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Long-term Monitoring of Coho Salmon and Steelhead During Freshwater Life Stages in Coastal Marin County

2018 Annual Report (Revised with Costs)

Natural Resource Report NPS/SFAN/NRR—2020/2192

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ON THIS PAGE
Field staff performing electrofishing surveys in Olema Creek, Marin County, CA.
Photo courtesy of National Park Service

ON THE COVER
Crew member attempts to recover otoliths from an adult coho salmon carcass in Redwood Creek, Marin County CA.
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Long-term Monitoring of Coho Salmon and Steelhead During Freshwater Life Stages in Coastal Marin County

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Natural Resource Report NPS/SFAN/NRR—2020/2192

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Executive Summary

The San Francisco Bay Area Network (SFAN) monitors populations of coho salmon (Oncorhynchus kisutch) and steelhead (O. mykiss) in watersheds at Point Reyes National Seashore, Golden Gate National Recreation Area, and Muir Woods National Monument. The watersheds, including Olema Creek, Redwood Creek, and Pine Gulch Creek, represent the majority of streams supporting salmonids in Marin County, California, and support the southernmost stable populations of coho salmon on the Pacific Coast. The National Park Service SFAN Inventory and Monitoring Program and California Department of Fish and Wildlife (CDFW) have supported monitoring of multiple coho salmon life stages in coastal Marin County watersheds since 1998. Monitoring includes:

- adult escapement surveys, which document the number of adult salmonids that successfully "escape" ocean fisheries and return to their natal streams to spawn, as well as the number of redds (gravel nests where salmonids lay their eggs) created; and
- outmigrant smolt trapping, where the number of smolts (at least year-old juvenile salmonids that have undergone changes to cope with a marine environment) are captured, measured and counted as they make their way towards the ocean; and
- basinwide juvenile coho surveys and summer index reach monitoring which seek to quantify the number of juvenile salmonids present in the watersheds during the summer months.

Multiple life-stage monitoring allows for a more accurate representation of the coho population, especially given the complex life history of the coho salmon. Coho salmon have a three-year life-cycle in which they spend the first year of life in their natal stream followed by nearly two years in the ocean before returning to their natal stream to spawn. Since generations of related fish reproduce every third year, the coho population is divided into three distinct year classes, or cohorts. Cohorts may be labeled 1, 2, and 3. Cohort 1 was the first to be monitored by NPS in 1997-1998 as one generation returned to spawn in the winter and the next hatched and emerged in spring and were surveyed as juveniles during the summer. These fish were surveyed again when they left the creeks as smolts in 1999 and for a third time as spawning adults in the winter of 2000-2001. Succeeding generations of cohort 1 hatched in 2001, 2004, 2007, 2010, 2013, and 2016. Cohort 2 are those fish that hatched in 1999, 2002, 2005, 2008, 2011, 2014, and 2017 and cohort 3 fish hatched in 2000, 2003, 2006, 2009, 2012, 2015, and 2018. This report presents a summary of monitoring results for the 2017-2018 spawner season, 2018 smolt trapping season, and 2018 summer juvenile surveys. The adults and juveniles monitored belong to different generations of cohort 3, while the year-old outmigrating smolts belong to cohort 2.

Adult coho escapement surveys on Olema Creek for 2017-2018 showed a slight increase in cohort 2 adults returning to spawn (8 redds in 2017-2018 compared to 6 redds in 2014-2015). Redwood Creek adult escapement increased significantly from 4 redds in 2014-2015 to 54 redds in 2017-2018. This substantial increase can mostly be attributed to the release of 188 adult coho on January 12, 2018 as part of the Rescue and Captive Rearing Project led by CDFW. Pine Gulch Creek had no adult coho observed for the eighth year in a row.

On Olema Creek, a basinwide juvenile coho population estimate of 1,301, 95% CI [960, 1,642] was calculated. The basinwide juvenile coho population estimate for Redwood Creek was 4,475, 95% CI [3,613, 5,337]. The Olema Creek juvenile population estimate for 2018 was slightly higher than the estimate for 2015 which is the last time this cohort was observed as juveniles. Redwood Creek's 2018 juvenile coho population estimate was almost double the 2015 estimate which, again, was mostly due to the adult coho release. No juvenile coho were observed on Pine Gulch Creek.

The 2018 Olema Creek coho smolt production estimate of 572, 95% CI [39, 1,576] is higher than anticipated but still within reasonable expectations given the summer 2017 juvenile estimate of 400, 95% CI [181:619]. On Redwood Creek, the 2018 smolt estimate was 751, 95% CI [579, 923] which is also higher than expected but plausible given the summer 2017 juvenile estimate (873, 95% CI [606, 1,140]). The relatively high smolt estimate for each stream is likely due to increased overwinter survival by juveniles. Based on the absence of juvenile coho during the summer of 2017, smolt trapping was not implemented in Pine Gulch Creek during the spring of 2018.

List of Acronyms

CCCESU:	Central California Coast Evolutionarily Significant Unit
CDFW:	California Department of Fish and Wildlife
CI:	Confidence Interval
CMP:	California Department of Fish and Wildlife Coastal Monitoring Plan
CO YoY:	Coho Young-of-Year
GOGA:	Golden Gate National Recreation Area
GSS:	General Systematic Survey
I&M:	Inventory and Monitoring Program
MMWD:	Marin Municipal Water District
MUWO:	Muir Woods National Monument
NMFS:	National Marine Fisheries Service
NPS:	National Park Service
PIT:	Passive Integrated Transponder
PORE:	Point Reyes National Seashore
SFAN:	San Francisco Bay Area Network
SD:	Standard Deviation
SH 1+:	Steelhead one year or older
SH YoY:	Steelhead Young-of-Year
SPAWN:	Salmon Protection and Watershed Network
Year-Year:	All year-year references refer to the spawning year
WY:	Water Year (October-September)

1 Introduction

The San Francisco Bay Area Network (SFAN) has identified salmonids as one of the network's vital signs, or indicators of ecosystem health. Monitoring a balanced and integrated set of vital signs meets the scientific monitoring needs of current park management, but will also help detect unanticipated environmental conditions in the future. Salmonids represent a particularly high priority vital sign for SFAN because coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) are important indicators of ecosystem health, provide important links between marine and freshwater ecosystems, have endangered or threatened status, and garner high public interest.

Salmonids are monitored at three National Park Service (NPS) units within SFAN including Golden Gate National Recreation Area (GOGA), Muir Woods National Monument (MUWO), and Point Reyes National Seashore (PORE). Ongoing monitoring of coho salmon by the SFAN within the Olema Creek, Pine Gulch Creek, and Redwood Creek watersheds in coastal Marin County is supported through the California Department of Fish and Wildlife (CDFW) Contract P1630402 to the Point Reyes National Seashore Association. These monitoring efforts continue salmonid research initiated and conducted by the SFAN since 1997. The primary focus of this monitoring program is to document federally and state listed endangered coho salmon population distribution and trends within these watersheds. In addition, monitoring has been conducted to document information of federally threatened steelhead and other fish species within the monitored watersheds.

The SFAN Salmonid Monitoring Protocol v4.0 (Reichmuth et al. 2010) documents methods used by the SFAN in salmonid monitoring within coastal Marin County since 1997. Any deviations or additions in methodology are highlighted in the Methods section.

This report includes summary results of adult escapement, smolt trapping, habitat surveys, index reach surveys, and basinwide snorkel surveys for Olema Creek, Pine Gulch Creek, and Redwood Creek as well as adult escapement for Cheda Creek, a tributary to Lagunitas Creek, conducted during 2018, and summarized in comparison with all previous years of monitoring. These watersheds are located within the Lagunitas Creek and Bolinas Hydrologic Sub-Areas (HSA) of the Bodega and Marin Hydrologic Units. The monitoring efforts conducted through this program contribute to our understanding of population dynamics and condition within the coastal Marin County Area (Figure 1).

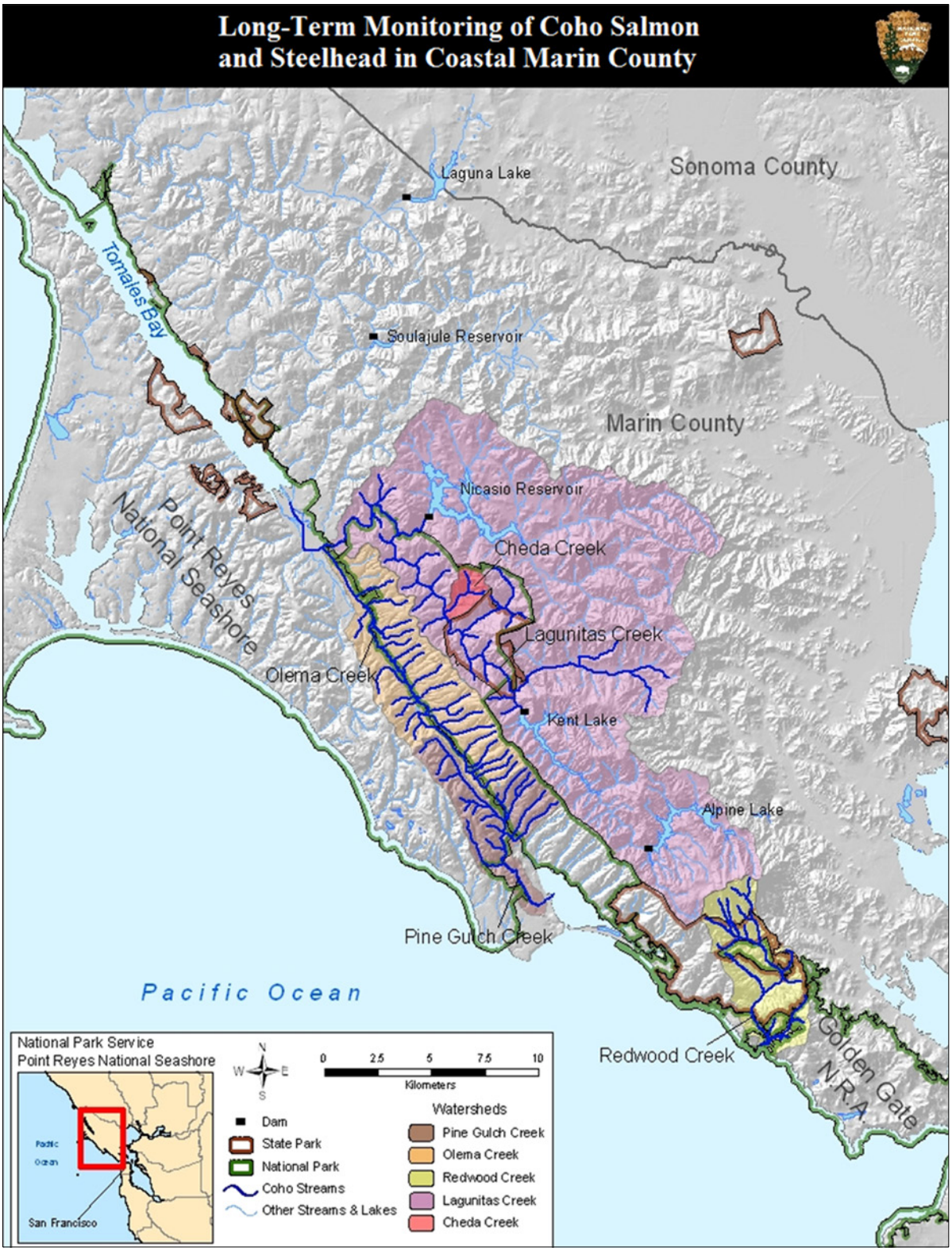

Figure 1. Streams supporting coho salmon in coastal Marin County. The National Park Service monitors streams in Point Reyes National Seashore (Olema and Pine Gulch Creeks) and Golden Gate National Recreational Area (Redwood and Cheda Creeks).

1.1 Background

Spawning populations of coho salmon and steelhead have declined significantly from historic numbers in the coastal streams of central California. It has been estimated that existing naturally spawning coho salmon stocks comprise only 1% of their historical number along the west coast and that as many as 46% of California's coho salmon populations have been extirpated from their watersheds (Brown et al. 1994).

Dramatic declines in salmonid populations throughout coastal watersheds have occurred with changes in watershed condition as a result of land use and development. Salmonids require connected surface flow for migration and dispersal (dams and culverts typically are barriers), cold temperatures (<70°F) and high dissolved oxygen levels (>4.5 mg/l; Moyle 2002, Brett and Blackburn 1981). While most salmonids have been affected by watershed development, coho salmon are particularly susceptible due to their semelparous (they spawn only a single time prior to death) three year life cycle requiring an entire year of residence in freshwater prior to smolting and migrating to the ocean. Although steelhead also require year-round high-quality water, their ability to spawn more than once and to reside in either freshwater or marine systems for variable lengths of time allows the species far greater ability to adjust to changing watershed conditions.

Based on historical regional accounts, numbers of coho salmon and steelhead have been severely depleted. Coastal Marin County streams and their associated watersheds currently containing populations of coho salmon and steelhead include Lagunitas Creek (including Olema Creek tributary), Redwood Creek, and Pine Gulch Creek. Some of the factors believed to have contributed to the declines in anadromous fish runs within these streams include (NMFS 2012):

- dam construction and loss of hydrologic connectivity;
- historic logging and sediment delivery to the channel;
- removal of large woody debris and limited riparian areas;
- stream channel and habitat alteration;
- loss of spawning and rearing habitat;
- water withdrawals, extreme hydrologic and climatic events;
- marine over-harvesting
- changes to ocean food webs, including reduced primary production.

1.2 Fishes Monitored by this Protocol

The primary species monitored through this program are coho salmon and steelhead. However, other aquatic species including sculpin (*Cottus spp.*), California roach (*Hesperoleucus symmetricus*), lamprey (*Lampetra spp.*), and threespine stickleback (*Gasterosteus aculeatus*) are captured and documented through our monitoring efforts.

The general biology of coho salmon is described in detail in Hassler (1987) and Sandercock (1991). The coho salmon is an anadromous, semelparous fish species, migrating from marine water back to freshwater for a single chance at reproduction. Natural populations of coho salmon are known to exist in the Lagunitas (including Olema tributary), Pine Gulch, and Redwood Creek watersheds (Smith 2001, Brown and Ketcham 2002). Coho salmon were listed as a threatened species within the central California coast coho salmon evolutionarily significant unit (CCCESU) in 1996 by the National Marine Fisheries Service (NMFS; Federal Register 1996), and the CCCESU was downgraded in status (upgraded listing protection) to endangered in 2005 (Federal Register 2005). The CCCESU includes all naturally spawned populations of coho salmon from Punta Gorda in northern California south to and including the San Lorenzo River in central California, as well as populations in tributaries to San Francisco Bay, excluding the Sacramento-San Joaquin River system. In 2004, the California Fish and Wildlife Commission added coho salmon populations between San Francisco and Punta Gorda to the list of species protected under the California Endangered Species Act (coho populations south of San Francisco were already listed as endangered). This endangered listing became effective in 2005.

The general biology of steelhead is described in detail in Moyle (2002). Steelhead are the anadromous form of rainbow trout and are iteroparous, meaning they can spawn more than once. Steelhead are known to exist in most perennial watersheds within Marin County. Due to dramatic declines in population numbers, NMFS was petitioned to list this species throughout much of the California coast; steelhead were listed as a threatened species in 1997 (Federal Register 1997). The central California coast steelhead distinct population segment includes all naturally spawned populations of steelhead (and their progeny) in California streams from the Russian River (inclusive) to Aptos Creek (inclusive), and the drainages of San Francisco, San Pablo, and Suisun Bays eastward to Chipps Island at the confluence of the Sacramento and San Joaquin Rivers, excluding the Sacramento-San Joaquin River Basin. The artificially propagated stocks from the Don Clausen Fish Hatchery and the Kingfisher Flat Hatchery are also included (Federal Register 2006).

1.3 Monitoring Rationale

Salmonids produce high numbers of offspring per individual— a life history strategy that offsets high rates of mortality that occur throughout their life cycle. In freshwater systems, there is a large range of mortality rates experienced by coho juveniles during early development due to annual variations in stream condition and habitat quality (Moyle 2002). By winter, mortality rates generally begin to increase with higher flow events, peaking in the spring as fish smolt and move downstream (Chapman 1965, Manning 2001). In Lagunitas Creek, researchers have observed high juvenile densities in the summer, followed by very low smolt outmigration the following spring (Stillwater Sciences 2008). On the north coast of California and Oregon, monitoring has shown that in areas where adult escapement is adequate to seed watersheds, the production of coho smolts is likely limited by winter habitat availability and overwinter survival (Nickelson and Lawson 1998).

Our monitoring of multiple life stages will help characterize potential population bottlenecks in the watershed. Observation of adult escapement and redd density in the winter, juvenile density in the

summer months, and smolt outmigration during the spring allows us to track cohorts through documented bottlenecks and identify if and where watershed-specific limiting factors exist.

1.3.1 Monitoring Questions

This monitoring program was developed to answer the following questions excerpted from the SFAN Salmonid Monitoring Protocol v4.0 (Reichmuth et al. 2010):

- What habitat constraints exist in the parks that currently impede or limit salmon recovery efforts?
- Are parks meeting resource protection mandates relative to salmonid habitat protection?
- Is the condition (e.g., length, weight, presence of abnormalities) of coho salmon changing over time?
- What is the annual production of juvenile coho salmon outmigrants in Olema, Redwood, and Pine Gulch Creeks?
- What is the annual escapement of adult coho salmon in Olema, Redwood, Pine Gulch, and Cheda Creeks?
- What is the annual abundance of juvenile coho salmon within Olema, Redwood, and Pine Gulch Creeks during summer base flow conditions?
- What are the changes in salmonid densities at preexisting index reach locations in Olema, Redwood, and Pine Gulch Creeks?

The following questions may be answered in part by this monitoring protocol but additional information will need to be gathered through park or partner efforts:

- What is the survivorship between life stages for each coho salmon cohort within Olema, Redwood, and Pine Gulch Creeks?
- What are the changes in timing and distribution of salmonid spawning, adult sex ratios, and escapement estimates in select streams at PORE and GOGA?
- What are the overall population trends of each coho cohort within GOGA and PORE watersheds?

1.3.2 Monitoring Objectives

This monitoring program was developed to meet the following objectives excerpted from the SFAN Salmonid Monitoring Protocol v4.0 (Reichmuth et al. 2010):

1. Determine long-term trends in distribution and abundance, size (length) of spawning coho salmon by counting numbers of spawners, carcasses, and redds along reaches in Olema, Cheda, Redwood, and Pine Gulch Creeks.

2. Determine long-term trends in abundance and condition of coho salmon smolts by conducting spring smolt trapping near the mouths of Olema, Redwood, and Pine Gulch Creeks.

3. Determine long-term trends in abundance, distribution, and condition of juvenile coho salmon by conducting summer basinwide surveys (general systematic surveys [GSS]) at Olema, Redwood, and Pine Gulch Creeks.

4. Determine long-term trends in summer density, size, and age composition of coho salmon at preexisting index reaches in Olema, Redwood, and Pine Gulch Creeks.

5. Identify gross changes in habitat (e.g., pool:riffle ratio) in Olema, Redwood, and Pine Gulch Creeks during basinwide GSS surveys.

1.4 Watershed Background

Olema Creek is the largest undammed watershed in coastal Marin County, California (Figure 1) and an important stream for coho salmon and steelhead within the CCCESU. The 15.9 km stream flows northwest through the Olema Valley, the landward expression of the San Andreas Fault Zone. Its confluence with Lagunitas Creek lies at the head of the ecologically significant Tomales Bay. Protected from development, the 37.6 square km (14.5 square mile) watershed is primarily contained within the boundaries of PORE and the GOGA north district. The watershed provides habitat for four federally protected aquatic species: California freshwater shrimp (*Syncaris pacifica*) – endangered; coho salmon – endangered; steelhead – threatened; and the California red-legged frog (*Rana draytonii*) – threatened. Olema Creek is the focal point of hydrologic, water quality, and fisheries monitoring within PORE.

Lagunitas Creek and its tributaries (Nicasio Creek, San Geronimo Creek, Devil's Gulch, Cheda Creek, Bear Valley Creek, and Olema Creek) drain more than 230 square km of western Marin County (Figure 1). The headwaters of the Lagunitas Creek mainstem lay within the 53,000 ha watershed lands administered by the Marin Municipal Water District (MMWD). The mainstem originally totaled approximately 40 km of perennial stream draining the northern slope of Mt. Tamalpais, but it was reduced by more than 50% after construction of Alpine Dam in 1918 and Peters Dam in 1953. Because neither dam has provision for fish passage, their construction resulted in permanent loss of the upper portion of the drainage to anadromous fish.

The portions of the Lagunitas drainage most significant for salmonids are under a number of ownerships. Approximately 12 km of the mainstem is bordered by NPS lands (north district GOGA). A major tributary, San Geronimo Creek, flows through privately held land in San Geronimo Valley. Devil's Gulch lies almost entirely within Samuel P. Taylor State Park with its headwaters in NPS lands.

Cheda Creek, lying entirely within GOGA lands, is a small perennial tributary of the Lagunitas Creek watershed and provides critical habitat for coho salmon and steelhead (Figure 1). Prior land-use practices within the Cheda Creek drainage has resulted in alterations to the natural hydrology and degraded riparian conditions. These factors have negatively impacted salmonid populations, water

quality, and the ability of the aquatic ecosystem to function properly. The construction of a fish passage structure in the fall of 2000 was part of an overall watershed restoration project initiated by the NPS to restore the system to a more natural and sustainable condition.

Redwood Creek is a 19.4 square km (7.5 square mile) coastal watershed in southern Marin County, California (Figure 1). Redwood Creek flows southwest from the flanks of Mt. Tamalpais, through MUWO, discharging to the Pacific Ocean through Big Lagoon at Muir Beach. Protected from development, the watershed is primarily contained within the boundaries of Mt. Tamalpais State Park, GOGA, and MUWO. The watershed provides habitat to three federally protected species (coho salmon – endangered; steelhead – threatened; and the California red-legged frog – threatened). According to the NMFS Genetics Laboratory, the coho salmon found in Redwood Creek represent a genetic outlier within the CCCESU with genetic distance from all other samples collected within the CCCESU and the Southern Oregon-Northern California Coast Evolutionarily Significant Unit (Bjorkstedt et al. 2005).

Pine Gulch Creek drains a 19.4 square kilometer (7.5 square mile) watershed in coastal Marin County, California, and is the primary freshwater input to Bolinas Lagoon (Figure 1). Pine Gulch Creek is located within the CCCESU where coho salmon and steelhead occur. The watershed supports a population of steelhead, and it is generally accepted that Pine Gulch Creek supported a native self-sustaining population of coho salmon into the 1970s. It was likely the drought of the late 1970s coupled with in-stream damming during the same period that severely depleted multiple cohorts and led to unsuitable conditions for continued survival of the species within the Pine Gulch watershed. In 2001, SFAN documented the return of coho salmon to the watershed beginning with the recovery of a coho carcass, and subsequent documentation of coho juveniles in the watershed the following summer (Brown and Ketcham 2002). Based on genetic tests, the coho which have returned to Pine Gulch Creek are likely strays from Redwood Creek, demonstrating a natural expansion of the genetically distinct Redwood Creek stock into a nearby watershed in PORE (Garza and Gilbert-Horvath 2003).

2 Sampling Design and Methods

This program includes strategies to monitor coho salmon and steelhead at a variety of life stages. All Standard Operating Procedures (SOPs) for winter adult spawner surveys, spring outmigrant smolt trapping, summer juvenile coho basinwide surveys, and summer index reach surveys are documented in the SFAN Salmonid Monitoring Protocol version 4.0 (Reichmuth et al. 2010). The methods described in this report are provided as a summary of detailed methods within the SFAN Salmonid Monitoring Protocol. These methods have been used by the SFAN for salmonid monitoring within coastal Marin County since 2009. Many of the methods associated with the project are consistent with draft CDFW biotic monitoring guidelines (Collins 2003). Maps of Olema, Redwood, and Pine Gulch Creeks with survey locations are shown in Figures 2-4.

2.1 Adult Coho and Steelhead Escapement Surveys

Annually, spawner surveys are conducted in watersheds within and adjacent to SFAN park units, including PORE, GOGA, and MUWO. These surveys concentrate primarily on federally endangered coho salmon and federally threatened steelhead in an attempt to quantify the adult escapement. "Escapement" refers to the number of adult fish that successfully pass through a fishery to reach the spawning grounds located in freshwater streams. Coho and steelhead data collected as a part of these surveys contribute to Monitoring Objective 1 and include number of live adult fish observed, number of adult fish carcasses observed, and number of redds observed. These surveys were first conducted on Olema Creek in 1997, Cheda Creek in 1998, Redwood Creek in 1994, and Pine Gulch in 2000. Standard Operating Protocols 5, 6, 9, and 11 document field and analytical methods for the adult salmon escapement monitoring efforts (Reichmuth et al. 2010).

2.1.1 Adult Coho and Steelhead Survey Field Methods

Program staff and trained volunteers conduct surveys for coho and steelhead spawners and redds each winter and spring during the coho and steelhead spawning season to quantify escapement and determine spawning density and distribution. Surveys conducted during the spring months are conducted to capture the entire steelhead spawning season and are typically performed only after spring freshets, when adult steelhead spawning increases. The adult coho in-stream migration window typically spans from late November to early February, while the window for steelhead spawning begins in late December and usually ends by late April. Start and end dates for each season vary depending on in-stream flows and spawning activity. Adult coho salmon runs within the CCCESU typically peak in January and are compressed into a very short window, because upstream migration coincides with brief yet substantial winter discharges (Weitkamp et al. 1995). Surveys are conducted approximately every week from late November through early February, although storms and high stream flows often dictate less frequent surveys. Redd detection is the key factor in determining adult steelhead abundance, and redds can be detected as a feature within the streambed weeks after they are constructed as long as there are no storm events that lead to increased streambed mobility. Storms are less intense during the spring which allows for more efficient adult steelhead surveys, because redds remain undisturbed and are relatively easy to detect.

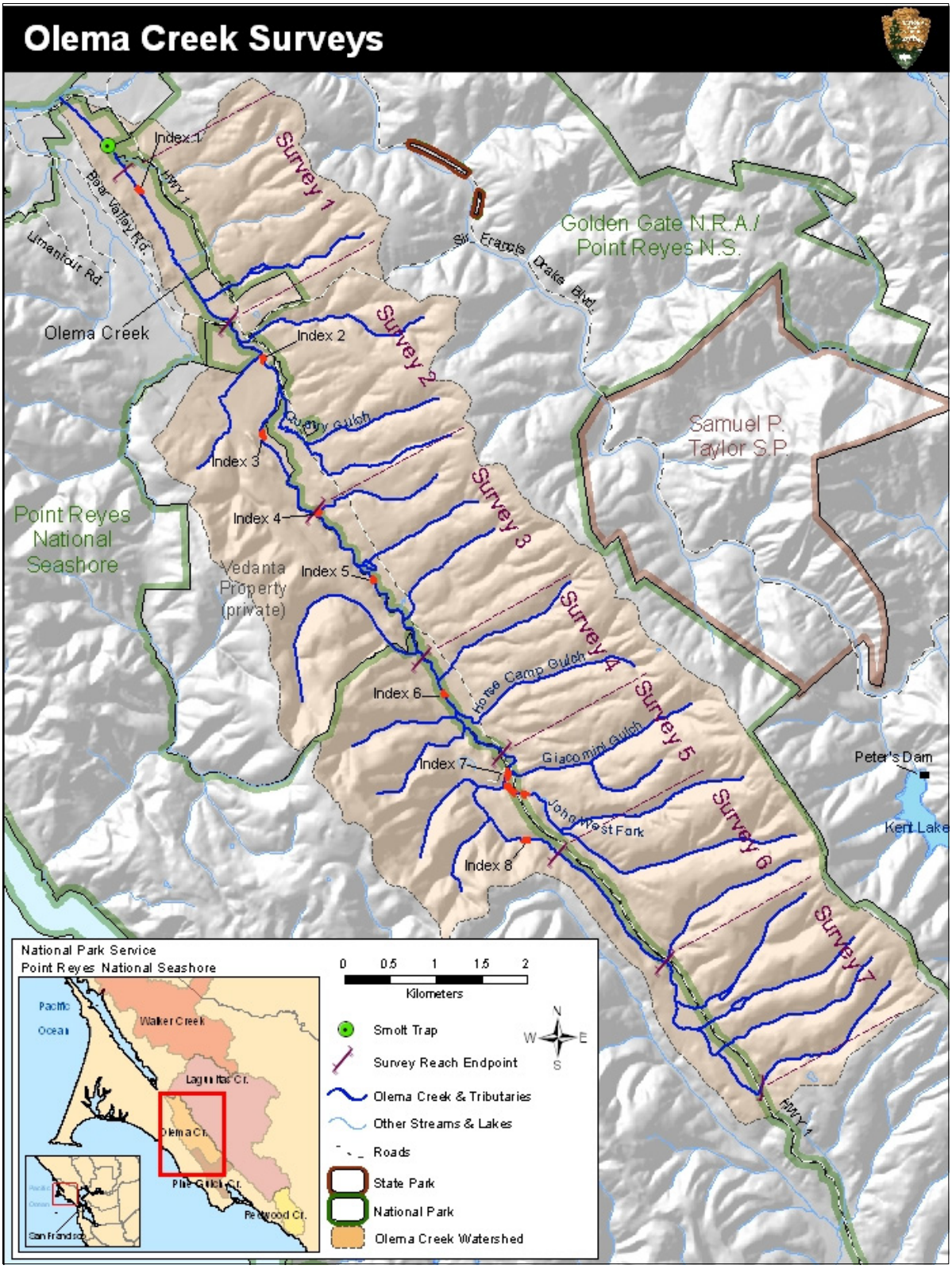

Figure 2. Olema Creek survey locations. Adult spawner reaches, summer index reaches, and smolt trap locations are shown.

Figure 3. Redwood Creek survey locations. Adult spawner reaches, summer index reaches, and smolt trap locations are shown.

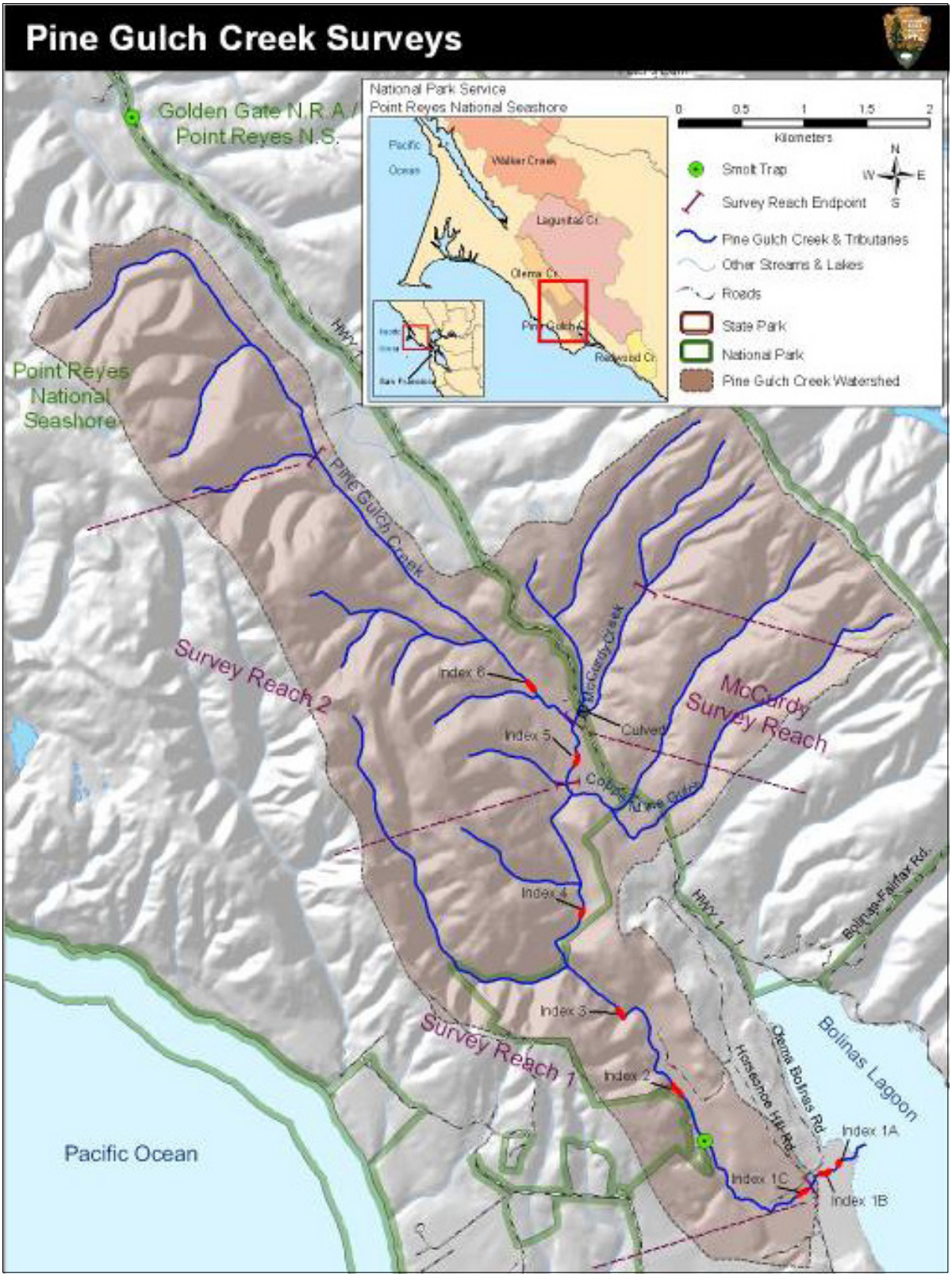

Figure 4. Pine Gulch Creek survey locations. Adult spawner reaches, summer index reaches, and smolt trap locations are shown.

During spawner surveys, observers walk upstream through 2-4 km creek reaches (Figures 2-4) and along creek margins and banks, where possible, to look for live fish, carcasses, and redds. Although the extent of spawner survey reaches are fairly consistent from year to year, variations in survey extent can occur due to stream conditions, restoration activities, and staff availability (Appendix A, Tables A2 and A5). Live fish are identified to species and sex, and fork length (FL) is visually estimated to the nearest 5 cm. Carcasses are measured (FL) to the nearest cm, identified to species and sex, and marked to prevent double counting. Scale and tissue samples are collected from carcasses for age and genetic analysis. Redd measurements are taken to the nearest 0.1 m. Redds are marked with flagging tied to elevated vegetation generally on the opposite stream bank to avoid disturbance of eggs. Because redds are stationary and can be observed over time, redd monitoring is targeted to determine spawning success.

Particular care is taken not to disturb redds or actively spawning adults. Locations of all live fish, carcasses, and redds are recorded in reference to permanent tags placed every 100 m along each stream.

2.1.2 Changes to Methodology

The program continues to seek the latest in salmonid monitoring methods and technology. To this end, changes may be made in the program methods that are not currently reflected in the published protocol (Reichmuth et al. 2010). In order to make clear where current methodologies differ from the published protocol, any updates will be included in the annual report until such a time as the published protocols can reflect the updated methods.

In addition to the collection of scale and tissue samples, otoliths are retrieved from all viable carcasses for stable isotope analysis. Carcasses are also scanned using a handheld Passive Integrated Transponder (PIT) tag reader to determine if the carcass contains a PIT tag. Redd measurements are now based on pit and tailspill area, instead of total area as detailed in Reichmuth et al. 2010. Length is recorded for both the pit and the tailspill as is the average width (average calculated from two width measurements). Redds are assigned an age code for any future mark-recapture studies, which will eventually be used to estimate survey efficiency and provide an alternative method for estimating escapement when survey conditions are unfeasible. In accordance with current methodology, all redd and fish locations are recorded using the nearest downstream monument tag. New survey methods include the collection of geospatial data for both redd and fish observations. Finally, staff members are using both a regression analysis as proposed by Gallagher and Gallagher (2005) and a known-nearest-neighbor algorithm (Garwood and Larson 2014) in an effort to classify redds of unknown salmonid species retroactively. These methodologies have been suggested by the Coastal Monitoring Plan (CMP) technical advisory committee to estimate species for redds in which species was not determined by field staff.

2.2 Outmigrant Coho Smolt Trapping

For a detailed description of sampling design rationale, locations, and methods used during the outmigrant smolt trapping season, please refer to SOPs 3, 4, 6, 9 and 11 in Reichmuth et al. 2010.

Outmigrant smolt trapping is performed annually from March through May on Olema and Redwood Creeks. A smolt trap is also installed near the mouth of Pine Gulch Creek in years following the detection of juvenile coho during summer basinwide surveys. Trapping operations were initiated on Pine Gulch in 2002, Olema Creek in 2004, and Redwood Creek in 2005. Outmigrant trapping is intended to census the number of coho smolts leaving the watershed, and the smolt data obtained through the trapping contributes to Monitoring Objective 2. Although trapping operations are focused on coho smolts, information regarding steelhead smolt outmigration is also documented. Trapping results can also help quantify dates of fry emergence and growth rates through the spring season. Outmigrant traps provide presence/non-detect information and size data for other aquatic species during periods not covered by summer/fall monitoring activities.

2.2.1 Coho Smolt Trap Field Methods

Trapping is conducted continually for a 2-3 month period during the spring and requires daily field checks by staff. The fyke/pipe traps used by this program are based on methods developed in northern California for trapping small streams (Manning and Roelofs 1996, Manning 2001) and have proven effective for the current monitoring sites. They are designed to catch fish moving downstream and, with efficiency estimated via mark-recapture techniques, result in a smolt production estimate calculated using DARR 2.0.2 software (Bjorkstedt 2010) in program R or using Chapman modification of the Petersen equation (Schneider 2000). The Chapman modification of the Petersen equation (Schneider 2000) is only used when the recapture distribution or number of marked coho are not sufficient to produce an estimate using the DARR 2.0.2 software (Bjorkstedt 2010).

During each site visit, a random subsample of coho and steelhead smolts (fish of at least one year of age that have undergone physiological changes in preparation for heading out to sea), steelhead parr (juveniles of at least one year of age that show no signs of smoltification), and coho and steelhead fry (recently hatched and emerged juveniles) are measured (FL) to the nearest mm and weighed to the nearest 0.01 g. The subsample for each species and age class is typically the first 10 randomly selected individuals; however, since all fish anesthetized for mark-recapture purposes are measured and weighed, they are included in size analyses. Trap site locations within each watershed were determined by suitable channel morphology and access (Figures 2-4).

In most years, trapping operations are conducted over an 11-week period during the spring months. Start and end dates vary seasonally and are dependent on in-stream flows and trap production. Traps are generally installed in March, once flows have subsided from winter peaks and have stabilized. In some years, spring rains occasionally increase flows enough to compromise trap operation. Coho smolt migration typically ends by late May or early June coinciding with a drop in stream flows, so traps are removed at this time. In each of the monitored watersheds, the SFAN I&M program maintains a stream gauge for measurement of average daily discharge. An Onset-brand temperature logger is deployed in each trap box for the duration of operation.

2.2.2 Changes to Methodology

Smolt outmigrant trapping methods have remained mostly unchanged. Three updates that are not yet included in the protocol are the use of PIT tags for the mark-recapture studies, and the use of MS-222 (Tricaine Methanesulfonate) for anesthetizing fish prior to tag implant and handling. PIT tags,

because of their unique identification system, allow fish to be tracked on an individual basis enabling a more accurate estimate of outmigrant production. Alka-Seltzer® is no longer used by staff during fish processing as the program has transitioned to only using MS-222.

2.3 Juvenile Coho and Steelhead Surveys

Monitoring juvenile salmonids during their freshwater residence phase provides information on overall population trends in distribution, abundance, and condition (Monitoring Objective 3), particularly when combined with adult spawning data and smolt emigration data (Collins 2003). Sampling is most effective during summer and fall base flow conditions, when water clarity is greatest and conditions are more conducive to observation and capture of juvenile salmonids.

The primary activities conducted in the watersheds include basinwide GSS and index reach monitoring during the summer/fall sampling period. Complete published field methods are documented in SOPs 1, 2, 6, and 9 in Reichmuth et al. 2010. The descriptions of field methods for summer juvenile coho and steelhead monitoring are organized by survey type, since a variety of surveys are utilized during the summer juvenile monitoring season. Although multiple survey techniques may be deployed within the same sampling period, each survey type is treated as a standalone survey.

2.3.1 Basinwide General Systematic Surveys

Basinwide survey techniques, developed by Hankin and Reeves (Dollof et al. 1993), provide statistically valid estimates of stream habitat type and salmonid population size for a broad area or entire stream. Basinwide surveys involve a two-stage sampling design using both snorkeling and electrofishing. This two-stage sampling combines labor-intensive data collection for a randomly selected subsample of units correlated with data from a less labor-intensive sampling technique to achieve representation while reducing effort. Sampling units are classified as pool (scour pool, plunge pool, or mid-channel pool), flatwater, or riffle using level III of the CDFW classification system (Flosi et al. 1998). Every fifth pool unit is flagged for snorkeling, and several measured widths are taken for the purpose of calibrating the estimated width. All large woody debris, live or dead, providing in-stream shelter during summer base flow conditions is counted and recorded within each habitat unit. Program staff survey each of the previously determined pools with a single- to triple-pass snorkel count, using dive lights to search under vegetation, woody debris, and undercut banks. Only coho are counted, but the presence of steelhead and non-salmonid fish is also noted. Typically, snorkeling is calibrated by follow-up electrofishing of randomly selected dive units to provide an unbiased calibration method.

For each electrofished unit, a random subsample of coho young-of-year (CO YoY), steelhead young-of-year (SH YoY), and steelhead one year or older (SH 1+) are measured (FL) to the nearest mm and weighed to the nearest 0.01 g. This subsample typically includes the first 10 randomly selected individuals of each species and age class.

2.3.2 Index Reach Monitoring

Index reaches are sampled at SFAN parks during summer/fall base flow periods to assess fish abundance and distribution within each index on Olema Creek, Redwood Creek, and Pine Gulch

Creek. Using this technique, established stream reaches approximately 100 m in length and distributed intermittently along the creeks' full lengths have been surveyed annually since the mid- to late-1990s (Figures 2-4). Index reach surveys include both fish sampling and detailed habitat assessments.

Each index reach contains two or more contiguous habitat units, which are identified and sampled individually. Each habitat unit is isolated with block nets and sampled separately using standard multiple pass depletion electrofishing methods (Bohlin et al 1989). Habitat measurements and assessments are made for the index reaches after fish sampling is completed.

2.3.3 Changes to Methodology

During snorkel surveys, a handheld GPS device is used to record the geospatial location of each snorkeled habitat unit. The GPS device saves each location as a waypoint, and all waypoints are downloaded in-office immediately following a survey. In recent years, the lower densities of juveniles within the stream have precipitated an increase in sampling frequency. At a minimum, every fifth pool is sampled. More commonly, every fourth pool and tenth flatwater with a depth greater than 0.2 m is flagged for snorkel surveys. In an effort to increase accuracy of juvenile estimates, pool units are given one of three complexity rankings which are non-complex, less than 50% open water or depth exceeds ability to electrofish, and less than 20-30% open water. Most units of a certain complexity, depth, or size have been skipped in the past due to an inability to accurately electrofish these units for possible calibration. These pools are now snorkeled, if feasible, and calibration is performed using repeat snorkel passes. Fish in these units are later seined for biotic information and tagging. Juvenile coho of size (≥65 mm) may be anesthetized and marked with a PIT tag for growth and survival studies. Finally, sampled units are *either* seined or electrofished, not both. If electrofishing is deemed too hazardous for a specific unit, and the unit must be sampled, a seine is employed. Due to time limitations and inconsistency in data between years, index reaches in Pine Gulch Creek were removed from the sampling schedule during the summer of 2018.

3 Monitoring Results

Monitoring data presented below are organized first by monitoring procedure (escapement surveys, outmigrant smolt surveys, basinwide juvenile surveys, and index reach juvenile surveys) and then by watershed. For context, rainfall data are also presented.

3.1 Rainfall

Rainfall data were collected for Olema Creek during the 2018 water year (October 2017 – September 2018). Total rainfall for water year 2018 was lower than the historical average. The total rainfall amount for coho spawning months, November through February, was also well below the historical average. December rainfall (0.12 inches) was the lowest amount on record for the month since Water Year (WY) 1990.

Total rainfall on Redwood Creek for 2018 was also below average. Redwood Creek experienced the driest December and February on record (WY1999-Present) with only 0.19 inches and 0.36 inches of rainfall, respectively. A significant storm event in early April resulted in the highest rainfall amount (6.02 inches) ever recorded for the month at Redwood Creek.

3.2 Data from Escapement Surveys

In the 2017-2018 spawning year, the SFAN conducted escapement surveys starting in early November and continuing through the beginning of April. Surveys were conducted in Olema, Cheda, Redwood, and Pine Gulch Creeks, including select associated tributaries.

These surveys were first conducted using the current survey methods on Redwood Creek in 1997, Olema Creek in 1997, Cheda Creek in 1998, and Pine Gulch in 2000. Historical results for coho redd density on all streams monitored in Marin County by the SFAN, MMWD, and SPAWN are presented in Appendix A, Table A1.

3.2.1 Olema Creek

Coho escapement data for Olema Creek shows that run timing is highly dependent on the rainfall-runoff conditions within the watershed. Unlike Lagunitas Creek, Olema Creek is an unregulated stream, so attraction flows during the spawning season are entirely dependent on natural weather patterns. Adult coho salmon runs within the CCCESU are compressed into a very short window, with upstream migration coinciding with brief peak winter discharges, which typically occur in December and January (Weitkamp et al. 1995). In recent years, these peak winter discharges have been occurring later in the coho spawning window.

Olema Creek watershed spawner survey information includes data collected on 13.8 km of the mainstem, primarily Reaches 1 through 6, and John West Fork, the largest tributary to Olema Creek (Figure 2). Spawner surveys were also conducted on two smaller tributaries, Boundary Gulch and Horse Camp Creek. When possible, the mainstem of Olema Creek and its tributaries are combined for data summaries and analysis.

Survey Timing and Environmental Conditions

Our monitoring efforts have documented certain years when flows necessary to allow adult salmonids entry into the watershed did not occur until mid-January. In those years, coho were observed in the estuary waiting for Olema Creek attraction flows. In other years, rains in November generated flows that would allow coho early access to the watershed. Even when this early entry opportunity has occurred, few coho have been observed migrating upstream. Based on historical data, peak spawning activity in Olema Creek occurs between mid-December (Julian weeks 50 and 51) and mid-January (Julian weeks 1-3). Typically, the peak count will follow a large flow event, encouraging fish that were waiting at the mouth of the watershed to enter and spawn. Data on historical timing of the coho run, rainfall during the run, and spawning activity observed on Olema Creek watershed can be found in Appendix A, Table A2.

For the 2017-2018 season, the first survey was performed on 14 November 2017 and only included Reach 1 of Olema Creek. A total of thirteen surveys were conducted in Olema Creek between 14 November 2017 and 12 March 2018. The mean interval between surveys was 9.8 days during the primary coho spawning season (November through February). Seven-day rainfall totals for Julian weeks within peak spawning months (December and January) ranged from a low of 0.00 inches during Julian week 50 to a high of 4.58 inches during Julian week 2. Average water clarity at the time of each survey ranged from 50 cm to over 100 cm. The onset of rainfall and subsequent higher flows appeared to be related to live fish observations.

John West Fork tributary surveys were conducted on 11 January 2018 and 24 January 2018. The survey on 11 January was conducted concurrently with Olema Creek mainstem surveys. Average water clarity at the time of each survey was 50 cm.

Boundary Gulch was surveyed on 24 January 2018 with water clarity to 70 cm. Horse Camp Creek was also surveyed on 24 January 2018 and had poor water clarity to 30 cm. Tributary surveys generally preceded the mainstem surveys and were dependent on flow. Historical spawning data for Olema Creek tributaries can be found in Appendix A, Table A3.

Live Coho and Steelhead

While live coho observations do not accurately represent the total number of spawning adults, it is worth noting that 84 adult coho were observed during surveys on the Olema Creek mainstem. No coho adults were observed on John West Fork, Boundary Gulch, or Horse Camp Creek. For Olema Creek mainstem, the first live adult coho was observed on 11 January 2018.

Although steelhead trout are not the primary focus of this study, observations of live adult steelhead were recorded using the same method for recording live adult coho. Due to the reproductive strategy of adult steelhead, the number of returning spawners is assumed to be much higher than the observed count. Twenty-seven adult steelhead were observed during the 2017-2018 spawner surveys on the mainstem of Olema Creek. No steelhead adults were observed on John West Fork. Six adult salmonids observed on Olema Creek mainstem could not be positively identified as either coho or steelhead.

No live coho or steelhead were observed on Boundary Gulch and Horse Camp Creek.

Coho and Steelhead Carcasses

Fourteen coho carcasses were recovered during the 2017-2018 spawner season on Olema Creek mainstem. No carcasses were recovered on tributaries.

Four steelhead carcasses were recovered on Olema Creek mainstem, and no steelhead carcasses were recovered on John West Fork. Eleven carcasses on the Olema Creek mainstem could not be identified to species.

Coho and Steelhead Redds

Redd counts provide the most spatially accurate representation of spawning densities in the watershed. Within Olema Creek, monitoring efforts have allowed for analysis of redd data per 100 m section of stream since 1997-1998. Accumulation of these data show high use areas for spawning within the Olema and John West Fork watersheds.

Eight confirmed coho redds were observed in the mainstem of Olema Creek during the 2017-2018 season. Coho redds were found in reaches two through four. No redds were observed on John West Fork. Of the eight confirmed coho redds in the Olema Creek mainstem, seven were measured, and the average surface area was 4.98 m^2. The density of coho redds on the mainstem was 0.58 redds/km.

Twenty-seven confirmed steelhead redds were observed on the mainstem of Olema Creek. No steelhead activity was observed on John West Fork. All steelhead redds were measured, and the average surface area was 2.65 m^2. Steelhead redd density on the mainstem was 1.96 redds/km.

A total of nineteen redds in the Olema Creek watershed could not be classified to species due to lack of fish on redd or stream conditions (i.e. high turbidity). The unknown redds were reclassified using the K-nearest neighbor algorithm (kNN) developed by Ricker et al. (2013) which relies on temporal and spatial data of known redds. Species designation for an unknown redd is based on the three closest known neighbors which may also include live fish observations (Garwood and Larson 2014). After kNN analysis, five of the 19 unknown redds were reclassified as coho and the remaining 14 as steelhead, yielding a total count of 13 coho redds and 41 steelhead redds. As a result, coho redd density increased to 0.95 redds/km, and steelhead redd density increased to 2.97 redds/km for Olema Creek mainstem.

Coho Spawning Trends

Overall trends in coho spawning on Olema Creek, based on observed redds, are shown below in Figure 5. The three cohorts are represented as primary colors (yellow-1, blue-2, and red-3) to show relationships between spawning runs. Cohort 1 suffered a sharp decline and produced its lowest number of redds during the 2009-2010 spawner season. The cohort rebounded slightly in 2012-2013 and continued to show improvement in 2015-2016. Cohort 2 showed a rapid increasing trend in spawning over the first three generations before falling off sharply in 2007-2008. It held relatively steady with a slight increase in 2013-2014 compared to the 2010-2011 season, before hitting a record low in 2016-2017. Cohort 3 continued to struggle with a substantial decline in spawning from 2002-2003 to 2005-2006, before no adult coho, coho carcasses, or coho redds were observed in 2008-2009.

In 2011-2012, the cohort returned in modest numbers, and similar production was observed the following generation. Redd abundance for the 2017-2018 season was the second highest on record and almost double the number of redds observed the previous time cohort 3 returned to spawn.

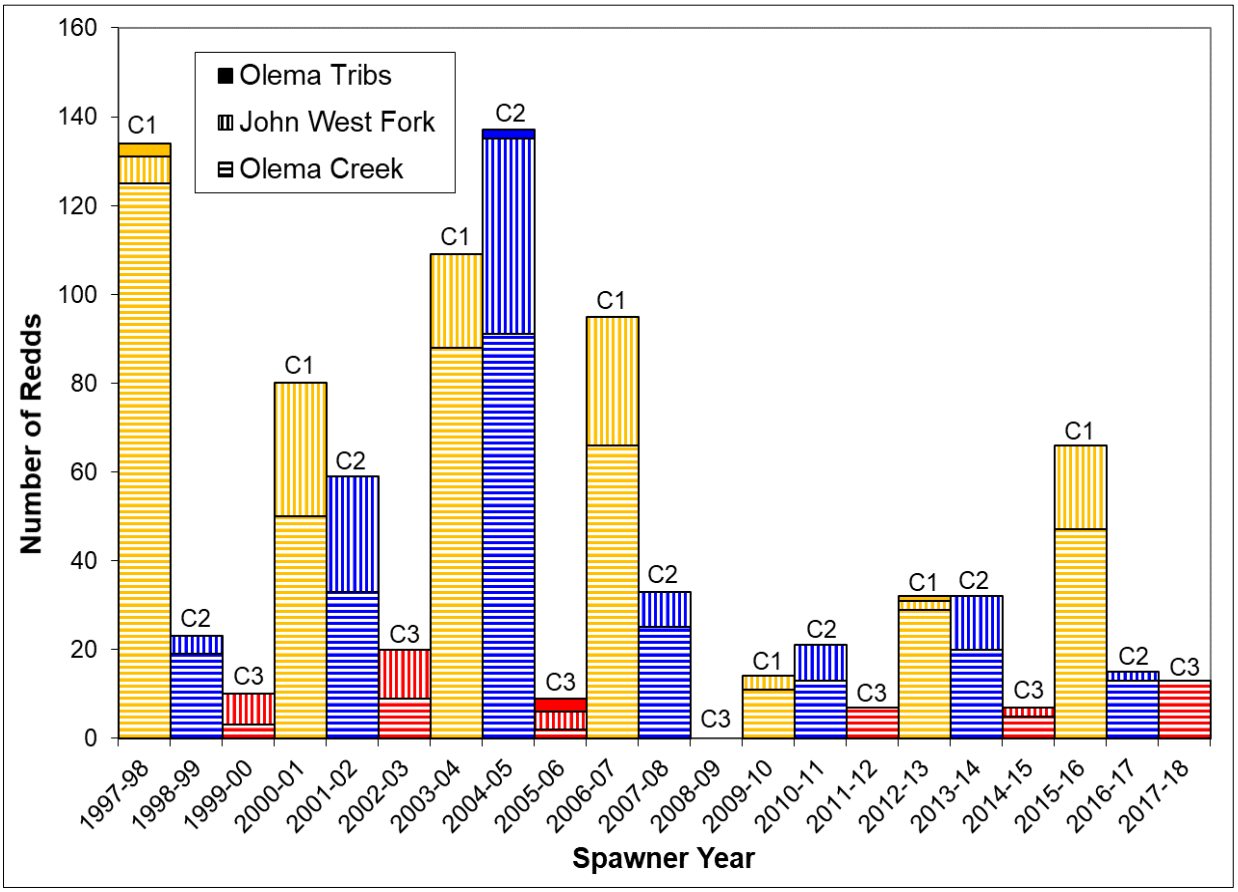

Figure 5. Coho salmon redd results for the Olema Creek watershed by cohort for winter 1997-1998 through winter 2017-2018. Cohorts are designated by color (cohort 1 shown in yellow, cohort 2 shown in blue, cohort 3 shown in red) and creeks are designated by pattern (Olema Creek in horizontal lines, John West Fork in vertical, and other Olema tributaries in a solid color).

Live Coho and Coho Carcass Biotics

Information on live adult coho and coho carcasses were collected during each field survey; information on sex ratios for live fish and carcasses are reported in Tables 1 and 2, respectively.

Table 1. Sex ratio percentages and mean fork length (FL) of live coho within Olema Creek Watershed for the period 1997-2017 compared to 2017-2018. SD = standard deviation.

Period	Type[a]	Year	Live Coho				
			Sample Size	Sex Ratio %	n[b] for FL	Mean FL (cm)	FL SD (cm)
Cumulative	M	1997-2017	730	37	702	63	7.2
	F	1997-2017	874	44	852	61	6.0
	J	1997-2017	279	14	279	39	5.2
	Unk	1997-2017	94	5	52	57	7.3
	All	–	1,977	100	–	–	–
Current	M	2017-2018	18	21	13	55	7.9
	F	2017-2018	13	16	12	58	6.9
	J	2017-2018	47	56	47	42	3.1
	Unk	2017-2018	6	7	6	53	4.2
	All	–	84	100	–	–	–

[a]M = Male, F = Female, J = Jack, Unk = Unknown

[b]n = Number of fish measured for fork length (FL)

Table 2. Sex ratio percentages and mean fork length (FL) of coho carcasses within Olema Creek Watershed for the period 1997-2017 compared to 2017-2018. SD = standard deviation.

Period	Type[a]	Year	Carcasses				
			Sample Size	Sex Ratio %	n[b] for FL	Mean FL (cm)	FL SD (cm)
Cumulative	M	1997-2017	156	34	113	66	7.9
	F	1997-2017	192	41	152	65	5.1
	J	1997-2017	44	9	44	43	3.7
	Unk	1997-2017	72	16	11	65	7.1
	All	–	464	100	–	–	–
Current	M	2017-2018	1	7	1	50	–
	F	2017-2018	4	29	0	-	–
	J	2017-2018	1	7	1	43	–
	Unk	2017-2018	8	57	0	–	–
	All	–	14	100	–	–	–

[a]M = Male, F = Female, J = Jack, Unk = Unknown

[b]n = Number of fish measured for fork length (FL)

3.2.2 Cheda Creek Coho and Steelhead Escapement

Cheda Creek is a small but important tributary of the Lagunitas Creek watershed and provides critical habitat for coho salmon and steelhead. Cheda Creek spawner survey information includes data collected on 1.4 km.

Survey Timing and Environmental Conditions
Only one survey was performed on Cheda Creek during the 2017-2018 season on 24 January 2018. Water clarity for the survey was 60 cm.

Live Coho and Steelhead
No live adult coho or steelhead were observed during the survey.

Coho and Steelhead Carcasses
One carcass was observed on 24 January 2018 but could not be identified to species.

Coho and Steelhead Redds
Two redds which could not be identified to species were observed and measured on Cheda Creek. Average surface area for the unknown redds was 3.1 m^2. The redd density for Cheda Creek was 1.4 redds/km. The kNN algorithm reclassified both unknown redds as coho.

Cheda Creek Watershed Coho Escapement History
The dataset for adult escapement within Cheda Creek includes 20 years of survey information and has documented the return of coho to this small tributary of Lagunitas Creek (Appendix A, Table A4).

3.2.3 Redwood Creek Coho and Steelhead Escapement
Review of the past 20 years of coho salmon escapement monitoring information for Redwood Creek indicates that run timing is highly dependent on the rainfall-runoff condition within the watershed. Redwood Creek is an unregulated stream with variable environmental conditions that limit flows in the winter season. Initial adult salmonid access to Redwood Creek depends on the breaching of a sand bar at its confluence with the Pacific Ocean. In late fall/early winter, a breach usually occurs due to a substantial storm event, king tide, or combination of the two; consistent rainfall is needed for a sustained breach. In normal years, adult coho salmon upstream migration coincides with brief peak winter discharges, typically occurring in December and January (Weitkamp et al. 1995).

Redwood Creek watershed spawner survey information includes data collected on 8.1 km of the mainstem, primarily Reaches 1 through 3, and Fern Creek, the largest tributary to Redwood Creek (Figure 3). Spawner surveys were also conducted on two smaller tributaries, Green Gulch and Kent Canyon. When possible, the mainstem of Redwood Creek and its tributaries are combined for data summaries and analysis.

Survey Timing and Environmental Conditions
Fourteen surveys were conducted in Redwood Creek between 15 November 2017 and 12 April 2018. The mean interval between surveys during the primary coho spawning season (November-February) was 10.9 days. Seven-day rainfall totals for Julian weeks within peak spawning months (December and January) ranged from a low of 0.00 inches during Julian weeks 50 and 52 to a high of 4.02 inches during Julian week 2. Average water clarity at the time of each survey ranged from 30 cm to over 100 cm. Historical information on timing of past runs, rainfall during the run period, and spawning activity observed on Redwood Creek can be found in Appendix A, Table A5.

Green Gulch, Fern Creek, and Kent Canyon are the three main tributaries to Redwood Creek. Fern Creek was surveyed three times on days when mainstem surveys were also performed to eliminate the possibility of inflating adult spawner numbers by double counting fish; water clarity was at least 100 cm at the time of each survey. Surveys on Green Gulch and Kent Canyon were dependent on flow. Lower Green Gulch and Kent Canyon were surveyed on 30 January 2018. Water clarity was 30 cm on Green Gulch and 40 cm on Kent Canyon at time of survey.

Live Coho and Steelhead

On 12 January 2018, 188 adult coho spawners, captured as juveniles in Redwood Creek and raised to maturity at Don Clausen Fish Hatchery in Sonoma County, CA, were released as part of an emergency rescue rearing project led by the California Department of Fish and Wildlife. Eighty-nine of those fish were adult females, and 87 were adult males. The remaining 12 fish were jacks, or precocious males. During the 2017-2018 spawner season, 187 live coho were observed on the mainstem of Redwood Creek, with 130 of those observed fish displaying neon-colored hatchery floy-tags (58 pink [female] and 72 green [male]). Twenty adult steelhead and six unknown salmonids were also observed this season. No adult salmonids were observed in the tributaries.

Coho and Steelhead Carcasses

Twenty-four confirmed coho carcasses were recovered on Redwood Creek mainstem. Of those 24 carcasses, 18 were hatchery-reared fish (7 female and 11 male). Two steelhead carcasses were also recovered this season. Two carcasses recovered on the mainstem could not be identified to species. No carcasses were observed on tributaries.

Coho and Steelhead Redds

Fifty-four confirmed coho redds were observed during the 2017-2018 spawner season. Redds were documented in all three reaches of the mainstem. Of the 54 confirmed coho redds, 44 were measured. The average surface area for coho redds was 3.88 m^2, while the total density of redds on the mainstem was 6.67 redds/km. No confirmed coho redds were observed on Fern Creek, Green Gulch, or Kent Canyon tributaries.

Fourteen confirmed steelhead redds were observed on Redwood Creek mainstem, and eight of the 14 redds were measured. The average surface area for steelhead redds was 2.0 m^2. Steelhead redd density on the mainstem was 1.72 redds/km. No confirmed steelhead redds were observed on Fern Creek, Green Gulch, or Kent Canyon.

A total of 39 redds in Redwood Creek mainstem could not be classified to species due to lack of fish on redd or stream conditions (i.e. high turbidity). The unknown redds were reclassified using the kNN analysis After kNN analysis, 35 of the 39 unknown redds were reclassified as coho and the remaining four as steelhead, yielding a total count of 89 coho redds and 18 steelhead redds. As a result, coho redd density increased to 11 redds/km, and steelhead redd density increased to 2.22 redds/km for Redwood Creek mainstem. The K-nearest neighbor method is currently under review by the CMP Technical Team, but results were included for comparison.

Coho Spawning Trends

Overall trends in coho spawning on Redwood Creek, based on observed redds, are shown below in Figure 6. The three cohorts are represented as primary colors (yellow-1, blue-2, and red-3) to show relationships between spawning runs. Cohort 1 spawning had been relatively consistent since 2006-2007 until a slight decline in redd production was observed during the 2015-2016 season. Cohort 2 redd abundance increased significantly from 2001-2002 to 2004-2005 before falling off sharply during the 2007-2008 spawner season. Since 2007-2008, cohort 2 redd production has gradually increased, but still remains at a critical level. Cohort 3 redd abundance has consistently been in the single digits with the exception of 2005-2006 and 2017-2018. The 2017-2018 season saw a major uptick in redd production thanks, in part, to the rescue rearing project led by CDFW. For all years, the majority of spawning occurs on the mainstem of Redwood Creek, with limited spawning on Fern Creek and Kent Canyon during years with higher abundance. Coho spawning has yet to be observed on the Green Gulch tributary.

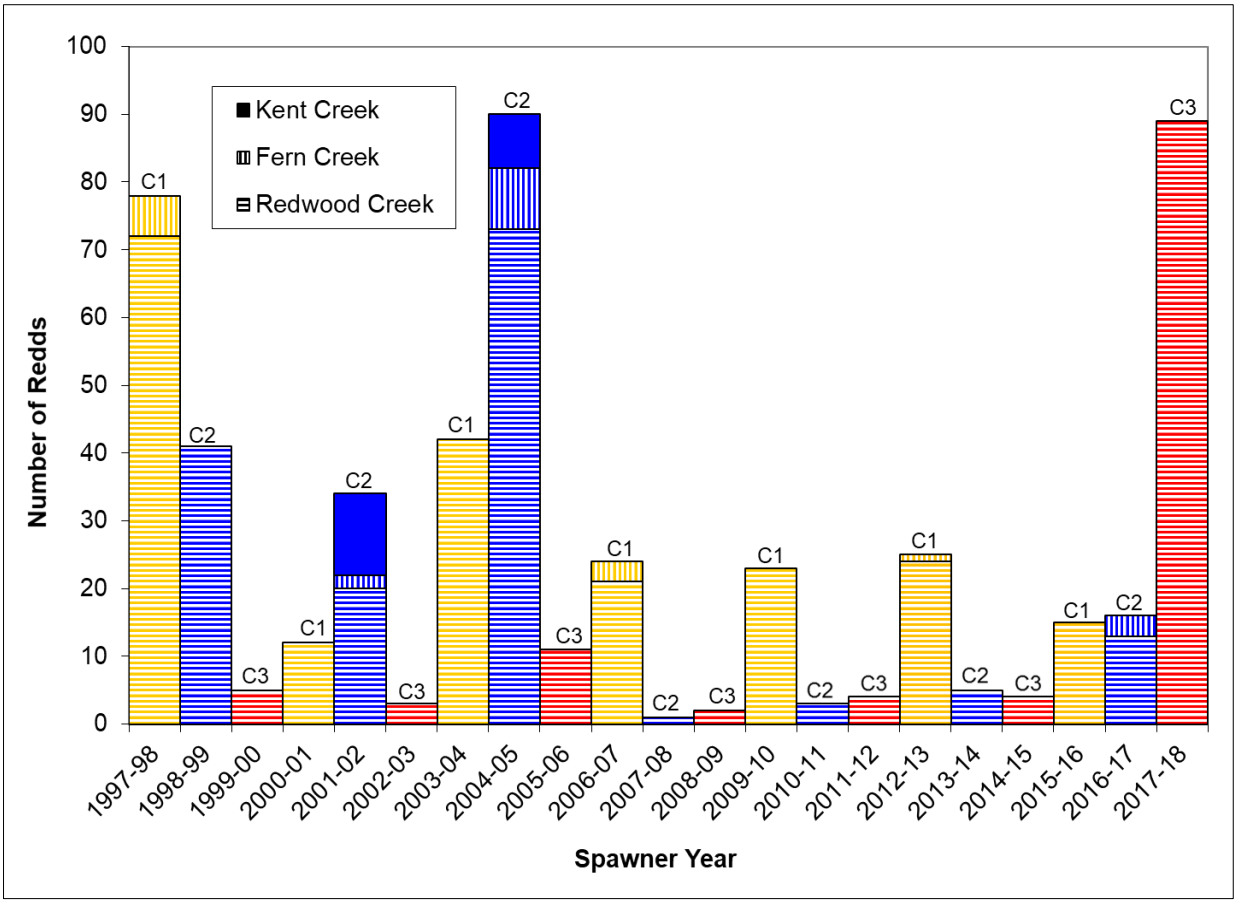

Figure 6. Coho salmon redd numbers in the Redwood Creek watershed by cohort for winter 1997-1998 through winter 2017-2018. Cohorts are designated by color (cohort 1 shown in yellow, cohort 2 shown in blue, cohort 3 shown in red), and creeks are designated by pattern (Redwood Creek in horizontal lines, Fern Creek in vertical, and Kent Creek in a solid color).

Live Coho and Coho Carcass Biotics

Information on live coho and coho carcasses were collected during each field survey. Sex ratios for live coho and coho carcasses are reported for 2017-2018 in Tables 3 and 4. Information presented includes both hatchery-reared and wild fish.

Table 3. Sex ratio percentages and mean fork length (FL) of live coho within the Redwood Creek watershed for the period 1997-2017 compared to 2017-2018. SD = standard deviation.

			Live Coho				
Period	**Type[a]**	**Year**	**Sample Size**	**Sex Ratio %**	**n[b] for FL**	**Mean FL (cm)**	**FL SD (cm)**
Cumulative	M	1997-2017	364	32	361	62	8.2
	F	1997-2017	488	42	473	59	6.3
	J	1997-2017	167	14	167	40	7.8
	Unk	1997-2017	135	12	107	56	5.9
	All	–	1,154	100	–	–	–
Current	M	2017-2018	76	41	72	62	6.9
	F	2017-2018	76	41	73	61	6.0
	J	2017-2018	33	18	33	43	2.5
	Unk	2017-2018	2	1	1	50	-
	All	–	187	100	–	–	–

[a]M = Male, F = Female, J = Jack, Unk = Unknown

[b]n = Number of fish measured for fork length (FL)

Table 4. Sex ratio percentages and mean fork length (FL) of coho carcasses within the Redwood Creek watershed for the period 1997-2017 compared to 2017-2018. SD = standard deviation.

			Carcasses				
Period	**Type[a]**	**Year**	**Sample Size**	**Sex Ratio %**	**n[b] for FL**	**Mean FL (cm)**	**FL SD (cm)**
Cumulative	M	1997-2017	58	25	51	66	7.6
	F	1997-2017	111	47	98	63	5.7
	J	1997-2017	22	9	22	41	4.7
	Unk	1997-2017	45	19	14	64	4.6
	All	–	236	100	–	–	–
Current	M	2017-2018	3	15	3	57	5.8
	F	2017-2018	11	55	4	63	6.8
	J	2017-2018	4	20	4	41	7.2
	Unk	2017-2018	2	10	0	–	–
	All	–	20	100	–	–	–

[a]M = Male, F = Female, J = Jack, Unk = Unknown

[b]n = Number of fish measured for fork length (FL)

3.2.4 Pine Gulch Creek Coho and Steelhead Escapement

Survey Timing and Environmental Conditions

One survey was conducted on 7 km of Pine Gulch Creek on 31 January 2018. Seven-day rainfall totals for Julian weeks within peak spawning months (December and January) ranged from a low of 0.00 inches during Julian week 50 to a high of 4.58 inches during Julian week 2. Average water clarity at the time of the survey was 90 cm.

Live Salmonids and Salmonid Carcasses

No live adult coho or steelhead spawners were observed on Pine Gulch Creek during the 2017-2018 season. One steelhead carcass was recovered on 31 January 2018.

Coho and Steelhead Redds

No coho redds were observed on Pine Gulch Creek during the 2017-2018 season. One steelhead redd was observed with an area of 3.2 m^2.

Pine Gulch Creek Watershed Coho Escapement History

The dataset for the adult escapement within Pine Gulch Creek includes 18 years of survey information following the discovery of one adult coho salmon during 2000-2001. Since this discovery, live adult coho and/or coho spawning activity have only been documented in the watershed 7 out of the 18 years (Appendix A, Table A6). The 2008-2009 season is the last time successful coho spawning occurred on Pine Gulch Creek.

3.3 Spring 2018 Outmigrant Coho Smolt Trapping Results

Results for smolt trapping are reported by Julian week (Appendix B, Table B1) to support analysis between monitoring years and watersheds. For the 2018 season, traps were installed during Julian week 13 due to mid-March storms. Since juvenile coho were not observed in Pine Gulch Creek during summer 2017 surveys, the stream was not monitored for smolt outmigration in 2018. Only Olema Creek and Redwood Creek data are included in this report. Smolt production estimates are only calculated for coho due to differences in outmigration timing between coho and steelhead smolts. Anecdotal information collected on steelhead smolt, SH 1+, steelhead SH YoY, and CO YoY are also summarized in this section.

3.3.1 Coho Smolt Outmigration Environmental Conditions and Timing

The onset of smoltification is likely controlled by photoperiod, but other cues such as spring weather patterns, changes in stream flow, and lunar phases may also influence the timing and rate of coho smolt outmigration (Spence and Hall 2010). Coho smolt downstream migration occurs from March through early June in Marin County, CA. Historically, Olema Creek coho smolt outmigration peaks during Julian weeks 16-18, and Redwood Creek outmigration peaks during Julian weeks 17-19 (Figures 7 and 8). In 2018, Olema Creek smolt outmigration peaked a week later when compared to historical timing. Coho smolt outmigration timing on Redwood Creek was relatively similar to the historical average (Figure 8). For both streams, the majority of smolts were captured during Julian week 17, shortly after storm events in early and mid-April.

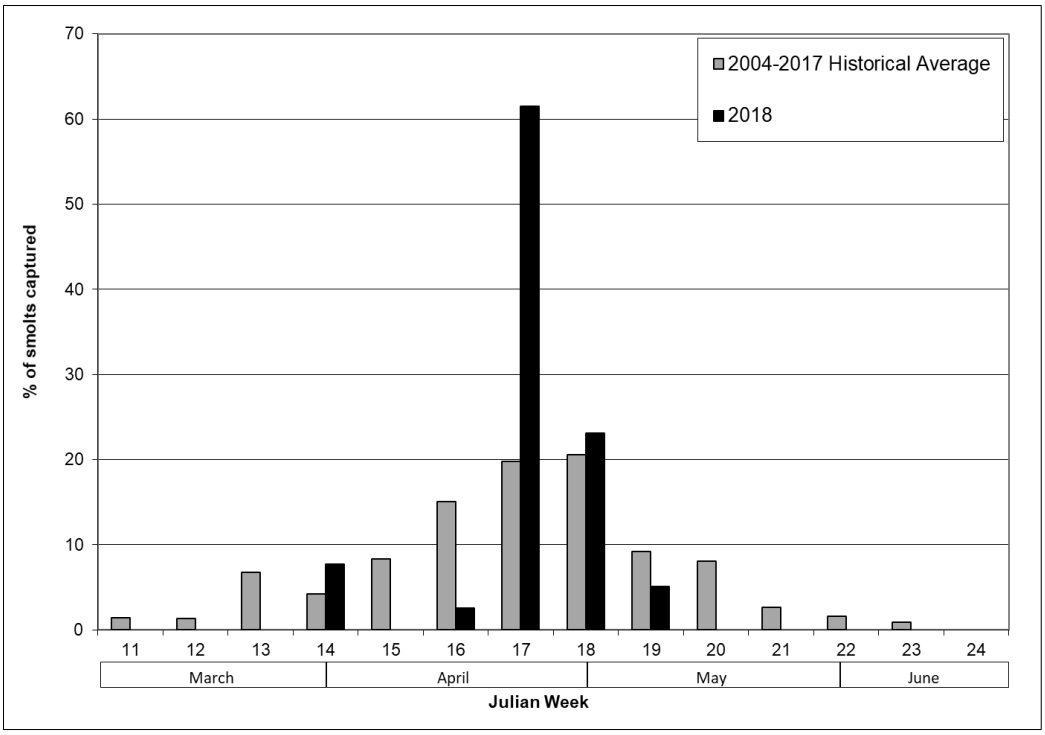

Figure 7. Percent of total coho smolts captured in the trap by Julian week for Olema Creek in 2018 compared to the historical average, 2004-2017.

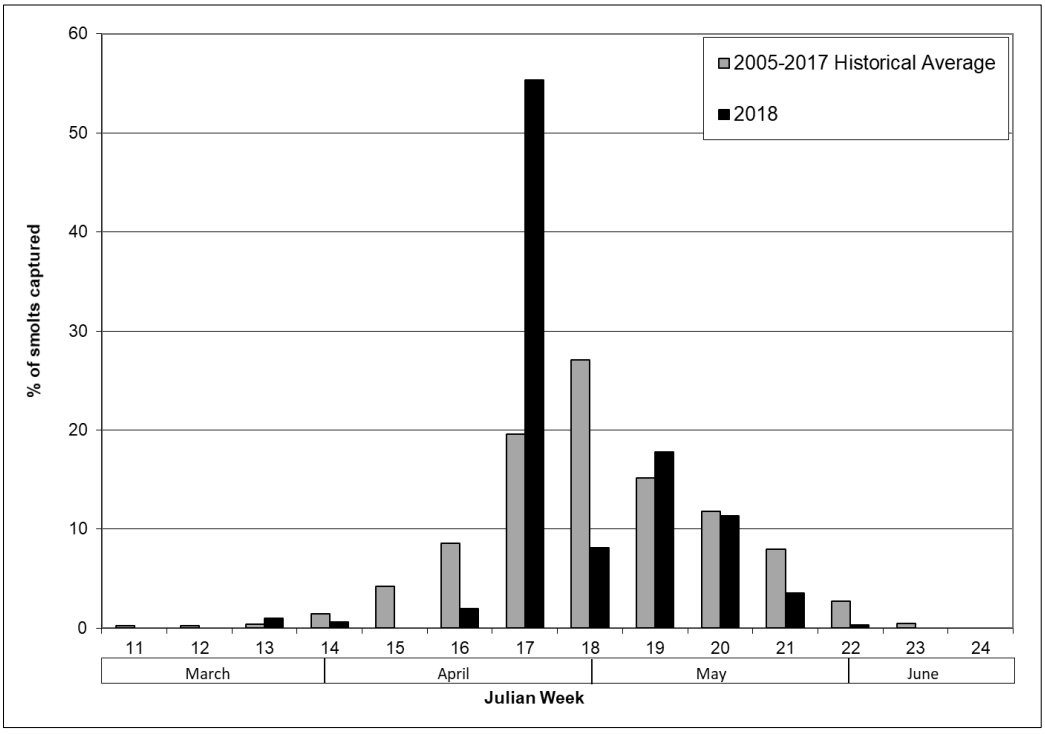

Figure 8. Percent of total coho smolts captured in the trap by Julian week for Redwood Creek in 2018 compared to the historical average, 2005-2017.

Spring Coho Outmigration Rainfall

Rainfall amounts were collected from gauges located at the Olema Valley Weather Station near Olema Creek and at the Highway 1 Bridge on Redwood Creek. A total of 12.92 inches of precipitation was recorded at the Olema Valley Weather Station during the 2018 smolt trapping season (March through May). The rain gauge at the Highway 1 Bridge on Redwood Creek recorded 11.50 inches of precipitation during the same period. For the 2018 trapping season, rainfall amounts at both Olema and Redwood Creek were much higher than the historical averages (8.71 inches and 6.38 inches, respectively).

Spring Coho Smolt Trap Water Temperature

Water temperatures were recorded on a fifteen minute interval using Onset HOBO® data loggers. Temperatures within the mainstem smolt traps on Olema Creek and Redwood Creek were within the tolerable range (less than 22 ºC) for coho salmon (Moyle 2002) throughout the season. During trapping operations, Olema Creek had an average temperature of 13.0 ºC (1.55 standard deviation [SD]), a maximum of 16.2 ºC, and a minimum of 7.9 ºC. Redwood Creek had an average temperature of 12.8 ºC (1.12 SD), a maximum of 15.1 ºC, and a minimum of 9.3 ºC.

3.3.2 Olema Creek Smolt Trapping Coho and Steelhead Results

For the 2018 outmigrant trapping study on Olema Creek, the smolt trap was in place for 60 days during the period 27 March to 31 May 2018. The trap was fully operational for 59 days and partially operational for one day. Trapping operations were suspended on April 1 and April 6-10 due to storm events.

The trap captured a total of 39 coho smolts, with a mortality rate of 0%. The overall recapture rate for marked coho smolts was 9% (2/22). DARR analysis of the coho smolt data stratified by day estimated capture probability at 6% for the first half of the season and 20% for the second half. The Olema Creek coho smolt production estimate for the 2018 season is 572, 95% CI [39, 1,576]. Figure 9 shows a summary of coho smolt production estimates for Olema Creek traps spring 2005 through 2018; smolt production estimates are calculated for coho only.

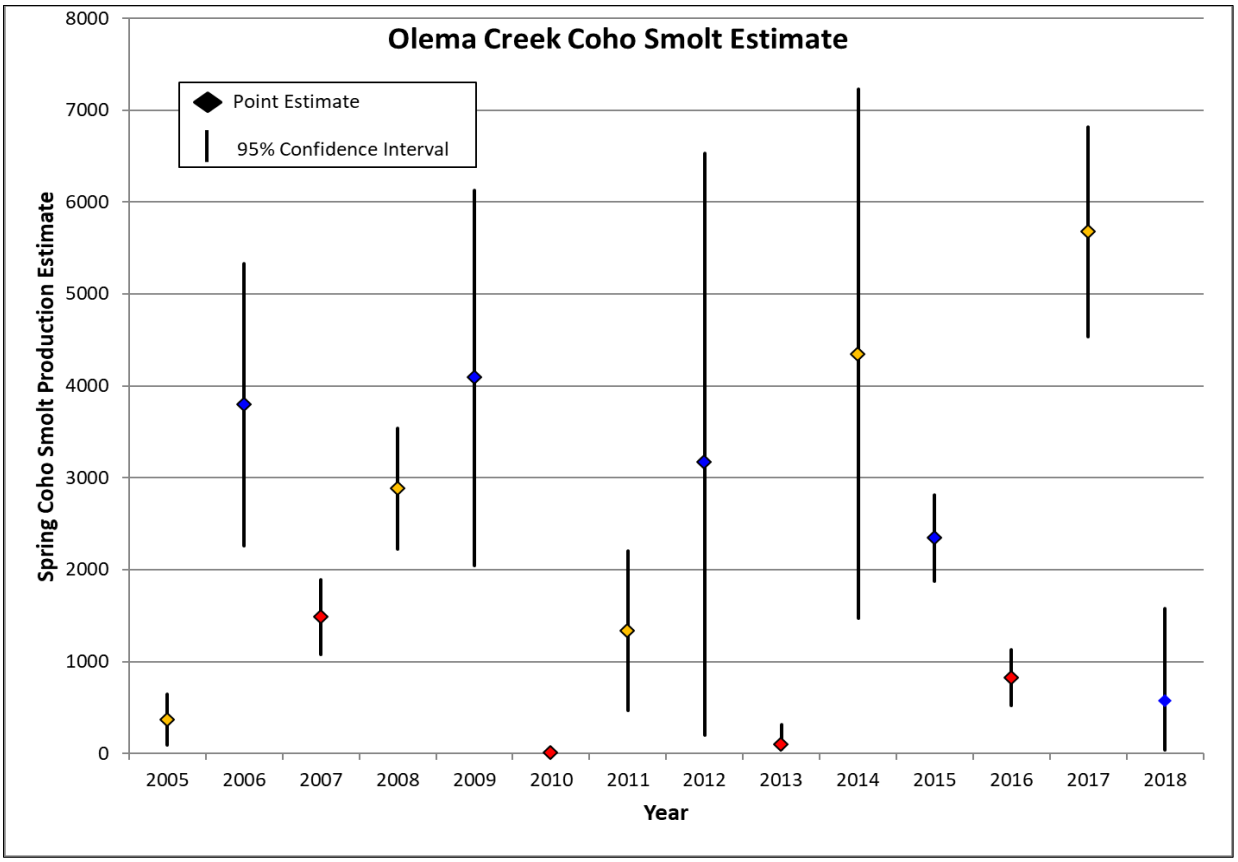

Figure 9. Coho smolt production estimates for Olema Creek, spring 2005-2018. The 2005 and 2013 estimates were calculated using the Chapman modification of the Petersen estimate equation, not using the DARR program. The 2010 estimate is the raw count and the 2004 estimate is not repeatable due to lack of mark recapture documentation. Cohorts are designated by color (cohort 1 shown in yellow, cohort 2 shown in blue, cohort 3 shown in red).

Additionally, the trap captured a total of three CO YoY, 34 steelhead smolts, 74 SH 1+, and 34 SH YoY. All CO YoY and SH YoY were captured mid-late May. The mortality rate was 0% for all salmonids captured in the Olema smolt trap this season.

A total of 22 coho smolts were implanted with PIT tags during the trapping season on Olema Creek. Tagged individuals had an average fork length of 124 mm and a median fork length of 125 mm. The average weight of tagged smolts was 20.1 g, and the median weight was 19.9 g. Two tagged smolts were subsequently recaptured with no observed mortality. These smolts spent an average of seven days in the system prior to recapture. Time spent upstream of the trap ranged from five to nine days, with a median of seven days. During 2017 summer basinwide surveys, 25 juvenile coho were implanted with PIT tags. No summer tags were recaptured during 2018 smolt trapping operations.

3.3.3 Redwood Creek Smolt Trapping Coho and Steelhead Results

The Redwood Creek smolt trap was in place and fully operational for 60 days during the period 28 March to 1 June 2018. Trapping operations were temporarily suspended on April 1 and April 6-10 due to storm events.

The mainstem trap captured a total of 309 coho smolts and the mortality rate was 2% (5/309). The overall recapture rate for marked coho smolts was 41% (57/139). DARR analysis of the coho smolt data stratified by day estimated capture probability at 41% for the entire smolt trapping season. The total Redwood Creek coho smolt production estimate is 751, 95% CI [579, 923]. Figure 10 shows a summary of coho smolt production estimates for Redwood Creek traps spring 2005 through 2018; smolt production estimates are calculated for coho only.

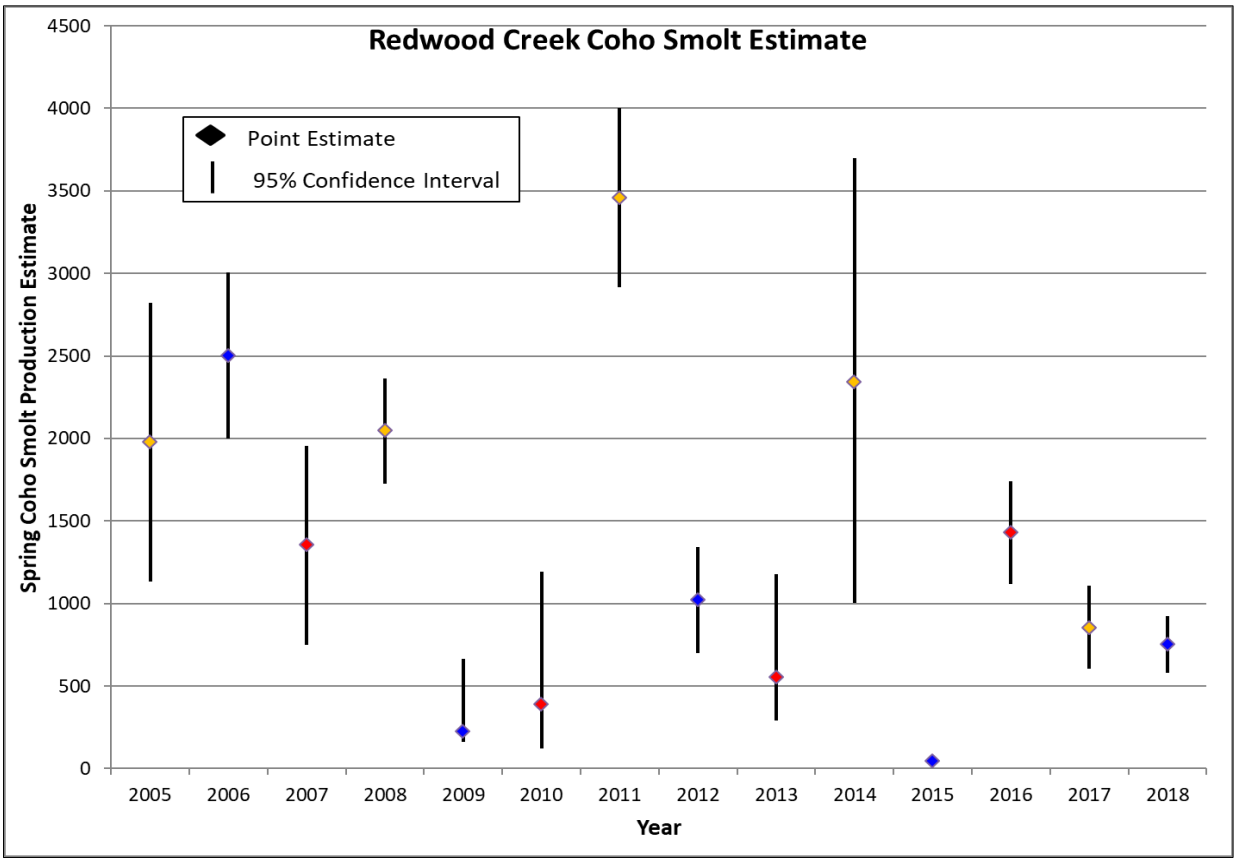

Figure 10. Coho smolt production estimates for Redwood creek, spring 2005-2018. The 2009 estimate was calculated using the Chapman modification of the Petersen estimate equation, not using the DARR program. The 2015 estimate is the raw count. Cohorts are designated by color (cohort 1 shown in yellow, cohort 2 shown in blue, cohort 3 shown in red).

A total of 54 steelhead smolts, 92 SH 1+, and two SH YoY were captured, with mortality rates of 0%, 1% (1/92), and 0%, respectively. Also captured were 142 CO YoY, with a mortality rate of 1% (2/142).

A total of 139 coho smolts were tagged on Redwood Creek during the 2018 trapping season. Tagged individuals had an average fork length of 102 mm and a median fork length of 100 mm. The average weight of tagged fish was 10.9 g, and the median weight was 10.2 g. Of the 139 tagged coho smolts, 57 were subsequently recaptured. Marked smolts spent an average of ten days in the system prior to recapture. Time spent upstream of the trap ranged from one day to 34 days, with a median of ten

days. The mortality rate for recaptured coho smolts was 4% (2/57). During 2017 summer basinwide surveys, 65 juvenile coho were implanted with PIT tags. Only one of these tagged juveniles was recaptured this season at the Redwood smolt trap. The fish showed an increase in length of 28 mm and an increase in weight of 6.82 g.

3.3.4 Coho and Steelhead Smolt Size and Condition

Length and weight data provide critical information that contributes to an understanding of fish health, survival, and condition factors. In addition, length and weight data allow for estimating fork length frequency, growth rates, and biomass production. Throughout the 2018 smolt trap operations, staff recorded fork lengths to the nearest mm and weights to the nearest 0.01 g of a subsample of fish caught in each trap.

Olema Creek Coho and Steelhead Smolt Fork Length and Weight

A total of 35 coho smolts were measured for fork length (mm) and weighed (0.01 g). Coho smolt fork lengths measured throughout the spring 2018 monitoring efforts on Olema Creek ranged from 104 mm to 155 mm. The highest length frequency was in the 126 mm to 130 mm length interval, representing 26% of the coho smolts measured. Mean and median weights are reported to the nearest 0.1 g. The mean and median coho smolt weight for the duration of the 2018 Olema trapping season was 19.6 g (SD 4.98 g). Figures 11 and 12 show fork length and weight data for coho smolts captured during smolt trapping operations spring 2004 through 2018.

All 34 steelhead smolts captured on Olema Creek were measured for fork length. Steelhead smolt fork lengths ranged from 115 mm to 175 mm, and the highest frequency of steelhead smolt fork lengths occurred within the 146 mm to 150 mm and 171 mm to 175 mm length intervals, with each interval representing 15% of the measured population. Figure 13 shows fork length information collected from steelhead smolts on Olema Creek beginning spring 2004.

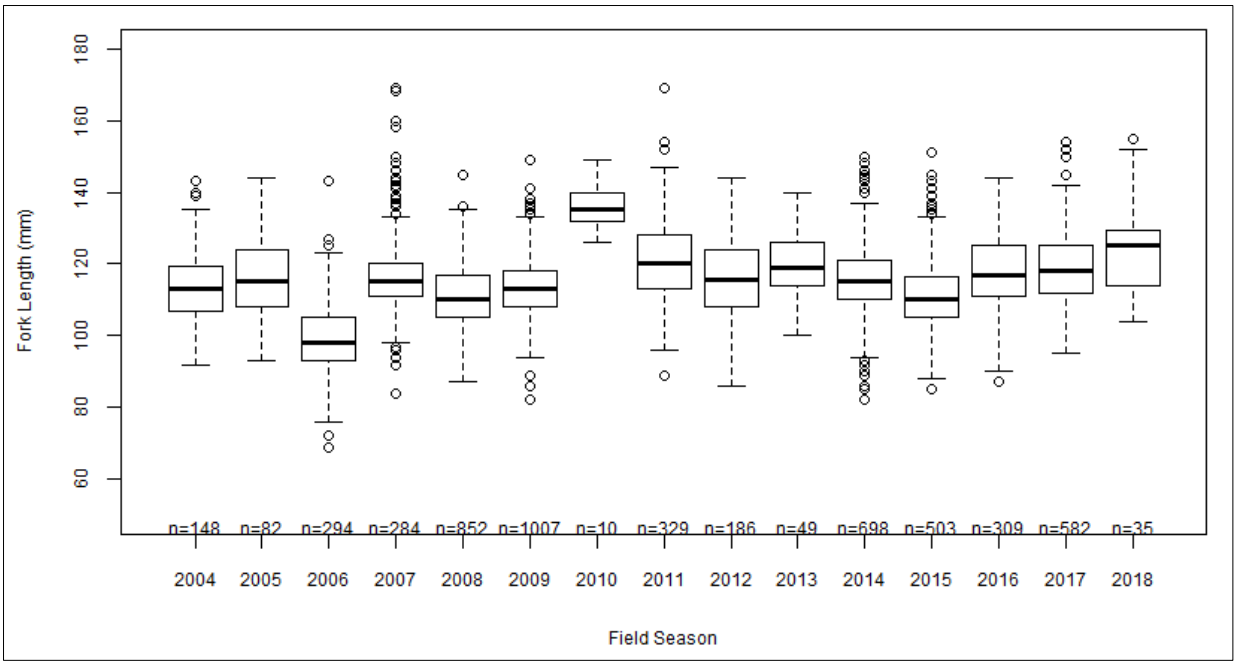

Figure 11. Box and whisker plots of coho salmon smolt fork length data for Olema Creek, 2004-2018. Dark lines represent medians, circles represent outliers, and n is sample size.

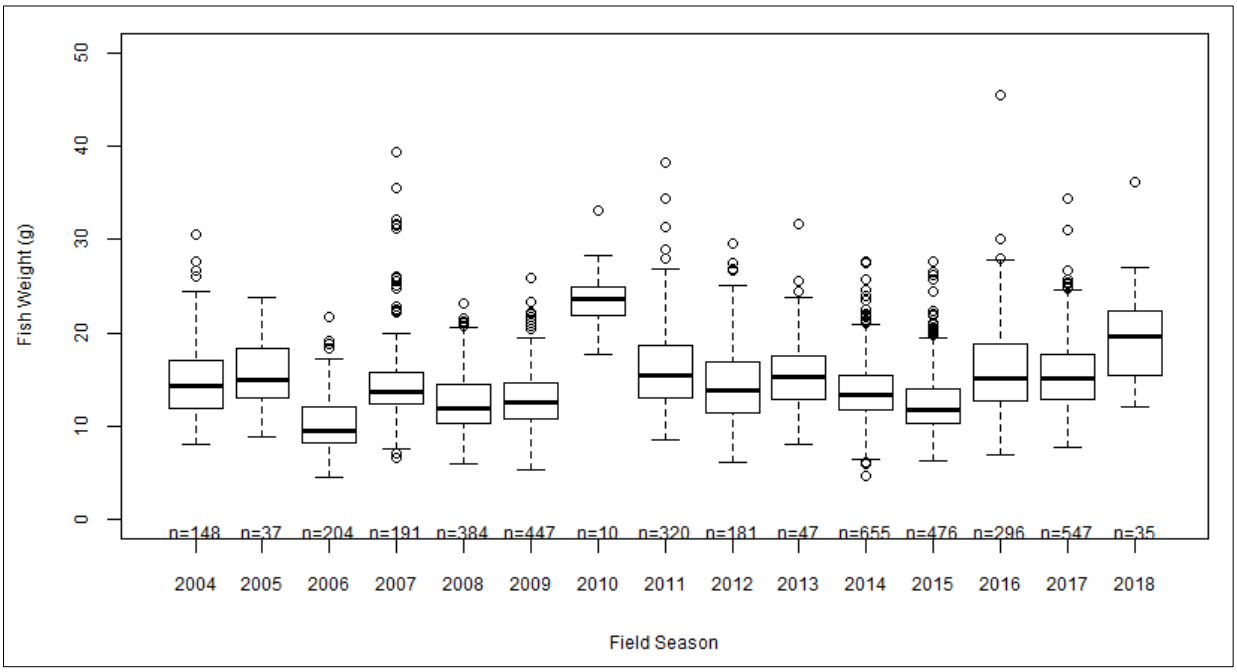

Figure 12. Box and whisker plots of coho salmon smolt weight data for Olema Creek, 2004-2018. Dark lines represent medians, circles represent outliers, and n is sample size.

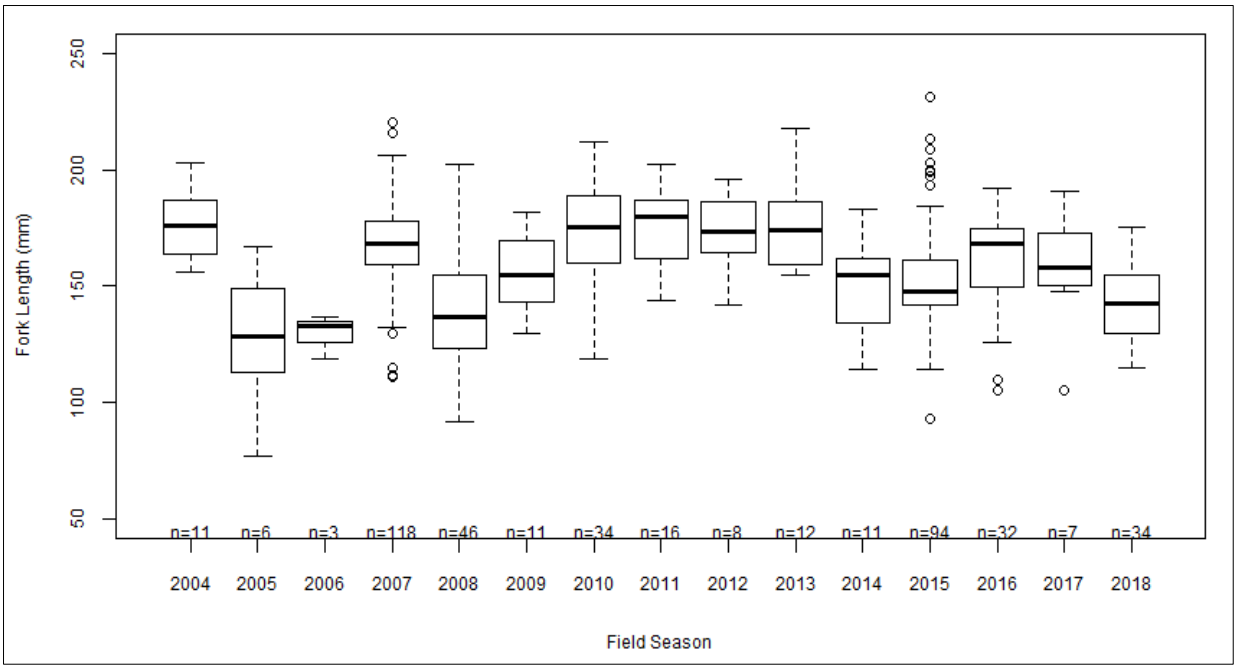

Figure 13. Box and whisker plots of steelhead smolt fork length data for Olema Creek, 2004-2018. Dark lines represent medians, circles represent outliers, and n is sample size.

Redwood Creek Coho and Steelhead Smolt Fork Length and Weight

A total of 240 coho smolts were measured for fork length (mm), and 235 of these fish were also weighed (0.01 g). Coho smolt fork lengths measured throughout the 2018 outmigrant trapping season ranged from 72 mm to 144 mm. The highest length frequency of coho smolts on Redwood Creek was in the 91 mm to 95 mm length interval, representing 20% of the coho smolts measured. Mean and median weights are reported to the nearest 0.1 g. The mean coho smolt weight for the duration of the 2018 trapping season was 10.7 g (SD 3.13 g), and the median weight was 10.1 g. Figures 14 and 15 show fork length and weight data for coho smolts captured on Redwood Creek.

All 54 steelhead smolts captured on Redwood Creek were measured for fork length. Steelhead smolt fork lengths ranged from 99 to 175 mm. The highest frequency of steelhead smolt fork lengths occurred within the 151 to 155 mm length interval, accounting for 13% of the steelhead smolts measured. Figure 16 shows fork length information for steelhead smolts captured on Redwood Creek.

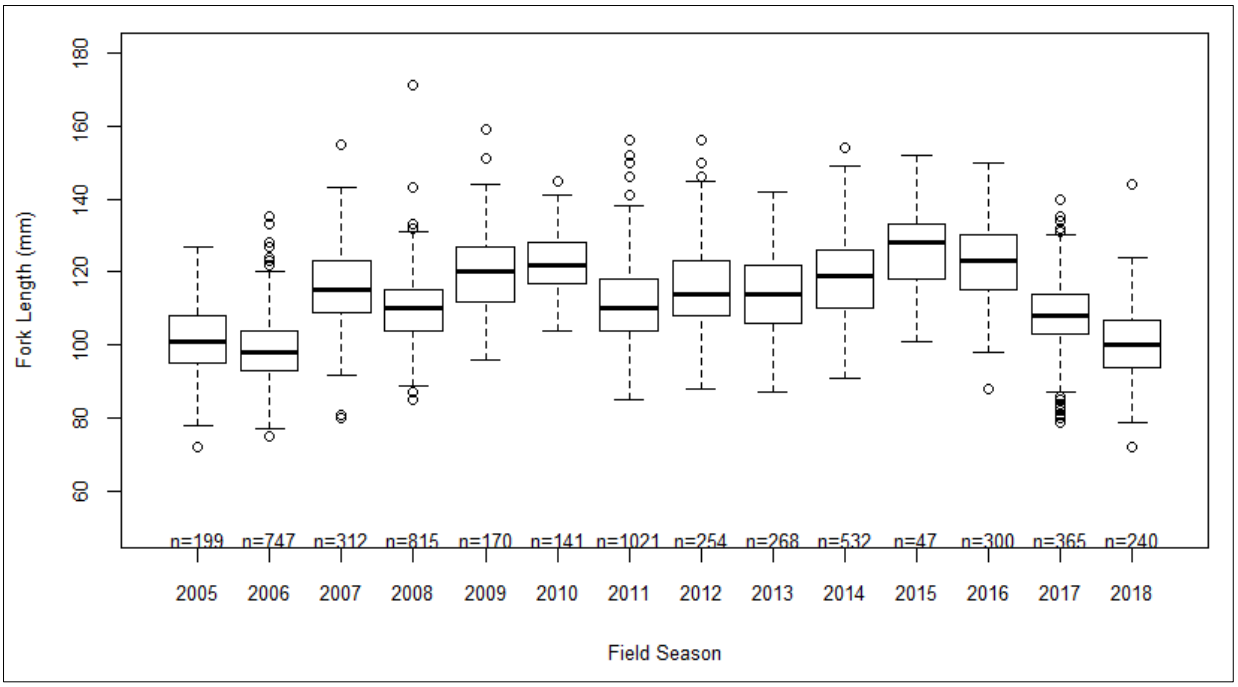

Figure 14. Box and whisker plots of coho salmon smolt fork length data for Redwood Creek, 2005-2018. Dark lines represent medians, circles represent outliers, and n is sample size.

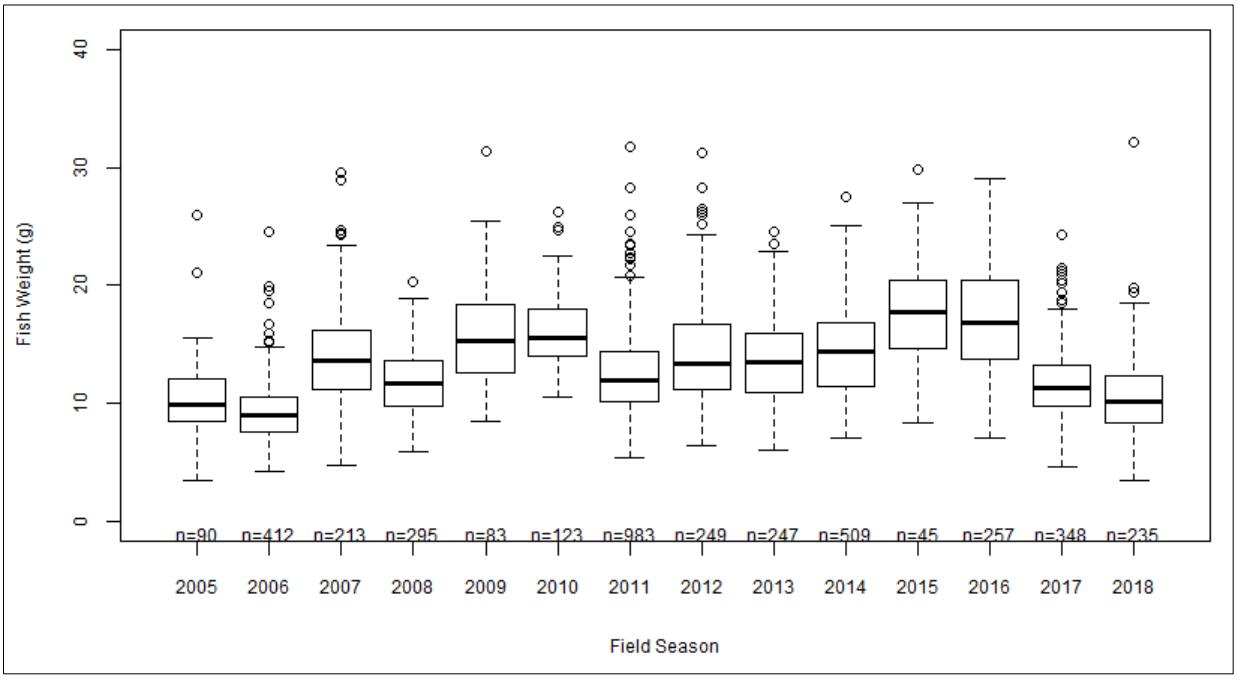

Figure 15. Box and whisker plots of coho salmon smolt weight data for Redwood Creek, 2005-2018. Dark lines represent medians, circles represent outliers, and n is sample size.

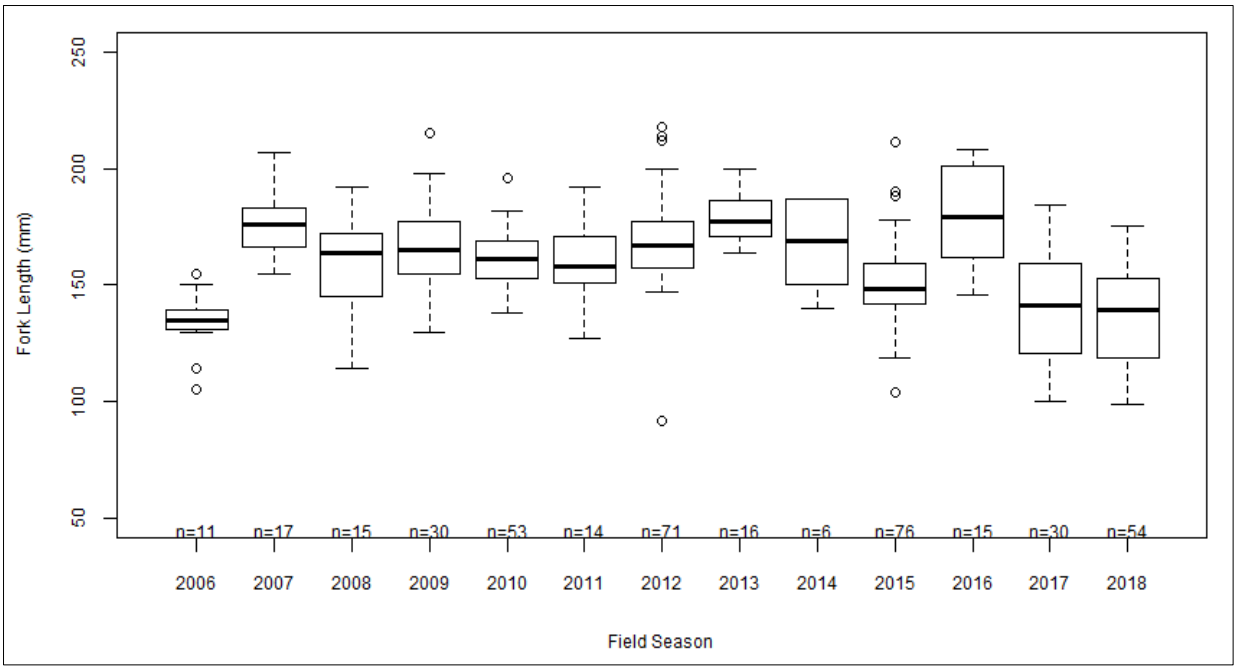

Figure 16. Box and whisker plots of steelhead smolt fork length data for Redwood Creek, 2006-2018. No steelhead smolts were measured in 2005. Dark lines represent medians, circles represent outliers, and n is sample size.

Coho and Steelhead Fulton's Condition Factor

Length is the principal factor affecting the weight of fishes. In spite of this, there can be significant differences in weight distribution among similar size fish of the same species within a particular watershed. In order to compare length-weight relationships, we applied the Fulton's condition factor (K-factor) to establish comparable indices of condition (Murphy and Willis 1996). Fulton's condition factor is a ratio relating fish length to fish weight, allowing for the measurement of the relative biomass of a fish. Therefore, only fish with both an associated fork length and weight can be used to calculate K-factor ratios.

Table 5 shows mean and median length, weight, and K-factor for coho smolts captured during 2018 smolt trap sampling on Olema and Redwood Creeks, while Table 6 shows mean and median fork length, weight, and K-factor for steelhead smolts caught during smolt trap sampling. Mean and median weights are reported to the nearest 0.1 g. Generally, two sample sizes are presented for each species and watershed. The first sample size is the total number of fish measured for fork length, while the second sample size represents those fish which were also weighed. Fish in the second sample size were used for calculating mean K-factor. If only one sample size is shown, all fish measured for fork length were weighed. Historical fork length, weight, and K-factor data for salmonid smolts on Olema and Redwood Creeks is in Appendix A, Tables A7 through A10.

Table 5. Coho smolt mean and median fork length, weight, and K-factor calculated during 2018 for the trapping locations on Olema and Redwood Creeks. Two sample sizes are presented when the sample size of smolts measured for length (presented first) differed from the sample size of smolts both measured and weighed (presented second). FL = fork length, SD = standard deviation.

Watershed	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-factor	K-factor SD
Olema Creek	35	124	125	11.3	19.6	19.6	4.98	1.02	0.08
Redwood Creek	240, 235	101	100	9.5	10.6	10.1	3.15	1.01	0.08

Table 6. Steelhead smolt mean and median fork length, weight, and K-factor calculated during 2018 for the trapping locations on Olema and Redwood Creeks. Two sample sizes are presented when the sample size of smolts measured for length (presented first) differed from the sample size of smolts both measured and weighed (presented second). FL = fork length, SD = standard deviation.

Watershed	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-factor	K-factor SD
Olema Creek	34, 33	143	143	18.2	31.9	31.1	10.75	1.04	0.09
Redwood Creek	54, 51	137	140	19.9	25.5	26.7	9.20	0.97	0.09

3.3.5 Smolt Trap Summary of Non-salmonid Total Catch

On Olema Creek, a total of 704 non-salmonid aquatic vertebrates were captured during the 2018 trapping season. The majority of the non-salmonid catch was comprised of sculpin (46%) and California roach (41%). Of the 1,028 non-salmonid aquatic vertebrates captured in the mainstem Redwood Creek trap, 848 (83%) were three-spined stickleback. Historical non-salmonid catch information is in Appendix A, Tables A11 and A12.

3.4 Juvenile Coho and Steelhead Basinwide 2018 Results

Summer juvenile monitoring results are provided for Olema Creek, Redwood Creek, and Pine Gulch Creek.

3.4.1 Olema Creek

The 2018 summer habitat survey and basinwide snorkel surveys of Olema Creek were initiated at monument tag 15, the current Olema Creek smolt trapping site, and surveyed to monument tag 150, adjacent to the Randall Ranch House. The measured basinwide survey length for the main channel was 12.9 km. Stream segments totaling approximately 1.0 km in length were not sampled as they were (1) deemed inaccessible due to dense vegetation, (2) deemed marshlands with no defined channel, or (3) because we had concerns with water quality, specifically, high concentrations of fecal coliform.

Habitat Survey

A total of 1,184 mainstem habitat units were identified in the 12,945 m Olema Creek survey reach. Pool units were the dominant habitat type available to fish, measuring 7,536 m and accounting for 58% of the total mainstem length, up 2% from the previous year. Habitat composition data for Olema Creek are located below in Table 7. Intermittent conditions were observed approximately 10 km upstream from the mouth of Olema Creek. Dry sections of streambed accounted for 12% of the total length surveyed, also up 2% from the previous year. Side channel and backwater units were also measured but not incorporated into the basinwide habitat analysis. Overall, 728 m of side channel habitat and 440 m of backwater habitat was measured during the survey. Flatwater and riffle habitat types accounted for 82% of the total side channel habitat length.

Total wetted mainstem survey length was 11,453 m and was used to calculate side channel and backwater density, 6.4 m per 100 m and 3.8 m per 100 m, respectively. For the 2018 season, both side channel and backwater density were higher than the historical averages of 6.2 m per 100 m and 2.2 m per 100 m.

Table 7. Habitat composition of Olema Creek coho survey reach, summer 2018. Measured total length is used to calculate percentages of length per habitat type.

Unit Type	Total length (m)	% of length	# of units	% of units
Pool	7,536	58	416	35
Flatwater	1,724	13	286	24
Riffle	2,194	17	333	28
Dry	1,491	12	149	13
Total	12,945	100	1,184	100

Woody debris information collected during the basinwide habitat survey is summarized for 2005-2017 and 2018 (Table 8) and may be used to identify trends in wood availability and recruitment. The total wetted mainstem survey length was used to calculate densities. When compared to the historical average, density of small woody debris jams was 50% less in 2018. Both the 10-20 cm and 20-50 cm woody debris categories had significantly higher (at least one standard deviation) densities in summer 2018.

Table 8. Summary of basinwide in-stream woody debris (WD) per 100 m during summer base flow conditions in Olema Creek. Average 2005-2017 compared to 2018.

Field season	Survey length (# 100 m sections)	Root Wads per 100 m	LWD[a] Jams per 100 m	SWD[b] Jams per 100 m	10-20cm WD[c] per 100 m	20-50cm WD[c] per 100 m	>50cm WD[c] per 100 m
2005-2017 Average	114.7	1.3	0.5	0.6	2.7	2.5	0.8
2018	114.5	1.2	0.4	0.3	3.6	4.1	0.8

[a]LWD Jams = 10 or more pieces of large woody debris

[b]SWD Jams = 10 or more pieces of small woody debris

[c]10-20 cm, 20-50 cm, >50 cm refer to diameter of individual pieces of woody debris

Coho Snorkel Counts and Basinwide Estimate

Snorkel surveys were conducted on 19% of the delineated pools and 16% of flatwaters with a depth of 0.2 m or greater. Coho were observed in 49% (40 of 82) of pools and 9% (2 of 22) of flatwaters. The raw count of juvenile coho was 347, giving an estimate of 3.3 coho per snorkel unit. Nineteen (18%) of the 104 units were electrofished within a day following the snorkel counts, and two (2%) of the 104 pools were re-snorkeled immediately following the initial pass using the method of bounded counts. *Microfish* and bounded count population estimates for the resampled pools were used to calibrate the snorkel counts. The 2018 basinwide estimate for juvenile coho was 1,301, 95% CI [963, 1,639]. Summer coho population estimates with 95% confidence interval were calculated for the basinwide survey reach from 2004 to 2018 and are included in Figure 17.

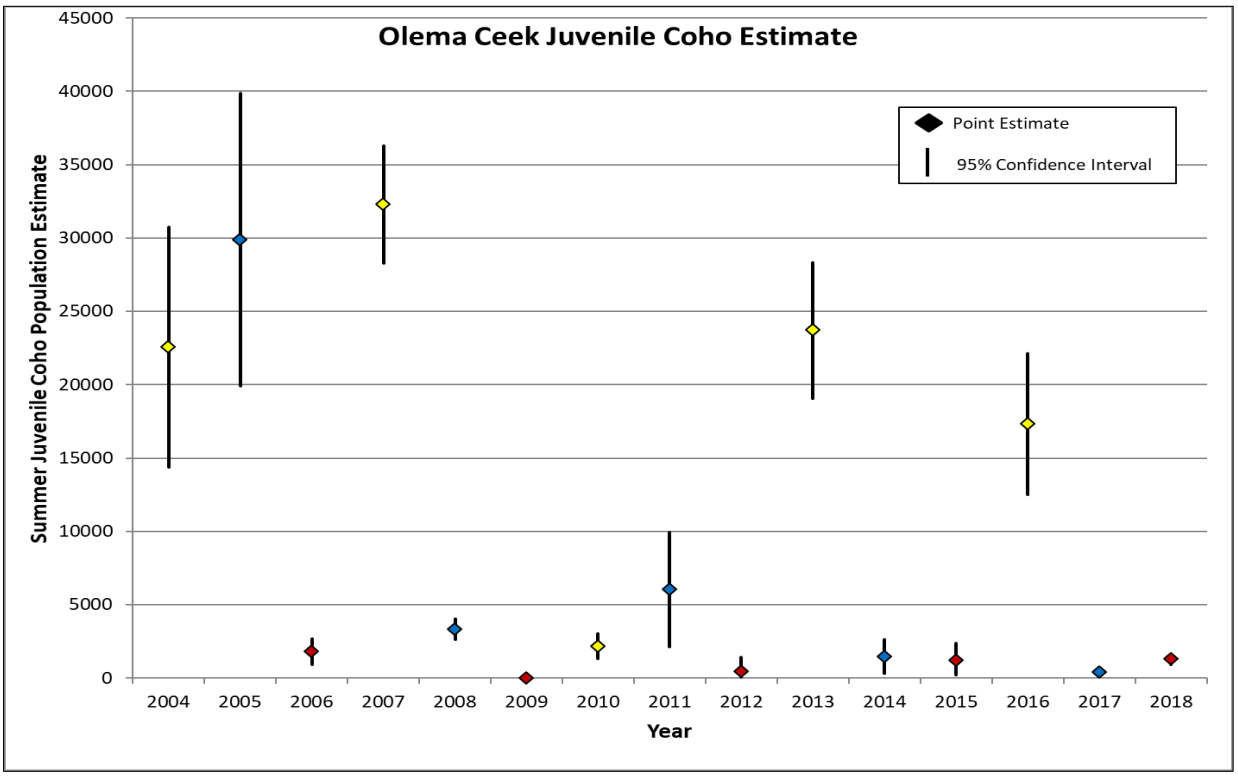

Figure 17. Summer juvenile coho basinwide population estimates for Olema Creek, 2004 through 2018. Cohorts are designated by color (cohort 1 shown in yellow, cohort 2 shown in blue, cohort 3 shown in red).

Summer Coho and Steelhead Measurement Information

As part of the summer basinwide monitoring surveys, a random subsample of fish are measured for fork length (mm) and weighed (0.01 g) within each electrofished unit. With only 38 total juvenile coho captured on Olema Creek this season, the random subsample included all 38 fish. Coho fork lengths measured throughout the summer 2018 monitoring efforts on Olema Creek ranged from 60 mm to 82 mm. The highest frequency of fork lengths for coho juveniles occurred within the 71 mm to 75 mm length interval, representing 47% of the subsample of coho measured in 2018. Mean and

median weights are reported to the nearest 0.1 g. The Olema Creek mean and median coho juvenile weight was 4.4 g (SD 0.85 g). Figures 18 and 19 show representations of fork lengths and fish weights for coho juveniles caught on Olema Creek during summers 2010 through 2018.

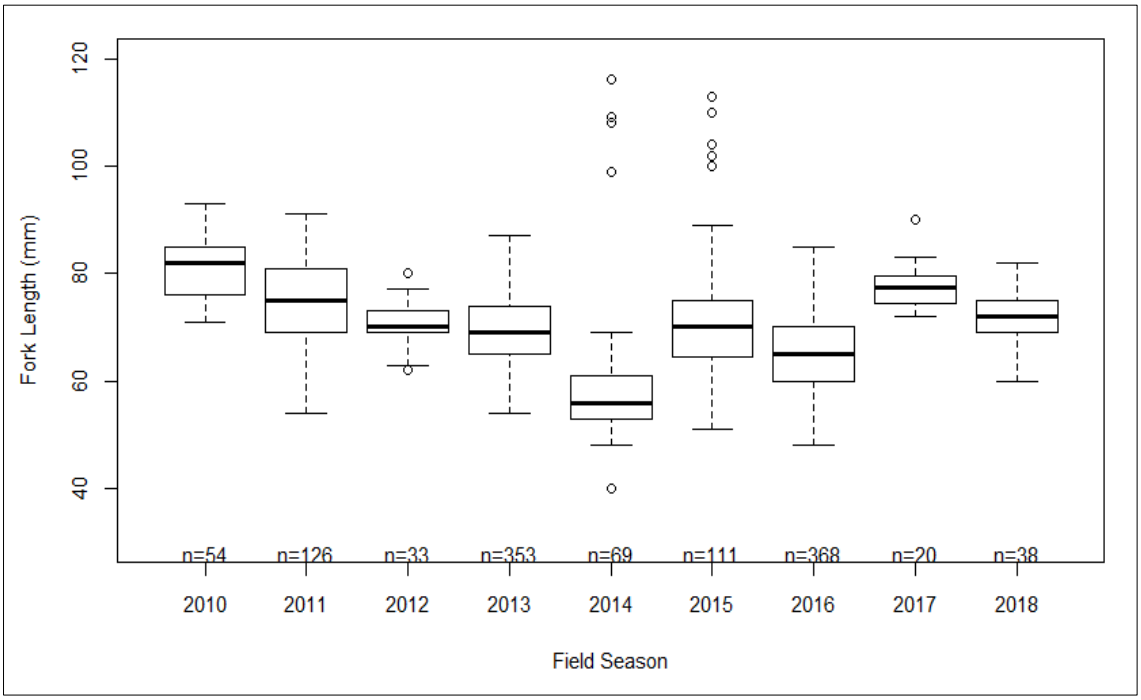

Figure 18. Box and whisker plots of juvenile coho fork length data for basinwide Olema Creek, summer 2010-2018 (no coho captured in 2009). Dark Lines represent medians, circles represent outliers, and n is sample size.

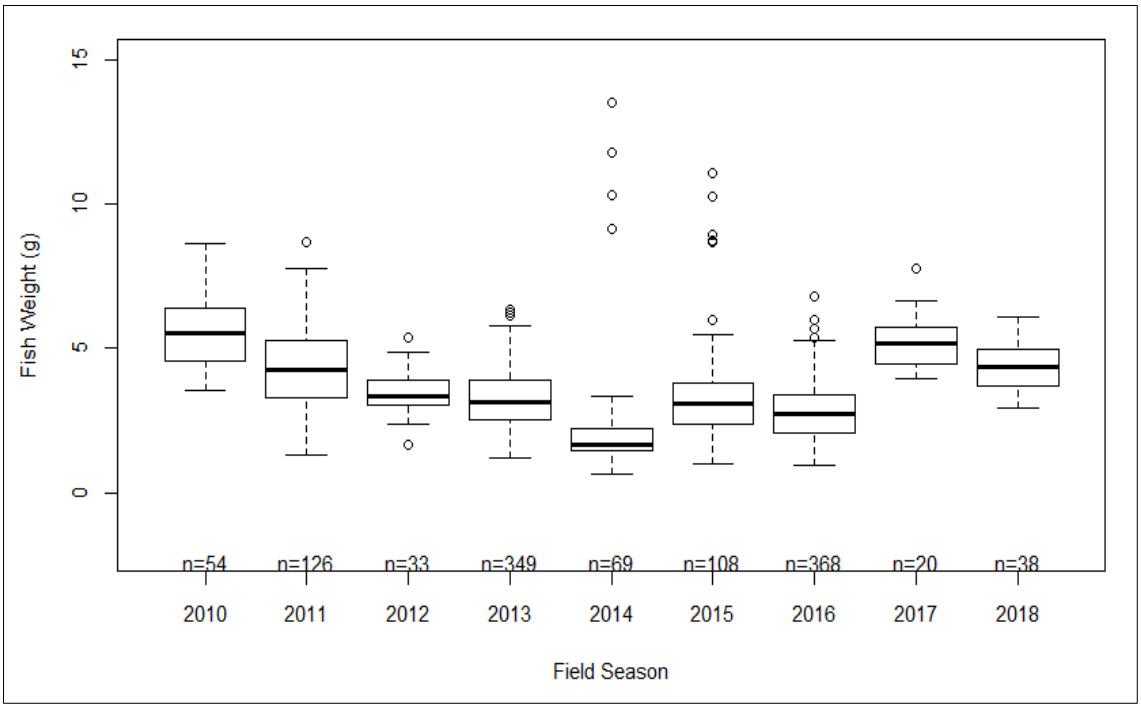

Figure 19. Box and whisker plots of juvenile coho weight data for basinwide Olema Creek, summer 2010-2018 (no coho captured in 2009). Dark Lines represent medians, circles represent outliers, and n is sample size.

Within the Olema Creek sample, 307 steelhead were measured for fork length (mm). Of those 307 fish, 305 were also weighed (0.01 g). The size range for steelhead was 45 to 187 mm. Fork length frequencies were used to establish age class bins. The highest frequency of fork lengths for steelhead occurred within the 61 to 65 mm length interval, representing 19% of the sample. The Olema Creek mean steelhead young-of-year (SH YoY) weight was 3.0 g (SD 1.47 g), with a median weight of 2.6 g. The mean weight of steelhead one year or older (SH 1+) was 23.8 g (SD 13.80 g), with a median weight of 18.7 g. Figures 20 and 21 show fork length information collected from Olema Creek SH YoY and SH 1+ for summers 2009 through 2018.

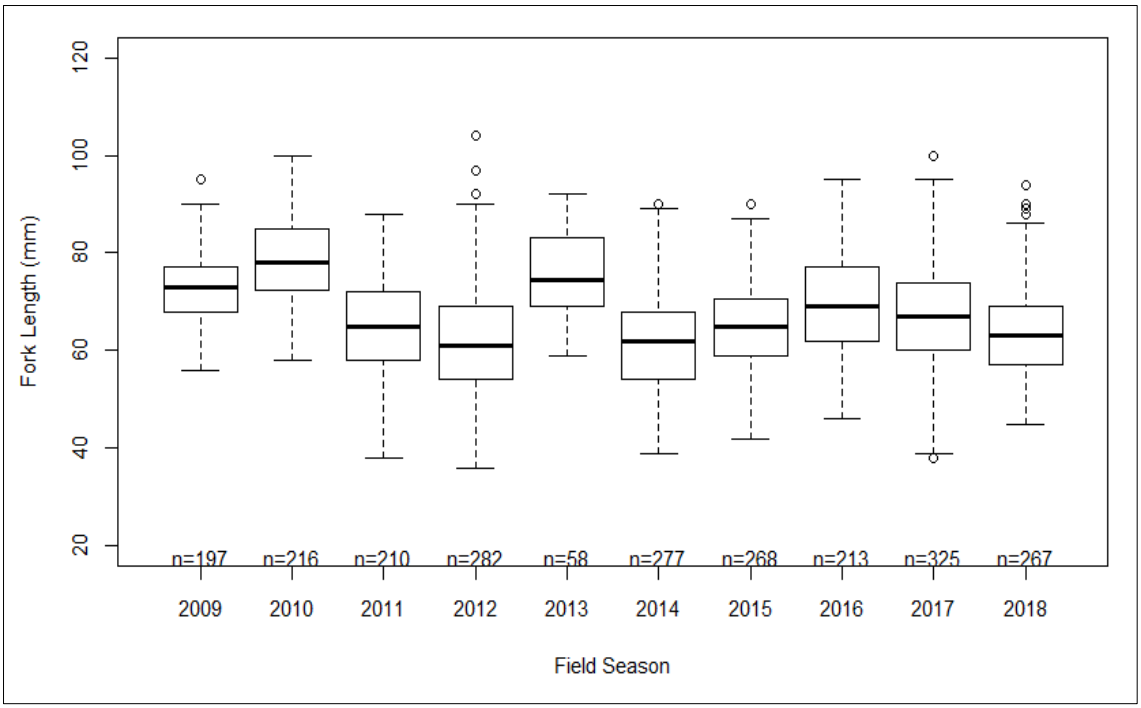

Figure 20. Box and whisker plots of young-of-year steelhead fork length data for basinwide Olema Creek, summer 2009-2018. Dark Lines represent medians, circles represent outliers.

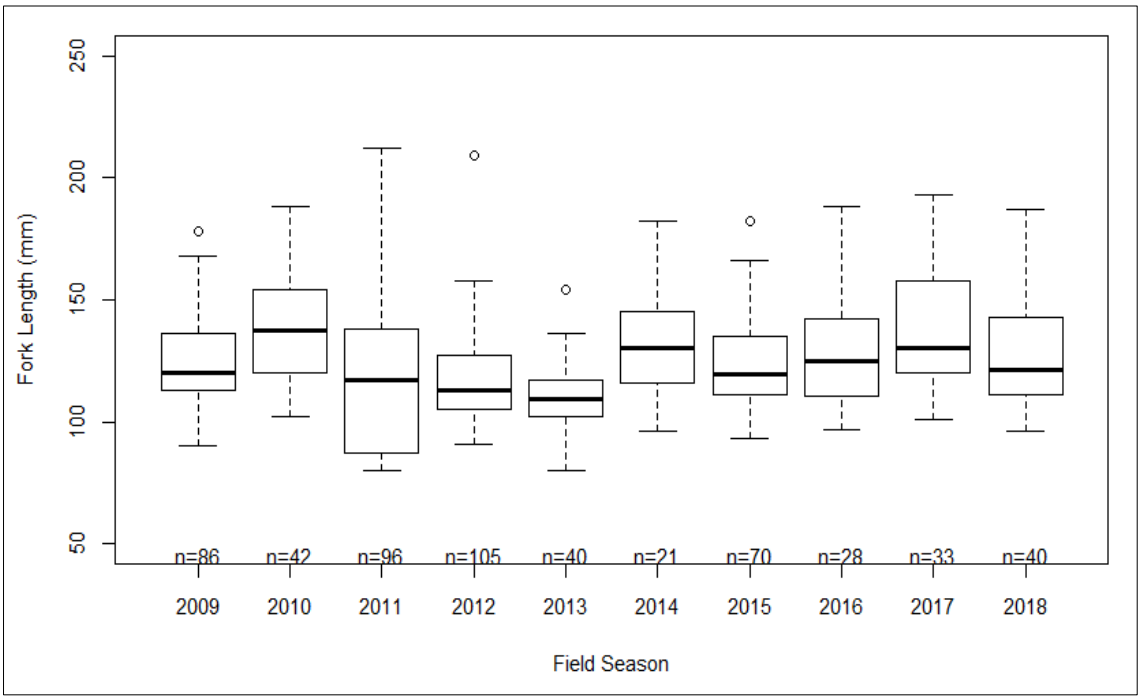

Figure 21. Box and whisker plots of 1+ steelhead fork length data for basinwide Olema Creek, summer 2009-2018. Dark Lines represent medians, circles represent outliers.

Coho and Steelhead Fulton's Condition Factor

Table 9 shows mean and median fork length, weight, and K-factor data for juvenile coho captured during 2018 basinwide sampling on Olema Creek. Table 10 shows the length, weight, and K-factor data for steelhead YoY and steelhead 1+ caught during basinwide sampling. Mean and median weights are reported to the nearest 0.1 g. Generally, two sample sizes are presented for each species and age class. The first sample size is the total number of fish measured for fork length, while the second sample size represents those fish which were also weighed. Fish in the second sample size were used for calculating mean K-factor. If only one sample size is shown, all fish measured for fork length were weighed.

Table 9. Mean and median fork length, weight, and K-factor calculated for coho measured and weighed in the basinwide calibration pools on Olema Creek mainstem, summer 2018. Two sample sizes are presented when the sample size of coho measured for length (presented first) differed from the sample size of coho both measured and weighed (presented second). FL = fork length, SD = standard deviation.

Species	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-Factor	K-Factor SD
Coho	38	72	72	4.7	4.4	4.4	0.85	1.14	0.10

Table 10. Mean and median fork length, weight, and K-factor calculated for steelhead measured and weighed in the basinwide calibration pools on Olema Creek mainstem, summer 2018. Two sample sizes are presented when the sample size of steelhead measured for length (presented first) differed from the sample size of steelhead both measured and weighed (presented second). FL = fork length, SD = standard deviation, YoY = young-of-year, 1+ = one year or older.

Species	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-Factor	K-Factor SD
Steelhead YoY	267, 266	64	63	9.7	3.0	2.6	1.47	1.08	0.10
Steelhead 1+	40, 38	128	122	23.4	23.8	18.7	13.80	1.05	0.09

3.4.2 Redwood Creek

The 2018 summer habitat and basinwide snorkel surveys of Redwood Creek were initiated at the confluence of Redwood Creek and the Pacific Ocean, and continued upstream to monument tag 74, within Mt. Tamalpais State Park. The measured basinwide survey length for the main channel was 8.5 km. An additional 0.8 km was surveyed on Fern Creek, a tributary to Redwood Creek.

Habitat Survey

A total of 670 mainstem habitat units were identified within the 8,546 m Redwood Creek survey reach. Pool units were the primary habitat type accounting for 5,090 m and 60% of the total mainstem length. Dry units were not observed on the mainstem during surveys. Habitat composition data for Redwood creek can be found below in Table 11. Overall, 565 m of side channel habitat and

352 m of backwater habitat units were measured during the basinwide survey. Riffle units accounted for 55% of the side channel habitat length.

An additional 768 m were surveyed in Fern Creek, a tributary to Redwood Creek. Riffle units accounted for the majority (52%) of the length. Pool units represented 26% of the length, while flatwater and dry units accounted for the remaining 22%. There was only one dry habitat unit recorded on Fern Creek and had a length of 2 meters.

The total wetted mainstem survey length was used to calculate the density of side channel and backwater habitat, 6.6 m per 100 m and 4.1 m per 100 m, respectively. The density of side channel and backwater habitats in 2018 were considerably higher than the historical averages (2004 to 2017 side channel average of 4.5 m per 100 m, 2004 to 2017 backwater average of 1.9 m per 100 m).

Table 11. Habitat composition of Redwood Creek coho survey reach, summer 2018. Measured total length is used to calculate percentages of length per habitat type.

Unit Type	Total length (m)	% of length	# of units	% of units
Pool	5,090	60	274	41
Flatwater	1,195	14	134	20
Riffle	2,261	26	262	39
Dry	0	0	0	0
Total	8,546	100	670	100

Woody debris information collected during the basinwide habitat survey is summarized for 2005-2017 and 2018 (Table 12) and may be used to identify trends in woody debris availability and recruitment. Since no dry units were observed, total mainstem survey length was used to calculate densities. Three of the six woody debris categories, including root wads, 10-20 cm wood, and 20-50 cm wood, had above-average densities for summer 2018.

Table 12. Summary of basinwide in-stream woody debris (WD) per 100 m during summer base flow conditions in Redwood Creek. Average 2005-2017 compared to 2018.

Field season	Survey length (# 100 m sections)	Root Wads per 100 m	LWD[a] Jams per 100 m	SWD[b] Jams per 100 m	10-20cm WD[c] per 100 m	20-50cm WD[c] per 100 m	>50cm WD[c] per 100 m
2005-2017 Average	81.6	1.1	0.4	0.7	3.4	2.8	1.2
2018	85.5	1.2	0.3	0.4	3.7	3.2	1.0

[a]LWD Jams = 10 or more pieces of large woody debris

[b]SWD Jams = 10 or more pieces of small woody debris

[c]10-20 cm, 20-50 cm, >50 cm refer to diameter of individual pieces of woody debris

Woody debris information was also collected on Fern Creek. The category of 10-20 cm woody debris had the highest density at 3.4 per 100 m. Small woody debris jam density was the lowest at 0.3 per 100 m on both Fern Creek and mainstem Redwood Creek.

Coho Snorkel Counts

Snorkel surveys were conducted on 26% of the delineated pools and 14% of flatwaters with coho observed in 92% (65 out of 71) of the sampled pools and 58% (7 out of 12) of sampled flatwater units. A total of 1,075 coho were counted in the 83 snorkeled units, giving a raw average of 13.0 coho per snorkel unit. An additional eight pools were snorkeled on Fern Creek. No coho juveniles were observed on Fern Creek pools during the snorkel surveys. Sixteen of the 83 snorkeled units (19%) were electrofished within a day following the snorkel counts. *Microfish* population estimates for the electrofished units were used to calibrate the snorkel counts. On Fern Creek, one pool with a snorkel count of zero coho was subsequently electrofished for calibration, and no coho were captured. The 2018 basinwide estimate for juvenile coho was 4,475, 95% CI [3,613, 5,337]. Summer coho population estimates with 95% confidence interval were calculated for the basinwide survey reach from 2005 through 2018 (Figure 22).

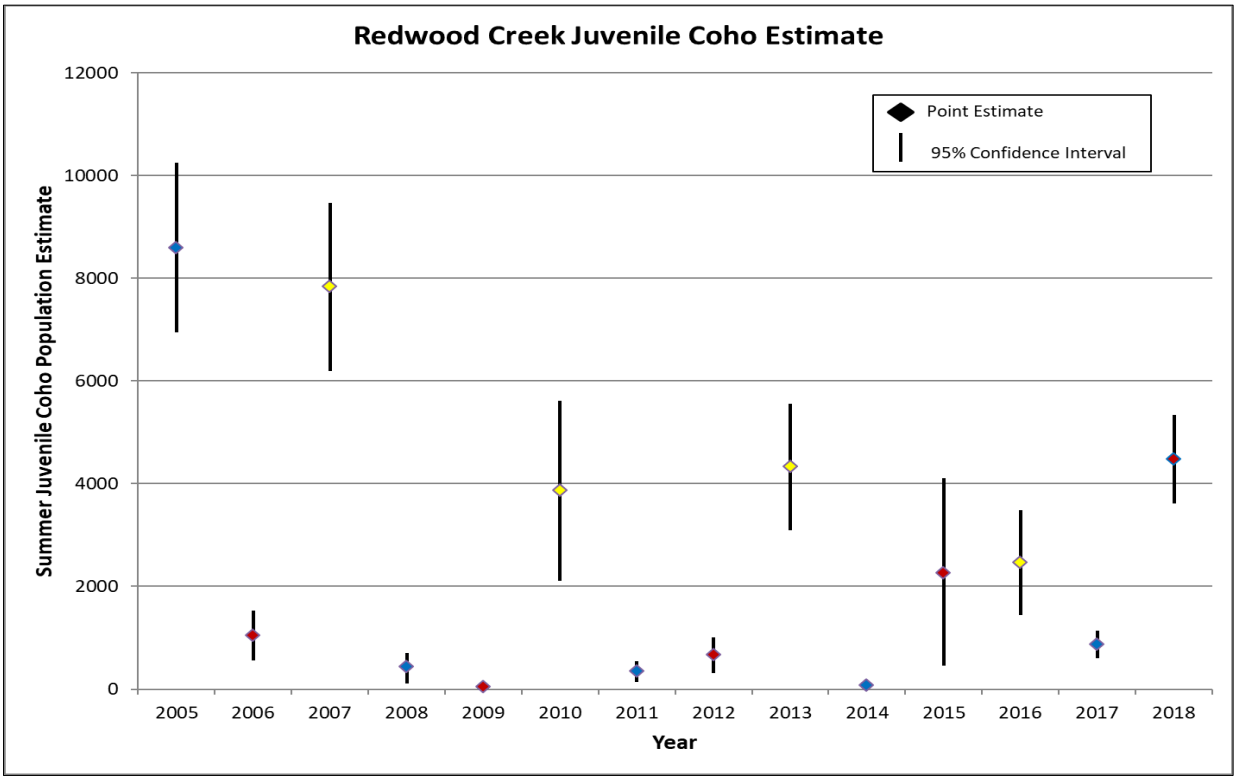

Figure 22. Summer juvenile coho basinwide population estimates for Redwood Creek, 2005-2018. Cohorts are designated by color (cohort 1 shown in yellow, cohort 2 shown in blue, cohort 3 shown in red).

Summer Coho and Steelhead Measurement Information

A random sample of 141 juvenile coho were measured for fork length (mm), and 136 of those fish were also weighed (0.01 g). Coho fork lengths measured during 2018 summer basinwide monitoring of Redwood Creek ranged from 53 mm to 119 mm. The highest fork length frequencies for coho occurred within the 61 to 65 mm and 66 to 70 mm length intervals, representing 57% of the sample. Mean and median weights are reported to the nearest 0.1 g. The Redwood Creek mean coho weight

was 3.4 g (SD 1.28 g), and the median weight was 3.1 g. Coho juvenile fork length and weight information collected from Redwood Creek during basinwide sampling during summers 2010 through 2018 are represented in Figures 23 and 24.

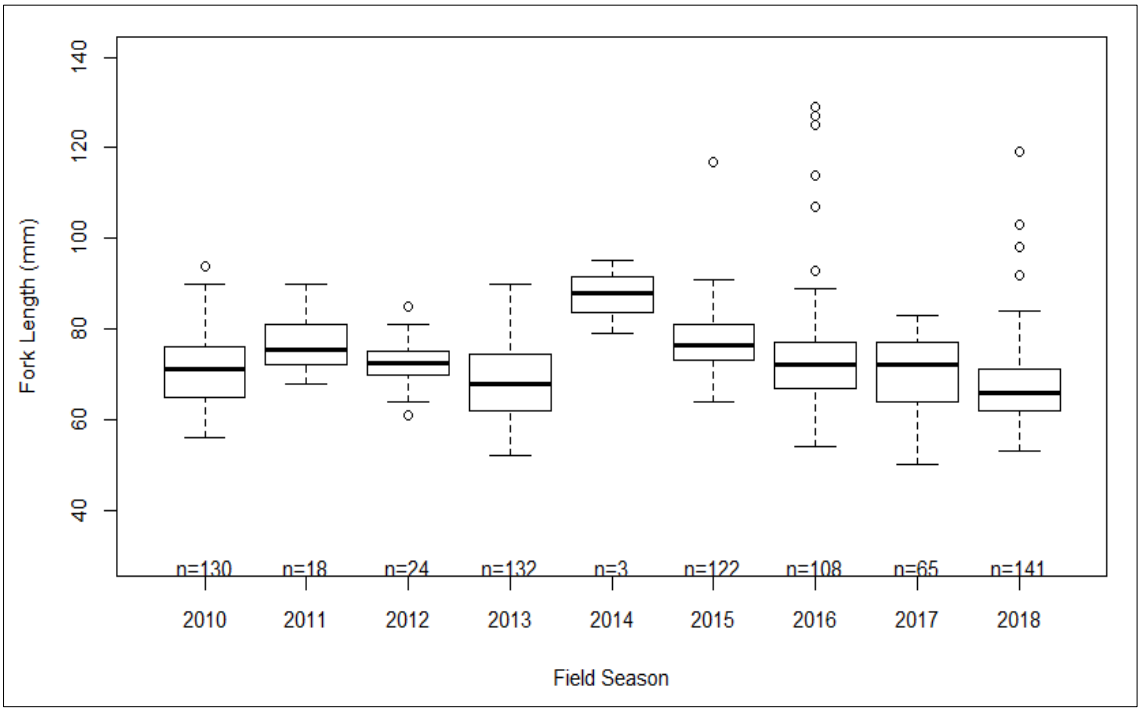

Figure 23. Box and whisker plots of juvenile coho fork length data for basinwide Redwood Creek, summer 2010-2018 (no coho captured in 2009). Dark Lines represent medians, circles represent outliers.

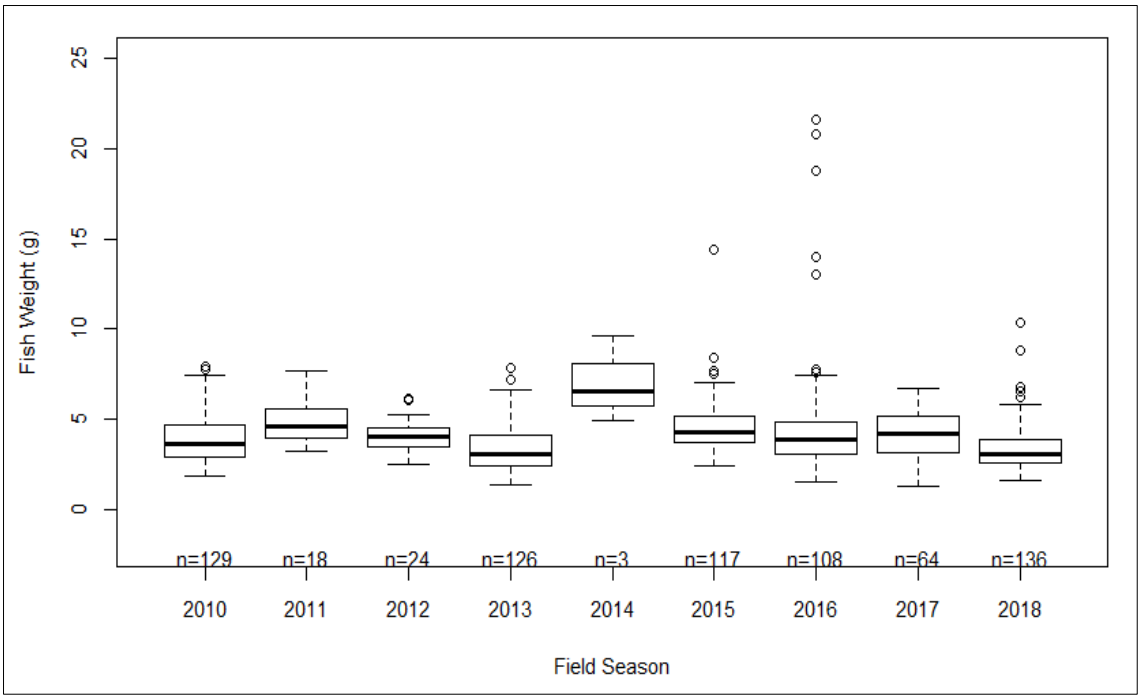

Figure 24. Box and whisker plots of juvenile coho weight data for basinwide Redwood Creek, summer 2010-2018 (no coho captured in 2009). Dark Lines represent medians, circles represent outliers.

Within the Redwood Creek sample, 250 steelhead were measured for fork length (mm), and 238 of those fish were also weighed (0.01 g). The size range for steelhead was 34 mm to 215 mm. Fork length frequencies were used to determine age class bins. The highest fork length frequencies for steelhead occurred within the 66 to 70 mm and 106 to 110 mm length intervals, representing 17% of the sample. Steelhead fork length frequency was similar across most size intervals. The Redwood Creek mean SH YoY weight was 3.7 g (SD 1.57 g), and the median weight was 3.4 g. The mean SH 1+ weight was 16.3 g (SD 8.63 g), and the median weight was 13.8 g. Figures 25 and 26 show representations of fork length data for SH YoY and SH 1+ captured on Redwood Creek for summers 2009 through 2018.

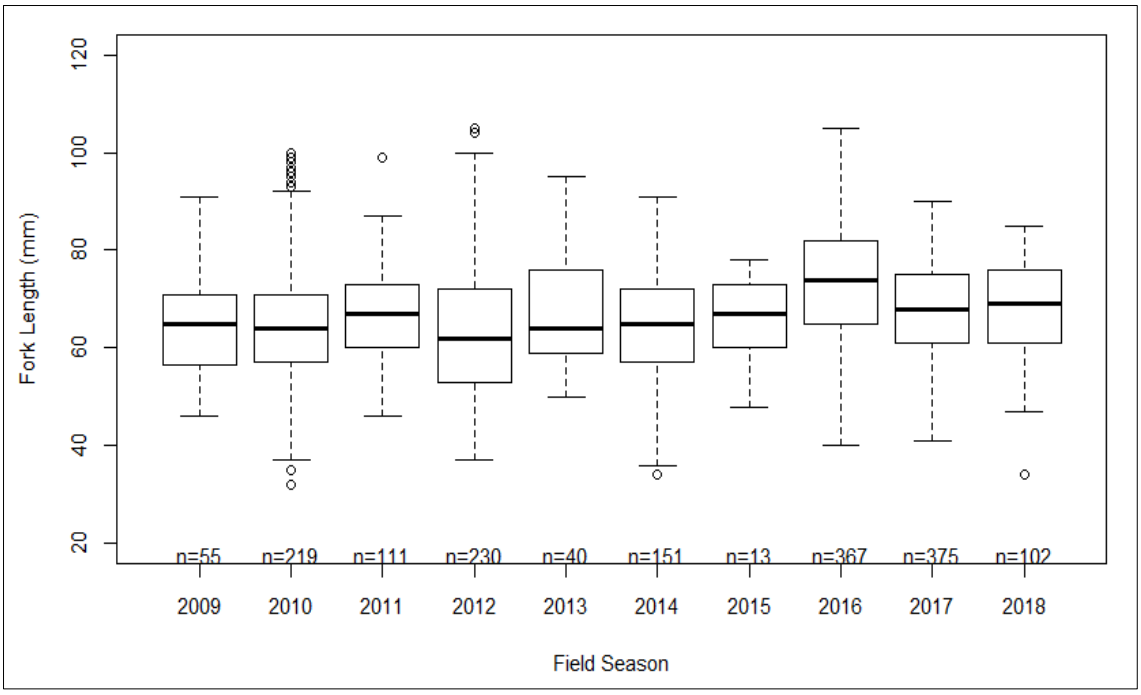

Figure 25. Box and whisker plots of young-of-year steelhead fork length data for basinwide Redwood Creek, summer 2009-2018. Dark Lines represent medians, circles represent outliers.

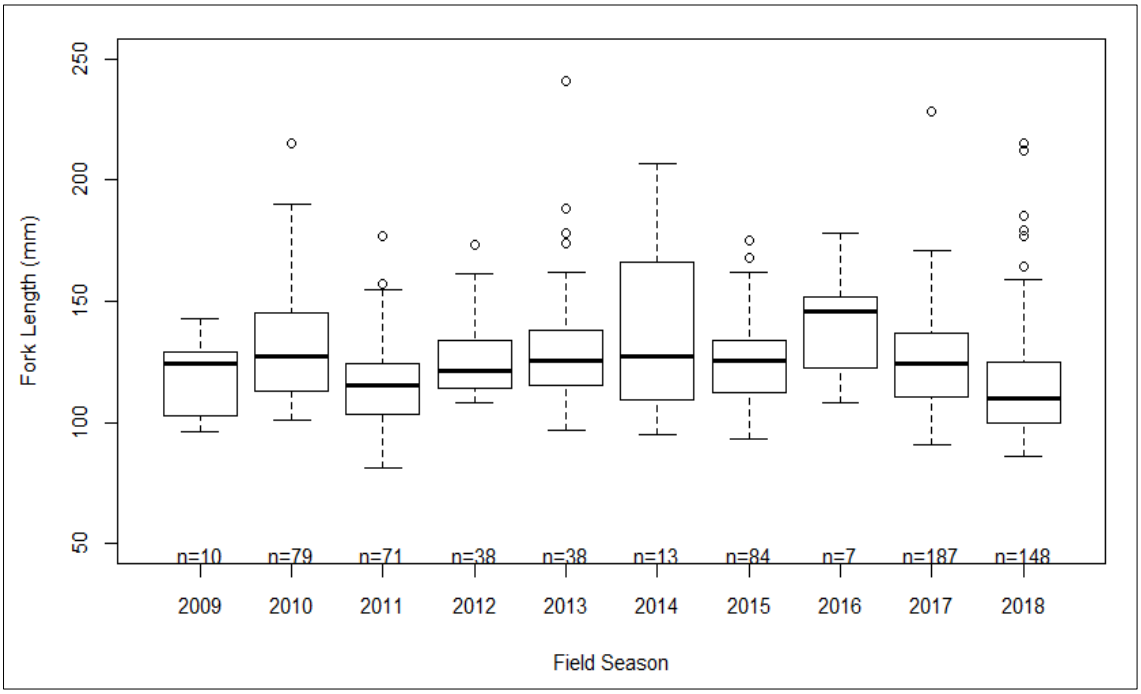

Figure 26. Box and whisker plots of 1+ steelhead fork length data for basinwide Redwood Creek, summer 2009-2018. Dark Lines represent medians, circles represent outliers.

Coho and Steelhead Fulton's Condition Factor

Table 13 shows mean and median length, weight, and K-factor for coho captured during basinwide sampling on Redwood Creek in summer 2018. Table 14 shows the comparisons between steelhead YoY and steelhead 1+ length, weight, and K-factors for Redwood Creek. Mean and median weights are reported to the nearest 0.1 g. Generally, two sample sizes are presented for each species and age class. The first sample size is the total number of fish measured for fork length, while the second sample size represents those fish which were also weighed. Fish in the second sample size were used for calculating mean K-factor.

Table 13. Mean and median fork length, weight, and K-factor for coho measured and weighed in the basinwide calibration pools on Redwood Creek mainstem, summer 2018. Two sample sizes are presented when the sample size of coho measured for length (presented first) differed from the sample size of coho both measured and weighed (presented second). FL = fork length, SD = standard deviation.

Species	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-Factor	K-Factor SD
Coho	141, 136	67	66	8.9	3.4	3.1	1.28	1.10	0.12

Table 14. Mean and median fork length, weight and K-factor calculated for steelhead measured and weighed in the basinwide calibration pools on Redwood Creek mainstem, summer 2018. Two sample sizes are presented when the sample size of steelhead measured for length (presented first) differed from the sample size of steelhead both measured and weighed (presented second). FL = fork length, SD = standard deviation, YoY = young-of-year, 1+ = one year or older.

Species	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-Factor	K-Factor SD
Steelhead YoY	102, 98	68	69	9.9	3.7	3.4	1.57	1.07	0.13
Steelhead 1+	148, 140	115	110	22.7	16.3	13.8	8.63	1.07	0.09

3.4.3 Pine Gulch Creek

The 2018 summer habitat and basinwide surveys of Pine Gulch Creek were initiated at monument tag 15 and continued upstream to monument tag 92, above the Teixeira Ranch within PORE. The measured basinwide habitat survey length for the main channel was 8.3 km.

Habitat Survey

A total of 814 mainstem habitat units were identified in the 8,333 m Pine Gulch Creek survey reach. Pool and riffle units comprised the majority of the habitat types measuring a total of 7,175 m. Habitat composition of Pine Gulch Creek can be seen in Table 15. No dry units were observed this season. Side channel and backwater units were also measured but not incorporated into the basinwide habitat calculations. Overall, 667 m of side channel habitat and 367 m of backwater habitat units were measured during the basinwide habitat survey. Riffle habitat units represented 53% of the total side channel habitat length.

Table 15. Habitat composition of Pine Gulch Creek coho survey reach, summer 2018. Measured total length is used to calculate percentages of length per habitat type.

Unit Type	Total length (m)	% of length	# of units	% of units
Pool	3,869	46	325	40
Flatwater	1,158	14	146	18
Riffle	3,306	42	343	42
Dry	0	0	0	0
Total	8,333	100	814	100

The total survey length was used to calculate the densities of side channel and backwater habitat, 8.0 m per 100 m and 4.4 m per 100 m, respectively. The density of side channel habitat in 2018 was comparable to the historical average of 8.3 m per 100 m while the density of backwater habitat for the season was more than double the historical average of 1.9 m per 100 m.

Woody debris information collected during the basinwide habitat survey is summarized for summers 2005-2017 and 2018 (Table 16) and may be used to identify trends in wood availability and recruitment over time. Since no dry units were observed, total mainstem survey length was used to calculate in-stream wood debris densities. For summer 2018, only the 10-20 cm and 20-50 cm woody debris categories had densities higher than their historical averages. Small woody debris jam density was less than half of the historical average.

Table 16. Summary of basinwide in-stream woody debris (WD) per 100 m during summer base flow conditions in Pine Gulch Creek. Average 2005-2017 compared to 2018.

Field season	Survey length (# 100 m sections)	Root Wads per 100 m	LWD[a] Jams per 100 m	SWD[b] Jams per 100 m	10-20cm WD[c] per 100 m	20-50cm WD[c] per 100 m	>50cm WD[c] per 100 m
2005-2017 Average	90.1	0.9	0.4	0.8	3.4	3.0	1.2
2018	83.3	0.7	0.3	0.3	4.0	3.2	0.9

[a]LWD Jams = 10 or more pieces of large woody debris

[b]SWD Jams = 10 or more pieces of small woody debris

[c]10-20 cm, 20-50 cm, >50 cm refer to diameter of individual pieces of woody debris

Coho Snorkel Counts

Snorkel surveys were conducted on 20% of the delineated pools (65 of 325) and 12% (14 of 116) of flatwaters, with no coho observations in any of the 79 snorkeled units. Eleven of the snorkeled units (14%) were electrofished within a day following the snorkel counts, and no coho were captured. In addition to the 11 electrofished units, four pools (5%) were re-snorkeled immediately following the initial pass using the method of bounded counts. *Microfish* and bounded count population estimates for the resampled units were used to calibrate the snorkel counts. Due to the absence of juvenile coho during 2018 basinwide surveys, a population estimate with 95% confidence interval was not calculated. A population estimate has not been calculated for Pine Gulch Creek since 2009 due to the apparent extirpation of the species from the watershed.

Summer Steelhead Measurement Information

A total of 84 steelhead were measured for fork length (mm) during the summer basinwide surveys on Pine Gulch Creek. Of those 84 steelhead, 78 were also weighed (0.01 g). The size range for steelhead was 44 mm to 159 mm. Fork length frequencies were used to determine age class intervals. The highest frequency of fork lengths for steelhead occurred within the 51 to 55 mm length interval, representing 15% of the sample. Steelhead fork length frequency was similar across most size intervals this season. The Pine Gulch Creek mean SH YoY weight was 2.5 g (SD 1.19 g), and the median weight was 2.3 g. The Pine Gulch Creek mean SH 1+ weight was 17.0 g (SD 7.28 g), and the median weight was 14.8 g. Figures 27 and 28 show SH YoY and SH 1+ fork length information collected during basinwide surveys on Pine Gulch Creek for summers 2009 through 2018.

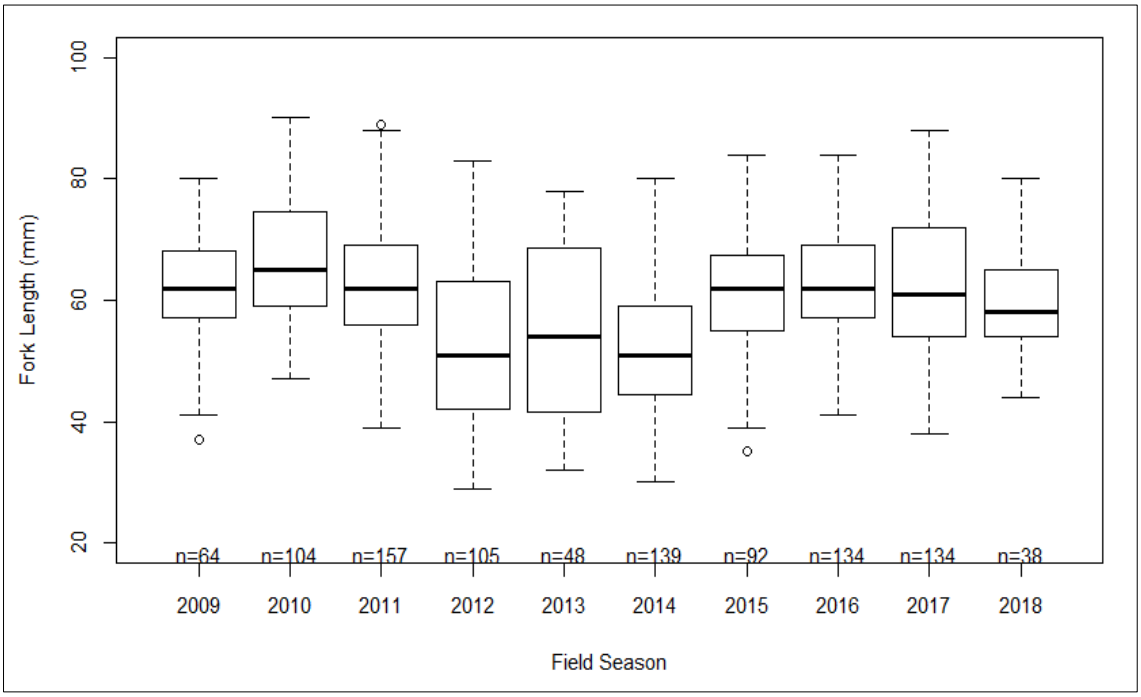

Figure 27. Box and whisker plots of young-of-year steelhead fork length data for basinwide Pine Gulch Creek, summer 2009-2018. Dark Lines represent medians, circles represent outliers.

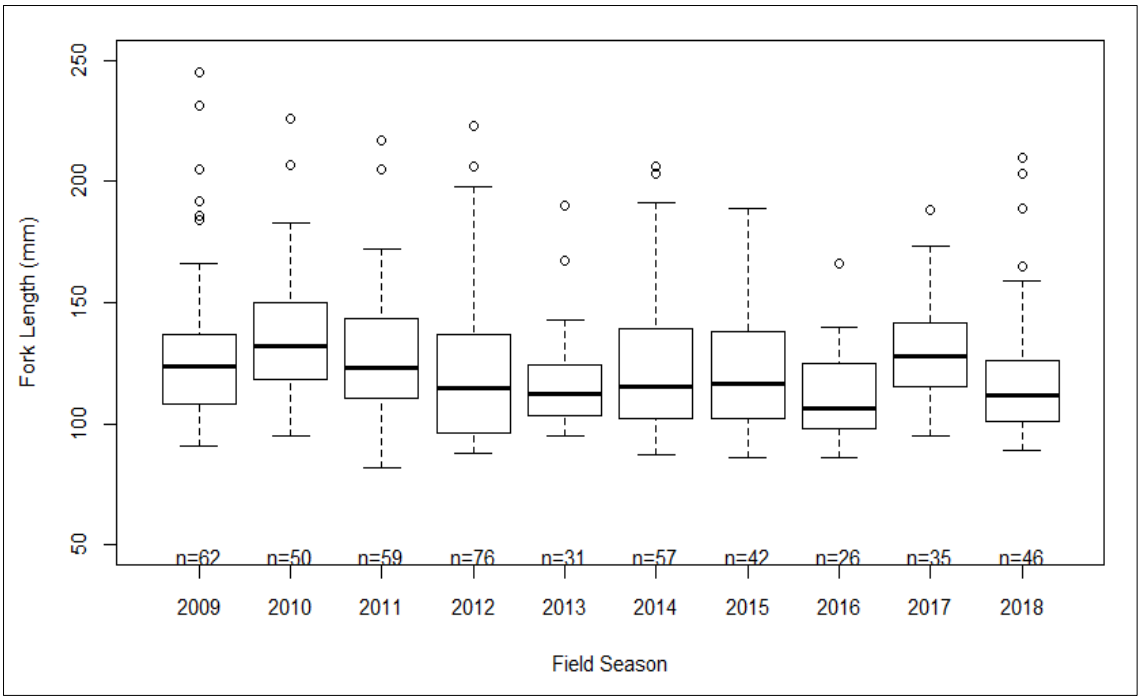

Figure 28. Box and whisker plots of 1+ steelhead fork length data for basinwide Pine Gulch Creek, summer 2009-2018. Dark Lines represent medians, circles represent outliers.

Steelhead Fulton's Condition Factor

Table 17 shows a summary of steelhead YoY and steelhead 1+ fork length, weight, and K-factor data for basinwide monitoring on Pine Gulch Creek. Mean and median weights are reported to the nearest 0.1 g. Generally, two sample sizes are presented for each age class. The first sample size is the total number of fish measured for fork length, while the second sample size represents those fish which were also weighed. Fish in the second sample size were used for calculating mean K-factor. If only one sample size is shown, all fish measured for fork length were weighed.

Table 17. Mean and median fork length, weight, and K-factor calculated for steelhead measured and weighed in the basinwide calibration pools on Pine Gulch Creek mainstem, summer 2018. Two sample sizes are presented when the sample size of steelhead measured for length (presented first) differed from the sample size of steelhead both measured and weighed (presented second). FL = fork length, SD = standard deviation, YoY = young-of-year, 1+ = one year or older.

Species	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-Factor	K-Factor SD
Steelhead YoY	38, 37	60	58	8.6	2.5	2.3	1.19	1.10	0.12
Steelhead 1+	46, 41	120	112	27.3	17.0	14.8	7.28	1.13	0.10

3.5 Coho and Steelhead 2018 Index Reach Monitoring Results

Juvenile coho salmon and steelhead monitoring results are provided for Olema Creek and Redwood Creek. Index reach sampling was discontinued on Pine Gulch Creek due to the absence of coho juveniles during basinwide monitoring for the ninth consecutive season.

3.5.1 Olema Creek Legacy Index Reach Sampling

Index reach 1 has not been sampled in the past ten years. In 2009, Index Reaches 4 and 8 were removed from the sampling regime due to access and staffing considerations.

Index Reach Habitat Information

In 2018, the index reach habitat surveys showed that pools accounted for the highest percentage of habitat surface area within all sampled index reaches. With the exception of Index Reach 5, flatwater and riffle habitat types represented less than 30% of the total surface area in each sample reach. Index reach habitat composition for 2018 can be found in Appendix A, Table A13.

Index Reach Total Salmonid Catch

The results presented in Table 18 are the summer 2018 total catch documented through index reach electrofishing activities and show salmonid sample size variation between reaches. Both coho and steelhead were found in all sampled index reaches this season. Total salmonid catch along with habitat information described in the next section is used for additional density calculations in this report. Historical catch numbers can be found in Appendix A, Table A14.

Table 18. Summary of total catch by species for Olema Creek mainstem index reach sample locations, summer 2018. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older, NS = not sampled.

	Index Reach								
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**total**
CO	NS	17	12	NS	7	20	6	NS	62
SH YoY	NS	52	114	NS	105	54	65	NS	390
SH 1+	NS	6	7	NS	10	5	7	NS	35

Salmonid per Meter by Index Reach

The results of our monitoring efforts show distinct differences in salmonid numbers and fish per meter based on index reach. Number of fish per meter is calculated using total catch from electrofishing surveys. Data presented in Figure 29 represent all habitat units surveyed within Olema Creek index reaches in 2018, and can be viewed in Appendix A, Table A15. Coho YoY were captured in all five index reaches and had the highest number per meter in Index Reach 6. Steelhead 1+ per meter was the same in Index Reaches 5 and 7.

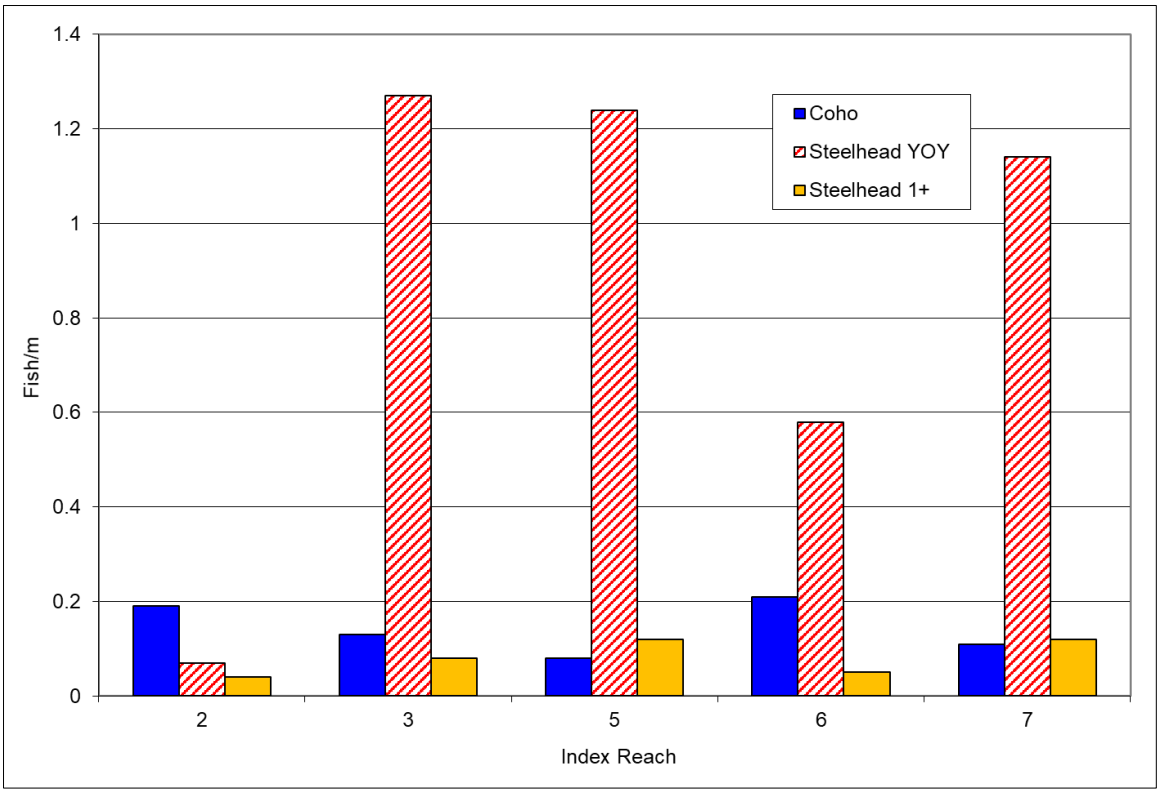

Figure 29. Coho and steelhead juvenile fish per meter according to index reach on Olema Creek, 2018.

Juvenile Coho and Steelhead Measurements

As part of the summer index reach monitoring, a subsample of fish were measured for fork length (mm) and weighed (0.01 g) within each surveyed habitat unit. Mean and median weights are reported to the nearest 0.1 g. A total of 55 coho juveniles were measured and weighed during index reach electrofishing activities on Olema Creek. The size range for coho was 64 mm to 82 mm. Mean and median fork length for coho juveniles was 73 mm (SD 4.5 mm), and the mean and median weight was 4.3 g (SD 0.89 g). Steelhead age is based on fork length frequencies, and each sample year has different fork length size frequencies. Within the 2018 Olema Creek sample, 274 steelhead were measured for fork length and weight. The size range for SH YoY was 41 mm to 95 mm (n=247), while the size range for SH 1+ was 96 mm to 185 mm (n=27). Mean fork length for SH YoY was 64 mm (SD 9.5 mm), and median fork length was 63 mm. The mean SH YoY weight was 3.1 g (SD 1.49 g), and median weight was 2.7 g. Mean fork length for SH 1+ was 125 mm (SD 24.4 mm), with a median fork length of 119 mm. The mean SH 1+ weight was 22.4 g (SD 14.66 g), and the median weight was 17.5 g.

3.5.2 Redwood Creek Legacy Index Reach Sampling

In 2018, six of the seven index reaches were surveyed by SFAN staff. Index Reach 7 no longer exists due to restoration activities.

Index Reach Habitat Information

In 2018, pool habitat was the prevalent habitat type by length and surface area identified within Index Reaches 3 through 6. Flatwater habitat was the dominant habitat type in Index Reach 2, while riffle habitat units represented 62% of the total surveyed length in Index Reach 1. Index reach habitat composition for 2018 can be found in Appendix A, Table A16.

Index Reach Total Salmonid Catch

The results presented in Table 19 are the total catch documented through electrofishing activities in the Redwood Creek index reaches for 2018. No coho were captured in Index Reach 1 which consisted mostly of riffle habitat. The majority of coho were captured in Index Reaches 5 and 6 which are located at the downstream extent of index reach monitoring in the creek. For historical index reach catch 2004 through 2018, refer to Appendix A, Table A17.

Table 19. Summary of total catch by species for Redwood Creek mainstem index reach sample locations, summer 2018. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older, NS = not sampled.

	Index Reach							
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
CO	0	22	15	14	72	54	NS	177
SH YoY	20	57	25	26	36	6	NS	170
SH 1+	9	34	46	77	43	49	NS	258

Salmonid fish per meter by Index Reach

Number of fish per meter is calculated using the total catch from electrofishing surveys. Data presented in Figure 30 are based on all habitat units surveyed within each index reach in 2018 and can be viewed in Appendix A, Table A18. Coho YoY per meter was only slightly higher in Index Reach 5 compared to Index Reach 6.

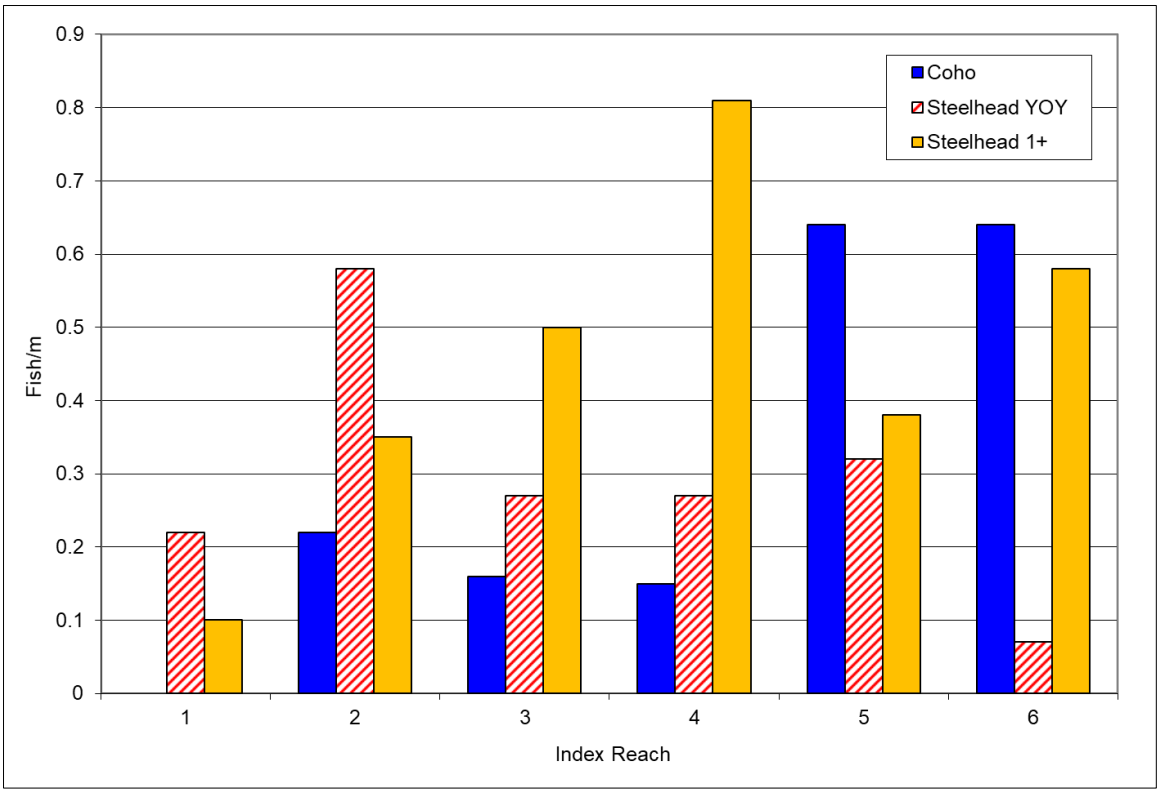

Figure 30. Coho and steelhead juvenile fish per meter according to index reach on Redwood Creek, 2018.

Juvenile Coho and Steelhead Measurements

As part of the summer monitoring program, a subsample of fish are measured for fork length (mm) and weighed (0.01 g) within each sampled habitat unit. Mean and median weights are reported to the nearest 0.1 g. Within the Redwood Creek sample, 145 coho juveniles were measured for fork length and weighed. The size range for coho was 52 mm to 99 mm. Mean and median fork length for coho was 68 mm (SD 6.5 mm). The mean coho weight was 3.5 g (SD 1.12 g), and the median weight was 3.4 g. Age classes for steelhead were determined using fork length frequencies. A total of 374 steelhead were measured. The size range for steelhead YoY was 40 mm to 85 mm (n=151), while the size range for steelhead 1+ was 86 mm to 178 mm (n=223). Mean fork length for steelhead YoY was 70 mm (SD 9.2 mm), and median fork length for steelhead YoY was 71 mm. The mean fish weight for steelhead YoY was 3.9 g (SD 1.56 g) and the median weight was 3.8 g. Mean fork length for steelhead 1+ was 115 mm (SD 18.0 mm), with a median fork length of 113 mm. The mean steelhead 1+ weight was 16.9 g (SD 8.47 g), and the median weight was 15.2 g.

3.5.3 Pine Gulch Creek Legacy Index Reach Sampling

In 2018, index reach sampling was suspended on Pine Gulch Creek after reviewing both the data and effort required to complete this sampling. The suspension of index reaches in Pine Gulch Creek was determined due to changes in sample locations, a relatively short dataset, reduction in ease of access because of road conditions and new large woody debris jams, lack of coho in recent years, and time constraints to complete summer field work.

4 Discussion

Coastal Marin County watersheds are some of the most intensely monitored watersheds for coho salmon within the CCCESU. In addition to SFAN/CDFW funded monitoring of coho on Olema Creek, Redwood Creek, Pine Gulch Creek, and Cheda Creek, extensive monitoring is conducted by MMWD on Lagunitas Creek, Devils Gulch, and the mainstem of San Geronimo Creek, and by SPAWN on tributaries of San Geronimo Creek. Through SFAN monitoring efforts, significant information has been documented regarding coho salmon behavior, life history, distribution, and population trends. Though a relatively small geographic area, the coastal Marin County watersheds support a significant proportion of the CCCESU coho salmon. The scope of this life-cycle monitoring program allows for characterization of regional patterns observed in the CCCESU.

The Olema Creek count of 13 coho salmon redds for 2017-2018 was more than double the number of redds observed in 2014-2015 (6 redds). The Redwood Creek redd count of 85 was a significant increase when compared to the 2014-2015 count (4 redds); this can mostly be attributed to the release of 188 adult coho salmon as part of the Coho Salmon Rescue and Captive Rearing Project led by CDFW. These fish were captured as juveniles in Redwood Creek during summer 2015 and reared to adulthood at Don Clausen Fish Hatchery in Sonoma County, CA before being released back into Redwood Creek this season. No adult coho were observed in Pine Gulch Creek, marking the ninth consecutive season in which successful coho spawning has not occurred in the watershed.

The 2018 smolt production estimate on Olema Creek watershed was lower than the 2015 estimate, when cohort 2 smolts were last in the system. Factors contributing to this apparent decline include but are not limited to: fewer coho juveniles in summer 2017 compared to 2014 and temporary suspension of trapping operations in April 2018 due to storm events. However, the 2018 coho smolt production estimate of 572, 95% CI [39, 1,576] was higher than expected given the summer 2017 juvenile estimate of 400, 95% CI [181, 619]; this is likely due to high overwinter survival and under-detection of juveniles during summer 2017 basinwide surveys. On Redwood Creek, the 2018 smolt estimate was 751, 95% CI [579, 923] and represents an increase from 2015 when only 47 total coho smolts were captured.

This report also includes fork length and weight data for coho smolts captured during spring 2018 outmigrant monitoring. Smolt size is directly related to ocean survival (Miller and Sandros 2003), with smolts of larger size at the time of ocean entrance having a higher chance of surviving to adulthood. For Olema Creek, the coho smolt mean fork length, weight, and K-factor were the second highest on record, and mean weight and K-factor were each more than one standard deviation above their respective historic averages (Appendix A, Table A7). The coho smolt mean fork length and weight for Redwood Creek were each one of the lowest on record, while mean K-factor was the highest since 2005 (Appendix A, Table A9). Comprehensive smolt trapping is in its fifteenth year of operation at Olema Creek and fourteenth year at Redwood Creek. Additional years of data will help refine our understanding of variation and the range in size of smolts leaving these coastal Marin County watersheds.

For Olema Creek, a 2018 basinwide population estimate of 1,301, 95% CI [963, 1,639] was calculated which is similar to the estimate of 1,176, 95% CI [224, 2,397] for 2015 when this cohort was last in the system. The 2018 juvenile population estimate for Olema Creek was lower than expected given the increase in redd production; one contributing factor could be increased fry mortality during storm events in March and April. The 2018 population estimate for Redwood Creek was 4,475, 95% CI [3,613, 5,337] coho juveniles which is almost double the estimate for 2015 (2,265, 95% CI [458, 4103]). Again, the coho juvenile estimate was lower than expected given the number of documented redds and is likely a result of fry mortality during spring storms. No coho juveniles were observed on Pine Gulch Creek for the ninth consecutive summer. It appears coho salmon have been extirpated from this watershed.

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Table A1. Coho spawner survey redd density history for mainstem Lagunitas Creek, San Geronimo Creek, Devil's Gulch, Olema Creek, Redwood Creek, and Pine Gulch including total redds, survey length (km) and redd per km for spawner years 1997-1998 through 2017-2018.

Years	Lagunitas Creek[a]			San Geronimo Creek[a,b]			Devil's Gulch[a]			Olema Creek[b]			Redwood Creek[b]			Pine Gulch		
	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km
1997-1998	80	10.7	7.5	121	7.0	15.3	52	3.2	16.3	134	20.8	6.4	78	9.2	8.5	N/A	N/A	N/A
1998-1999	92	10.7	8.6	60	7.0	6.6	32	3.2	10	23	17	1.4	41	9.2	4.5	N/A	N/A	N/A
1999-2000	139	10.7	13.0	61	7.0	8.3	3	3.2	0.9	10	12.8	0.8	5	8.2	0.6	N/A	N/A	N/A
2000-2001	119	12.8	9.3	74	7.0	8.0	11	3.2	3.4	80	19.3	4.1	12	9.2	1.3	0	9.5	0
2001-2002	79	12.8	6.2	145	7.0	14.5	59	3.7	16.1	59	15.4	3.8	34	9.2	3.7	2	9.5	0.2
2002-2003	71	12.8	5.5	61	7.0	5.6	24	3.7	6.6	20	17	1.2	3	9.2	0.3	1	9.5	0.1
2003-2004	124	12.8	9.7	205	7.0	19.8	48	3.7	13.1	109	15	7.3	42	9.2	4.6	0	9.5	0
2004-2005	120	12.8	9.4	268	7.0	19.7	112	3.7	30.6	138	20.9	6.6	90	9.6	9.4	3	9.5	0.3
2005-2006	53	12.8	4.1	102	7.0	6.9	33	3.7	8.9	9	17	0.5	11	9.6	1.1	1	9.5	0.1
2006-2007	128	12.8	10	143	7.0	16.7	55	3.7	14.9	95	18	5.3	24	9.2	2.6	0	9.5	0
2007-2008	87	12.8	6.8	55	7.0	6.6	6	3.7	1.6	33	18	1.8	1[c]	9.6	0.1	2	9.5	0.2

[a] Lagunitas Creek, San Geronimo Creek, and Devil's Gulch coho redd data provided by Marin Municipal Water District.

[b] Includes redds from all surveyed tributaries.

[c] No redd was observed during spawner surveys. Subsequent summer basinwide surveys determined that at least one coho redd was constructed but not observed during spawner surveys.

[d] No juveniles were observed the following summer.

Table A1 (continued). Coho spawner survey redd density history for mainstem Lagunitas Creek, San Geronimo Creek, Devil's Gulch, Olema Creek, Redwood Creek, and Pine Gulch including total redds, survey length (km) and redd per km for spawner years 1997-1998 through 2017-2018.

Years	Lagunitas Creek[a]			San Geronimo Creek[a,b]			Devil's Gulch[a]			Olema Creek[b]			Redwood Creek[b]			Pine Gulch		
	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km	Total redds	Survey length	Redd per km
2008-2009	25	12.8	2.0	1	7.0	0.1	0	3.7	0	0	18	0	2	8.6	0.2	1[c]	9.5	0
2009-2010	42	12.8	3.3	7	7.0	1	2	3.7	0	14	18.3	0.8	23	9.2	2.5	0	9.5	0
2010-2011	32	12.8	2.5	42	7.0	5.7	6	3.7	0	21	18	1.2	3	9.6	0.3	0	9.5	0
2011-2012	94	12.8	7.3	22	7.0	0.4	10	3.7	0	7	18	0.4	4	9.6	0.4	1[d]	9.5	0.1
2012-2013	108	12.8	8.4	63	7.0	8.4	44	3.7	0.5	32	18	1.8	25	9.6	2.6	0	8.0	0
2013-2014	172	12.8	13.4	10	7.0	1.0	5	3.7	1.4	32	18	1.8	5	8.6	0.6	0	8.0	0
2014-2015	79	12.8	6.2	37	7.0	5.3	20	3.7	5.4	7	18	0.3	4	8.6	0.5	0	8.0	0
2015-2016	91	12.8	6.2	96	7.0	5.3	31	3.7	5.4	66	18	2.7	15	9.9	0.6	0	7.3	0
2016-2017	49	12.8	3.8	78	7.0	11.1	31	3.7	8.4	15	18	0.8	16	9.9	1.6	0	7.3	0
2017-2018	72	12.8	5.6	19	7.0	2.7	11	3.7	3.0	13	18	0.7	85	9.9	8.6	0	7.3	0

[a] Lagunitas Creek, San Geronimo Creek, and Devil's Gulch coho redd data provided by Marin Municipal Water District.

[b] Includes redds from all surveyed tributaries.

[c] No redd was observed during spawner surveys. Subsequent summer basinwide surveys determined that at least one coho redd was constructed but not observed during spawner surveys.

[d] No juveniles were observed the following summer.

Table A2. Coho salmon run timing, average total rainfall by month, total carcasses and redds documented in surveys for spawner years 1997-1998 through 2017-2018 on the Olema Creek watershed.

		Total monthly rainfall (in)				Olema Creek spawner summary			
Years	**Run timing**	**Nov**	**Dec**	**Jan**	**Feb**	**Survey reach (km)**	**# surveys**	**Total carcass counts**	**Total redds**
1997-1998	Nov 16 – Jan 8	10.31	3.48	17.99	24.68	20.8[a]	8	39	134
1998-1999	Dec 8 – Jan 30	7.48	2.21	7.66	15.61	17.0[b]	6	13	23
1999-2000	Dec 2 – Feb 1	5.20	0.99	7.15	12.77	12.8[c]	2	9	10
2000-2001	Jan 16 – Feb 8	1.54	1.31	6.45	8.07	19.3[d]	4	96	80
2001-2002	Nov 27 – Jan 11	9.81	15.03	5.08	3.55	15.4[e]	4	30	59
2002-2003	Jan 7 – Jan 21	3.30	17.33	3.75	2.34	17.0[b]	4	16	20
2003-2004	Dec 17 – Feb 10	2.71	12.14	5.13	7.68	15.0[f]	6	40	109
2004-2005	Dec 15 – Feb 9	2.51	10.49	6.41	4.99	20.9[g]	6	72	138
2005-2006	Dec 6 – Jan 26	2.39	16.31	7.88	4.27	17.0[h]	3	11	9
2006-2007	Dec 18 – Feb 16	5.54	7.64	1.09	9.93	18.0[i]	6	32	95
2007-2008	Dec 5 – Jan 24	1.09	6.76	14.66	4.54	18.0[i]	8	5	33
2008-2009	Dec 27 & Feb 20	3.15	3.17	1.22	11.40	18.0[i]	11	0	0

[a] Includes the mainstem of Olema Creek (Reaches 1-7), Headwaters Tributary, Eucalyptus Gulch, Randall Gulch, John West Fork, Giacomini Gulch, Horse Camp Creek, Boundary Gulch, and Quarry Gulch.

[b] Includes the mainstem of Olema Creek (Reaches 1-6) and John West Fork.

[c] Includes the mainstem of Olema Creek (Reaches 2-5), John West Fork, Giacomini Gulch, Horse Camp Creek, Water Tank Creek, and Boundary Gulch.

[d] Includes the mainstem of Olema Creek (Reaches 1-7), John West Fork, Giacomini Gulch, Horse Camp Creek, Boundary Gulch, and Quarry Gulch.

[e] Includes the mainstem of Olema Creek (Reaches 2-6), Randall Gulch, John West Fork, Horse Camp Creek, Boundary Gulch, and Quarry Gulch.

[f] Includes the mainstem of Olema Creek (Reaches 2-6), Headwaters Tributary, John West Fork, Giacomini Gulch, and Horse Camp Creek.

[g] Includes the mainstem of Olema Creek (Reaches 1-7), Headwaters Tributary, Randall Gulch, John West Fork North, John West Fork, Giacomini Gulch, Horse Camp Creek, Boundary Gulch, and Quarry Gulch.

[h] Includes the mainstem of Olema Creek (Reaches 2-7), Headwaters Tributary, John West Fork, Giacomini Gulch, Horse Camp Creek, Boundary Gulch, and Quarry Gulch.

[i] Includes the mainstem of Olema Creek (Reaches 1-6), John West Fork, Giacomini Gulch, Horse Camp Creek, Boundary Gulch, and Quarry Gulch.

Table A2 (continued). Coho salmon run timing, average total rainfall by month, total carcasses and redds documented in surveys for spawner years 1997-1998 through 2017-2018 on the Olema Creek watershed.

		Total monthly rainfall (in)				Olema Creek spawner summary			
Years	**Run timing**	**Nov**	**Dec**	**Jan**	**Feb**	**Survey reach (km)**	**# surveys**	**Total carcass counts**	**Total redds**
2009-2010	Dec 14 – Jan 29	1.41	5.15	12.51	7.23	18.3[j]	9	6	14
2010-2011	Dec 10 – Jan 20	5.21	12.28	2.09	6.97	18.0[i]	11	13	21
2011-2012	Jan 26 – Feb 23	5.58	0.63	7.00	2.29	18.0[i]	14	12	7[k]
2012-2013	Nov 19 – Jan 30	9.20	12.16	1.04	0.70	18.0[i]	15	19	32[k]
2013-2014	Feb 13 – Mar 5	1.21	0.48	0.00	11.58	18.0[i]	28	18	32[k]
2014-2015	Dec 9 – Jan 6	4.92	17.88	0.12	3.47	18.0[i]	16	10	7[k]
2015-2016	Dec 16 – Feb 3	2.20	11.17	11.22	1.40	18.0[i]	12	32	66[k]
2016-2017	Nov 30 – Jan 16	3.76	7.33	16.28	13.35	18.0[l]	9	0	15[m]
2017-2018	Jan 11 – Feb 7	4.34	0.12	8.15	1.00	18.0[n]	13	14	13[m]

[i] Includes the mainstem of Olema Creek (Reaches 1-6), John West Fork, Giacomini Gulch, Horse Camp Creek, Boundary Gulch, and Quarry Gulch.

[j] Includes the mainstem of Olema Creek (Reaches 1-6), John West Fork, John West Fork North, Giacomini Gulch, Horse Camp Creek, Boundary Gulch, and Quarry Gulch.

[k] Final redd count based on Gallagher equation (Gallagher and Gallagher 2005).

[l] Includes the mainstem of Olema Creek (Reaches 1-6), John West Fork, Horse Camp Creek, Boundary Gulch, and Quarry Gulch.

[m] Final redd count based on kNN analysis (Ricker et al. 2013).

[n] Includes the mainstem of Olema Creek (Reaches 1-6), John West Fork, Horse Camp Creek, and Boundary Gulch.

Table A3. Coho salmon spawning survey including number of tributaries surveyed, total live adults counted, total carcasses, and total redds for the Olema Creek watershed excluding the John West Fork. These tributaries include Boundary Gulch, Giacomini Creek, Horse Camp Creek, and Quarry Gulch, spawner years 1997-1998 through 2017-2018.

Years	Number of tributaries surveyed	Total live	Total carcasses	Total redds
1997-1998	6	4	1	3
1998-1999	0	0	0	0
1999-2000	2	0	0	0
2000-2001	4	0	0	0
2001-2002	4	1	0	0
2002-2003	0	0	0	0
2003-2004	2	0	0	0
2004-2005	6	2	3	3
2005-2006	4	3	0	3
2006-2007	3	3	0	0
2007-2008	4	0	0	0
2008-2009	4	0	0	0
2009-2010	3	0	0	0
2010-2011	4	1	0	0
2011-2012	4	0	0	0
2012-2013	4	2	0	1
2013-2014	4	0	0	0
2014-2015	2	0	0	0
2015-2016	3	0	0	0
2016-2017	4	0	0	0
2017-2018	2	0	0	0

Table A4. Coho salmon spawning survey including number of surveys, survey length, total carcasses, and total redds for Cheda Creek, spawner years 1998-1999 through 2017-2018. N/A = Survey length not defined.

Years	Number of surveys	Survey length (km)	Total carcasses	Total redds
1998-1999	2	N/A	0	0
1999-2000	1	N/A	0	0
2000-2001[a]	2	1.4	0	0
2001-2002	5	1.2	0	3
2002-2003	3	1.2	1	1
2003-2004	3	1.2	0	6
2004-2005	5	1.3	1	6
2005-2006	4	1.3	1	2
2006-2007	3	1.3	1	7
2007-2008	5	1.3	0	1
2008-2009	1	1.3	0	0
2009-2010	3	1.3	0	0
2010-2011	5	1.3	0	0
2011-2012	4	1.3	1	4
2012-2013	5	1.3	2	2
2013-2014	1	1.3	0	1
2014-2015	2	1.3	2	4
2015-2016	4	1.7	5	5
2016-2017	4	1.7	3	4
2017-2018	1	1.4	0	2[b]

[a] First winter after fish passage project was completed

[b] Final redd count based on kNN analysis (Ricker et al. 2013).

Table A5. Coho salmon run timing, average total rainfall by month, total carcasses and redds documented in surveys for spawner years 1997-1998 through 2017-2018 on the Redwood Creek watershed. N/A = Data not available for this time period.

		Total monthly rainfall (in)				Redwood Creek spawner summary			
Years	**Run timing**	**Nov**	**Dec**	**Jan**	**Feb**	**Survey reach (km)**	**# surveys**	**Total carcass counts**	**Total redds**
1997-1998	Nov 25 – Jan 23	N/A	N/A	N/A	N/A	9.2[a]	7	24	78
1998-1999	Dec 5 – Feb 24	3.28	1.49	5.27	8.47	9.2[a]	11	10	41
1999-2000	Jan 19 – Feb 18	2.72	0.59	5.95	0.00	8.2[b]	6	1	5
2000-2001	Dec 21 – Mar 8	0.00	0.00	4.39	6.07	9.2[a]	5	11	12
2001-2002	Dec 8 – Feb 6	0.00	0.00	0.83	3.56	9.2[a]	5	50	34
2002-2003	Jan 1 – Feb 5	2.18	13.04	1.23	1.83	9.2[a]	5	3	3
2003-2004	Dec 4 – Feb 6	2.62	3.45	7.21	6.38	9.2[a]	5	25	42
2004-2005	Dec 11 – Feb 3	0.8	7.59	3.66	3.09	9.6[c]	7	63	90
2005-2006	Dec 7 – Feb 9	2.19	12.57	0.00	3.48	9.6[c]	5	5	11
2006-2007	Nov 20 – Jan 23	2.58	4.27	0.63	3.63	9.2[a]	9	6	24
2007-2008	NA	1.79	7.84	16.23	2.23	9.6[c]	8	0	1[e]
2008-2009	Dec 31 – Feb 10	N/A	3.62	1.03	8.92	8.6[d]	10	2	2
2009-2010	Dec 14 – Feb 9	1.15	4.01	9.33	3.96	9.2[a]	8	10	23
2010-2011	Dec 2 – Jan 21	2.62	10.27	1.90	5.90	9.6[c]	13	1	3[f]
2011-2012	Nov 29 – Feb 8	2.31	0.52	4.45	1.75	9.6[c]	14	8	4[f]
2012-2013	Nov 6 – Jan 17	5.56	8.98	0.99	0.59	9.6[c]	11	17	25[f]

[a] Includes the mainstem of Redwood Creek, Fern Creek, and Kent Creek.

[b] Includes the mainstem of Redwood Creek and Fern Creek.

[c] Includes the mainstem of Redwood Creek, Fern creek, and the lower Redwood Creek restoration area.

[d] Includes the mainstem of Redwood Creek, Fern Creek, Kent Creek, and the lower Redwood Creek restoration area.

[e] No redd was observed during spawner surveys. Subsequent summer basinwide surveys determined that at least one coho redd was constructed but not observed during spawner surveys.

[f] Final redd count based on Gallagher equation (Gallagher and Gallagher 2005).

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Table A5 (continued). Coho salmon run timing, average total rainfall by month, total carcasses and redds documented in surveys for spawner years 1997-1998 through 2017-2018 on the Redwood Creek watershed. N/A = Data not available for this time period.

		Total monthly rainfall (in)				Redwood Creek spawner summary			
Years	**Run timing**	**Nov**	**Dec**	**Jan**	**Feb**	**Survey reach (km)**	**# surveys**	**Total carcass counts**	**Total redds**
2013-2014	Feb 12 – Feb 19	3.14	0.61	0.38	14.27	8.6[d]	13	1	5[f]
2014-2015	Dec 8 – Jan 7	3.67	13.56	0.01	2.15	8.6[d]	11	0	4[f]
2015-2016	Dec 26 – Jan 26	1.42	6.15	8.11	1.14	9.9[g]	12	3	15[f]
2016-2017	Dec 9 – Jan 30	3.60	5.61	11.34	10.06	9.9[g]	12	2	16[h]
2017-2018	Jan 10 – Feb 6	3.47	0.19	6.19	0.36	9.9[g]	14	24	85[h]

[d] Includes the mainstem of Redwood Creek, Fern Creek, Kent Creek, and the lower Redwood Creek restoration area.

[f] Final redd count based on Gallagher equation (Gallagher and Gallagher 2005).

[g] Includes the mainstem of Redwood Creek, Fern Creek, lower Green Gulch, Kent Creek, and the lower Redwood Creek Restoration area.

[h] Final redd count based on kNN analysis (Ricker et al. 2013).

Table A6. Coho salmon spawning survey including number of surveys, survey length, total carcasses, and total redds on the Pine Gulch Creek mainstem for spawner years 2000-2001 through 2017-2018.

Years	Year class	Number of surveys	Survey reach (km)	Total carcasses	Total redds
2000-2001	1	3	7.0	0	0
2001-2002	2	2	9.0	0	2
2002-2003	3	2	8.0	2	1
2003-2004	1	6	9.0	0	0
2004-2005	2	3	10.0	0	3
2005-2006	3	4	9.5	0	1
2006-2007	1	4	9.5	0	0
2007-2008	2	3	9.5	0	2
2008-2009	3	1	9.5	0	0
2009-2010	1	1	9.5	0	0
2010-2011	2	1	9.5	0	0
2011-2012	3	1	9.5	0	1
2012-2013	1	2	8.0	0	0
2013-2014	2	2	8.0	0	0
2014-2015	3	3	8.0	0	0
2015-2016	1	3	7.3	0	0
2016-2017	2	1	7.3	0	0
2017-2018	3	1	7.0	0	0

Table A7. Mean and median fork length, weight, and K-factor calculated for coho smolts measured and weighed in the Olema Creek smolt trap 2004-2018. Mean and median weights are reported to the nearest 0.1 g. Generally, two sample sizes are presented for each year. The first sample size is the total number of fish measured for fork length, while the second sample size represents those fish which were also weighed. Fish in the second sample size were used for calculating mean K-factor. If only one sample size is shown, all fish measured for fork length were weighed. FL = fork length, SD = standard deviation.

Year	Life Stage	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-factor	K-factor SD
2004	Smolt	148	114	113	9.7	14.9	14.4	4.03	1.00	0.07
2005	Smolt	82, 37	116	115	10.9	15.9	15.0	3.89	1.01	0.13
2006	Smolt	294, 204	99	98	9.9	10.2	9.6	3.07	1.04	0.10
2007	Smolt	284, 191	117	115	11.3	14.7	13.6	4.73	0.91	0.07
2008	Smolt	852, 384	111	110	8.9	12.5	11.9	3.11	0.90	0.07
2009	Smolt	1007, 447	113	113	7.8	12.9	12.5	2.79	0.88	0.06
2010	Smolt	10	136	135	6.7	24.1	23.6	4.17	0.94	0.06
2011	Smolt	329, 320	121	120	10.8	16.1	15.4	4.33	0.89	0.06
2012	Smolt	186, 181	117	116	10.7	14.6	13.8	4.41	0.89	0.06
2013	Smolt	49, 47	120	119	9.1	15.8	15.3	4.66	0.91	0.11
2014	Smolt	698, 655	115	115	9.9	13.6	13.3	3.15	0.88	0.08
2015	Smolt	503, 476	111	110	9.6	12.3	11.7	3.31	0.88	0.06
2016	Smolt	309, 296	118	117	11.2	16.1	15.2	4.81	0.95	0.06
2017	Smolt	582, 547	118	118	9.6	15.5	15.1	3.68	0.93	0.07
2018	Smolt	35	124	125	11.3	19.6	19.6	4.98	1.02	0.08

Table A8. Mean and median fork length, weight, and K-factor calculated for steelhead smolts measured and weighed in the Olema Creek smolt trap 2004-2018. Mean and median weights are reported to the nearest 0.1 g. Two sample sizes are presented when the sample size of steelhead measured for length (presented first) differed from the sample size of steelhead both measured and weighed (presented second). FL = fork length, SD = standard deviation.

Year	Life Stage	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-factor	K-factor SD
2004	Smolt	11	177	176	15.4	55.3	50.6	14.37	0.99	0.09
2005	Smolt	6	127	129	32.5	22.9	22.3	15.85	0.94	0.13
2006	Smolt	3	130	133	9.5	25.0	28.6	6.39	1.13	0.09
2007	Smolt	118, 109	169	169	18.7	41.7	39.7	13.59	0.85	0.08
2008	Smolt	46, 34	139	137	27.0	27.3	24.9	13.01	0.92	0.09
2009	Smolt	11	156	155	17.4	33.6	32.6	10.43	0.86	0.05
2010	Smolt	34, 31	174	175	22.6	48.2	44.9	17.80	0.88	0.07
2011	Smolt	16, 14	175	180	17.4	43.3	44.4	12.98	0.80	0.04
2012	Smolt	8	173	174	17.6	40.0	40.2	8.70	0.77	0.11
2013	Smolt	12	177	174	20.2	48.5	44.8	17.44	0.84	0.06
2014	Smolt	11, 8	148	155	21.9	32.1	34.0	10.77	0.85	0.06
2015	Smolt	94, 91	153	148	21.2	32.7	28.3	15.50	0.86	0.07
2016	Smolt	32, 29	161	169	20.7	41.3	45.7	13.17	0.98	0.08
2017	Smolt	7	157	158	27.3	37.2	37.0	14.90	0.93	0.12
2018	Smolt	34, 33	143	143	18.2	31.9	31.1	10.75	1.04	0.09

Table A9. Mean and median fork length, weight, and K-factor calculated for coho smolts measured and weighed in the Redwood Creek smolt trap, 2005-2018. Mean and median weights are reported to the nearest 0.1 g. Two sample sizes are presented when the sample size of steelhead measured for length (presented first) differed from the sample size of steelhead both measured and weighed (presented second). FL = fork length, SD = standard deviation.

Year	Life Stage	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-factor	K-factor SD
2005	Smolt	199, 90	101	101	9.5	10.4	9.8	3.12	1.02	0.11
2006	Smolt	747, 412	98	98	8.4	9.2	9.0	2.41	0.98	0.07
2007	Smolt	312, 213	116	115	10.5	14.2	13.6	4.08	0.90	0.07
2008	Smolt	815, 295	110	110	8.8	11.8	11.6	2.71	0.90	0.07
2009	Smolt	170, 83	120	120	11.2	15.8	15.3	4.18	0.89	0.04
2010	Smolt	141, 123	123	122	7.6	16.0	15.6	3.08	0.86	0.05
2011	Smolt	1,021, 983	111	110	9.6	12.4	12.0	3.12	0.89	0.06
2012	Smolt	254, 249	116	114	11.8	14.3	13.4	4.37	0.90	0.09
2013	Smolt	268, 247	113	114	10.5	13.7	13.5	3.54	0.92	0.09
2014	Smolt	532, 509	118	119	10.9	14.5	14.4	3.54	0.86	0.07
2015	Smolt	47, 45	127	128	10.1	17.9	17.8	4.15	0.86	0.05
2016	Smolt	300, 257	123	123	10.4	17.3	16.9	4.40	0.92	0.05
2017	Smolt	365, 348	108	108	9.7	11.7	11.4	2.97	0.91	0.07
2018	Smolt	240, 235	101	100	9.5	10.6	10.1	3.15	1.01	0.08

Table A10. Mean and median fork length, weight, and K-factor calculated for steelhead smolts measured and weighed in the Redwood Creek smolt trap, 2006-2018 (no steelhead smolts caught in 2005). Mean and median weights are reported to the nearest 0.1 g. Two sample sizes are presented when the sample size of steelhead measured for length (presented first) differed from the sample size of steelhead both measured and weighed (presented second). FL = fork length, SD = standard deviation.

Year	Life Stage	Sample Size	Mean FL (mm)	Median FL (mm)	Mean FL SD	Mean Weight (g)	Median Weight (g)	Mean Weight SD	Mean K-factor	K-factor SD
2006	Smolt	11, 10	134	135	14.3	22.9	22.0	5.90	0.99	0.11
2007	Smolt	17, 16	177	176	13.4	45.5	43.6	11.25	0.80	0.04
2008	Smolt	15, 11	159	164	21.2	36.1	39.5	14.16	0.86	0.09
2009	Smolt	30, 26	167	165	17.7	39.5	37.1	12.17	0.80	0.06
2010	Smolt	53, 48	161	161	12.1	34.7	35.4	7.06	0.83	0.06
2011	Smolt	14, 13	159	158	18.0	32.0	31.1	10.42	0.80	0.08
2012	Smolt	71, 67	169	167	18.3	39.0	36.4	12.39	0.79	0.06
2013	Smolt	16, 14	178	178	10.4	46.3	45.2	7.99	0.82	0.04
2014	Smolt	6	167	169	19.3	40.5	39.4	12.84	0.85	0.04
2015	Smolt	76, 74	150	149	17.2	28.5	27.3	9.37	0.82	0.09
2016	Smolt	15	180	179	22.7	53.0	48.5	20.76	0.87	0.05
2017	Smolt	30, 28	141	142	23.7	27.4	25.7	10.89	0.92	0.08
2018	Smolt	54, 51	137	140	19.9	25.5	26.7	9.20	0.97	0.09

Table A11. Summary of non-salmonid information for Olema Creek mainstem trap operations, 2004-2018.

Watershed	Year	Trap dates		BF[a]	CAN/ RSN[a]	CRAY[a]	LAM[a]	PL[a]	RLF[a]	RO[a]	SCU[a]	STK[a]	SUC[a]	WPT[a]	OTH[b]	Totals
		From	To													
Olema Creek	2004	30-Mar	28-May	19	0	14	15	0	0	274	243	3,083	144	0	3	3,795
	2005	27-Mar	31-May	234	0	0	33	0	0	1,006	117	648	58	1	0	2,097
	2006	18-Apr	9-Jun	4	0	5	5	1	52	420	644	2,998	3	5	5	4,142
	2007	18-Mar	26-May	6	0	16	35	0	1	3,190	356	1,110	140	2	1	4,857
	2008	19-Mar	30-May	11	1	17	2	3	7	158	228	30	2	1	0	460
	2009	11-Mar	29-May	1	1	12	109	0	77	554	335	782	8	2	5	1,886
	2010	19-Mar	28-May	1	2	3	27	0	44	3,187	110	1,353	7	0	0	4,734
	2011	1-Apr	3-Jun	0	0	4	1	1	1	671	204	451	5	0	2	1,340
	2012	4-Apr	31-May	0	2	13	0	0	57	195	217	234	0	1	0	719
	2013	14-Mar	31-May	1	1	24	5	0	9	118	399	211	0	0	1	769
	2014	20-Mar	5-Jun	0	3	15	0	0	1	189	244	256	0	1	0	709
	2015	5-Mar	5-Jun	2	2	4	0	0	3	233	241	126	0	1	1	613
	2016	25-Mar	26-May	3	1	7	0	0	293	460	88	523	1	1	6	1,383
	2017	16-Mar	2-Jun	2	0	10	0	0	7	421	145	704	0	0	3	1,292
	2018	28-Mar	1-Jun	2	0	28	0	0	0	287	326	61	0	0	0	704
Historical average				**20**	**1**	**10**	**17**	**<1**	**39**	**791**	**255**	**894**	**26**	**1**	**2**	**2,057**

[a] Species Code: BF = bullfrog (*Rana catesbeina*, non-native), CAN = California newt (*Taricha torosa*), CRAY = signal crayfish (*Pacifastacus leniusculus,* non-native), LAM = lamprey spp. (*Lampetra* spp.), PL= Pacific lamprey, RLF = California red-legged frog (*Rana draytonii*), RO = California roach (*Hesperoleucus symmetricus*), RSN = rough-skinned newt (*Taricha granulosa*), SCU = sculpin spp., STK = threespine stickleback (*Gasterosteus aculeatus*), SUC = Sacramento sucker (*Catostomus occidentalis*), and WPT = western pond turtle (*Clemmys marmorata*).

[b] OTH = other and includes the following species: bluegill (*Lepomis macrochirus*, non-native), Ensatina salamander (*Ensatina eschscholtzii*), FS = California freshwater shrimp (*Syncaris pacifica*), green sunfish (*Lepomis cyanellus*, non-native), golden shiner (*Notemigonus cyrsoleucas*, non-native), mosquito fish (*Gambusia affinis*, non-native), Pacific tree frog (*Hyla regilla*), red-eared slider (*Pseudemys scripta elegans*, non-native), spotted salamander (*Ambystoma maculatum*, non-native), and unclassified species.

Table A12. Summary of non-salmonid information for Redwood Creek mainstem trap operations, 2005-2018.

Watershed	Year	Trap dates		CAN/ RSN[a]	CRAY[a]	RLF[a]	SCU[a]	STK[a]	OTH[b]	Totals
		From	To							
Redwood Creek	2005	27-Mar	31-May	11	0	0	24	5,343	0	5,378
	2006	18-Apr	9-Jun	10	7	0	133	117	4	271
	2007	18-Mar	26-May	50	44	0	93	57	6	250
	2008	19-Mar	30-May	62	33	0	151	38	0	284
	2009	11-Mar	29-May	51	9	0	220	74	2	356
	2010	19-Mar	28-May	24	13	0	340	193	1	571
	2011	1-Apr	3-Jun	27	6	1	397	11	0	442
	2012	4-Apr	31-May	268	11	0	764	1,051	0	2,094
	2013	14-Mar	31-May	536	16	2	1,074	2,241	1	3,870
	2014	20-Mar	5-Jun	307	9	6	777	184	1	1,284
	2015	5-Mar	5-Jun	265	10	5	121	276	0	677
	2016	25-Mar	26-May	118	1	1	105	204	1	430
	2017	16-Mar	2-Jun	108	5	3	30	943	2[c]	1,091
	2018	28-Mar	1-Jun	125	12	3	32	848	3	1,023
Historical average				**140**	**13**	**2**	**304**	**827**	**2**	**1,287**

[a] Species Code: CAN = California newt (*Taricha torosa*), CRAY = signal crayfish (*Pacifastacus leniusculus,* non-native), RLF = California red-legged frog (*Rana draytonii*), RSN = rough-skinned newt (*Taricha granulosa*), SCU = sculpin spp., and STK = threespine stickleback (*Gasterosteus aculeatus).*

[b] OTH = other and includes the following species: California giant salamander (*Dicamptodon ensatus*), Ensatina salamander (*Ensatina eschscholtzii*), FS = California freshwater shrimp (*Syncaris pacifica*), Pacific tree frog (*Hyla regilla*), California roach (*Hesperoleucus symmetricus*), striped bass (*Morone saxatilis*), and unclassified species.

[c] Two possible freshwater shrimp captured. No photos for verification. They were most likely juvenile crayfish.

Table A13. Summary of index reach habitat composition; shows extent of area sampled and variation between reaches; Olema Creek, summer 2018. NS = not sampled.

Index reach	Habitat type	# of units	Length		Surface area	
			sampled (m)	% of total	Sampled (m^2)	% of total
1	NS	NS	NS	NS	NS	NS
2	Pool	2	78.1	89.56	321.65	95.36
	Riffle	1	2.6	2.98	4.94	1.46
	Flatwater	1	6.5	7.45	10.73	3.18
	TOTAL	4	87.2	–	337.32	–
3	Pool	2	57.7	64.47	204.84	73.83
	Riffle	3	18.5	20.67	38.92	14.03
	Flatwater	2	13.3	14.86	33.67	12.14
	TOTAL	7	89.5	–	277.43	–
4	NS	NS	NS	NS	NS	NS
5	Pool	3	39.3	46.56	160.08	64.51
	Riffle	3	13.0	15.40	22.78	9.18
	Flatwater	5	32.1	38.03	65.31	26.32
	TOTAL	11	84.4	–	248.17	–
6	Pool	4	75.9	81.26	284.54	87.45
	Riffle	2	17.5	18.74	40.85	12.55
	Flatwater	0	0	0	0	0
	TOTAL	6	93.4	–	325.39	–
7	Pool	3	39.9	69.88	206.07	82.17
	Riffle	1	5.2	9.11	19.50	7.78
	Flatwater	1	12.0	21.02	25.20	10.05
	TOTAL	5	57.1	–	250.77	–
8	NS	NS	NS	NS	NS	NS
Total	Pool	14	290.9	70.67	1,177.18	81.80
	Riffle	10	56.8	13.80	126.99	8.82
	Flatwater	9	63.9	15.52	134.91	9.37
	TOTAL	33	411.6	–	1,439.08	–

Table A14. Summary of total salmonid catch by species within Olema Creek mainstem index reach sample locations, 2004-2018. Shows variation between years and distribution within watershed. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older, NS = not sampled.

		Index reach								Total
Year	**Species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**–**
2004	CO	NS	186	352	NS	295	239	175	164	1,411
	SH YoY	NS	147	231	NS	182	44	20	39	663
	SH 1+	NS	6	10	NS	26	24	10	8	84
2005	CO	NS	206	255	NS	269	361	191	186	1,468
	SH YoY	NS	72	97	NS	180	67	38	44	498
	SH 1+	NS	10	5	NS	13	15	7	7	57
2006	CO	NS	92	36	0	4	2	9	18	161
	SH YoY	NS	55	77	93	80	65	37	43	450
	SH 1+	NS	37	67	24	54	32	6	20	240
2007	CO	NS	123	170	233	332	217	156	160	1,391
	SH YoY	NS	112	135	241	120	51	10	36	705
	SH 1+	NS	9	22	16	19	15	3	8	92
2008	CO	NS	3	42	12	22	9	7	0	95
	SH YoY	NS	113	145	181	103	40	23	2	607
	SH 1+	NS	3	9	13	6	4	1	1	37
2009	CO	NS	0	0	NS	0	0	0	NS	0
	SH YoY	NS	11	16	NS	48	21	25	NS	121
	SH 1+	NS	12	19	NS	6	6	5	NS	48
2010	CO	NS	28	9	NS	8	10	41	NS	96
	SH YoY	NS	91	42	NS	69	61	61	NS	324
	SH 1+	NS	45	16	NS	4	11	11	NS	87
2011	CO	NS	31	19	NS	28	29	94	NS	201
	SH YoY	NS	40	90	NS	101	75	30	NS	336
	SH 1+	NS	34	28	NS	27	13	9	NS	111
2012	CO	NS	1	0	NS	1	0	0	NS	2
	SH YoY	NS	84	194	NS	39	27	39	NS	383
	SH 1+	NS	12	15	NS	5	9	15	NS	56
2013	CO	NS	20	91	NS	82	120	147	NS	460
	SH YoY	NS	5	16	NS	75	4	1	NS	101
	SH 1+	NS	9	18	NS	27	10	4	NS	68
2014	CO	NS	3	4	NS	19	21	17	NS	64
	SH YoY	NS	98	213	NS	346	39	18	NS	714
	SH 1+	NS	6	4	NS	3	5	0	NS	18

Table A14 (continued). Summary of total salmonid catch by species within Olema Creek mainstem index reach sample locations, 2004-2018. Shows variation between years and distribution within watershed. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older, NS = not sampled.

		Index reach								Total
Year	**Species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**–**
2015	CO	NS	0	64	NS	0	80	1	NS	145
	SH YoY	NS	21	74	NS	231	35	22	NS	383
	SH 1+	NS	11	27	NS	6	9	9	NS	62
2016	CO	NS	119	131	NS	98	83	80	NS	511
	SH YoY	NS	56	68	NS	73	19	2	NS	218
	SH 1+	NS	8	9	NS	7	4	2	NS	30
2017	CO	NS	2	7	NS	2	0	9	NS	20
	SH YoY	NS	87	167	NS	238	73	60	NS	625
	SH 1+	NS	5	8	NS	16	3	3	NS	35
2018	CO	NS	17	12	NS	7	20	6	NS	62
	SH YoY	NS	52	114	NS	105	54	65	NS	390
	SH 1+	NS	6	7	NS	10	5	7	NS	35

Table A15. Summary of total salmonid catch and density estimates for each species by index reach on Olema Creek, summer 2018; illustrates variation between reaches and provides a general idea of distribution within watershed. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older, NS = not sampled.

Index reach	Species	Total catch # of fish	Density	
			Fish/m	Fish/m^2
1	NS	NS	NS	NS
2	CO	17	0.19	0.05
	SH YoY	52	0.07	0.02
	SH 1+	6	0.04	0.01
3	CO	12	0.13	0.04
	SH YoY	114	1.27	0.41
	SH 1+	7	0.08	0.03
4	NS	NS	NS	NS
5	CO	7	0.08	0.03
	SH YoY	105	1.24	0.42
	SH 1+	10	0.12	0.04
6	CO	20	0.21	0.06
	SH YoY	54	0.58	0.17
	SH 1+	5	0.05	0.02
7	CO	6	0.11	0.02
	SH YoY	65	1.14	0.26
	SH 1+	7	0.12	0.03
8	NS	NS	NS	NS

Table A16. Summary of index reach habitat composition; shows extent of area sampled and variation between reaches; Redwood Creek, summer 2018. NS = not sampled.

Index reach	Habitat type	# of units	Length		Surface area	
			sampled (m)	% of total	sampled (m^2)	% of total
1	Pool	3	35.3	38.24	103.04	35.78
	Riffle	3	57.0	61.76	184.94	64.22
	Flatwater	0	0.0	0	0	0
	TOTAL	6	92.3	–	287.98	–
2	Pool	3	30.1	30.68	126.43	32.49
	Riffle	2	28.9	29.46	107.11	27.52
	Flatwater	2	39.1	39.86	155.63	39.99
	TOTAL	7	98.1	–	389.17	–
3	Pool	4	66.7	72.74	291.41	84.93
	Riffle	2	16.0	17.45	25.60	7.46
	Flatwater	1	9.0	9.81	26.10	7.61
	TOTAL	7	91.7	–	343.11	–
4	Pool	5	58.1	61.03	225.78	76.44
	Riffle	4	26.2	27.52	50.28	17.02
	Flatwater	2	10.9	11.45	19.30	6.53
	TOTAL	11	95.2	–	295.36	–
5	Pool	4	82.7	73.84	321.80	77.63
	Riffle	3	29.3	26.16	92.73	22.37
	Flatwater	0	0.0	0	0	0
	TOTAL	7	112.0	–	414.53	–
6	Pool	3	61.7	73.54	263.35	78.83
	Riffle	1	8.6	10.25	41.02	12.28
	Flatwater	2	13.6	16.21	29.72	8.90
	TOTAL	6	83.9	–	334.09	–
7	NS	NS	NS	NS	NS	NS
Total	Pool	22	334.6	58.37	1,331.82	64.52
	Riffle	15	166.0	28.96	501.68	24.30
	Flatwater	7	72.6	12.67	230.75	11.18
	TOTAL	44	573.2	–	2,064.25	–

Table A17. Summary of total salmonid catch (not including Dr. Smith information) by species for Redwood Creek mainstem index reach sample locations, 2004-2018. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older, NS = not sampled.

		Index Reach							Total
Year	**Species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**–**
2004	CO	NS	42	95	74	158	71	NS	440
	SH YoY	NS	6	22	19	24	4	NS	75
	SH 1+	NS	19	8	17	15	13	NS	72
2005	CO	23	59	77	93	164	236	339	991
	SH YoY	44	38	41	70	77	178	82	530
	SH 1+	5	12	12	10	14	9	4	66
2006	CO	6	21	21	38	3	9	0	98
	SH YoY	36	77	26	20	5	17	4	185
	SH 1+	2	23	21	20	11	20	1	98
2007	CO	54	138	215	120	146	89	8	770
	SH YoY	90	161	305	170	212	392	144	1,474
	SH 1+	8	43	10	11	7	11	7	97
2008	CO	0	2	6	0	23	3	NS	34
	SH YoY	84	79	103	120	101	79	NS	566
	SH 1+	10	19	23	20	21	12	NS	105
2009	CO	0	5	2	27	5	0	0	39
	SH YoY	104	87	85	55	27	21	25	404
	SH 1+	14	7	20	40	15	2	3	101
2010	CO	0	19	53	34	69	49	NS	224
	SH YoY	63	125	92	93	102	51	NS	526
	SH 1+	14	45	38	26	29	33	NS	185
2011	CO	0	14	6	2	2	0	NS	24
	SH YoY	79	71	20	38	39	15	NS	262
	SH 1+	13	55	24	33	29	25	NS	179
2012	CO	13	11	16	8	1	2	NS	51
	SH YoY	85	79	32	84	64	22	NS	366
	SH 1+	5	16	7	17	13	7	NS	65
2013	CO	38	86	26	21	25	5	NS	201
	SH YoY	3	6	13	2	2	0	NS	26
	SH 1+	4	9	6	15	9	6	NS	49
2014	CO	0	1	2	1	3	3	NS	10
	SH YoY	58	78	91	112	148	72	NS	559
	SH 1+	1	4	8	3	4	0	NS	20

Table A17 (continued). Summary of total salmonid catch (not including Dr. Smith information) by species for Redwood Creek mainstem index reach sample locations, 2004-2018. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older, NS = not sampled.

		Index Reach							Total
Year	**Species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**–**
2015	CO	0	4	1	28	11	29	NS	73
	SH YoY	0	1	0	5	0	3	NS	9
	SH 1+	4	36	19	62	20	13	NS	154
2016	CO	7	73	34	30	10	13	NS	167
	SH YoY	30	126	68	118	120	109	NS	571
	SH 1+	1	14	3	2	13	23	NS	56
2017	CO	15	20	2	5	16	3	NS	61
	SH YoY	140	272	93	95	138	59	NS	797
	SH 1+	9	67	68	113	88	49	NS	394
2018	CO	0	22	15	14	72	54	NS	177
	SH YoY	20	57	25	26	36	6	NS	170
	SH 1+	9	34	46	77	43	49	NS	258

Table A18. Summary of total salmonid catch and density estimates for each species by index reach on Redwood Creek, summer 2018; illustrates variation between reaches and provides a general idea of distribution within watershed. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older, NS = not sampled.

Index reach	Species	Total catch # of fish	Density	
			Fish/m	Fish/m^2
1	CO	0	0.00	0.00
	SH YoY	20	0.22	0.07
	SH 1+	9	0.10	0.03
2	CO	22	0.22	0.06
	SH YoY	57	0.58	0.15
	SH 1+	34	0.35	0.09
3	CO	15	0.16	0.04
	SH YoY	25	0.27	0.07
	SH 1+	46	0.50	0.13
4	CO	14	0.15	0.05
	SH YoY	26	0.27	0.09
	SH 1+	77	0.81	0.26
5	CO	72	0.64	0.17
	SH YoY	36	0.32	0.09
	SH 1+	43	0.38	0.10
6	CO	54	0.64	0.16
	SH YoY	6	0.07	0.02
	SH 1+	49	0.58	0.15
7	NS	NS	NS	NS

Appendix B. Julian Week Numbers

Table B1. List of Julian weeks and their calendar equivalents in a non-leap year.

Julian Week Number	Inclusive Dates
1	Jan 01 - Jan 07
2	Jan 08 - Jan 14
3	Jan 15 - Jan 21
4	Jan 22 - Jan 28
5	Jan 29 - Feb 04
6	Feb 05 - Feb 11
7	Feb 12 - Feb 18
8	Feb 19 - Feb 25
9	Feb 26 - Mar 04
10	Mar 05 - Mar 11
11	Mar 12 - Mar 18
12	Mar 19 - Mar 25
13	Mar 26 - Apr 01
14	Apr 02 - Apr 08
15	Apr 09 - Apr 15
16	Apr 16 - Apr 22
17	Apr 23 - Apr 29
18	Apr 30 - May 06
19	May 07 - May 13
20	May 14 - May 20
21	May 21 - May 27
22	May 28 - Jun 03
23	Jun 04 - Jun 10
24	Jun 11 - Jun 17
25	Jun 18 - Jun 24
26	Jun 25 - Jul 01
27	Jul 02 - Jul 08
28	Jul 09 - Jul15
29	Jul 16 - Jul 22
30	Jul 23 - Jul 29
31	Jul 30 - Aug 05
32	Aug 06 - Aug 12
33	Aug 13 - Aug 19
34	Aug 20 - Aug 26
35	Aug 27 - Sep 02

Table B1 (continued). List of Julian weeks and their calendar equivalents in a non-leap year.

Julian Week Number	Inclusive Dates
36	Sep 03 - Sep 09
37	Sep 10 - Sep 16
38	Sep 17 - Sep 23
39	Sep 24 - Sep 30
40	Oct 01 - Oct 07
41	Oct 08 - Oct 14
42	Oct 15 - Oct 21
43	Oct 22 - Oct 28
44	Oct 29 - Nov 04
45	Nov 05 - Nov 11
46	Nov 12 - Nov 18
47	Nov 19 - Nov 25
48	Nov 26 - Dec 02
49	Dec 03 - Dec 09
50	Dec 10 - Dec 16
51	Dec 17 - Dec 23
52	Dec 24 - Dec 31

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