Persistence and Effectiveness of Livewood as Large Wood in River Restoration

Danielle Charleston, Melissa Hassler, Kelsey Wilson

University of California Berkeley

Professor Matt Kondolf

River Restoration

Fall 2018

Table of Contents

Abstract

In this study we evaluate the effectiveness of using livewood as large wood in river restoration projects, specifically in central California. We study two river restoration projects, Butano Creek in San Mateo County and Scotts Creek in Santa Cruz County, that demonstrate how use of livewood aids in small debris aggradation, increases pool depth and supports pool scour, improves salmonid habitat, and increases stream complexity. We identify the potential cost savings of using onsite alder trees compared to traditional redwood in large wood complexes (LWCs). We use photo comparison, habitat surveys, and a survey of livewood survival to evaluate the success of using livewood in LWCs. Preliminary data shows that the use of large livewood is as successful as redwood large wood at creating pools, aggregating woody debris, and increasing channel complexity. Historically, use of livewood in restoration projects has been minimal due to concerns of durability and longevity. Evaluating the longevity of the livewood in LWCs will need continued monitoring and is beyond the scope of this study.

Introduction

The presence of large wood in streams plays an important role in channel hydraulics, geomorphology, and ecological processes (Abbe and Montgomery, 1998). However, historical management practices commonly involved the removal of wood in streams to mitigate flooding and protect property downstream from the movement of large debris. The lack of instream wood has had serious effects, such as incision, erosion, channel width, and increased velocities (Keller and Swanson, 1979). Increased velocities leads to increased bed shear and continued incision, eventually disconnecting a channel with its floodplain.

Large wood in streams creates more hydraulically dynamic streams and creates environments that are conducive to the survival of salmonid populations (Gallagher et al., 2014). There has been a significant reduction in salmonid populations throughout the Pacific Northwest due to factors such as overfishing, anthropogenic global warming, rapid land use change, and man-made obstacles like dams and weirs. The life cycle for salmonids begins in their natal freshwater stream, where they hatch and can spend upwards of a year before out migrating. For juveniles to be successful there must be adequate refuge habitat and connectivity to the ocean, where they spend the majority of their adult life before returning to their natal streams to spawn and die.

The presence of large wood is essential in creating and maintaining the habitat necessary to support salmonid populations. For some salmonids, pools are considered critical habitat through all stages of life (Nickelson et al., 1992). Large wood forms wood jams within the active channel, which typically induce the development of pools underneath or directly downstream of these jams and pool depth and volume have been found to positively correlate with salmonid populations (Gallagher et al., 2014).

Large wood in streams may address incision concerns and potentially reduce risk of flooding downstream by reconnecting the floodplain. Sediments and nutrients are retained behind these jams and over time the aggradation of jams can raise the streambed and reconnect the stream to its floodplain. The connectivity of a stream and floodplain upstream can attenuate peak flows downstream. Additionally, the roughnesses associated with large wood reduces average stream velocities, potentially slowing bank erosion and incision rates (Keller and Swanson, 1979).

In channels lacking large wood, restoration efforts may involve the implementation of large wood complexes (LWCs). Common LWC designs include anchoring a dead redwood log and/or rootwad within the active channel as a key piece in an installation. Conifers are typically used due to their slow decay rates and an apparent standardization of practices. The effect of large wood in promoting fish habitat has been documented in Alaska, Washington, and Oregon, where conifers are readily available. This leads to a standardization of methods that promoted the use of conifers (such as redwood) in restoration projects, even in locations where conifers were not prevalent.

Where redwood logs are not readily available, building large wood complexes from locally available wood (eg, alder) is preferable to importing redwood over long distances from a sustainability perspective. However, wood of such species may decay rapidly. Opperman (2008) found that in areas dominated by broad leaved hardwood trees, such as alders and willows, major wood jams were stabilized by key living pieces present. Large livewood is naturally anchored to the ground, decays at a slower rate, and the addition of foliage provides more friction against flows and habitat for diverse organisms. Constructing LWCs with key living pieces could eliminate the need for bolts and cables and reduce material costs, while still effectively increasing habitat complexity and restoring vital natural processes.

Project Sites

There are two streams in Central California in which experimental restoration projects were completed to help determine the feasibility of constructed living LWCs. Butano Creek and Scotts Creek drain two watersheds where broad leaved hardwood trees are more prevalent in the riparian corridors of the lower watersheds than conifers. A significant portion of Butano Creek runs through decommissioned agricultural land before flowing through a culvert and then joins Pescadero Creek to drain out to the ocean (Figure 1).

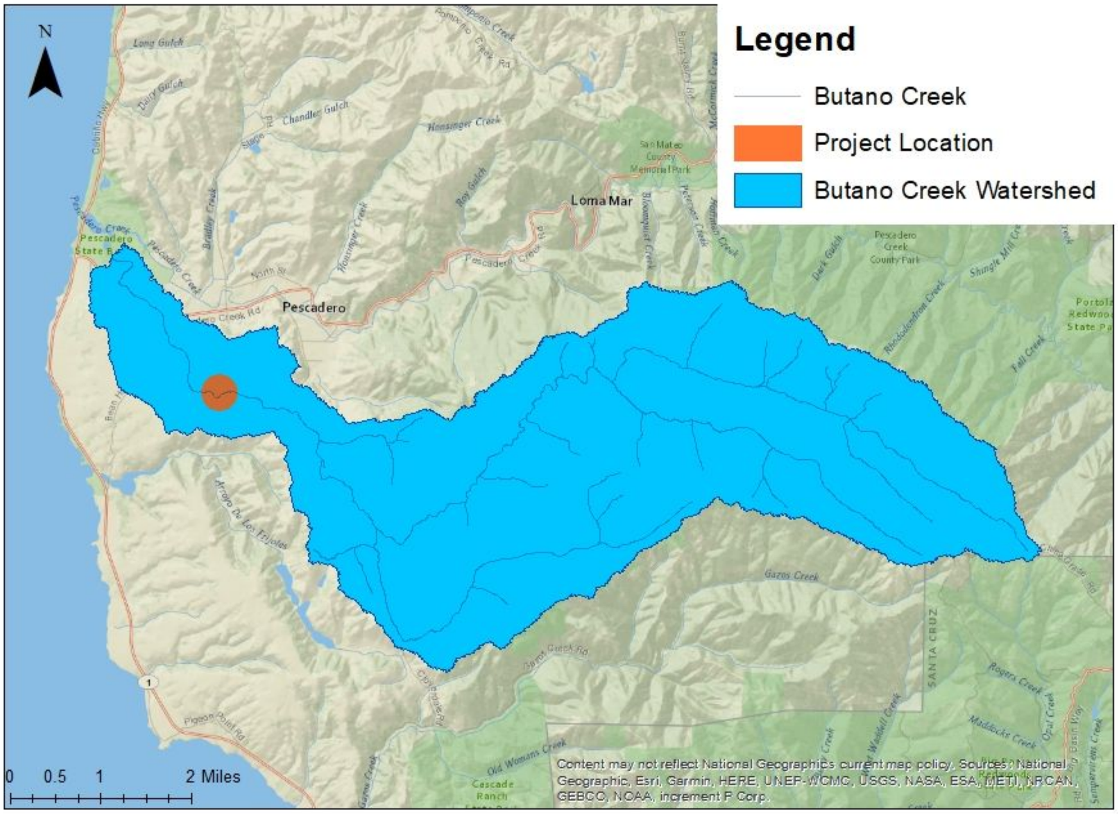

Figure 1: Butano Creek Watershed

Map of Butano Creek watershed showing Butano Creek and the project location.
Created by Kelsey Wilson with ArcGIS

Extensive timber removal from Butano Creek watershed led to significant deposition of sediment downstream. In 2016, prior to construction, Butano Creek was dominated by a shallow planar bed (Fisher, 2018). The goal of installing LWCs on was to increase stream complexity and increase biodiversity (Fisher, 2018). There are five installations along Butano Creek, four installations are made up of channel-spanning LWCs with one structure consisting of only boulder components (Figure 2).

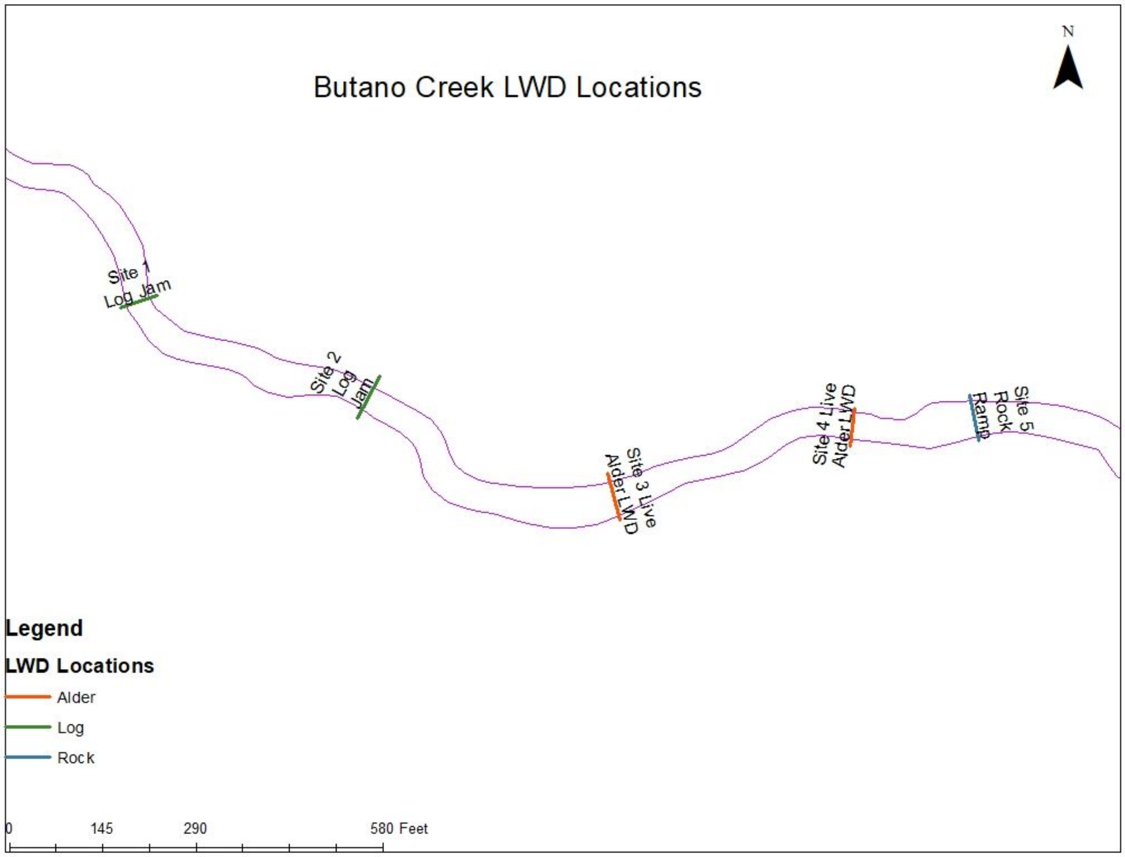

Figure 2: Butano Creek Restoration Project

Schematic map of the Butano Creek restoration project. A total of 5 sites with varied types of infrastructure. Sites 3 and 4 used live Alder to create LWCs.
Created by Kelsey Wilson on ArcGIS with data from Jared Fisher.

Two of the LWCs, those furthest downstream, incorporate both alders, redwood logs, and redwood root wads. At these two locations the redwood trunks and root wads were anchored to boulders. The two living LWCs upstream were constructed using alders located along the bank, which were pulled down into the channel and the partially intact root systems covered in soil to the extent possible. The living LWCs were both left unanchored (Fisher, 2018). There was also a “rock ramp” installed furthest upstream, which we did not consider the effects of in our analysis.

Scotts Creek drains a 190 km^2 watershed, located in northern Santa Cruz County (Figure 3). Scotts Creek supports both Central California Coast (CCC) Steelhead Trout (*Oncorhynchus mykiss*) and the most southern population of CCC Coho Salmon (*O. kisutch*) in North America. The watershed has a history of agricultural and pastoral land use. There is a hydrological research facility operated by California Polytechnic State University, San Luis Obispo. The goal of implementing LWCs at Scotts Creek was to improve refuge habitat and rearing opportunities for salmonid populations. To accomplish this the quantifiable goal was to increased instream wood, increased percent stream cover, the creation of deeper pools, and the reconnection of the stream to its floodplain (Cook, 2016).

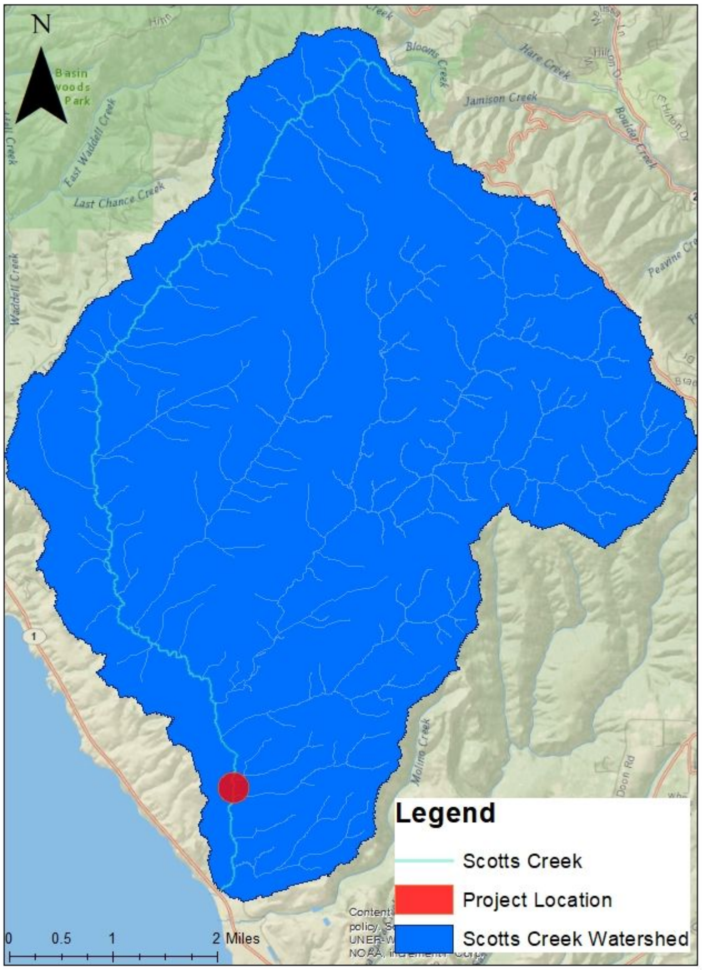

Figure 3: Scotts Creek Watershed

Map of Scotts Creek watershed showing Scotts Creek in light blue, the other streams in the watershed, and the project location.
Created by Kelsey Wilson with ArcGIS

There are three distinct phases of LWCs along Scotts Creek. Phase 1, 2, and 3 are made up of 4, 9, and 11 LWCs, respectively. Most LWCs contain a combination of redwood logs and or root wads, alders, willows, and boulders, with the exception of three standalone alder recruits in Phase 2 and a number of alder-only structures in Phase 3. Phase 1 was constructed in 2014 and incorporates the smallest proportion of livewood (Figure 4).

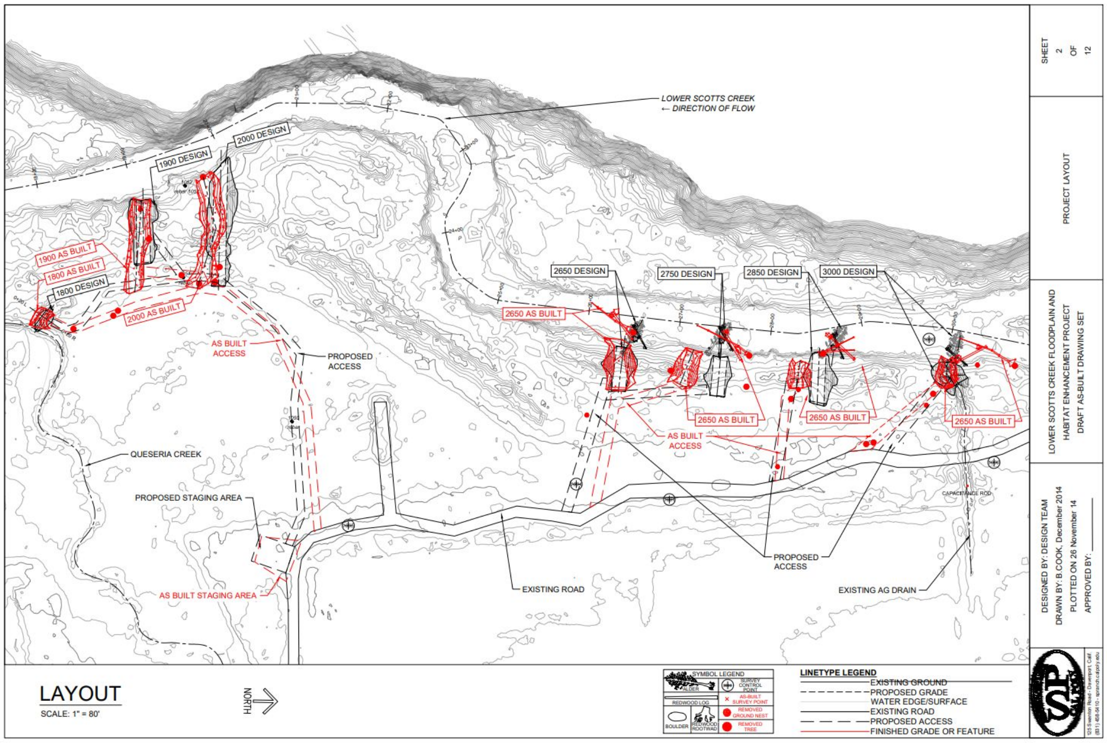

Figure 4: Scotts Creek Phase 1

Phase 1 project plans showing the proposed installation plan, as well as the actual installed elements in red.
Plans provided by Ben Cook.

Less than 1000 feet upstream from Phase 1, Phase 2 was constructed in 2015 with more live wood than Phase 1 (Figure 5).

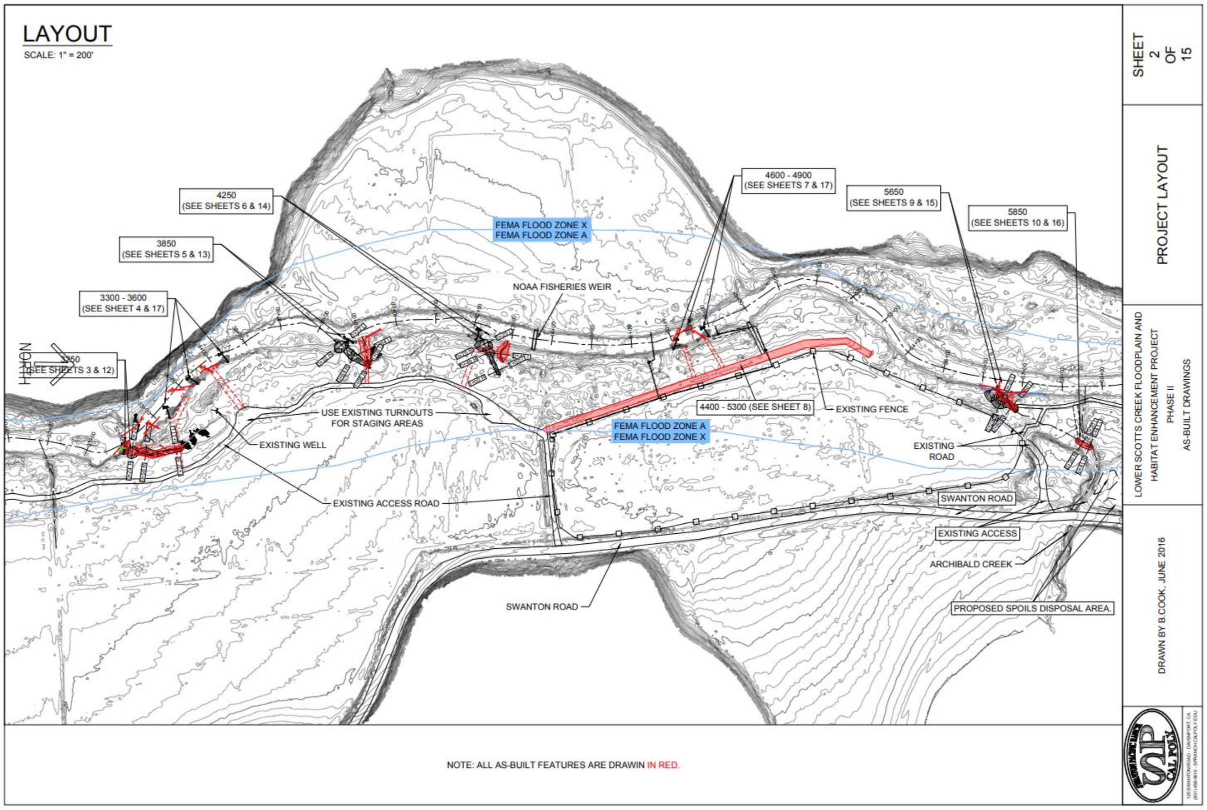

Figure 5: Scotts Creek Phase 2

Phase 2 project plans showing the proposed installation plan, as well as the actual installed elements in red.
Plans provided by Ben Cook.

In 2017, Phase 3 was constructed upstream of Phase 2 (Figure 6). These most recent LWCs incorporated the highest proportion of living wood. Phase 3 is the only phase to have a LWC composed of only unanchored living alders as well a LWC that incorporated willow as the living key piece (Cook, 2016). Both project sites are summarized in Table 1.

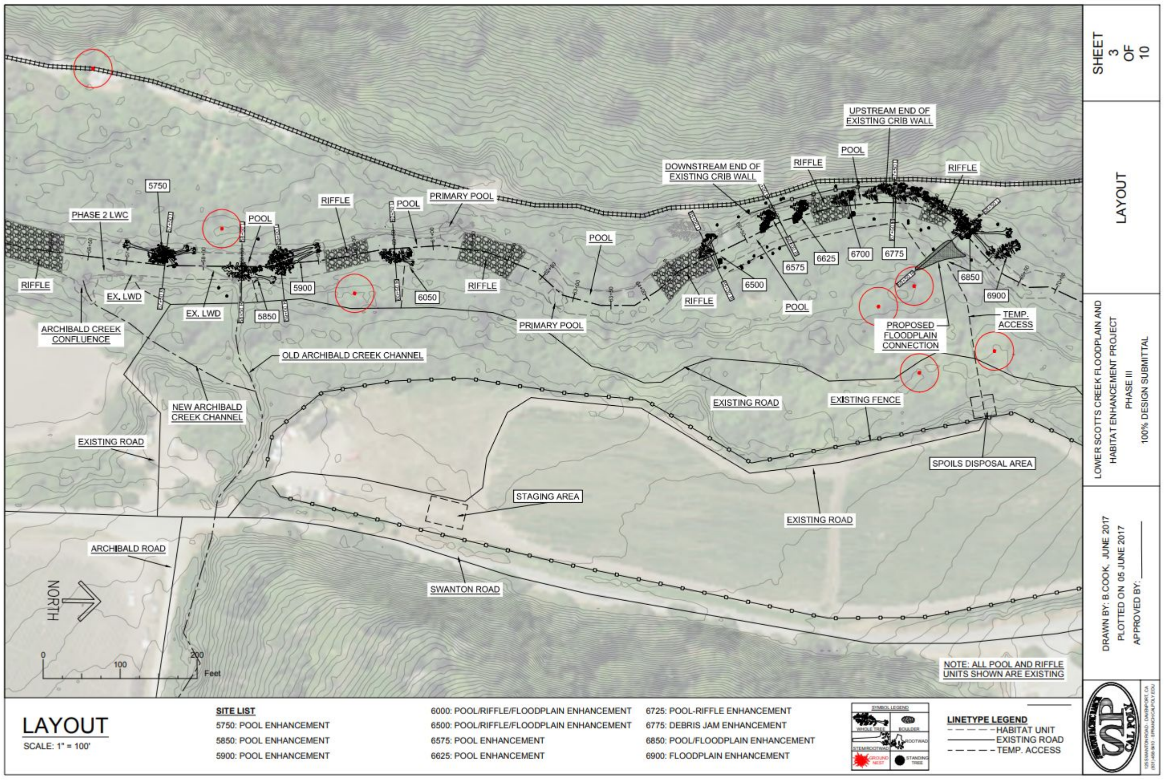

Figure 6: Scotts Creek Phase 3

Phase 3 project plans showing the proposed installations.
Plans provided by Ben Cook.

Table 1: Summary of Sites

Site	Construction Date	Site Description
Butano	2016	2 LWCs mixed (redwood + alder), anchored 2 LWCs all alder, unanchored 1 boulder structure
Scotts - Phase 1	2014	4 LWCs mixed (redwood + alder + boulder), anchored
Scotts - Phase 2	2015	9 LWCs mixed (redwood + alder + boulder), anchored
Scotts - Phase 3	2017	9 LWCs mixed (redwood + alder + boulder), anchored 1 LWC mixed (redwood + willow + boulder), anchored 1 LWC all alder, unanchored

Objectives

Our first objective is to document the survival rate and persistence of livewood in large wood complexes, and the extent of their influence on creating pools for salmonid habitat, aggregating woody debris, and increasing channel complexity. The second objective is to compare the persistence and effectiveness of using livewood as large wood as compared to more traditional redwood large wood installations.

Methods

The effectiveness of these projects were based on their ability to increase salmonid habitat, which we equated to basic geomorphic characteristics. We assessed the extent of habitat primarily by measuring the frequency and volume of pools. At Butano Creek, Jarrad Fisher, a Senior Conservation Project Manager with the San Mateo Resource Conservation District, completed a pre-construction baseline pool survey in 2016 and a post- construction survey in 2017 (Fisher 2018). Our team assisted Fisher with the 2018 survey in October.

Fisher followed the survey methods in “Stream Channel Reference Sites an Illustrated Guide to Field Technique” (Harrelson et al., 1994). We completed the survey by starting at a georeferenced point upstream and measuring along the thalweg. Along the stream reach we noted basic characteristics as either pool, riffle, or run. Pools were defined as over twelve inches deep. The depth, width, and length of each pool were recorded. Maximum depth and critical riffle were also recorded to confirm pool existence during the dry season.

The habitat survey for Scotts Creek has been completed annually by research staff at Cal Poly's Swanton Pacific Ranch since 2013, when a baseline condition survey was initially conducted by Ashley Brubaker Hillard, a masters student at Cal Poly. Various personnel have conducted the surveys since 2013 and have created as-built drawings and performed monitoring for each of the three phases since the installation of Phase 1 in 2014.

At Scotts Creek, in addition to annual topographic/bathymetric survey data, Swanton Ranch research staff have been performing wood surveys, pebble counts, shelter values, streamflow monitoring, field measurements, photos and direct visual observations. Our team joined Ben Cook and Madelyn Savan, research assistants with Swanton Ranch, for a portion of the 2018 observation on Scotts Creek. The annual data collected includes:

- Pool frequency, depth, and volume
- Number of primary pools per unit length of stream
- Percent stream cover
- Number, size, and location of LWCs
- Extent of decay of livewood

Researchers measure survival rate of livewood by the extent of foliage and decay. This is done via photos and visual inspection of trees in the wood jams as well as trees that have been naturally recruited into the stream by the complexes. They also examine trunks for signs of decay, such as rot, and record the extent of intact branches and live foliage. We followed suit when collecting data for 2018 monitoring.

Research staff use several features to determine the persistence of large wood in complexes and wood jams. Stability is qualified by whether key pieces still span the creek and if the installation has maintained its location or been washed downstream. The volume of the wood jams and quantity of key (large) pieces in the complex are tracked as more quantitative components. The composition of the wood jams is also examined; species of tree, live vs. dead pieces, and large vs. small wood.

Per the Scotts Creek Phase 1 WCB Monitoring Report, Swanton Ranch research staff have selected and implemented components of physical habitat assessment protocol described in the California Salmonid Stream Habitat Restoration Manual, Part VIII (California Department of Fish and Wildlife, 1997). They adapted additional protocols for monitoring the project from Scientific Protocol for Salmonid Habitat Surveys within the Columbia Habitat Monitoring Program (Bouwes et al., 2011).

Results

Survivorship Survey

Two years after installation, the Butano Creek project has two Alders (Figure 7) that are partially alive, see Table 2. On site 4, a total of three root wads with six boles were used to create the LWC. Of those six boles, two showed signs of sprouting, the remaining four appeared dead with no growth. On site 3 there are two root wads with four boles. The first root wad did not appear alive, the second root wad showed some signs of sprouting on one bole.

Figure 7: Site 3 Butano Creek

Area of new growth on one bole.

Close up of new growth at site 3.

Photographs by Kelsey Wilson

Table 2: Butano Creek Livewood Survivorship

Location	Site 3	Site 4
Total boles	4	6
Alive	1	2
Dead	3	4
Survivor %	25%	33%

Scotts Creek LWCs using livewood was completed in three phases, Table 3 outlines the number of livewood pieces used. Each LWC structure in Phase 1 consisted of a combination of redwood stems and/or root wads, live alder, and boulder ballasts. Four live alders were used and as of 2018 all four are dead, but still intact. Phase 2 used a total of fourteen live alders and all are dead, but intact. Phase 3 used a total of eleven live alders, two of which show signs of growth.

Table 3: Scotts Creek Livewood Survivorship

Phase	Phase 1 2014	Phase 2 2015	Phase 3 2017
Total boles	4	14	11
Alive	0	0	2
Dead	4	14	9
Survivor %	0%	0%	18%

Pool Count

Butano Creek has seen an increase in the number of pools and the depth of pools after the installation of the live LWCs, see Table 4. There has been a 200% increase in pool count. Average pool depth has increased by almost 8 cm. Pool length and width has almost doubled since project completion.

Table 4: Butano Creek Pool Count

Year	2016	2017	2018	% Change
Number of Pools	4	9	12	200%
Avg. Pool Depth (cm)	50.25	49.67	58.63	17%
Avg. Pool Length (cm)	32.5	47.55	63.39	95%
Avg. Pool Width (cm)	14.25	20.1	27.83	95%

Scotts Creek has seen an overall increase in the number of pools (based on topo and habitat surveys), pool length, and width since the installation of live LWCs. In 2016 after Phase 1 was completed there were 40 pools, after Phase 3 was completed in 2018 there were a total of 33 pools. Although the total number of pools appeared to decrease based on habitat typing data, the average size and depths increased. The average pool depth since 2016 has almost tripled with the pool length almost doubling. The average pool width has increased by a third, see Table 5.

Table 5: Scotts Creek Pool Count

Year	2016	2017	2018	% Change
Number of Pools	40	11	33	-17.5%
Avg. Pool Depth (cm)	39	159	110	182%
Avg. Pool Length (cm)	2011	2579	3727	85%
Avg. Pool Width (cm)	677	847	902	33%

Debris Accumulation

At Butano and Scotts Creek we visually confirmed that the livewood LWCs are accumulating small woody debris during storm events. We observed livewood that is no longer living has accumulated small debris. In Butano Creek, a large redwood trunk and stump have been recruited by LWCs on site 4 and 3, respectively (Figures 8 and 9).

	
Figure 8: Butano Creek Site 3 A large redwood log on the bank of the creek that accumulated upstream of the LWC at site 3 in Butano Creek. Photograph by Kelsey Wilson	**Figure 9: Butano Creek Site 4** A large stump accumulated between the two alder boles at site 3 in Butano Creek. Photograph by Kelsey Wilson

There is also small debris accumulation on site 3 (Figure 10). Phase 1 of Scotts Creek has naturally recruited additional alders as well as small debris (Figure 11). Phase 2 of Scotts Creek has accumulated small woody debris (Figure 12).

Figure 10: Butano Creek Site 4

Small debris has accumulated on top of the alder on site 4.
Photograph by Kelsey Wilson

Figure 11: Scotts Creek Phase 1

Small debris has accumulated on the alders on Scotts Creek phase 1 LWC installation.
Photograph by Kelsey Wilson

Figure 12: Scotts Creek Phase 2

Small debris has accumulated along the alders on Scotts Creek phase 2 LWC installation.
Photograph by Kelsey Wilson.

Stream Complexity

At Butano Creek, before the LWCs were constructed, the reach was mostly planar bed with straight widening channels (Fisher, 2018). After the restoration project the reach has become more hydraulically dynamic with pools as well as a more sinuous channel. This is reflected in the project photo series for site 3 (Figure 13) and for site 4 (Figure 14).

Pre-Construction 2016	Post-Construction 2016	Summer 2017	Fall 2018

Figure 13: Butano Creek Site 3

A series of georeferenced photographs taken by Jared Fisher, at site 3, to track the changes of the creek before and after the restoration project.

Pre-Construction 2016	Post-Construction 2016	Summer 2017	Fall 2018

Figure 14: Butano Creek Site 4

A series of georeferenced photographs taken by Jared Fisher, at site 4, to track the changes of the creek before and after the restoration project.

Fisher collected pre- and post-construction DEMs (digital elevation models) to analyze the exact changes in the reach (Figure 15), which shows the channel changing since the installations of the LWCs.

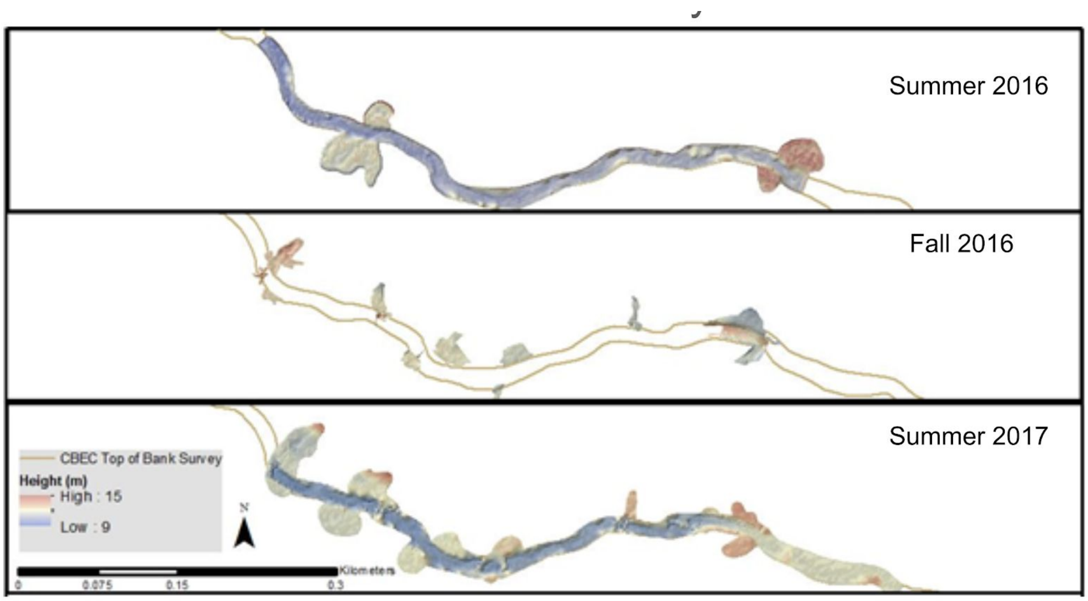

Figure 15: Butano Creek DEM

DEMs showing pre- and post-construction elevations in the Butano Creek. These were gathered by Jared Fisher using a Total station.

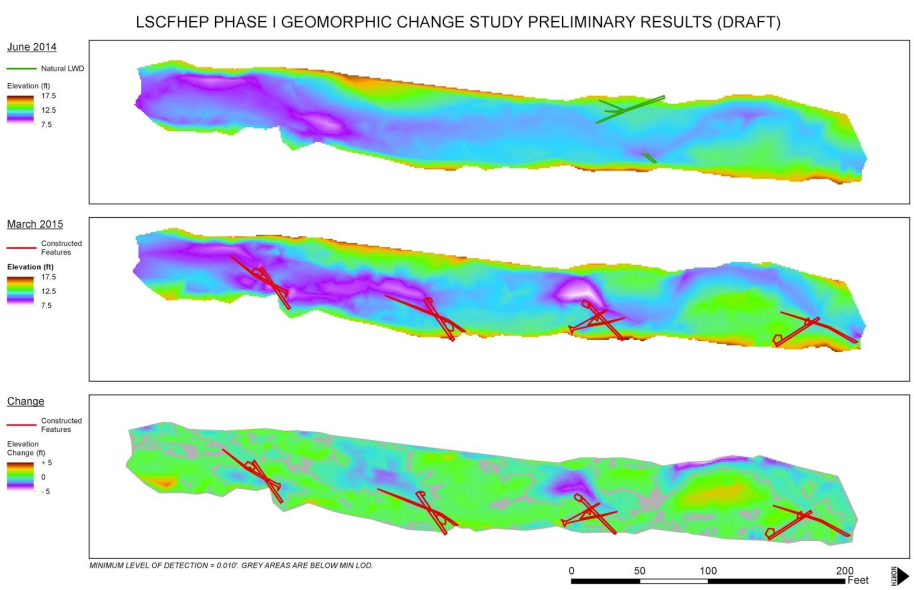

Figure 16: Scotts Creek Phase 1

Cal Poly Researchers measured geomorphic changes on phase 1 using a Total station.

Cal Poly Researchers have measured geomorphic stream changes on Scotts Creek since the completion of Phase 1 and 2. The recruitment of live wood increased the volume and roughness of the large wood complexes, and contributed to the hydraulic effectiveness of the wood structures at doing work in the stream channel and influencing hydraulic processes of pool scour, bar/riffle deposition, and sediment sorting. The geomorphic changes for Phase 1 show pool creation and an increase in streambed depth variation (Figure 16). Phase 2 geomorphic changes show more dispersed pool areas as well as some naturally recruited large wood (Figure 17). Geomorphic analysis revealed that overall habitat volume increased for Phases 1 and 2. A geomorphic analysis for Phase 3 has not yet been completed.

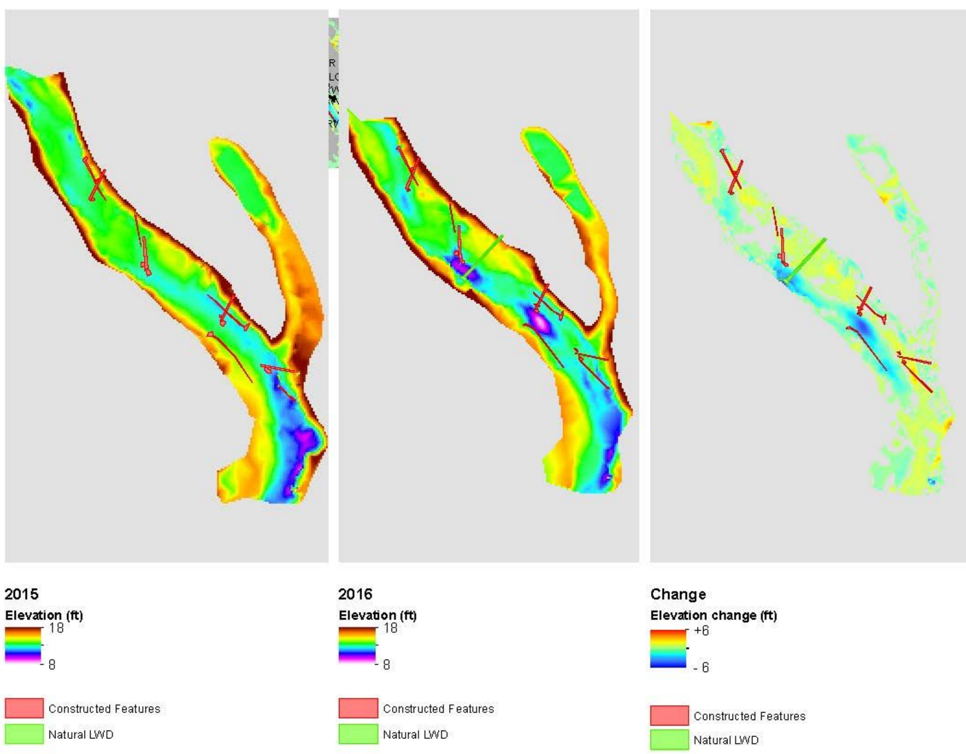

Figure 17: Scotts Creek Phase 2

Cal Poly Researchers measured geomorphic changes on phase 2 using a Total station.

Discussion

The large wood complexes that utilize live hardwood in Butano and Scotts Creek have been successful in creating additional salmonid habitat in terms of the accumulation of additional wood and the increase in pool quantity and volume. Although a majority of the alders have not survived more than a few years after placement, they have persisted and the oldest alders, installed in 2014, have trunks intact.

The instream advantages of using livewood are twofold: live trees are more resistant to decay, and the branches and foliage of live trees provide more shelter and aid in recruitment of additional debris for habitat. Dead hardwood components do not provide the same extent of shelter as they lose foliage and branches, but they continue to create habitat and recruit additional trees even after dying, and have resisted decay thus far since their placement in 2014-2016.

A complicating factor in the recruitment and survivorship of alders at Butano Creek is the presence of the alder beetle. Groves of alders along the reach being restored have been affected by the beetle, which weakens the trees and may lead to accelerated natural recruitment above the effects of the installations. However, once recruited (either by design or naturally), the trees are already weakened and have a lower chance of survival than healthy recruits.

Another motivation in using live hardwoods is the potential economic and environmental advantage of utilizing local material instead of having to truck in redwoods. As mentioned in the introduction, a significant amount of research has been done on using large wood complexes in steam restoration in the Pacific Northwest, where conifers prevail. Although redwood has proven to be an effective and durable material to use as large wood, at sites like these stretches of Butano and Scotts Creek, it is not always readily available. The Swanton Ranch research assistants we worked with at Scotts Creek are examining this aspect.

As of 2018, the unanchored livewood complexes at both Butano and Scotts Creek appear to be stable in their original project locations. The Butano restoration project was completed in 2016 and the two unanchored alder complexes persisted through the big water year that directly followed. A live wood complex was installed without redwood anchors in the 2017 Phase 3 of the Scotts Creek restoration. The winter of 2017 was fairly dry, so not much can be said yet about the effectiveness or stability of these features. At Scotts Creek, some of the redwood features that were anchored with carabiners swung to one side of the creek during winter 2016, perhaps rendering them less effective at creating habitat or aggregating additional wood. Future monitoring is needed to ascertain if these features will persist through major flow events and successfully create additional pools and shelter for salmonid habitat.

Future Actions

The most common technique for active recruitment at both sites involved pulling the trees down from the bank into the channel using an excavator. The living trees were then placed so that the rootwad lay in the creek channel, but we observed that some of the rootwads were exposed to the air while the stream was at fall flow levels, as opposed to having full water or soil coverage. A valuable area of continued research would be recruitment techniques that promote the survivorship of alders, ideally in an area without the alder beetle infestation as a factor.

Securing alder trees in place of redwood trunks with anchored redwood root wads significantly reduces the volume of redwood needed, and as shown in these restoration projects, has proven stable over a high flow season. Data collected since 2014 show that wood jams comprised of combination livewood/redwood features are able to persist at least four years. Once the effective lifetime has been determined, long-term cost analyses can compare the cost effectiveness of livewood, combination, and redwood installations.

Although the recruited alders did not have high survivorship, an interesting phenomenon we observed was that willows had taken root on some of the alder features (Figure 18). In addition to continued research on alder survivorship, an area for future investigation could involve combination installations that involve more resilient species like willow.

Figure 18: Live willow recruitment

A live willow tree has been recruited on one of the alder installation at Scotts Creek.
Photograph by Melissa Hassler

Conclusion

We have seen that using livewood in river restoration aids in increasing stream complexity and is effective in small wood accumulation as well as increasing pool depth and creation, which are essential components of salmonid habitat. Continued monitoring of livewood complexes will be needed to determine if the longevity of livewood is comparable to redwood. More research on the use of other species of trees, such as willows, has potential to offer more options for livewood in restoration projects involving large wood installations.

References Cited

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

Bouwes, N., Moberg, J., Weber, N., Bouwes, B., Bennett, S., Beasley, C., Jordan, C., Nelle, P., Polino, M., Rentmeester, S., Semmens, B., Volk, C., Ward, M.B., White, J. 2011. Scientific Protocol for Salmonid Habitat Surveys within the Columbia Habitat Monitoring Program.

California Department of Fish and Wildlife. 1997. California Salmonid Stream Habitat Restoration Manual, Part VIII. *Wildlife and Fisheries Division.*

Cook, B. O. 2016. Lower Scotts Creek Floodplain and habitat Enhancement Project. *California Polytechnic State University, San Luis Obispo.*

Fisher, J.N. 2018. Butano Creek Floodplain Restoration Geomorphic Response. *San Francisco State University.*

Gallagher, S. P., Ferreira, J., Lang, E., Holloway, W., Wright, D.W. 2014. Investigation of the Relationship Between Physical Habitat and Salmonid Abundance in Two Coastal Northern California Streams. *California Fish and Game.* 100:4.

Harrelson, Cheryl C; Rawlins, C. L.; Potyondy, John P. 1994. Stream channel reference sites: an illustrated guide to field technique. *Gen. Tech. Rep.* RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.

Keller, E.A., Swanson, F.J.. 1979. Effects of Large Organic Material on Channel Form and Fluvial Processes. *Earth Surface Processes.* 4:4.

Nickelson, T.E., Rodgers, J.D., Johnson, S.L., Solazzi, M.F. 1992. Seasonal Changes in Habitat Use by Juvenile Coho Salmon (*Oncorhynchus kisutch*) in Oregon Coastal Streams. *Can. J. Fish. Aquat. Sci.*49:783.

Opperman, J.J., Meleason, M., Francis, R.A., Davies-Colley, R. 2008. “Livewood”: Geomorphic and Ecological Functions of Living Trees in River Channels. *BioScience* 58:11.