Title

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Abstract

Increasing incidence of severe wildfires may undermine efforts to restore salmonid habitat in California streams. As fires leave denuded watersheds vulnerable to erosion in heavy winter rains, fine sediment will fill in channel beds, potentially harming critical salmonids habitat. In the Russian River watershed, hundreds of millions of dollars have been invested to restore threatened and endangered salmonid habitat, study migrating populations, and diversify dwindling native populations with broodstock. The following project, developed in collaboration with Sonoma County Water Agency and California Sea Grant, establishes baseline geomorphic conditions (post-fire, pre-storm) for a 770-foot reach of Mill Creek with the goal to better understand post-fire geomorphology and inform ongoing adaptive management of the fisheries program.

Mill Creek is a tributary to Dry Creek in the Russian River watershed that burned with mixed severity in the Walbridge Fire from August 17 - September 17, 2020. Data was collected nearly two months after the fire, and prior to the first substantial rain event of the year. In the study area, the creek had a sinuosity of 1.13, dropping 7.11 feet in elevation along 869.35 linear feet measured along the thalweg. Water depth ranged from 1.99 feet to 0.18 feet, with long pools and flat water punctuated by short riffles. Pebble counts taken at the downstream, midpoint, and upstream portions of the study site skewed toward coarse river rocks, ranging from large gravel to small cobble. The cross sections at the downstream and upstream ends of the site demonstrate a steep slope on river left and a wide floodplain on river right. At its midpoint, the cross section constricts to an incised, steep channel form with earthen banks.

Baseline geomorphic data confirms Mill Creek's value in meeting physical habitat criteria for Coho salmon spawning grounds and juvenile refugia. Varied elevation creates numerous pool and riffle habitats, providing spawning habitat in the pool tail and rich food production in the riffles. High proportions of gravel and cobble are consistent with Coho spawning habitat in the pool tail crest, as well as demand for invertebrates among juveniles. Woody debris in the stream channel cools water temperatures and can provide refuge habitat for juveniles.

While this project confirms the present value of Mill Creek's physical features to salmonid restoration, the impacts of the Walbridge Fire on the creek are not yet known. Based on a low to moderate fire severity in the watershed, a gentle start to the rainy season, and a historic adaptation to disturbance, it is reasonable to hope that Walbridge Fire impacts may be within a tolerable range for threatened and endangered salmonid. This survey establishes baseline data to enable researchers to monitor future changes in channel form and sedimentation. Tracking changes in channel bed elevation, presence of pools and riffles, and sediment make-up will provide additional context to observed changes in salmonid populations and inform adaptive management of the broodstock program and fisheries restoration.

1. Introduction

1.1 Fire

From the Mid-Holocene to European colonization, California landscapes experienced frequent fires as a result of indigenous burning and lightning fires (Pyne, 1982). Many ecosystems of California thus evolved to depend on frequent fire disturbance to increase terrestrial and aquatic biodiversity, improve plant resilience, reduce pests and diseases, and increase water yield (Fule, 2004; Wiedinmyer, 2010; Pyne, 1982; Dwire, 2003). Following two centuries of fire suppression and logging, California is again experiencing fires at pre-colonization levels (CalFire, 2020; Stephens, 2007). In densely vegetated, pest- and drought-stressed watersheds, however, California fires are now often larger, longer-burning, and more severe than pre-colonization fire regimes, with unknown impacts to terrestrial and aquatic ecologies (Steel, 2015; Mann et al, 2016; Westerling, 2011). This paper considers the conditions of freshwater ecosystems and fisheries under a changing fire regime.

1.2 Fire and Water

The degree of fire impact on freshwater ecosystems depends largely upon fire severity and fuel type (Robichaud, 2010; Dwire, 2003). Fire severity is a measurement of the impact of fire on vegetation and soil, encompassing both fire intensity (how hot?) and duration (how long?). Severe fires destroy ground cover, decreasing infiltration and evapotranspiration, and subsequently increasing erosion and runoff rates during storms and snowmelt (Robichaud, 2010; Johansen et al., 2001). Severe fires are additionally correlated with hydrophobic soils, which similarly promote runoff and erosion (Wohlgemuth, 2007). Bare ground and hydrophobic soils both generally lead to increases in water quantity, as well as increased sediment and nutrient concentrations in rivers and streams (Hallema, 2019; Wohlgemuth & Robichaud, 2007). Sedimentation can change the geomorphology of rivers and streams, altering channel form and impacting aquatic habitat composition with fine sediment (Moody, 2009). Post-fire sedimentation is generally heaviest after the first heavy rainfall and within the first rainfall year, before vegetation can reestablish (Robichaud, 2010).

In addition to soil, eroded sediment contains ash. Ash can contain high concentrations of nutrients or carcinogenic organic compounds, depending on fuel type and fire severity, and can lead to degraded water quality and changes to stream pH (Santín, 2015). As California wildfires increasingly reach into the wildland-urban interface (WUI), new and potentially catastrophic contaminants are introduced to waterways through volatilized buildings, cars, septic systems, and chemicals. Early monitoring of waterways downstream from burned WUIs indicate presence of heavy metals, polycyclic aromatic hydrocarbons (PAH), per- and polyfluoroalkyl substances (PFAS), nitrites, and nitrates (Stein, 2012; Burton, 2016; Bourzac, 2018). The loss of vegetation can also increase stream temperature in the short term (Koontz, 2018). While some riparian habitats are well-adapted to disturbance and return to pre-fire conditions within one to three years of the fire, the increasing severity and frequency of disturbance events may have detrimental effects, particularly to vulnerable aquatic and plant species (Reeves, 2006; Beche, 2005; Dwire, 2003).

1.3 Fire, Water, & Fish

As in all subjects pertaining to California freshwater ecology, the fate of threatened and endangered fisheries are of particular concern. High-severity wildfires in California threaten to further undermine salmonid fisheries through changes to stream temperature, pH, water quality, and sedimentation (Wainwright, 2013; Leonard, 2017).

Fine sediment, readily mobilized through wildfire, is expected to be particularly detrimental to these keystone species. In excess, fine sediment will fill pools (Wohl and Cenderelli, 2000) and smother gravel spawning beds (Lisle, 1989), which reduces the flow of oxygen to salmonid embryos, killing alevins (Greig et al, 2005; Everest, 1987; Goode, 2012). The impact of wildfire on this cycle is more complicated than initially hypothesized. The duration of fine sediment delivery to the stream is of critical importance: an acute pulse of fine sediment, as following a severe wildfire, is understood to be far less detrimental than a sustained press of sediment from a roadway (Detenbeck, 1992; Goode, 2012). The timing of the disturbance relative to spawning season is another key consideration. Where disturbances occurred during or before spawning, recovery times were significantly shorter than systems in which disturbances occurred after spawning (Detenbeck, 1992). In conditions of low fire severity and moderate winter storms, it is possible to observe no measurable change to pool channel characteristics (Spina, 2000).

Sedimentation has also been linked to reduced diversity of benthic macroinvertebrates, the primary food source for stream fishes (Rehn, 2010) and decreases in the biomass of aquatic species (Hosseini et al., 2017; Reeves et al., 2006).

When fires destroy riparian canopy cover, stream temperatures often increase, with detrimental impacts to salmonid species. Temperature has a non-linear effect on salmon, but is generally understood to increase fish metabolism, and thus their demand for food, leading to competition and starvation (Beakes et al, 2014). In one long-term study of fish in a fire-affected watershed of Arizona, managers continued stocking endangered Gila trout for two decades following the fire. They eventually conceded extinction, citing high stream temperatures due to loss of streamside canopy cover (Leonard et al, 2017).

Under certain habitat conditions, wildfires can have a net positive impact on salmonid physical habitat conditions. In one study of Wenatchee River subbasin in Washington, the most substantial modeled change to habitat conditions was the deposition of additional wood in the stream channel, improving key refugia habitat for juvenile (Flitcroft et al, 2016). This study aligns with a growing body of literature suggesting that natural cycles of disturbance and recovery are critical to the recovery of anadromous salmonids in the west (Reeves, 1995).

The impact of fire to salmonid recovery depends not only on fire severity and subsequent precipitation, but on the highly specific conditions of fish habitat, population, and life history patterns in the particular reaches of the impacted watershed (Rieman, 2003). Where habitats are fragmented, and local populations are small, it becomes possible for a disturbance to lead to a local extinction (Rieman, 2003; Dunham, 2003). This occurred in a stream outside Santa Barbara, CA, when a stream was hit directly by flame retardant, leading to a large fish kill (Cooper, 2009).

Nonetheless, evidence suggests that most fish populations in the west are adapted to disturbance and recover quickly from fire, provided no barriers to fish immigration are present (Gresswell 1999; Reeves, 2006). As watershed ecologists and foresters call for a new relationship with fire on the land, some fish biologists are responding with curiosity, seeking nuanced understanding of site specific responses to fire disturbance (Bisson et al, 2003; Rieman, 2003). Thus, studies that integrate characterizations of physical disturbance with longitudinal data of salmonid populations become particularly useful (Bisson et al, 2003; Rieman, 2003). Research has additionally called for greater study of low and moderate severity fires (Bixby et al, 2015)

At a local and applied level, fisheries managers seek that site-specific context of the impact of fire on physical habitat conditions in order to adaptively manage their fisheries restoration programs (personal communication, Gregg Horton 10/26/2020; Dunham, 2003; Rieman, 2003). Geomorphic surveys and long-term monitoring can aid researchers and conservation projects in better understanding the channel habitat, and possible changes in habitat over-time to inform better conservation decisions. This project contributes to a growing body of knowledge on the varied impacts of wildfire to riparian systems.

2. Problem Statement

The Walbridge Fire burned 55,209 acres of mixed conifer, hardwood, and chaparral in northwestern Sonoma County (north San Francisco Bay; see map, Figure 1) from August 17 to September 17, 2020 (Press Democrat, 2020). The fire destroyed 157 homes and 293 structures, and burned up to the southern edge of Lake Sonoma Reservoir, a critical water storage facility for the region. The fire was patchy, producing low to moderate severity impacts (Coho Partnership, 2020; Hwang, 2020).

Prior to the fire, creeks within the Walbridge fire footprint, or the geography of the area that burned, as well as downstream waterways contained critical habitat for endangered Coho salmon (*Oncorhynchus kisutch*) and threatened Steelhead trout (*Oncorhynchus mykiss)* and Chinook salmon (*Oncorhynchus tshawytscha)*. A local consortium of resource agencies monitors coho salmon in the

Russian River watershed; 21% of the reaches monitored through this program are located within the Walbridge fire perimeter (see Figure 1; Coho Partnership, 2020). On the eastern flank of the fire, several impacted tributaries drain into Dry Creek. Dry Creek is a critical water supply link in which the National Marines Fisheries Services has mandated more than $81 million in salmonid restoration projects in recent years (Press Democrat, 2020; National Marine Fisheries Services, 2008). Restoration activities include excavating side- and cross-channels, adding secured logs and boulders to provide refugia, and planting native plants along the riparian banks (Sonoma Water, 2020). Substantial erosion from the Walbridge Fire scar could undermine this decades-long effort to reestablish salmonid habitat in an impacted watershed.

In addition to Dry Creek, tributaries within the fire footprint contain critical salmonid habitat, including several streams that are part of the Russian River Coho Salmon Captive Broodstock Program. Through the Broodstock Program, hatchery-bred juvenile Coho salmon are released into the watershed to augment and diversify the dwindling native population (California Sea Grant, 2020). Figure 1 shows the tributaries of the Russian River watershed recognized as important coho salmon habitat (Pierce, 2020; Sonoma Water and California Sea Grant, 2019).

The varied life history of salmonids makes these species particularly dependent upon diverse habitat types. Thus, preserving and restoring physical habitat features has become a focus of efforts to restore fisheries (Schindler, 2011). Within this field, experts identified spawning habitat and juvenile refuge sites as primary physical habitat features needed to support Coho salmon recovery (Mull, 2007; Schindler, 2011; National Park Service). Spawning habitat is characterized by cool, clean, low-velocity pools with cobble to pebble sized sediment in the pool tail. As noted above, excessive fine sediment can smother eggs. In the spring, juvenile Coho prefer cool and deep pools, as well as areas of low velocity refuge (NPS; Woelfle-Erskine, C., 2017; Lestelle, 2007; personal communication, Gregg Horton 10/26/2020).

Following the Walbridge Fire, fish biologists and water managers are concerned that winter storms will transport large volumes of sediment to critical cold water pool habitat. This would impact the upcoming spawning season and undermine long-term restoration efforts (National Park Service; personal communication, Gregg Horton 10/26/2020). As high-severity fire incidence increases in California watersheds, fisheries scientists seek a more nuanced understanding of the relationship between fire severity, sedimentation, and impacts to aquatic habitat.

Our project was developed in collaboration with the Environmental Resources Team at Sonoma County Water Agency (Sonoma Water), who monitor salmonid populations in Dry Creek and its tributaries, support the Broodstock Program, and lead federally mandated habitat restoration projects in Dry Creek (National Marine Fisheries Services, 2008). Sonoma Water intends to survey a series of fire-impacted tributaries of Dry Creek throughout winter 2020-2021 to track geomorphic changes associated with post-wildfire sedimentation. This project establishes a baseline geomorphic survey of a reach of Mill Creek, tributary to Dry Creek, located within the Walbridge Fire Footprint (Figure 1, Figure 3).

2.1 Study Area: Mill Creek

Our study area is a 770-foot long reach of Mill Creek, located roughly 100 feet downstream of the Palmer Creek confluence (see map, Figure 3). Mill Creek is a tributary of Dry Creek (see map, Figure 1). The watershed is steep, dropping over 1500 feet from ridgeline to mainstem in two miles (see map, Figure 2). The land is largely privately owned hardwood, chaparral, and conifer forest. Despite a history of heavy logging, the creek contains habitat conducive to Coho and is considered a high priority watershed for Coho recovery, with some of the best summer rearing habitat in the Russian River watershed (Coho Partnership, 2020; National Marine Fisheries Services, 2008; personal communications, Gregg Horton 10/26/2020). The creek and one of its tributaries, Palmer Creek, are stocked with juvenile Coho from the Broodstock Program, and monitored every winter to document survival rates (Coho Partnership, 2020). These two streams are particularly valuable for fisheries restoration efforts, as sections of each are perennial, and thus critical for summertime rearing habitat (Coho Partnership, 2020).

Though portions of the Mill Creek watershed experienced high-severity fire during the Walbridge Fire, the majority of impacts are moderate to low (Coho Partnership, 2020). The southern bank of the creek, river right of the study site, is a local edge of the fire. Within the study area, the fire was all low severity, leaving much of the tree canopy intact, as well as some ground-level shrubs near the wetted edge of the stream. In most of the Mill and Palmer stream corridors, including the study area, the riparian cover did not burn. Two small rain events (< 0.5”) occurred within the burn area in November, 2020. As of writing, no major storm events had occurred. For these reasons, it is reasonable to hope that sedimentation and changes to temperature in Mill Creek may be moderate as a result of the Walbridge Fire.

The fire was contained by mid-September. Coho salmon spawning season generally runs November to January (CA Department of Fish & Wildlife, 2020). As noted above, disturbance that occur prior to spawning are generally linked to shorter recovery times for fish communities than disturbance that occurs after spawning. Additionally, only one seasonal dam lies between the study area and the ocean, and it is accompanied by a new and sophisticated fish passage system.

Structures and other human development are few in the burn area, so toxic runoff from burned structures and equipment is expected to be limited. Fire retardant was used during the fire suppression effort, with unknown consequences.

Prior to this study, no geomorphic surveys have been conducted in Mill Creek.

3. Methods

The objective of our study was to create a baseline of Mill Creek's geomorphology against which future surveys can be compared. The study is designed to be repeated after the first flush and after periodic rain events over several seasons. These rain events are expected to deliver additional sediment to the creek from burn areas, altering the form of the stream and potentially impacting salmonid spawning habitats. Taken together, the longitudinal studies are an attempt to document the change in Mill Creek's physical form, mainly in terms of salmonid habitat. The physical data collected includes three primary data types: cross section and long profile of the streambed elevations, habitat typing data, and sediment size grain classification. In partnership with Sonoma Water, the team adapted standard methods from the Fisheries Restoration Grant Program (FRGP), *California Salmonid Stream Habitat Restoration Model* from the California Department of Fish and Wildlife (CDFW), *Stream channel reference sites: An illustrated guide to field technique*, from the United States Forest Service (USFS), Pebble Count Methods, from the West Virginia Department of Environmental Protection, and Scientific Protocol for Salmonid Habitat Surveys Within the Columbia Habitat Monitoring Program (CHaMP), prepared by CHaMP.

To initiate data collection, the team measured the study site and delineated points of interest by stream features, especially in terms of habitat units. The site was marked with flagging to identify waypoints of interest and GPS coordinates were recorded with a Trimble. Due to the steep channel walls and heavy vegetative cover, GPS accuracy was low throughout the survey. These waypoints were identified locations to conduct pebble counts, as photo points, habitat units, and cross section locations. We took field photos at 100ft intervals where a photo was captured upstream, downstream, left bank and right bank of the location. The team identified fourteen habitat units within the reach using the CDFW Level II classification as described in the FRGP Habitat Restoration Manual:

Level II Habitat Types: RIFFLE:
(Low-Gradient Riffle, High-Gradient Riffle, Cascade, Bedrock Sheet)
FLATWATER:
(Pocket Water, Run, Step Run, Glide, Edgewater)
POOL:
(Plunge Pool, Mid-Channel Pool, Dammed Pool, Step Pool, Channel Confluence Pool, Trench Pool, Lateral Scour Pool - Root Wad Enhanced, Boulder Formed, Bedrock Formed, and Log Enhanced, Corner Pool, Secondary Channel Pool, Backwater Pool - Boulder Formed, Root Wad Formed, and Log Formed)

Our team defined a pool or a riffle if the parameters described in the FRGP Habitat Restoration Manual covered an area of three square meters, and in the case of the pool designation, if it was at least one foot deep in that area. Control elevation and two other monuments were also established so future surveys could identify the bottom of the site.

Next, we calculated the length of the study reach. This was achieved by taking five measurements of the bankfull width, each measurement upstream from the last. The average value of these widths were multiplied by twenty to give us the total length of our reach, 770ft (Harrelson, 1994). The bottom of the site, Station Zero, was identified at the start of a habitat unit, just above a riffle crest and monumented with rebar for future reference on both sides of the stream, so as not to be disturbed by high flows. One of the rebar monuments established an elevation benchmark from which all stream elevation would be measured. A third monument was placed for the sake of redundancy, in case of washout. Survey monuments were handled with great care knowing that the validity of this study hinges upon meticulously measured monuments and benchmarks in order to capture even the slightest change in channel morphology (Harrelson, 1994). Photos and GPS waypoints were recorded to aid in locating the monuments in the future.

The survey team conducted a long profile and cross sections of the 770ft. reach. Our team started downstream and made our way upstream so as to not disturb the sediment from the pebble count (Figure 4). For the long profile, we collected ground elevation data of the creek bed in the thalweg also highlighting upstream of- in the middle of- and downstream of- every riffle and pool habitat identified using an auto-level and stadia rod; capturing each inflection point of the stream bed. Riffles and pools were identified in the field based on visual observation of water turbidity.

In addition to the long profile, three cross-section surveys were conducted, one at the top, midpoint and bottom of the reach (Figure 4). In each cross section, we placed a marker on either side of the bank where the cross section begins and ends. We collected ground elevation data from one marker across the creek perpendicular to flow to the other marker also measuring distance between topographical inflection points.

While one team conducted the long profile and cross section survey, the other engaged in pebble count, photos, and habitat typing. Habitat units were numbered sequentially and identified with habitat type, pool tail embeddedness, and large woody debris count (LWD), and pebble counts. Our team followed Wolman Pebble Count procedure and obtained 100 samples at every sample site. Samples were chosen evenly across the cross section perpendicular to water flow, with surveyors standing downstream of the sample area. In order to randomize the sample collection, surveyors averted or closed their eyes when making each individual sample selection. Each sample was sorted into the appropriate pebble count size range (Table 3.). When applicable, the intermediate axis was used to determine sediment size category, sediment too small to measure such as silt and sand, or too big to measure, such as bedrock, was determined visually.

Most of the data collection was conducted over three visits between November 5-9, 2020. The team wanted to take measurements before the first rain, although there was a light drizzle on the second day of survey.

4. Results

4.1 Cross Section and Long Profile

The results of our long profile can be seen in Figure 5 and the results of the three cross sections can be seen in Figure 6. The study area has a linear length of 770 feet and a long profile length of 869.35 feet, meaning the reach has a sinuosity of 1.13. We collected a total of 335 bed elevation data points. There was a total elevation difference of 7.11 feet within the reach. Water depth ranged from 0.18 feet to 1.99 feet in the 18 locations water-depth data was collected (Figure 5). In addition to a slight slope, the long profile shows variability in bed elevation which coordinate with the location of pool and riffles within the reach. For instance, the marker for Habitat Unit 2 (HU2) in the long profile is at the tail end of a dip in elevation while water level stays constant, clearly the sign of a pool habitat (Figure 6). Comparing the three cross-sections, it is evident that the channel bed is not uniform but varies throughout the reach. Cross Section 1, located in the downstream of the reach, has a relatively wide river bed compared to cross sections upstream in cross section 2 and 3. Cross section 2, located in the middle of the reach, has a narrow river bed with deep incised earthen banks (Figure 6). Cross Section 3 is also narrow, but it’s right bank has a gradual slope that can overflow in high waters (Figure 6).

4.2 Habitat Typing

Within the study area we identified 14 habitat units considered important for continued observation (Figure 5 & 7). Of the 14 habitat units identified, nine pool habitats were identified, three riffle habitats were identified, and two flatwater habitats were identified (Table 1). In order to retain a better understanding of the study area, photos from the specified field survey photo points are shown in Table 2.

4.3 Sediment Size Grain Classification

The results of the pebble counts can be seen in Table 3. The grain size distribution of the three pebble count locations and the composite average of the three sites were found following the methodology explained in Kondolf (1997) and can be seen in Figure 8. Grain distribution for the three pebble count locations and for the average composite for the entire study area can be seen in Figure 8.

D50 for the sediment population in pebble count 1 and 2 were within the very coarse gravel range, 39mm and 48mm respectively. D50 for the sediment population in pebble count 3 was 26mm, and for the composite average 35mm, both within the coarse gravel size range. The majority of the sediment identified were from medium gravel to small cobble. Pebble count 3 had the largest percent of sand and silt and very fine gravel, a cumulative percent of 14% compared to 5% in pebble count 2 and 3% in pebble count 1.

5. Discussion

The long profile, cross section, and pebble counts we conducted were done as a baseline survey for this reach and are the first to be conducted in any of the creeks impacted by fire in Sonoma County that are identified as important Coho habitat. This baseline marks the beginning of a long-term process of monitoring planned for this reach by Sonoma Water to identify post-fire sedimentation impacts on channel form, and the subsequent impacts on fish habitat. It is important to note that this baseline was done almost two months after the Walbridge wildfire occurred, and some impact from the fire may already have taken place before the baseline data was collected. That being said, the most severe post-fire sedimentation impacts are expected after heavy rainfall within the first rain year after a fire (Robichaud, 2010; Hueso-Gonzalez et al., 2018; Wondzell, 2001), which supports the value of this baseline to future monitoring of post-fire sedimentation impacts.

This baseline of the Mill Creek study area provides insight into why Coho salmon are found in this area. The long profile and cross sections show that the study area in Mill Creek varies in elevation, supporting a range of water depths and velocities in the channel. Habitat typing identified a number of pool and riffle habitats, typical of the range of habitat preferred by the endangered Coho salmon (personal communication, Gregg Horton 10/26/2020; Peter et al., 1988). Field photos show coverage in the stream by wood and leaves and undercut banks, another feature that is conducive to Coho salmon. The presence of woody debris and vegetation in the streambed (Table 2) are important habitat features to take note of as they provide cover for Coho (Lestelle, 2007).

From the pebble counts, we can assess the grain size distribution to see how coarse the sediment population is overall. Sediment size is an important factor determining habitat suitability for salmonid spawning. Sediment needs to be small enough that the adult salmon can move them to dig with their tails and create redds to lay their eggs, but there can not be too large a concentration of fine sediment so as to block water flow and access of eggs to dissolved oxygen or to burry and entomb hatchlings (Kondolf & Wolman, 1993; Kondolf, 1997; Kondolf, 2000). Kondolf & Wolman (1993) found that salmonid spawned in locations with sediment ranging from 5.4 to 78mm. In our results, we can see that pebble count 1 and 2 had higher D50 sizes than this range, with D50 of 39mm and 48mm respectively. Pebble count 3 and the composite average were both within the range, with D50 of 26mm and 35mm respectively. Though the D50 in pebble count 1 and 2 are slightly higher than those found in Kondolf (1993), they are not larger by much and may still be suitable sites for coho spawning. Sediment makeup is also important in determining food availability for juvenile salmon (personal communication, Gregg Horton 10/26/2020). Coho are drift feeders (Nielsen, 1992), and though they are able to dig for food if necessary, they prefer habitats where their prey does not have fine sediment to bury itself in (personal communication, Gregg Horton 10/26/2020). As such, Coho prefer to eat invertebrates such as the mayfly, caddisfly, and stonefly who are often found in water habitats with gravel and cobble dominant beds (personal communication, Gregg Horton 10/26/2020; Nielsen, 1992).

In Kondolf, 2000, the maximum percent of fine sediment of a certain size was identified for coho in different case studies in the literature. This review found that coho were found in locations with a maximum of 7.5-21% of sediment smaller than point-82mm, and a maximum of 30-36% of sediment smaller than 3.35mm. Coho salmon lay their eggs in the winter and incubate until mid to late spring, the timing of the fire well before spawning takes place is promising that impacts from fire may be low, but long-term sedimentation still needs to be monitored. Percent fine sediment should be found from bulk sampling of sediment, but in our study, we were only able to do pebble counts. If resources are available in the future, bulk sampling would provide an important addition to this survey. Still, we can report the percent fine sediment identified in the pebble count to use as a baseline. We can see that the percent fine sediment in each pebble count location of our study area was below the maximum identified in the literature. Sediment in pebble count 3 had the largest percent of fine sediment, 5% of sediment smaller than 2mm, and 14% smaller than 4mm.

There is concern that extreme post-fire sedimentation could fill in pool habitats, cover gravel and cobble riverbeds with fine sediment, and change the dynamics of the ecosystem to be unfavorable to Coho salmon and other species (Pierce, 2020; David et al., 2009). As the first heavy rains will signal both the return of adult Coho back to the tributary for spawning, and heavy post-fire sedimentation, the important creek habitats within and downstream of the Walbridge fire footprint require special monitoring and restoration attention. Changes in channel form and sediment make-up in the streambed could have longer impacts on the spawning and successful incubation of the endangered Coho salmon (David et al., 2009), as well as other fish in the tributary. Four months after the fire, heavy rains have still not occurred. If rain events are gentle, there is hope that sedimentation will not be as severe. This hope is heightened by the low to moderate severity of the Walbridge fire within the study area basin.

Coho, at varying life stages, is consistently found within tributary habitats such as Mill Creek which may be negatively impacted by fires. Fortunately, Coho individuals do not all follow the same strict timeline for smolting and spawning, even among their hatch-mates. Some juvenile Coho will stay in the tributaries they are born for under a year after they hatch, others for more than a year before smolting. Likewise, some Coho will remain in the ocean for 6-8 months before returning to spawn, while others will stay for more than a year before returning in the fall/winter to spawn (personal communication, Gregg Horton 10/26/2020). This means that the entire population will not be directly impacted when there is a disturbance such as drought, flood, or fire. Not all Coho which will spawn in Mill Creek and other creeks impacted by the Walbridge fire will make their way up the tributaries this winter, some partition of the population will remain until next fall and may be able to avoid the worst of the fire impacts.

6. Conclusions

The geomorphic baseline survey conducted in this study shows the presence of channel features preferred by Coho salmon including availability of pool habitats, grain size distribution D50 of 26-48mm, low percent of fine sediment, and availability of woody debris. It is unclear what the impact of post-fire sedimentation will be on the reach and surrounding tributaries. Because the Walbridge fire was moderate to low severity within the study area basin, there has been no heavy rainfall within the first few months after the fire, and the fire event occurred well before spawning, it is possible that the Walbridge fire may prove to be a healthy fire disturbance for this section of Mill Creek. Our surveys will help provide a baseline for future monitoring and habitat assessment. Sonoma County Water will take the lead in continuing this survey into the future. Tracking changes in channel bed elevation, presence of pools and riffles, and sediment make-up will allow researchers to predict changes in Coho populations and identify what, if any, restoration measures are needed. Special attention should be paid to grain size distribution D50 and percent fine sediment. There is also a need for more survey sites in other creeks impacted by fires in order for researchers and conservation teams to better evaluate larger scale impacts on Coho salmon habitat. This study provides a first step towards that goal, and further work in this tributary.

7. References Cited

Beche, L. A., Stephens, S., Resh, V. H. 2005. Effects of prescribed fire on a Sierra Nevada (California, USA) stream and its riparian zone. *Forest Ecology and Management,* Vol. 218, Issue 1-3, pages 37-59. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0378112705004457

Bisson, P. A., Rieman, B. E., Luce, C. Hessburg, P. F., Lee, D. C., Kershner, J. L., Reeves, G. H. Gresswell, R. E. 2003. Fire and aquatic ecosystems of the western USA: current knowledge and key questions. Forest Ecology and Management, Volume 178, Issues 1–2, Pages 213-229, ISSN 0378-1127. https://doi.org/10.1016/S0378-1127(03)00063-X

Bisson, P. A., Sullivan K., & Nielsen, J. L. (1988) Channel Hydraulics, Habitat Use, and Body Form of Juvenile Coho Salmon, Steelhead, and Cutthroat Trout in Streams, Transactions of the American Fisheries Society, 117:3, 262-273, DOI: 10.1577/1548-8659(1988)117<0262:CHHUAB>2.3.CO;2

Bixby, R. J., Cooper, S. D., Gresswell, R. E., Brown, L. E., Dahm, C. N., and Dwire, K. A. 2015. Fire effects on aquatic ecosystems: an assessment of the current state of the science. Freshwater Science, Volume 34, Number 4. Retrieved from: https://www-journals-uchicago-edu.libproxy.berkeley.edu/doi/full/10.1086/684073#_i7

Bourkaz, K. 2018. Monitoring water quality after wildfires: Researchers are just starting to study how blazes like California's devastating Camp Fire may contaminate watersheds. Chemical & Engineering News, Vol. 96, Issue 48. https://cen.acs.org/environment/water/Monitoring-water-quality-wildfires/96/i48

Burton CA, Hoefen TM, Plumlee GS, et al. 2016. Trace Elements in Stormflow, Ash, and Burned Soil following the 2009 Station Fire in Southern California. PLOS ONE 11, e0153372.

California Sea Grant. 2020. Russian River Coho Salmon and Steelhead Monitoring Report: Winter 2019/20. Windsor, CA. https://caseagrant.ucsd.edu/sites/default/files/2019-2020_WinterReport_CA%20SeaGrantFinal.pdf

Coho Partnership, 2020. https://cohopartnership.org/home/watersheds/watersheds-2-3/

Cooper, S. D., 2009. Fish kill in Maria Ygnacio Creek associated with the Jesusita Fire, Memo to M.H. Capelli, National Marine Fisheries Service, Santa Barbara, CA.

Data Downloads. Sonoma Veg Map: Sonoma County Vegetation Mapping & LIDAR Program. http://sonomavegmap.org/data-downloads/#webmap

David W. Jensen, E. Ashley Steel, Aimee H. Fullerton & George R. Pess (2009) Impact of Fine Sediment on Egg-To-Fry Survival of Pacific Salmon: A Meta-Analysis of Published Studies, Reviews in Fisheries Science, 17:3, 348-359, DOI: 10.1080/10641260902716954

Dunham, J.B., Young, M. K., Gresswell, R. E. and Rieman, B. E. 2003. Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasions. Forest Ecology and Management, Volume 178, Issues 1–2, Pages 183-196. Retrieved from: http://www.sciencedirect.com/science/article/pii/S0378112703000616.

Dwire, K.A., Kauffman, J.B. (2003). Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management 178(1-2) https://doi.org/10.1016/S0378-1127(03)00053-7.

Everest, F.H., Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell, C.J. Cederholm. 1987. Fine sediment and salmonid production: a paradox. E.O. Salo, T.W. Cundy (Eds.), Streamside Management: Forestry and Fishery Interactions, University of Washington Institute of Forest Resources, Seattle, WA, pp. 98-142

Flitcraft, R. L., Falke, J. A., Reeves, G. H., Hessburg, P. F., McNyset, K. M., Benda, L. E. 2015. Wildfire may increase habitat quality for spring Chinook salmon in the Wenatchee River subbasin, WA, USA. Forest Ecology and Management, 359, 126-140. http://dx.doi.org/10.1016/j.foreco.2015.09.049

FLOSI, GARY, et al. "CALIFORNIA SALMONID STREAM HABITAT RESTORATION MANUAL, FOURTH EDITION." California Department of Fish and Wildlife, State of California The Resources Agency California Department of Fish and Game Wildlife and Fisheries Division, May 2010, wildlife.ca.gov/Grants/FRGP/Guidance.

Fule, P. Z., Cocke, A. E., Heinlein, T. A., Covington, W. W. (2004). Effects of an intense prescribed forest fire: is it ecological restoration? Restoration Ecology, 12:2, 220-230. https://doi.org/10.1111/j.1061-2971.2004.00283.x. Retrieved from: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1061-2971.2004.00283.x

Goode, J. R., Luce, C. H., Buffington, J. M. Enhanced sediment delivery in a changing climate in semi-arid mountain basinds: Implications for water resource management and aquatic habitat in the northern Rocky Mountains. 2012. Geomorphology, Volumes 139-140, Pages 1-15. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0169555X11003187

Greig, S.M., Sear, D.A. Carling, P.A. 2005. The impact of fine sediment accumulation on the survival of incubating salmon progeny: implications for sediment management. Science of the Total Environment, 344, pp. 241-258

Hallema, D., Sun, G., Caldwell, P., Robinne, F. N., Bladon, K. D., Norman, S., Liu, Y., Cohen, E. C., and McNulty, S. 2019. *Wildland fire impacts on water yield across the contiguous United States.* U.S.

Department of Agriculture Forest Service, Southern Research Station. Asheville, NC. https://www.fs.usda.gov/treesearch/pubs/58095

Johansen, M.P., Hakonson, T.E., Breshears, D.D. (2001). Post-fire runoff and erosion from rainfall simulation: contrasting forests with shrublands and grasslands. Hydrological Processes 15(15). https://doi.org/10.1002/hyp.384.

Kondolf, G.M. (2000): Assessing Salmonid Spawning Gravel Quality, Transactions of the American Fisheries Society, 129:1, 262-281

Kondolf, G.M., Wolman, M.G. (1993). The Sizes of Salmonid Spawning Gravels. Water Resources Research, Vol. 29, No. 7, 2275-2285. 93WR00402.tY043,! 397/93/93WR-00402505.00.

Kondolf, G.M (1997). Application of the Pebble Count: Notes on Purpose, Method, and Variants. Journal of the American Water Resources Association Vol 33, No. 1.

Koontz, E. D., Steel, A., Olden, J. D. 2018. Stream thermal responses to wildfire in the Pacific Northwest. Freshwater Science, Vol. 37, No. 4. Retrieved from: https://www.journals.uchicago.edu/doi/abs/10.1086/700403

Leonard, J.M., Magaña, H.A., Bangert, R.K. *et al.* Fire and Floods: The Recovery of Headwater Stream Systems Following High-Severity Wildfire. *fire ecol* **13,** 62–84 (2017). https://doi-org.libproxy.berkeley.edu/10.4996/fireecology.130306284

Lestelle, Lawrence. 2007. Coho Salmon Life History Patterns in the Pacific Northwest and California. Prepared for U.S. Bureau of Reclamation Klamath Area Office. Retrieved from http://www.defendruralamerica.com/files/LestelleReport.pdf

Lisle, E. 1989. Sediment transport and resulting deposition in spawning gravels, north coastal California. Water Resources Research, 25, pp. 1303-1319

Kristin E. Mull & Margaret A. Wilzbach (2007) Selection of Spawning Sites by Coho Salmon in a Northern California Stream, North American Journal of Fisheries Management, 27:4, 1343-1354, DOI: 10.1577/M06-054.1

Moody, J.A., Martin, D. A. (2009). Synthesis of sediment yields after wildland fire in different rainfall regimes in the western United States. International Journal of Wildland Fire, 18, 96-115. https://doi.org/10.1071/WF07162. Retrieved from: https://pubs.er.usgs.gov/publication/70032717

National Marine Fisheries Services, 2008. Water Supply, Flood Control Operations, and Channel Maintenance conducted by the U.S. Army Corps of Engineers, the Sonoma County Water Agency, and the Mendocino County Russian River Flood Control and Water Conservation Improvement District in the Russian River watershed. https://evogov.s3.amazonaws.com/185/media/159660.pdf

National Park Service. Coho Salmon: Habitat and Climate Matter. Golden Gate National Recreation Area, Muir Woods National Monument, Point Reyes National Seashore. Accessed November 20, 2020. https://www.nps.gov/articles/coho-habitat-and-climate.htm

Nielsen, J. 1992. Microhabitat-Specific Foraging Behavior, Diet, and Growth of Juvenile Coho Salmon. Transactions of the American Fisheries Society, Volume 121, Issue 5. https://doi.org/10.1577/1548-8659(1992)121<0617:MFBDAG>2.3.CO;2.

"Pebble Count Methods." West Virginia Department of Environmental Protection, West Virginia Department of Environmental Protection, dep.wv.gov/Pages/default.aspx.

Columbia Habitat Monitoring Program. "Scientific Protocol for Salmonid Habitat Surveys Within the Columbia Habitat Monitoring Program." May 2016, doi:10.13140/RG.2.1.4609.6886.

Harrelson, Cheryl C, et al. "Stream Channel Reference Sites: An Illustrated Guide to Field Technique." 1994, USFS, doi:10.2737/rm-gtr-245.

Hueso-Gonzalez, P., Martinez-Murillo, J. F., Ruiz-Sinoga, J. D. (2018). Prescribed fire impacts on soil properties, overland flow and sediment transport in a Mediterranean forest: A 5 year study. Science of the Total Environment, 636: 1480-1489. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S004896971831636X?via%3Dihub

Mann ML, Batllori E, Moritz MA, Waller EK, Berck P, Flint AL, Flint LE, and Dolf E. 2016. Incorporating anthropogenic influences into fire probability models: effects of human activity and climate change on fre activity in California. PLoS ONE 11:e0153589.

Pierce, S.N. (2020). The Walbridge Fire and salmon habitat. Sea Grant California. https://caseagrant.ucsd.edu/blogs/the-walbridge-fire-and-salmon-habitat

Press Democrat. Work to continue on second half of Dry Creek restoration. Callahan, Mary. April 22, 2019. https://www.pressdemocrat.com/article/news/work-to-continue-on-second-half-of-dry-creek-restoration/

Press Democrat. A month later, burn scar of Walbridge fire spans northwestern Sonoma County. Callahan, Mary. September 18, 2020. https://www.pressdemocrat.com/article/news/a-month-later-burn-scar-of-walbridge-fire-spans-northwestern-sonoma-county/

Pyne, S.J. (1982). Fire in America: a Cultural History of Wildland and Rural Fire. Princeton University Press, Princeton, New Jersey, USA, p. 654.

Reeves, G.H.; Benda, L.E.; Burnett, K.M.; Bisson, P.A.; Sedell, J.R. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. American Fisheries Society Symposium. 17: 334-349

Reeves, Bisson, Rieman, Benda (2006). Postfire Logging in Riparian Areas. Conservation Biology 20(4) https://doi.org/10.1111/j.1523-1739.2006.00502.x.

Rehn, A. C., 2010. The Effects of Wildfire on Benthic Macroinvertebrates in Southern California. Report to the San Diego Regional Water Quality Control Board, San Diego, CA. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.353.481&rep=rep1&type=pdf

Rieman, B., Lee, D., Burns, D., Gresswell, R., Young, M., Stowell, R., Rinne, J., Howell, P. 2003. Status of native fishes in the western United States and issues for fire and fuels management. Forest Ecology and Management, Volume 178, Issues 1–2, Pages 197-211. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0378112703000628

Robichaud, P. R., Ashmun, L. E., Sims, B. D. (2010). Post-fire treatment effectiveness for hillslope stabilization. USDA, Forest Service, Rocky Mountain Research Station.

Santín C, Doerr SH, Otero XL, Chafer CJ (2015) Quantity, composition and water contamination potential of ash produced under different wildfire severities. *Environmental Research* **142**, 297–308.

Schindler, D.E., Augerot, X., Fleishman, E. et al. 2011. Climate Change, Ecosystem Impacts, and Management for Pacific Salmon. Perspective: Fisheries Management. https://doi.org/10.1577/1548-8446-33.10.502

Sonoma Water and California Sea Grant. 2019. Implementation of California Coastal Salmonid Population Monitoring in the Russian River Watershed. Santa Rosa, CA. 72 pp. + appendices. https://caseagrant.ucsd.edu/sites/default/files/CMPDataReport_2015-2019_0.pdf

Spina, A. P. & D. R. Tormey, 2000. Postfire sediment deposition in geographically restricted steelhead habitat. North American Journal of Fisheries Management 20: 562–569.

Steel, Z. L., Safford, H. D., Viers, J. H. 2015. The fire frequency-severity relationship and the legacy of fire suppression in California forests. Ecosphere, Vol. 6, Issue 1, pages 1-23. Retrieved from: https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/ES14-00224.1

Stein ED, Brown JS, Hogue TS, et al. 2012. Stormwater contaminant loading following southern California wildfires. Environmental Toxicology and Chemistry 31, 2625–2638.

Wainwright, T. C. and Weitkamp, L. A. "Effects of Climate Change on Oregon Coast Coho Salmon: Habitat and Life-Cycle Interactions," Northwest Science 87(3), 219-242, (1 August 2013). https://doi.org/10.3955/046.087.0305

Westerling AL, Bryant BP, Preisler HK, Holmes TP, Hidalgo HG, Das T, Shrestha SR. 2011. Climate change and growth scenarios for California wildfire. Available at: http://climate.calcommons.org/bib/climate-change-and-growth-scenarios-california-wildfre

Wiedinmyer, C., Hurteau, M. D. (2010). Prescribed fire as a means of reducing forest carbon emissions in the western United States. Environmental Science & Technology, 44, 6, 1926-1932.

Woelfle-Erskine, C., Larsen, L., and Carlson, S. M. 2017. Abiotic habitat thresholds for salmonid over-summer survival in intermittent streams. *Ecosphere*, Vol. 8, Issue 2. Retrieved from: https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/ecs2.1645

Wohl, E., Cenderelli, D.A.. 2000. Sediment deposition and transport patterns following a reservoir sediment release. Water Resources Research, 36, pp. 319-333.

Wohlgemuth, Robichaud, P.R. (2007). The Effects of Selected Post-fire Emergency Rehabilitation Techniques on Small Watershed Sediment Yields in Southern California. USDA Forest Service. Retrieved from: https://www.academia.edu/download/43029352/The_Effects_of_Selected_Post-fire_Emerge20160224-26862-30iqgx.pdf

Wondzell, S. M. (2001). The influence of forest health and protective treatments on erosion and stream sedimentation in forested watersheds of eastern Oregon and Washington. *Northwest Science, Vol. 75*, 128-140. Retrieved from: https://research.wsulibs.wsu.edu/xmlui/handle/2376/989

8. Figures

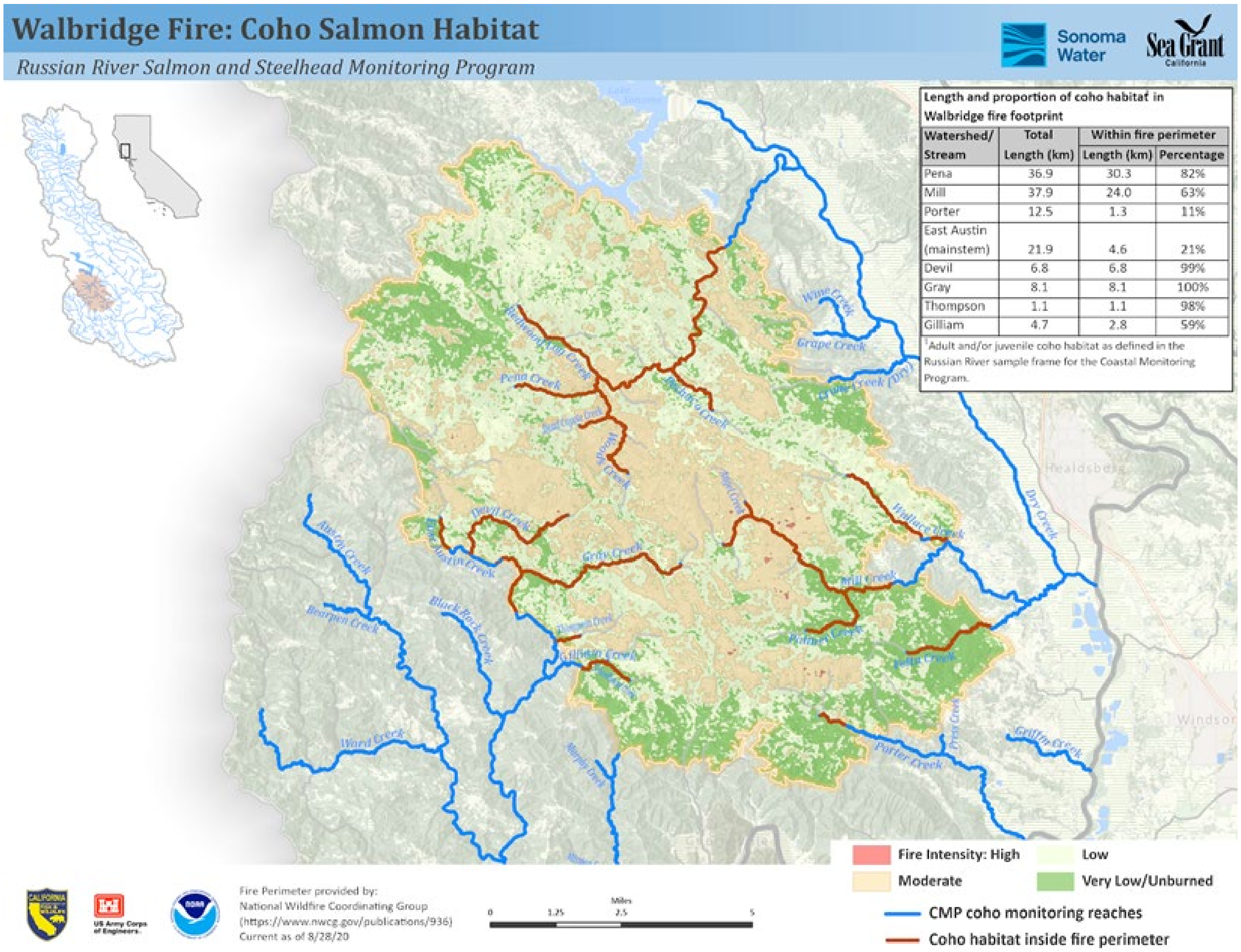


Figure 1. Walbridge Fire Footprint along with tributaries of the Russian River monitored through the Russian River Salmon and Steelhead Monitoring Program (Map source: Sonoma Water, 2020).

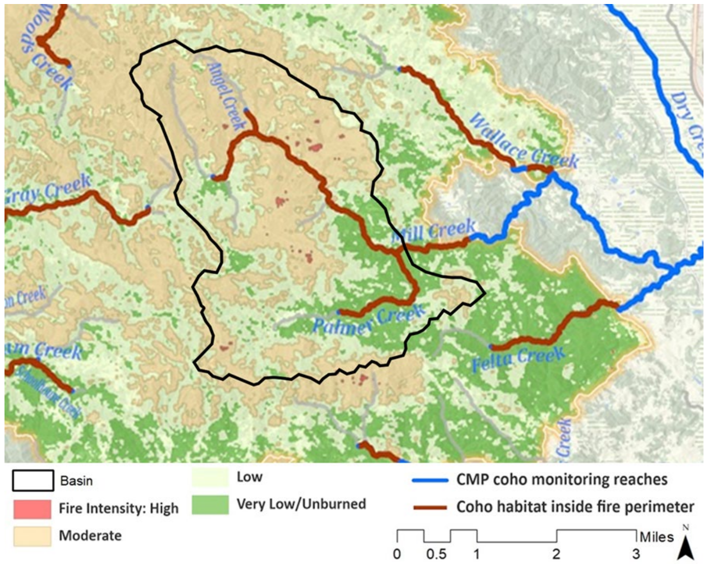


Figure 2. Basin of the study area denoted in black over the Walbridge fire footprint (Map source: Sonoma Water, 2020).

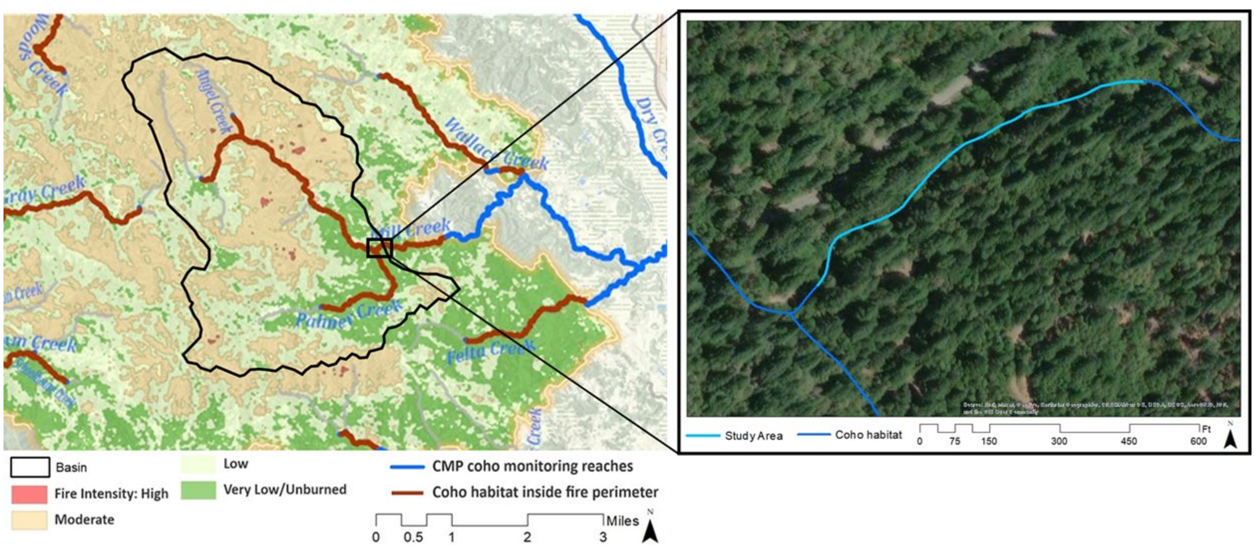


Figure 3. Study area within Mill Creek (Map source: Sonoma Water, 2020).

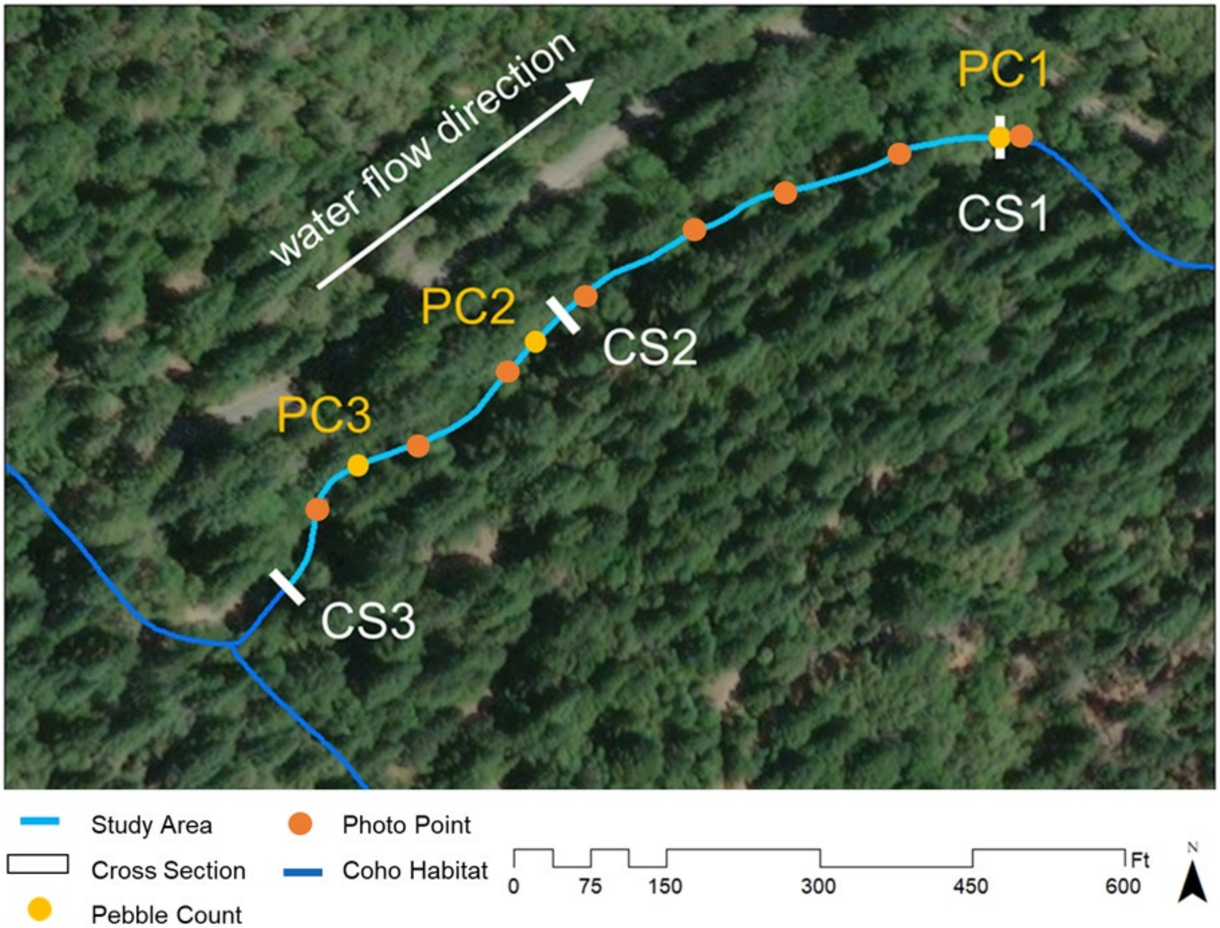


Figure 4. Study site showing flow direction as well as where cross sections, pebble counts, and photo points were located.

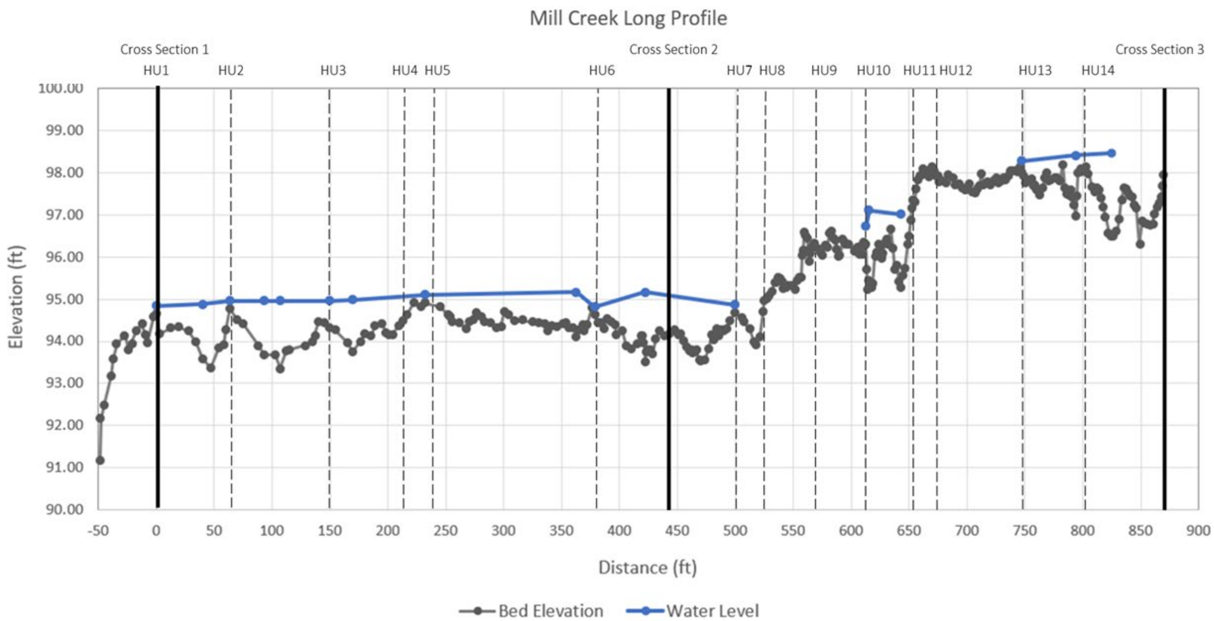
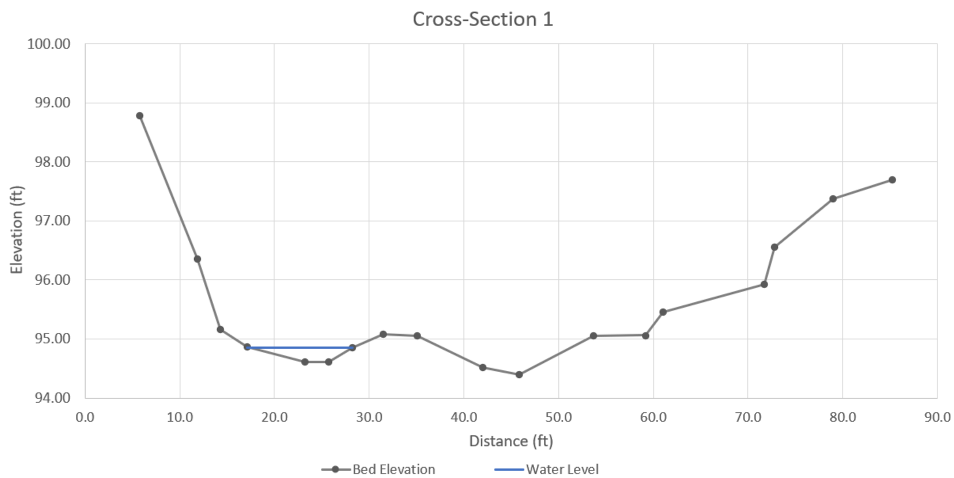
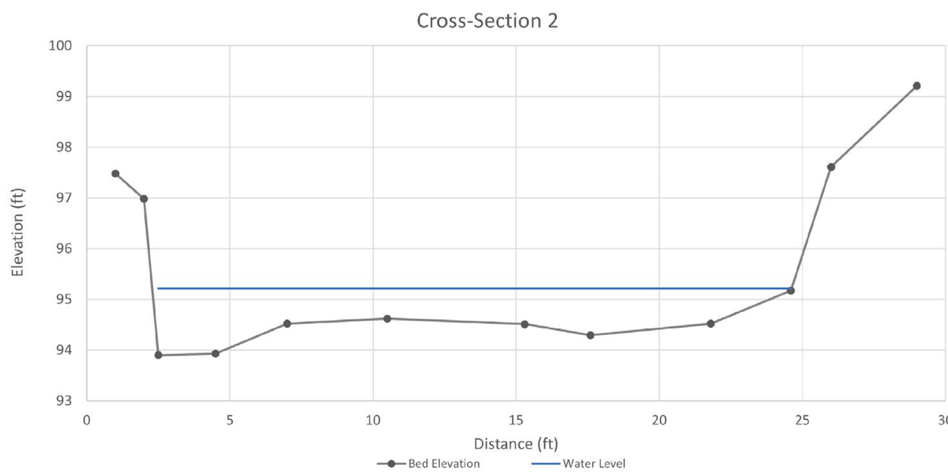


Figure 5. Long profile of the study area. Bed elevation of the thalweg is shown in grey as a line graph with dots at the data points; surface water elevation is shown as dots; downstream staring point of habitat units are marked with dashed vertical lines labeled with "HU" and numbered (HU1, HU2, etc.); and cross section locations are marked with solid lines, note Habitat Unit 1 and Cross Section 1 overlap.



a)



b)

c)

Figure 6. Cross sections facing downstream showing bed elevation in grey and water level in blue; a) Cross section 1 located at 0 ft marker in HU1; b) cross-section 2 located at 330 ft marker' c) cross section 3 located at 770 ft marker, water level data missing.

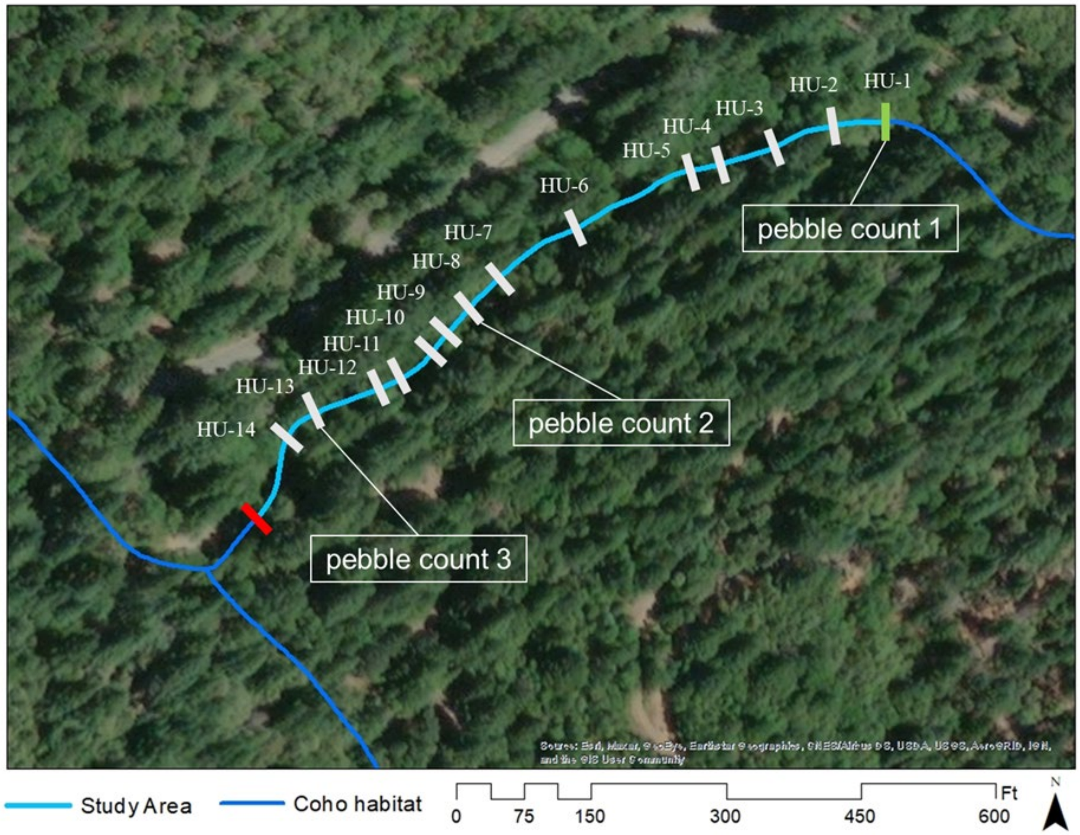


Figure 7. Location of the 14 Habitat Units identified in the field survey along with location of cross section and pebble count points, water flow direction, and long profile.

9. Tables

Table 1. Habitat Type of each of the 14 Habitat Units identified.

HU#	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Type	pool	pool	pool	riffle	pool	pool	pool	riffle	flat-water	pool	riffle	flat-water	pool	pool

Table 2. Photos from the eight field survey photo points

Upstream	River left	Downstream	River right
Photo point 0			
			
Photo point 1			
			
Photo point 2			
			
Photo point 3			

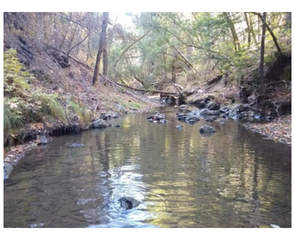
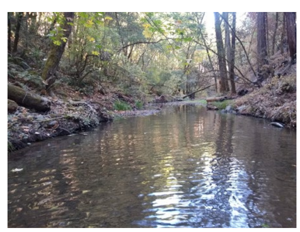

		

Photo point 4			

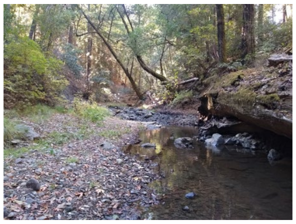


Photo point 5			
			
Photo point 6			
			
Photo point 7			
			

Table 3. Results of the three pebble counts

Class name	Size ranges (mm)	PC 1 percent	PC 1 cum percent	PC 2 percent	PC 2 cum percent	PC 3 percent	PC 3 cum percent
Sand and Silt	**<2**	1	1	2	2	5	5
Gravel (very fine)	**2-4**	2	3	3	5	9	14
Gravel (fine)	**4-8**	5	8	8	13	2	16

Gravel (medium)	**8-16**	7	15	14	27	15	31
Gravel (coarse)	**16-32**	28	43	12	39	30	61
Gravel (very coarse)	**32-64**	31	74	23	62	24	85
Cobble (small)	**64-128**	24	98	25	87	9	94
Cobble (large)	**128-256**	2	100	6	93	3	97
Boulder or Bedrock	**>256**	0		7	100	3	100

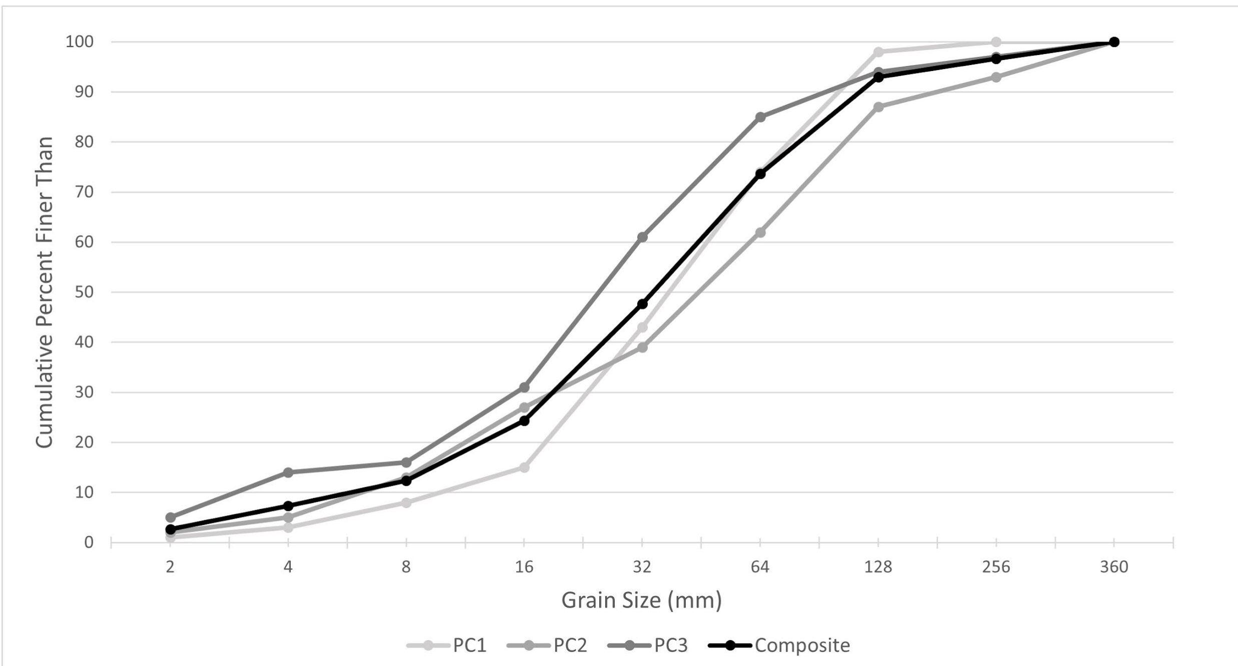


Figure 8. Grain Size Distribution for three pebble count locations in the study area of Mill Creek and a composite grain size distribution showing the average of the three results.