno-Entrix and CHM2Hill (2011) and 4 sites exceeded this range (Upper and Lower Junction City, Lorenz Gulch, and Upper Douglas City). A total of 7,591 LW pieces (class I: n=3,320; class II: n =3,702; class III: n=569) have been placed in the restoration reach since 2006 (Appendix A, Table A1). Figure 3 provides a comparative example of the increase in LW loading by the TRRP between 2006 and 2014.

Objective 2: Summarize the number and type of installed LW structures.

A total of 1,919 LW structures have been installed in the restoration reach since 2006 (Table 2). Forty-three percent (n=826) are structures placed in the “other” category. The morphology and degree of anchoring of structures in this category are highly variable (Figure 4). Forty-one percent (n=777) are log deflectors either placed singly or in small groups along one bank. Eight percent are in the Wildlife category (on terrace/near peak streamflow level) indicating negligible interaction with streamflow. Examples of these LW structure types can be seen in Figure 5. Six percent (n=115) are CWJ’s that increased in number per river kilometer over time (Figure 6). The number of LW pieces incorporated

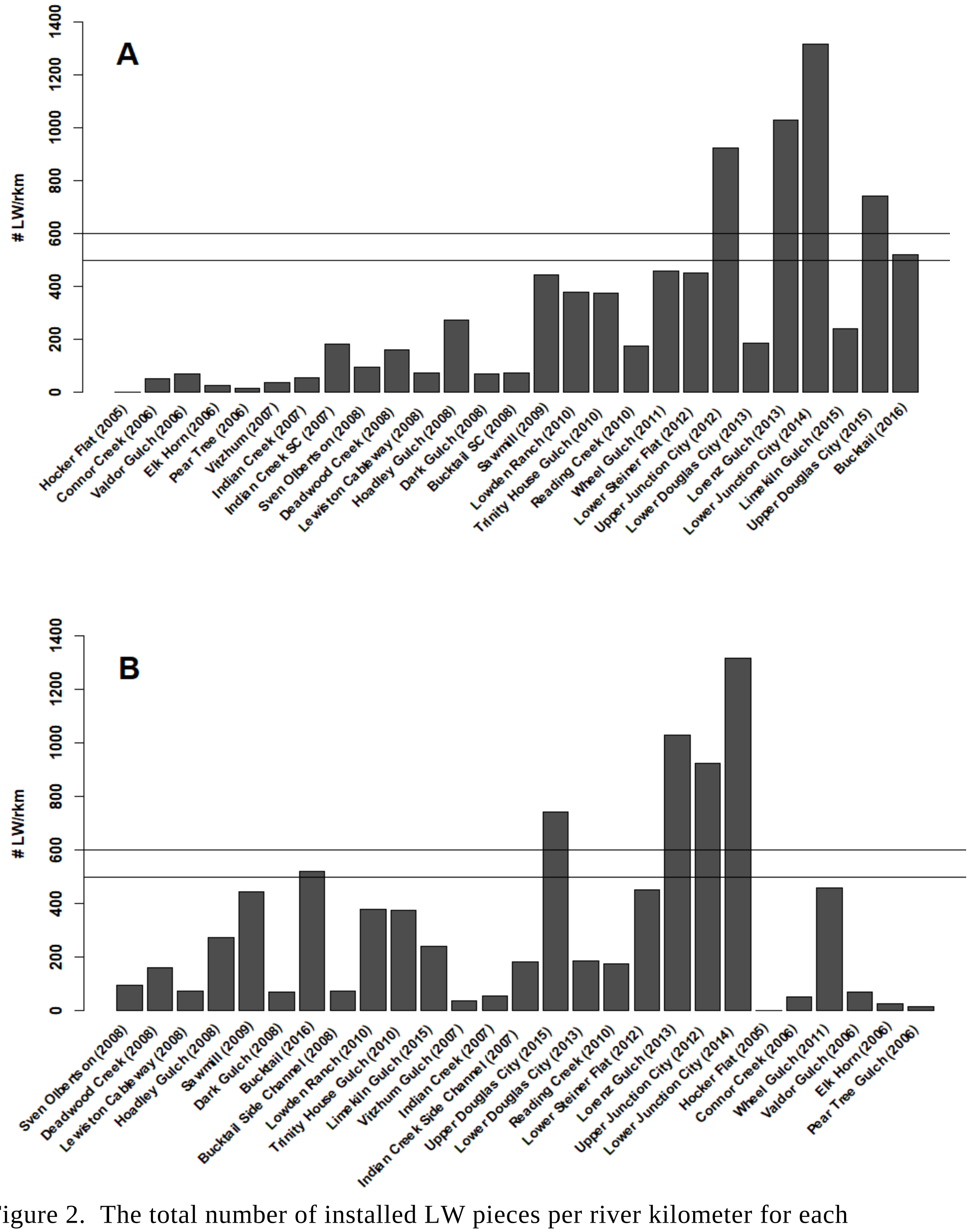

Figure 2. The total number of installed LW pieces per river kilometer for each rehabilitation site after construction. The lines indicate the range of Trinity River-specific recommendations for large wood loading (Cardno Entrix and CH2MHill, 2011). Sites are ordered chronologically (A) and longitudinally (B) from left to right with year of construction in parentheses.

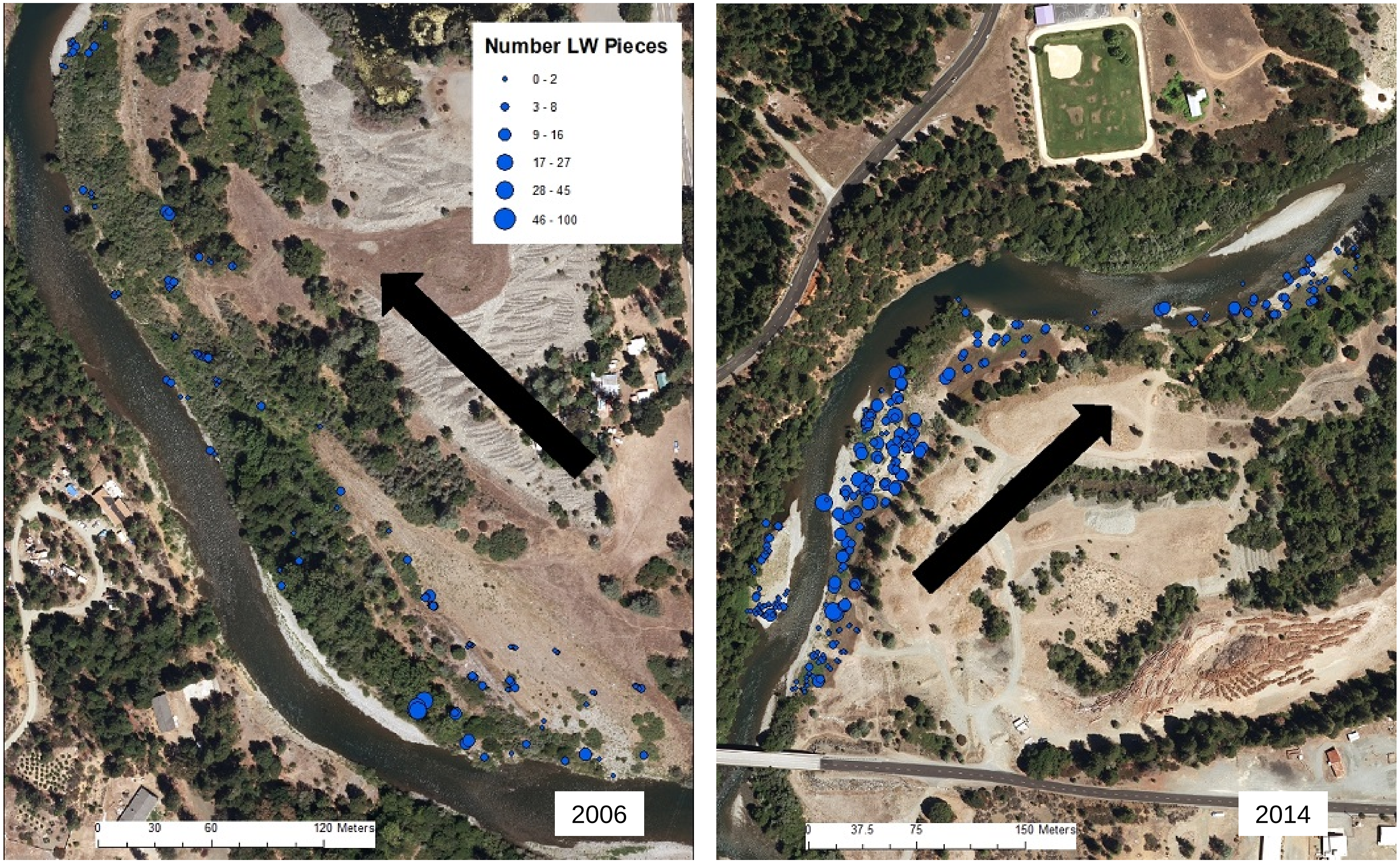

Figure 3. Aerial views of Connor Creek (left) and Lower Junction City (right) rehabilitation sites illustrating the increase in LW placement from 2006 to 2014. After construction, Connor Creek had 52 LW pieces per km while Lower Junction City had 1,315 LW pieces per km. Symbol size indicates the number of LW pieces and the arrow indicates direction of streamflow. Both sites are approximately 0.6 km in length.

Table 2. The number and type of LW features at TRRP rehabilitation sites. The orientation of V shaped weirs, log weirs and log deflectors are noted by US=upstream, DS=downstream, P=perpendicular to stream flow, D= diagonal to stream flow, S=single or multiple pieces on one bank, P= paired/wing on two banks. Constructed wood jams (CWJ) consist of numerous anchored LW. Wildlife indicates LW on terrace or near peak flood zone. Other indicates any LW not in previous categories. Sites are ordered chronologically by year of construction.

		V Weir		Log Weir		Log Deflector		CWJ	Wildlife	Other
Site	Year of Construction	US	DS	P	D	S	P			
Hocker Flat	2005									
Connor Creek	2006									13
Valdor Gulch	2006					21				26
Elk Horn	2006					5				4
Pear Tree Gulch	2006					2				1
Vitzhum Gulch	2007					10				10
Indian Creek	2007					4				6
Indian Creek Side Channel	2007					32			2	50
Sven Olbertson	2008	4			1	21				20
Deadwood Creek	2008	2				7				3
Lewiston Cableway	2008					7				13
Hoadley Gulch	2008	2				16				15
Dark Gulch	2008	3		1		58				39
Bucktail Side Channel	2008		1			8				1
Sawmill	2009	3	1	2		60		1		148
Lowden Ranch	2010					12		8	75	61
Trinity House Gulch	2010	3				22	1	1		24
Reading Creek	2010	1				26				35
Wheel Gulch	2011	3				13		2		15
Lower Steiner Flat	2012					21		2		8
Upper Junction City	2012				1	53		18		24
Lower Douglas City	2013					3		3		2
Lorenz Gulch	2013				1	59		4	11	99
Lower Junction City	2014					53	5	47		43
Limekiln Gulch	2015	1	1	2	1	62	5	7		35
Upper Douglas City	2015					74		7	1	40
Bucktail	2016	1	3	5	1	115	2	15	68	91

Figure 4. Examples of variation in LW placed in the "other" category (i.e. not constructed as a weir, deflector or CWJ). A). Connor Creek (2006), B). Lewiston Cableway (2009), C). Limekiln Gulch (2016), D). Bucktail (2017).

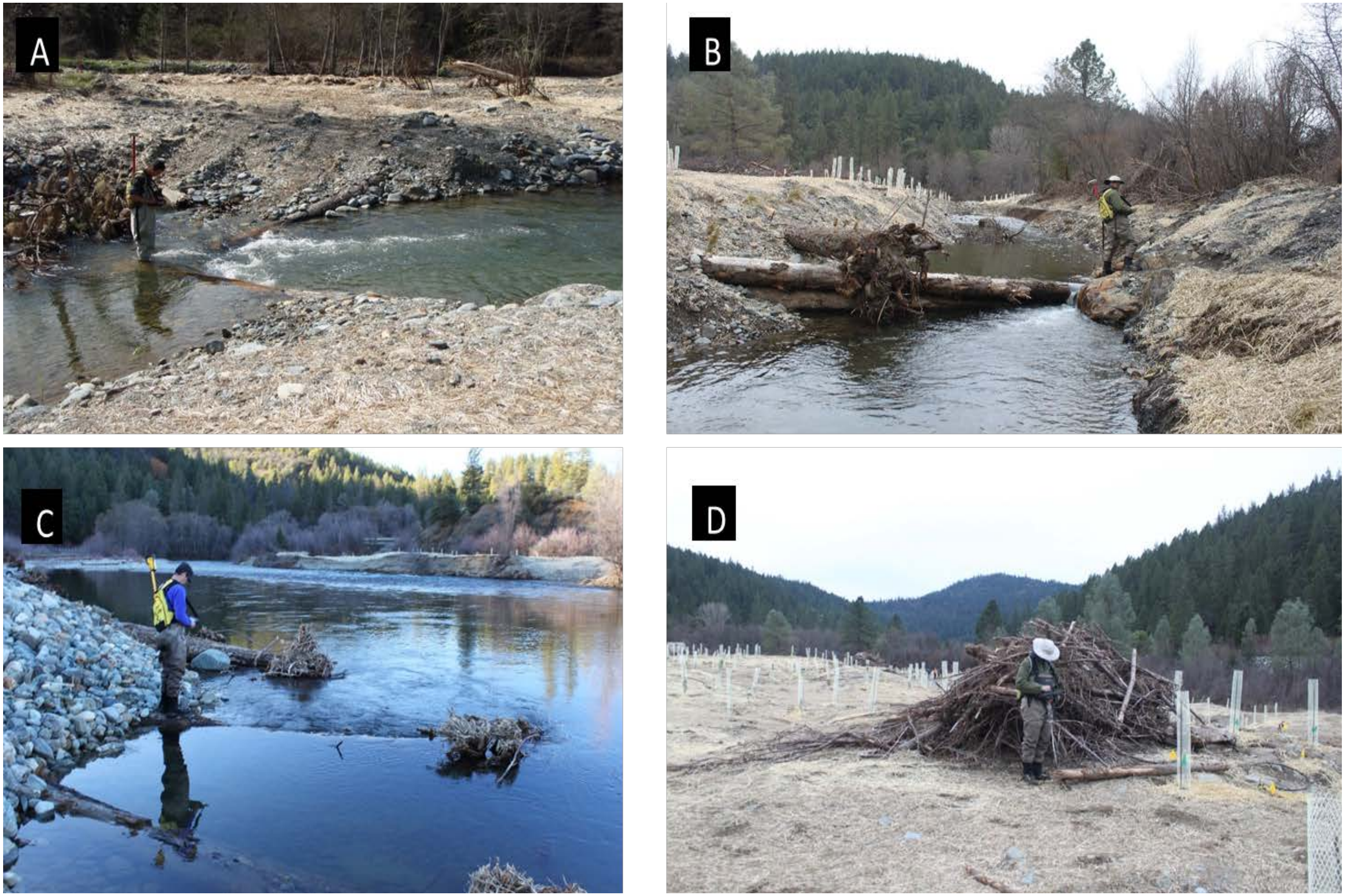

Figure 5. Examples of LW structures. A). V Weir, B). Log Weir, C). Log Deflector, D). Wildlife.

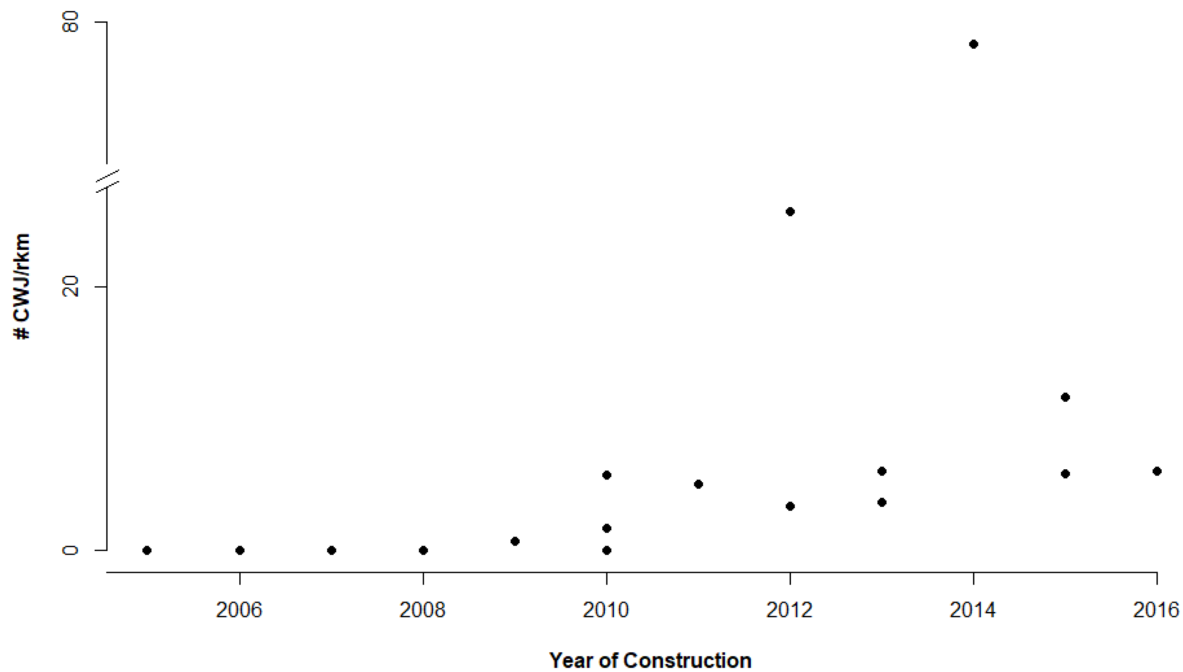

Figure 6. The number of constructed wood jams per river kilometer over the study period. The y-axis contains a break to highlight the increasing trend in wood jam density over time and the relatively high number of wood jams placed at Upper (n=26) and Lower (n=78) Junction City in 2012 and 2014, respectively.

into CWJ's was variable (median=13, range=3-70) as was the size and level of complexity of these structures (Figures 6 and 7, Appendix A, Table A2). The CWJ with 70 LW pieces was installed at Lorenz Gulch (Figure 8). V weirs (n=29) and log weirs (n=15) constitute approximately 2% of LW structures (Figure 5).

Objective 3: Summarize the location of LW pieces and constructed wood jams relative to channel location and streamflow inundation.

The placement of a majority of LW pieces began to transition from the main channel to off-channel features in 2008 (Figure 9). Eighty-two percent (class I: n=2,895; class II: n=3,006; class III: n=392) of LW pieces were placed in off-channel features (Figure 9; Appendix A, Table A3) and 61% (class I: n=1,887; class II: n=2,308; class III: n=437) were installed within the bankfull channel and are inundated at streamflows at or below14.2 cms. Figure 10 provides an example of LW placement relative to streamflow inundation.

Similarly,86% (n=99/115) of CWJ's were placed in off-channel features; Lower Junction City is an outlier with 44 of 47 CWJ's placed in off channel features. Sixty three percent (n=72/115) of CWJ's were installed within the bankfull channel inundated at streamflows at or below 14.2 cms.

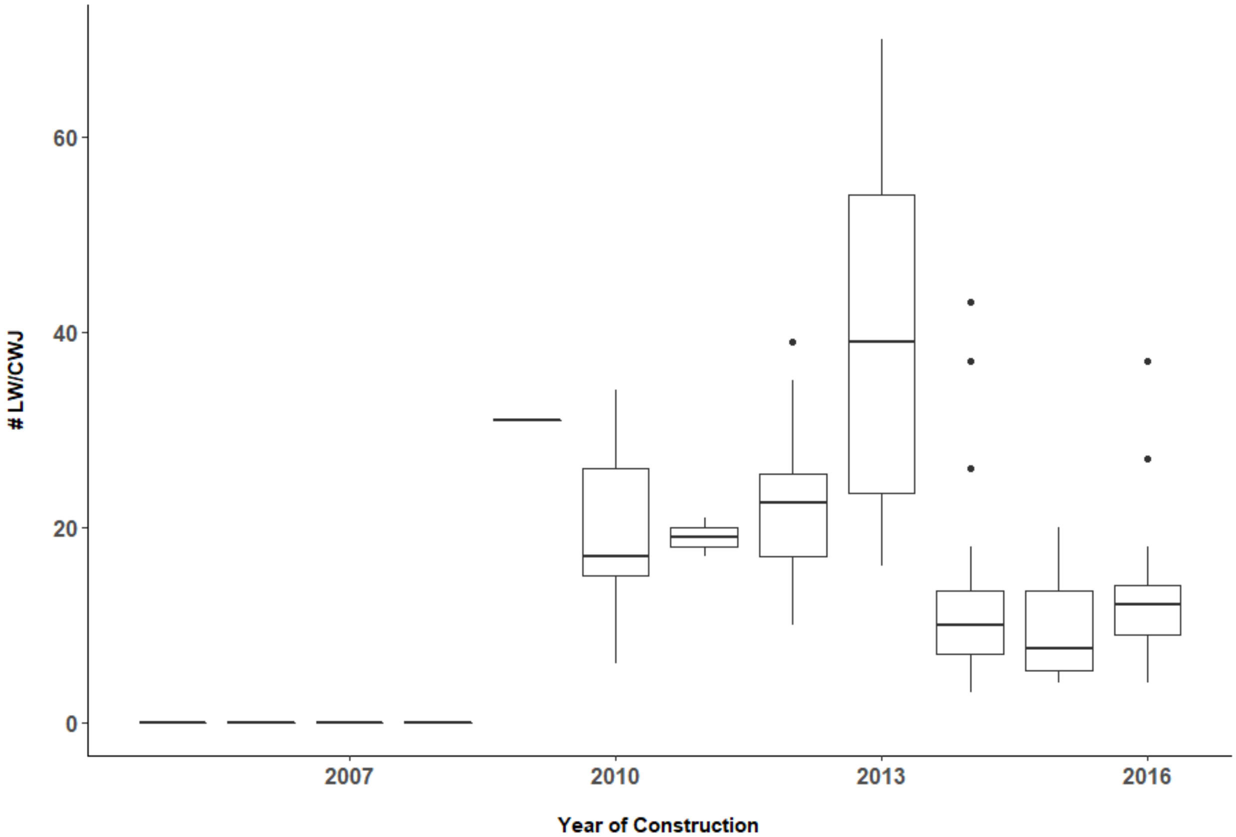

Figure 7. Variation in the number of LW pieces per CWJ over the study period. Horizontal lines indicate the median, boxes around the median indicate the interquartile range, thin vertical lines equal 1.5* the interquartile range and black circles indicate outliers. There were no CWJ's installed between 2005 and 2008 and only one was installed in 2009.

Objective 4: Compare LW installation objectives described in rehabilitation site design reports to as-built conditions after construction.

The inclusion of specific objectives for numbers of LW pieces per structure, per size class or per river kilometer in design reports has become more common in recent years. Eight rehabilitation sites (Valdor Gulch, Wheel Gulch, Lower Douglas City, Lorenz Gulch, Lower Junction City, Limekiln Gulch, Upper Douglas City and Bucktail) include specific LW augmentation objectives and only two (Valdor Gulch and Wheel Gulch) were constructed prior to 2013 (Appendix B1). With the exception of a few minor deviations, these objectives (28/37) were met or exceeded. For example, objectives for Lorenz Gulch included 708 individual LW elements and approximately 6 LW structures. Our survey of this site documented 1,133 LW pieces (Appendix A, Table A1), one Log Weir, 59 Log Deflectors and four CWJ's (Table 2).

More general objectives that outlined where LW should be placed within a site or within a particular channel rehabilitation feature were found in design reports for 10 sites (Sven Olbertson, Deadwood Creek, Hoadley Gulch, Sawmill Gulch, Dark Gulch, Lowden Ranch, Indian Creek, Reading Creek, Trinity House Gulch and Elkhorn). Overall, these objectives (16/16) were met or exceeded (Appendix B2). For example, in 2006 and 2010, LW was

Figure 8. Examples of variation in CWJ size and complexity. A). Limekiln (2015), B). Lower Douglas City (2013), C). Wheel Gulch (2011), D). Lorenz Gulch (2013).

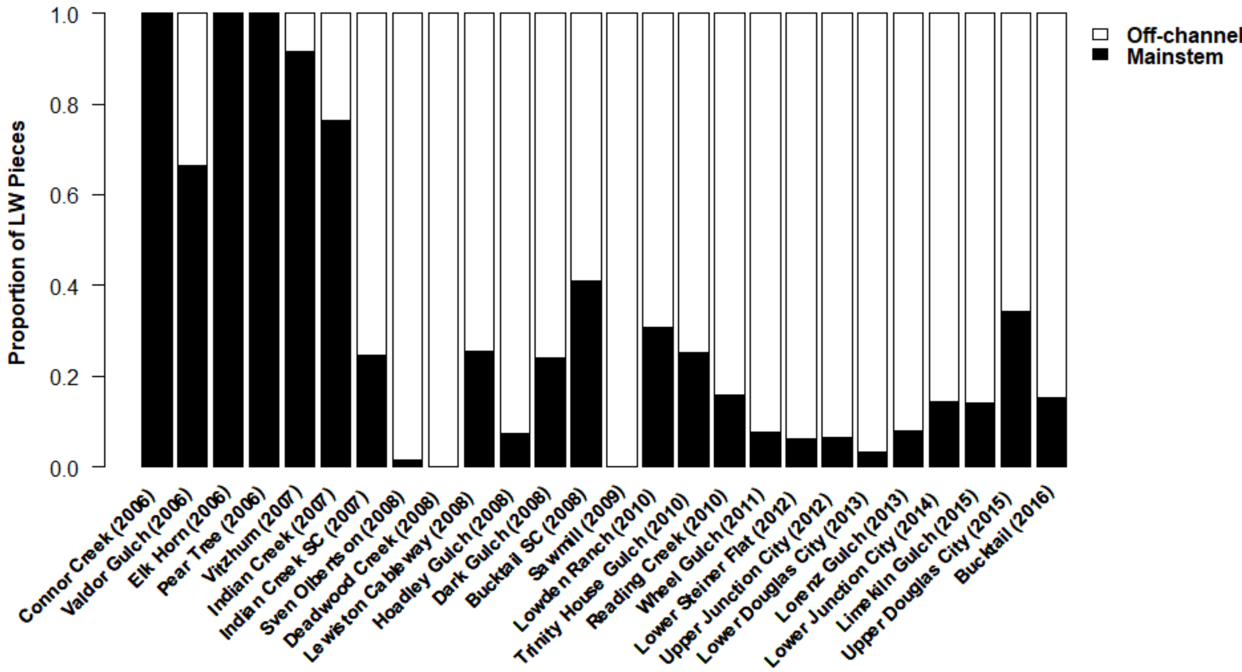

Figure 9. The proportion of LW pieces in the mainstem (closed bars) and in off-channel features (open bars). Sites are ordered chronologically by year of construction in parentheses.

added to the alcove at Elkhorn and the low flow side channel at Reading Creek, respectively.

The design documents for Lewiston Cableway, Vitzhum Gulch, Lower Steiner Flat, Upper Junction City, Hocker Flat, Connor Creek and Pear Tree did not contain any specific objectives for LW placement (Appendix B3).

Discussion

In response to historical and current anthropogenic impacts to the Trinity River, the restoration reach has been the focus of many different restoration activities from the 1980's and continuing to the present. Prior to the establishment of the TRRP in 2000, the Trinity River Basin Fish and Wildlife Restoration Program sought 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 (USBR 1992; USFWS and Hoopa Valley Tribe 1999). The channel rehabilitation projects included the construction of feathered edges and off-channel habitats such as alcoves (USBR 1992) and side channels (Glase 1994; USFWS and Hoopa Valley Tribe 1999).

When the TRRP began implementing channel rehabilitation projects the restoration reach

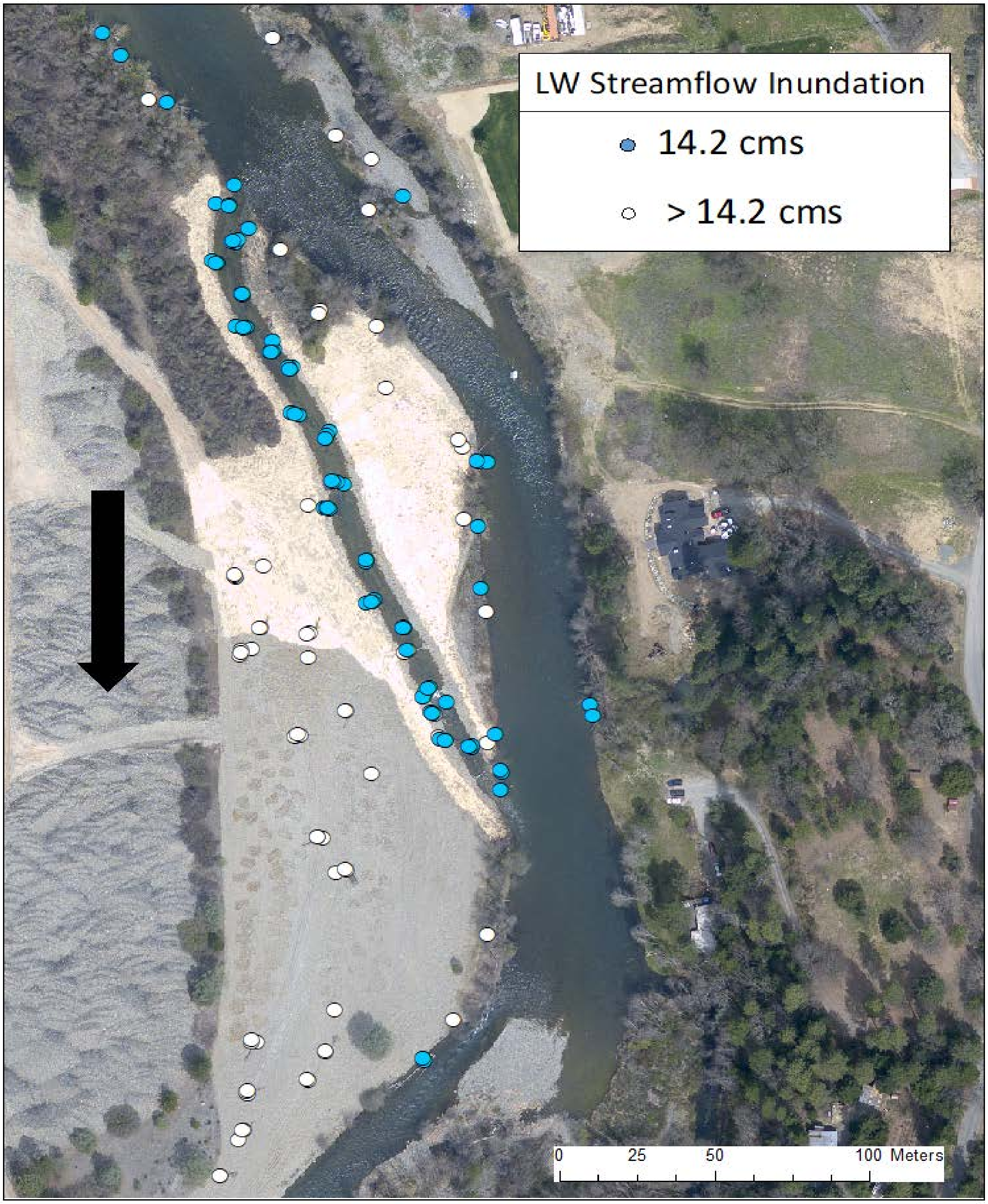

Figure 10. LW placement at Dark Gulch rehabilitation site relative to streamflow inundation in 2008. Symbols indicate any LW (pieces, structures). The arrow indicates direction of streamflow.

was envisioned as a completely alluvial system that was restricted from being more dynamic by riparian berms stabilized by dredge piles and reduced flow variation and thus the first channel construction activities were relatively simple consisting mostly of berm removal and floodplain lowering. However, site design processes began to evolve as early rehabilitation sites were evaluated and the program realized that only about 25% of the reach is alluvial (Buffington et al 2014). This new awareness elicited a change in priorities for the nature of channel rehabilitation efforts, which led to the construction of more complex channel features and an increase in the placement of individual LW pieces and structures. This development reflects an evolving design philosophy of creating immediate geomorphic changes to the channel and associated increases in habitat (Boyce et al 2018) while simultaneously expecting subsequent fluvial processes to alter the rehabilitated channel and LW configurations.

The LW inventory presented here clearly documents the increasing awareness by the TRRP of the importance of LW in riverine systems evidenced by the general increasing trend in the number of LW pieces per river kilometer over time (Figure 2A). Although five sites meet or exceed the range (500-600 pieces LW/rkm) of recommended LW loading for the Trinity River, there does not appear to be an effect of a particular TRRP design team on this metric. TRRP rehabilitation site designs are created by a series of multi-disciplinary teams or design teams from constituent partner organizations (see Appendix B for list of partner organizations). For instance, the Federal team designed Limekiln Gulch, with a relatively low density of LW pieces (240/rkm) and Lower Junction City, with the highest density (1,315 pieces LW/rkm). Similarly, Upper (743 pieces LW/rkm) and Lower (186 pieces LW/rkm) Douglas City were designed by the Hoopa Valley Tribe team. These results suggest that despite the overall increase in LW augmentation by the program, logistical constraints (e.g. LW availability or site access), the geomorphic context, site and/or feature specific objectives as well as budgetary considerations may influence the density of LW placed at particular rehabilitation sites.

The recommendation of 500-600 pieces of LW/rkm was suggested for the entire restoration reach (Cardno Entrix and CH2MHill 2011). We did not conduct LW surveys in segments of the restoration reach that have not been rehabilitated. Recent TRRP riparian monitoring efforts (Hoopa Valley Tribe and McBain Associates 2015, 2017), however, reported 32 and 40 pieces LW/rkm in non-rehabilitated portions of the restoration reach, respectively, suggestive of an insufficient reach-wide LW load. These riparian monitoring surveys use six size classes compared to our use of three, but their lower threshold for what defines LW is the same as in this study. The longitudinal distribution of LW density by rehabilitation site (Figure 2B) indicates sites in the mid to lower section of the restoration reach meet the Cardno Entrix and CH2MHill recommendations. With the exceptions of Upper Junction City, Lorenz Gulch and Bucktail, each rehabilitation site was surveyed more than once (Table 1). Those data along with future riparian monitoring efforts will provide an opportunity for a follow up analysis to gain insight into how LW installations have changed over time including a summarization of natural recruitment or loss of LW relative to annual peak streamflows that have occurred in the restoration reach.

Overall, greater than 60% of all LW pieces and CWJ’s were placed in off-channel features and are inundated at streamflows at or below 14.2 cms. This reflects the importance of areas outside of the mainstem for juvenile salmonid habitat and indicates a majority of TRRP LW interacts with streamflow for much of the water year. Extended interaction at multiple streamflows will have important implications for the effect of LW placement on the retention of natural and subsequently entrained TRRP LW, on sediment aggradation/degradation and general fluvial processes throughout the restoration reach. Assessing LW dynamics with our re-visit surveys could provide information about LW re-distribution within and outside of the restoration reach. This information could help explain changes in geomorphology and correlated trends in juvenile salmonid habitat availability we have documented in the restoration reach (Goodman et al 2016) and at rehabilitation sites (Boyce et al 2018), which could provide a revised perspective on the hypothesis that the combined effects of TRRP restoration activities will increase juvenile habitat availability over time.

The density (#/rkm) of CWJ's increased over our study period (Figure 6), while size class composition (Appendix A, Table A2) and number of LW pieces per CWJ were variable (Figure 7). The complexity of CWJ's can be represented by any number of metrics such as the type and degree of anchoring or the arrangement of LW pieces within CWJ's among other possibilities. We chose to assess complexity by the number of LW pieces because those data were easily accessed and the other methods were beyond the scope of our survey methods. It is perhaps not surprising that this measure of complexity would be variable given the year-to-year variation in rehabilitation site designs and logistical constraints mentioned above. Many of the smaller, less complex CWJ's were constructed to provide habitat benefits including escape cover and velocity refugia for juvenile salmonids, whereas the larger, heavily anchored CWJ's (Figure 8 B and D) were constructed with the goal of providing habitat benefits but also effecting hydraulic or geomorphic changes to the river channel. For example, it was hypothesized that placement of large wood structures at the entrances to anabranches in the lower section of the Lowden Ranch rehabilitation site, would help prolong the functioning of these off channel features by maintaining their connection to the mainstem at multiple streamflows (TRRP 2011). To date, this hypothesis appears to be supported as the anabranches are contiguous with the mainstem at all streamflows. Additionally, an increase in surface flow was observed between 2011 and 2017 entering the constructed side channel at the top of the site on river left, which also has a large wood structure at its entrance (USFWS, Hoopa Valley Tribe and Yurok Tribe, unpublished data). These examples along with the many demonstrated benefits of LW in the literature, provide justification for integrating LW into specific aspects of rehabilitation site design as well as the general restoration strategy of the program, which immediately increase the abundance and quality of fish habitats, but also influence fluvial processes in the restoration reach over longer time frames.

LW has been hypothesized to create a positive feedback system whereby large diameter trees typically with associated root balls initiate the formation of wood jams that cause sediment accretion and build-up of alluvial patches. These areas can ultimately stabilize either in the channel or riparian zone, which facilitates subsequent re-generation of tree species that can eventually be recruited as new LW pieces (Collins et al 2012). This "floodplain large-wood cycle" hypothesis was developed by synthesizing research on the relationship between physical parameters and ecological functioning and how forest species composition and channel dimensions affect fluvial processes. It also has the potential to provide a practical way for river restoration programs to initiate a particular trajectory to enhance ecological and geomorphic complexity while also accounting for logistical considerations and flow management priorities. The large diameter/long trees that initiate this cycle are often referred to as “key pieces” (Keller and Swanson 1979; Abbe and Montgomery 1996; Collins et al 2012) and, according to Abbe and Montgomery (2003), would have to be greater than 19 m in length to function in that capacity on the Trinity River assuming a post-TRD bankfull width of approximately 38 m (USFWS and Hoopa Valley Tribe 1999). Our surveys did not systematically identify the number of key pieces placed during construction of all rehabilitation sites; however, three class III pieces exceeding this length were placed at Limekiln Gulch (A. Martin, YTFD, personal communication, May, 2018). The LW objectives for Bucktail (HVTFD et al 2015) included 0-30 key pieces. We reviewed our LW survey photographs for Bucktail and estimated that one placed log falls into that category.

If the TRRP adopts the “floodplain-large wood cycle” as a model for developing a LW management strategy for the restoration reach, it should consider the appropriate ratio of key pieces to smaller LW pieces commonly referred to as “racking” material as well as the appropriate metrics to address specific monitoring objectives or hypotheses related to the amount and function of placed LW. Counting the number of LW pieces will continue to be an informative metric for the program; however, estimating the volume of placed LW could be another informative metric for comparison among and between restoration sites (Wohl et al 2010; USBR and ERDC 2016). Our survey methods and the inherent uncertainty of estimating the length and/or dbh of partially buried LW precluded the application of this metric to this analysis. However, a revised sampling protocol could be developed to make these estimates more accurate by surveying during and immediately after construction or by making LW assessments a core component of design reports.

The majority of TRRP LW pieces are Douglas fir (Pseudotsuga menziesii) and pine (Pinus spp.) with a very small percentage of hardwood species (A. Martin, YTFD, personal communication, November, 2017). Depending on the size, type and context of where it is deposited in the channel, fluvial wood can persist for years to several decades (Latterell and Naiman 2007). The depletion rate of coniferous species is substantially longer than hardwood species with a mean residence time of 30 years (Hyatt and Naiman 2001); however, much longer residence times have been reported (Keller and Tally 1979; Montgomery and Abbe 2006). Most constructed or installed wood structures remain in place and continue to provide benefits for a decade or longer (Roni et al 2015). The longevity of fluvial wood and constructed wood structures in conjunction with continued TRRP LW augmentation and riparian restoration may provide the conditions and time necessary for a cycle of natural LW generation, recruitment and transport to begin interacting with TRRP LW features and eventually reduce the need for augmentation.

A properly conceived and implemented LW management strategy by the TRRP will use all available information to balance program goals, ecosystem requirements and public and infrastructure safety. This outcome will be achieved, in part, by integrating general LW (Wohl et al 2010; USBR and ERDC, 2016) and Trinity River-specific LW recommendations (Hoopa Valley Tribe et al 2011; Cardno Entrix and CH2MHill 2011) into rehabilitation site designs. A more thorough and explicit integration of LW augmentation objectives into site design reports would facilitate quantitative evaluation of this component of the restoration program. It is hoped that given the constraints imposed by infrastructure considerations, streamflow management priorities and the limited alluvial nature of the Trinity River channel itself, that the management of LW augmentation along with other TRRP actions will restore ecological and fluvial processes, which will increase and sustain natural salmonid production.

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Literature Cited

Abbe, T.B., and D.R. Montgomery 1996. Large Woody Debris Jams, Channel Hydraulics and Habitat Formation in Large Rivers. Regulated Rivers: Research & Management 12(23):201–22.

Abbe, T.B., and D.R. Montgomery 2003. Patterns and processes of wood debris accumulation in the Queets river basin, Washington. Geomorphology 51: 81-107.

Abbe, T.B., A. Brooks, and D.R. Montgomery. 2003. Wood in River Restoration and Management. pp. 367-389 in: S. Gregory et al. (ed.), Wood in World Rivers. American Fisheries Society, Bethesda, Maryland.

AECOM. 2013. Historic context for mining along the Trinity River. Prepared for the US Bureau of Reclamation and the US Bureau of Land Management. Sacramento, CA.

Allan, J.H., and Lowe, S. 1997. Rehabilitating mainstem holding and rearing habitat. Chapter 11, pp. 1-9 in P.A. Slaney and D. Zaldokas (Eds.). Fish Habitat Rehabilitation Procedures. Watershed Restoration Technical Circular No. 9. Watershed Restoration Program, Ministry of Environment, Lands and Parks, Vancouver, BC.

Anderson, J. W., R. A. Ruediger, and W. F. Hudson. 1984. Design, placement and fish use of instream structures in southwestern Oregon. Pages 165–180 in T. J. Hassler, editor. Proceedings: Pacific Northwest stream habitat management workshop. American Fisheries Society, Humboldt Chapter, Arcata, California.

Armantrout, N. B., compiler. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.

Bailey, J. 2008. The other California Gold: Trinity County Placer Mining, 1848-1962. Technical Service Center, U.S. Bureau of Reclamation. Project Tracking Number 07-NCAO-211, Denver, CO.

Beechie, T.J., and S. Bolton. 1999. An approach to restoring salmonid habitat-forming processes in Pacific Northwest watersheds. Fisheries, 24:4, 6-15, DOI: 10.1577/1548-8446(1999)024<0006: AATRSH>2.0.CO; 2

Beechie, T.J., and T.H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. Trans. Am. Fish. Soc. 126: 217-229.

Benke, A.C., Henry III, R.L., Gillespie, D.M., and R.J. Hunter. 1985. Importance of snag habitat for animal production in southeastern streams. Fisheries 10: 8-13.

Bilby, R.E. 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. Ecology, 62: 1234-1243.

Bilby, R.E., and J.W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in Western Washington. Transactions of the American Fisheries Society 118(4):368–378.

Boyce, J., D.H. Goodman, N.A. Som, J. Alvarez and A. Martin. 2018. Trend Analysis of Salmon Rearing Habitat Restoration in the Trinity River at Summer Base Streamflow, 2005-2015. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TR 2018-31, Arcata, California.

Buffington, J., C. Jordan, M. Merigliano, J. Peterson, and C. Stalnaker. 2014. Review of the Trinity River Restoration Program following Phase 1, with emphasis on the Program's channel rehabilitation strategy. Prepared by the Trinity River Restoration Program's Science Advisory Board for the Trinity River Restoration Program with assistance from Anchor QEA, LLC, Stillwater Sciences, BioAnalysts, Inc., and Hinrichsen Environmental Services.

Cardno Entrix and CH2MHill 2011. Trinity River Large Wood Analysis and recommendation report. Report to the U.S. Bureau of Reclamation, Trinity River Restoration Program. Cardno Entrix, South Lake Tahoe, California.

CH2MHill. 2011. Final design report: Trinity River Restoration Program Lower Steiner Flat rehabilitation site design. Report to the TRRP (Trinity River Restoration Program). CH2MHill, Boise, Idaho.

Chamberlain, C., D. Gaeuman, D. Bandrowski, and E. Wiseman. 2012. Final design report, Upper Junction City (UJC) channel rehabilitation project site - phase II. TRRP (Trinity River Restoration Program) report. TRRP, Weaverville, California.

Coe, H.J., Kifney, P.M., Pess, G.R., Kloehn, K.K., and M.L. McHenry. 2009. Periphyton and invertebrate response to wood placement in large Pacific coastal rivers. River Research and Applications, 25: 1025-1035.

Collins, B. D., D. R. Montgomery, K. L. Fetherston, and T. B. Abbe. 2012. The Floodplain Large-Wood Cycle Hypothesis: A Mechanism for the Physical and Biotic Structuring of Temperate Forested Alluvial Valleys in the North Pacific Coastal Ecoregion. Geomorphology 139/140:460–470.

Crispin V, House R, Roberts D. (1993). Changes in instream habitat, large woody debris, and salmon habitat after the restructuring of a coastal Oregon stream. North Am J Fish Manag 13: 96-102.

DWR (California Department of Water Resources). 2010. Design report: Trinity River - Wheel Gulch rehabilitation site (river mile 76.0-76.4). Report to the Trinity River Restoration Program. DWR, Red Bluff, California.

Evans, J.F. 1979. Evaluation of riparian vegetation encroachment, Trinity River, California. Trinity River Fish and Wildlife Task Force, Report.

Flores, L., Larranaga, A., Diex, J., and A. Elosegi. 2011. Experimental wood addition in streams: effects on organic matter storage and breakdown. Freshw. Biol. 56(10): 2156-2167.

Frederiksen, Kamine, and Assoc. 1980. Proposed Trinity River basin fish and wildlife management program. Trinity River Basin Fish and Wildlife Task Force, Report.

Gallagher, S.P. 1999. Experimental Comparisons of Fish Habitat and Fish Use between Channel Rehabilitation Sites and the Vegetation Encroached Channel of the Trinity River. U.S. Fish and Wildlife Service, Arcata, CA.

Glase, D. 1994. Progress Report. Evaluation of Artificially Constructed Side Channels as Habitat for Salmonids in the Trinity River, Northern California, 1991-1993. USFWS, Trinity River Restoration Program. Trinity River Fishery Resource Office, Weaverville, CA.

Goodman, D.H., N.A. Som, J. Alvarez, and A. Martin. 2015. A mapping technique to evaluate age-0 salmon habitat response from restoration. Restoration Ecology 23(2): 179-185.

Goodman, D.H., J. Alvarez, N.A. Som, A. Martin, and K. De Juilio. 2016. The effects of restoration on salmon rearing habitats in the restoration reach of the Trinity River at an index streamflow, 2009 to 2013. Arcata Fisheries Technical Report Number TR 2016-25, report to the Trinity River Restoration Program (TRRP). U.S. Fish and Wildlife Service, Arcata, California.

Hardy, T.B., T.Shaw, R.C. Addley, G.E. Smith, M. Rode, and M. Belchik. 2006. Validation of Chinook fry behavior-based escape cover modeling in the Lower Klamath River. International Journal of River Basin Management. 4(3):169-178.

House, R.A., and Boehne, P.L., 1985, Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream: North American Journal of Fisheries Management, v. 5, p. 283–295.

Hoopa Valley Tribal Fisheries Department and McBain Associates. 2016. Water Year 2015 Trinity River Restoration Program Riparian Monitoring Report. Report to the Trinity River Restoration Program (TRRP), Hoopa Valley Tribal Fisheries Department, Hoopa, California.

Hoopa Valley Tribal Fisheries Department and McBain Associates. 2017. Water Year 2016 Trinity River Restoration Program Riparian Monitoring Report. Report to the Trinity River Restoration Program (TRRP), Hoopa Valley Tribal Fisheries Department, Hoopa, California.

Hoopa Valley Tribal Fisheries Department, McBain Associates, Domenichelli and Associates, and Cardno. 2015. Final design document: Trinity River, Bucktail (river mile 105.3 – 106.25). Report to the TRRP (Trinity River Restoration Program). HVTFD, Hoopa, California.

Hoopa Valley Tribe, McBain & Trush, Inc., and Northern Hydrology and Engineering. 2011. Channel Rehabilitation Design Guidelines for the Mainstem Trinity River. Prepared for the Trinity River Restoration Program, Weaverville, California. HVTFD, Hoopa California.

Hoopa Valley Tribal Fisheries Department, McBain & Trush, Domenichelli and Associates, and Cardno ENTRIX. 2013. Final design document: Trinity River, Douglas City rehabilitation site, (River Mile 93.6-94.6). Report to the TRRP (Trinity River Restoration Program). HVTFD, Hoopa, California.

Hyatt, T.L., and Naiman, R.J., 2001. The residence time of large woody debris in the Queets River, Washington USA. Ecological Applications 11, 191-202.

Keller, E.A., and Swanson, F.J. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes and Landforms 4, 361-380.

Keller, E.A., and Tally, T. 1979. Effects of large organic debris on channel form and fluvial processes in the coastal redwood environment. In: Rhodes, D.D., Williams, G.P., and (Eds.) Adjustments of the Fluvial System. George Allen and Unwin, London, UK, pp. 169-197.

Krause, A. 2010. One hundred and fifty years of sediment manipulation on the Trinity River, CA. 2nd Joint Federal Interagency Conference. Las Vegas, NV. Advisory Committee on Water Information.

Latterell, JJ, and Naiman, R.J. 2007. Sources and dynamics of large logs in a temperate floodplain river. Ecological Applications 17, 1127-1141.

Lester, R.E., Wright, W., Jones-Lennon, M., and Rayment, P. 2009. Large versus small wood in streams: the effect of wood dimension on macroinvertebrate communities. Vol. 72, 2015 Fund. Appl. Limnol. 174(4): 339–351. doi:10.1127/1863-9135/2009/0174-0339.

Locke, A., C. Stalnaker, S. Zellmer, K. Williams, H. Beecher, T. Richards, C. Robertson, A. Wald, A. Paul, and T. Annear. 2008. Integrated approaches to riverine resource management: case studies, science, law, people, and policy. Instream Flow Council, Cheyenne, Wyoming.

Moffett, J.W., and S.H. Smith. 1950. Biological investigations of the fishery resources of Trinity River, California. Special Scientific Report-Fisher No. 12 from the U.S. Fish and Wildlife Service.

Montgomery, D.R., and Abbe, T.B. 2006. Influence of logjam-formed hard points on the formation of valley-bottom landforms in an old-growth forest valley, Queets River, Washington, USA. Quaternary Research 65, 147-155.

Montgomery, D.R., Abbe, T.B., Buffington, J.M., Peterson, N.P., Schmidt, K.M., and J.D. Stock. 1996. Distribution of bedrock and alluvial channels in forested mountain drainage basins. Nature, 381: 587-589.

Naiman, R. J., E. V. Balian, K. K. Bartz, R. E. Bilby, and J. J. Latterell. 2002. Dead Wood Dynamics in Stream Ecosystems. Pages 23–48 in W. F. Laudenslayer Jr., P. J. Shea, B. E. Valentine, C. P. Weatherspoon, and T. E. Lisle (eds.), Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests. Gen. Tech. Rep. PSW-GTR-181. U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Roni, P., T. J. Beechie, G. R. Pess, and K. M. Hanson. 2015. Wood Placement in River Restoration: Fact, Fiction and Future Direction. Canadian Journal of Fisheries and Aquatic Sciences 72(3): 466-478.

Stewart, G.B., Bayliss, H.R., Showler, D.A., Sutherland, W.J. and A.S Pullin. 2009. Effectiveness of engineered in-stream structure mitigation measures to increase salmonid abundance: a systematic review. Ecol. Appl. 19(4): 931-941. Doi:10.1890/07-1311.1. PMID: 19544735.

Sullivan, R.M., and Bair, J.H. 2004. Trinity River Restoration Program revegetation philosophy. Draft Document http://www.trrp.net/DataPort/doc.php?id=453

Thompson, D.M. 2006. Did the pre-1980 use of in-stream structures improve streams? A reanalysis of historical data. Ecol. Appl. 16(2): 784-796.

TRRP (Trinity River Restoration Program). 2008. Status Report: Vitzhum Gulch (AU Bend) Mechanical Channel Rehabilitation. TRRP. Weaverville, California.

TRRP (Trinity River Restoration Program). 2011. Phase I design summary fact sheets (combined package). TRRP. Weaverville, California.

USBR (U.S. Bureau of Reclamation). 1992. Status of the Trinity River Basin Fish and Wildlife Restoration Program. Report from the Trinity River Fish and Wildlife Restoration Task Force.

USBR (United States Bureau of Reclamation). 2009. Trinity River Restoration Program, channel rehabilitation and sediment management for remaining phase 1 and phase 2 sites--Part 1: draft master EIR and Part 2: Environmental Assessment/draft EIR. Trinity River Restoration Program, Weaverville, CA.

USBR (U.S. Bureau of Reclamation) and ERDC (U.S. Army Engineer Research and Development Center). 2016. National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure. USBR Pacific Northwest Regional Office, Boise, Idaho.

USDOI (U.S. Department of the Interior). 2000. Record of decision Trinity River mainstem fishery restoration, final environmental impact statement/environmental impact report.

USFWS. 1989. Annual report, Trinity River flow evaluation. U.S. Fish and Wildlife Service, Coastal California Fish and Wildlife Office, Arcata, CA.

USFWS. 1997. Physical Habitat and Fish Use of Channel rehabilitation Projects on the Trinity River. U.S. Fish and Wildlife Service, Arcata, CA.

USFWS and Hoopa Valley Tribe. 1999. Trinity River Flow Evaluation Final Report. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, CA and Hoopa, CA.

United States Fish and Wildlife Service (USFWS), United States Bureau of Reclamation (USBOR), Hoopa Valley Tribe (HVT), and Trinity County (TC). 2000. Trinity River Draft and Final Environmental Impact Statement/Environmental Impact Report EIS/EIR.

USFWS (U.S. Fish and Wildlife Service), USFS (U.S. Forest Service), USBR (U.S. Bureau of Reclamation), and NMFS (National Marine Fisheries Service). 2014. Final design report: Limekiln Gulch rehabilitation project. Report to the TRRP (Trinity River Restoration Program). TRRP, Weaverville, California.

USFWS (U.S. Fish and Wildlife Service), USFS (U.S. Forest Service, USBR (U.S. Bureau of Reclamation), and NMFS (National Marine Fisheries Service). 2014. Final design report, Lower Junction City rehabilitation project. TRRP (Trinity River Restoration Program), Weaverville, California.

U.S. Geological Survey, 20141010, NLCD 2011 Land Cover (2011 Edition, amended 2014), 3 x 3 Degree: NLCD2011_LC_N39W120: U.S. Geological Survey.

Vigil, R. 2015. Year 1 (2013) Monitoring Report [revegetation of Upper Junction City and Lower Steiner Flat channel rehabilitation sites]. Restoration Resources, Rocklin, CA

Whiteway, S.L., P.M, Biron, A. Zimmermann, O. Venter and J.W.A. Grant. 2010. Do in-stream restoration structures enhance salmonid abundance? A meta-analysis. Can. J. Fish. Aquat. Sci.67 (5):831-841. Doi: 10.1139/F10-021.

Wohl, E., Cenderelli, D.A., Dwire, K.A., Ryan-Burkett, S.E., Young, M.K., and K.D. Fausch. 2010. Large in-stream wood studies: a call for common metrics. ESEX Commentary, Earth Surf. Process. Landforms 35, 619-625.

Appendices

Appendix A. The number of LW pieces by size class, constructed wood jam and channel location.

Table A1. The number of LW pieces by size class placed in TRRP rehabilitation sites. Sites are ordered by year of construction.

Site	Year of Construction	Length (km)	Class I	Class II	Class III	Total	LW/rkm
Connor Creek	2006	0.6	6	22	3	31	52
Valdor Gulch	2006	1.4	22	77	2	101	72
Elk Horn	2006	0.9	2	20	1	23	26
Pear Tree Gulch	2006	0.5	5	2	1	8	16
Vitzhum Gulch	2007	1.2	8	34	5	47	39
Indian Creek	2007	0.3	2	15	0	17	57
Indian Creek Side Channel	2007	1.1	30	164	9	203	185
Sven Olbertson	2008	0.7	19	43	5	67	96
Deadwood Creek	2008	0.1	5	11	0	16	160
Lewiston Cableway	2008	0.7	27	22	2	51	73
Hoadley Gulch	2008	0.2	18	33	4	55	275
Dark Gulch	2008	2.4	49	106	18	173	72
Bucktail Side Channel	2008	0.18	0	10	3	13	73
Sawmill	2009	1.40	238	325	59	622	444
Lowden Ranch	2010	1.4	223	270	41	534	381
Trinity House Gulch	2010	0.6	93	124	9	226	377
Reading Creek	2010	1.4	65	177	6	248	177
Wheel Gulch	2011	0.4	74	109	1	184	460
Lower Steiner Flat	2012	0.6	111	153	7	271	452
Upper Junction City	2012	0.7	240	377	29	646	923
Lower Douglas City	2013	0.5	24	57	12	93	186
Lorenz Gulch	2013	1.1	773	340	20	1,133	1,030
Lower Junction City	2014	0.6	403	348	38	789	1,315
Limekiln Gulch	2015	1.2	156	115	17	288	240
Upper Douglas City	2015	0.6	132	183	131	446	743
Bucktail	2016	2.5	595	565	146	1,306	522

Table A2. The number of LW pieces in each constructed wood jam (rows). Rehabilitation sites are ordered chronologically by year of construction from the top.

Site	Year of Construction	Class I	Class II	Class III	Total
Sawmill	2009	4	23	4	31
Lowden Ranch	2010	0	5	1	6
		6	7	0	13
		5	6	4	15
		2	13	2	17
		6	12	4	22
		10	14	2	26
		15	11	3	29
		10	15	9	34
Trinity House Gulch	2010	3	12	2	17
Wheel Gulch	2011	11	6	0	17
		9	12	0	21
Lower Steiner Flat	2012	5	12	0	17
		15	12	0	27
Upper Junction City	2012	2	8	0	10
		5	5	0	10
		6	6	0	12
		9	3	3	15
		6	11	0	17
		5	13	0	18
		10	10	1	21
		9	12	0	21
		12	9	1	22
		8	14	1	23
		10	11	2	23
		15	9	0	24
		14	9	1	24
		4	21	0	25
		7	21	4	32
		16	17	0	33
		18	14	3	35
		4	31	4	39
Lower Douglas City	2013	5	10	1	16
		11	11	2	24
		4	28	7	39

Table A2 continued. The number of LW pieces in each constructed wood jam. Rehabilitation sites are ordered chronologically by year of construction from the top.

Site	Year of Construction	Class I	Class II	Class III	Total
Lorenz Gulch	2013	14	9	0	23
		20	16	7	43
		50	10	5	65
		44	23	3	70
Lower Junction City	2014	0	3	0	3
		3	0	1	4
		3	1	0	4
		0	4	0	4
		4	1	0	5
		1	4	0	5
		2	3	0	5
		1	4	0	5
		3	3	0	6
		4	2	0	6
		1	5	0	6
		5	1	1	7
		4	2	1	7
		6	1	0	7
		5	3	0	8
		3	4	1	8
		4	5	0	9
		5	3	1	9
		3	6	0	9
		4	3	2	9
		5	5	0	10
		5	5	0	10
		8	2	0	10
		5	5	0	10
		6	5	0	11
		8	3	0	11
		6	5	0	11
		2	6	3	11
		6	6	0	12
		5	6	1	12
		10	2	0	12
		4	8	0	12
		8	4	1	13

Table A2 continued. The number of LW pieces in each constructed wood jam. Rehabilitation sites are ordered chronologically by year of construction from the top.

Site	Year of Construction	Class I	Class II	Class III	Total
Lower Junction City	2014	6	7	0	13
		8	5	0	13
		12	2	0	14
		2	11	1	14
		8	6	0	14
		9	6	0	15
		5	10	0	15
		10	6	0	16
		12	4	0	16
		10	7	0	17
		12	6	0	18
		8	9	9	26
		8	25	4	37
		15	23	5	43
Limekiln Gulch	2015	3	1	0	4
		0	4	0	4
		0	4	1	5
		2	4	0	6
		2	10	0	12
		0	10	4	14
		4	8	2	14
Upper Douglas City	2015	0	5	0	5
		3	3	0	6
		0	6	1	7
		6	2	0	8
		0	7	3	10
		6	6	4	16
		7	6	7	20
Bucktail	2016	0	2	2	4
		1	1	2	4
		0	5	0	5
		2	6	1	9
		6	0	3	9
		0	4	5	9
		0	6	4	10
		5	7	0	12
		5	4	3	12
		6	6	0	12
		10	2	2	14
		8	6	0	14
		10	3	5	18
		5	22	0	27
		5	17	15	37

Table A3. The number of LW pieces placed in mainstem (MS), side channels (SC) and high flow channels (HFC) in TRRP rehabilitation sites. NA indicates LW above floodplain on terrace. Sites are ordered upstream to downstream from top left to bottom right.

Site	Size Class	MS	SC	HFC	NA
Sven Olbertson	I		19		
	II		43		
	III	1	4		
Deadwood Creek	I		5		
	II		11		
	III				
Lewiston Cableway	I	5	22		
	II	6	16		
	III	2			
Hoadley Gulch	I	2	16		
	II	2	31		
	III		4		
Sawmill	I	55	142	41	
	II	80	199	46	
	III	14	38	7	
Dark Gulch	I	15	28	6	
	II	48	41	17	
	III	8	7	3	
Bucktail	I	52	458	24	61
	II	75	401	48	41
	III	55	77	6	8
Bucktail SC	I				
	II		10		
	III		3		
Lowden Ranch	I	85	56		82
	II	118	97		55
	III	16	22		3
Trinity House Gulch	I	27	66		
	II	26	98		
	III	4	5		
Limekiln Gulch	I	15	133	8	
	II	24	91		
	III	5	12		

Site	Size Class	MS	SC	HFC	NA
Vitzhum Gulch	I	8			
	II	30		4	
	III	5			
Indian Creek	I	2			
	II	15			
	III				
Indian Creek SC	I	7	49	4	
	II	42	140	12	
	III	1	37	1	
Upper Douglas City	I	45	53	34	
	II	41	94	48	
	III	68	52	11	
Lower Douglas City	I	9	11	4	
	II	18	11	28	
	III	3	2	7	
Reading Creek	I	18	22	25	
	II	21	48	108	
	III		3	3	
Lower Steiner Flat	I	6	76	29	
	II	9	116	28	
	III	2	4	1	
Lorenz Gulch	I	134	586	53	
	II	72	244	24	
	III	12	8		
Upper Junction City	I	10	183	47	
	II	27	250	100	
	III	5	21	3	
Lower Junction City	I	39	21	343	
	II	61	50	237	
	III	13	7	18	
Connor Creek	I	6			
	II	22			
	III	3			

Table A3 continued. The number of LW pieces placed in mainstem (MS), side channels (SC) and high flow channels (HFC) in TRRP rehabilitation sites. NA indicates LW above floodplain on terrace. Sites are ordered upstream to downstream from top left to bottom right.

Site	Size Class	MS	SC	HFC	NA
Wheel Gulch	I	19	44	11	
	II	35	64	10	
	III		1		
Valdor Gulch	I	13	9		
	II	52	25		
	III	2			
Elk Horn	I	2			
	II	20			
	III	1			
Pear Tree	I	5			
	II	2			
	III	1			

Appendix B. Comparison of LW objectives described in rehabilitation site design reports to as-built conditions after construction. Each site is underlined with year of construction and the TRRP design team is in parentheses. Hoopa Valley Tribal Fisheries Department (HVTFD), California Department of Fish and Wildlife and Department of Water Resources (CA State), U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service and U.S. Forest Service (Federal)

B1: rehabilitation sites with specific objectives in the form of recommended numbers of LW pieces per structure, per size class or per river kilometer.

Valdor Gulch 2006 (HVTFD):

Design report:

R2 (12.7 cms/450 cfs side channel): large wood was added in the side channel as single pieces and up to ~ 6 pieces were placed at the head of the island.

As-built:

34 LW pieces placed in R2; four size class II at head of island. Objective met.

Wheel Gulch 2011 (CA State):

Design report:

R2 (low flow side channel): wood structures having not more than 3 logs each.
R3 (alcove): LW structures may be placed in-line in the center of the alcove or along the banks, but not staggered in a way that would prevent sediment supplied by side channel and Wheel Gulch from flushing out of the alcove.

As-built:

R2: objective met with the exception of one Log deflector-S.
R3: objective met.

Lorenz 2013 (Federal with Cardno Entrix):

Design report: Overall, 708 individual LW elements with approximately 6 LW structures.

IC-2: wood structure with estimate of 25 class I, 50 class II.
IC3: main channel split flow with 30 class I, 51 class II.
IC-4: medial bar with large wood, 20 class I, 40 class II.
R1: side channel with wood placement, 38 class I, 69 class II.
R2: multiple loose locations 60 class I, 100 class II.
W1: pond with 20 class I, 40 class II.

As-built: exceeded objective for LW elements (n=1,133). Four CWJ's, 1 Log Weir-D and 59 Log Deflector-S structures. The numbers below are in order, size class I, II, III.

IC-2: (20, 16, 7), objective not met.
IC3: (35, 15, 2), objective not met
IC-4: (44, 23, 3), objective not met
R1: (75, 21, 2), objective not met.
R2: (123, 37, 1), objective not met.
W1: (103, 70, 0), objective met.

Lower Douglas City 2013 (HVTFD):

Design report: overall LW objectives were adopted from the Trinity River channel design guide (5-230 LW pieces/rkm).

R5 (bank revetment/infrastructure protection): regularly spaced logs with rootwads perpendicular to flow, partially buried; matrix of smaller logs.
IC-5 (mid channel bar): addition of large wood with intact branches and rootwads facing upstream, partially buried;
IC-6 (mid channel bar): incorporating large wood with intact branches and rootwad, with rootwad facing upstream; 12 logs.

As-built: overall objective was met (186 LW pieces/rkm). The numbers below are in order, size class I, II, III.

R5: objective met.
IC-5: objective met (11, 11, 2).
IC-6: objective met (5, 10, 1).

Lower Junction City 2014 (Federal):

Design report:

IC-3 (constructed bar): recommended approximately 29 logs to be pinned by 87 logs.
R1/R2: (floodplain/alcove): abundant LW throughout.
C4: (log grade control): recommended approximately 23 log structure to discourage head cutting between R1 and R3.
IC-4 (lowered floodplain): an apex LW jam will be installed to divert water into secondary channel.
R4 (lowered floodplain): numerous LW placements.

As-built: The numbers below are in order, size class I, II, III.

IC-3: (n=27 total; 8, 9, 9). Objective met. LW data does differentiate between logs and pin logs.
R1/R2: objective met.
C4: this feature is not present in the Design 2D as-built shapefile. There are CWJ's in that area with approximately 14 logs each. Objective met.
IC-4: objective met.
R4: numerous LW placements present. Objective met.

Limekiln 2015 (Federal):

Design report:
R3 (channel expansion): LW placement.
IC-1 (6-10 class II, 1-2 size class III).
R1 (side channel): abundant LW.
R2 (side channel): abundant LW.
IC-2, -3 and -4 (large wood jams): each with approximately 15 size class II logs.
IC-5 and -6 (side channel expansions and grade controls): approximately 6 size class II logs.
R5 riverine wood placement
R6 riverine wood placement.

As-built: The numbers below are in order, size class I, II, III.
R3: objective met.
IC-1: (6, 4, 3), objective met.
R1: objective met.
R2: objective met.
IC-2 (n=4), IC-3 (n=10), IC-4 (n=8). Objective not met.
IC-5 (n=2 size class III), IC-6 (n=4 size class II). Objective not met.
R5 no wood, objective not met.
R6 (3, 14, 3). Objective met.

Upper Douglas City 2015 (HVTFD):

Design report: overall LW objectives were adopted from the Trinity River channel design guide (5-230 LW pieces/rkm).

R1 (high flow channel): large wood to reduce flow.
R2 (bank lowering and shaping): place large wood along backside of constructed surfaces.
R3 (bank lowering and shaping): place wood throughout constructed surface.
IC-1 (skeletal bar/alcove): Burry large wood into upstream end of bar. Place large wood in existing channel downstream of Project Area IC-1.
IC-2 (bank lowering and reshaping): Place large wood along right bank of constructed mainstem channel.
IC-3 (skeletal bar/alcove): Incorporate large wood (1-2 ft. diameter in high flow scour channel and head of skeletal bar). Place large wood in alcove.

IC-4 (large wood placement): place large wood habitat structures within existing side channel.

As-built: overall objective was met (743 LW pieces/rkm). The numbers below are in order, size class I, II, III.

R1: objective met.
R2: objective met.
R3: objective met.
IC-1: objective met.
IC-2: objective met.
IC-3: objective met.
IC-4: objective met.

Bucktail 2016 (HVTFD):

Design report: Specific objectives were adopted from Trinity River Channel Design Guide:

(50-230 LW pieces/rkm)
(0-30 key pieces)

As-built:

(520 LW pieces/rkm). Objective met.
Approximately 1 key piece. Objective met.

B2: rehabilitations sites with general objectives that outlined LW placement locations within a site or within a particular channel rehabilitation feature.

Elkhorn 2006 (CA State): design modifications made in the field during construction.

> Design report: large wood added to R1 alcove and R5 feathered edge. Tree trunks are buried in river bank.
>
> As-built: objectives were met.

Indian Creek 2007 (TRRP): Design modifications made in the field during construction.

> Design report: TRRP staff supervised the placement of a small amount of large woody debris in the R-8 side channel, on the R-8 floodplain, and in the R-1 notches during construction. A very small amount of wood was placed along the main channel banks.
>
> As-built: objectives were met.

Sven Olbertson 2008 (HVTFD): Design modifications made in the field during construction. Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.

> Design report:
> > R1 (side channel): increase LW.
>
> As-built: wood was included at entrances to R1.

Deadwood Creek 2008 (HVTFD): Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.

> Design report:
> > R3 (low flow side channel): LW placed within low flow side channel.
>
> As-built: objective was met.

Hoadley Gulch 2008 (HVTFD): Design modifications made in the field during construction. Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.

> As-built: large wood was added to R5 (constructed floodplain) to provide cover and immediately benefit fry and juvenile salmonids.

Dark Gulch 2008 (CA State):

> Design report:

R3: LW with rootballs in low flow channel

As-built: objective met.

Sawmill 2009 (HVTFD/McBain and Trush): Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.

Design report: placement of a giant log jam feature that included logs pile driven into the bank at the R-8 meander.

As-built: a similar feature at R2 meander (4, 23, 4) with piles.

Lowden 2010 (Federal):

Design report:

Objective 3: increase LW storage; preserve anabranch (IC-3, IC-5, R7) openings by constructing large-wood structures at their inlets.
IC-1: LW placed at opening to R1 to encourage scour and sediment transport to help keep channel entrance open.

As-built: LW structures were designed in the field during construction (IC-1, R-1, R-2, R-3) and fulfilled objective 3 and IC-1 recommendations.

Reading Creek 2010 (HVTFD): Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.

Design report: overall, increase large wood storage.

R3 (low flow side channel): LW placement for habitat.
R5 (floodplain and high flow scour channel): LW placed along low water edge.

As-built: objectives were met.

Trinity House Gulch 2010 (HVTFD): Design modifications made in the field during construction. Although large woody debris is shown on the drawings, final placement was directed by TRRP and assigned Program Partner Staff.

Design report: overall, increase LW storage

R2 (low flow side channel): LW for habitat.
R1 (floodplain): LW placement.

As-built: objectives were met.

B3: rehabilitation sites with no objectives for LW placement.

Pear Tree 2006 (CA State).
Connor Creek 2006 (HVTFD).
Vitzhum Gulch 2007 (TRRP).
Lewiston Cableway 2008 (HVTFD).
Lower Steiner Flat 2012 (Federal).
Upper Junction City 2012 (Federal).