Waddell Creek CZU Post-fire Surveys 2020-2023

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10 September 2023

INTRODUCTION

Following the CZU Lightning Fire in August 2020, the Waddell Creek streamside, and a portion of the upper slope between Stevens Camp and the confluence of the east and west forks, was walked upstream, and the streamside was also walked to about mile 3.6 on the West Fork in October to observe habitat conditions in the accessible stream and riparian corridor (Smith 2020). Fish sampling at three annually sampled sites farther downstream found the stream channel unaffected by the fire. Fish abundance was typical of recent years, but access for sampling farther upstream with direct fire effects was not possible (Smith 2020).

2021 METHODS and RESULTS (most of Smith 2021b, but without the 2021 photos)

The 2020 effort was followed up in 2021 by surveys in June and October to assess streamside and channel habitat conditions following the unusually mild and dry 2020-2021 winter (Smith 2021a and Smith 2021b). The fire had not burned to the streamside downstream of mile 2.6 (Stevens Camp), but had burned upslope on both sides of the stream and progressively farther into and through the riparian corridor between miles 2.8 and 3.6 (Figure 1, and see photos in Smith 2021a and 2021b). Upstream of mile 2.6, some burned and toppled trees fell into the stream channel, and unburned riparian and streamside alders (*Alnus rhombifolia*) were apparently cooked and had few or no leaves through June 2021. These effects progressively increased upstream of mile 2.8, where the fire burned through the riparian border in varying intensity to the stream from both slopes.

In burned forest most redwoods (*Sequoia sempervirens*) greater than 1 foot diameter survived, although trunks and branches were burned. Epicormic trunk and branch sprouts were present on surviving redwoods by October 2021. However, much of the canopy and stream shading was lost, leaving "bottlebrush redwoods." Most small redwoods appeared to be dead. Burned tanbark oaks (*Lithocarpus densiflorus*), live oaks (primarily *Quercus agrifolia*), madrones (*Arbutus menziesii*), and California bays (*Umbellularia californica*) had lost all or most of their canopy, but most had basal sprouts by June or October 2021. Almost all burned Douglas firs (*Pseudotsuga menziesii*) died, unless substantial canopy was left. Most alders, including those with no apparent burn marks, still lacked leaves in October 2021, so the extent of their survival was in doubt. Most burned riparian and lower slope big-leaf maples (*Acer macrophyllum*) appeared to have suffered mortality in 2020, but basal sprouts were present on some by June 2021 and basal sprouts and sparse canopy leaves were widespread on maples by October 2021.

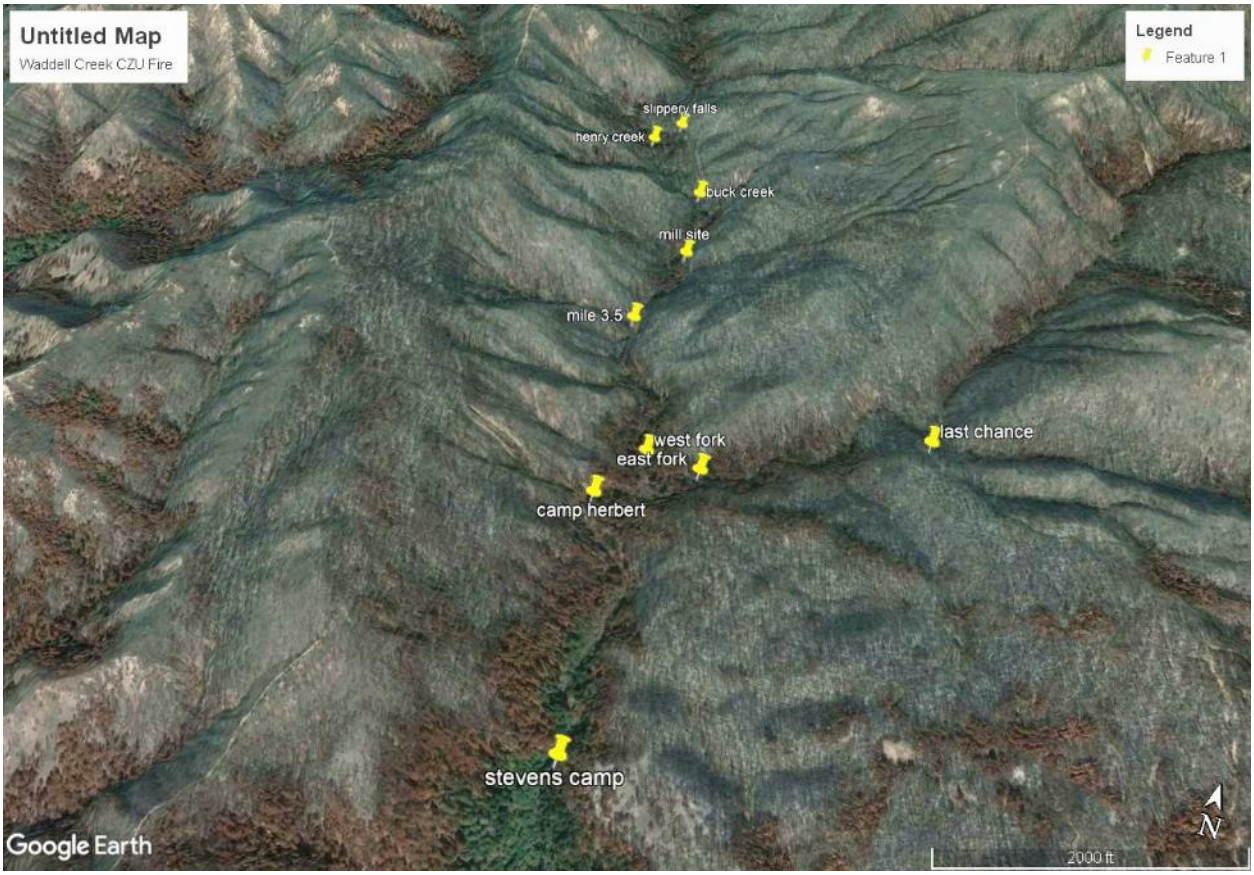


Figure 1. Google Earth aerial photo of Waddell Creek watershed from downstream of Stevens Camp (mile 2.55) to the upper watershed of the East and West forks (taken in fall 2020 after the CZU Fire). The green streamside is intact riparian and lower upslope forest. Orange is medium burned forest extending upstream to mile 3.6+ (Mill Site). Remainder of the watershed in gray is severely burned upland with mostly standing or downed burned trees only. Yellow icons are historical fish sampling sites used since 1992.

The very dry conditions in winter 2020-2021 (Figure 2, stream flow in Pescadero Creek) prevented the establishment of significant ground cover on burned slopes surrounding the stream in 2021, especially on the generally much higher and steeper western slope. Tree roots of fire-damaged and dead trees were still capable of holding soil in place. Ground Cover in the riparian corridor and stream terrace was moderately developed by October 2021. Wood added to the stream was sparse in 2021, and was mostly limited to burned and toppled trees from the moist riparian corridor. A large partial logjam at mile 2.8+ was at the bottom of a small west slope debris flow. A second jam at mile 3.45 on the West Fork was from toppled streamside trees. Some pre-exiting channel wood burned, including a very large log jam at mile 3.4 on the West Fork, which had often been a fish passage barrier since 1998.

The extensive loss of canopy between mile 2.75 and 3.6+ resulted in increased algal growth and warmer stream conditions, with mean water temperature in late June–through late July 18-19°C, with daily ranges around 4°C (Figures 4-6 and Smith 2021b). Farther downstream where the canopy was not lost, at Twin Redwoods Camp, mean temperature in late June through July was 17-18°C, with daily range usually less than 3°C (Figure 7). 2022 results were similar. At Gazos Creek little shading was lost in the steelhead-accessible reach due to the fire, and mean water temperatures at three sites in mid-June through mid-August were 16°C, with daily ranges of 2-2.5°C. The warm water temperatures at Waddell Creek would have delayed potential fish sampling by electrofisher until at least mid-September, but salvage logging on the adjacent private property restricted access until mid-October anyway. A large October storm then eliminated potential sampling. However, juvenile steelhead (*Oncorhynchus myskiss*) were seen throughout the reaches surveyed for fire damage.

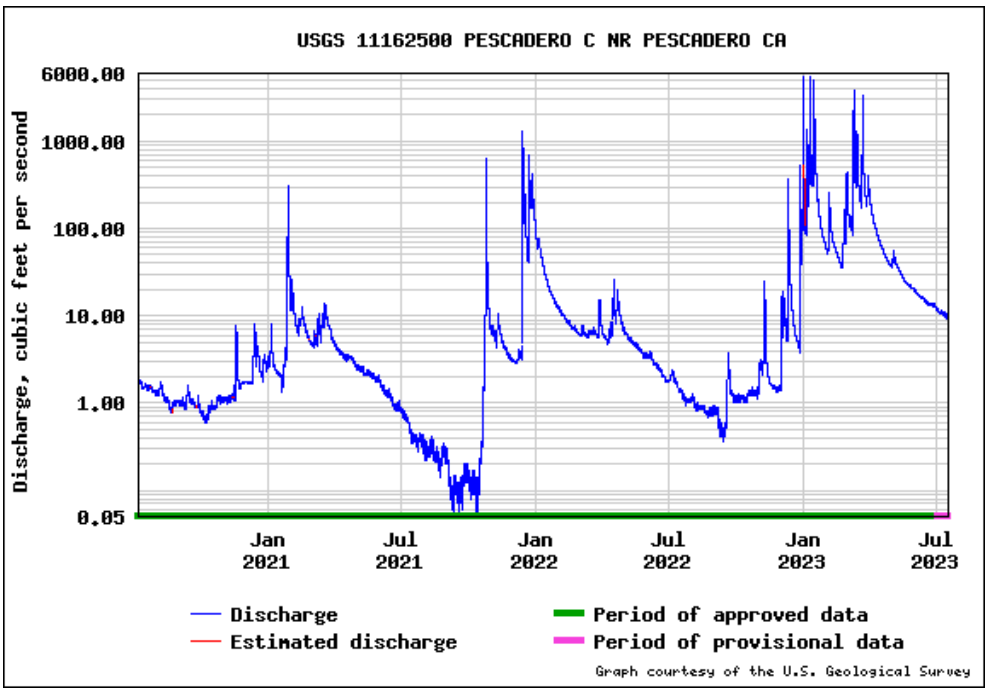


Figure 2. Logarithmic graph of runoff in Pescadero Creek in October 2020 – July 2023, as a pattern surrogate for ungaged Waddell Creek, showing a single modest rain/runoff event in January 2021 and much more intensive rain/runoff in October and December 2021, with drought by January 2022. From December 2022 through March 2023 repeatedly very intense storms produced more sediment inputs and substantial above-bank floods in Waddell Creek.

With the mild winter (Figure 2), and despite the general lack of ground cover, debris flows and other sources of sediment to the stream channel were restricted in winter 2020-2021. Two west slope debris flows, a relatively small one at mile 2.8 and a very large one from the west slope at the confluence of the forks (mile 3.0+), resulted in substantial filling of the channel and

elimination of deeper pools with fines and small mudstone gravel between the forks and mile 2.7 (Figure 3). On the west fork between miles 3.4 and 3.5 there was significant stream aggradation from steep west slope erosion. Elsewhere the stream channel of Waddell Creek, including at fish sampling sites used annually since 1992 (Smith 2020), was not significantly altered. Summer stream flow in 2021 was apparently increased compared to that expected in such a dry year, due to the loss of forest canopy soil water demands in the watershed from tree deaths and substantial reduction in leaf area of most surviving trees. The summer stream flow effect could persist for years.

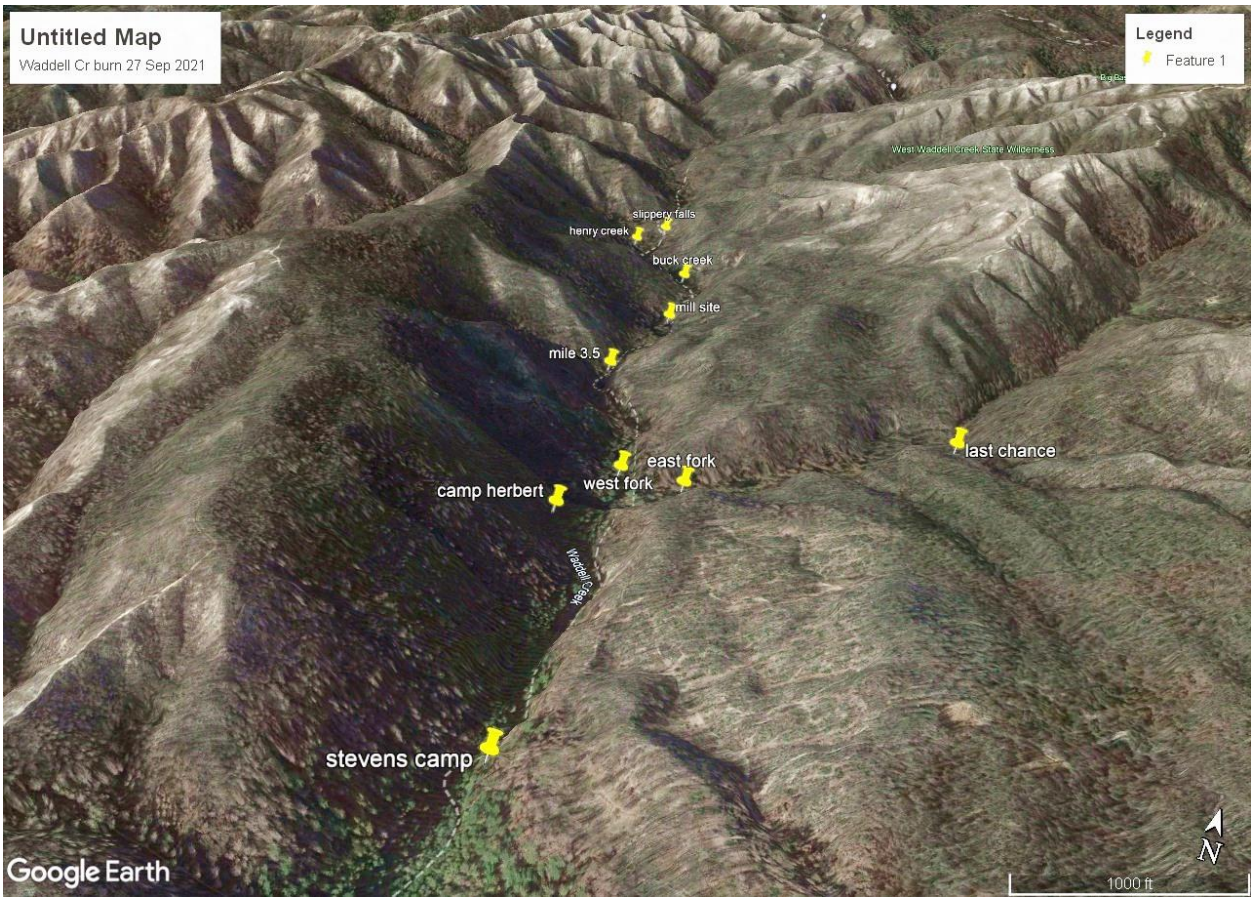


Figure 3. Google Earth aerial photo from 27 September 2021 from downstream of Stevens Camp (mile 2.55) upstream to the upper watershed of the East and West forks of Waddell Creek. The riparian corridor, lowermost east slope, and the west slopes of Waddell and lower West Fork Waddell had partially intact forest canopy. Drought conditions (with the exception of limited January 2021 rain) resulted in establishment of only very limited vegetative ground cover in 2021 beneath burned standing and downed trees.

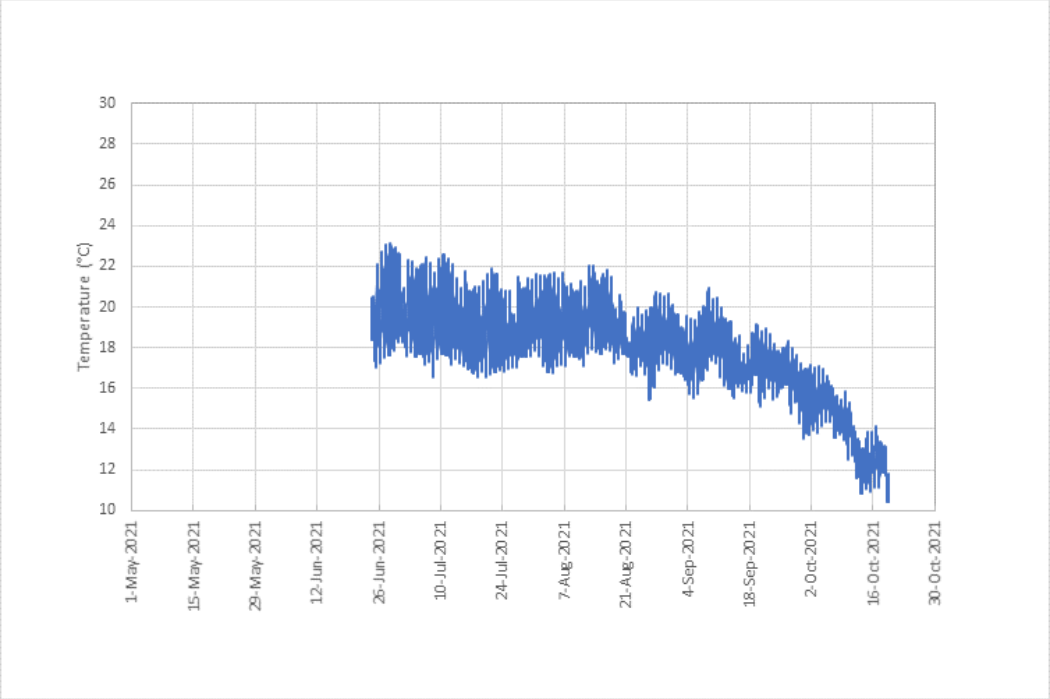


Figure 4. Water temperature in Waddell Creek at the Upper West Fork for 24 June through 19 October 2021.

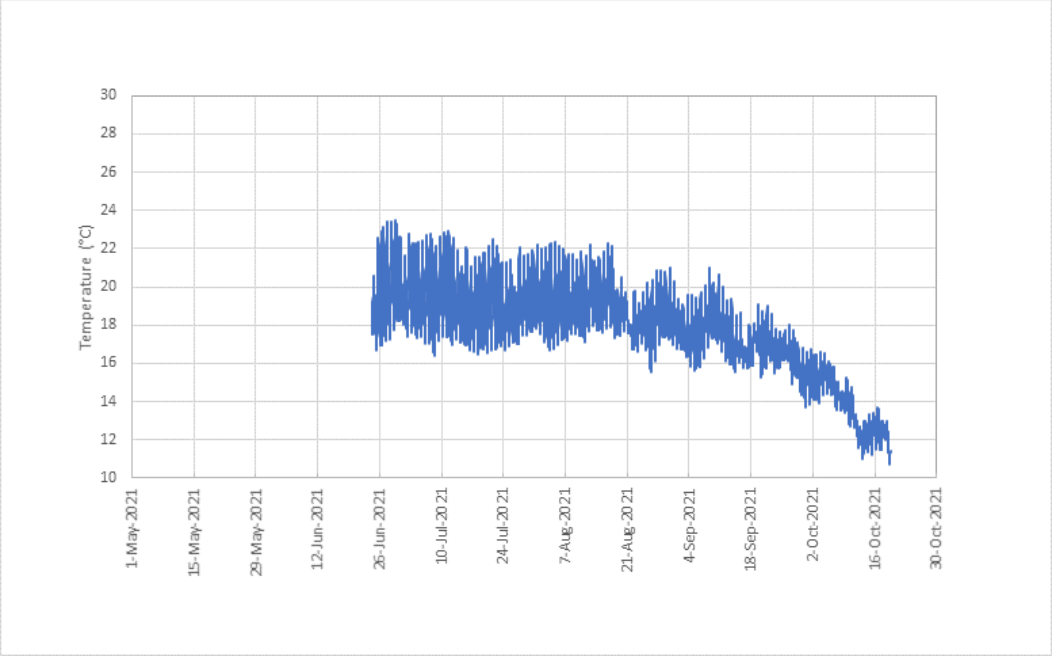


Figure 5. Water temperature in Waddell Creek at the Lower East Fork for 24 June through 19 October 2021.

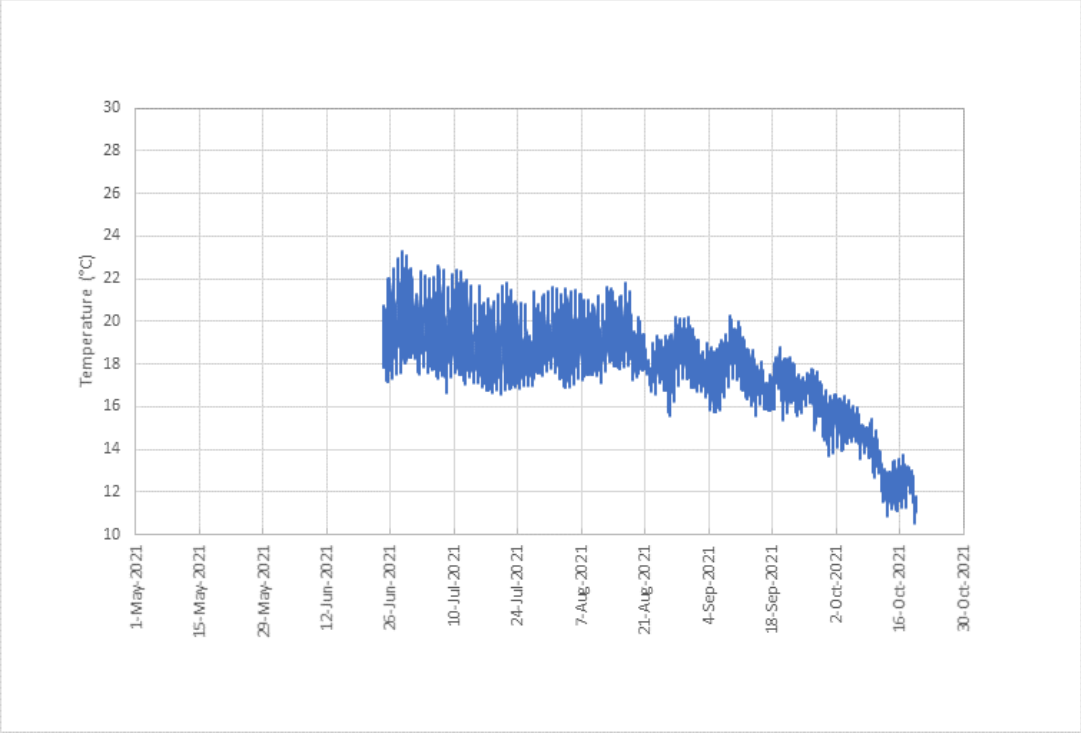


Figure 6. Water temperature in Waddell Creek at the Lower West Fork for 24 June through 19 October 2021.

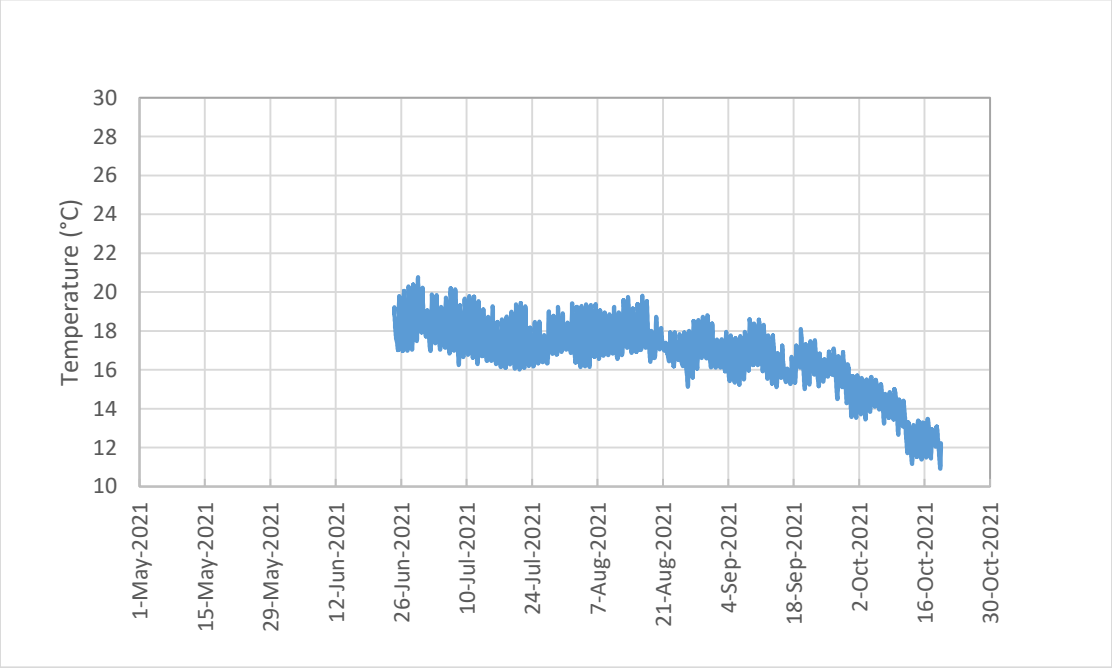


Figure 7. Water temperature in Waddell Creek at Twin Redwoods for 24 June through 19 October 2021.

2022 METHODS and RESULTS (most of Smith 2022c, but without the 2022 photos)

In October and December 2021, relatively heavy rainfall and runoff occurred (Figure 2), despite another drought year, which threatened to produce the extensive post-fire erosion that the Waddell Creek watershed was largely spared by the very mild 2020-21 winter. The lack of ground cover on most slopes prior to the October and December storms also increased the likelihood of erosion and deposition impacts to the Waddell Creek channel. High winds in winter through early summer 2022 might also have increased falling of dead and fire damaged trees, substantially increasing wood loading to the channel. High storm runoff might also have transported channel wood and organized log jams as habitat features that could act as fish passage barriers or as valuable pool-forming structures. The wetter early winter should also have substantially increased herb and shrub ground cover. In addition, the fate of the streamside alders, most of which appeared to have died upstream of mile 2.75, was of interest, as alders were a major component of stream shading and stream water temperature moderation. Therefore, it was important to resurvey the Waddell Creek watershed in 2022 to evaluate changes to stream habitat, especially in a year when significant runs of endangered coho salmon (*O. kisutch*) had apparently occurred elsewhere in Santa Cruz County (Joe Kiernan, NOAA Santa Cruz Laboratory, pers. comm.).

In June and early July 2022 the habitat conditions were resurveyed from mile 1.2 upstream to mile 3.6+ (on the West Fork of Waddell), on the lower portion of the East Fork, and upslope on the east slope logging and State Park road between Stevens Camp (mile 2.6) and the confluence of the East and West forks (mile 3.0+). Resurveys were also conducted during fish sampling in October.

On 22 June 2022 the streamside habitat was spot checked from near Alder Camp (mile 1.2) upstream to mile 2.5 and walked on the streamside trail from upstream of Stevens Camp (mile 2.6) to the confluence of the East and West Forks of Waddell Creek and then upstream to above mile 3.6 on the West Fork. On 1 July the logging road and State Park road from Stevens Camp up the east slope above the stream and then down to the confluence of the forks was surveyed; this was to gage fire effects with elevation on the slope and effects from miles 2.6 to 3.1. Then about 0.3 miles on the East Fork was surveyed. The return to Stevens Camp was by the streamside trail, which allowed a second survey of that reach. Notes and 200+ photographs documented habitat conditions for comparison with notes and photographs from 2021. The habitat conditions of individual stream mesohabitats (pools, runs, riffles, wood structures) were more intensively investigated at 8 fish sampling sites used almost annually since 1992. Stream distances for notes and photos for the streamside surveys were estimated, based upon road mileages at fish sampling sites documented in fish investigations prior to 1998. Distances on the slope bypass road were approximated to be equivalent to stream distance locations.

As in 2021, on 22 June five Hobo water temperature recorders were installed between Twin Redwoods Camp (mile 1.8) and mile 3.6+ on the West Fork, and with one on the East Fork near the confluence. Recorders measured temperature every 15 minutes; they were retrieved in October. Electrofisher sampling of seven of the historic fish sampling sites was conducted in October, and additional photos taken during sampling were added to this report. Spot checking farther downstream was also conducted in October, which discovered a major new logjam (a potential significant fish passage barrier) upstream of mile 0.6 (the first bridge).

Tree Mortality and Toppling

A major finding in 2022 was the confirmation that most of the alders that were apparently cooked and leafless in 2021 had died. A few of the streamside alders farther downstream (mile 2.8) and at the confluence of the forks survived (Smith 2022c). Otherwise, alders were killed where the fire reached to or close to the stream, even though they lacked burn scars. The loss of most of the upstream alders reduced or eliminated seed sources for reestablishing the alders. New young alders were extremely scarce or absent, except farther downstream where much of the riparian border was intact. Extensive death and toppling of alders provided most of the new channel wood present in 2022, including additions to the 2021 log jam at mile 2.8+ and at the first bend above the confluence on the East Fork (Smith 2022c). There were few fallen trunks of dead and damaged upslope trees that reached the streamside in either 2021 or 2022.

Most maples that appeared dead in early 2021 had basal sprouts by 2022, including upslope trees. Some smaller tanoaks and redwoods that were thought dead in 2021 had basal sprouts in 2022 (Smith 2022c).

Ground Cover

Ground cover, with a wide variety of herbs and shrubs (including blackberry *Rubus* spp.), had substantially increased in the riparian corridor and terraces by 2022, so that bare soil was absent, except where bedrock was exposed. Therefore, the riparian corridor and terraces, when present, were potentially able to capture some or most of the sediment from upslope erosion.

Upslope, blue blossom (*Ceanothus thyrsiflorus*) and French broom (*Genista monspessulana*) were an abundant ground cover on unshaded eastern slopes. However, on the steeper, drier western slopes, especially from mile 2.8-3.6+ and beyond on Waddell and West Fork Waddell creeks, had only very sparse ground cover in 2022 and as protection against erosion in winter 2022-2023.

Slope Erosion

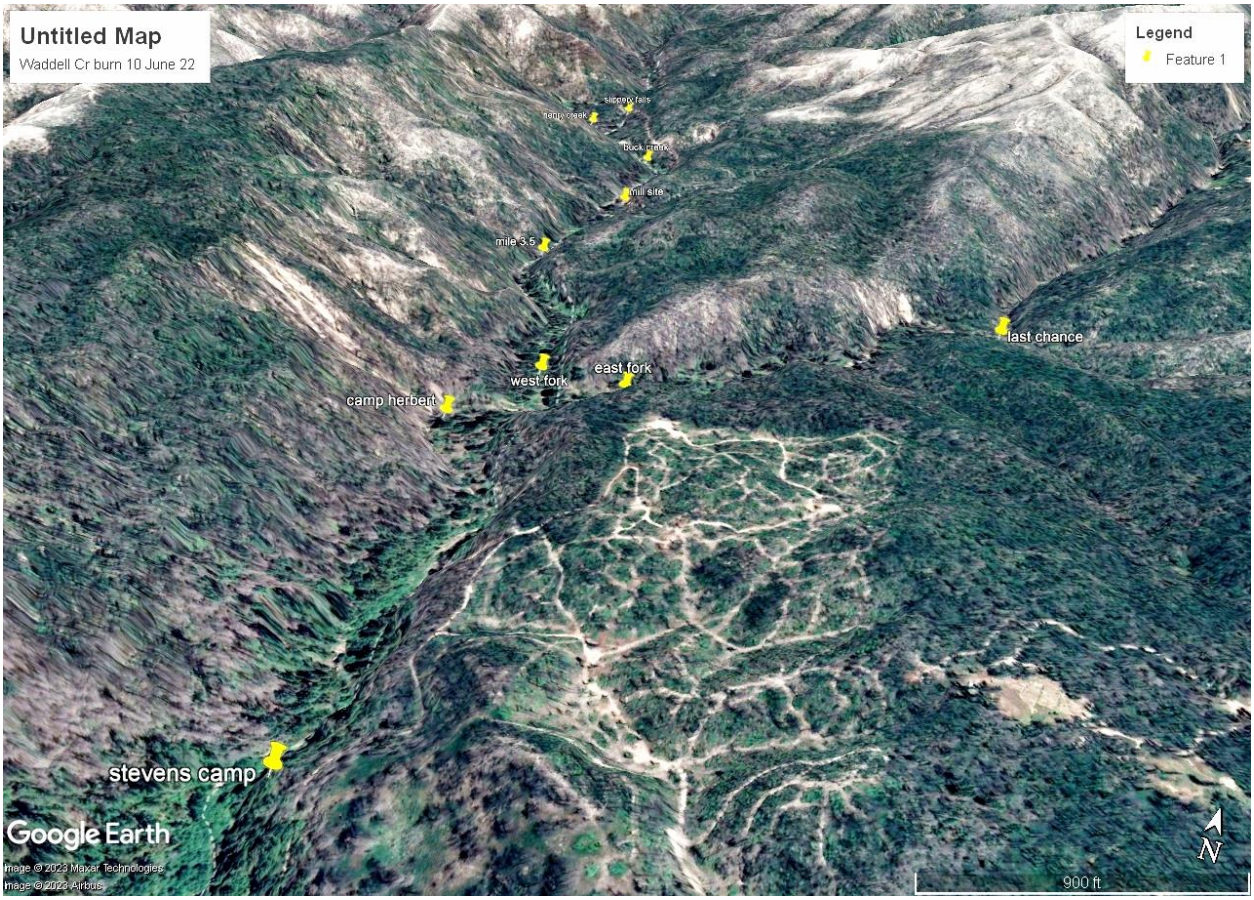
The burned east slope between miles 2.0 and 3.6+ did not appear to have delivered significant sediment to the stream channel in 2021 or 2022 (Smith 2022c). "Tramway Springs" (mile 2.05), and a seasonal drainage a just upstream (mile 2.15), had carried some coarse sediment across the road, but it apparently didn't enter the stream channel. "Aunt May" Creek, just downstream of Stevens Camp (mile 2.6), is spring-fed and perennial, but low gradient; there was no evidence of sediment deposition at its mouth. Upstream of the forks there was no evidence of east slope sediment flow across the streamside trail into the riparian zone.

The upper eastern slopes that were surveyed along the logging road and state park road between Stevens Camp and the forks did not have apparent slope gullying or gullying on the roads (Smith 2022c). The logging road had effective water breaks installed in 2021, but the steeper state park road down to the forks has no water breaks, but was still in good condition, without gullies. Dense, head-high blue blossom *Ceanothus* and French broom, which would have developed after the December rains, occupied large portions of the State Park road down to the forks.

The generally steeper (55-60% mean slope) west slope showed evidence of substantial new slope erosion at Twin Redwoods Camp (mile 1.8), between miles 2.8 – 3.0+ (the forks), and especially between

miles 3.3 and 3.5 where several large seasonal drainages discharged to the creek (Smith 2022c). Farther upstream of the survey area the burn was even more severe (Figure 1), so the upstream reaches were also major sources of sediment to the surveyed channel.

On steep exposed slopes and cliffs, especially on the west slope downstream of the confluence of the forks and upstream on the West Fork, it appeared that heating by the fire cooked the Santa Cruz Mudstone, and expansion of the rock shattered it into small angular gravels that were easily eroded from the slopes (Smith 2022c). The amount of fine mudstone gravel in the channel was unusual, especially in the half mile downstream of the forks in 2021 and upstream on the West Fork of Waddell Creek in 2022.



Figures 8. Google Earth aerial photo from 10 June 2022 from downstream of Stevens Camp (mile 2.55) upstream to the upper watershed of the East and West forks of Waddell Creek. The large debris scarp (ridge top to stream) on the west slope above Camp Herbert at the confluence of the forks deposited sediment in the stream more than half way (Mile 2.7) down to Stevens Camp in 2021. Erosion in 2022 from the west slope of the West Fork of Waddell deposited sediment, filling almost all pools between the confluence of the forks and mile 3.6+ (see also Figure 9).

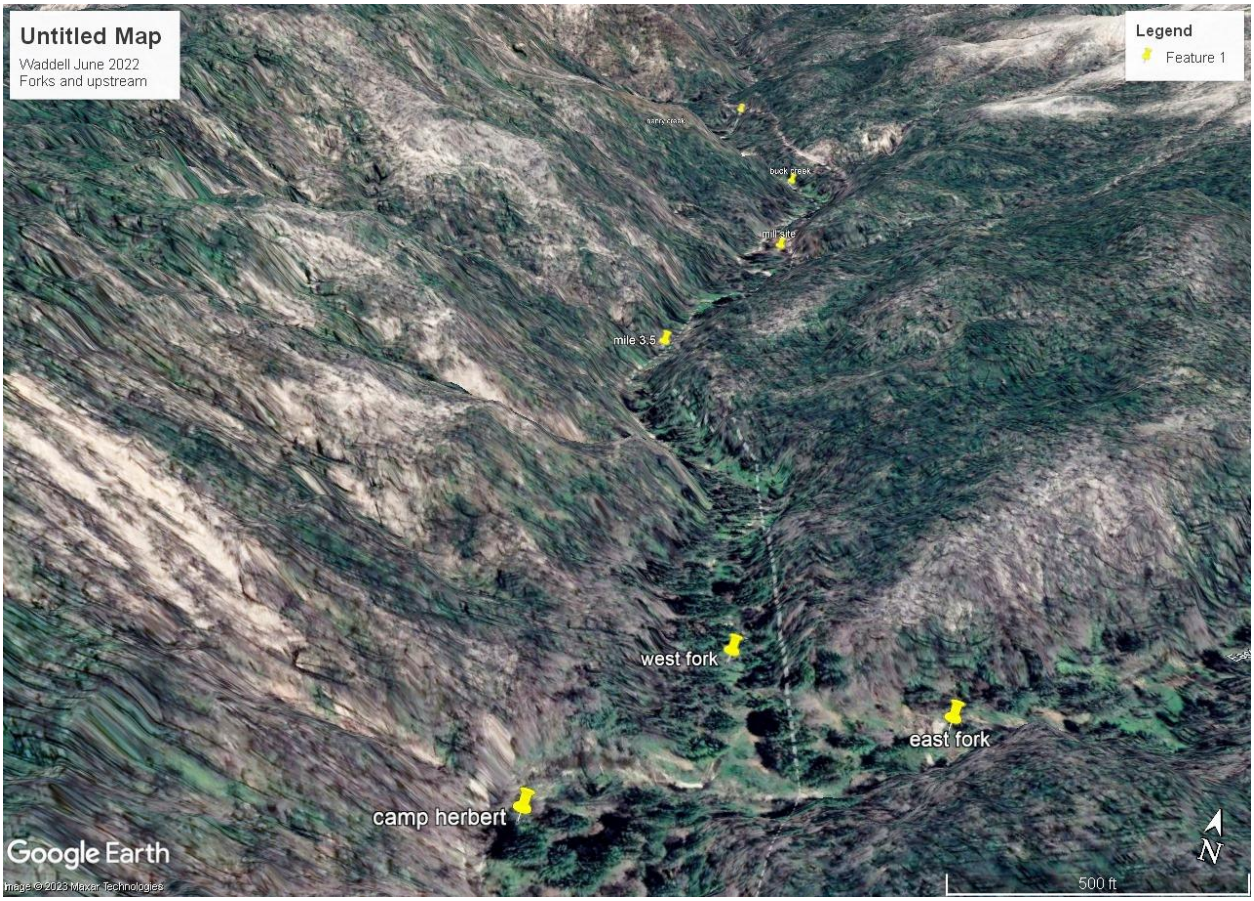


Figure 9. Google Earth aerial photo from 10 June 2022 from the confluence of the forks upstream. West slope Waddell Creek erosion filled almost all West Fork pools. The east slope above the West Fork of Waddell Creek did not apparently contribute to stream sedimentation. The north slope above the East Fork (lower right) also lost its forest. However, the north-facing slope suffered only a moderate burn. Pools on the lower East Fork were not substantially impacted in 2022 (or 2023).

Figure 10. Google Earth aerial photo from 10 June 2022 between Stevens Camp (mile 2.55) and the East and West forks of Waddell Creek. In 2021 streambed sedimentation and pool filling extended from the forks downstream half way to Stevens Camp. In 2022, erosion from the west slopes of Waddell and West Waddell creeks extended streambed sedimentation downstream to at least mile 1.75 (Twin Redwoods Camp). The upper east slopes and hilltops between Stevens Camp and the East Fork (right in the photo) are private property that was salvage logged for redwood in 2021; the green is primarily blue blossom *Ceanothus.*

Main Stem Waddell Creek and West Fork Channel Deposition

Channel deposition by fines and small Santa Cruz Mudstone gravel was substantial in 2022 (Smith 2022c). Most of the volume of deeper pools on the West Fork was reduced to restricted depressions around bends or structure at regular fish sampling sites (near the confluence and at mile 3.6+) and elsewhere. The aggradation rearranged and buried the logjam and step that had formed in 2021 at mile 3.45. On the main stem, the channel between the forks and mile 2.8 was aggraded, and former large pools filled from inputs in 2021. However, in 2022 the deposition, including finer materials, extended much farther downstream. Aggradation was substantial just downstream of Stevens Camp (mile 2.55) and at Twin Redwoods Camp (mile 1.75). Significant filling occurred as far downstream as below Alder

Camp (mile 1.2). Regular fish sampling pools at miles 1.2, 1.8, 2.2 and 2.65 had substantial reductions in volume. The upslope inputs in October and December 2021, and transport of the low specific gravity Santa Cruz Mudstone fines and small gravel, substantially increased and extensively spread degraded stream habitat in winter 2021-2022.

East Fork Forest Conditions and Slope Erosion

The East Fork suffered forest burn similar to that on the West Fork with similar effects on upslope and riparian forest. However, the slopes farther upstream of Last Chance Creek are of much more erosion-resistant Butano Sandstone, compared to the fragmented Santa Cruz Mudstone on Waddell and West Waddell creeks and the lower reaches of the East Fork (Smith 2022c).

East Fork Channel Conditions

The stream substrate on the East Fork, and in riffles immediately downstream of the forks, is dominated by small boulders and cobbles of Butano Sandstone. The input of mudstone fines and gravel from slopes in the lower portion of the East Fork must have been minimal in 2021-2022 and/or the materials were rinsed through the cobble and boulder armored streambed (Smith 2022c). The lower East Fork habitats checked in 2022 had lost much of the streamside canopy of alders and other trees, but the stream substrate was generally clean sandstone gravels, cobbles and boulders. Deeper pools had fines, but there was no evidence of significant pool filling. The East Fork had by far the best habitat in the Waddell Creek watershed in 2022. However, (toxic?) fish kills and low fish abundance on the East Fork (and below it on the main stem) have been an apparent problem since 1999), possibly originating on Last Chance Creek or farther upstream (Smith 2020).

Fish Abundance in 2022

Electrofish sampling was conducted in October. During the habitat surveys in June and July juvenile steelhead (and coho) appeared to be very scarce. Sampling in October found coho present at 5 of 7 sites and steelhead at all sites, but at extremely low densities at all sites (mean of 7 steelhead and 2 coho per hundred feet of sampled habitat; Smith 2022d). The mobile streambed produced by the fines and fine gravel loading in winter 2021-2022 could have affected redd survival and egg hatchability for steelhead and coho. However, the channels at Gazos Creek and in the Scott Creek watershed suffered somewhat similar sediment inputs and flood-flow transport, channel rearrangements, and filling of pools, but had unusually high steelhead (and coho in Scott Creek) abundances (Smith 2022a and 2022b). Therefore, spawner access may have been the problem in Waddell Creek.

The substantial reduction in the amount and quality of pool habitat observed in 2022 should have affected summer rearing conditions for coho and yearling steelhead (Smith 2020 and 2022d). Overwintering survival for both steelhead and coho was probably also reduced by the decline in abundance, complexity, and size of pools.

The addition of fallen trees to the channel can help create and enlarge pools and also increase pool complexity and escape cover. However, despite heavy tree mortality or trunk death of basal sprouting trees like tanbark oaks, relatively little wood had so far been added to the channel. Most new wood is from the extensive death and fall of riparian alders. Alder wood tends to disintegrate rapidly, without the longer–term persistence of some other hardwoods or of conifers (Leicester 2005*).* Much of the added wood in 2022 was collected by the storm flows in small to large logjams; most are not likely fish

passage issues. A large jam was present in 2021 at mile 2.85+, and it tripled in length in 2022. It still appeared passable, but could get worse. Another large jam had formed at about mile 0.85 in 2021, but also was likely passable. However, that jam was gone in 2022, but apparently contributed to a new very large log jam in an entrenched channel above mile 0.6. That new jam was tightly packed, 6-8 ft high, and extended across the entire flood plain. It appeared to be a very significant potential fish passage barrier, and might have contributed to the general scarcity of fish upstream in 2022. Some steelhead and coho may have passed the site in December 2021 at high flows or before the logjam formed. When spot checked in December 2022, after the first large rains, it had been substantially breached, and was open to fish passage in winter 2022-2023.

2023 METHODS

In January 2022 through March 2023 very heavy rains produced substantial flood flows (Figures 2 and 11), similar to those in the severe El Nino year of 1997-98, which caused erosion of stream banks and flood plain, toppling of streamside trees, and scouring, sedimentation, and filling of pools (Smith 1998).

On 25 and 26 August 2023 the streamside was walked and the stream channel spot-checked from miles 0.65 (above Highway 1) upstream to mile 3.7 on the West Fork and on the lower 0.2 miles of the East Fork. Notes and photos from 2021, 2022, and 2023 were compared for channel conditions, including changes in channel width, pool development and depth, stream substrate conditions, and changes in channel and floodplain trees and downed wood. Particular attention was paid to long-term (since the 1990's) fish sampling sites at miles 0.65, 1.2, 1.8, 2.2, 2.65, 3.0 on Waddell Creek, miles 3.15 and 3.6 on the West Fork, and miles 0.1-0.2 on the East Fork. At those sites the same channel reach and even the same habitats have been repeatedly sampled in the past. Fish Sampling will be conducted in October.

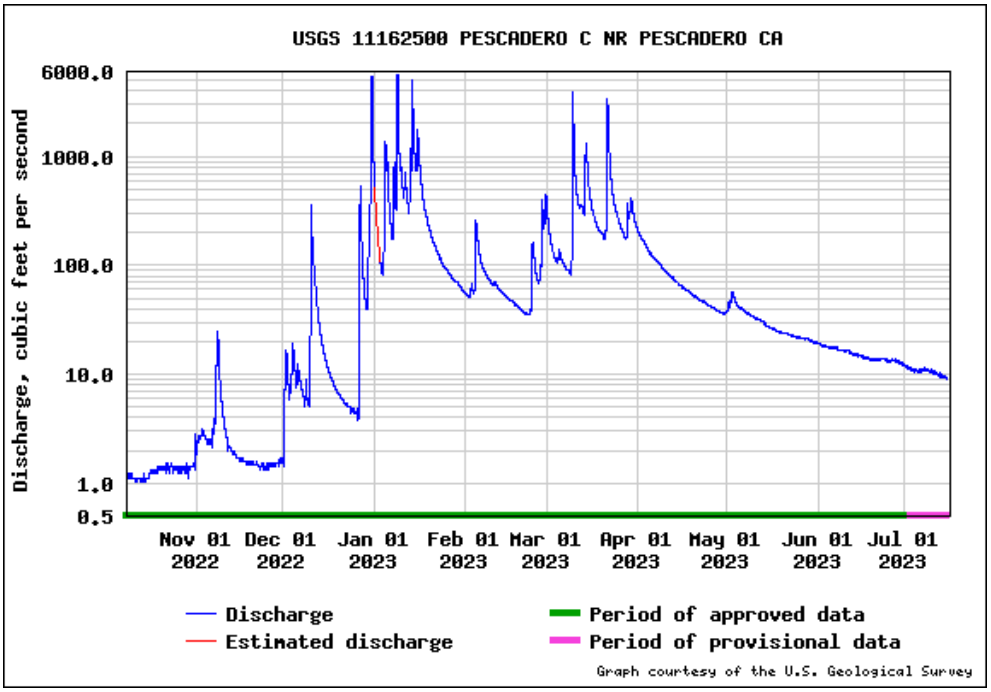


Figure 11. Runoff in Pescadero Creek in October 2022 through July 2023, showing the intense December-January and March periods of repeated large floods.

2023 RESULTS AND DISCUSSION

In 2021, and especially in 2022, the slope erosion and streambed sedimentation effects could be observed by debris flows on the west slope of the stream and by the filling of pools with the resulting sediment. However, since there was extensive channel aggradation and pool filling by 2022, and the flood flows in December 2022-March 2023 were capable of moving large amounts of channel sediment and eroding stream banks, the sources of channel changes could not be directly distinguished.

Tree Mortality and Toppling

Most of the dead bank and floodplain alders that were still standing in 2022 were toppled by wind or high flows in 2023. In addition, live bank alders in 2022 were toppled by the 2023 high flows, especially in miles 1.2 – 2.9, where alders made up most of the streamside trees. Douglas firs killed by the fire apparently were toppled by wind in 2023 on slopes and also near the stream (such as at miles 1.75+ and 2.6+). However, little new wood other than alders was added to the stream channel in 2023. Upslope, dead trees are abundant and fallen trees common, but are unlikely to reach the channel after falling, unless in a debris flow on the steep west slope.

Wood Movement

The high flows in 2023 moved much of the pre-existing channel wood around. Most dramatically the logjam at mile 2.85, which formed at a debris flow with fallen trees in 2021, and grew by an order of magnitude with accumulated dead alders in 2022, was washed out by the floods in 2023. It re-formed even larger at mile 2.7. Fallen alders and redwoods from bank erosion at mile 0.1+ on the East Fork in 2022 rearranged the channel bend. The wood was gone and the channel rearranged again with the flood flows in 2023.

New jams were formed from alders at miles 1.2 and 3.1+, but a 2022 jam was lost at mile 1.2. The jam at mile 0.65 that was judged to be a potentially significant fish barrier in 2022 was breached by December 2022 storms and dismantled by later 2023 storms. Large wood that provided pool-producing scour was lost or buried by sediment at miles 1.75+, 2.15-2.2, and 3.15. The net result of the wood additions since the fire and winter floods is that much of the added wood is clustered in a few large jams or scattered in the flood plain or on stream banks. Most of the channel now has little anchored wood. On the other hand a single large, deep and complex pool survived at Twin Redwoods Camp (mile 1.8). It was formed by a fallen (and still alive) California bay in 1998.

Ground Cover

Ground cover in the riparian corridor and terraces and east slopes was substantially recovered by 2022 and increased with wet conditions in 2023. The wet winter in 2023 has finally added to the ground cover on the steep western slopes of West Waddell Creek. However, most of the west slope is still bare of ground cover, except near the stream; erosion of the west slope will continue.

Main Stem Waddell and West Fork Slope Erosion and Channel Deposition in 2023.

The near lack of protective ground cover on the west slope from mile 2.9 to 3.6+ (and farther upstream) on Waddell and West Waddell creeks before the heavy winter 2022-2023 rains indicates that significant

additional slope erosion and streambed sedimentation likely occurred in 2023. However, most of the pools in that reach were already filled by 2022. Pools at mile 2.9 and 3.1 - 3.15 had additional filling, which indicates additional sediment input. Channel aggradation and pool filling at miles 1.2-2.7, farther downstream, apparently came from sediment carried downstream by the very high 2023 storm flows; there is little indication of streamside sediment input to the channel within the reach. None of the channel inspected on Waddell or West Waddell creeks showed any improvement in 2023. Gazos Creek showed fire effects similar to Waddell Creek in 2021 and 2022, with extensive filling of pools in 2022. However, on Gazos Creek some new pools were scoured and old pools reestablished at wood structure in 2023 (Smith 2023). High flows on Waddell Creek might have been expected to also scour new deep, complex habitat around large wood or bends in the channel, but there is presently little anchored large wood in the channel for winter flows to scour around. In hip boots you could probably walk almost the entire widened, shallow channel, although you would also have to negotiate a few large concentrations of alders in log jams.

East Fork Forest Conditions and Slope Erosion

The East Fork suffered forest burn similar to that on the West Fork, with similar effects on upslope and riparian forest. The general east-west direction of the East Fork results in a dry south-facing slope on the right bank and a north-facing slope on the left bank. The live forest on the south-facing slope is now confined to the base of the slope and the terrace. The left bank has surviving and recovering forest on the terrace and the slope. The terraces are sufficient in many places to capture sediment from the south-facing slope. Father upstream on the East Fork (above Last Chance Creek) the geology shifts from the fractured Santa Cruz Mudstone, which disintegrates and erodes to angular gravels and lightweight cobbles, to the more resistant Butano Sandstone, which erodes to large gravels, cobbles, and boulders. This reduces the input of small gravels to the East Fork and results in a cobble and boulder-dominated stream bed.

East Fork Channel Conditions

In the past, storm flows from the steeper East Fork have usually been greater than those on the West Fork. In 2023 the flood flows rearranged the East Fork channel and carried cobbles and boulders, primarily of Butano Sandstone, down below the confluence of the forks. A 2 ft diameter boulder of Santa Cruz Mudstone, that was the marker for a rebar anchor a temperature logger, was gone from the trail ford in 2023. Despite the heavy storm flows, there was no significant filling of the two deep pools at the East Fork fish sampling site. There was a fine coating of silt in the pools, but sand or gravels apparently were swept through the armored bed, rather than deposited; depth of the pools has not been significantly reduced. Because of stream orientation, the high south slope provides substantial shade, despite the loss of streamside alders. As in 2022, presently the best stream channel habitat is on the East Fork.

Recovery Prospects

Juvenile steelhead use a variety of habitats, but pools, especially with fast-water heads of pools for feeding, are preferred habitat of coho salmon and yearling steelhead. Complex pools and logjams also provide overwintering habitat as refuges against floods (Smith 2020 and 2022d). Western pond turtles (*Emys marmorata*) at Waddell Creek heavily used the lagoon, but in upstream areas they were associated with complex woody pools with basking opportunities in summer (Abel 2010). California red-

legged frogs (*Rana draytonii*) were strongly associated with complex woody pools during both day and night at Waddell Creek (Keung 2015). Stream habitat recovery at Waddell Creek will be achieved when deep and complex woody pools are commonly included in the mix of habitats in the stream. Those habitats are presently extremely scarce.

Major storms in 1982 (with severe debris flows) and 1983 deposited large amounts of sediment on the main stem of Waddell Creek and on the West Fork. Spot observations in 1984 found that pools were relatively small and/or shallow on the lower West Fork and on much of the main stem of Waddell Creek. The estuary/lagoon at the mouth of the stream was largely filled with sand and gravel. Many streamside alders were also toppled by the 1982 and 1983 storms. However, by 1992-1997 (after 10-15 years) fish, pond turtle, and red-legged frog studies in the watershed found that fast-growing alders had significantly recovered on the stream banks. Pools had also flushed much of the sediment in the winters of 1985, 1986, and 1992-1997.

In 1998 floods eroded stream banks, toppling many streamside trees, including multi-trunked redwoods that produced a major log jam at mile 3.4, which was then a frequent potential barrier to steelhead upstream access (Smith 1998 and 2020). Other fallen trees and partial logjams were common on the main stem of Waddell Creek. Channels were rearranged and new pools created at bends and at wood or bank structure. The overall sediment impacts from 1998 were substantial but relatively short-lived (10 years), however.

The impacts of those storms were far less than those of the 2020 CZU Fire, which killed and damaged streamside vegetation upstream of mile 2.75 and especially the upslope forest on the steep west slope upstream of mile 2.75 on Waddell and West Fork Waddell creeks. Erosion of the steep upper west slope is likely to continue for years, due to the death of so many trees and the slow development of ground cover. The extensive loss of streamside alders due to the fire, the widened channel from aggradation, and the high 2023 winter flows will also retard channel improvement until new alders are able to establish, grow, and narrow the channel (15+ years). Reestablishment of alders, and the shade they provide, will also be important for reducing summer water temperatures.

Acknowledgments

Tonja Chi and Ruth Sundermeyer assisted with the field assessments in October 2020 and June 2021. Jeff Micko assisted with the assessments in June and July 2022. Troy Guy assisted with the assessments in October 2022. Ruth Sundermeyer and Troy Guy assisted with the assessments in August 2023.

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APPENDIX A: Photos (from downstream to upstream)

Main Stem of Waddell Creek

Photo 1. Mile 0.65 (from Highway 1). Looking downstream to the bridge above the lagoon. Winter 2023 flows reached to the bottom of bridge several times and flowed through the flood plain with wood to agricultural fields on the left bank. Streamside alders were toppled and the channel widened and flattened.

Photo 2. Mile 0.65, looking upstream. First pool upstream had been concentrated near the right bank, at a legacy log (left in photo), but the thalweg moved to the center of the channel and the sandy-bedded pool now extends bank to bank. Wood carried by the flood was caught in trees at the top (8+ ft) of the bank (left).

Photo 3. Mile 0.65, looking upstream. Narrow run habitat along the right bank was replaced by shallow sand and fine gravel glide habitat across most of the shallow, leveled channel.

Photo 4. Mile 0.65, looking upstream. Local scour at a left bank root wad provides habitat in an otherwise broad, shallow channel.

Photo 5. Mile 0.65, looking upstream. In 2022 a 10 ft high, tightly packed, bank to bank logjam was present at the upstream limit of the lagoon. It was judged to be a likely severe fish passage problem (16 October 2022 photo). December 2022 storms breached the jam along the left bank, eliminating any passage problem.

Photo 6. Mile 0.65, looking upstream. Winter storms in 2023 dismantled the jam, and most of the abundant wood of the jam was carried downstream or on to the floodplain.

Photo 7. Mile 1.2, looking downstream. Prior to 2023, this corner pool at the cliff was more than 80 ft long and 6-10 ft deep. Sediment transported by the 2023 floods filled 80+ percent of the pool volume. Only 15 ft of the pool is now deep (4.5-5 ft).

Photo 8. Mile 1.2, looking upstream from the cliff pool to the fish sampling site. The wide shallow, fine gravel and sand glide habitat lost depth and undercut banks along the left bank.

Photo 9. Mile 1.2, looking upstream. The second sampling habitat, is now a wide, shallow sandy-bedded glide. Bank scour and structure is gone.

Photo 10. Mile 1.2, looking downstream. In 2002-2021 this was a deep pool with a left bank back-water alcove. The alcove was lost and the pool was half filled in 2022 and was almost completely filled in 2023.

Photo 11. Mile 1.2, looking upstream. In 2021 this was a moderately deep pool (to 3 ft). In 2022 the pool was locally deep near and under a channel-spanning partial log jam. The jam was gone in 2023, and a shallow pool (< 2ft) pool remains.

Photo 12. Mile 1.2, looking upstream from the edge of the eroded, reinforced road. Boulders to protect the road produce pool scour.

Photo 13. Mile 1.25, upstream of the sampling site, looking upstream. An 8+ ft high log jam, primarily of alders, spans almost all of the channel. At higher flows the jam could be bypassed along the right bank.

Photo 14. Mile 1.25, looking upstream from the jam in photo 13. Additional wood is trapped by mid-channel alders, now in the middle of a split channel.

Photo 15. Mile 1.75+, looking upstream to the Twin Redwoods Camp sample site. The downstream portion of the former deep pool and glide was leveled and filled in 2022.

Photo 16. Mile 1.75+, former head of the first Twin Redwoods sample pool, looking downstream. The thalweg was shifted from left bank to right bank, eliminating the complex head of pool habitat. The deep remnant of the former pool, associated with large wood, was filled, leaving only a log sticking out of sediment near the left bank.

Photo 17. Mile 1.75+, looking downstream. Glide with scour and undercuts along both banks was aggraded with fines and mudstone gravels in 2022. In 2023 the channel was widened, toppling streamside alders. Very shallow except at channel-spanning fallen alders.

Photo 18. Mile 1.75+, across the road at base of the east slope. Fire scars are present on redwoods and some fallen Douglas firs.

Photo 19. Mile 1.75+, looking upstream. Formerly deep pool with undercut bank and wood structure near the tail, was 60% filled in 2022, but with a deep remnant. In 2023, the pool was completely filled, with a sandbar along the upstream left bank.

Photo 20. Mile 1.75+, looking at west (right) bank. Fire damaged alders and Douglas firs toppled by high flows and wind in 2023. Canopy shade was lost. Channel is wide and shallow.

Photo 21. Mile 1.8, looking downstream. Wide, shallow, sunny channel. Standing and fallen Douglas firs on right bank.

Photo 22. Mile 1.8, looking upstream. The downstream portion of the long, deep (swimming) pool was mostly filled by the right bank slope failure in 2022. In 2023 almost all of the pool was shallow, except immediately around in-channel wood at the channel bend.

Photo 23. Mile 1.8, looking downstream. 2022 slope failure scarp and channel wood at the bend shown in photo 22.

Photo 24. Mile 1.8, looking upstream. The fallen, but living, California bay along the left bank has supported a deep pool since 1998. In 2022 toppled alders from both banks provided scour at the pool through winter 2023. This is the only large, deep, and complex habitat remaining at the fish sampling site.

Photo 25. Mile 1.8, looking downstream at the pool in photo 24 and the bend and failed slope downstream.

Photo 26. Mile 1.8, looking upstream. A series of pools and glides upstream of the pool in photos 24 and 25, are wide, simple, and shallow.

Photo 27. Mile 2.05. "Tramway Springs," a wet year perennial drainage upslope of the road.

Photo 28. Mile 2.05. The Tramway Springs drainage channel downstream of the road was eroded deeper in 2023 and deposited sediment near Waddell Creek.

Photo 29. Mile 2.1, looking upstream. Burned Douglas firs fallen in 2023 across the road from the east slope.

Photo 30. Mile 2.15, looking upslope across road. Seasonal drainage carried sediment and angular mudstone gravels across road and down to Waddell Creek in 2023.

Photo 31. Mile 2.15+. The partially burned east slope above the road has fully reestablished ground cover, with trunk and basal sprouting by California bays and basal sprouting by tanbark oaks. Part of the upslope Douglas firs survived.

Photo 32. Mile 2.15+, looking downstream. The downstream portion of the lower fish sampling pool at the site was filled by fines and gravels in 2022 and 2023.

Photo 33. Mile 2.15+, looking downstream. In 2022 this was the upstream portion of the lower fish sampling pool. The pool had been mostly filled in 2022, except for a short (30 ft) section of scour around a cluster of left bank wood. In 2023 the entire pool was filled, leaving one buried log sticking out at the bottom of the left bank sand/gravel bar.

Photo 34. Mile 2.15+, looking upstream. The remnant wood in the pool in photo 33 is in the foreground. Farther upstream a fallen multi-trunked alder spans the shallow low flow channel.

Photo 35. Mile 2.15+, looking downstream. Farther upstream from Photo 34, a wood jam on the right bank floodplain and several channel-spanning downed alders were present at the shallow channel.

Photo 36. 2.15+, looking upstream. Another cluster of fallen alders spanned the wide, shallow channel, which replaced glide and shallow pool habitat in 2023.

Photo 37. Mile 2.2, looking upstream. In 2023 the channel rearranged and split around stream-side alders. A shallow pool upstream was filled by fines and gravels.

Photo 38. Mile 2.2, looking upstream. A cluster of pools around root wads and downed alders in 2021 was rearranged in 2022, and then the wood and complex pool habitat was mostly eliminated by the high stream flows in 2023.

Photo 39. Mile 2.2, looking upstream. The original (2005-2019) upstream fish sampling pool was bypassed (to the channel in photo 38) due to a logjam in 2020, leaving an isolated low flow pool. High flows in 2023 filled the pool with sediment.

Photo 40. Mile 2.6+, looking downstream from the high left bank. The downstream portion of the formerly long, deep pool filled in 2022. The entire pool was substantially filled in 2023.

Photo 41. Mile 2.6+, looking upstream from right bank trail on high bank. Numerous large burned Douglas firs fell across the trail and into channel 2023.

Photo 42. Mile 2.6+, looking downstream at fallen firs, sand/gravel bar, and filled middle portion of formerly large, deep pool.

Photo 43. Mile 2.6+, looking across channel to filled pool and dead, transported alders caught on 10 ft high bank.

Photo 44. Mile 2.6+, looking upstream at shallow upstream remnant of the formerly deep pool.

Photo 45. Mile 2.6+, looking upstream above sharp channel bend in photo 44. The shallow channel was widened and large wood and a deep pool were eliminated in 2023.

Photo 46. Mile 2.65, looking at floodplain upstream of bend. Flood flows deposited fallen alders 10 ft up on the floodplain in 2023.

Photo 47. Mile 2.7, looking downstream (20 June 2022 photo). Dead and down alders and fallen Douglas fir from upslope. Narrow channel along the left bank, with remainder of channel vegetated.

Photo 48. Mile 2.7, looking downstream (2023 repeat of photo 47). Channel scoured from bank to bank by high flows in 2023, with abundant downed alders forming a very large new jam across the channel downstream.

Photo 49. Mile 2.7, looking downstream at jam formed in 2023 from fallen alders, including from jam present in 2021 and 2022 at mile 2.85+, which washed out and downstream in 2023.

Photo 50. Mile 2.75, looking upstream. Bank alders lost, with a widened, shallow, gravel channel.

Photo 51. Mile 2.75+, looking downstream. Fire burned to stream banks. Most remaining bank alders were lost in 2023, with large fallen redwood washed to site by winter flows. Fine mudstone gravels were rinsed downstream and replaced by cobbles in the channel along the redwood in 2023.

Photo 52. Mile 2.85+, looking at east slope. Redwoods with basal, trunk, and branch sprouts, and tanbark oaks with basal sprouts. Ground cover well established.

Photo 53. Mile 2.85+, looking upstream. Site of right bank debris flow in 2021 and large partial log jam formed from toppled trees in the debris flow. The jam was greatly enlarged with fallen alders from floodplain alder forest upstream in 2022. The jam and alders were gone in 2023, and are part of the large new jam downstream at mile 2.7.

Photo 54. Mile 2.9-, looking upstream. Remnant of dense floodplain alder forest, mostly killed by fire, and added to logjam immediately downstream in 2022.

Photo 55. Mile 2.9, looking downstream from near the bottom of the bypass trail. Streamside alders dead and down.

Photo 56. Mile 2.9+, looking downstream. By 2022 this large, deep pool was more than half-filled with small mudstone gravel. In 2023, the lower 2/3 of the pool was very shallow, and the pool was 90% filled with silt, sand, and gravel. Deep (3 ft) water was confined to the head of the pool at an old, large, carved redwood trunk near the left bank.

Photo 57. Mile 2.9+, looking upstream. As in 2022, the upstream habitat (to near the confluence of the forks) was an aggraded, filled channel. A west slope debris flow from rim to stream (visible at the right bank upstream) was the source of most sediment in 2021-2022.

Photo 58. Mile 3.0, looking at East slope. Ground cover has fully recovered, and redwoods have basal sprouts and trunk epicormic sprouts; tanbark oaks with dead trunks have basal sprouts.

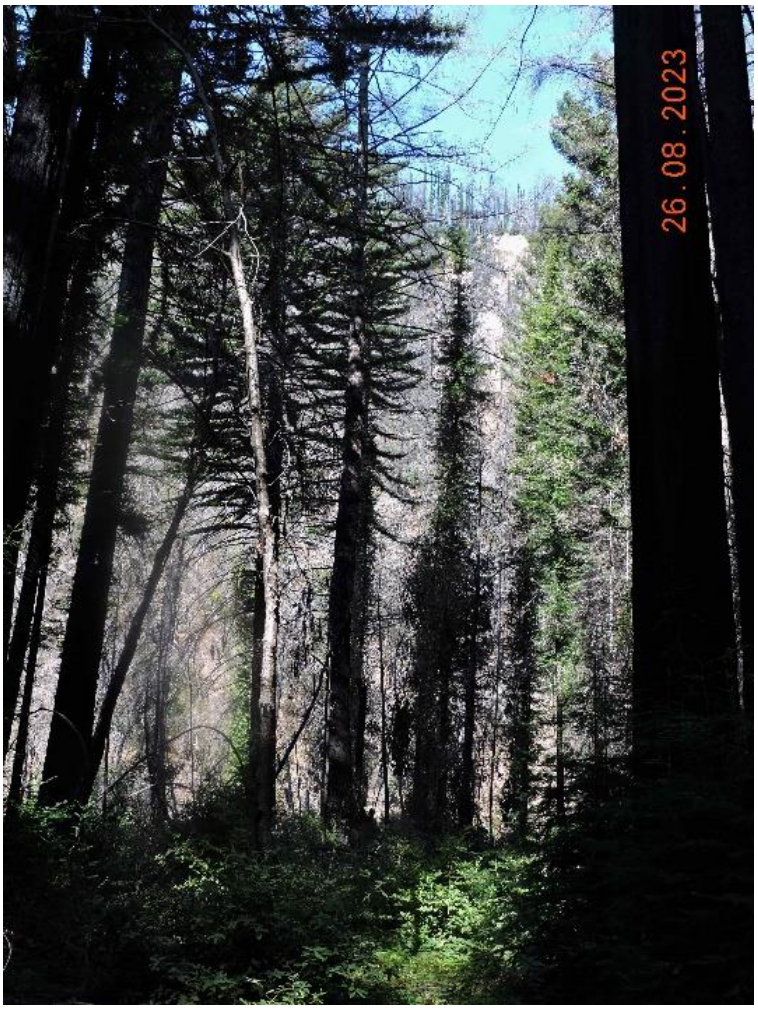

Photo 59. Mile 3.05+, at Camp Herbert, looking towards west slope. Douglas firs were killed, but redwoods survived with trunk and branch sprouts. The rim to stream steep slope with the debris flow in 2021 is in the background.

West Fork

Photo 60. West Fork, mile 3.1+, looking downstream. Former long, deep, fish-sampling pool mostly filled in 2022, now with logjam in downstream portion.

Photo 61. West Fork, mile 3.1+, looking upstream. Pool and glide habitat partially filled in 2022, now with aggraded channel mostly filled with fines and gravel.

Photo 62. West Fork, mile 3.1+, looking upstream. Tail of large pool upstream was filled as narrow run habitat in 2022.

Photo 63. West Fork, mile 3.15, looking downstream to old redwood (nurse) log supporting a 3 ft diameter redwood. Site of 3-4+ ft deep pool (and undercut log) from 1992-2021 (often too deep to sample). The pool was mostly filled and shortened in 2022, and was completely filled with fines and gravel in 2023.

Photo 64. West Fork, mile 3.15, looking upstream immediately above the filled pool in photo 63. A transported root wad and other wood has produced a small, deep pool.

Photo 65. West Fork, mile 3.15, looking downstream past pool in photo 64 to the location of former pool in photo 63.

Photo 66. West Fork, mile 3.15, looking upstream. Deep pool with right bank alcove and backwater through 2021 (frequently too deep to sample effectively). Was filled in 2022, and was narrowed in 2023.

Photo 67. West Fork, mile 3.15, looking upstream. Third deep pool, with cross-channel log creating scour in 2005-2021, was filled with gravel in 2022 and 2023.

Photo 68. West Fork, mile 3.2, East Slope. Well-developed ground cover on moderate slope. Redwoods with epicormic sprouting on trunk and branches and standing tanbark oaks with basal sprouts.

Photo 69. West Fork, mile 3.4. Dense streamside habitat at a 1998 very large logjam (a frequent partial fish barrier) that was substantially burned in 2020. Passable in rearranged aggraded channel in 2022 and 2023.

Photo 70. West Fork, mile 3.45, looking across channel to west slope. In 2022 a fallen tree had accumulated substantial wood and in 2023 the remnants produced a small backwater pool in the aggraded channel. Some ground cover vegetation finally began to develop on the west slope in 2023.

Photo 71. West Fork, mile 3.5. The east slope has dense ground cover and redwoods with basal and trunk sprouts. Douglas firs were killed by the fire.

Photo 72. West Fork, mile 3.5. Fire survival was poor on the west slope except near the stream; most Douglas firs and many redwoods were killed. Most of the slope is still lacking ground cover, which has somewhat increased compared to 2021-2022.

Photo 73. West Fork, mile 3.5. In a trailside wetland, 5 large burned redwoods had fallen in 2021, but had epicormic trunk sprouts on the prone trunks in 2022. The trunk sprouts were dead in 2023, but basal sprouts were alive.

Photo 74. West Fork, mile 3.55. Steep west slope with heavy tree mortality and limited ground cover to protect against erosion.

Photo 75. West Fork, mile 3.55. Steep west slope with surviving redwoods and ground cover near the stream, but dead trees and sparse ground cover upslope.

Photo 76. West Fork, mile 3.55+. Bedrock near the stream and in the channel. All alders killed by fire, but streamside maples with basal sprouts to 10+ ft high in 2023.

Photo 77. West Fork, mile 3.55+. East slope with dead Douglas firs, but redwoods and maples with basal sprouts, and redwoods with trunk sprouts. Slope well-protected by ground cover and trees.

Photo 78. West Fork, mile 3.6-. Looking across to west slope. Eroding gully with remnants of sediment and log delta spilling into stream. Much of the wood from 2022 was washed away in 2023. Terrace to the left of gully is likely a remnant of an old debris flow.

Photo 79. West Fork, mile 3.6+, looking downstream. Sprouted maples and ground cover near stream. Gravel and bedrock channel.

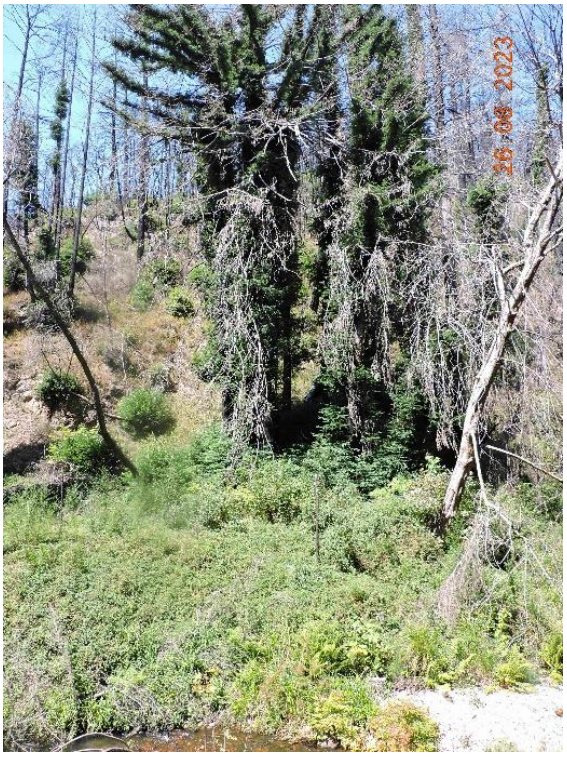

Photo 80. West Fork, mile 3.6+. West slope with trees and ground cover near stream and mostly dead trees and sparse ground cover upslope.

Photo 81. West Fork, mile 3.6+, looking upstream. Terrace trees mostly intact, but severely aggraded stream channel.

Photo 82. West Fork, mile 3.6+. Redwoods on the east slope, which is less steep than the west slope, are slowly recovering, but Douglas firs are dead.

Photo 83. West Fork, mile 3.6++, looking downstream. Uppermost fish sampling pool was long (130 ft) and 3+ ft deep through 2021. In winters of 2021-2022 and 2022-2023 it was completely filled with fines and gravels, and channel wood was lost.

Photo 84. West Fork, mile 3.6++, looking downstream. Telephoto shot of the severely damaged west slope from the same photo location as photo 83.

Photo 85. West Fork, mile 3.6++, looking upstream. This large pool immediately upstream of the pool in photo 83 was previously too deep to electrofish. In 2022 it was 95% filled with fines and gravels, except for a small scour pocket at the upstream end. In 2023, even the pocket was filled. A new, large, fallen Douglas fir spans the upstream portion in 2023.

Photo 86. West Fork, mile 3.6++, looking across the channel to the right bank terrace. Large trees are recovering on the terrace, but the forest is backed by a steep, eroding, west slope with few live trees.

East Fork

Photo 87. East Fork, mile 0.05, looking downstream to the confluence from the trail ford. Almost all alders along the stream and on in the terrace on the right bank at the confluence were killed by fire. The rim to stream bare slope from the 2021 debris flow on the west slope at the confluence is visible in the background.

Photo 88. East Fork, mile 0.05, looking upstream from the trail ford. Alders and Douglas firs were killed. Tanbark oaks with basal sprouts on dead trunks, and redwoods recovering with epicormic sprouts. Channel with additional Butano sandstone and mudstone cobbles and boulders carried downstream in 2023 winter floods. A 2 ft diameter mudstone boulder adjacent to a rebar stake (for temperature logger attachment) was carried away by the high flows.

Photo 89. East Fork, mile 0.1, looking upstream. Bedrock pool upstream of footbridge. Some silt on bottom, but no pool filling. The head of the pool was cut off by cobbles and boulders from the channel realignment in the upstream bend to the left by high flows in December 2021. However, the bend was completely rearranged in 2023. A secondary flood channel directly upstream in 2023 removed the materials deposited in the head of the pool in 2022.

Photo 90. East Fork, mile 0.1+, looking upstream from near the pool in photo 89. The 1998-2021 channel was to the left (right bank) in the photo. The 2022 channel was pushed to the right by fallen and transported trees in the upstream bend (filling the head of the pool in photo 89). In 2023 the floods removed the wood, and the channel returned to the 1998-2021 position.

Photo 91. East Fork, mile 0.1+, looking downstream at the cobble bar shown in photo 90. Bank alders still present in 2022 are now gone.

Photo 92. East Fork, mile 0.1+, looking downstream. July 2022 photo of the same area shown in photo 91. Alders and redwoods burned and/or fallen from the eroded bank in the bend had forced channel to the left and away from the 1998 storm pools and large downed redwood near right bank.

Photo 93. East Fork, mile 0.1+, looking downstream to the big bend shown in photos 90-92. A secondary left bank flood channel directly entered the pool in photo 89 and cleared the material deposited in 2022.

Photo 94. East Fork, mile 0.15, looking upstream. Alders were killed by fire and removed by high flows in 2022. Terrace and lower slope redwoods recovering with trunk and branch epicormic sprouts.

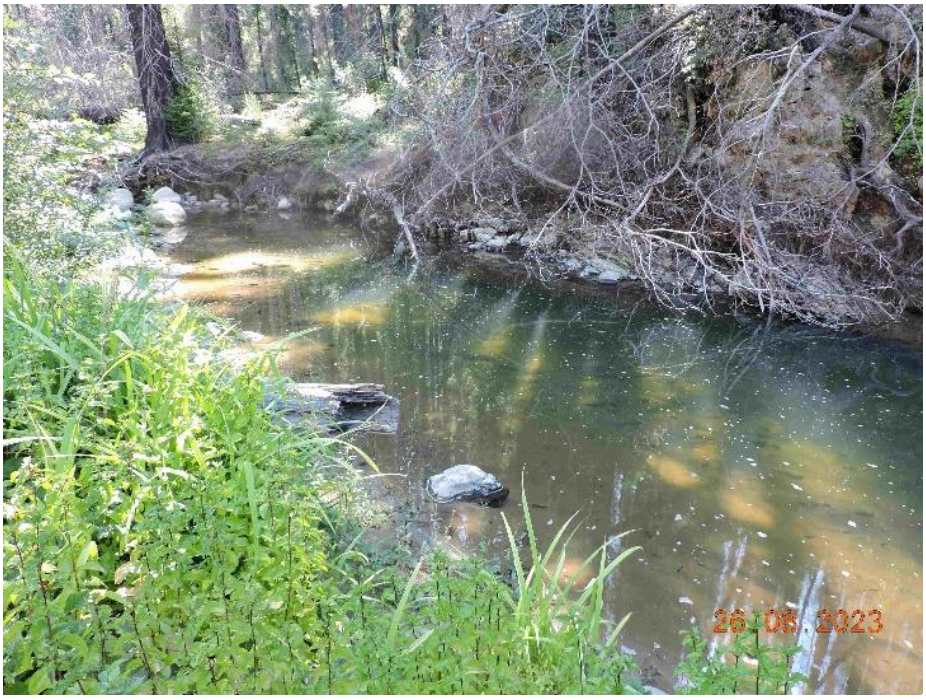

Photo 95. East Fork, mile 0.2, looking upstream. This persistent, deep pool (3+ ft) had only some filling with fine sediment in 2022 and 2023.

Photo 96. East Fork, mile 0.2 (July 2022 photo). South slope with burned, but recovering, redwoods. Few tanbark oaks, with dead trunk, but basal sprouts. The few Douglas firs are dead.

Photo 97. East Fork, mile 0.2. The north (south-facing) slope above the stream, has sparse surviving redwoods at the base of the slope. Dead trees upslope (mostly Douglas firs). Most tanbark oaks also dead, but some with basal sprouts.

Photo 98. East Fork mile 0.2+ (July 2022 photo). Dead streamside alders, but recovering redwoods with epicormic sprouts on the terrace above the stream.