Little Shasta River Aquatic Habitat Assessment

Authors:

Andrew Nichols, Robert Lusardi, Ann Willis

Prepared for:

The Nature Conservancy

July 2017

Center for Watershed Sciences
University of California, Davis • One Shields Avenue • Davis, CA 95616-8527

Contents

Little Shasta River Aquatic Habitat Assessment

Introduction

The Shasta River and its tributaries provide critical spawning and rearing habitat for threatened and endangered salmonids within the lower Klamath River Basin of northern California and southern Oregon (NRC, 2004; NOAA, 2012). Over the last decade, conservation and restoration activities in the Shasta River Basin have principally focused on channel reaches along the mainstem Shasta River and spring-fed reaches of the Shasta River tributaries including Big Springs Creek, Parks Creek and Hole in the Ground Creek (e.g. Jeffres et al., 2008; Nichols et al., 2010; Willis and Deas, 2012; Willis et al., 2012). These tributaries are all located adjacent to the upper reaches of the Shasta River and accessible to anadromous fish (rkm 50 to 65). Several tributaries are also found entering the lower reaches of the Shasta River (rkm 0 to 25), of which the Little Shasta River and Yreka Creek are the largest by annual flow volume (McBain & Trush, 2013). The Little Shasta River is prominent among these tributaries due to its reliance on both groundwater and precipitation/snowmelt runoff for streamflow (NCRWQCB, 2006; McBain & Trush, 2013).

Recent hydrologic and water temperature assessment activities along the Little Shasta River (Nichols et al., 2016) suggest the upper reaches accessible to anadromous salmonids (rkm 18.5 to rkm 25) may provide suitable thermal and structural aquatic habitat for cold-water fishes. Data collected throughout the 2015 water year showed that approximately 3 ft^3/s of cool water remained in the Little Shasta River above rkm 18.5 (see Figure 1 and Figure 2) throughout the annual irrigation season (March through October). However, channel reaches downstream from rkm 18.5 had zero flow (or were dry) through much of the same period. Understanding the spatial and temporal distribution of aquatic habitats, stream flow, water temperature, and food webs suitable for anadromous salmonids in the Little Shasta River is critical for planning and implementing potential conservation and restoration actions.

This report summarizes stream habitat, stream flow, water temperature, and food web resources (stream invertebrates) in the segment of the Little Shasta River extending from rkm 18.6 to 20.9 (Figure 1 and Figure 2) during the 2016 field season. The objectives of the monitoring study were to assess the character and distribution of salmonid habitat, with particular focus on both physical habitat and food web function. The channel reach assessed as part of this study remained "wet" throughout the 2015 and 2016 irrigation seasons, and is generally considered the reach of the Little Shasta River most likely to provide suitable structural and thermal habitats for juvenile fish rearing in the river (Nichols et al., 2016).

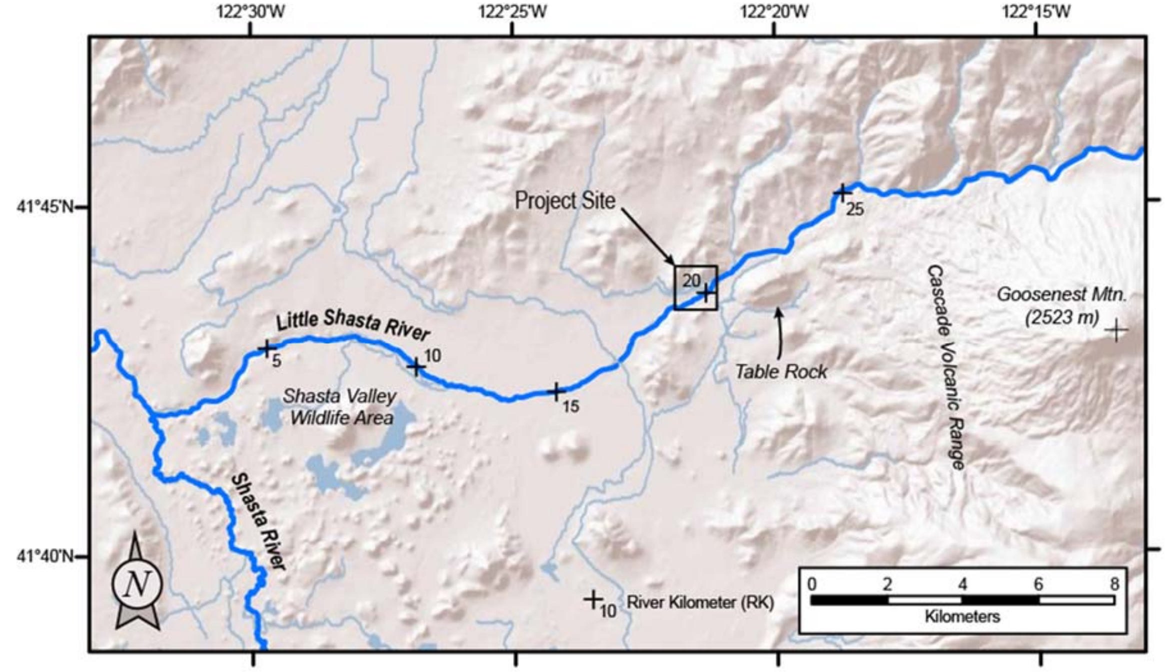

Figure 1. Little Shasta River Valley with the project site identified.

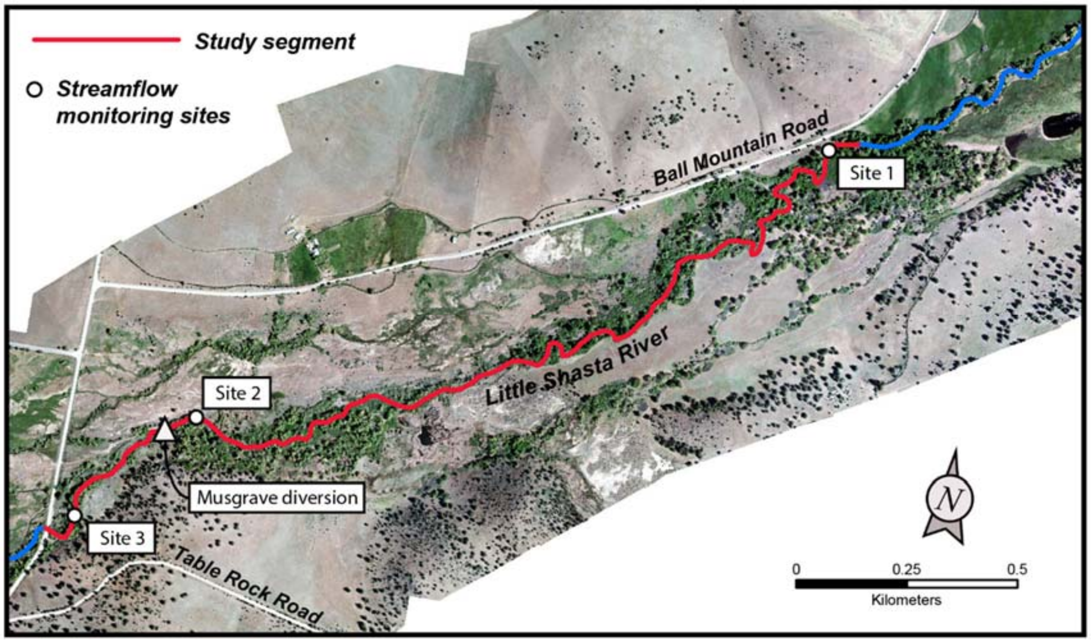

Figure 2. Little Shasta River stream flow, water temperature, habitat mapping, and food web analysis segment (rkm 18.6 to 20.9).

Methods

Habitat mapping

To assess stream habitat conditions throughout the 2.3 km study segment, salmonid habitats were inventoried using methodologies presented in the California Salmonid Stream Habitat Restoration Manual (CADFG, 2010). Specifically, habitat types were used to describe the areal extent and distribution of available wetted habitats during summertime periods of low flow (~ 4 ft^3/s). Habitat typing was performed on August 17 and 18, 2016 and utilized all four levels of classification presented in the California Salmonid Stream Habitat Restoration Manual, which provide more descriptive categories of riffle or pool habitat types as the levels increase (Figure 3).Within Level IV, 24 possible habitat types are identified and generally distinguished by morphological conditions (gradient, depth, substrate size) and causes of pool formation. Habitats exhibiting lengths less than the wetted width of the channel (~ 5 m) were not mapped as individual habitat units.

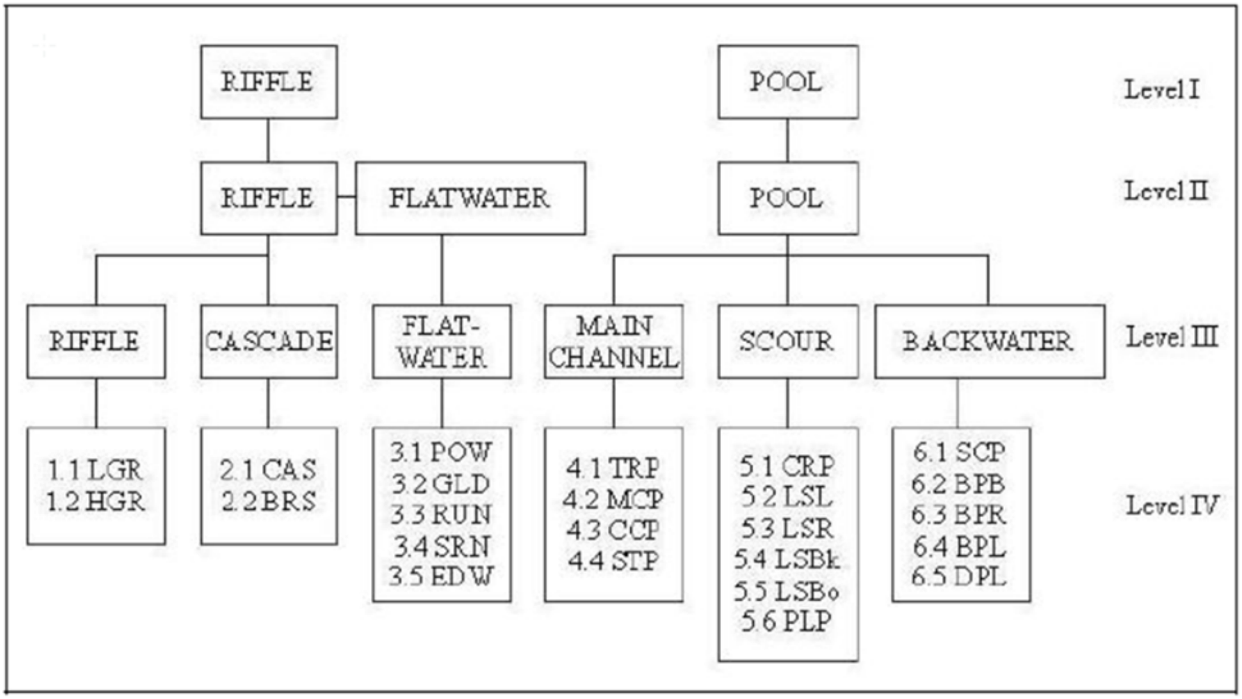

Figure 3. A summary of the habitat type hierarchy in each of the four levels defined by the California Salmonid Stream Habitat Restoration Manual (CDFG 2010). Figure taken from CDFG (2010).

Initial stream reconnaissance identified four dominant habitat types throughout the assessed segment the Little Shasta River. Low gradient riffle (LGR) and run (RUN) habitats appeared as the dominant typologies. Similarly, pool formation throughout the river segments was dominated by lateral scour forced by the presence of root wads (LSR), as well scour associated with bends in the river channel (i.e., corner pools - CRP). Representative pictures of these four habitat types are shown in Figure 4.

Figure 4. Prominent habitat types throughout the study segment of the Little Shasta River. LGR = “low-gradient riffle”; RUN = “run”; LSR = “lateral scour pool – root wad enhanced”; CRP = “corner pool”.

Habitat types were mapped in the field on prints of 1:300 scale color orthophotographs. High-resolution digital elevation model data and hillshade maps were used to identify the channel location on the aerial photographs when the channel was obscured by riparian tree canopy. Following field-mapping, identified habitat units were subsequently digitized in the geographic information system (GIS) ArcMap 10.3.1, allowing for quantification of the areal extent of available habitats and the visualization of habitat distribution throughout the study segment (Figure 5).

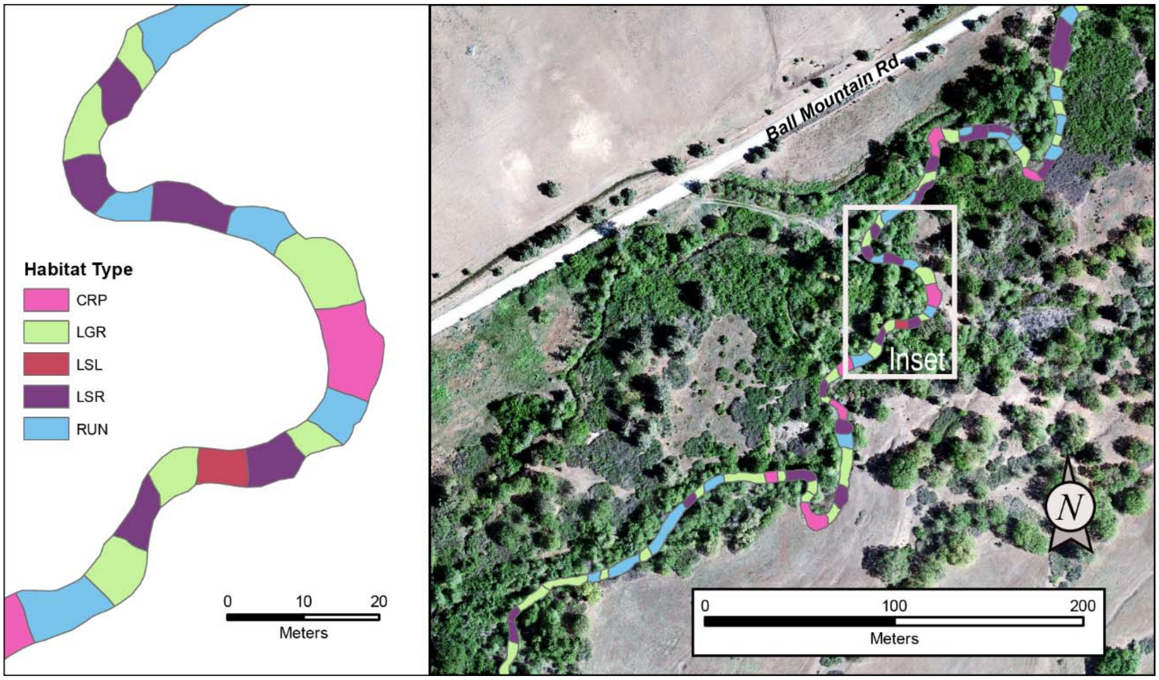

Figure 5. Habitat typing along a reach of the Little Shasta River. Habitat types present within map inset: CRP = "corner pool"; LGR = "low-gradient riffle"; LSL = "lateral scour pool – log enhanced"; LSR = "lateral scour pool – root wad enhanced"; RUN = "run".

Stream flow and water temperature

Stream flow was monitored at three sites during the 2016 field season: site 1 (river kilometer 20.9), site 2 (rkm 19.2), and site 3 (rkm 18.6). At sites 1 and 2, a pressure transducer was placed in a vertical stilling well to record water temperature and river stage (m) at 15-minute samplings intervals between October 1, 2015 and September 30, 2016. Solinst Levelogger pressure transducers have an accuracy of 0.3 cm over a depth range of 0-5 m. Site 3, stage data was provided by The Nature Conservancy.

Periodic discharge measurements were performed across the range of observed stream flows at each monitoring site following standard measurement and computational methods (Rantz 1982). River stage-discharge relationships were quantified using standing rating methodologies (Rantz 1982), from which continuous stream flow time-series were generated. Measured river stages greater than those observed during periodic discharge measurements (and corresponding discharges) were excluded from the streamflow time series.

Food web sampling

Three distinct multi-habitat stream invertebrate samples were collected within the project reach (RK 18.6-20.9) on August 17 and 18, 2016 (site names: "lower", "middle" and "upper"), with each reach measuring 150 m. Sixteen (16) subsamples were then collected at evenly spaced intervals (10 m) within each reach in a downstream to upstream pattern and alternating between river left, center, and right. Alternating locations every 10 m ensured that a diversity of habitat (pool, riffle, run, etc.) was sampled. The pattern was repeated until the end of the reach. For each sample, stream invertebrates were collected using a d-frame kick net (sampling area = 30.48

cm^2; 500 µm mesh) by vigorously disturbing the streambed to a depth of 5 cm for 30 seconds. The 16 resulting subsamples for each sample were then composited into a bucket and elutriated to remove sand, silt, and gravel. Each composite sample (n = 3) was passed through a 250 µm sieve and all retained material was preserved in 95 percent ethyl alcohol and returned to the laboratory for processing and identification.

In the laboratory, each invertebrate sample was randomly subsampled using a Folsom plankton splitter to reach a minimum count of 500 organisms. Stream invertebrates were identified using Merritt et al. (2008), Thorp and Covich (2001), Smith (2001), Wiggins (1996), as well as various taxonomic specific references. Ostracoda, Oligochaeta, and Arachnida were identified to class, while Chironomidae was identified to family. Specimens in poor condition or in very young instars were left at the next highest taxonomic level. We selected five common stream invertebrate metrics including density (number·m^{-2}), taxonomic richness, EPT (Ephemeroptera, Plecoptera and Trichoptera) richness, functional feeding group membership, and organism tolerance values (number sensitive versus tolerant individuals). Details describing each metric is provided in Appendix B. Tolerance values are a measure of an organism's ability to survive and reproduce in the presence of known levels of stressors. Tolerance values range from zero (highly intolerant) to 10 (highly tolerant). We classified sensitive species as those with tolerance values of 0, 1, or 2, while tolerant species were defined as those with values of 7, 8, 9, and 10. Tolerance values are literature based and can be found in Merrit et al. (2008) and Appendix B. Functional feeding group designations are based on how an organism acquires food and include: (i) collectors that gather or filter fine particulate matter, (ii) shredders which consume coarse particulate matter, (iii) grazers which consume epilithon and, (iv) predators, which capture and feed on other consumers. Invertebrate density was calculated using the known area sampled by the d-frame kick net and extrapolating to invertebrates per meter squared. Invertebrate density is a proxy for salmonid food availability.

Results

Habitat mapping

Habitat mapping identified 14 distinct salmonid habitat types throughout the study segment (Table 1, Figure 6). The cumulative area of mapped habitat types (Figure 6) indicated that low gradient riffles (LGR: 5,558 m^2) and runs (RUN: 3,615 m^2) were the most prominent habitats throughout the segment, an observation consistent with pre-mapping reconnaissance. Often, LGR and RUN habitats were co-located, with RUN and LGR habitats transitioning into each other. Of the cumulative habitat area mapped throughout the study segment, 66% was comprised of LGR and RUN habitats. Pool habitats were also quite prevalent throughout the study segment. The dominant pool habitats were "lateral scour pool – root wad enhanced" (LSR; 2,945 m^2), indicating channel obstructions associated with submerged riparian tree roots were a prominent driver of pool formation. Sharp channel bends also produced corner pool (CRP; 579 m^2) habitats adjacent to exposed gravel and cobble point bars.

At selected locations, woody debris (WD) jams controlled channel hydraulics and created complex habitat units comprised of multiple pool types, including upstream dammed pools (DPL), downstream plunge pools (PLP), and mid-channel pools (MCP) (Figure 7). Observed

WD jams were generally considered "combination" jams (Abbe and Montgomery 2003), formed by the collection of water-borne debris on in-situ "key members" derived from local tree fall. Some WD jams deflected flow, while others spanned the entire low flow channel width. While habitats within and adjacent to LWD exhibited the most morphologically and hydraulically diverse habitat conditions, the areal extent of these habitat comprised less than 2% of the total habitat area throughout the study segment.

Table 1. Habitat types identified along the Little Shasta River study segment

Level III and IV habitat types	
BPL	Backwater Pool - Log Formed
BPR	Backwater Pool - Root Wad Formed
CRP	Corner Pool
DPL	Dammed Pool
EDW	Edgewater
HGR	High Gradient Riffle
LGR	Low Gradient Riffle
LSL	Lateral Scour Pool - Log Enhanced
LSR	Lateral Scour Pool - Root Wad Enhanced
MCP	Mid-Channel Pool
PLP	Plunge Pool
RUN	Run
SCP	Secondary Channel Pool
SRN	Step Run

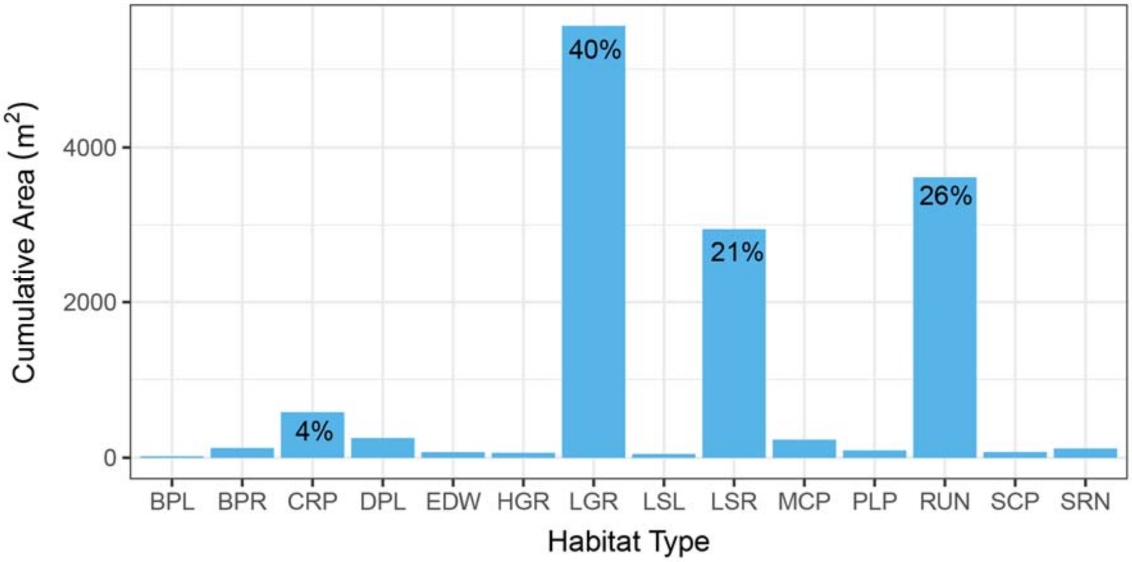

Figure 6. Cumulative area (m^2) of habitats types present throughout the entire 2.3 km study segment (RK 18.6 to 20.9). The percentage of cumulative total habitat area is presented for the following habitat types: CRP = "corner pool"; LGR = "low-gradient riffle"; LSR = "lateral scour pool – root wad enhanced"; RUN = "run". Each of the remaining habitat types represent less than 2% of cumulative habitat area mapped throughout the study segment.

Figure 7. Little Shasta River habitats associated with woody debris jams.

One notable feature was the presence of a potential passage barrier, the Musgrave diversion, at rkm 19.1. Approximately 86% of all habitat, and 89% of pool habitat, is located upstream of the Musgrave diversion. Additional work is underway to assess the potential effect of the Musgrave diversion on discrete coho life stages.

Stream flow and water temperature

Rating curves were developed at each of the three stream flow monitoring sites. High flows during January 2016 dislodged stage gages at sites 1 and 2; rating curves at those sites were developed using data from February through November 2016 (Table 2). At site 1, rated flows ranged from 4.3 ft^3/s to 70.6 ft^3/s; at site 2, rated flows ranged from 4.2 ft^3/s to 59.2 ft^3/s. At site 3, stage data was provided from December 2015 through October 2016; rated flows ranged from 0.8 ft^3/s to 64.8 ft^3/s. Rating curves for each site are presented in Appendix A.

Table 2. A summary of the maximum and minimum flow rated for each monitoring site, and the period of record included in the calculated time series discharge.

Site # (rkm)	Minimum	Maximum	Period
Site 1 (20.9)	4.3	70.6	02/16-11/10/2016
Site 2 (19.2)	4.2	59.2	02/16-11/10/2016
Site 3 (18.6)	0.8	64.8	12/15/15-10/20/2016

Calculated stream flow and measured water temperature data from site 1 (rkm 20.9) are presented to illustrate the general patterns observed at all three monitoring sites (Figure 8). Stream flow continues to show the same flashy winter precipitation/snowmelt runoff pattern that was observed in 2015, followed by a gradual decline through the spring and early summer to baseflow. The snow-water content during the 2016 monitoring period was a stark contrast to the unprecedented zero-snowpack conditions of 2015 (Nichols et al. 2016); on April 1, 2016, the snow-water content at the Little Shasta River gage was 130% of normal. Peak stream flows during the winter rainfall-runoff events exceeded the rating curve for each site; rapid flow changes during winter precipitation events made catching peak flow measurements challenging. The snowmelt recession persisted until July 2016, after which baseflow persisted through

October 2016, the end of the monitoring period. Plots of calculated stream flow and measured water temperatures for sites 2 and 3 are included in Appendix A.

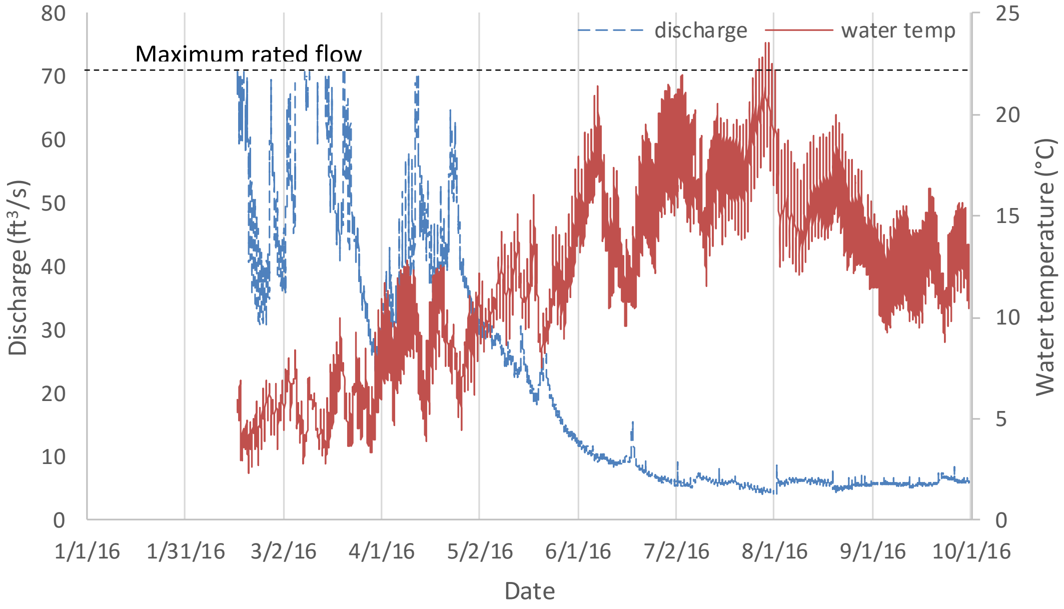

Figure 8. Stream flow (calculated) and water temperature (measured) at site 1 (rkm 20.9) for the 2016 monitoring season.

Though stream flow patterns were generally similar at each monitoring site, high flows and backwater effects prevented a full characterization of stream flow for the study reach. During winter (January through March), flows exceeded those were measured at all three sites. In addition, a downstream flashboard dam created backwater effects at site 3. River stage increased due to the backwater effect and was “interpreted” as high flow by the rating curve. As a result, continuous stream flows could not be accurately assessed at this site from February through June 2016. However, backwater effects seemed to be negligible by late summer; a time series of stream flow was calculated from July 1-September 30, 2016 at site 3 (Supplemental data).

Stream flow changes were examined between each monitoring site. Diversions reduced the amount of flow at downstream sites. Average monthly stream flow decreased an average of 1.8 ft^3/s from site 1 to site 2, and 2.3 ft^3/s from site 2 to site 3 (Table 3). While the channel remained wet throughout the study period, minimum flows at sites 1-3 were approximately 1-4 ft^3/s. These flows were consistent with baseflows observed during the 2015 assessment (Nichols et al. 2016).

Table 3. A summary of monthly maximum, minimum, and average stream flow (calculated) and water temperature (measured) at sites 1, 2, and 3.

	Stream flow (ft^3/s)			**Water temperature (°C)**		
Site 1	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**
FEB	>70.7*	30.7	48.8	6.9	2.3	4.7
MAR	>70.7*	23.2	46.5	10.4	2.8	5.9
APR	70.1	24.2	41.4	12.8	3.9	8.7
MAY	32.9	12.1	22.9	17.3	7.6	11.4
JUN	15.5	5.6	9.0	21.5	9.6	15.4
JUL	9.2	4.3	5.8	23.5	11.5	17.5
AUG	8.8	4.3	5.8	22.2	11.4	15.6
SEP	8.5	5.2	6.0	16.4	8.8	12.4
Site 2	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**
FEB	>59.2*	41.5	51.0	7.4	2.3	5.0
MAR	>59.2*	23.3	42.8	10.7	2.9	6.1
APR	58.7	24.5	35.0	13.2	4.1	9.0
MAY	33.3	10.9	22.3	17.6	7.7	11.6
JUN	15.0	4.1	7.8	22.0	9.8	15.9
JUL	7.1	2.2	4.4	24.4	11.8	18.2
AUG	6.7	2.3	4.1	23.0	11.9	16.7
SEP	7.2	3.8	4.8	16.5	8.8	12.9
Site 3	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**
FEB	na	na	na	9.2	2.9	7.5
MAR	na	na	na	11.7	3.1	7.1
APR	na	na	na	13.3	4.3	9.2
MAY	na	na	na	18.0	8.0	12.0
JUN	na	na	na	23.3	10.2	14.6
JUL	6.6	1.0	1.8	26.0	12.2	18.9
AUG	7.6	1.0	1.9	24.4	12.6	17.6
SEP	17.8	1.6	2.6	17.5	9.1	13.5

*highest rated discharge for this site; actual flows exceeded rating curve

Water temperatures in the Little Shasta River were examined for seasonal patterns to identify general periods of heating and cooling, as well as the distribution of water temperatures for each month during the monitoring period. Water temperatures in July and August were more closely examined at each site as the period coincided with seasonally elevated water temperatures and minimum stream flow conditions. Consistent with the 2015 assessment, water temperatures exceeding 20°C were examined; previous studies have used 20°C (as an instantaneous metric (USEPA 2003)) as a guideline to distinguish between desirable and elevated water temperature for salmonid cold-water aquatic habitat. On-going studies suggest that site-specific water temperature thresholds are context-specific and may be strongly influenced by food availability (i.e., macroinvertebrates) – that is, if food resources are sufficient, fish may be able to tolerate higher stream temperatures. A preliminary macroinvertebrate analysis is included in this study, and is part of on-going research in the Little Shasta River.

Water temperatures during the 2016 monitoring period followed similar patterns to those observed during the 2015 assessment (Nichols et al. 2016). Water temperatures generally increased until July, then decreased (Figure 9). At site 1, water temperatures ranged between 15.5-19.3°C in July (25th-75th percentile temperature range), with an annual maximum of 23.5°C. Water temperatures exceeded 20°C approximately 10% of July and less than 3% of August. At site 2, water temperatures ranged between 16.6°C and 19.9°C in July (25th-75th percentile temperature range), with an annual maximum of 24.4°C. Water temperatures exceeded 20°C approximately 25% of July and 3% of August. At site 3, water temperatures ranged from 16.9°C to 20.8°C (25th-75th percentile temperature range), with an annual maximum of 26.0°C. Water temperatures exceeded 20°C approximately 25% in July and 10% in August. These temperatures were warmer compared to the annual maximums observed in the 2015; factors contributed to the elevated water temperatures could include reduced streamflow, interannual variability, and compounded effects on groundwater and surface water availability due to the extended drought.

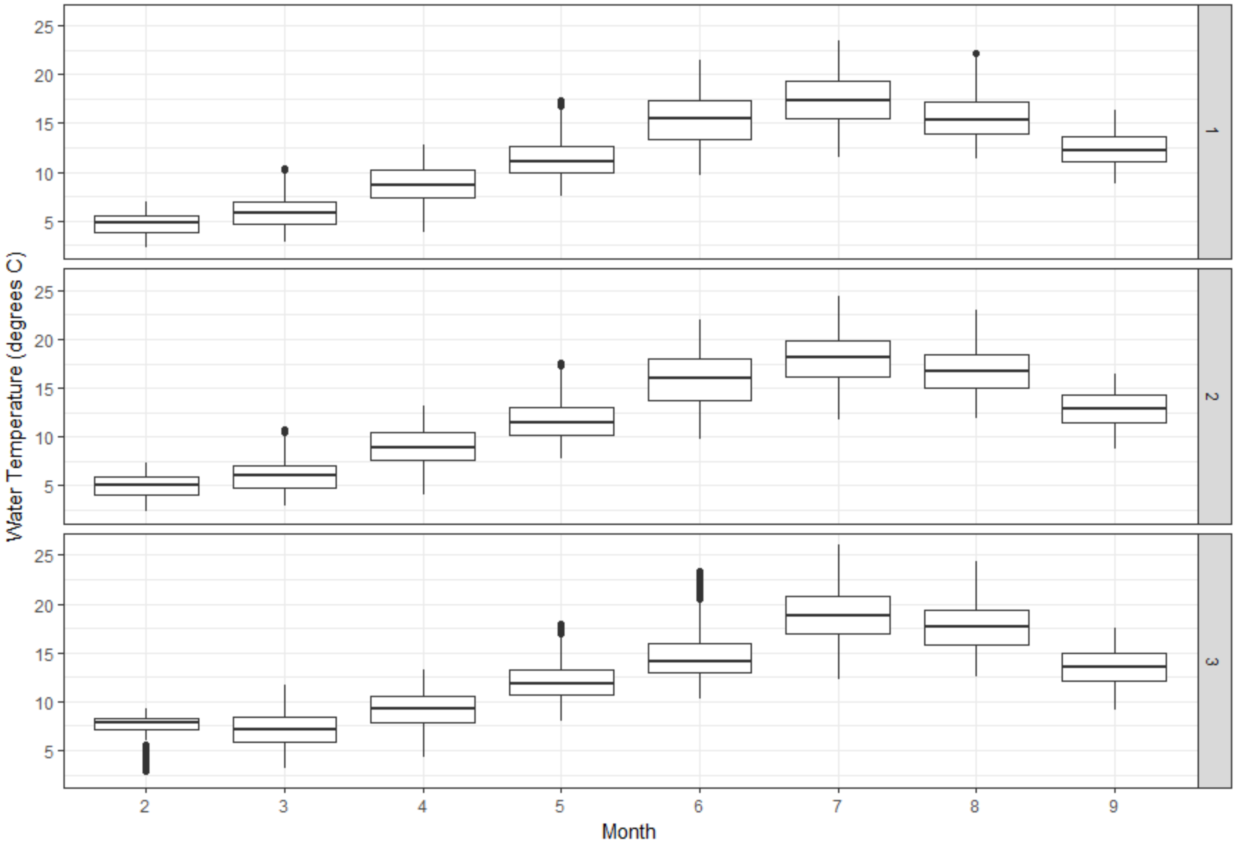

Figure 9. Interquartile distribution of observed water temperature, by month, at each of the three stage/water temperature monitoring sites. Boxes indicate 25th, 50th, and 75th percentile distributions; black dots indicate outliers.

A closer examination of water temperatures in July and August show that elevated (>20°C) water temperatures tended to coincide with periods of minimal baseflow and persistent warming. At site 1, the first day when water temperatures exceeded 20°C was June 7, though multiple days of consecutive elevated temperatures began towards the end of June (Table 4). Periods of the longest consecutive days extended from the end of June into the beginning of July, and again at the end of July through early August. At site 1, the annual maximum water temperature occurred after seven days of persistent warming from July 23 to July 30 (Figure 10). However, while maximum temperatures were elevated, this period also illustrated the greatest diurnal variation (i.e., the difference between the warmest and coolest daily water temperature), with an average of 5.8°C. This was above the average diurnal variation (4.8°C) for the period July 1-September 30, 2016. Maximum water temperatures then declined and, beginning August 2, remained under 20°C for the rest of the monitoring period. During this time, baseflows remained relative stable, between 4.3-9.2 ft^3/s (average 5.8 ft^3/s). Similar patterns were observed at sites 2 and 3; plots of their observed water temperatures and calculated stream flow during July and August are included in Appendix A. Additional work is underway to identify management alternatives that may reduce maximum water temperatures during targeted periods when temperatures increase over consecutive days.

Table 4. A summary of the number of days when water temperatures exceeded 20°C.

Month	# days exceeding 20°C (# consecutive days)
April	0 (0)
May	0 (0)
June	6 (9*)
July	14 (9*†)
August	3 (9†)
September	0 (0)
Total	**23**

*number of consecutive days extended from June 27-July 5, 2016; † July 25-August 2, 2016

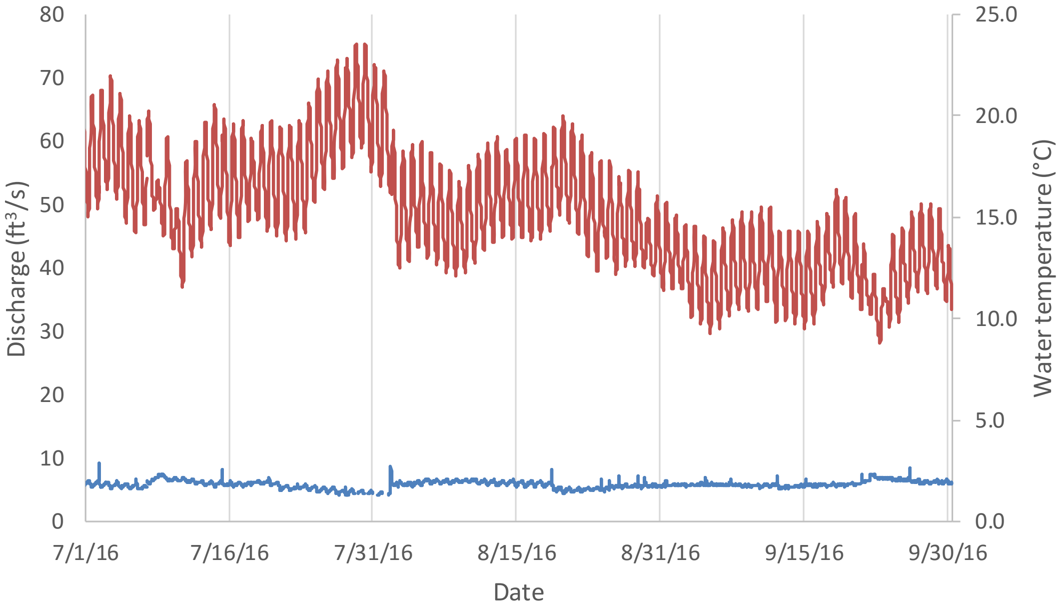

Figure 10. Stream flow (calculated-blue) and water temperature (observed-red) at site 1 in the Little Shasta River for July and August during the 2016 study period.

Food web sampling

Mean density and taxa richness of stream invertebrates for the entire study reach was 2,741 individuals·m^{-2} (SE = 690) and 32 taxa (SE = 0.66). The middle reach exhibited approximately a two-fold increase in invertebrate density when compared with lower and upper reaches, but we found little difference in taxa richness between reaches (Figure 11). Mean EPT richness was 14 taxa (SE = 0.66), but similarly showed little difference between the sampled reaches. Mayflies, caddisflies, and stoneflies showed significant contributions to the invertebrate assemblage as did several sensitive taxa. Sensitive taxa accounted for up to 23% (upper reach) of the entire stream invertebrate assemblage (mean percentage = 16.7%). The reach supported several highly sensitive species including, *Epeorus (*family: Heptageniidae*), Lepidostoma (*family: Lepidostomatidae*), Glossosoma (*family = Glossosomatidae*),* and *Zapada (*family: Neumoridae). Conversely, very few tolerant taxa were found throughout the study reach.

Functional feeding groups were represented throughout the project reach (Figure 12). Generally, collectors (collectors, gatherers, and filterers) dominated the study reaches accounting for up to ~67% of the entire assemblage. This suggests that fine particulate organic matter is an important food resource fueling the production of invertebrates throughout the study reach. Grazers were most dominant in the lowest reach sampled (i.e., immediately above the Hart/Haight diversion), suggesting that autotrophic production of epilithic algae was an important downstream invertebrate food resource. Shredders also showed differences in their relative abundance depending on reach. Shredders were most dominant in the upper reach of the project site, suggesting that coarse particulate matter is likely an important food resources there. High shredder densities are typical of forested headwater streams and are consistent with the predictions of the River Continuum Concept and functioning stream ecosystems (Vannote et al. 1980).

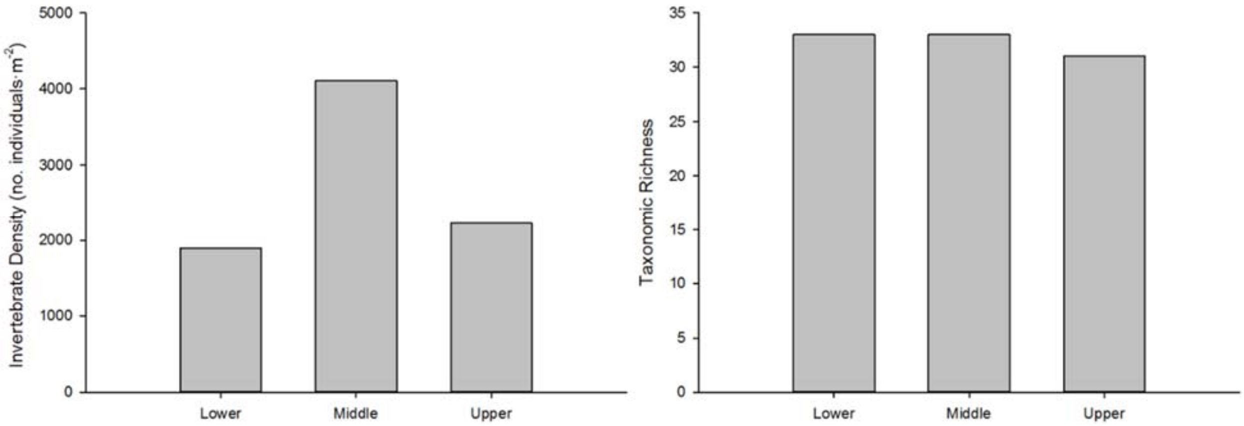

Figure 11. Invertebrate density and taxonomic richness over three reaches on the Little Shasta River between rkm 18.6 and 20.9. Lower, middle and upper represent three distinct sample reaches sampled with the project reach.

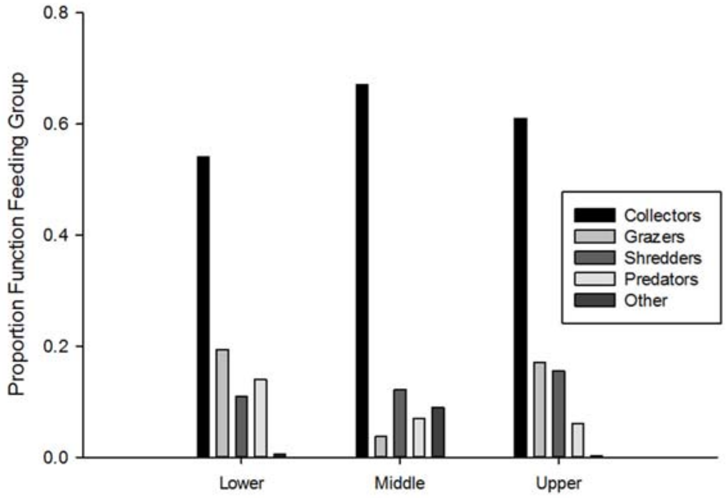

Figure 12. Proportion function feeding groups associated with three reaches on the Little Shasta River between rkm 18.6 and 20.9. Lower, middle and upper represent three distinct sample reaches sampled with the project reach.

Conclusions and recommendations

Conservation activities in the Shasta River basin have generally addressed two major issues. First, a lack of physical habitat that could support anadromous fish, and second, a lack of fish to utilize that habitat. The findings of this study identify a notable distinction for the Little Shasta River in the context of broader conservation efforts:

Whereas many projects have had to rehabilitate habitat prior to reintroducing anadromous fish, the study reach of the Little Shasta River already provides quality habitat for salmonids, as well as other coldwater fishes.

An examination of structural, thermal, and macroinvertebrate data shows that these critical elements overlap to create desirable habitat conditions. Key findings include:

- During low water, summertime periods (1.8-6.0 ft^3/s), habitat conditions between rkm 18.6 and 20.9 is dominated by low-gradient riffle (40%), run (26%), and a mosaic of “pool” (32%) habitats. Flow obstruction by root-wads of riparian trees was the dominant mechanism of pool formation (67%) throughout the study segment. The most complex aquatic habitats identified throughout the study reach were associated with WD jam structures. High flows during 2017 have transported substantial amounts of WD, and preliminary observations show that the channel has altered since the 2016 assessment. However, <2% of the habitat area in the study segment exhibited habitat types formed through interactions of streamflow with WD structures.
- Though elevated water temperatures (>20°C) occurred in the Little Shasta River, in general, aquatic habitat upstream of site 2 remained desirable through the study period. These initial results suggest that the Little Shasta River provides important oversummering habitat for coho during low flows.

- A high diversity of stream invertebrates were present at moderate densities. While densities are less than those observed on the Shasta River and Big Springs Creek (see Nichols et al. 2008), densities are similar to other snowmelt rivers in adjacent watersheds. The project reach supported a highly diverse assemblage with numerous sensitive taxa, characteristic of a functioning stream ecosystem capable of supporting juvenile salmonid rearing.

Several factors may limit full utilization of this high quality habitat by anadromous fish. The primary impairment remains insufficient stream flow at various downstream reaches (outside of the study area) during periods when migrating fish require connectivity to move between habitats. Qualitative field observations suggest that within the study reach, water depths on low gradient riffles throughout the study segment would not impede upstream or downstream movement of rearing fish. However, the Musgrave diversion structure may limit passage for salmonids.

Based on the habitat typing and food web data, the following recommendations identify data needed to further identify habitat suitability for cold-water salmonids throughout all life stages:

- Continue monitoring snow course, stream flow, and water temperature conditions; habitat inventories; and food web sampling to track interannual variability of available habitat. Characterize food availability during winter;

- Monitor vertical variability of water temperature in pool habitat to determine whether thermal refugia are present;

- Use detailed topographic and water surface elevation surveys (e.g. Willis et al., 2015) of representative pool habitats to help quantify holding capacity for rearing juvenile salmonids during periods of lower flow;

- Conduct repeated snorkel surveys to identify the fish assemblage and determine habitat usage and preference. Study fish movement, potentially using rainbow trout as surrogates for coho salmon, to understand potential passage limitations or habitat preferences.

- 89% of pool habitat is located upstream of the Musgrave diversion. Passage should be assessed at this site.

References

Abbe, T. B., & Montgomery, D. R. (2003). Patterns and processes of wood debris accumulation in the Queets river basin, Washington. Geomorphology, 51(1), 81-107.

CADFG. 2010. California salmonid stream habitat restoration manual, Fourth Edition, Volume 1, Part III.

Jeffres, C. A., Buckland, E., Hammock, B., Kiernan, J. D., King, A. M., Krigbaum, N., Nichols, A. L., Null, S. E., Deas, M. L., Mount, J. F., and Moyle, P. B., 2008, Baseline Assessment of Salmonid Habitat and Aquatic Ecology of the Nelson Ranch, Shasta River, California, Water Year 2007. Prepared for the United States Bureau of Reclamation, Klamath Area Office.

McBain & Trush, I. 2013. Study plan to assess Shasta River salmon and steelhead recovery needs.

Merritt, R. W., K. W. Cummins, and M. B. Berg. 2008. An introduction to the aquatic insects of North America. 4th edition. Kendal/Hunt Publ. Co., Dubuque, IA.

NCRWQCB. 2006. Staff Report for the Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Loads. Santa Rosa, CA.

Nichols, A. L., Jeffres, C. A., Willis, A. D., Corline, N. J., King, A. M., Lusardi, R. A., Deas, M. L., Mount, J. F., and Moyle, P. B. 2010. Longitudinal Baseline Assessment of Salmonid Habitat Characteristics of the Shasta River, March to September, 2008. Prepared for U.S. Bureau of Reclamation Klamath Basin Area Office by U.C. Davis Center for Watershed Sciences and Watercourse Engineering, Inc.

Nichols, A. L., Willis, A. D., Lambert, D., Limanto, E., and Deas, M. L. 2016. Little Shasta River Hydrologic and Water Temperature Assessment: April to December 2015. Report prepared for The Nature Conservancy.

NOAA. 2012. SONCC Coho Recovery Plan (DRAFT). Prepared by National Marine Fisheries Service, Southwest Regional Office.

NRC. 2004. Endangered and Threatened Fishes in the Klamath River Basin: Causes of Decline and Strategies of Recovery, The National Academies Press, The National Academies Press, Washington, DC.

Rantz, S.E., 1982. Measurement and computation of streamflow: volume 2, computation of discharge (No. 2175). USGPO,.Smith, D. G. 2001. Pennak's freshwater invertebrates of the United States. John Wiley and Sons, New York, New York.

Thorp, J. H., and A. P. Covich. 2001. Ecology and classificant of North American freshwater invertebrates. Academic Press, San Diego, CA.

USEPA. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E., 1980. The river continuum concept. Canadian journal of fisheries and aquatic sciences, 37(1), pp.130-137.

Wiggins, G. B. 1996. Larvae of the North American caddisfly genera (Trichoptera). 2nd edition. University of Toronto Press, Toronto, Canada.

Willis, A. D., Campbell, A. M., Fowler, A. C., Babcock, C. A., Howard, J. K., Deas, M. L., and Nichols, A. L. 2015. Instream flows: New tools to quantify water quality conditions for returning adult Chinook salmon: Journal of Water Resources Planning and Management, v. 142, no. 2, p. 04015056.

Willis, A. D., and Deas, M. L. 2012. Response to restoration: Water temperature conditions in Big Springs Creek and surrounding waterways, 2009-2011; A report for The Nature Conservancy, prepared by Watercourse Engineering, Inc., September 2012. .

Willis, A. D., Deas, M. L., Jeffres, C. A., Mount, J. F., Moyle, P. B., and Nichols, A. L., 2012, Executive Analysis of Restoration Action in Big Springs Creek, March 2008-September 2011, prepared for National Fish and Wildlife Foundation.

Appendix A Habitat typing

Habitat typing was completed using the methods defined in the California Salmonid Stream Habitat Restoration Manual (CDFG 1998). These methods categorize habitat using a four-level system, with each level providing more detailed descriptions of pool or riffle habitat. The most detailed level, Level IV, identifies 24 habitat types, which were used to categorize habitat in the Little Shasta River (Table A-1).

Table 5. The name, abbreviation, and description of the 24 habitat types defined in the California Salmonid Stream Habitat Restoration Manual (CDFG 1998). Level IV habitat types are grouped by the Level III categories. Habitat types with an asterisk (*) indication those most commonly identified in the Little Shasta River study reach. Table recreated from CDFG (1998).

Habitat type	Abbreviation	Description
RIFFLE		
*Low Gradient Riffle	LGR	Shallow reaches with swiftly flowing, turbulent water with some partially exposed substrate. Gradient <4%, substrate is usually cobble dominated.
High Gradient Riffle	HGR	Steep reaches of moderately deep, swift, and very turbulent water. Amount of exposed substrate is relatively high. Gradient is >4%, and substrate is boulder dominated.
CASCADE		
Cascade	CAS	The steepest riffle habitat, consisting of alternating small waterfalls and shallow pools. Substrate is usually bedrock and boulders.
Bedrock Sheet	BRS	A thin sheet of water flowing over a smooth bedrock surface. Gradients are highly variable.
FLATWATER		
Pocket Water	POW	A section of swift-flowing stream containing numerous boulders or other large obstructions which create eddies or scour holes (pockets) behind the obstructions.
Glide	GLD	A wide, uniform channel bottom. Flow with low to moderate velocities, lacking pronounced turbulence. Substrate usually consists of cobble, gravel, and sand.
*Run	RUN	Swiftly flowing reaches with little surface agitation and no major flow obstructions. Often appears as flooded riffles. Typical substrate consists of gravel, cobble, and boulders.
Step Run	SRN	A sequence of runs separated by short riffle steps. Substrate is usually cobble and boulder dominated.
Edgewater	EDW	Quiet, shallow area found along the margins of the stream, typically associated with riffles.

		Water velocity is low and sometimes lacking. Substrate varies from cobbles to boulders.
MAIN CHANNEL POOL		
Trench Pool	TRP	Channel cross sections typically U-shaped with bedrock or coarse grained bottom flanked by bedrock walls. Current velocities are swift and the direction of flow is uniform.
Mid-Channel Pool	MCP	Large pools formed by mid-channel scour. The scour hole encompasses more than 60% of the wetted channel. Water velocity is slow, and the substrate is highly variable.
Channel Confluence Pool	CCP	Large pools formed at the confluence of two or more channels. Scour can be due to plunges, lateral obstructions or scour at the channel intersections. Velocity and turbulence are usually greater than those in other pool types.
Step Pool	STP	A series of pools separated by short riffles or cascades. Generally found in high-gradient, confined mountain streams dominated by boulder substrate.
SCOUR POOL		
*Corner Pool	CRP	Lateral scour pools formed at a bend in the channel. These pools are common in lowland valley bottoms where stream banks consist of alluvium and lack hard obstructions.
L. Scour Pool – Log Enhanced	LSL	Formed by flow impinging against a partial channel obstruction consisting of large woody debris. The associated scour is generally confined to <60% of the wetted channel width.
*L. Scour Pool – Root Wad Enhanced	LSR	Formed by flow impinging against a partial channel obstruction consisting of a root wad. The associated scour is generally confined to <60% of the wetted channel width.
L. Scour Pool – Bedrock Formed	LSBk	Formed by flow impinging against a bedrock stream bank. The associated scour is generally confined to <60% of the wetted channel width.
L. Scour Pool – Boulder Formed	LSBo	Formed by flow impinging against a partial channel obstruction consisting of a boulder. The associated scour is generally confined to <60% of the wetted channel width.
Plunge Pool	PLP	Found where the stream passes over a complete or nearly complete channel obstruction and drops steeply into the streambed below, scouring our a depression; often large and deep. Substrate size is highly variable.
BACKWATER POOLS		

Secondary Channel Pool	SCP	Pools formed outside of the average wetted channel width. During summer, these pools will dry up or have very little flow. Mainly associated with gravel bars and may contain sand and silt substrate.
Backwater Pool – Boulder Formed	BPB	Found along channel margins and caused by eddies around a boulder obstruction. These pools are usually shallow and are dominated by fine-grain substrate. Current velocities are quite low.
Backwater Pool – Root Wad Formed	BPR	Found along channel margins and caused by eddies around a root wad obstruction. These pools are usually shallow and are dominated by fine-grained substrate. Current velocities are quite low.
Backwater Pool – Log Formed	BPL	Found along channel margins and caused by eddies around a large woody debris obstruction. These pools are usually shallow and are dominated by fine-grained substrate. Current velocities are quite low.
Dammed Pool	DPL	Water impounded from a complete or nearly complete channel blockage (log debris jams, rock landslides or beaver dams). Substrate tends to be dominated by smaller gravel and sand.

Appendix B Macroinvertebrate metrics

Table 6. A summary of the macroinvertebrate metrics and their expected response to general disturbances.

Macroinvertebrate Metric	**Metric Description**	**Expected Response to Disturbance**
Density	Number or organisms per m^2.	Decrease
Taxonomic Richness	Total number of unique taxa (genus level taxonomic resolution in most cases).	Decrease
EPT Richness	Number of taxa in the orders Ephemeroptera, Plecoptera, and Trichoptera.	Decrease
Functional Feeding Groups	Proportion of the macrobenthos that acquire food through collecting, grazing, shredding, or are predators.	Variable
Tolerance Values	Value between 0 and 10 weighted by abundance of individuals with designated tolerances derived from the literature.	Increase

Table 7. A summary of the macroinvertebrates sampled in the Little Shasta River study reach. Details regarding functional feeding groups (FFG) and tolerance values are provided where available.

Phylum	**Class**	**Order**	**Family**	**Genus**	**FFG**	**Tolerance Values**
Arthropoda	Insecta	Ephemeroptera	Baetidae	Baetis	CG	5
				Callibaetis		
				Diphetor	CG	
				Pseudocloeon		5
			Ephemerellidae	Serratella	CG	1
			Heptageniidae	Epeorus	SC	1.5
			Leptophlebiidae	Paraleptophlebia	CG	4
		Plecoptera	Chloroperlidae	Sweltsa	P	1
			Nemouridae	Zapada	SH	2
			Perlidae	Calineuria	P	2
				Hesperoperla	P	1
			Perlodidae	Skwala	P	2
		Hemiptera	Corixidae	Trepobates (A)	P	10
		Trichoptera	Brachycentridae	Micrasema (L)	SH	1
			Glossosomatidae	Glossosoma (L)	SC	0

Phylum	**Class**	**Order**	**Family**	**Genus**	**FFG**	**Tolerance Values**
				Glossosoma (P)		
			Hydropsychidae	Ceratopsyche (L)	CF	4
				Hydropsyche (L)	CF	4
			Hydroptilidae (L)	Ochrotrichia (L)	PH	4
				Ochrotrichia (P)	PH	4
			Lepidostomatidae	Lepidostoma (L)	SH	1
			Limnephilidae	Psychoglypha (L)	SH	2
			Rhyacophilidae	Rhyacophila (L)	P	1
			Uenoidae (P)		SC	0
		Megaloptera	Sialidae	Sialis (L)	P	4
		Coleoptera	Elmidae (L)	Ampumixis (L)	CG	4
				Cleptelmis (L)	CG	4
				Cleptelmis (A)	CG	4
				Optioservus (L)	SC	4
				Optioservus (A)	CG	4
				Ordobrevia (A)	CG	4
				Zaitzevia (L)	CG	4
				Zaitzevia (A)	CG	4
			Psephenidae	Psephenus (L)	SC	4
		Diptera	Chironomidae		CG	6
			Empididae (L)	Chelifera (L)	P	6
			Simuliidae	Simulium (L)	CF	6
			Simuliidae	Simulium (P)		
			Tipulidae	Dicranota (L)	P	3
		Odonata	Calopterygidae	Hetaerina	P	
			Coenagrionidae	Argia	P	7
			Gomphidae	Octogomphus	P	1
	Crustacea	Ostracoda			CG	8
	Arachnida	Trombidiformes			P	8
Mollusca	Gastropoda		Physidae	Physa	SC	8
			Planorbidae	Ferrissia	SC	6
			Pleuroceridae	Juga	SC	7
	Bivalvia	Veneroida	Sphaeriidae		CF	8
Annelida	Oligochaeta				CG	5

Appendix C Supplemental data

Rating curves

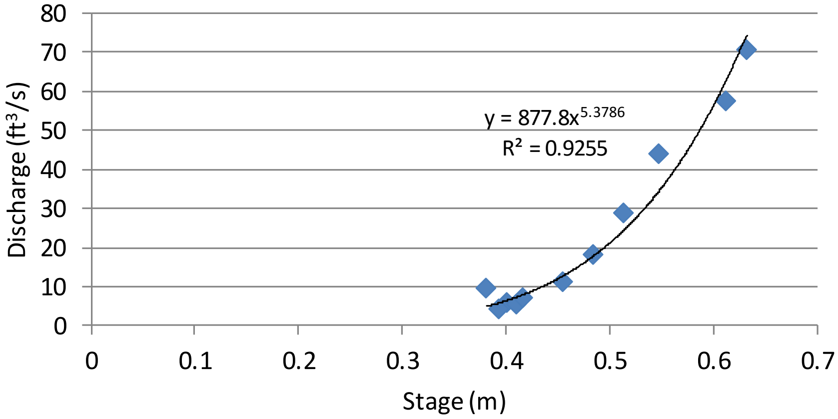

Figure B-1. Rating curve to calculate stream flow at rkm 20.9 from February-October 2016.

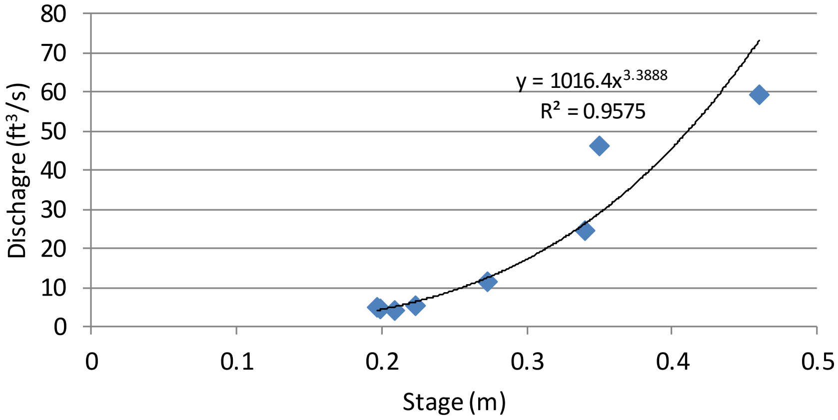

Figure B-2. Rating curve to calculate stream flow at rkm 19.2 from February-October 2016.

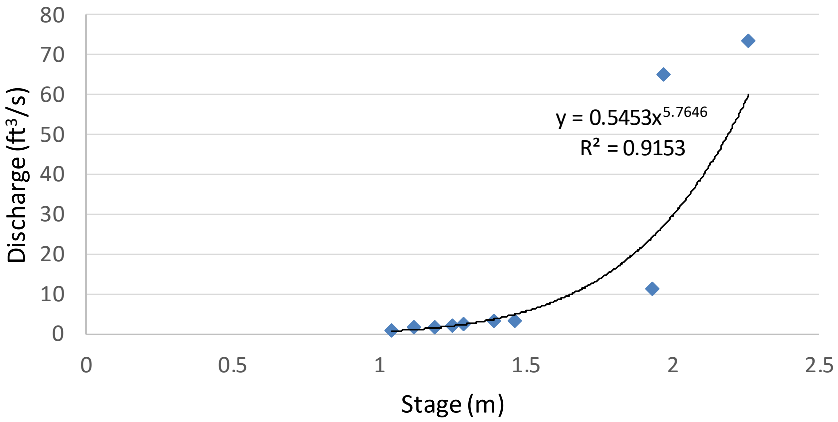

Figure B-3. Rating curve to calculate stream flow at rkm 18.6 from February-October 2016.

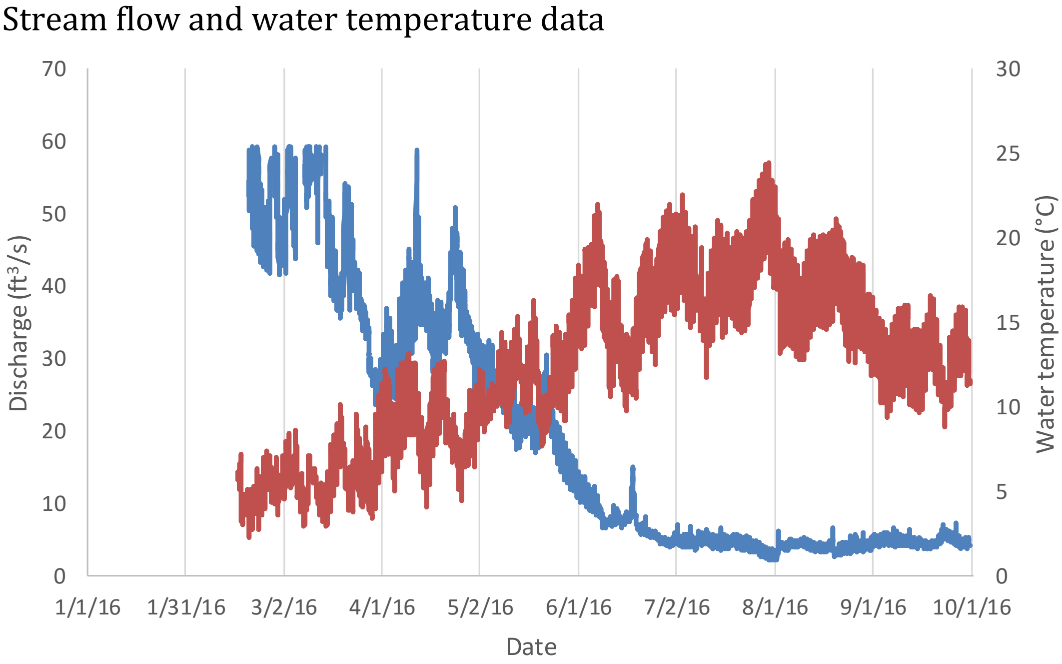

Figure B-4. Stream flow (calculated) and water temperature (measured) at rkm 19.2 for the 2016 monitoring season.

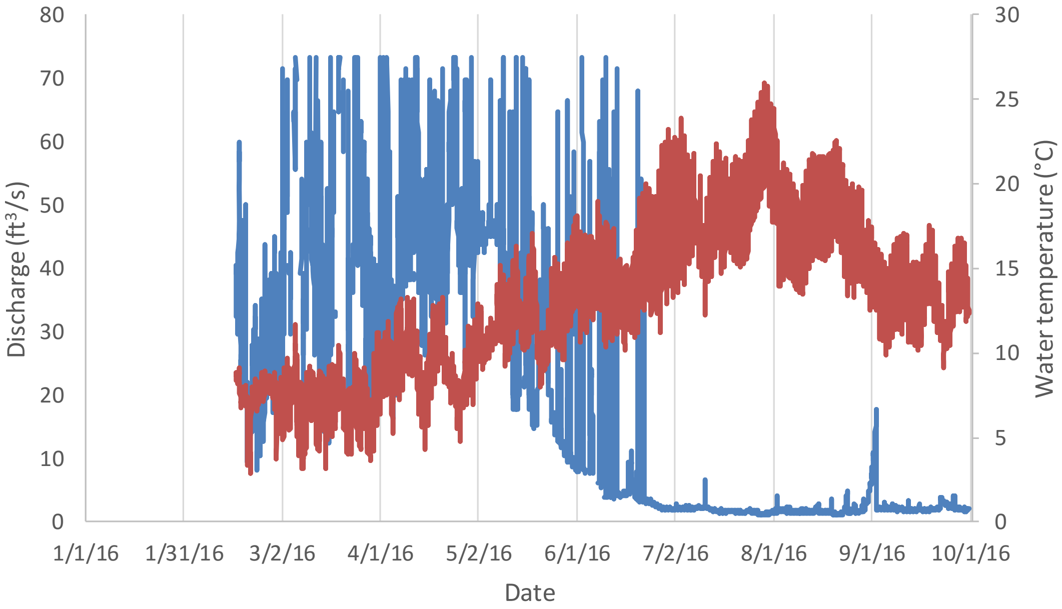

Figure B-5. Stream flow (calculated) and water temperature (measured) at rkm 18.6.

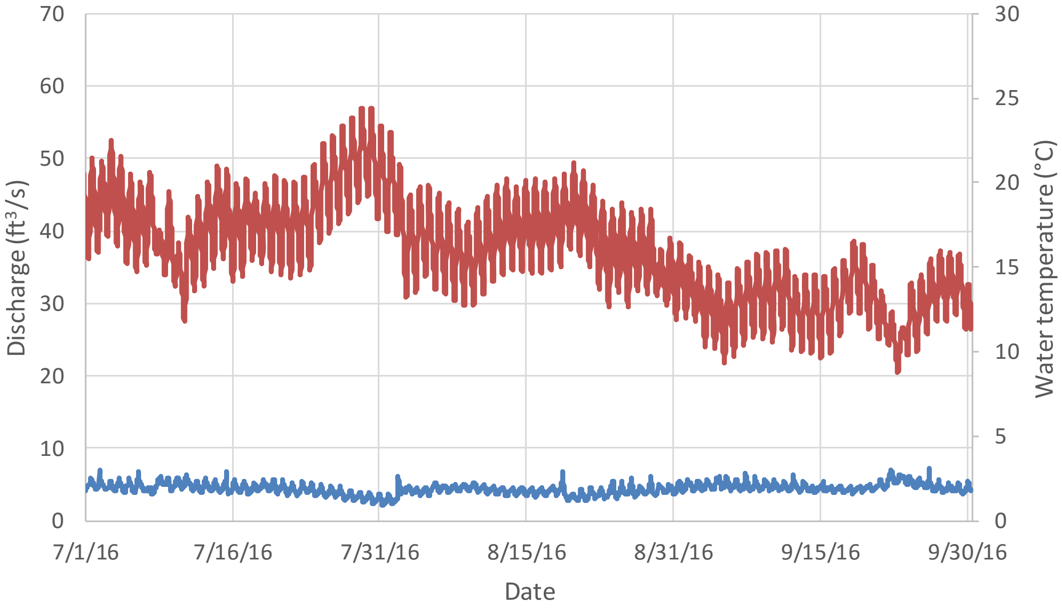

Figure B-6. Stream flow (calculated) and water temperature (observed) at site 2, rkm 19.2, in the Little Shasta River for July and August 2016.

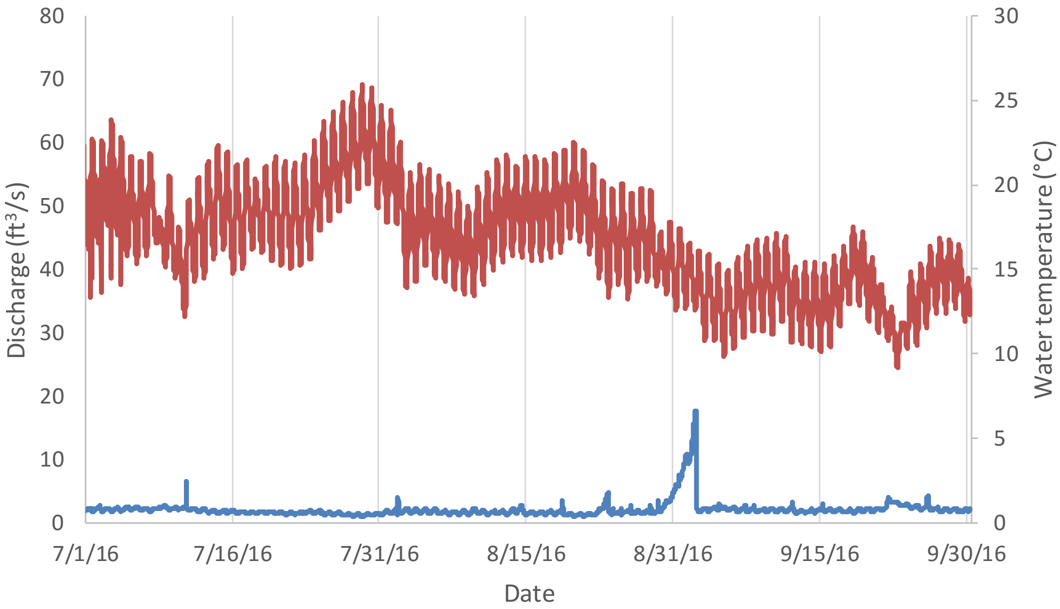

Figure B-7. Stream flow (calculated) and water temperature (observed) at site 3, rkm 18.6, in the Little Shasta River for July and August 2016.