Scott River Beaver Dam Analogue Coho Salmon Habitat Restoration Program 2017 Monitoring Report

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Executive Summary and Key Findings

This report summarizes the Scott River Beaver Dam Analogue Restoration Project monitoring and adaptive management efforts for the 2017 calendar year and is intended to meet reporting requirements for California Department of Fish and Wildlife and North Coast Regional Water Quality Control Board permits issued and National Fish and Wildlife Foundation, US Fish and Wildlife Service and Klamath River Coho Enhancement funds allocated for this project. Additional reporting information can be found in the three Scott River Watershed Council 2017 construction, maintenance and adaptive management reports for beaver dam analogues: (1) Mid-French Side Channel BDA 2017 Construction and Adaptive Management Report; (2) Miners Creek BDA Summer/Fall 2017 Maintenance and Adaptive Management Field Note. and (3) Sugar Creek BDA Summer 2017 Field and Adaptive Management Note. Full citations are provided in the Reference section at the end of this document.

The Sugar Creek BDA restoration site showed continued improvement in most measured biological and physical habitat conditions.

- The habitat rearing capacity for juvenile coho salmon increased by 8% to a total of 7,493 juvenile coho relative to 2016, and an overall 20-fold increase in habitat capacity since the restoration project began.
- The total area of wetted habitat (streams, ponds and permanently flooded wetlands) increased by 11% from 2016, to a total of 9,129 m^2 (2.3 acres). This does not include riparian areas.
- The volume of aquatic habitat in the BDA ponds increased by about 40% relative to 2016.
- Stream temperatures continued to improve and generally stayed within or close to the range optimal for coho salmon during the summer. Spikes in summertime water temperatures were attenuated relative to the upstream environment, presumably because of the increased buffering capacity of the larger volumes of water stored behind the BDAs.
- Groundwater monitoring suggests that for every 30 cm of height that the BDAs are raised, groundwater levels rise 15 cm or more, as far as 0.9 kilometer up valley. There were also less dramatic increases observed as much as 350 m down valley. A conservative estimate suggests that the lower BDA in Sugar Creek increased water storage capacity by about 37,000 m^3 (about 30 acre-feet). It is likely that the area of groundwater influenced by the BDAs extends beyond the limits of our groundwater monitoring network.
- Beaver activity increased, with beaver actively modifying both BDAs.
- Juvenile coho population estimates decreased by about 25%. This may be due to the severe flooding the previous winter that may have destroyed salmon redds. Observations of coho redds in Sugar Creek and French Creek sub-basins suggests that many of them are constructed in granitic sands rather than gravel, and thus would easily be damaged by high flows.
- Juvenile coho populations were at about 36% of capacity, while at the French Creek control site, the population was at about 61% of capacity. These figures suggest that either low numbers of returning adults or possibly low egg-to-fry survival may be limiting production

in both systems. Current spawning conditions are poor, with many adult coho spawning in sand or in cobble with sand-filled interstices. It is possible that improved spawning conditions may increase egg-to-fry survival.

- PIT tag antennas were installed at French Creek and Sugar Creek to measure coho salmon outmigrant rates and overwinter survival. Preliminary results indicate that relatively few coho (7%) outmigrated from French Creek in the spring of 2017, while a much higher percentage (40%) of tagged coho in Sugar Creek outmigrated. This suggests that overwintering slow-water habitat may be limiting production in French Creek.

An experiment was conducted to test the passability of BDAs by placing PIT-tagged juvenile coho and steelhead downstream of two BDAs. A series of PIT antennas on and upstream of the BDAs detected 97% of the coho upstream of one BDA and detected 89% of the coho upstream of both BDAs. Most of the coho moved upstream within 36 hours of being released. The juvenile salmonids had a choice of either swimming around the BDAs up a steep, roughened riffle, or jumping over them (jump heights of 40 cm and 30 cm). There was a slight preference for swimming around rather than jumping over for both species, but 49% of the coho jumped over at least one of the BDAs and the majority that jumped, jumped over the 40 cm high BDA.

Data collected from PIT tag detections at the Sugar Creek and French Creek arrays showed that juvenile coho salmon redistribute or outmigrate on the ascending limb of the spring and fall hydrograph. At both locations we saw spring outmigration occurring in April when flows increased due to spring freshets. In the fall, many fish from French Creek left the tributary, presumably to find overwintering habitat (i.e. slow water with cover), while in Sugar Creek, no fish moved downstream. Data from the PIT antennas indicate a number of tagged fish entered the off-channel pond in Sugar Creek in the fall and then moved in a diurnal pattern to and from the pond in the morning and evening. They may be possibly moving to feed in the Sugar Creek ponds during the night, and to rest and digest in the relatively warm waters of the off-channel ponds during the day, behavior that has been observed in other systems.

The Sugar Creek and Miners Creek BDAs continued to be adaptively managed, with repairs and improvements made to both sites to maximize their benefits to rearing coho and to keep the habitat moving on an upward recovery trajectory.

Physical habitat measurements showed that repair of breached segments of BDAs resulted in rapid increases in water depth and habitat volume upstream of the BDAs and raised groundwater levels in the nearby alluvial aquifer.

Two “step” BDAs were constructed in Sugar Creek below the downstream-most BDA. The purpose of these structures was to add stability to the structure by minimizing downstream scour that could undermine (and has undermined) the structure.

Four BDAs were constructed in a French Creek side channel to increase the amount of slow-water overwintering habitat for juvenile coho salmon. This may reduce the fall outmigration rates and improve overwinter survival in the French Creek system, something that will be tested in the coming years.

The Miners Creek BDA Restoration Project continues to show modest improvements in habitat conditions, but because it is not well monitored, these are mostly qualitative assessments. Juvenile coho fry were observed using the site in early spring and there was abundant spawning within and upstream of the area. The porous nature of the sandy, decomposed granite which makes up the majority of the alluvium results in the loss of continuous flow within the reach during the summer. While the BDAs appear to have extended the duration of flow and the area of inundation, there appears to be insufficient flow to keep water at the surface during the summer. Interpretation of the effects of the BDAs is complicated by agricultural water withdrawals upstream, which may be overriding the hydrologic benefits accrued by the BDAs.

ACKNOWLEDGEMENTS

The authors extend our gratitude to all the individuals, groups, and agencies who have contributed to this project in 2017 and have helped to our evolving understanding of beaver dam analogues and how they can be used as a restoration tool. Our thanks to the following, with apologies for any omissions: Bob Pagliuco, *NOAA Restoration Center*; Serena Doose, Ryan Fogerty, Shari Hagwood, Dave Johnson & Rebecca Reeves, *US Fish and Wildlife Service Partners Program*; Anne Butterfield & Colleen Walters, *National Fish and Wildlife Foundation;* Demian Ebert, *PacifiCorp;* Annie Yates & the Board of Directors, *Bella Vista Foundation*; Eli Scott, Jake Shannon & Jonathan Warmerdam of the *North Coast Regional Water Quality Control Board;* Curt Babcock, Jennifer Bull, Mike Harris, Mary Olswang, Janae Scruggs, Mark Smelser, *California Department of Fish and Wildlife*; Joey Howard, PE., *Cascade Stream Solutions*; Kenneth Brink, Mike Polmateer, Toz Soto & Clayton Tuttle, *Karuk Tribe*; Sarah Rockwell, Jeff & Jaime Stephens, *Klamath Bird Observatory*; *Scott Valley Landowners* Samual Betzen, Mike Kalpin, Jerry Lewis, Bill & Jeffy Marx, Michael & Betsy Stapleton, Becky Schenone, the Farmers Ditch Company, the Tobias Ranch & the Whipple Ranch*;* Brian Cluer & Don Flickinger, *NOAA Fisheries*; Bill & Patty Parry *of North Rivers Construction*; Rocco Fiori, *Fiori Geosciences*; Darren Ward, Professor, *Humboldt State University*; Lindsay Magranet, *Siskiyou Resource Conservation District*; Sarah Beesley, *Yurok Tribe*, Will Harling, *Mid Klamath Watershed Council* and Michael & Lynn Thamer, *Community Members*.

Scott River Watershed Council Board of Directors Larry Alexander, Dan Gerson, Jeff Horner, Michael Stapleton, Craig Thompson and Steve Ziegler; and most important of all, the fine field and office staff of the *Scott River Watershed Council* that served in 2017- Linda Bailey, Isis Hayden, Jess McArthur, Collin McCloskey, Dale Munson, Joe Pedro, Amanda Schmalenberger, Kristen Sellmer, Jennifer Silveira, Earl Summers, Wade Dedobbeleer and Peter Thamer.

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PERMITS

The Scott River BDA Restoration Project is covered by the following permits, all permits are held by the Scott River Watershed Council: Lake and Streambed Alteration Agreement providing coverage for Sugar Creek and Miners Creek, Permit **#LSAA 1600-2014-0094-R1;** 401 certification for Sugar Creek and Miners Creek (retired prior to the start of construction in September, 2018 for Sugar Creek restoration efforts, but remained in place for Miners Creek restoration efforts), **WDID # 1A14055WASSI, ICM PIN No: LW-806806 Waterboard NOA;** New 401 for Sugar (HREA consistency determination pending), **CW 840314 WDID No: 1A17a7 60WNSI;** French Creek 401certification, **CW-828580 WDID NO 1A161386WNSI** and French Creek HREA consistency determination, **1653-2017-003-001-R1.**

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OVERVIEW

Basis for Beaver Restoration in the Scott Valley

The Scott River Beaver Dam Analogue Restoration Project is a series of restoration projects designed to enhance coho salmon populations by mimicking the actions of beaver through the use of beaver dam analogues to create cool, slow-water habitat (Pollock et al, 2014). Such habitat can be used throughout the year for rearing by juvenile coho salmon, and as deep holding pools for returning adults. Juvenile salmonids showed improved survival, smolt production and growth in beaver ponds and other slow water habitat rich in cover (e.g. see Roni et al. 2006, Rosenfeld et al. 2008, Bouwes et al. 2015). Beaver dams and similar structures also improve streamflows through groundwater recharge and decrease temperatures through increased hyporheic exchange, thus improving coho salmon habitat through multiple mechanisms.

The Scott Valley was once abundant with beaver and was initially named Beaver Valley. In the 19th century, beginning in the 1830s, trappers removed thousands of beavers from the valley and the ponds and wetlands that they sustained largely disappeared. Today slow-water rearing habitat, such as that formed by beaver dams, is limited to a few isolated locations in the Scott Valley and this likely reduces coho salmon production potential. However, there still exists potential for beaver to recolonize many stream reaches within the Scott Valley and increase coho salmon smolt production potential by several orders of magnitude. Were this to occur, habitat capacity models suggest it should measurably increase overall coho salmon production in the Klamath River system (e.g. see Goodman et al. 2010, 2015).

Coho smolt production from slow water habitat of all kinds averages about $0.37/m^2$, with active beaver ponds tending to be on the higher end of the production range (> $1.0/m^2$ (Roni et al. 2006, Rosenfeld et al. 2008). Smolt survival estimates from the Scott River range from 1.5%-18%, with an average of about 5% (Knechtle and Chesney 2013), suggesting around 1500 smolts and 22-270 adult coho salmon could be produced per acre of slow water habitat created, depending on ocean survival rates. In the past decade, California Department of Fish and Wildlife (CDFW) estimates that the annual median number of Scott River adult coho salmon returns was 285 (Knechtle and Chesney 2013 and CDFW video weir counts from 2007-2016), suggesting that creation of a relatively small number of beaver ponds or other slow water habitat could potentially increase coho salmon populations.

This habitat restoration project has been working with a growing list of cooperating landowners in the Scott Valley who want to use beaver to improve habitat conditions for coho salmon and in doing so provide an example of public-private partnerships that cost-effectively restore salmon habitat.

This project utilizes beaver dam analogues, one of the beaver habitat restoration tools described by Pollock et al. (2015) and adopted by the National Marine Fisheries Service, the United States Forest Service and the Bureau of Land Management as a preferred restoration approach on federal lands in the Pacific Northwest (NMFS 2013). This restoration approach works to help beaver build and maintain dams that will provide slow-water rearing habitat for juvenile salmonids.

Coho Salmon in the Scott River

The Scott River supports a Core, Functionally Independent Population of Southern Oregon Northern California Coast (SONCC) coho salmon (*Oncorhynchus kisutch*), one of the most productive natural stocks in the Klamath River basin (NMFS 2014). Although the Scott River population is likely above the depensation threshold (242 adult coho salmon) as defined in the SONCC Coho Salmon Recovery Plan, two weak brood years and the continued presence of stressors has significantly reduced the size of the population over time. To attain viability, 6,500 spawners are required in the Scott River coho salmon population. In the past 10 years, adult returns have ranged from 62 to 2,731, with an average of 688 and a median of 285 (Knechtle and Chesney 2015, CDFW-Yreka 2016).

A limiting factor analysis for coho salmon in the Scott River identified a lack of suitable rearing habitat during the summer and winter months as a probable limitation for smolt production (SRWC, 2006). Similarly, NOAA Fisheries determined in their Recovery Plan (NMFS 2014), that the juvenile life stage was the most limited in the population. During the spring and fall, juvenile coho salmon redistribute from their natal habitats in search of suitable summer or winter rearing locations. For example, Tom Martin Creek, a tributary immediately downstream of the mouth of the Scott River totaling only 180 feet in length, was estimated to have 748 non-natal juvenile coho rearing there during the summer on 2012 (Witmore 2014). Presumably, these individuals left their natal streams in Scott River during the summer and were utilizing the cold water in Tom Martin Creek as refugia. Gorman (2016) found that individual juvenile coho salmon in the Shasta and Scott Rivers who outmigrated as young-of-the-year (YOY), possibly due to poor natal conditions, experience a higher proportion of juvenile mortality than those rearing in natal streams, consistent with observations in other systems (Bennett et al. 2015). High juvenile mortality while transitioning to a non-natal stream could, in turn, lead to decreased future adult returns. This mortality could have particularly large effects on returns when, as in 2014, a drought year, the abundance of YOY outmigrants was much larger than the number of smolt outmigrants within a cohort (AFRAMP Annual Report 2014, AFRAMP Annual Report 2015). Further, Gorman (2016) presumed through otolith analysis and PIT tag detections that natal rearing contributes more to population persistence in the Shasta River than non-natal rearing.

The SONCC Coho Salmon Recovery Plan (NMFS 2014) prioritizes recovery actions that enhance and extend surface flow connectivity in the Scott River and tributaries so that sufficient instream flows are available for juvenile coho salmon. Also prioritized are actions to increase summer and winter rearing habitat through increase floodplain connectivity.

SITE DESCRIPTION

The Scott River Watershed

The Scott River is located in the Klamath and Marble Mountains of Western Siskiyou County in Northwest California (Figure 1). The Scott River watershed is approximately 520,000 acres (813 square miles) and is a major tributary to the Klamath River. The East Fork and the South Fork of the Scott River merge at Callahan to form the Scott River. From Callahan, the Scott River flows to the northwest about 60 miles where it joins the Klamath River 2 miles above Hamburg. The watershed has a north-south length of about 25 miles and extends in an east-west direction for about 10 miles at its widest part. The area has a human population of about 8000, with “major” population centers in Etna, Fort Jones, Greenview and Callahan. The major industries are agriculture, cattle, timber and recreation. The Pacific Crest Trail passes near the town of Etna and as such, is a major resupply point for hikers. Hay, largely alfalfa, is the chief agricultural crop and is dependent upon irrigation for successful production. Agricultural activities are concentrated on the wide valley floor, while timber harvest is focused on private lands on the hillslope immediately above the valley, while recreational activities, as well as summer grazing, occur mostly on the National Forest lands at higher elevations.

Geology and Groundwater Hydrology

The bedrock in the area, dating from pre-Silurian to Late Jurassic and possibly Early Cretaceous time, consists of consolidated rocks whose fractures yield water to springs at the valley margins and in the surrounding upland areas. The oldest rocks are the Salmon hornblende schist and Abrams mica schist, a sequence of completely recrystallized sedimentary and volcanic rocks of pre-Silurian age (Figure 2). Overlying these rocks with profound unconformity along the eastern part of Scott Valley are beds consisting of more than 5,000 feet of sandstone, chert, slate, and limestone of probable Silurian age. Along the northern part of the area, the Salmon and Abrams schists are unconformably overlain by andesitic and basaltic volcanic rocks altered to greenstone and greenstone schist. Beginning in Late Jurassic and perhaps continuing into Early Cretaceous time, the Klamath Mountains were the scene of profound orogeny. The rocks were strongly folded and faulted and were invaded by a series of magmas which solidified into rocks ranging in composition from peridotite, now largely altered to serpentine, to granodiorite (Figure 2). The granodiorite is the youngest of all the consolidated rocks in the area (Mack 1958).

The valley alluvial fill consists of a few isolated patches of older alluvium (Pleistocene) found along the valley margins and of younger alluvium which includes stream-channel, flood-plain, and alluvial-fan deposits of recent age. The recent deposits underlie and form the alluvial plains of Scott and Quartz Valleys, the valley of Oro Fino Creek and the fans at the valley margins, and extend in tongues up the valleys of tributary streams (Figure 2).

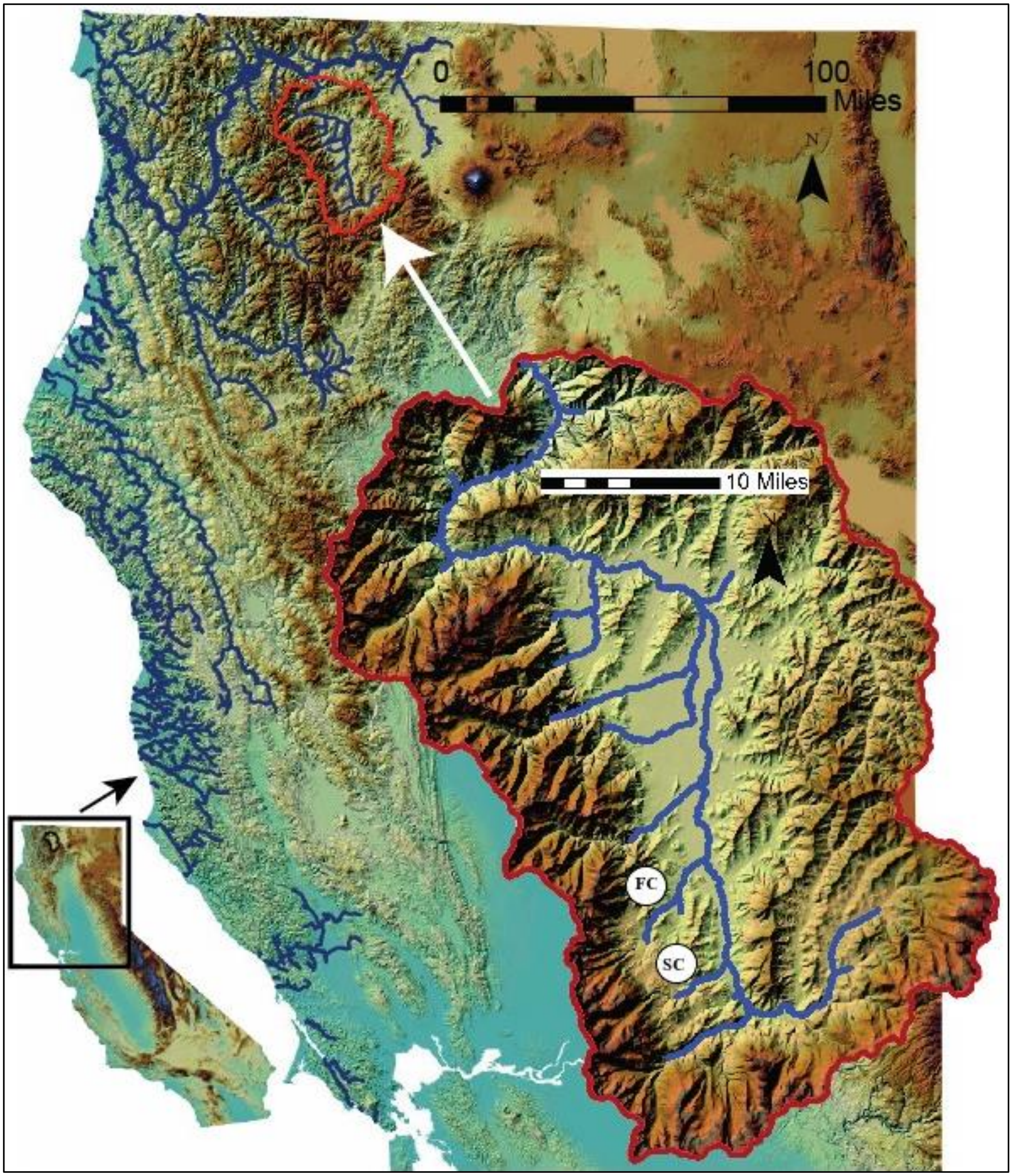

Figure 1. Location of the Scott River, a major tributary to the Klamath River, in the context of the major remaining streams in California with coho salmon (blue lines). Within the Scott River watershed, the French Creek (FC) Sugar Creek (SC) study areas are highlighted. Miners Creek is the small tributary to French Creek, entering from the south about 3.5 km upstream from the French Creek-Scott River confluence. The large volcano just to the east of the Scott River watershed is Mt. Shasta.

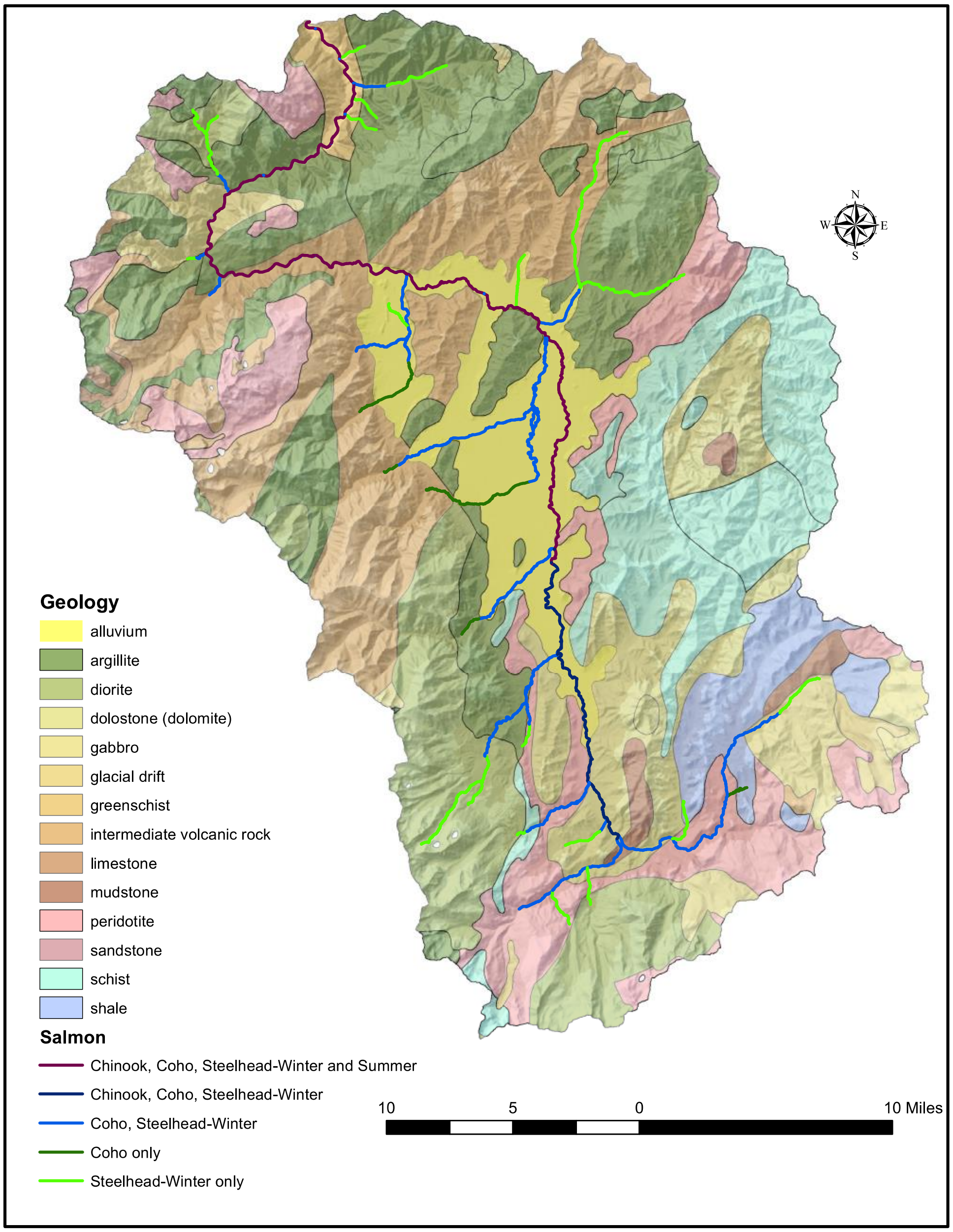

Figure 2. Geology and distribution of salmon in the Scott River watershed. Most of the salmon-bearing streams are on the west side of the watershed, where snowpack, precipitation and stream flows are greater, relative to the drier east side.

In addition to the mainstem of the Scott River, major salmonid-bearing tributaries are Mill Creek, Shackleford Creek, French Creek, Miners Creek, Sugar Creek, Kidder Creek, Patterson Creek, South Fork of the Scott River and the East Fork of the Scott River. Etna Creek and Moffett Creek are other producers. Thickness of the recent alluvial deposits reaches a maximum of more than 400 feet in the wide central part of the valley between Etna and Greenview. The most permeable alluvium underlies the flood plain of the Scott River. The major irrigation wells in the area, which yield from 1,200 to 2,500 gallons per minute (gpm), are on the Scott River flood plain between Etna and Fort Jones. The average specific yield of the flood-plain sediments is estimated at 15 percent. The alluvial deposits along the west side of the valley comprise the fans deposited by the major western tributary streams and the deposits forming the gently sloping zones of ground-water discharge near the base of the fans. Hydrologic data indicate that these deposits are of much lower permeability than the flood-plain deposits with which they merge to the east. Specific yield of the alluvium underlying the fans and discharge zones is estimated to range from 5 to 7 percent (Mack 1958).

Hydrology

In the Scott Valley, the average seasonal precipitation is 21.7 inches, but may exceed 70 inches annually in the western mountains, and exceed 30 inches in the eastern mountains. The average annual temperature in the Valley is 50.3° F. Streamflow in the Scott River is primarily driven by fluctuations in snowpack and the quality of the water year. Much of the Scott Valley consists of highly permeable sediment that creates significant connectivity between the stream surface water and the underlying aquifer. During normal precipitation years, the aquifer is recharged during the winter and spring, with groundwater accretion supplementing surface water during periods of low flow. The river and tributaries flow subsurface in some locations during the summer months and in years with low levels of precipitation. The Scott River experiences significant flooding. The largest flood at the USGS gage below Fort Jones (established 1941) occurred on December 22, 1964 (54,600 cfs) The second largest flood occurred on December 22nd, 1955 (38,500 cfs) and the fourth largest and most recent major flow event occurred on January 1, 1997 (34,300 cfs). Within the past two decades, few flows have exceeded 15,000 cfs. Although there is extensive rip rap along the mainstem, virtually all large floods cause significant bank erosion. As recently as 2015, a > 15,000 cfs flood initiated an avulsion in the tailings reach, breaching a levee and creating a new flow path that extended for miles before returning to the mainstem just above French Creek.

Snow surveys have been performed in the Scott River Watershed since 1946 at Middle Boulder 1 (Elev. 6600 ft) in the Scott Mountains. The Scott River is dependent on the snow pack during the summer months and the April 1st snow surveys are used by water managers to forecast the water supply. Water year 2017 was an above average water year with snow water equivalence of 122% of average on the May 1, 2017 snow survey. The entire watershed was returned to average conditions in 2017. Water year 2016 had significantly improved water supply from the previous critical drought years. Snow surveys documented 97% of snow water equivalence on April 1, 2016. Dry conditions persisted into 2016 with conditions split between D0 and D1 on April 5, 2016 and throughout the summer. The 2015 April 1st snow survey documented an average snow depth and equivalent water content of less than one percent at the eight surveyed snow courses (USFS-KNF, 2015). The winter of water year 2015 (October 1, 2014-September 30 2015) was the warmest in California's recorded history causing most of the precipitation to fall as rain. Water year 2015 was the fourth year of drought in the Scott River watershed. The watershed was classified as D2 (Severe Drought) by the United States Drought Monitor on March 31, 2015 (NDMC, et al., ND). The watershed was classified as D2 on April 1, 2014, as D0 (Abnormally Dry) on April 2, 2013 and was split between D0 and D1 (Moderate Drought) on April 3, 2012.

Previous Restoration Efforts in the Scott Valley

The Scott River and tributaries have been significantly altered since the first fur trappers discovered the watershed in the 1830's. Beaver removal and gold mining were the first significant landscape altering practices in the 19th century. Massive placer mining in the tributaries and main stem Scott River created a legacy of tailing piles that significantly reduce flood plain connectivity and riparian forest condition (Figure 3). The main stem Scott River was straightened, cleared and leveed in the late 1930's to reduce the frequency of flooding in the Scott Valley downstream of Etna Creek. The second largest flood for the period of record for the USGS gage below Fort Jones (established 1941) occurred on December 22nd, 1955 (38,500 cfs) causing significant bank and soil degradation in the Scott River. The largest flood in the period of record occurred on December 22, 1964 (54,600 cfs) and the fourth largest and latest historic flow event occurred on January 1, 1997 (34,300 cfs). A concerted effort to stabilize the banks of the Scott River using large rock was led by the Soil Conservation Service (now Natural Resources Conservation Service) and landowners to protect the prime agricultural land of the Scott Valley following the 1955 and subsequent floods (SRWC & SRCD, 2014).

Riparian restoration in the Scott River began in the early 1990's and has continued to date. A large riparian restoration effort was implemented in the southern portion of the main stem Scott River downstream of the tailings pile in 1998 to accelerate the recovery of the riparian forest following the 1997 flood. Grazing exclusion fencing has been installed throughout the watershed to protect riparian areas and stream banks that could be impacted by livestock. Assessments of riparian restoration projects and the current morphology of the Scott River's channel, banks and floodplain led to the development of a strategy to continue riparian and stream channel restoration (SRWC & SRCD, 2014).

Surface water diversions within the range of coho salmon have fish screens to prevent loss of fish into the irrigation ditches. Observations of adult coho spawning in the South Fork Scott River in 2001 were the first documentation of coho in this higher gradient stream. Several unscreened surface water diversions in the South Fork were immediately screened upon the discovery that coho utilize the South Fork. The Siskiyou RCD has worked with landowners in the Scott River Watershed to protect and enhance riparian and stream habitat for anadromous salmonids.

Figure 3. The tailings reach in the upper mainstem of the Scott River, just downstream of the confluence with Sugar Creek, showing the overturned substrate and the lack of riparian vegetation and aquatic habitat simplification. River flow is from left to right. The tailings are the symmetrical mounds of cobble on river left. There is about 6 kilometers of such habitat, most of which dries up during the summer months, though subsurface water persists within 1-2 m of the surface and is occasionally seen in deep scour pools.

Description of BDA Restoration Sites

Sugar Creek, French Creek and Miners Creek are the three streams within the Scott River watershed that are discussed in this report and where BDA restoration and monitoring sites are located. Miners Creek is a tributary to French Creek, entering about 3.5 km up from the mouth, while Sugar Creek and French Creek drain from the west side of the Scott Valley, directly into the upper mainstem of the Scott River (Figure 1).

Sugar Creek

The Sugar Creek restoration site is located at the mouth of Sugar Creek at its confluence with the Scott River, upstream to the Highway 3 bridge. The reach is a dredged channel flowing through high mounds of mine tailings on the Scott River floodplain. The restoration site is complex, with multiple mesohabitats and monitoring stations referenced throughout this report (Figures 4 and 5). The site includes two primary, channel spanning Beaver Dam Analogue restoration structures, BDA 1.0 and BDA 2.0, constructed in 2014, inclusive of a river left wing on BDA 1.0 on a formerly dry side channel (Side Channel 1). Additionally, two “step” BDAs located downstream of BDA 1.0 on the mainstem (BDA 1.1 and BDA 1.2) were constructed in 2017 to reduce scour below BDA 1.0 that could undermine the structure.

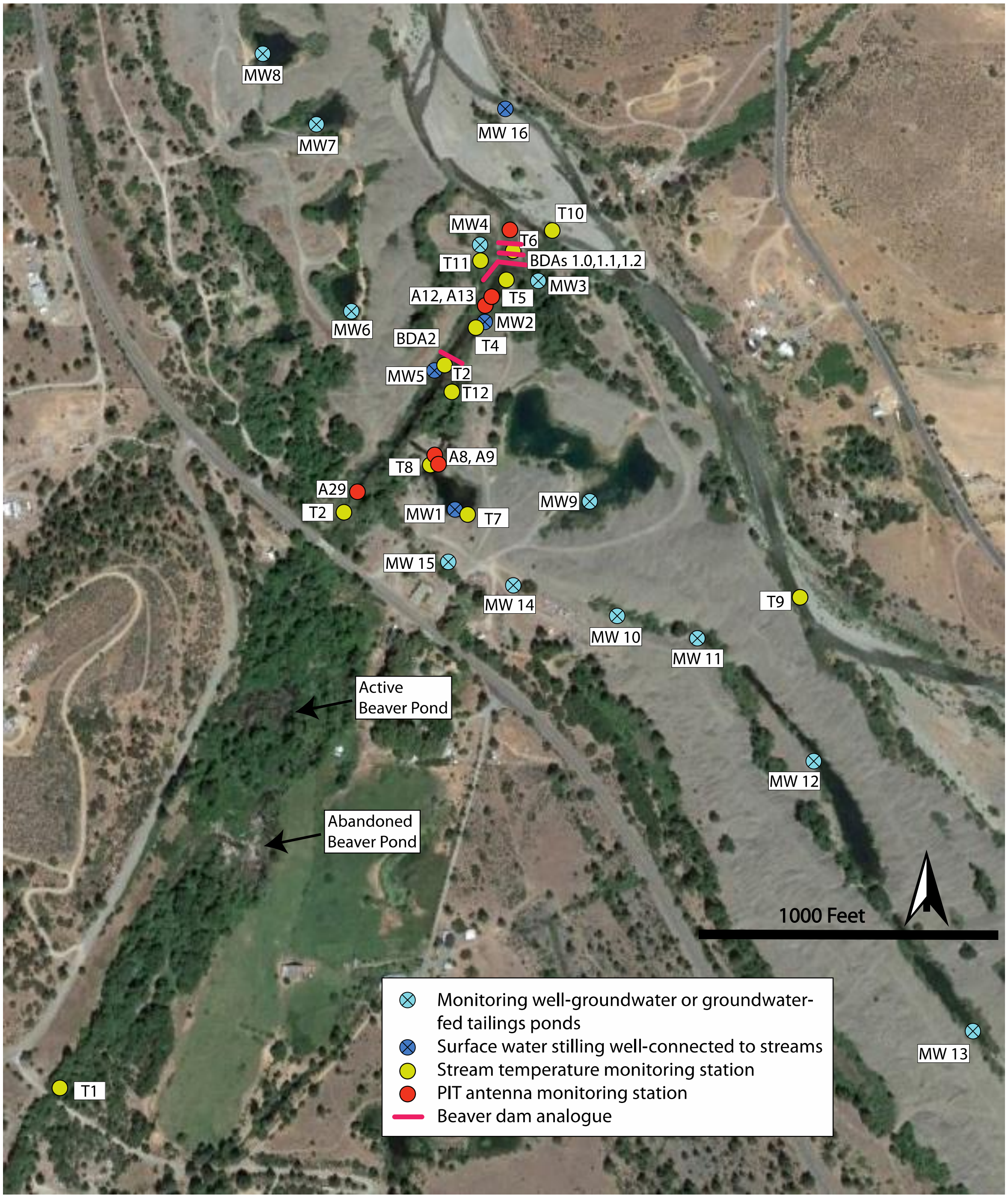

Figure 4. Overview of the lower Sugar Creek BDA restoration site and associated network of monitoring stations. The Scott River flows from right to left, generally on the right side of the valley, passing by small linear hills of mine dredge tailings and dredge ponds on the west side of the valley. On Sugar Creek, 1.6 km upstream of T1 (lower left corner) is a stream discharge station (CA DWR #F25890).

The Sugar Creek site also includes a mine tailings pond (off-channel pond) that the Siskiyou Resource Conservation District connected to the BDA 2.0 pond via a short constructed channel, in October 2015 (Figure 5). Improvements to BDA 2.0 by beaver have flooded a low-lying vegetated area on river right that is referred to as “the marsh”. Within it were abandoned beaver channels that were formerly wet only during high flows. Except for two vegetated islands, the entire area is now flooded throughout the year and is almost entirely covered by emergent vegetation and an overhead canopy of primarily alder. During modification of the tailings pond (OCP), the RCD also created a small channel that connects the upstream end of the beaver channels to the OCP, helping to improve flows through the marsh. This combined channel network and adjacent area is collectively referred to as Side Channel 2, while the constructed channel that connects the tailings pond to the BDA 2.0 Pond is Side Channel 3 (Figure 5).

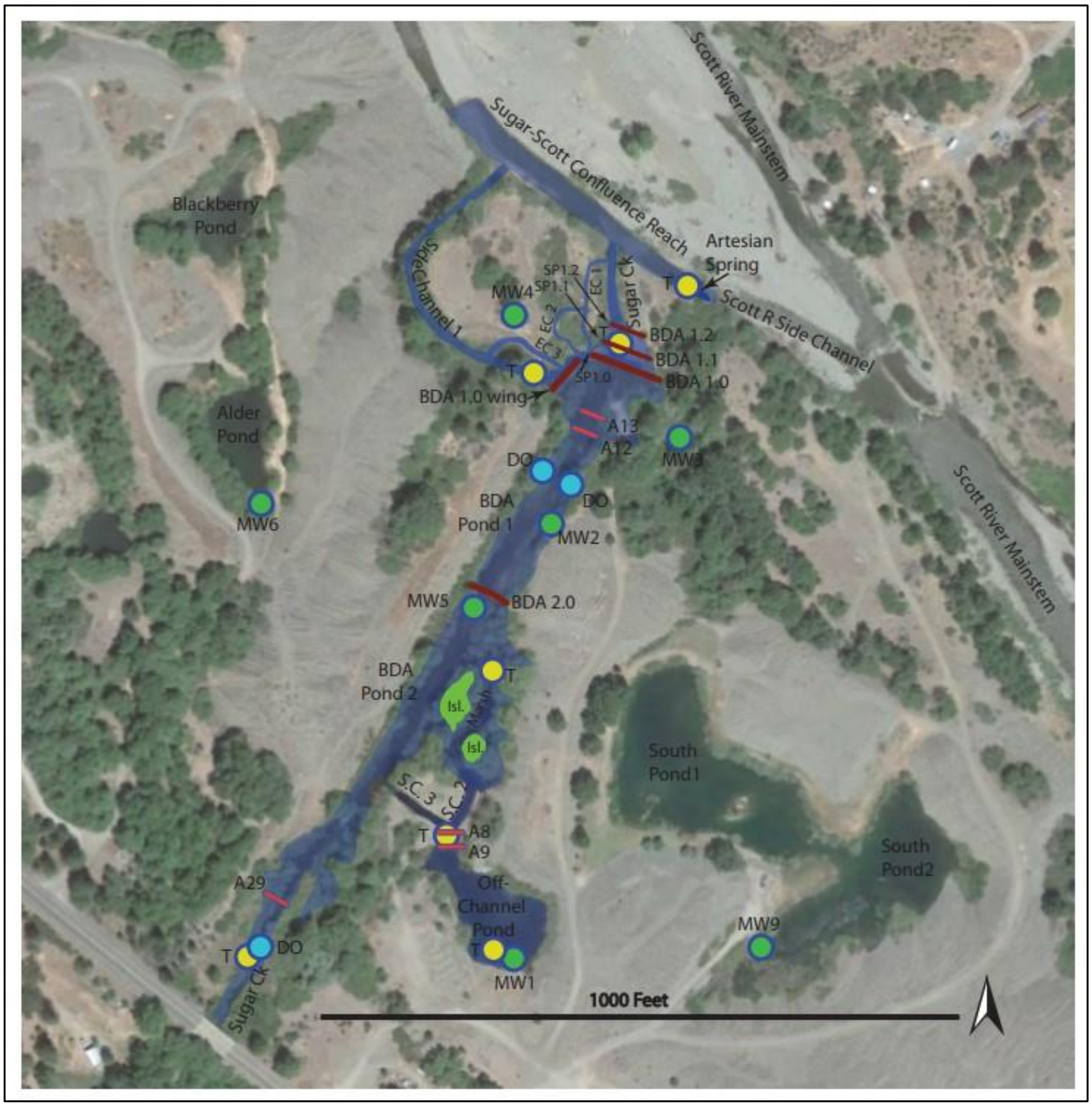

Figure 5. Detail overview of the lower Sugar Creek BDA restoration site, showing the location of the BDAs, and the areas of inundation and side channels formed, as of November, 2017. Also shown are the PIT tag monitoring stations, surface and groundwater monitoring wells, where water surface elevations and water temperatures are continuously monitored, surface water temperature monitoring stations and surface water dissolved oxygen monitoring stations. SC=Side Channel, EC=emerging side channels, forming by flow dispersion caused by the BDAs, and SP = side passage, short channels around the ends of BDAs. Also shown is an artesian spring that formed shortly after the installation of BDA 1.0, presumably a result of the increase in head pressure caused by a ground and surface water elevation increase of 2.5 feet upstream of the BDA.

Because the site is within the Scott River floodplain in an area that was dredged for gold, the native stratigraphy has been thoroughly destroyed, resulting in highly porous surface material and lowered alluvial groundwater levels (Figure 6). The stream bed surface itself is composed mostly of decomposed granitic sands, though in steeper riffles the substrate is mostly tailings cobbles. The groundwater flows just below the stream bed, and in places this flow intersects deep pools, providing cool water inputs to the Sugar Creek restoration complex. However, the tailing cobble mounds are generally inhospitable to the growth of vegetation, limiting riparian vegetation to low-lying areas in between the mounds (e.g. the marsh) and along a narrow band adjacent to Sugar Creek. There is a beaver colony upstream of the site, with several active and abandoned dams (Figure 4). This is likely the source of the beaver that have been observed at the restoration site and that have modified both BDA 1.0 and BDA 2.0.

Figure 6. Top: Sugar Creek prior to BDA restoration in July, 2014. Flow is from left to right. At the upstream end of the restoration reach, several hundred meters from where this photograph was taken, a small amount of flow persisted throughout the year, but it ceased flowing where the underlying substrate transitioned from hillside bedrock to the porous alluvial mine tailings of the Scott River floodplain. Bottom: Conditions in September, 2017, as viewed from the top of BDA 1.0, a slightly different vantage point, about 10 m downstream from the top photograph. Two trees labeled in both the photographs provide perspective.

French Creek

A control reach was established in mainstem French Creek for the purpose of comparing a stream thought to be in reasonably good health and supporting relatively high numbers of coho salmon, to the Sugar Creek restoration site (Figure 7).

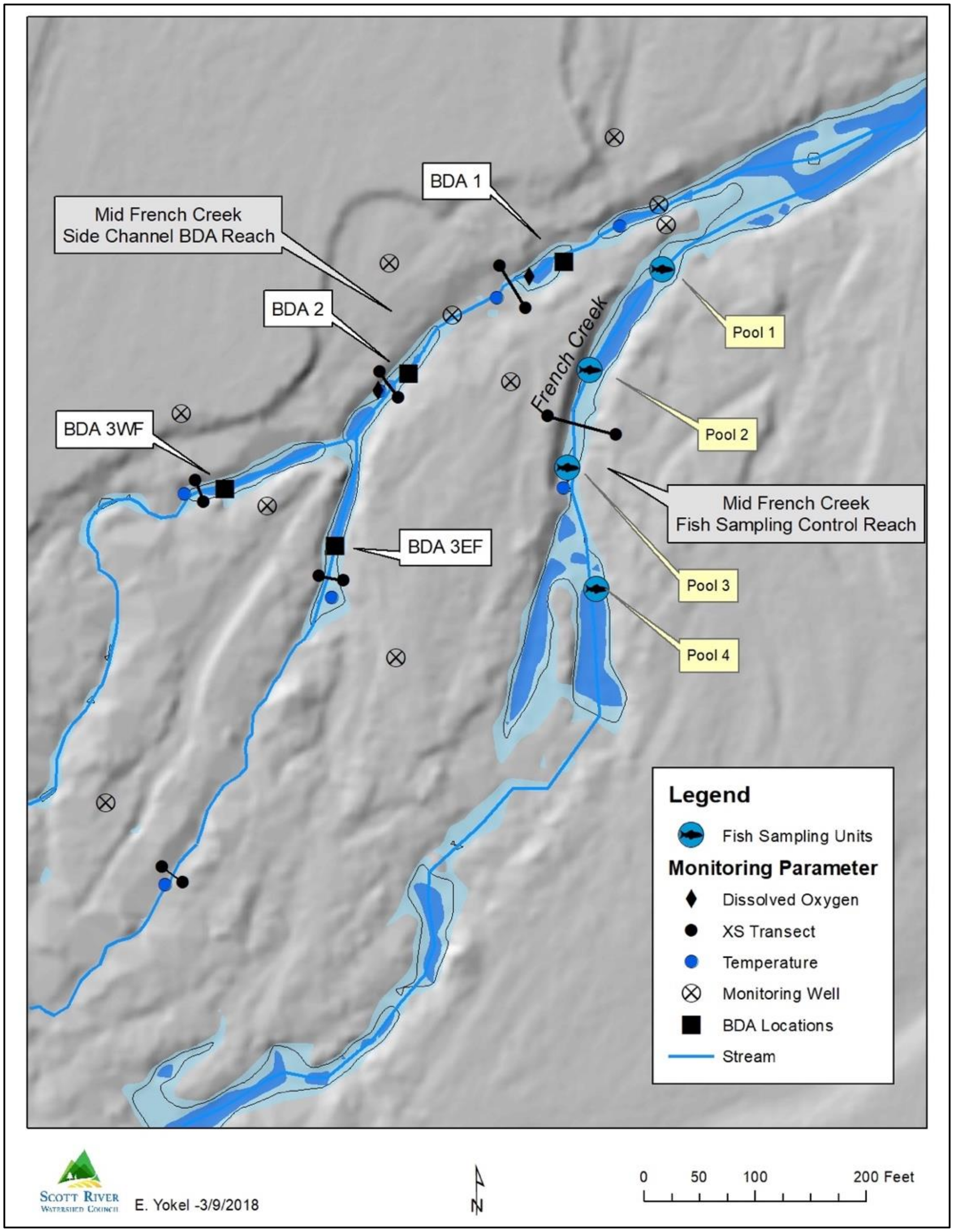

Figure 7. LIDAR map of French Creek Control Reach and a small adjacent side channel with a west fork and east fork, treated with BDA restoration structures. The Control Reach includes four pools, sampled for summertime population estimates of juvenile salmonids. Temperature, groundwater monitoring wells and dissolved oxygen monitoring stations are also noted.

Figure 8. High flows on a typical reach in French Creek, near the control site. The river right side is rip-rap covered with Himalayan blackberry (top). French Creek side channel during winter high flows, prior to installation of BDAs. The channel generally flows through dense riparian vegetation, but is lacking in deep pools (bottom).

This site is located in an area that has an extensive riparian floodplain forest of willows, cottonwood, alder and Ponderosa pine, though the stream itself is entrenched, relatively linear, and armored with rip-rap on river right for much of its length. Monitoring wells installed by the landowner indicate a steady supply of groundwater a few feet from the surface and some of this water likely intersects with the stream in deep pools and other areas where there is a sufficient hydraulic head to force upwelling. The stream bed is a mix of decomposed granitic sands overlying embedded cobbles, with a cobble-gravel mix in the steeper riffles. In 2017, a restoration treatment of 4 small BDAs was implemented in an adjacent side channel (Figure 8) in an attempt to create more off-channel slow water habitat for overwintering coho salmon.

Miners Creek

The Miners Creek restoration site includes two BDAs that were initially constructed in 2015. Miners Creek is a small tributary to French Creek, entering upstream of the French Creek BDA restoration and control sites. Prior to construction, Miners Creek consisted of a small channel flowing through alluvium composed mostly of porous, decomposed granitic sands, and that with the exception of a few isolated pools, dried up during the summer. However, there was sufficient water to support a willow forest near the stream, and conifers such as Ponderosa pine grow on the edges of the floodplain (Figure 9). There are also grassy benches on the valley floor, and cattle are occasionally grazed in there. Beaver activity is very limited at the Miners Creek site.

Figure 9. The Miners Creek floodplain near the BDA restoration site showing the sandy, porous alluvium. The small creek flows near the Ponderosa pine in the background

METHODS

We collected data on a number of physical and biological parameters to monitor changes in conditions over time and to compare restored sites with control sites where restoration did not occur (e.g., Sugar Creek v. French Creek mainstem). Physical data were collected for (1) stream temperatures (2) groundwater temperature (3) surface water elevations (4) groundwater elevations, (5) water velocities, (6) water depth and (7) instream cover. Biological monitoring focused on salmonid usage, but birds and beaver were also monitored to a limited extent. We also conducted a small experiment to monitor the passability of the constructed beaver dam analogues to juvenile salmonids. The layout of the monitoring networks at each of the sites, inclusive of ground and surface water monitoring wells, temperature loggers, PIT antennas and BDAs, is shown in Figures 4,5 and 7.

Temperature and Water Surface Elevations

A network of temperature and water surface elevation monitoring stations was established at each site that included groundwater wells and surface water "stilling" wells equipped with Onset water level loggers, which measure both water levels and temperature. These stations collect data throughout the year. During the summer, surface water temperature was measured at additional stations using Onset Tidbit temperature loggers (Figures 4,5 and 7). To supplement the monitoring well data, we also performed a more extensive water surface elevation study at low water conditions in summer. This allowed us to compare water surfaces over a greater area and to better understand the relationship between water surface elevations on the Scott River relative to our restoration area at the mouth of Sugar Creek as it crosses the mine tailings of the Scott River floodplain. To provide context to the temperature and water surface elevation data, we also obtained discharge information on Sugar Creek at RKM 2.6 from a stream gage operated by the California Department of Water Resources (Sugar Creek near Callahan (F25890). The certified record for the CDWR station contains daily average discharge (cfs) for the range of rated flow. Discharge in excess of approximately 30 cfs was beyond the rating table during WY15 and discharge in excess of approximately 75 cfs was beyond the rating table during WY16 and WY17. Therefore, any high flow events beyond those flows are not reported.

Sixteen surface or groundwater monitoring wells have been established at the Sugar Creek restoration site since 2014, and these have been used to track the extent of the effects of the BDAs on water surface elevations. Throughout the area, there are a number of isolated dredge tailing ponds fed almost entirely by groundwater and with no surface outlet. These serve as convenient locations to measure groundwater elevations. In 2014, two water surface elevation (WSE) monitoring wells were established in BDA Pond 1 and in the off-channel pond, that is, locations that are connected to a flowing stream. (MW2 and MW1, respectively), and two groundwater WSE stations were established on the right and left floodplains near BDA 1.0. (MW3 and MW4, respectively) before BDA construction. Eleven additional surface water and groundwater WSE stations have since been established in the area of BDA influence from 2015 to 2017 (Figure 4), as we recognized that the BDAs were influencing groundwater elevations over a much larger area than originally anticipated. Additionally, a WSE monitoring station in the main stem of the Scott River (MW16) was established in 2017.

Eleven WSE stations were established in the French Creek restoration site prior to installation of the BDA structures in late June 2017 (Figure 7). The BDA structures were constructed in a naturally occurring side channel of French Creek. Measured WSE shows existing base flows for the reach. Long term data will be collected to detect changes in WSE post BDA construction.

The reported WSEs are the calculated elevations above mean sea level in feet per the vertical datum NAVD88. Reference point elevations of all monitoring stations were documented with a RTK GNSS survey system and computed with NGS OPUS using the GEIOD 12B. The reference point elevations in conjunction with manual measurements and continuous 15-minute logger depth data were used to calculate the station's WSE.

Habitat Capacity

The capacity of the Sugar Creek restoration site and the French Creek control site to produce juvenile coho salmon was estimated by collecting data on water velocity, water depth and percent cover along cross-section transects. These data were then used to populate the juvenile salmonid habitat capacity model developed by Goodman et al. (2010, 2015) in the nearby Trinity River basin. This model uses depth, velocity and cover measurements to estimate the habitat capacity of pre-smolt outmigrants of coho and Chinook salmon. We measured these variables along cross sections in both the treatment and control reaches to estimate capacity, and then scaled up to the site-level. Repeat surveys were performed in 2016 and 2017. Prior to project construction on Sugar Creek, the channel dried up, so habitat capacity for a non-drought year was estimated using aerial photography and field examination of the dry bed to estimate width and cover. Velocity and depth were assumed to be optimal (i.e. < 0.5 m/s and < 1 m, respectively). The model does not consider temperature as a potential limiting factor.

Velocity was measured using a Swoffer flow meter and depth with a stadia rod. Cover was recorded as presence/absence data at 1.5 m intervals along each transect. Cover included large wood, beaver caches, emergent and aquatic vegetation, submerged vegetation, overhanging vegetation, deep water and cut banks. The dominant bed substrate size was also recorded. Based on the velocity, depth and cover measurements, habitat capacity was estimated on a per area basis by applying the fish density data from Goodman et al. (2010) for four different combinations of depth, velocity and cover.

Juvenile Salmonids

Fish utilization was evaluated at Sugar Creek and French Creek using passive integrated transponder (PIT) tags to make several mark-recapture population estimates (Seber 1973) over the course of the summer and early fall. These repeated efforts also allowed us to measure growth. We used a network of PIT antennas in the Sugar Creek restoration complex to monitor movement, habitat use, timing of outmigration, and survival (see Figure 5 for Sugar Creek PIT antenna network configuration). We also used PIT antennas near the mouth of French Creek to monitor outmigration dates and estimate survival.

For the mark-recapture method, juvenile salmonids (coho, steelhead and a few Chinook) were captured using beach seines, and then anesthetized in an Alka-Seltzer bath. Salmonids were identified to species, weighed to the nearest tenth of a gram, and the length measured to the nearest mm. Those with a fork length (FL) of 65 mm or greater were scanned for a PIT tag and if none were detected, they were tagged (marked) with 12.5 mm FDX PIT tags (Biomark, Inc.) inserted into the peritoneal cavity with a syringe and needle. Fish were released in the area from which they were captured following recovery in a recovery tank or cage with aerated water. The following day, the exact process was repeated in the same location, except that any captured fish that had been tagged the previous day were noted as “recaptures”.

The Miners Creek site was shallow but complex during the summer, and by mid-summer, surface flow had ceased throughout much of the area. It was not feasible to sample multiple days using seines to make population estimates. However, in mid-July, beach seines were used to capture and PIT tag some fish in an attempt to measure survival and condition factor.

By repeating this mark-recapture process at each site several times from mid-Summer through early Fall, we were able to tag hundreds of fish at each site which we could then use to track movements with PIT antennas. The PIT antenna construction was based on the methodology described by Prentice (2008). We used Biomark IS1001 reader boards to monitor the antennas. Because of the remote location, the antennas and reader boards were powered by solar panels and batteries. Details on the entire PIT antenna and power station design are described by

Pollock and Brooks (in preparation). At the Sugar Creek restoration site, PIT antennas, with readers and power stations, were constructed and used to “recapture” tagged individuals remotely (see Figure 5). A station with two antennas was set up in the lower BDA A Microsoft Access PIT tag database was created for the Scott River Watershed, where data could be stored and then analyzed to provide information regarding daily, seasonal, and annual movement patterns. Information from this database is also sent to the larger Klamath River Basin PIT tag database, which is managed by the U.S. Geological Survey.

Fish Passage Across Beaver Dam Analogues

An experiment was performed to evaluate BDA structures for juvenile salmonid passage suitability in the Fall of 2017. Downstream of Sugar Creek’s BDA 1.0, a pool was formed between the newly installed step BDAs (BDA 1.1 and 1.2). Captured in BDA Pond 1 were 156 juvenile coho salmon and 40 juvenile steelhead trout. Each fish was PIT-tagged and released downstream of BDA 1.0 in the “release pool.” A network of antennas was set up to detect fish at various passage pathways including over topping flow that required a fish to jump and side channel passage around the BDA structures.

Beaver, Birds, Riparian Vegetation and Photopoints

The Klamath Bird Observatory (KBO) is partnering with SRWC to monitor the ecological changes resulting from the implementation of BDAs, and to assess the success of stream and riparian habitat restoration. The KBO is using riparian vegetation as a metric of success along with migratory bird presence, as birds provide a robust measure of the ecosystem as a whole. Active beaver sites, with all of their associated habitat complexity, may support more species of birds than sites without beavers. Birds provide an excellent monitoring tool to track changes in ecosystems because they respond quickly to habitat change, individual species represent different aspects of healthy riparian habitat. The KBO will use focal riparian bird species as indicators of successful restoration and can identify habitat components that have not yet been achieved as restoration progresses.

In 2015-2017, the KBO completed a two-year snapshot of bird populations and riparian vegetation at four restoration sites including Miners Creek and French Creek and one reference site, the Sugar Creek natural beaver complex upstream of Highway 3, to obtain pre- and early post-restoration baseline data. Monitoring of birds and vegetation will be replicated in the future and data will be compared before and after restoration, as well as with a reference site that represents target riparian conditions, to quantify changes over time and assess restoration success. The full report is contained in Rockwell and Stephens (2017). Riparian and Bird monitoring is not discussed any further in this document.

Beaver activity was qualitatively monitored through repeated presence-absence surveys that looked for evidence of beaver activity such as scent mounds, cut trees, chew sticks, dam-building or BDA modifications, lodges, caches and canals.

Several locations at the restoration sites were selected for photopoint monitoring to provide visual context for some of the changes that are occurring.

RESULTS

Temperature Monitoring

Sugar Creek

A network of thermistors has continuously monitored water temperature in the Sugar Creek restoration site since 2015 after BDAs were installed and the site became inundated with water (Figures 4 and 5). Monitoring locations include sites within the Sugar Creek restoration reach, Scott River, Sugar Creek off channel pond, and upstream of the Sugar Creek restoration reach.

Figure 10 shows the moving average weekly maximum temperature (MWMT) (°C) at Sugar Creek in WY17 compared to thermal optima and stressful ranges for coho salmon at various life stages (Richter and Kolmes 2005). The BDA pond provides good growing conditions for juvenile coho from mid-June through mid-October, while the off-channel pond provides good growing conditions from mid-July through early November. Temperatures in the off-channel pond are much more stable, presumably due to the alluvial groundwater influence at that site. Of all the sites, the off-channel pond remains within the thermal optima for coho salmon for the longest period of time. Temperatures in the nearby Scott River are significantly higher than at the restoration site and are in the stressful range for juvenile coho throughout most of the summer. In Sugar Creek at RKM 1.0, upstream of the restoration site and below the gage station, temperatures provide good growing conditions throughout the summer.

Recorded water temperatures in Sugar Creek's BDA Pond 1 show a different temperature regime during the base flow period of WY17 in comparison to WY16 (Figure 11). Surface water temperatures remained cooler during the summer of 2017 as compared to the previous year. This apparent temperature buffering may be due to a number of factors, including water volume and depth increases upstream of the BDAs, interaction with groundwater and increased shade from continued growth of riparian vegetation.

Analysis of the maximum Moving Weekly Average Temperature (MWAT) for each measured site from WY15 - WY17 in the Sugar Creek restoration site demonstrates cooler temperatures in WY17 compared to previous years (Table 1). The maximum MWAT (°C) in BDA Pond 1 decreased by 0.6° C from 2016 to 2017. The maximum MWAT in Sugar Creek at RKM 1.0 decreased 0.2° C from 2016 to 2017.

Water temperature in the Scott River upstream of Sugar Creek and the river left (RL) Scott River secondary channel downstream of the artesian spring (below the Farmers Ditch boulder vortex weir) illustrate a distinct surface water temperature signal (Scott River upstream of Sugar Creek) and a signal indicative of significant groundwater input (Table 1). The significantly cooler MWAT (17.1° C) and later date of MWAT occurrence (9/15/17) at the RL secondary channel location downstream of the artesian spring and upstream of the confluence of Sugar Creek is due to the groundwater influence and upstream disconnection to the surface water of the Scott River.

The MWAT (18.1° C) in the BDA Pond 1 Side Channel (Side Channel 1) is identical to the MWAT at the Sugar Creek RKM 0.05 station downstream of BDA 1.0. Side Channel 1 was dry at the temperature station from July 16 – July 27, 2017. The maintenance at BDA 1.0 that began on July 26th increased the WSE in BDA Pond 1; restoring connectivity in Side Channel 1.

The MWAT (17.6° C) in the Sugar Creek RKM 0.2 Marsh is the same as the MWAT in the Sugar OCP outlet indicating an equivalent groundwater effect at the two sites.

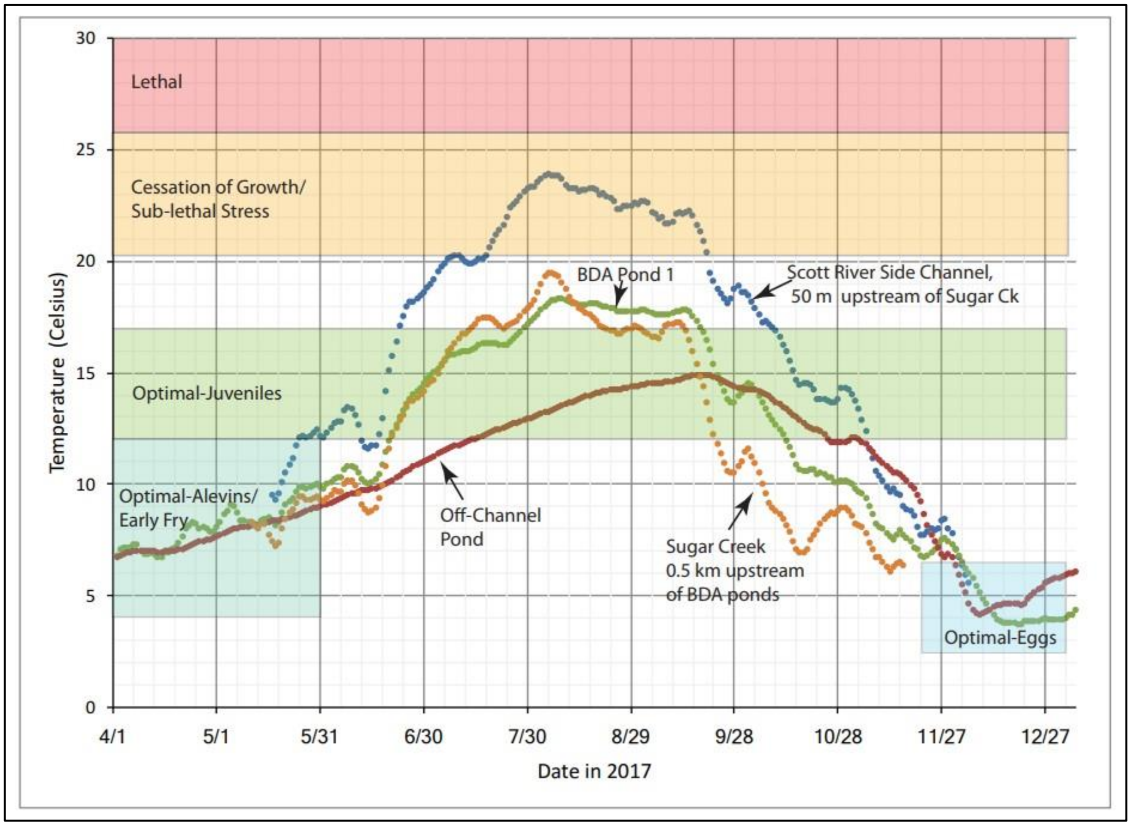

Figure 10. Moving weekly maximum temperature (MWMT) (°C) at Sugar Creek recorded in WY17. Thermal optimum and stressful ranges for coho salmon life stages based on Richter and Kolmes (2005).

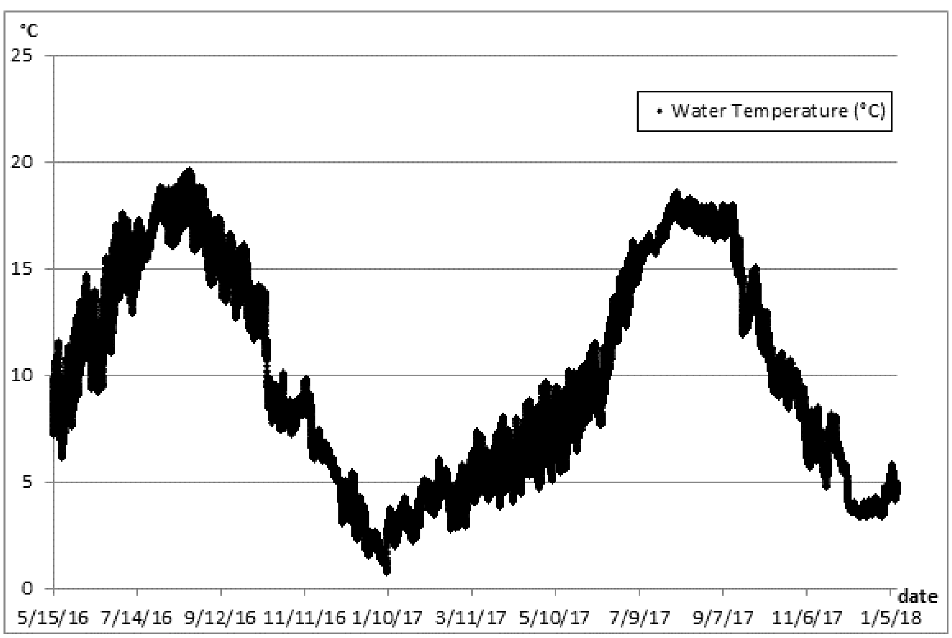

Figure 11. Water temperature (°C) in Sugar Creek BDA Pond 1 from May, 2016 through January, 2018.

Table 1. Recorded MWAT (°C) in and near the Lower Sugar Creek restoration site for WY15 - WY17. Date indicates the day the MWAT was recorded at that location. See Figures 4 and 5 for location map of temperature stations.

		WY 15		WY 16		WY 17	
Site #	Site Description	T (°C)	Date	T (°C)	Date	T (°C)	Date
T1	Upper Sugar Creek (RKM 1.0)	18.9	7/7/15	18.0	8/1/16	17.8	8/5/17
T2	Dwnst of Hwy 3 Bridge (RKM 0.4)	18.6	7/7/15	18.0	8/2/16	ND	ND
T3	BDA Pond 2 (RKM 0.2)	DRY		17.8	8/2/16	17.7	8/6/17
T4	BDA Pond 1 (RKM 0.1 - STA 2+50)	ND	ND	18.0	8/22/16	17.4	8/18/17
T5	BDA Pond 1 (RKM 0.1 - STA 0+50)	18.4	8/5/15	18.3	8/22/16	17.7	8/7/17
T6	Dwnst. BDA 1.0 (RKM 0.05)	DRY		18.5	8/22/16	18.1	8/7/18
T7	Sugar OCP	16.4	8/1/15	15.7	9/4/16	14.9	9/17/17
MW1	Sugar OCP (SUMW1s)	17.4	8/29/15	17.4	8/29/16	15.8	9/14/17
T8	Sugar OCP Outlet Channel	NA		17.5	8/26/16	17.1	9/12/17
T9	Scott R. upst. Sugar Cr. Confluence	ND	ND	ND	ND	19.8	8/4/17
T10	Scott R. (RL) upstr Sugar Cr.; dwnst. of spring	ND	ND	ND	ND	17.1	9/15/17
T11	Sugar Creek Side Channel 1	ND	ND	ND	ND	18.1	8/7/17
T12	Sugar Creek Marsh (RKM 0.2)	ND	ND	ND	ND	17.6	8/4/17
	Callahan Air Temperature	27.6	7/2/15	27.9	7/31/16	28.5	8/4/17

French Creek

At French Creek, water temperatures were recorded in the mainstem, downstream of the Miners Creek confluence and throughout the side channel where a series of BDAs were installed in 2017. Figure 12 shows that at all sites, water temperatures remained within or close to the thermal optima for coho salmon, with the exception of the French Creek mainstem, which rose close to stressful levels for a few weeks in early August.

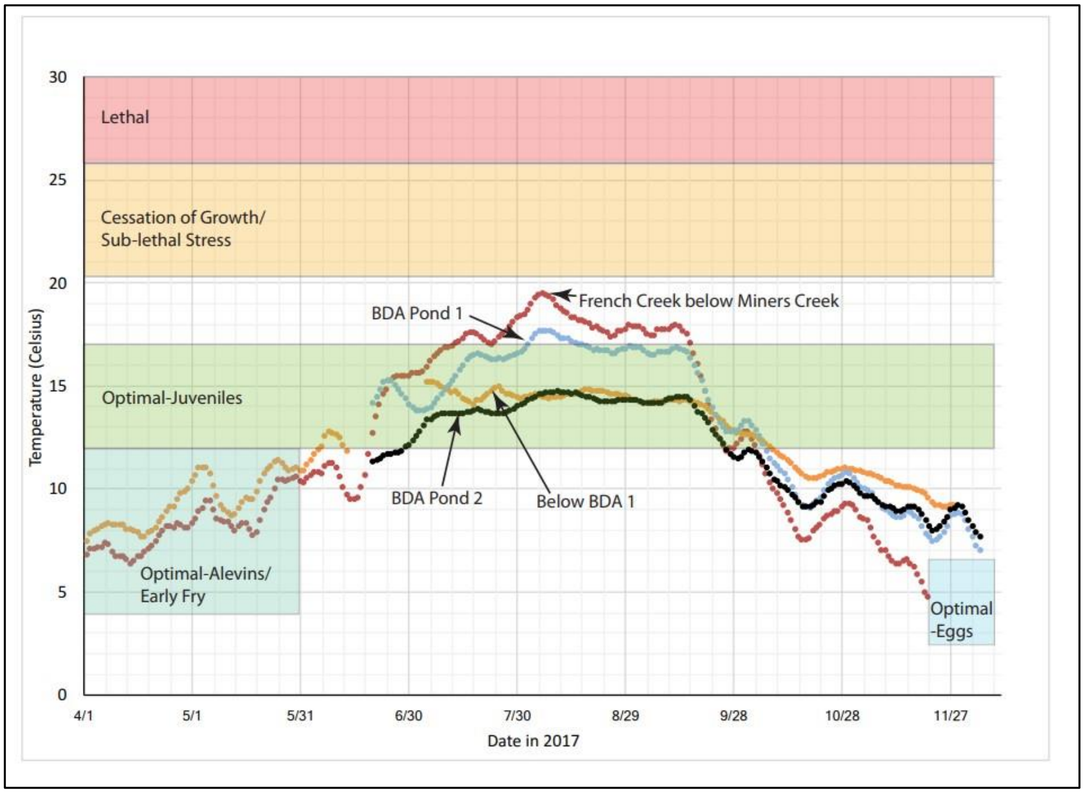

Figure 12. Moving average weekly maximum temperature (°C) in French Creek mainstem and Side Channel BDA Reach April-November, 2017. Thermal optimum and stressful ranges for coho salmon life stages based on Richter and Kolmes (2005).

Miners Creek

In Miners Creek, water temperature was recorded in four locations - upstream and downstream of the two BDAs. Water temperatures in French Creek, downstream of the Miners Creek confluence were compared in Figure 13. The BDA reach had areas of disconnection during summer and fish presumably moved downstream with receding flows. Above the BDA treatment reach, temperatures in Miners Creek rose to above 20 ^{0}C for a brief period in August, a level that can cause stress in coho salmon. Below the BDA ponds temperatures were much cooler, and close to or within the thermal optima for coho salmon throughout the summer. The difference may be due to increased groundwater storage in the alluvial valley that may be partially attributable to the BDAs. The upper BDA did accumulate a considerable amount of alluvium, and the amount and duration of flows in the reach appear to have improved relative to pre-project conditions, when the stream regularly ceased flowing during the summer months. However, interpretation of data is somewhat confounded by water withdrawals upstream of the site.

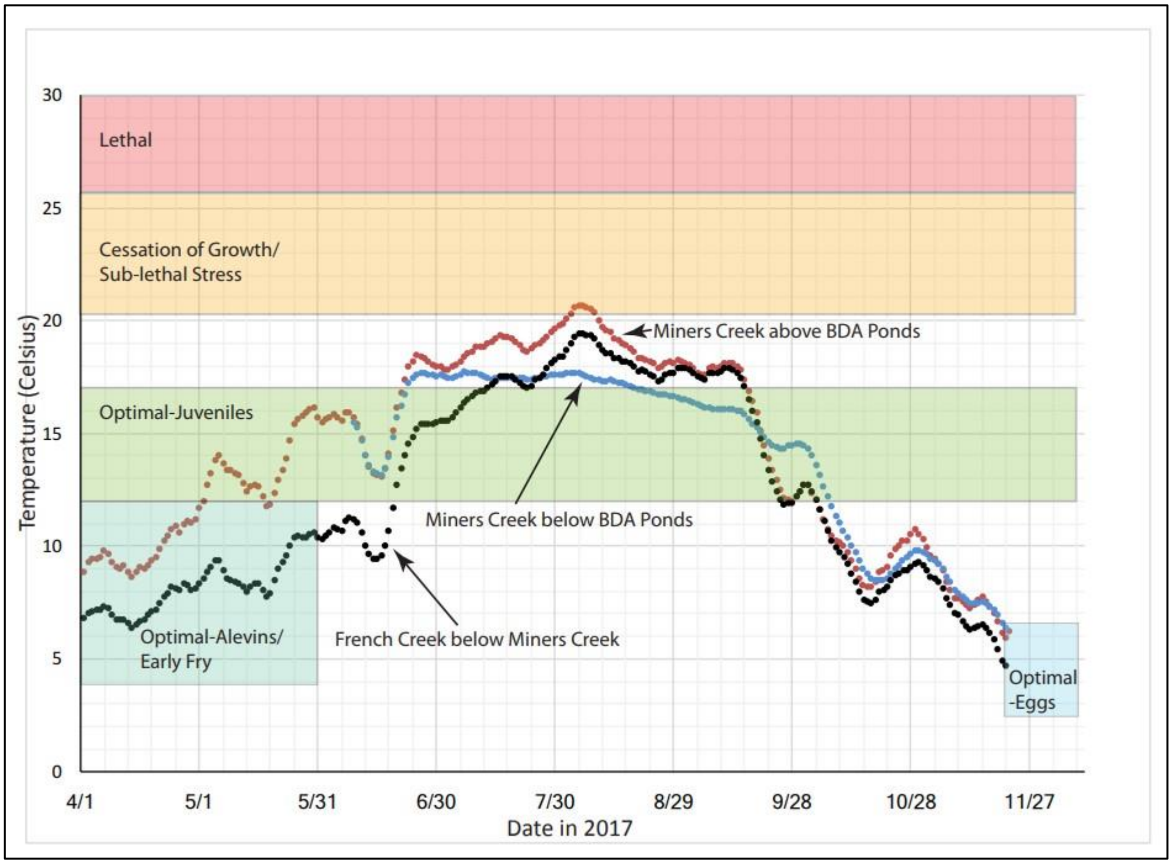

Figure 13. Moving average weekly maximum temperature (°C) in Miners Creek, April-November, 2017. Thermal optimum and stressful ranges for coho salmon life stages based on Richter and Kolmes (2005).

Water Surface Elevation and Discharge

Sugar Creek

Water Surface Elevations

Analysis of late Summer base flow water surface elevations in BDA Pond 1 shows a steady increase in the minimum late summer WSE each year, following restoration, with an overall increase of 107 cm (3.5 ft) from 2014-2017. (Table 2, Figure 14). In late July, 2014, prior to BDA completion, Sugar Creek ceased flowing at the site of the WSE station MW2 (see Figure 5). Analysis of WSE data collected at BDA Pond 1 indicates the groundwater water level at that time was approximately two feet below the stream bed elevation at approximately 2999.0 ft. The 2015 Water Year was also a poor water year and flow ceased for a brief period during the summer, but water levels remained just below the surface. In 2017, maintenance and beaver raised the crest elevation of both BDA 1 and BDA 2 to their current levels, with the BDA Pond 1 WSE averaging approximately 3002.5 ft throughout the Summer baseflow period.

As part of the process-based adaptive management approach to restoration that this project employs, and in an effort to mimic the behavior of beaver, repairs are regularly made to the

Sugar Creek BDA structures after flood damage that breaches the dams and lowers the pond level. Such repairs offer an opportunity to assess the extent to which water levels in the BDA ponds affect water levels in the ground and surface water monitoring wells at the site.

For example, maintenance performed from July 24th to August 5th, 2017 to fix a breached section of BDA 1.0, raised the WSE in BDA pond 1 by 27 cm (0.9 ft), but the monitoring wells further removed from the stream suggests a complex pattern of groundwater connections. Table 3 indicates that WSEs in the tailings ponds were raised from 0.7 to 0.1 ft, but the magnitude of the change was poorly correlated to distance from the BDA. By the end of the two-week repair period, groundwater surface elevations at some monitoring stations near the stream were raised 0.9 ft (27 cm) or more (e.g., MW3 and MW 4), others a slight distance away from the stream less than 0.1 feet (3 cm) (e.g., MW 15), while monitoring stations as far as 0.9 kilometer upstream recorded an WSE gain of 15 cm (0.5 feet) (e.g., MW13). The "control" well in the Scott River (MW16) showed no change in WSE during the same period, indicating changes were not attributable to changes in stream flow. These patterns suggest the possibility of multiple sources of groundwater recharge, and that some sites may be influenced more by hyporheic flow paths coming from the Scott River (e.g. MW 12) while others may have subsurface paths that are more directly connected to and affected by water levels in Sugar Creek (e.g. MWs 11 and 13).

In general, repairs to BDAs seem to have an almost immediate effect. For example, an increase in WSE resulting from repairs of a 20-foot breach to the BDA 1.0 structure on May 15th raised the WSE by approximately 27 cm (0.9 ft) in less than a day (Figure 15).

Overall, the monitoring well field documented that BDAs affect groundwater levels as far as 0.9 km upstream and 0.3 km downstream. The effects probably extend further in each direction, particularly upstream. Our furthest up valley and down valley monitoring wells both measured WSE increases at the time of BDA repairs (15.2 and 3 cm, respectively) (Table 3). Applying these figures across the upstream and downstream aerial extent of the well field we can conservatively estimate that the construction of BDA 1, a 76 cm high dam, has increased water storage in the valley floor alluvium by about 37,000 m^3, (30 acre-feet).

Table 2. Minimum yearly surface or ground water surface elevation at Sugar Creek BDA Pond 1.

Water Year	Minimum WSE (ft)	Date Minimum WSE Recorded
2014	2998.1	9/18/2014
2015	3000.0	8/31/2015
2016	3001.3	8/3/2016
2017	3001.6	7/21/2017

Table 3. Water Surface Elevation (WSE) monitoring stations in Lower Sugar Creek. Also shown are the WSEs for each monitoring station in the Sugar Creek network on 9/1/2017 and the change (delta) in WSE for each station between 7/26/17 and 8/9/17, when BDA 1.0 was repaired and the pond elevation was raised 30 cm (one foot). Negative numbers for distances mean that the site is down the Scott River valley, relative to Sugar Creek. See Figure 4 for a diagram of well locations. WSE = water surface elevation, DS=downstream; FP = Floodplain.

Well#	Distance to BDA 1 (m)	Distance to Sugar Ck (m)	WSE (m) 9/1/2017	WSE relative to BDA Pond 1 (cm)	Change in WSE after repair (cm)	Description
Down valley from Sugar Creek						
MW16	-193.5	-76.2	911.4	-387.1	0.0	Scott R. DS of Sugar
MW7	-266.7	-268.2	909.3	-591.3	6.1	Tailings pond
MW8	-373.4	-353.6	908.8	-640.1	3.0	Tailings pond
MW6	-182.9	-128.0	nd	nd	nd	Tailings pond
On floodplain near BDA 1						
MW4	-50.3	-48.8	912.5	-271.3	30.5	RL FP next to BDA1
MW3	30.5	30.5	914.9	-33.5	27.4	RR FP next to BDA1
Surface connection to Sugar Ck BDA Pond 1						
MW2	62.5	0.0	915.2	0.0	27.4	BDA Pond 1
MW5	129.5	0.0	915.3	3.0	18.3	BDA Pond 2
MW1	286.5	88.4	915.3	3.0	18.3	Off-Channel Pond
Up valley from Sugar Ck						
MW9	265.2	207.3	915.3	6.1	21.3	Tailings pond
Up valley from Sugar Creek-in long depression between tailing mounds						
MW15	341.4	118.9	915.6	42.7	0.0	Tailings pond
MW14	356.6	201.2	915.4	18.3	18.3	Tailings pond
MW10	396.2	338.3	915.6	33.5	3.0	Tailings pond
MW11	451.1	384.0	915.3	6.1	21.3	Tailings pond
MW12	600.5	557.8	916.2	94.5	3.0	Tailings pond
MW13	938.8	829.1	916.1	85.3	15.2	Tailings pond

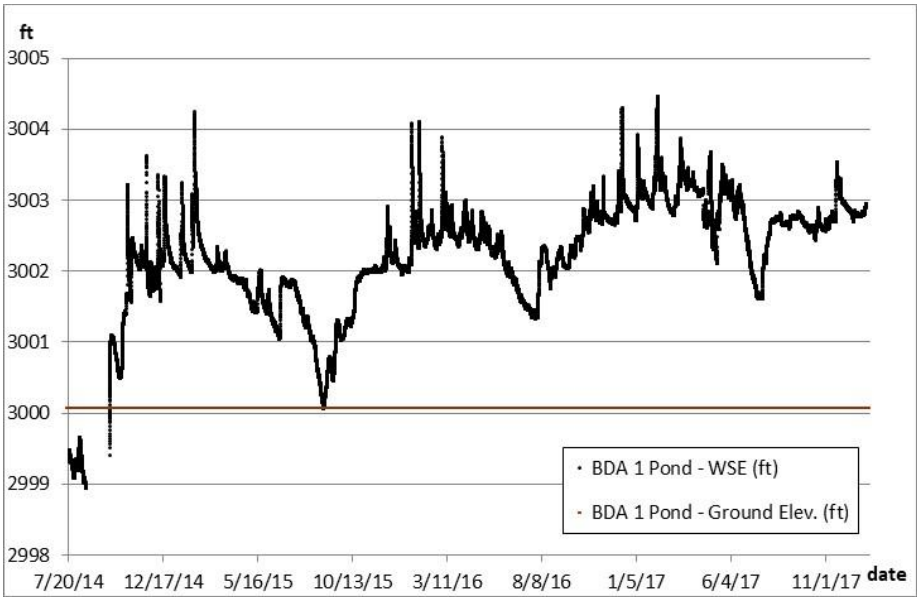

Figure 14. Water surface elevation (ft) as measured in BDA Pond 1 from July of 2014, when flow ceased at the time of installation, to November, 2017. The line just above 3000 ft is the bed surface elevation at the base of BDA 1.0. The low water points in 2015, 2016 and 2017 are from breaches that were repaired later in the year when flows receded.

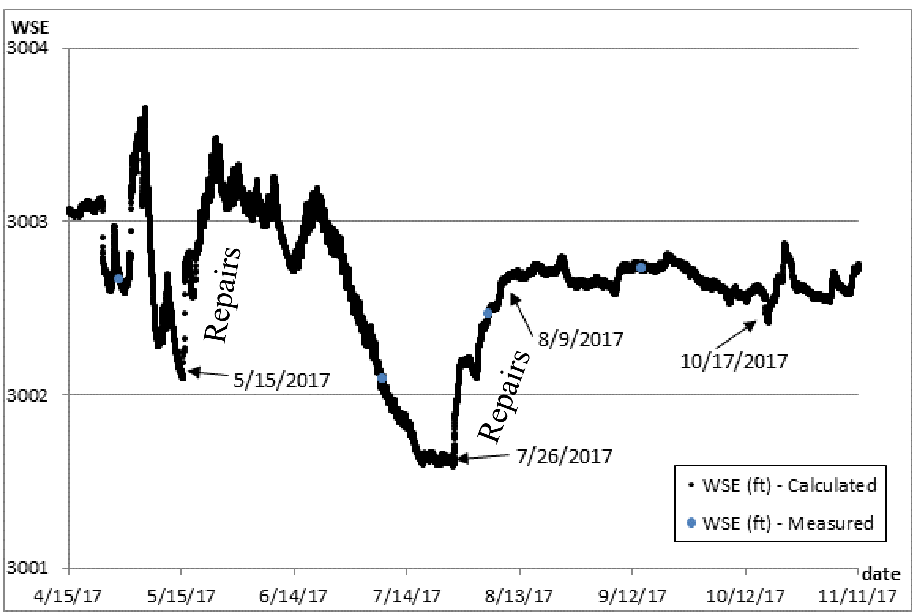

Figure 15. Water Surface Elevation (WSE) as measured at Sugar Creek's BDA Pond 1. Dates of significant maintenance activity noted. August 9th marks the end of a two-week period of repair activity that began July 26th. May 15th and October 27th repairs were one day events.

Discharge

Figure 16 shows the discharge data collected at the Sugar Creek stream gage during the last three water years, displaying the poor water year during water year 2015 (October 1, 2014-September 30, 2015), when flows rarely exceeded 20 cfs. This compares with the subsequent water years, when flows exceeded 20 cfs for most of the year. The data are useful to compare to the water surface elevation in the BPA ponds. A visual examination between Figures 14 and 16 indicates little relationship between discharge and pond water surface elevation. Comparison of the two figures also suggests that the BDA ponds have an attenuating effect on flows. At the ponds, the range of water surface elevations between significant flood events and base flow conditions is about 1.5 ft (45 cm) (Figure 14), whereas discharge ranges from > 70 cfs during floods, to as little as 2 cfs at baseflow (Figure 16).

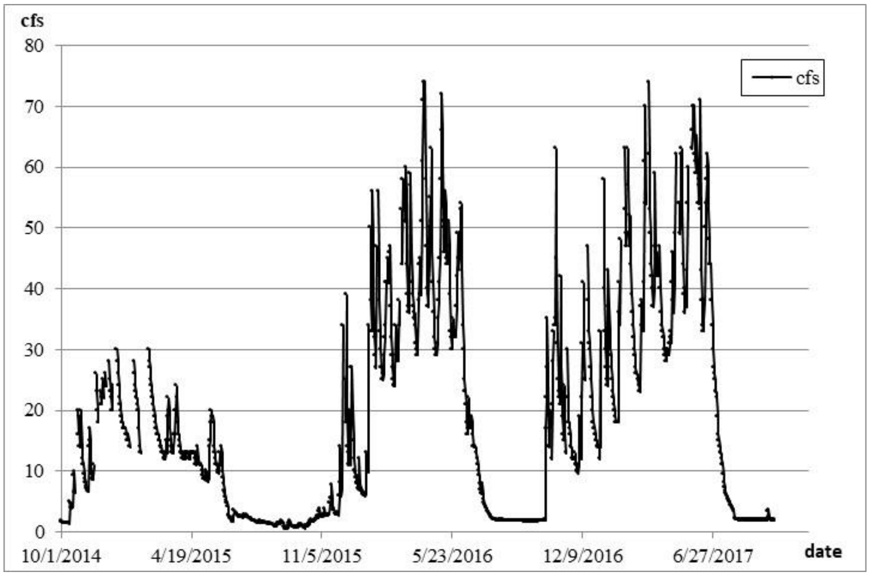

Figure 16. CDWR Certified Record for Sugar Creek near Callahan (F25890). Daily average discharge (cfs) for water years 2015-2017.

French Creek

Water Surface Elevations

Figure 17 shows the measured WSEs at the French Creek restoration site prior to and after BDA construction. Measured WSE shows existing base flows for the reach. The June 22nd 2017 BDA construction date on the French Creek side channel shows a corresponding WSE elevation gain in groundwater levels near the BDAs, but not in the monitoring well near the mainstem of French Creek (MW6). The data from MWs 4 and 5 also show a bifurcation in WSEs following BDA construction. Prior to construction (June 22, 2017), the difference in WSEs between the two monitoring wells, was about 0.2 ft, whereas after construction, the difference in WSEs has remained consistently at about 0.4 ft. Monitoring Well 5 measures the surface water elevation in the side channel upstream of a BDA, so an WSE gain is anticipated. The more muted WSE response and relatively quick dropoff in WSE in MW 4, a groundwater well about 50 feet from MW 5 on the left side of the channel suggests a somewhat porous alluvium that drains water relatively quickly. This is consistent with visual observation of the alluvium on cut banks, which appears to consist mostly of cobbles, coarse gravels and sand-filled interstices, with little fine silt or clays that would impede drainage.

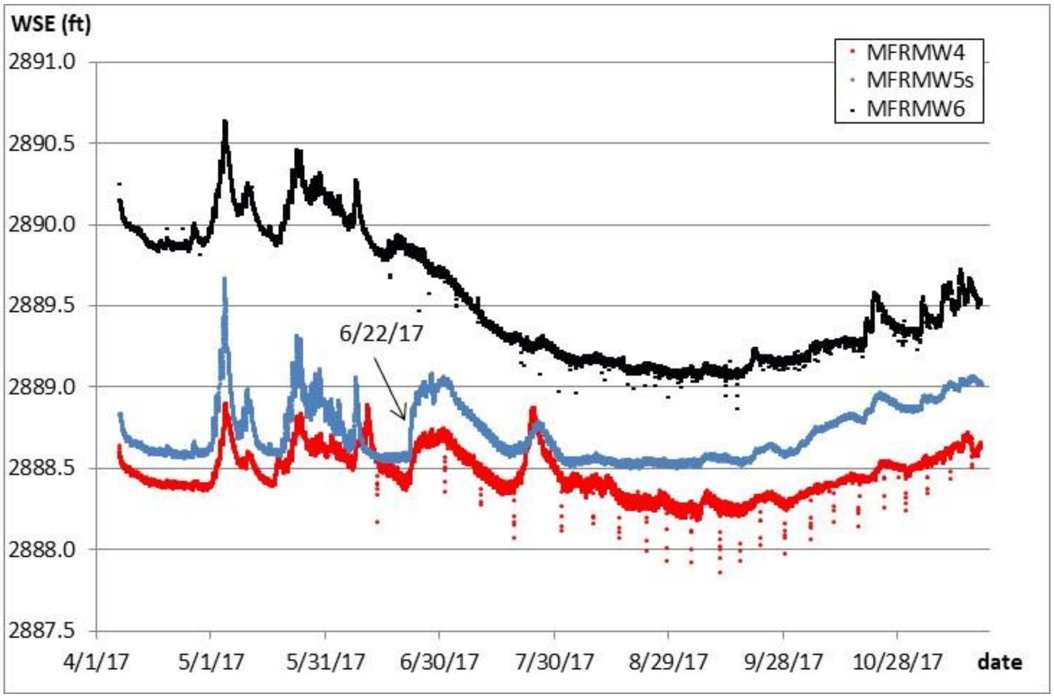

Figure 17. Measured water surface elevation in the French Creek restoration site during water year 2017. The June 22nd 2017 BDA construction date on the French Creek side channel shows a corresponding WSE elevation gain in groundwater levels near the BDAs, but not in the monitoring well near the mainstem of French Creek.

Salmonid Monitoring

Table 4 shows the number and species of fish tagged at French Creek, Sugar Creek and Miners Creek in the Summer and early Fall of 2017.

Table 4. Species composition of fish tagged in 2017.

Stream	Total Marked	Coho (%)	Steelhead (%)	Chinook (%)
French Creek	392	81.4%	16.6%	2.3%
Sugar Creek	1,272	80.8%	18.8%	0.4%
Miners Creek	75	92.0%	8.0%	0.0%

Site Fidelity

In Sugar Creek, fish that were tagged and recaptured by seine were evaluated for site fidelity. Below, Table 5 shows that nearly all fish were recaptured in the same location that they were initially captured, the exception that of five fish initially captured at the Scott River confluence, two (40%) moved upstream to BDA Pond 1. The results of this analysis support our working hypothesis that fish in BDA Pond 1 and BDA Pond 2 are functioning as separate populations, with little mixing.

In French Creek, site fidelity was not as strong, particularly in the downstream- most pools (Table 6). Fish that were captured in pool 1, were more likely to be recaptured in an upstream site than the original capture location. At the same time, the entire French Creek site is only about 11% the size of the Sugar Creek site, so between the two sites, fish site-fidelity was measured at different scales and the results are not directly comparable. The number of fish that remained in the French Creek site as a whole was high (see population estimates sub-section, below).

Table 5. Locations of initial capture and recapture in the Sugar Creek restoration site.

Sugar Creek-Initial Capture Site	Tagged and Recaptured	Recaptured in Same Location	Recaptured Elsewhere	Recapture Location
BDA Pond 1	259	99.6%	0.4%	BDA Pond 2
BDA Pond 2	46	97.8%	2.2%	OCP
Confluence	5	60.0%	40.0%	BDA Pond 1
Side Channel3	2	100.0%	0.0%	-

Table 6. Locations of initial capture and recapture in the French Creek control site.

French Ck- Intial Capture Site	Tagged and Recaptured	Recaptured in Same Location	Recaptured in Pool 1	Recaptured in Pool 2	Recaptured in Pool 3	Recaptured in Pool 4
Pool 1	14	35.7%	-	0.0%	57.1%	28.6%
Pool 2	4	75.0%	0.0%	-	25.0%	0.0%
Pool 3	102	74.5%	2.0%	2.0%	-	21.6 %
Pool 4	101	89.1%	0.0%	0.0%	10.9%	-

*some totals are greater than 100% as some fish were recaptured in more than one location

Further analysis of the movement patterns within BDA Pond 2 indicated that the sampled habitat was only a small part of the habitat being utilized by the fish captured there. Unlike BDA Pond 1, fish captured in BDA Pond 2, had a low likelihood of being recaptured and population estimates had high levels of error. As an example, during the July sampling event, 32 coho salmon were tagged in BDA Pond 2. Of these, 19 were subsequently detected somewhere on the PIT antenna network a total of 39 times through December, 2017. Ten of 39 were detected on the upstream antenna, near the head of BDA Pond 2, three were detected in Side Channel 2 (the marsh) and the rest (26 of 39) were detected at the pair of antennas at the mouth of the off-channel pond (see Figure 5 for antenna locations). The number of detections is not indicative of habitat use, because the marsh antenna was only operating for a brief period in July, and the BDA Pond 2 array has only been in operation since November, but the data do indicate the overall mobility of the fish and suggest that the off-channel pond is being used by fish tagged in BDA Pond 2.

Diurnal Migration Patterns

At the Sugar Creek Restoration Site, a diurnal movement pattern was detected at the off-channel pond during the winter season. During the period of January 30- March 21st, two antennas located in the outlet channel of the off-channel pond (A8 and A9) were used to detect directional movement of tagged fish in and out of the pond. Figure 18 shows fish exiting the off-channel pond near sunset and returning at dawn. A similar diurnal migration was documented during a different season (Summer) in tributaries of the mid-Klamath River; Tom Martin and Seiad Creeks (Witmore 2014).

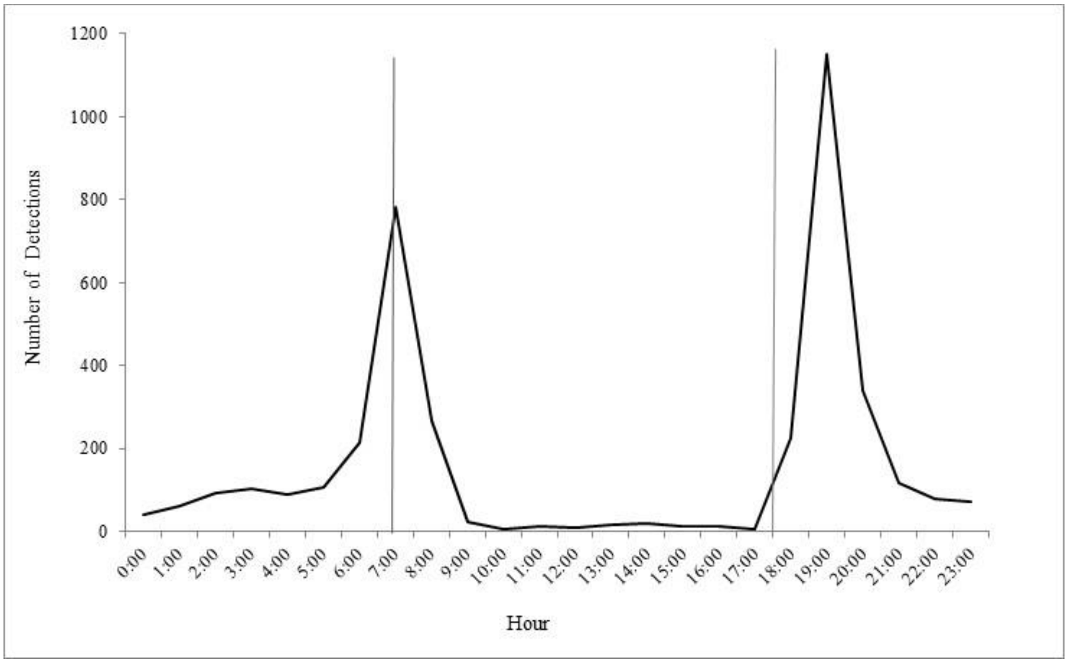

Figure 18. Diurnal movement pattern of juvenile coho salmon detected leaving the off-channel pond in the evening after sunset and returning at sunrise. The data were collected using PIT tag antennas placed at the outlet channel to the off-channel pond, January 30 – March 21, 2017. Vertical lines correspond to the average time of sunrise and sunset during the dates of detection.

Smolt Outmigration and Juvenile Redistribution

At the Sugar Creek restoration site, two antennas installed in BDA Pond 1 in early April, 2017, reliably detected tagged fish as they outmigrated from the site. However, because the antennas were in the pond where fish were rearing not all detections were indicative of outmigration. Therefore, we conservatively estimated that only fish tagged in BDA Pond 2 and subsequently detected on these antennas were identified as outmigrating. In French Creek, two antennas were set up in the mainstem of French Creek downstream of the Highway 3 bridge (RKM 1.0). These antennas were intended to detect PIT tagged salmonids as they outmigrated from the habitats upstream, where they were initially tagged. The antennas became operational on April 10, 2017 and the last data contributing to this report was downloaded on November 27, 2017.

In Sugar Creek, a total of 335 juvenile coho salmon were tagged in BDA Pond 2 during the summer of 2016. Of these fish, 135 (40%) were subsequently detected on the antennas in BDA Pond 1 as they were outmigrating in Spring, 2017. In French Creek 396 juvenile coho salmon were tagged in the summer of 2016, with only 28 (7%) detected downstream during the Spring, 2017 outmigration period (Figure 19). However, the following Autumn, we did detect a small amount of outmigrating in French Creek, detecting 17 fish out of the 392 fish marked in the

Summer of 2017 (4%) on the downstream antennas, and a similar Fall outmigration may have occurred the previous year.

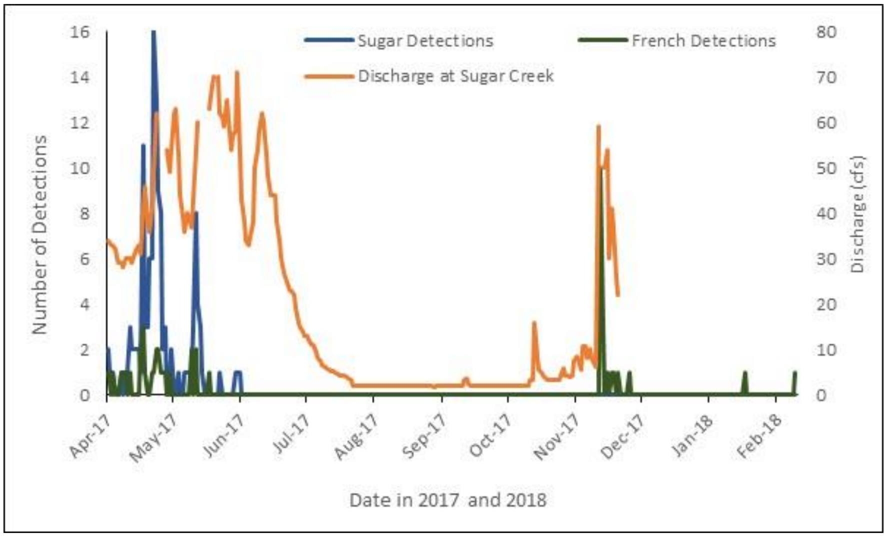

Figure 19. Number of fish detected outmigrating at the Sugar and French Creek arrays between April 10, 2017 and February 22, 2018. Sugar Creek detections include only juvenile coho salmon tagged in the upper BDA Pond 2. Detections in the lower BDA Pond 1 infer outmigration of juvenile coho salmon. Discharge at the Sugar Creek gage shown from April 10, 2017 to November 29, 2017.

Growth Rates

Growth rates of individual coho salmon were estimated using weights recorded during seine captures. When tagged individuals were recaptured, the change in weight was used to estimate rate of growth as a function of grams/grams/day. Optimal growth for coho salmon occurs between the water temperatures of 12.5-17.0°C (see section *Temperature* above).

Because we did not see significant movement between Sugar Creek's BDA Pond 1 and BDA Pond 2 (see Table 5), growth rates were estimated separately for these habitats. Figure 20 shows the estimated growth rates and standard error of the juvenile coho salmon in the Sugar and French Creek sites as compared to the estimated growth rates of coho salmon in tributaries of the mid-Klamath, using the same methods for estimation (from Witmore 2014). The BDA ponds showed high rates of growth, among the best of all sites examined (Figure 20). Relative to the other stream sites (Tom Martin and Cade Creeks), which are generally not as productive as ponds, the French Creek site showed good growth.

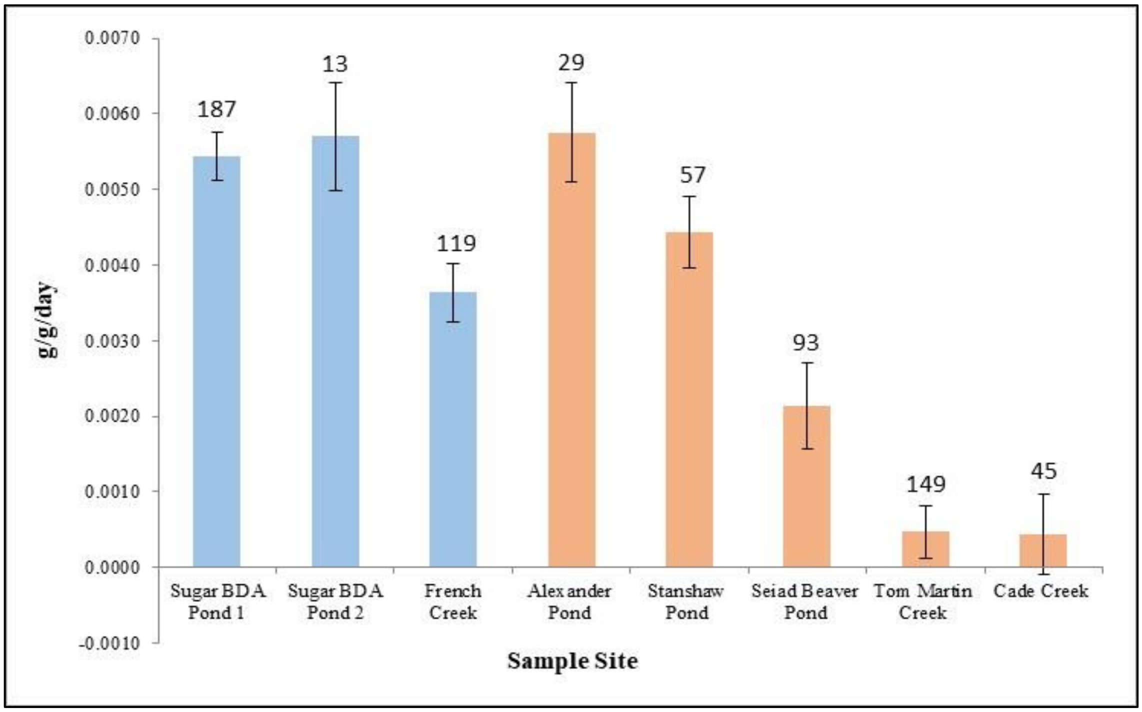

Figure 20. Average summer growth rates of juvenile coho salmon in Klamath River tributaries and Scott River restoration sites. The blue bars indicate growth rates estimated during the 2017 summer season and orange bars indicate growth rates estimated during the 2012 summer season. Numbers shown above the bars represent sample size for the calculation.

Biometric Comparisons

Because juvenile coho salmon that were captured display relative site fidelity (see Table 6), it was possible to compare biometric data collected for individuals from different habitats. These comparisons may provide an indication as to which habitats are more productive, contribute to higher growth rates, and/or increase survival of juvenile coho salmon.

Biometric comparisons are shown for measured fork lengths, weights, and Fulton's Condition Factor (K) (Ricker 1975, see also Nash et al. 2006). Fulton's Condition Factor is the ratio between a fish's weight and length raised to the third power and works under the assumptions of isometric growth that heavier fishes of a given length are in better condition.

Within the Sugar Creek restoration site, four habitats were sampled during the summer and fall of 2017. These were, (1) Scott River at the confluence with Sugar Creek, (2) BDA Pond 1, (3) Sugar Creek BDA Pond 2, and (4) Sugar Creek Off-Channel Pond. French Creek and Miners Creek biometrics are compared to the Sugar Creek fish (Table 7).

Table 7 shows that sizes of fish sampled at the various locations varied sometimes significantly. During the first sample event in late July, size of fish varied greatest between the Sugar Creek BDA Pond 2 and all other sites, with fish in BDA Pond 2 smaller than at all other sites, both in terms of length and weight, while BDA Pond 1, the Sugar-Scott confluence and French Creek all had fish of similar size. Towards the end of October, fish in Sugar Creek's BDA Pond 1 were larger than fish in other locations, and the other sites showed a range of sizes. The reasons for the size differences are not readily apparent.

Table 7. Comparison of coho salmon biometric data for Sugar Creek, French Creek and Miners Creek.

July 25, 2017 (Julian Week 30)						
	Sugar BDA Pond 1	Sugar BDA Pond 2	Sugar Confluence	Sugar OCP*	French Creek	Miners Creek*
Average Fork Length	68	59	69	-	69	-
Average Weight	3.7	2.8	3.8	-	3.7	-
Average K	1.13	1.08	1.14	-	1.11	-
October 25, 2017 (Julian Week 43)						
	Sugar BDA Pond 1	Sugar BDA Pond 2	Sugar Confluence	Sugar OCP*	French Creek	Miners Creek*
Average Fork Length	86	77	75	83	79	65
Average Weight	6.6	4.1	4.2	6.0	4.9	3.0
Average K	1.04	1.00	1.05	1.00	1.03	1.06

*Because sampling dates differed between locations, some figures were extrapolated using available growth rates for those specific sites. Only one sampling event occurred at Sugar Creek OCP and Miners Creek. Therefore, no growth statistics were available and figures could not be extrapolated. At Miners Creek, the sampling event occurred September 19; one month prior to the other data presented. Fish that were more than one year old were removed from analysis.

Population Estimates

The population of juvenile coho salmon utilizing the Sugar Creek BDA restoration site and the French Creek control site was estimated using the Lincoln-Peterson mark-recapture technique (Seber 1973). We conducted three mark-recapture events during the summer of 2017 for both of these locations. Because juvenile coho salmon redistribute during the spring and fall seasons, these capture events were conducted during the period of rearing when populations would be the most stable and representative of summer utilization (July-September).

Sugar Creek—During the 2017 season, 1272 juvenile salmonids were PIT-tagged in the Sugar Creek site, 81% of which were coho salmon, 19% steelhead trout, and 0.4% Chinook salmon. We attempted to directly estimate population size for both BDA Pond 1 and BDA Pond 2 in the months of July, August and September by applying mark-recapture techniques using PIT tags as markers. However, due to the habitat complexity and large size of the area used by the BDA Pond 2 fishes (e.g., the side channels, off-channel pond, marsh, etc.), we were unable to obtain reliable population estimates by subsampling a portion of that habitat. We were however able to obtain good population estimate of the BDA Pond 1 (Table 8). Using the data from BDA Pond 1, we were able to estimate populations for the rest of the restoration site by weighting each site according to its habitat capacity. A comparison of the estimated populations for each mesohabitat relative to the habitat capacity is provided in the next section, "Habitat Capacity Estimates for Juvenile Salmonids".

French Creek—The French Creek control site is located 3.5 km upstream of the confluence with Scott River. The control reach is a single thread channel with pool and riffle habitat. Four pools, interspersed with riffles, were sampled during the three mark-recapture efforts conducted in 2017. The total area of this control reach is approximately one-tenth the size of the Sugar Creek restoration complex.

During the 2017 season, 392 salmonids were tagged in the French Creek site. Of those fish, 319 were coho salmon, 65 were steelhead trout, and nine were Chinook salmon (Table 4). Population estimates for juvenile coho salmon in the French Creek control site and the calculated error for those estimates are shown below in Table 8. Calculated error is low due to a high rate of recapture and a much more intensive sampling effort per unit of habitat, relative to the Sugar Creek site. The population appears to have slowly declined from July through September, with apparent survival at 81%.

Table 8. Estimated population and standard deviation for juvenile coho salmon in Sugar Creek BDA Pond 1 and the French Creek control reach.

Site	July	SD	August	SD	September	SD
Sugar Ck-BDA Pond 1	1996	787	772	125	914	144
French Creek	269	37	254	13	218	13

Habitat Capacity Estimates for Juvenile Salmonids

The potential production of smolt outmigrants was estimated using the juvenile salmonid habitat capacity model developed by Goodman and others (2010, 2015) in tributaries to the Trinity River. This model uses depth, velocity and cover measurements to estimate the habitat capacity of pre-smolt outmigrants of coho and Chinook salmon. We measured these variables along cross sections in both the treatment and control reaches to estimate capacity, and then scaled up to the site-level (Table 9). Repeat surveys were performed in 2016 and 2017. Prior to project construction on Sugar Creek, the channel dried up, so habitat capacity for a non-drought year was estimated using aerial photography and field examination of the dry bed to estimate width and cover. Velocity and depth were assumed to be optimal (i.e. < 0.5 m/s and < 1 m, respectively). The model does not consider temperature as a potential limiting factor.

Sugar Creek

As of 2017, the site has the potential to produce just under 7500 coho pre-smolt outmigrants, inclusive of the beaver ponds, off-channel pond and side channels (Table 9). This is about an 18% increase over the 2016 production capacity of 6327 (Table 10), and a >2000% increase over pre-project conditions. The 2016-2017 change is largely a result of beaver activity raising the level of both dams sufficient to flood nearby vegetated benches. Relative to pre-project (2014) conditions, there has been: (1) a 16-fold increase in juvenile coho salmon habitat, (2) a 20-fold increase in habitat capacity measured as potential production of coho smolt outmigrants, (3) a 10-fold increase in outmigrants produced per unit stream length, (4) a doubling of stream length by activating side channels and, (5) a 25% increase in outmigrants produced per unit area (i.e. average habitat improvement per unit area).

Table 9. Habitat area and estimated total fish production potential, density and stream length, for each of the mesohabitats in the Sugar Creek restoration complex. pp=potential production of coho pre-smolt outmigrants and L = stream length.

Site	Area (m^2)	pp	pp/ m^2	pp/m	L (m)	Area (%)	pp (%)
2017 Conditions							
BDAP1	2572	2570	1.0	22.2	115.7	28%	34%
BDAP2	3276	2867	0.9	13.0	220.2	36%	38%
SCB-Marsh	879	1143	1.3	15.4	74.0	10%	15%
SCA	353	165	0.5	1.7	167.0	4%	2%
OCP	2049	748	0.4	5.7	131.0	22%	10%
Total-All	9129	7493	0.8	10.6	707.9	100%	100%
Ttl- BDAPs	6727	6579	1.0	16.1	409.9	74%	88%
2016 Conditions							
Site	Area (m^2)	pp	pp/m^2	pp/m	L (m)	Area (%)	pp (%)
BDAP1	2261	1732	0.8	16.0	108.1	26.7%	27.4%
BDAP2	3162	2947	0.9	14.0	210.9	37.3%	46.6%
SCB-Marsh	645	735	1.1	8.6	74.0	7.6%	11.6%
SCA	353	165	0.5	1.7	167.0	4.2%	2.6%
OCP	2049	748	0.4	5.7	131.0	24.2%	11.8%
Total-All	8471	6327	0.7	9.2	691.0	100.0%	100.0%
Ttl- BDAPs	6068	5414	0.9	13.8	393.0	72%	86%
Pre-project Conditions							
Site	Area (m^2)	pp	pp/m^2	pp/m	L (m)	Area (%)	pp (%)
Mainstem	533	350	0.7	1.0	355.0	100%	100%

Table 10. Year to year changes in habitat area and estimated total fish production potential, density and stream length, for each of the mesohabitats in the Sugar Creek restoration complex. pp=coho pre-smolt outmigrants and L = stream length.

2016-2017 Change in Conditions					
Site	Area (m^2)	pp	pp/m^2	pp/m	L (m)
BDAP1	14%	48%	30%	39%	7%
BDAP2	4%	-3%	-6%	-7%	4%
SCB-Marsh	36%	55%	14%	79%	0%
SCA	0%	0%	0%	0%	0%
OCP	0%	0%	0%	0%	0%
Total-All	8%	18%	10%	16%	2%
Total BDAPs	11%	22%	10%	17%	4%
2014-2016 Change in Conditions					
Site	Area (m^2)	Sm-Ttl	Sm/m^2	S/m	L (m)
Total-All	1491%	1706%	14%	828%	95%
2014-2017 Change in Conditions					
Site	Area (m^2)	Sm-Ttl	Sm/m^2	S/m	L (m)
Total-All	1614%	2038%	25%	972%	99%

French Creek

Four pool habitats in the Mid French Creek reach at RKM 3.5 have been sampled for juvenile salmonid population studies during the base flow period of 2016 and 2017. A habitat characterization survey was performed to estimate habitat capacity and to compare to the estimated population from the PIT tag mark-recapture effort. The length of each pool and riffle meso habitat was measured in the sampled reach. Representative transects in each sampled pool were identified. Wetted width, water depth, water velocity, stream bed substrate and habitat cover were assessed across each transect. Riffles were assumed to have a coho habitat capacity of zero. The total habitat capacity or potential production of the reach was estimated at 355 coho outmigrants (Table 11). On an area basis, the reach as a whole has the potential to produce about 0.4 fish/m^2.

The four pools have relatively high percentage of cover in the deep-water area of the scour holes. Pools 1 through 3 have greater than 70% cover at the deepest transect with Pool 4 having slightly less than 50% cover. Coarse woody debris is the dominant cover element in two of the four pools and the sub dominant cover element in one pool. Overhanging terrestrial vegetation, deep water and undercut banks created fish cover in the pools.

Visual observations suggest the fish sampling reach has a higher pool frequency than is characteristic of the surrounding reaches for the area that extends from the confluence of Miners

Creek with French Creek at RKM 4.6 to the HWY 3 Bridge at RKM 1.4. Though this area has a relatively high occurrence of pools and is generally good habitat, it has significant areas dominated by flatwater habitats with limited habitat complexity and fish cover outside of the stream margins.

Table 11. Habitat area and estimated total fish production potential, density and stream length, for the pool and riffle habitat in the French Creek control site. pp=potential production of coho pre-smolt outmigrants and L = stream length.

	Area (m^2)	pp-Ttl	pp/m^2	pp/m	L (m)	% all hab	% pp
Pool1	175	121	0.7	1.3	90	18%	34%
Pool2	51	24	0.5	0.6	42	5%	7%
Pool3	228	110	0.5	1.3	83	23%	31%
Pool4	140	99	0.7	1.7	58	14%	28%
Total-Pools	594	355	0.6	1.3	273	61%	100%
Total Riffles	380	0	0.0	0.0	175	39%	0%
Total Reach	973	355	0.4	0.8	448	100%	100%

Comparison of habitat capacity estimates with population estimates

The French Creek production potential estimate of 355 fish compares with an estimated early fall population of 218 juvenile coho salmon (see *Salmonid Monitoring* section above) and suggests that the habitat is undersaturated relative to its capacity, with the fall population at 61% of capacity, and this is prior to winter mortality. The much larger Sugar Creek restoration complex, has an estimated production potential of 7,493 fish and an estimated fall population of 2,665, or 36% of capacity, again, before winter mortality. This is consistent with spawner surveys in the fall of 2016, which showed much higher spawning activity in the French Creek watershed, relative to Sugar Creek. Relative to the entire Sugar Creek restoration site, on a unit area (m^2) basis the capacity of French Creek is about 75% that of the Sugar Creek restoration complex as a whole, indicating somewhat better habitat in Sugar Creek, particularly in the flooded areas upstream of the BDAs.

Fish Passage Across BDAs

An experiment was performed to evaluate BDA structures for juvenile salmonid passage suitability in the Fall of 2017. Downstream of Sugar Creek's BDA 1.0, a pool was formed between the newly installed step BDAs (BDA 1.1 and 1.2) (Figure 21). Captured in BDA Pond 1 were 156 juvenile coho salmon and 40 juvenile steelhead trout. Each fish was PIT-tagged and released downstream of BDA 1.0 in the "release pool." A network of antennas was set up to detect fish at various passage pathways including over topping flow that required a fish to jump and side channel passage around the BDA structures (Figure 21).

Table 12 details the movement patterns, and flow path preferences of juvenile coho salmon and steelhead trout after they were released into the pool below BDA 1.1. The detection efficiency of the antenna network was quite good. All (100%) of the tagged fish were detected at least once, somewhere in the antenna network: 93% were detected in the release pool, 94% were detected upstream of the first BDA (BDA 1.1), and 81% detected upstream of the second BDA (BDA 1.0). For juvenile coho, 97% were detected upstream of the first BDA (BDA 1.1), and 89% detected upstream of the second BDA (BDA 1.0). Overall, the juvenile coho had higher detection rates on the PIT antenna network than the steelhead.

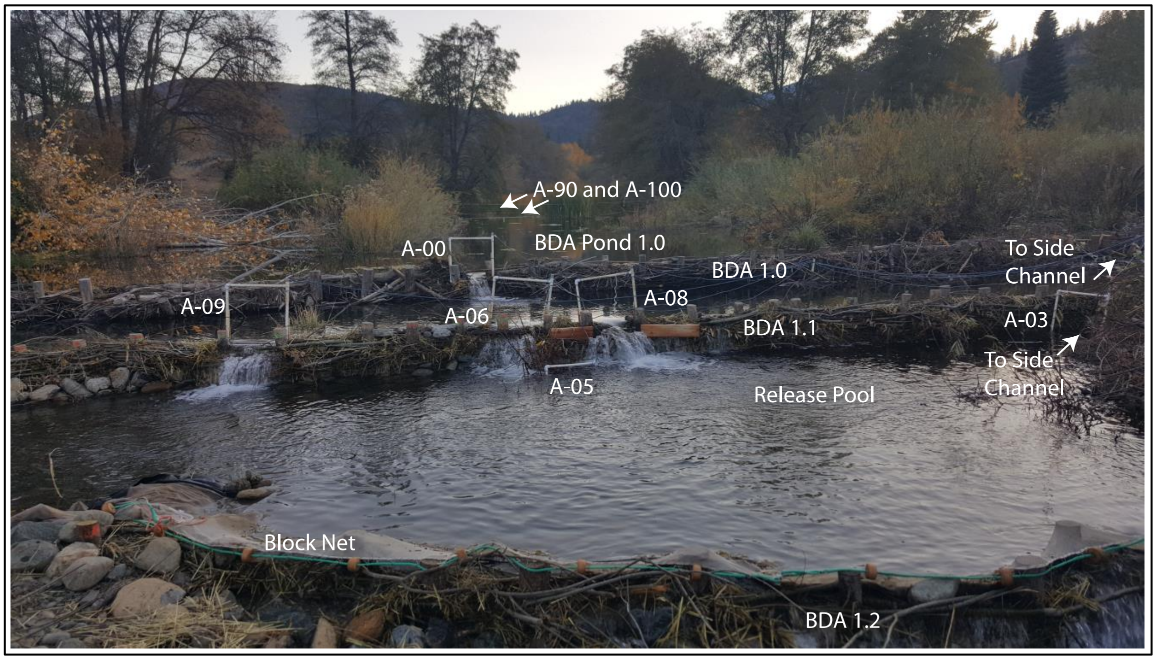

Figure 21. Layout of antennas to monitor the movement of 196 juvenile coho salmon and steelhead trout PIT-tagged and placed in the release pool. Drop over BDA 1.0 = 30 cm, drop over BDA 1.1 = 41 cm. Antenna 90 and Antenna 100 are approximately 30 and 40 m upstream of BDA 1.0, respectively. Just out of the picture on the right are antennas A-0B and A-0A on the upstream side channel and A-02 on the downstream side channel. Also not in view is another antenna below the stopnets to detect any downstream movement.

Juvenile coho reliably move to pools with cover (which is where the upstream antennas were placed), whereas juvenile steelhead occupy a variety of habitats. No fish were detected on an antenna placed below the stop net to detect any potential downstream escapees. Most of the fish moved upstream of the release pool within 36 hours of being released, particularly the coho salmon. Only one coho salmon was observed in the release pool 48 hours after release, while a half dozen or so juvenile steelhead stayed within the release pool for the duration of the two-week experiment.

Both species had a slight preference for crossing the BDAs using side channel passage, but many fish choose to jump over at least one of the BDAs (49% for coho, 43% for steelhead), the jump heights of which were 40 cm and 30 cm for BDAs 1.1 and 1.0, respectively. The lower BDA had three passageways for jumping and of the fish that jumped, there was a strong preference for the river left jump route, for reasons that are not entirely clear. Measurements of velocity profiles and jump heights suggest that the middle and left routes were similar. However, 39% of all fish passing BDA 1.1 used the left jump route, while just 11% used the middle jump route and just 4% used the right jump route (the remainder used the side channel). The right route was in a shallower part of the release pool and not where as much of the flow was concentrated. This is hypothesized to explain why that route was not preferred, but the middle and left routes were close to each other and seemingly quite similar in terms of their hydraulic properties. One possible explanation is that the hydraulic patterns of the release pool favored the left jump route.

Table 12. Summary of detection and movement of 196 juvenile coho salmon and steelhead trout released below two beaver dam analogues.

Metric	Coho-N	Coho-(%)	Stlhd-N	Stlhd-(%)	Total-N	Total-(%)
Released	156	100%	40	100%	196	100%
Detected after release	156	100%	40	100%	196	100%
Detected in release pool	143	92%	39	98%	182	93%
Detected upstream of release pool (BDA 1.1)	152	97%	32	80%	184	94%
Detected upstream of BDA 1.0	139	89%	20	50%	159	81%
Detected in BDA Pond 1	139	89%	20	50%	159	81%
Detected moving downstream	0	0%	0	0%	0	0%
BDA Passage Routes						
Detected using a side channel to cross a BDA	93	60%	25	63%	118	60%
Detected jumping over a BDA	77	49%	17	43%	94	48%
BDA-1.1 Passage Routes						
BDA1.1 Left Jump	66	42%	11	28%	77	39%
BDA1.1 Middle Jump	8	5%	13	33%	21	11%
BDA1.1 Right Jump	3	2%	4	10%	7	4%
All BDA1.1 Jump Passage	74	47%	17	43%	91	46%
BDA1.1 Side Channel Passage	61	39%	22	55%	83	42%
Total detected moving past BDA 1.1	129	83%	31	78%	160	82%
BDA 1.0- Passage Routes						
BDA 1.0 Jump	24	15%	0	0%	24	12%
BDA 1.0 small Side Channel Passage	9	6%	4	10%	13	7%
BDA 1.0 main Side Channel Passage	57	37%	14	35%	71	36%
All BDA 1.0 Side Channel passage	63	40%	15	38%	78	40%
Total detected moving past BDA 1.0	83	53%	15	38%	98	50%

Beaver Monitoring

We have made a number of qualitative observations of beaver activity at each of the sites, both visually and with motion-triggered cameras. All project sites have had observations of beaver activity, with the Sugar Creek site the most active. During the summer of 2016, we began to see increased beaver activity at BDA 2.0 in Sugar Creek. A 20-foot portion of BDA 2.0 on the thalweg on river left was damaged during a high flow event in the winter of 2016, lowering the water level of BDA Pond 2 to approximately the elevation of BDA Pond 1. Once the beaver began maintenance of the structure later in the year, there was a water elevation differential between the BDA Ponds 1 and 2. The beaver activity and maintenance at this location has been continuous since 2016, as has the water surface differential (Figure 22) In July of 2017, mud, branches and herbaceous material were found added to BDA 1.0 for the first time, suggesting that the beavers were beginning to actively maintain the structure. The beaver activity was significant enough to detect a change in WSE in the upstream monitoring wells. Other major beaver activity observed include the felling of a large cottonwood tree into BDA Pond 1, along with an increase of scent mounds around the area of BDA 1.0. A game camera was set up on BDA 2.0 in 2016 and has occasionally caught images of beaver working on the dam, mostly at night, as well as other animals such as river otters using the habitat (Figure 23).

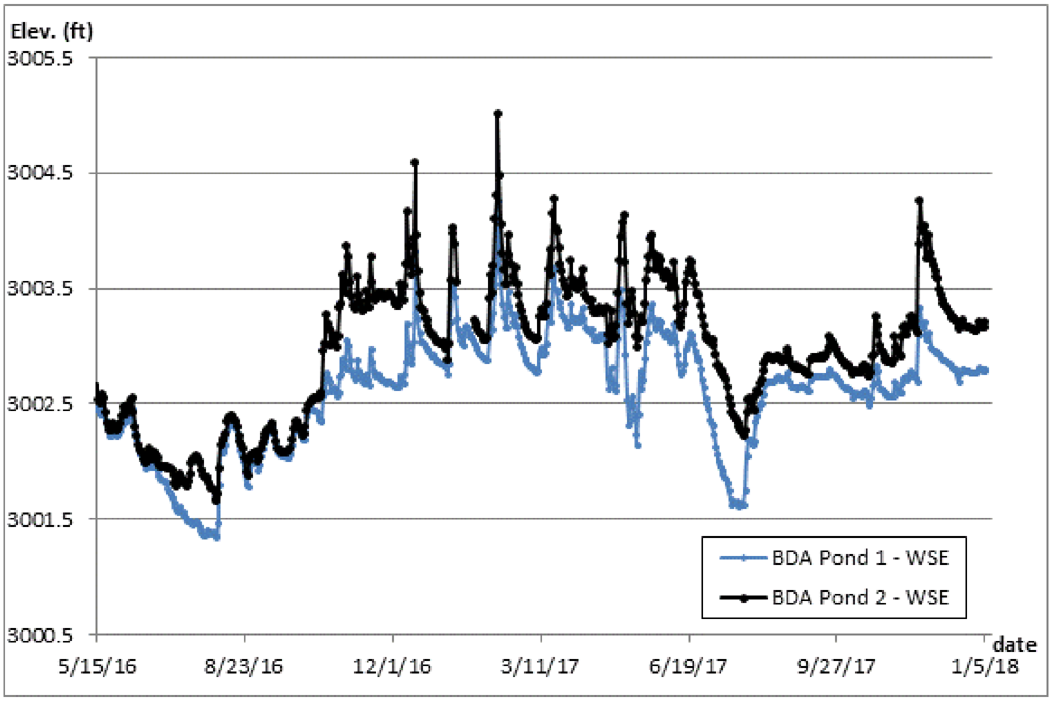

Figure 22. Water surface elevation differences between lower BDA Pond 1 and upper BDA Pond 2. Periods of notable WSE differences are attributable to beaver maintenance activities on BDA 2.0.

Figure 23. Top left: a river otter crossing a BDA 2.0 in Sugar Creek. Top right: two beaver modifying BDA 2.0 at night in Sugar Creek. Bottom right: aerial view of a section of BDA 2.0 repaired and maintained by beaver. Bottom left: A remains of a cottonwood tree felled and consumed by beaver in BDA Pond 1.

BDA Timeline of Construction Activities and Adaptive Management Actions

The Scott River Watershed Council (SRWC) adaptively managed throughout the year to improve instream conditions in the tributaries of Scott River using BDA restoration techniques. This type of work included maintenance of existing structures and construction of additional BDAs which is typical of the type of work a beaver colony might engage in if they were occupying the sites. Below is a chronological description of project work that the SRWC completed as part of their commitment to both adaptively manage existing restoration sites and expand BDA restoration efforts to new locations in the Scott River watershed.

Sugar Creek

Installation and Adaptive Management Prior to 2017

The two BDAs installed in lower Sugar Creek in July of 2014 were the first BDAs constructed in the state of California. The reach where they were constructed is a straightened channel that traverses through 50-foot-high cobble piles of dredger tailings (Figure 3). This reach of Sugar Creek historically dried or was reduced to a trickle at baseflow (Figure 6). However, evidence of an abandoned beaver dam was discovered near the confluence with the Scott River and the site was selected for the most downstream of the two BDAs to be constructed. The 2014 BDAs were installed in the midst of the drought, and experienced drying and desiccation of the materials as a result of the reach drying after installation. Because these BDAs were implemented under a pilot study, initial sealing and berming of the structures was minimal and they were constructed as postlines with a wicker weave (see Pollock et al. 2015). The tailings proved to be a difficult location in which to install posts because of the extensive cobble deposits, which limited post embedment depths.

Since 2014, BDA 1.0 has experienced significant site evolution, and accordingly, has been adaptively managed. Continuous flow through the side channel on river left was designed to alleviate the forces on BDA 1.0 and limited underscour of the structure. The SRWC has continued to observe and learn from dynamic site conditions at Sugar Creek and now believe in general that a series of smaller BDA structures would maintain better ecosystem function relative to a single, large structure.

The upstream BDA at Sugar Creek (BDA 2.0) that was built in 2014 was not completed due to permitting delays and then the onset of high flows in Fall, prior to completion. As a result, this structure experienced loss of posts and river left streambank scour in the winter 2014-15. No appreciable downstream-to-upstream water surface difference was observed at BDA 2.0 from the time of its construction until the summer of 2016, when beaver began to modify the structure. Beaver repaired the river left breach and sealed the BDA. In winter, 2016 SRWC staff helped maintain the BDA with some hand-weaving of stakes through the beaver-constructed portion of the dam to provide additional stability during winter high flows, but no further adaptive management has been necessary. See *Sugar Creek 2017 Adaptive Management Report* for more information.

Activities in 2017

March 23rd: A small scour hole developed on the right side (looking downstream) of BDA 1.0 and required modification to prevent additional scour and destabilization of the entire structure. The work also improved water retention, increasing the water level upstream. Materials used included the use of locally sourced river rock, mud and fines from the BDA pond, and vegetative material (weed free straw) to close the hole (Figure 24).

May 1st: Additional modification to the scour hole in BDA 1.0 (described above) was necessary to close the scour hole and used the same type of materials.

May 15th: A scour hole developed on the left side of BDA 1.0 and resulted in the loss of four posts and associated weave (Figure 25). This event was initiated during a high flow event that occurred in February 2017. Repair of this 20-foot section was performed with the use of hand tools. Staves were placed to support newly woven willow that was then filled with locally sourced river rock, mud and fines from the BDA pond, and vegetative material (weed free straw) to fill the spaces between the willow weave.

July 24th – August 5th: Additional work continued on BDA 1.0 that included ongoing plugging of scour holes and strengthening of the river left wing. This work increased surface water elevation in the restoration site and was also intended to prevent excessive downstream bed scour.

October: Due to ongoing concerns regarding continued scour and instability at BDA 1.0, two “step” BDAs (BDA 1.1 and BDA 1.2) were constructed immediately downstream to decrease the gradient between the primary BDA and its confluence with the Scott River (Figure 26). The step BDAs provide structural stability to BDA 1.0 and presumably improve fish passage for both adult and juvenile salmonids by reducing jump heights, though juvenile and adult salmonid monitoring upstream of the BDA suggests that fish passage was not an issue. The new BDA crests were designed to be at one foot water surface elevation differences from upstream to downstream in a stair-step fashion (Figure 26). In the 20-foot section of BDA 1.0 that had previously been repaired with hand tools on May 15th, we installed 6 additional posts, using a backhoe with a plate vibrator, to provide additional stability. Finally, the small gap between the main section and the left wing of BDA 1.0 was filled using 20 posts and willow weave. No filling or berming of the weave occurred in this new section to facilitate passage for juvenile fish through multiple flow pathways.

Figure 24. Scour hole undercuts BDA 1.0 at Sugar Creek.

Figure 25. A 20-foot section of BDA 1.0 that was scoured during a February 2017 flood, resulting in the loss of four posts and associated weave.

Figure 26. Construction of two step BDAs (BDA 1.1 and BDA 1.2) downstream of BDA 1.0 at Sugar Creek.

French Creek Side Channel

Overview

The Mid-French Side Channel has historically offered a small area of off-channel habitat just upstream of the planned BDA 1 site, with suitable water quality for both the summer and winter rearing of juvenile salmonids documented over two seasons of pre-implementation monitoring. The Mid-French side channel is a naturally occurring side channel located in the mid alluvial valley reach of French Creek in an area known for annual coho salmon spawning and rearing in the mainstem. This reach of French Creek has been identified by CDFW as being of high value for coho production, with a high incidence of coho salmon redds identified in most years. The side channel is disconnected from surface water at the upstream end during base flow conditions, but is connected annually during winter flows. The downstream end of the channel is connected to the mainstem all year. During base flow, the water present in the side channel is likely fed by hyporheic flow originating upstream in French Creek.

The goal of installing BDAs at this site was to create slow-water over-wintering habitat for juvenile coho salmon, and to provide another site to study the physical and biological effects of BDAs. More information can be found in *the French Creek Construction Report* (available from the Scott River Watershed Council).

2017 Activities

June 12-22: Four BDA sites were added to a naturally occurring side channel of French Creek with the objective to increase over winter rearing habitat for juvenile salmonids. At the downstream-most location of the constructed BDAs (BDA 1), a series of three BDAs with one foot crest height differentials were built. One additional BDA (BDA 2) was built approximately 175 feet upstream of the main side channel with the objective of increasing pool volume. Finally, two additional BDAs (BDA 3WF, BDA 3EF) were constructed about 225 feet further upstream in the side channel – one each at an east and west fork of the side channel so that the incision trench in these channels could be reduced by capturing sediment, and velocities of high flows could be dissipated in order to preserve downstream slow water habitat. As expected, the ponds behind these BDAs did not fill until French Creek flows increased in the fall. See Appendix A for French Creek construction report.

November: First signs of beaver were noted at the project site. Chew sticks, mud and rushes were placed on the BDAs, were noted at the BDA project site and appeared to be associated with the first significant rain event.

Miners Creek

Installation and Adaptive Management Prior to 2017

In 2015, two BDAs were constructed on lower Miners Creek just upstream of the confluence with French Creek in an alluvial valley with a stream slope < 1%. The Miners Creek headwaters are at lower elevation than French Creek and most other Scott River tributaries on the west side. Therefore, this system is more rain-dominated than snow melt-dominated. Its uplands are composed of erodible granitic soils that historically were hydraulically mined, resulting in a bedload composed primarily of decomposed granitic sands. Extensive coho salmon spawning and rearing has been documented by the Siskiyou Resource Conservation District. Goals of installing BDAs at the site were to improve slow water habitat for both summer and winter rearing, and to improve riparian conditions by bringing water levels closer to the surface of the alluvial valley floor for a longer period of time during the summer. During installation of the BDA posts, bedrock was encountered less than 2-3 feet from the surface in places and that limited depth of post embedment in certain portions of the BDAs. Additionally, the permit terms at the time of installation did not allow utilization of imported clay fines but required local materials to be used, so granitic sands, the finest-grained material onsite was used to seal the structures. As a result, the Miners Creek BDAs have remained relatively porous and the shallow depth of the posts has resulted in posts overturning during severe storms. However, the site continues to support considerable coho salmon spawning above and below the structures, and large numbers of emergence fry of both coho salmon and steelhead have been observed using the ponds upstream of the BDAs. These observations help evolve our understanding of how to adaptively manage sites to offer significant improvement in coho salmon rearing conditions in the Scott Watershed. See *Miners Creek Maintenance Report* (available from the Scott River Watershed Council) for more information.

2017 Activities

June 19-20: Moderate repairs of the two existing BDAs were required to fill scour holes that had been created by the high winter flows. Additional posts were pounded into the stream bed to replace posts that had been lost during winter flows. Onsite vegetative and substrate materials were used to seal and stabilize the BDAs. “Fish passage portals” (areas without mud and straw to fill weave) were left at the base of each BDA structure to provide passage to salmonids due to the rapidly dropping flows and the presumption that the stream reach would soon be dry. During this time period, the reach did dry between the two BDAs and disconnection continued downstream of the lower-most BDA.

November: A series of minor repairs were completed to seal both BDAs, eliminating the “fish passage portals” in the structure and increasing pool volume behind the structures. The repair successfully raised the pond staff gage water surface elevation by 1.25 feet. Further sealing of the portals occurred as water levels increased using locally available substrates. While considerably more silt was present on site than prior to BDA installation in 2014, the overall composition of the substrate remains a mix of sand, gravel, silt, and clay. See Appendix B for Miners Creek maintenance report.

Photo Point Monitoring of BDAs

There are three types of photos collected for the Scott River BDA projects since implementation in the summer of 2014. Feature photos, commonly known as photo points, landscape photos mostly using drone photography, and opportunistic photos which were used to document activities such as construction and will most likely not be repeatable. Below, is a subset of photos taken at each BDA restoration site.

Sugar Creek

In Sugar Creek, BDA 1.0 was constructed in July of 2014 and BDA 2.0 in September of 2014. A network of photo points was established in 2014 and additional points added in 2017 during the construction of the step BDAs, 1.1 and 1.2. In total, there are 43 points that have been established within the project area in order to give a visual perspective of the changing conditions over time.

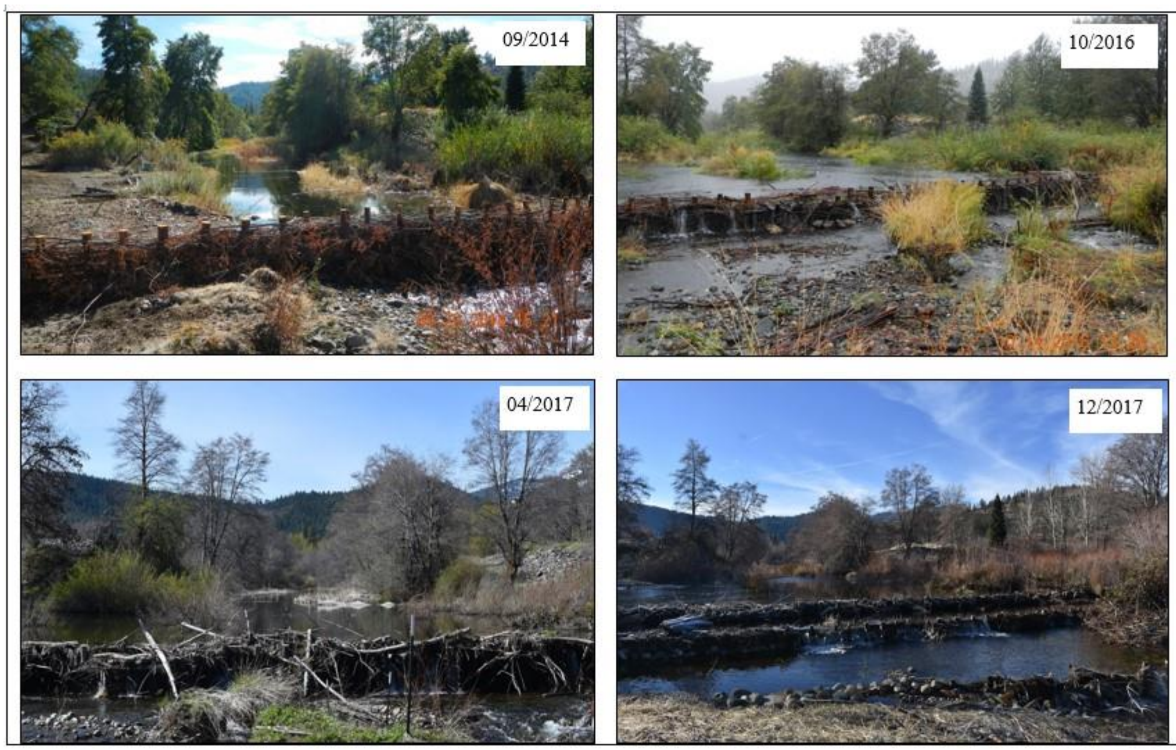

Figure 27. Sugar Creek feature photos. BDA 1.0 from 2014 to 2017.

Figure 28. Landscape Photos from Sugar Creek restoration site. Left photo: Sugar BDA 1.0 with step BDAs 1.1 and 1.2, Side Channel 1 to the right and flowing from BDA 1.0 wing, and recent cottonwood fallen by beavers. Right photo: Sugar BDA 2.0

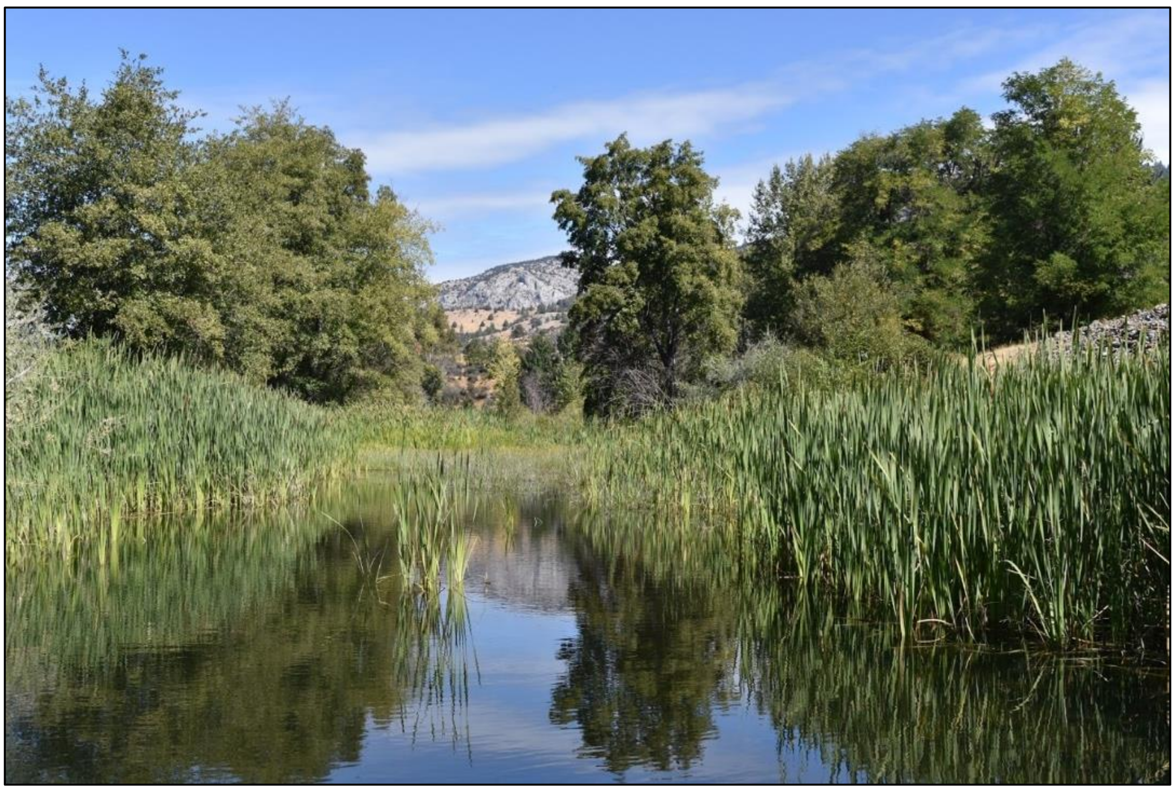

Figure 29. Sugar Creek BDA 1.0 three years after construction, showing emergent vegetation and mature riparian trees. Photo taken 9-23-2017.

French Creek

The French Creek BDAs were constructed in the summer of 2017. In total, there are 31 points with a total of 81 vantage points established within the project area in order to give a visual perspective of the changing conditions over time. Below, Figures 30 and 31 show feature, landscape, and opportunistic photos from the French Creek location.

Figure 30. Feature photos. BDA 1 post construction. Photos taken from bank of mainstem French Creek, looking toward the side channel, now containing BDA structures.

Figure 31. French Creek Beaver Dam Analogue 1 during construction. Photo taken 6-21-2017.

Miners Creek

The Miners Creek BDAs were constructed in 2015. There was a network of photo points established in 2015 including 8 points within the project area in to give a visual perspective of the changing conditions over time.

Figure 32. Miners Creek Feature Photos. Left photo: significant breach of BDA and draining of pond. Note location of ground water well with pipe extending approximately 5 feet above channel bed. Right photo: Significant aggradation behind repaired BDA one year later. Note location of same ground water well with pipe extending approximately one foot above channel bed.

Outreach Efforts

The Beaver Dam Analogues in the Scott Valley are the first to be permitted and built in California. As such, many questions have arisen regarding their ecological impacts, appropriate siting and construction techniques, and permitting pathways, both for construction and the adaptive management "aftercare" that is essential to the success of process-based restoration projects such as this. To help answer some of these questions, we have included a substantive monitoring program as part of this project and have undertaken numerous outreach efforts to communicate the results of these efforts (Table 13). An assumed, unanticipated and largely unfunded project responsibility has been to engage a wide interested audience, including regulatory authorities, restoration practitioners, and community members in defining needed information and sharing project results by providing field tours, educational events and lectures.

Table 13. Summary of Scott Valley BDA-related Outreach Events in 2017.

Date	Event	Location	Messages Delivered
March 2017	Article in North Coast Regional Water Quality Control Board Newsletter. NCRWQB staff author.	Electronic and Print	BDAs mimic natural beaver structures and deliver many of the same benefits. NCRWQCB is working with SRWC to understand BDA effects.
3/16/2017	Wood for Salmon Working Group. SRWC and NCRWQCB	Santa Rosa, Ca.	BDAs are a restoration technique that NCRWQCB has been involved in understanding, and that supports WQ goals.
3/27-3/28 2017	Coho Recovery Team. SRWC	Sacramento, Ca.	Discussion of BDA implementation and presentation of 2 seasons monitoring data.
3/29-4/1/2017	Salmon Restoration Conference SRWC	Davis, Ca.	BDAs are a process-based restoration technique that re-establish natural processes rather than create a static habitat feature. They require maintenance and adaptive management.
6/19-6/22/2017	SRWC BDA Workshop. SRWC, NOAA, CDFW, NCRWQCB, Rocco Fiori	Scott Valley	Lecture, discussion and hands-on experience in all aspects of BDA theory, construction, permitting and monitoring.
Summer 2017	National Wildlife Magazine. National Wildlife Federation Staff	Print and Electronic Magazine	Working with beavers can provide substantial ecological benefits including fish habitat and groundwater recharge,
9/23/2017	BDA Multi-Agency Task Force. SRWC	Meeting & Field Tour, Scott Valley	Explored BDA construction, fish passage and permitting issues.
10/17/2017	BDA Construction Workshop. SRWC	Scott Valley	Hands on BDA construction and theory.
11/15/2017	Featured in Sustainable Conservation Newsletter. SusCon Staff	Print and Electronic Newsletter	SRWC is an organization delivering cutting edge restoration and is an early adopter of new permitting opportunities.

DISCUSSION

Habitat Response to Sugar Creek Restoration

The capacity of the Sugar Creek restoration site to produce juvenile coho salmon has improved substantially since the restoration treatment. Prior to restoration, the capacity was estimated at 350 fish for years that the reach maintained connectivity. By 2016 the habitat capacity had increased 17-fold, and in 2017 the habitat continued to expand, to a 20-fold increase relative to pre-project conditions (Tables 10 and 11). Such a tremendous response is to be expected when converting a small, shallow, sometimes ephemeral stream into a series of relatively wide beaver ponds—deep pools with adjacent shallow shelves covered with emergent and aquatic vegetation, and in many places a riparian canopy of alders or willows. Such habitat provides ideal growing conditions for juvenile salmonids, particularly coho salmon.

Juvenile salmonid habitat quality can be estimated by measuring water depth, water velocity and proximity to cover. These three metrics describe habitat quality and can be used to estimate habitat capacity in terms of juvenile salmonids that an area can hold. Goodman et al.'s (2010) habitat capacity model, produced by measuring fish densities at various combinations of cover, depth and velocity, indicates that juvenile coho strongly prefer shallow, low velocity waters with cover.

This suggests that a key to creating good habitat is to provide lots of instream cover from riparian and emergent vegetation that will grow at depths $\leq$ 1 m. Such conditions also benefit if they are in close proximity to deeper swifter water, which brings in fresh water and food. The system will further benefit if there is good hyporheic exchange to help maintain cool water temperatures during the summer. The monitoring data we have collected at the Sugar Creek restoration site suggest that all of these conditions now exist. The temperature monitoring suggests that most of the restored habitat has temperature ranges ideal for juvenile coho and other salmonids throughout most of the year (see Figure 10), while the groundwater monitoring data suggests that the waters of the BDA ponds are well-connected to subsurface waters.

The marsh side channel, which is a series of beaver canals through a low bench of emergent vegetation that is now back flooded by BDA 2.0, provides the highest quality habitat. There is cover everywhere from emergent vegetation, large wood, a dense understory of riparian vegetation and an alder canopy above. The two BDA ponds also provide relatively good habitat, because of the cover along the edges of and shallow areas of the ponds, and onto some narrow floodplain benches that are now flooded throughout the year. There are also now places in the middle of the ponds that exceed the preferred depth of juvenile coho salmon (< 1m), and thus are rated as having lower habitat value than the edges. Overall, the two BDA ponds provide nearly two thirds (64%) of the habitat capacity, while the off-channel pond (OCP), the marsh side channel (SC2) and the distributary side channel (SC1) provide the rest.

The value of the OCP is rated conservatively as having relatively low habitat capacity because most of it is much deeper than the preferred coho depth. There is cover from the aquatic algae that grows on the bottom of the pond, but the habitat capacity rating is still poor because of the depth. The model was calibrated on flowing streams and may not be applicable for deep off-channel ponds. However, again there are no data to suggest what should be an appropriate habitat capacity rating for such a habitat type, if not the habitat capacity estimate used in the model.

Groundwater Response

The response of the local water tables to the construction of the Sugar Creek BDAs has been surprisingly extensive. A groundwater monitoring well placed 0.9 km up valley from BDA 1.0 showed a 15 cm change in WSE in response to a repair to BDA 1.0 that raised the WSE in BDA Pond 1 by 27 cm. We did not place any monitoring wells further upstream, but the data suggests that if we did, we would likely document a groundwater level response to changes in the height of the BDA. Preliminary analysis suggests that the network of groundwater monitoring wells conservatively suggest an estimated storage volume of 37,000 m^3 of water by BDA 1.0, or about 30 acre-feet. More detailed analysis will help to provide insights into the complex pattern of groundwater responses that seem to suggest that the valley floor alluvium has areas in close proximity to each other that are not necessarily well-connected hydrologically. Down valley from the BDAs, groundwater levels drop off rapidly, relative to the up valley levels but there was still a detectable change in groundwater surface elevations 350 m down valley from Sugar Creek.

Temperature Response

The temperatures at the Sugar Creek restoration site suggest a range of temperature regimes in the various mesohabitats, but all of them appear to be well-suited for salmonid rearing. This contrasts with the mainstem of the Scott River, which regularly exceeded levels thought to cause heat stress in juvenile salmonids (Figure 10). Temperatures at all sites (French, Miners and Sugar) generally seemed to stay in the range suitable for salmonid rearing, suggesting at least that in these reaches, temperature is not a factor limiting to growth or survival during the summer.

Juvenile salmonids

While a process-based restoration approach is more complex than is sometimes appreciated, and requires both local on-site knowledge and observation, it relies on a solid scientific conceptual framework that when applied properly, can achieve outstanding, highly cost-effective results. As an example, the Sugar Creek BDA restoration project has provided excellent habitat for juvenile salmonids while increasing water storage capacity, and each year the quality and quantity of habitat continues to improve. In terms of coho pre-smolt outmigrant the capacity of the lower Sugar Creek BDA Pond complex (about 7500 fish) is now greater than the actual estimated outmigrant population of the entire Scott River watershed for most years. Additionally, the actual estimated coho pre-smolt production of the Sugar Creek Pond complex is very high relative to the entire Scott River outmigrant population. Much of the reason for the success is that the project is viewed as an ongoing operation such that adjustments to the system can be made as needed (i.e. adaptive management) to optimize performance to keep it moving on a steady recovery trajectory.

The 20-fold increase in juvenile coho habitat capacity at the Sugar Creek restoration site, and the fact that the habitat was not close to being saturated, suggests that production bottlenecks may now become more apparent at other life-stages. While ocean conditions may limit adult survival, and that may be the ultimate production bottleneck, observations in Scott Valley tributaries suggests that egg-to-fry survival may be another production bottleneck. Most coho spawning we have observed occurs either in the sandy interstices of cobble-dominated beds, or else in sand-dominated beds (Figure 33). These observations are consistent with the observations of others (e.g., Cramer Fish Sciences, 2010), which suggests that elevated levels of fines, in particularly sand (aka decomposed granite) may be reducing the availability of quality spawning habitat in the Scott River basin, and that this may be affecting the production of fry, particularly in years when there are frequent floods during the winter.

Figure 33. A still from a video of coho salmon spawning in a sand-bedded portion of Miners Creek.

Observations of PIT-tagged juvenile coho salmon and steelhead trout suggest that they use the Sugar Creek Restoration mesohabitat in complex ways that we don't fully understand. There appears to be considerable seasonal movement and also diurnal movement, at least in the winter, between mesohabitats. The wintertime diurnal movement may be related to the need for fish to obtain food where it is abundant, such as the swifter waters of the mainstem of Sugar Creek, and the desire to minimize energy expenditures by remaining in low-velocity waters. There was considerable movement on a daily basis in and out of the off-channel pond. We speculate that fish are going to the mainstem of Sugar Creek to forage during the night, and then coming back to the off-channel pond during the day to rest and to digest their food in the relatively warmer waters of the off-channel pond, which in the winter is "warmed" by spring water (see Armstrong et al. 2013).

Available data from spring of 2017 also suggest relatively high rates of survival in the Sugar Creek restoration site and relatively low rates of survival in French Creek, the control site. The winter of 2017 had numerous floods, and water levels were often quite high. French Creek has limited off-channel habitat for fish to escape high flows of fast turbulent water (e.g see Figure 8), and it is not surprising under such conditions that survival would be low. Sugar Creek, in contrast, had over 2 acres of slow-water habitat, some of it deep, and some of it shallow and full of emergent vegetation. It has conditions generally considered ideal for overwintering coho salmon.

The PIT-tagged fish also provided an opportunity to assess how well juvenile coho salmon and steelhead trout can cross beaver dam analogues, and we were able to release juveniles below a

BDA and then monitor how long it took them to return to the upstream pond through the use of PIT antennas. We obtained exceptionally high detection rates for the released fish (Table 12). For coho salmon, we were able to detect that 97% of the released fish crossed a BDA and 89% were detected in BDA Pond 1. That most of these fish crossed the BDAs within 36 hours of release suggests that the BDAs provided little resistance to upstream movement. Both juvenile coho salmon and steelhead trout were able to jump over the BDAs, though there was a slight preference for swimming around the BDAs through a side channel passage rather than jumping over them. The fish had to cross two BDAs, the first of which was 40 cm in height, the second 30 cm in height. These heights are considerably greater than the 15 cm jump height that is often the maximum permitted in stream restoration projects.

Lessons Learned and Next Steps

BDA restoration is a low-cost, process-based approach that requires on-going adaptive management until such time as natural forces, such as beaver or geofluvial function, are sufficient to overcome the anthropogenic degradation that has required the restoration intervention. This approach is more akin to ongoing natural resource stewardship, similar to forestry or farming rather than conventional stream restoration approaches. Such conventional approaches are not only expensive, but they often fail because the underlying processes that create and maintain habitat are not well understood and the dynamic nature of stream systems often works in opposition to such engineered solutions.

Since the first BDAs were installed in 2014, a robust monitoring program has been implemented to evaluate the evolving ecosystem, and to address questions that arise as original sites mature and new restoration projects are undertaken (e.g. questions about fish passage across BDAs and fish movement within the complex habitat upstream of the BDAs). Lessons have been learned while studying and managing the BDAs and new questions have emerged. Below are a few points that capture some of the lessons learned and next steps the SRWC and partners aspire to achieve in the coming monitoring seasons.

- Deploy and maintain PIT antennas throughout the year and develop a more comprehensive network of PIT antennas, to better capture fish movement and to better understand the seasonal and diurnal variation in fish use of the various habitat types within a restoration area and within the larger stream system. Observations to-date suggest that juvenile coho salmon have complex habitat needs and move around quite a bit to find the best habitat. Understanding the seasonal and daily habitat conditions that coho prefer will help better understand how to restore habitat in the future.
- Work with CDFW staff in the management of the outmigrant screw trap near the mouth of the Scott River to better quantify the contribution the populations from the restored areas are making relative to the larger Scott River outmigrant population. Also learn about timing of outmigration, efficiency of antennas in French and Sugar to detect outmigration, travel time between antennas and screw trap, and use biometric data that may be gathered to inform overwinter growth.
- Identify if upstream migration is occurring in Sugar Creek using newly installed A29 antenna upstream of BDA Pond 2.
- Capture tagged fish during the winter period and early spring prior to outmigration, or in a downstream migration trap to gather additional biometric data to inform overwinter growth rates and determine size and condition at outmigration.

- Determine where diurnally migrating coho salmon go when they leave the OCP. Deploy additional antennas in Side Channel 2 (aka "The Marsh").
- Mark and recapture fish at Miners Creek if water conditions/occupancy allows to gather growth rate information for that site.
- Determine if French Creek fish continue to show fall redistribution behavior or if new BDAs have provided sufficient over winter habitat to keep fish in the site year round.
- Cut BDA post height to the desired "nape" or spill-over elevation to prevent accumulation of debris or over building by beaver on posts that are sticking up above the waterline. When dams are raised to an elevation beyond their design, it can create instability of the structure.

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