



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

2019 Annual Report



Crew member performing a spawner survey in Redwood Creek, Marin County CA.
NPS

Long-term monitoring of coho salmon and steelhead during freshwater life stages in coastal Marin County: 2019 annual report

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Abstract

The San Francisco Bay Area Network of the National Park Service Inventory and Monitoring Program monitors populations of federally endangered coho salmon (*Oncorhynchus kisutch*) and federally threatened steelhead (*O. mykiss*) in watersheds at Point Reyes National Seashore, Golden Gate National Recreation Area, and Muir Woods National Monument. This report provides a summary of observations made during the 2019 monitoring year, November 2018 through October 2019, along with historical monitoring data for the Olema Creek, Redwood Creek, and Pine Gulch Creek watersheds. Monitoring of multiple coho salmon life stages including winter adult escapement surveys, spring outmigrant smolt trapping, and summer juvenile basinwide and index reach surveys, inform park managers of both the current status and long-term trends of the species.

Overall, there was little change in coho salmon spawning in Olema Creek when compared to the last time this cohort was observed. In Redwood Creek, the adult coho salmon population was augmented with hatchery reared adults, resulting in a substantial increase in coho salmon spawning for the cohort. No significant change was detected for coho smolt abundance in Olema Creek, while smolt abundance increased in Redwood Creek. Summer juvenile coho abundance in both Olema and Redwood Creeks was lower than anticipated. No coho were observed in Pine Gulch Creek through our monitoring efforts for the ninth consecutive year.

List of Acronyms

1+: One year or older

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

FL: Fork Length

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

SD: Standard Deviation

SFAN: San Francisco Bay Area Network

SPAWN: Salmon Protection And Watershed Network

WY: Water Year

Year–Year: All year–year references refer to the spawning year

YoY: Young-of-Year

Executive Summary

The San Francisco Bay Area Network (SFAN) of the National Park Service (NPS) Inventory and Monitoring Program 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. 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.

The SFAN Inventory and Monitoring Program performs multiple life-stage monitoring in coastal Marin County watersheds for more informative representations of coho populations than if we monitored a single life stage—especially given the complex life history of the species. Coho salmon have a three-year lifecycle, spending 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 in each monitored stream consists of three distinct year classes, or cohorts, known as 1, 2, and 3. NPS staff began monitoring cohort 1 during winter 1997–1998 as the adults returned to spawn. Offspring of these adult coho hatched and emerged from redds in the spring, and crews surveyed their densities during the summer. Field crews surveyed cohort 1 again as out-migrating smolts in 1999, and for a third time as spawning adults in the winter of 2000–2001. Subsequent generations of cohort 1 hatched in 2001, 2004, 2007, 2010, 2013, 2016, and 2019. Cohort 2 fish 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 summarizes monitoring results for the 2018–2019 spawner season, 2019 smolt-trapping season, and 2019 summer basinwide season. This report also provides results for 2019 summer index-reach monitoring. The adults and juveniles monitored in 2019 belong to different generations of cohort 1, while the year-old out-migrating smolts belong to cohort 3. SFAN did not monitor cohort 2, as the majority of these individuals would be at sea and not expected in our 2019 freshwater surveys.

Overall, cohort 1 produced more redds compared to the last time they spawned; however, the distribution of redds was uneven among the three creeks surveyed. Adult coho surveys on Olema

Creek for 2018–2019 detected a similar number of redds compared to 2015–2016 when this cohort last spawned (i.e., 66 redds in 2015–2016 compared to 63 redds in 2018–2019), whereas Redwood Creek redd production increased substantially from 15 redds in 2015–2016 to 61 redds in 2018–2019. The release of 165 adult coho on December 18, 2018, as part of the Rescue and Captive Rearing Project led by CDFW, was largely responsible for the marked increase in redds. SFAN crews did not observe adult coho in Pine Gulch Creek during the 2018–2019 spawner season. Successful coho spawning has not occurred in the Pine Gulch watershed since the 2008–2009 season.

Although overwinter survival of coho juveniles is typically high on Olema Creek, our 2019 estimate of smolt abundance (407, 95% CI [94, 930]) reflected much lower than usual survival of the estimated 1,301, 95% CI [963, 1,639] juveniles from 2018. Program staff attributed the capture of only 94 coho smolts to a change in stream-channel geomorphology. In particular, channel avulsion upstream of the smolt trap resulted in a considerable amount of the flow bypassing the smolt trap. On Redwood Creek, the 2019 smolt estimate was 2,983, 95% CI [2,511, 3,455], which is plausible given the summer 2018 juvenile estimate (4,475, 95% CI [3,613, 5,337]). The relatively high smolt estimate for Redwood Creek is likely due to increased overwinter survival by juveniles. Since we did not observe any juvenile coho in Pine Gulch Creek during summer 2018 basinwide monitoring, the team did not operate smolt traps in the creek during Spring 2019.

We implemented a basinwide visualization technique to estimate the abundance of juvenile coho residing in Olema and Redwood Creeks during the summer of 2019. For Olema Creek, we calculated a basinwide juvenile coho population estimate of 8,978, 95% CI [5,373, 12,583]. This estimate was almost 50% lower than the estimate for 2016, the last time we observed cohort 1 as juveniles. The basinwide juvenile coho population estimate for Redwood Creek was 1,594, 95% CI [989, 2,199]. Redwood Creek's 2019 juvenile estimate was much lower than expected given the amount of spawning activity documented during the winter. Survey crews did not observe juvenile coho in Pine Gulch Creek during 2019 basinwide monitoring.

Introduction

The San Francisco Bay Area Network (SFAN) of the National Park Service (NPS) Inventory and Monitoring Program recognizes salmonids as a vital sign, or indicator of ecosystem health. Monitoring a balanced and integrated set of vital signs meets the scientific monitoring needs of current park management and aids with early detection of unanticipated changes in environmental conditions. Salmonids represent a particularly high priority vital sign for SFAN, because coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) are sensitive to ecosystem changes, provide important links between marine and freshwater systems, have federal endangered or threatened status, and garner high public interest.

This program monitors salmonids at three NPS units within SFAN including Golden Gate National Recreation Area (GOGA), Muir Woods National Monument (MUWO), and Point Reyes National Seashore (PORE). The California Department of Fish and Wildlife (CDFW) supports ongoing monitoring of coho salmon by SFAN staff within the Olema Creek (PORE and GOGA), Pine Gulch Creek (PORE), and Redwood Creek (GOGA and MUWO) watersheds in coastal Marin County through Contract P1630402 with the Point Reyes National Seashore Association. These monitoring efforts continue salmonid research initiated and conducted by SFAN since 1997. The program primarily focuses on documenting federally and state listed endangered coho salmon population distribution and trends within the watersheds mentioned above. Furthermore, SFAN staff designed the sampling methodology to also collect information on federally threatened steelhead and other fish species.

SFAN Salmonid Monitoring Protocol v4.0 (Reichmuth et al. 2010) documents methods used for monitoring salmonids in Marin County since 1997. We highlight any deviations from or additions to Reichmuth et al. 2010 in the Sampling Design and 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 2019 and summarized in comparison with all previous years of monitoring. These watersheds are located within the Lagunitas Creek and Bolinas Hydrologic Sub-Areas of the Bodega and Marin Hydrologic Units.

1.1 Background

Spawning populations of coho salmon and steelhead have declined significantly from historical numbers in the coastal streams of central California. Brown et al. (1994) 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.

Land use and development have altered coastal watershed conditions resulting in dramatic declines in salmonid populations, especially in central California. Salmonids require connected surface flow for

migration and dispersal (typical barriers include waterfalls, dams, and culverts), cold temperatures (<70 °F), and high dissolved oxygen levels (>4.5 mg/L; Moyle 2002, Brett and Blackburn 1981). While land development significantly impacts all salmonid species within a watershed, coho salmon are particularly susceptible due to their semelparous (spawn once before 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 high-quality stream conditions, they can adjust to changes more easily due to their reproductive strategy and ability to reside in freshwater or marine systems for variable lengths of time.

Based on historical regional accounts, coho salmon and steelhead populations have been severely depleted. Coastal Marin County streams that currently contain populations of coho salmon and steelhead include Lagunitas Creek, Olema Creek (major tributary to Lagunitas Creek), Redwood Creek, and Pine Gulch Creek. The National Marine Fisheries Service (NMFS; 2012) reported the following factors as contributing to declines in anadromous fish runs within these streams:

- 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.

The monitoring conducted by this program contributes to our understanding of salmonid population dynamics and condition within the coastal Marin County Area (Figure 1).

Long-Term Monitoring of Coho Salmon and Steelhead in Coastal Marin County

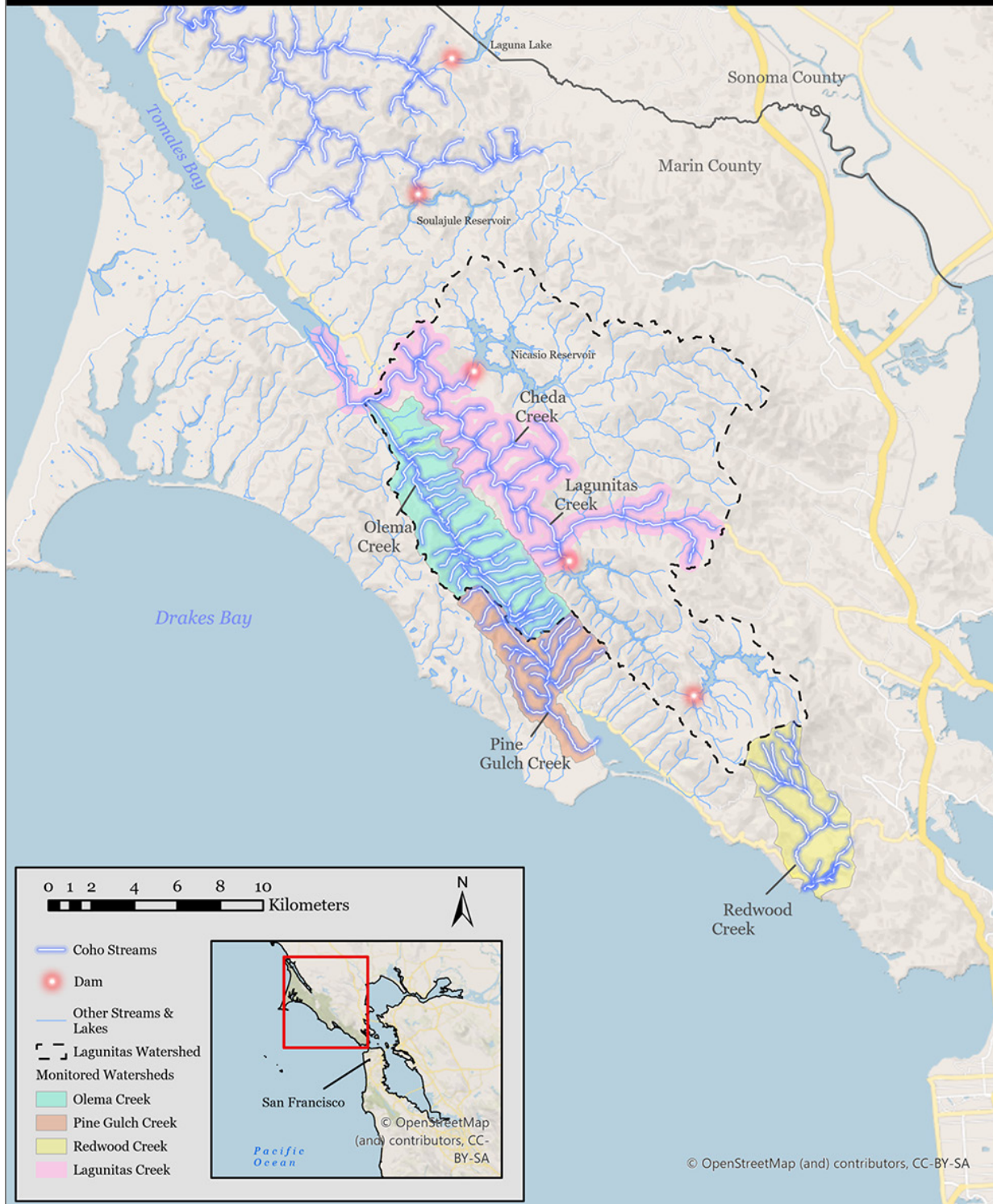


Figure 1. Streams supporting coho salmon in coastal Marin County. The National Park Service monitors streams in Point Reyes National Seashore (Olema and Pine Gulch Creeks) and Golden Gate National Recreational Area (Redwood and Cheda Creeks).

1.2 Fishes Monitored by this Protocol

This program primarily monitors populations of coho salmon and steelhead. However, we also capture and document other aquatic fish species including sculpin (*Cottus* spp.), California roach (*Hesperoleucus symmetricus*), lamprey (*Lampetra* spp.), threespine stickleback (*Gasterosteus aculeatus*), and non-native species during monitoring activities.

Hassler (1987) and Sandercock (1991) describe the general biology of coho salmon in detail. The coho salmon is an anadromous, semelparous fish species, migrating from freshwater to the ocean as a juvenile and back to freshwater as an adult for a single chance at reproduction. Biologists documented natural populations of coho salmon in the Lagunitas (including Olema tributary), Pine Gulch, and Redwood Creek watersheds (Smith 2001, Brown and Ketcham 2002). The National Marine Fisheries Service listed coho salmon as a threatened species within the central California coast coho salmon evolutionarily significant unit (CCCESU) in 1996 and changed the status to endangered in 2005 (Federal Register 1996, Federal Register 2005). The CCCESU includes all naturally spawned populations of coho salmon from Punta Gorda in northern California south to include the San Lorenzo River in central California, as well as populations in tributaries to the 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 went into effect in 2005.

Moyle (2002) described the general biology of steelhead in detail. Steelhead are the anadromous form of rainbow trout and are iteroparous, meaning they can spawn more than once. Steelhead exist in most perennial watersheds within Marin County. Due to dramatic declines in population numbers, NMFS listed steelhead 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, coho young-of-year (YoY) experience a wide range of mortality rates during early development (egg deposition to summer rearing) 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 during egg incubation and fry emergence from late winter to early spring (Lestelle 2007, Manning 2001). In Lagunitas Creek, researchers 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 showed that in areas where adult escapement is adequate to seed watersheds,

the abundance of coho smolts is likely limited by winter habitat availability and overwinter survival (Nickelson and Lawson 1998).

Monitoring multiple life stages will help characterize potential population bottlenecks in the watershed. By observing adult escapement and redd density in the winter, juvenile density in the summer months, and smolt outmigration during the spring, SFAN aims to track cohorts through documented bottlenecks and identify if and where watershed-specific limiting factors exist.

1.3.1 Monitoring Questions

This monitoring program strives to answer the following questions excerpted from 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?

Park and/or partner assistance is required to collect information and answer the following questions:

- 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 salmon cohort within GOGA and PORE watersheds?

1.3.2 Monitoring Objectives

This monitoring program focuses on meeting the following objectives excerpted from SFAN Salmonid Monitoring Protocol v4.0 (Reichmuth et al. 2010):

1. Determine long-term trends in the distribution, abundance, and 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 lie 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 the construction of Alpine Dam in 1918 and Peters Dam in 1953 reduced mainstem length by more than 50%. Because neither dam has provisions for fish passage, anadromous salmonids can no longer access the upper portion of the drainage.

The portions of the Lagunitas drainage most significant for salmonids are under a number of ownerships. NPS lands (north district GOGA) border approximately 12 km of the mainstem. 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 such as instream grazing within the Cheda Creek drainage caused alterations to the natural hydrology and degraded riparian conditions. These alterations negatively impacted salmonid populations, water quality, and the ability of the aquatic ecosystem to function properly. Therefore,

the NPS led construction of a fish-passage structure in the fall of 2000, which was part of a comprehensive project to restore the watershed to a more natural and sustainable condition.

Redwood Creek is a 22.7 square km (8.8 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 primarily lies within the boundaries of Mt. Tamalpais State Park, GOGA, and MUWO. The Redwood Creek 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 km (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 currently supports steelhead, and it is generally accepted that Pine Gulch Creek previously supported a native self-sustaining population of coho salmon until the 1970s (Ketcham and Brown 2003). The drought of the late 1970s coupled with instream damming during the same period likely depleted multiple cohorts and led to unsuitable conditions for the species within the watershed (Ketcham and Brown 2003). In 2001, SFAN documented the return of coho salmon to Pine Gulch Creek beginning with the discovery of a coho carcass, and subsequent documentation of coho YoY in the watershed the following summer (Brown and Ketcham 2002). Based on genetic tests, coho returning 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).

Sampling Design and Methods

SFAN developed four strategies to monitor these species at key life stages. Reichmuth et al. (2010) documented Standard Operating Procedures (SOPs) for winter adult spawner surveys, spring outmigrant smolt trapping, summer juvenile coho basinwide surveys, and summer index-reach surveys in the SFAN Salmonid Monitoring Protocol version 4.0. We provided the methods in this report as a summary of the more detailed methods within the protocol. SFAN crews used these methods for salmonid monitoring within coastal Marin County beginning in 2009. Many of the methods associated with the project are consistent with the CDFW Coastal Monitoring Plan (Adams et al. 2011) and are used for regional salmonid population trends.

2.1 Adult Coho and Steelhead Escapement Surveys

During the 2018–2019 season, we completed spawner surveys in watersheds within and adjacent to SFAN park units, including PORE, GOGA, and MUWO. These surveys concentrated primarily on federally endangered coho salmon and federally threatened steelhead to quantify adult escapement. “Escapement” refers to the number of adult fish that successfully pass through a fishery, commercial or recreational, to reach spawning grounds located in freshwater streams. Coho and steelhead data collected during surveys contributed to Monitoring Objective 1 and included number of live adult fish observed, number of adult fish carcasses observed, and number of redds observed. National Park Service staff first conducted these surveys on Redwood Creek in 1994, Olema Creek in 1997, Cheda Creek in 1998, and Pine Gulch in 2000. Reichmuth et al. (2010) documented field and analytical methods for adult salmon escapement monitoring efforts in Standard Operating Protocols 5, 6, 9, and 11.

2.1.1 Adult Coho and Steelhead Escapement Survey Field Methods

Program staff and trained volunteers conducted surveys for coho and steelhead redds and spawners during the 2018–2019 winter and 2019 spring to quantify escapement and determine spawning density and distribution. Crews performed surveys into spring to capture the entire steelhead spawning season. Most spring surveys were performed after freshets, when adult steelhead spawning activity was projected to increase. For the 2018–2019 spawner season, the adult coho migration window spanned from late November to late January, while steelhead spawning began in January and ended by mid-April. As in years prior, the arrival of rain in the fall and sustained flows into spring months determined the spawner season start and end dates. 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). In winter 2018–2019, field crews conducted surveys approximately every week from late November through early January. Following the first week of January, crews surveyed less frequently until the spring due to the federal government shutdown and high flow conditions throughout the month of February. A few surveys were conducted during the federal government shutdown by park partner organizations, but the frequency was less than the typical survey frequency. Storms were less frequent and intense during the spring months which allowed for higher fieldwork efficiency because redds remained undisturbed and were relatively easy to detect, even several weeks after spawning occurred.

During spawner surveys, observers walked upstream through 2–3-km creek reaches (Figures 2–4) and along creek margins and banks, where possible, to look for live fish, carcasses, and redds. Although the spawner survey reaches for the 2018–2019 season were consistent with past years, survey frequency differed due to a lengthy federal government shutdown along with variations in individual survey extent due to changes in survey access locations, stream conditions, and staff availability (Tables 2 and 4 in McNeill and Reichmuth 2024). Despite variations in survey distances, crews completed assigned spawner reaches within one field day. Observers classified live fish to species and sex and visually estimated fork length (FL) to the nearest 5 cm. Observers also attempted to identify carcasses to species and sex and marked each carcass to prevent recounting on subsequent surveys. We measured the FL of fully intact carcasses to the nearest cm and collected scale and tissue samples for aging and genetic analyses. Crews measured redd dimensions to the nearest 0.1 m and marked redds with flagging tied to elevated vegetation, typically on the opposite stream bank to avoid disturbance of eggs. Because redds are stationary and can be observed over time, the SFAN protocol used redd monitoring as a means of estimating spawning success.

We took particular care to avoid disturbing either redds or actively spawning adults. Survey crews recorded locations of all live fish, carcasses, and redds in reference to permanent tags placed every 100 m along each stream.

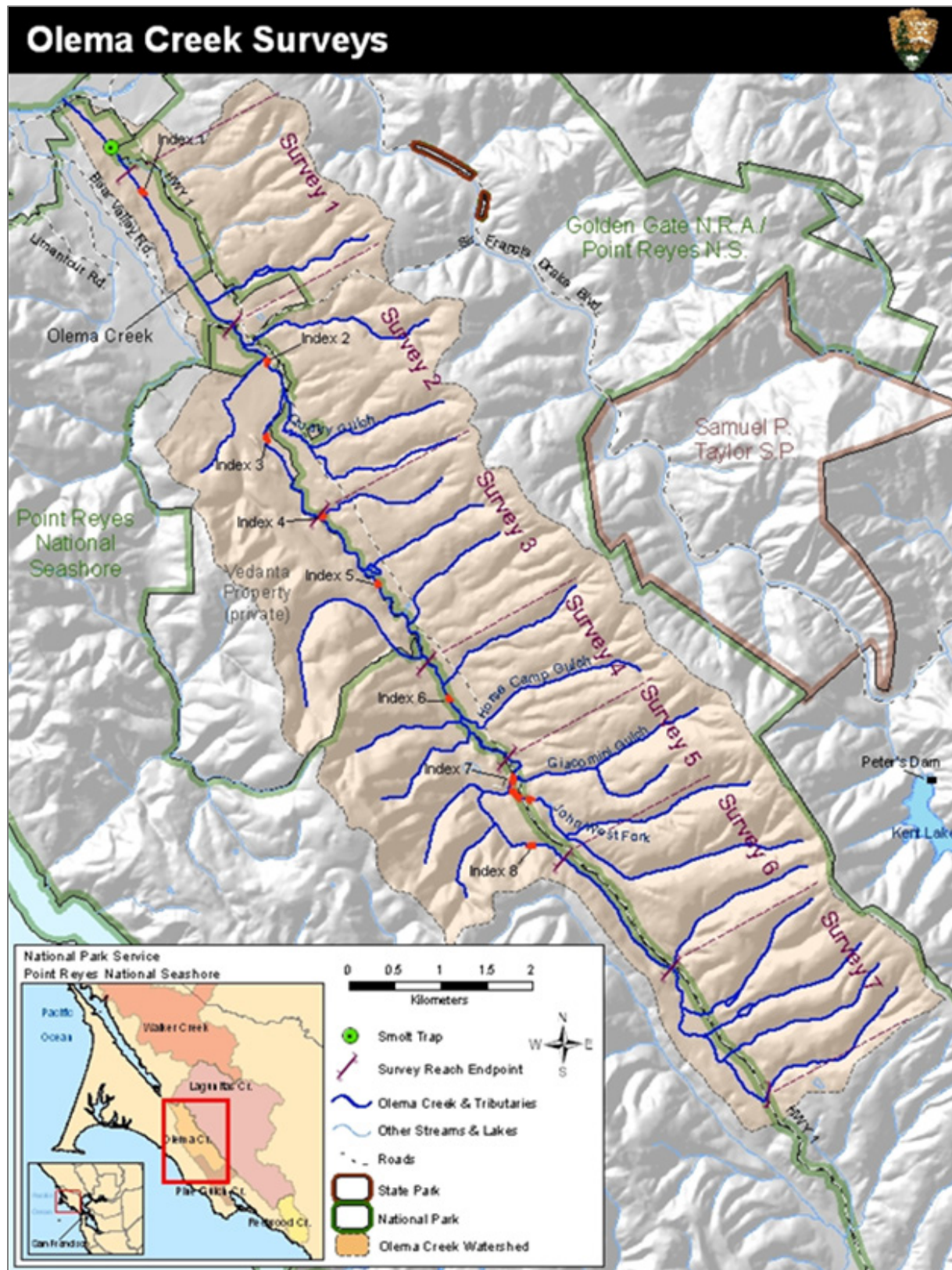
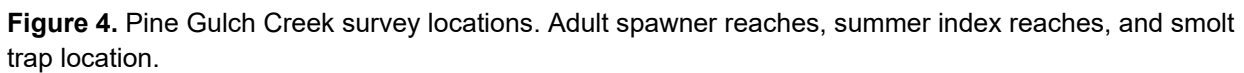


Figure 2. Olema Creek survey locations. Adult spawner reaches, summer index reaches, and smolt trap location.



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



2.1.2 Changes to Methodology

The program continued to seek improvements in salmonid monitoring methods and technology. To this end, changes were made in the program methods that are not currently reflected in the published protocol (Reichmuth et al. 2010); therefore, we describe those changes below.

Starting in winter 2009–2010, along with scale and tissue samples, field teams retrieved otoliths (bony structures in the inner ear cavity of fish that aid in balance and hearing) from all intact carcasses for stable isotope analysis. Observers also scanned carcasses using a handheld Passive Integrated Transponder (PIT) tag reader to determine if any had received PIT implants as a juvenile. We also updated the method for measuring redd area detailed in Reichmuth et al. 2010. With the new procedure, crews recorded length and average width for both the pit and tailspill: average width was calculated from two width measurements for each feature.

Starting winter 2015–2016, crew members collected locational coordinates for both redd and fish observations. These data were analyzed with a known-nearest-neighbor (KNN) algorithm (Garwood and Larson 2014) to retroactively classify the species of redds that were documented as unknown in the field. The Coastal Monitoring Plan (CMP) technical advisory committee suggested this new method for assigning the likely species when the adults that built the redd were not directly observed.

2.2 Outmigrant Coho Smolt Trapping

A detailed description of sampling design rationale, locations, and methods used during the 2019 outmigrant smolt-trapping season were documented in SOPs 3, 4, 6, 9 and 11 in Reichmuth et al. 2010.

Outmigrant trapping allows us to estimate the number of coho smolts leaving the watershed, and the smolt data obtained through trapping operations contributes to Monitoring Objective 2. We performed outmigrant smolt trapping from March through May on Olema and Redwood Creeks in 2019. And although crews installed a smolt trap near the mouth of Pine Gulch Creek in years following the detection of juvenile coho during summer basinwide surveys, we did not operate a trap at this location in 2019, because we observed no juvenile coho in Pine Gulch Creek during the 2018 surveys. Despite focusing efforts on coho smolt data collection, crews also collected information about steelhead smolt outmigration. Smolt trapping also helped quantify dates of fry emergence and growth rates through the spring season. Finally, outmigrant traps provided presence/non-detect information and size data for other aquatic species during April and May.

2.2.1 Outmigrant Coho Smolt Trap Field Methods

Field crews operated smolt traps daily for a 2-month period during the spring. SFAN crews installed fyke/pipe traps similar to those developed in northern California for trapping small streams (Manning and Roelofs 1996, Manning 2001), as this style of trap had proven effective. The traps were designed to catch fish moving downstream and, with efficiency estimated via mark-recapture techniques, allowed us to calculate a smolt-abundance estimate using DARR (Bjorkstedt 2005). The Chapman modification of the Petersen equation (Schneider 2000) is another tool for estimating smolt

abundance. We used this equation in years when the recapture distribution or number of marked coho were insufficient to produce an estimate with DARR estimator (Bjorkstedt 2005).

During each site visit, crews measured FL to the nearest mm and weight to within 0.01 g for a random subsample of coho and steelhead smolts (i.e., fish aged at least one year that have undergone physiological changes in preparation for saltwater), steelhead parr (i.e., juveniles aged at least one year that show no signs of smoltification), and coho and steelhead fry (i.e., recently hatched and emerged juveniles). The subsample for each species and age class was typically 10 randomly selected individuals captured. If less than 10 individuals for any species or age class were captured, all individuals were measured and weighed instead of a subsample. Calculated mean and median weights from these measurements are reported to within 0.1 g. Crews also measured and weighed smolts that were anesthetized for mark-recapture purposes and included them in size-structure analyses. We determined trapping locations based on channel morphology and accessibility (Figures 2–4). Field crews installed smolt traps in late-March, once flows subsided and stabilized from winter peaks. In past years, spring rains increased flows and compromised trap operations. This occurred in May 2019 on Olema and Redwood Creeks, so the program suspended operations until it was safe to resume. Coho smolt migration decreased substantially by late May as stream flows dropped, so traps were removed at that time. In each of the monitored watersheds, the SFAN I&M program maintained a stream gauge for measurement of average daily discharge. Crews deployed an Onset-brand temperature logger in each trap box for the duration of the smolt season.

2.2.2 Changes to Methodology

In 2019, smolt outmigrant trapping methods remained mostly unchanged compared to previous years. There were two updates to methodology not included in the protocol; crews utilized PIT tags starting spring 2009 for the mark-recapture studies, and in spring 2016, field crews began anesthetizing smolts with MS-222 (Tricaine Methanesulfonate) rather than Alka Seltzer® prior to processing. Beginning in 2013, we built and maintained stationary PIT arrays (not part of this protocol) near the smolt-trap sites to improve the measure of trap efficiency by detecting smolt movement and possible avoidance behavior after traps were removed at the end of the season.

2.3 Juvenile Coho and Steelhead Surveys

Monitoring juvenile salmonids during their freshwater-residence phase provided information on overall population trends in distribution, abundance, and condition (Monitoring Objective 3). We initiated surveys during summer and fall base-flow conditions, when water clarity and stream conditions were more conducive to observation and capture of juvenile salmonids.

Crews primarily conducted basinwide GSS and index-reach monitoring during the summer/fall sampling period in Olema Creek, Pine Gulch Creek, and Redwood Creek. Complete published field methods were documented in SOPs 1, 2, 6, and 9 in Reichmuth et al. (2010). The protocol organized the field methods for summer juvenile coho and steelhead monitoring by survey procedure because several kinds of surveys were used. We treated each survey procedure as a standalone sampling event.

2.3.1 Basinwide General Systematic Surveys

Basinwide survey techniques, developed by Hankin and Reeves (Dollof et al. 1993) and used by SFAN, provided statistically valid estimates of stream-habitat type and salmonid-population size for monitored streams. Basinwide surveys involved a two-stage sampling design of snorkeling and electrofishing. This type of sampling combined labor-intensive data collection for a randomly selected subsample of units with a less time-consuming sampling technique to achieve valid representation while reducing effort. Multiple-pass electrofishing is an established method to determine juvenile salmonid true count within a sample unit. The electrofishing surveys provided a basis for estimating detection probability when snorkeling, which we applied to snorkel counts to calculate an unbiased abundance estimate for pools we only snorkeled.

During habitat surveys, crews classified stream habitat units 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). The lead habitat surveyor also estimated the width for each habitat unit after measuring the length. Field crews flagged every fourth pool for snorkeling and measured several widths within these units for calibration of estimated widths. The number of width measurements required for calibration was determined by the unit length, with a minimum of two widths and maximum of six. We counted all large woody debris that provided instream shelter and recorded these counts for each habitat unit.

Crews then surveyed each of the previously flagged pools with a single pass snorkel count, using dive lights to search under vegetation, woody debris, and undercut banks. Snorkelers counted coho and noted the presence/absence of steelhead and non-salmonid fish. To calibrate results from snorkeling, we randomly selected units for follow-up electrofishing using a random number generator. Sections of Olema Creek and Pine Gulch Creek were deemed inaccessible or hazardous for electrofishing, so snorkelers used bounded counts (Murphy and Willis 1996) to calibrate pools in these areas. Here, snorkelers calibrated the initial snorkel pass with three repeat passes. To ensure reliable counts, snorkel crews allowed water clarity to improve before each repeat pass.

For each electrofished unit, a random subsample of coho YoY, steelhead YoY, and steelhead one year or older (1+) were measured for FL to the nearest mm and weighed to within 0.01 g. This subsample typically included 10 randomly selected individuals captured of a species and age class. If less than 10 salmonids for any age class were captured, all individuals were measured and weighed instead of taking a subsample. Calculated mean and median weights from these measurements are reported to within 0.1 g.

2.3.2 Index-Reach Monitoring

We sampled established index reaches in Olema Creek, Redwood Creek, and Pine Gulch Creek during the summer/fall base-flow period to assess fish abundance and distribution within each reach. These stream reaches were approximately 100-meters long and distributed intermittently along each creek's full length. NPS staff began surveying index reaches annually in the mid- to late-1990s (Figures 2–4). Index-reach surveys included both fish sampling and detailed habitat assessments.

Each index reach contained two or more contiguous habitat units, which were identified and sampled individually. Field crews isolated these units with block nets and sampled each separately using standard multiple-pass depletion electrofishing methods (Bohlin et al 1989). The survey team measured units for length and average width and assessed habitat structure for the index reaches after fish sampling was completed.

2.3.3 Changes to Methodology

SFAN has made minor changes to the juvenile salmonid methodology since the protocol was published in 2010 to ensure accurate and comprehensive data collection. Beginning summer 2016, snorkel crews used handheld Global Positioning System (GPS) devices to record the geospatial location of each snorkeled habitat unit. The GPS device saved location coordinates as waypoints, and staff downloaded all waypoints in-office immediately following a survey. The program increased sampling effort starting summer 2015 due to the lower densities of juvenile coho within monitored streams. Crews snorkeled every fourth pool and every tenth flatwater with a depth greater than 0.2 m. Beginning in the summer of 2017, the program developed a method for ranking pool complexity. We classified pools as either non-complex, complex with less than 50% open water, depth exceeds ability to electrofish, or complex with less than 30% open water. In the past, most habitat units with large amounts of woody debris, greater than one meter in maximum depth, and/or more than ~30 meters long were deemed too complex and skipped due to an inability to accurately electrofish them. However, in an effort to increase accuracy of juvenile estimates during 2019 basinwide surveys, crews snorkeled these complex pools where feasible and calibrated initial counts with bounded count repeat passes (Murphy and Willis 1996). The team later seined the pools to collect fish length and weight information and tag salmonids. For the latter, we anesthetized juvenile coho ≥ 65 mm and marked each with a PIT tag to inform future growth and survival studies. Finally, crews either seined or electrofished a sample unit, not both. If electrofishing was deemed too hazardous for a specific pool, and calibration was required, then we seined the pool with multiple passes. Crews discontinued Pine Gulch Creek index-reach surveys in 2018 due to time limitations and inconsistency in data among years.

2.4 Smolt and Juvenile Coho and Steelhead Condition

Although length is the principal determining factor affecting the weight of fishes, fish of the same species and within the same watershed can vary considerably in weight despite having similar lengths. To compare length-weight relationships, we applied the Fulton's condition factor (K-factor) to establish comparable indices of condition (Murphy and Willis 1996) for all smolt and juvenile salmonids measured and weighed. Fulton's condition factor is a ratio relating fish length to weight, allowing for calculation of the relative biomass of a fish. We calculated K-factors for all salmonids measured for FL and weighed.

Monitoring Results

We organized results first by monitoring procedure (escapement surveys, outmigrant smolt surveys, basinwide juvenile surveys, and index-reach juvenile surveys) and then by watershed. For context, we also presented rainfall data.

3.1 Rainfall

SFAN used rainfall data collected by the Western Regional Climate Center Olema Valley weather station for Olema Creek. Total rainfall for water year 2019 (October 2018–September 2019) was substantially higher than the historical average. The total rainfall amount for coho spawning months, November through February, was also well above the historical average. Moreover, the Olema Valley weather station recorded 4.67 inches of rainfall in May, which is the third highest amount on record for the month.

Total rainfall on Redwood Creek for 2019 was also well above average. Redwood Creek experienced the wettest February on record (WY1999–present) with 12.29 inches of rainfall. Substantial storm events resulted in the second highest rainfall (3.22 inches) ever recorded for the month of May at Redwood Creek.

3.2 Data from Escapement Surveys

In the 2018–2019 spawning year, crews conducted escapement surveys from 26 November through 9 April in Olema, Cheda, Redwood, and Pine Gulch Creeks, including select associated tributaries. Survey frequency during the peak coho spawning period between 22 December and 25 January was severely limited due to a partial federal government shutdown. During this period, field crews only performed three spawner surveys.

The NPS first conducted spawner surveys following current methodology on Olema Creek in 1997, Redwood Creek in 1997, Cheda Creek in 1998, and Pine Gulch in 2000; Olema and Cheda Creeks are part of the Lagunitas Creek watershed. MMWD and the Salmon Protection And Watershed Network (SPAWN) monitor other reaches within the Lagunitas Creek watershed. These groups have performed a similar level of monitoring for spawning adult salmonids since the late 1990s, and results should be analyzed in aggregate to make inferences on the population. Historical coho redd densities for all streams monitored in Marin County by SFAN, MMWD, and SPAWN are presented in Table 1 of McNeill and Reichmuth (2024; this table reveals annual fluctuations in spawning distribution and abundance between creeks).

3.2.1 Olema Creek Coho and Steelhead Escapement

In 2018–2019, Olema Creek watershed spawner survey information included data collected on 13.8 km of the mainstem, primarily Reaches 1 through 6, and 1.5 km of John West Fork, the largest tributary to Olema Creek (Figure 2). We did not survey smaller tributaries to Olema Creek this season, because the team was understaffed during a month-long federal government shutdown.

Survey Timing and Environmental Conditions

We conducted eight surveys in Olema Creek between 26 November 2018 and 16 April 2019. During the primary coho spawning season (November–February), the mean interval between surveys was thirteen days. Field crews did not survey Olema Creek mainstem in February due to sustained high flows throughout the month. Seven-day rainfall totals for Julian weeks within peak spawning months (December and January) ranged from a low of 0.01 inches during Julian week 4 to a high of 4.30 inches during Julian week 3. Live fish observations appeared to relate to the onset of rainfall and subsequent higher flows. Data on historical timing of the coho run, rainfall during the run, and spawning activity observed in the Olema Creek watershed can be found in Table 2 of McNeill and Reichmuth (2024).

We surveyed John West Fork tributary eight times between 30 November 2018 and 16 April 2019. We conducted most of these surveys concurrently with Olema Creek mainstem surveys. Average water clarity during surveys ranged from 55 cm to over 100 cm.

Live Coho and Steelhead

While live coho observations do not accurately represent the total number of spawning adults, it is worth noting that crews observed 96 adult coho during surveys on the Olema Creek mainstem. We also observed 15 live coho adults on John West Fork tributary. For Olema Creek mainstem, the first live adult coho was observed on 26 November 2018.

Although steelhead trout are not the primary focus of this study, field teams recorded observations of live adult steelhead 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. Crews observed 19 adult steelhead during the 2018–2019 spawner surveys on the mainstem of Olema Creek. We did not observe steelhead adults on John West Fork this season. Two adult salmonids observed on Olema Creek mainstem could not be positively identified to species.

Coho and Steelhead Carcasses

Field crews recovered six coho carcasses on Olema Creek mainstem and two coho carcasses on John West Fork during the 2018–2019 season.

No steelhead carcasses were recovered on Olema Creek mainstem, whereas two steelhead carcasses were recovered on John West Fork. Crews could not identify five carcasses to species on Olema Creek mainstem.

Coho and Steelhead Redds

Redd surveys allow for a consistent means to spatially represent spawning densities in the watershed. Within Olema Creek, SFAN began analyzing redd data per 100-m section of stream in 1997–1998. Collectively, these data show high-use areas for spawning within the Olema Creek watershed.

We documented 49 confirmed coho redds in reaches two through five of the mainstem of Olema Creek during the 2018–2019 season. Eight coho redds were observed in John West Fork tributary. Of

the 57 confirmed coho redds in the Olema Creek watershed, crews measured 28, and their average surface area was 4.74 (SD 2.01) m².

We also recorded three confirmed steelhead redds in the mainstem of Olema Creek and seven steelhead redds in John West Fork. Of the 10 confirmed steelhead redds, field teams measured eight, and their average surface area was 1.78 (SD 0.85) m².

Program staff could not classify 25 redds to species due to absence of fish or stream conditions (i.e., high turbidity, water depth, and habitat complexity) during time of observation. Overall, we documented coho redds throughout the Olema Creek mainstem and in John West Fork tributary, and we observed most steelhead redds in the upper reaches of the watershed (Figure 5).

We reclassified unknown redds 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, we reclassified six of the 25 unknown redds as coho and the remaining 19 as steelhead, yielding a total estimate of 54 coho redds on Olema mainstem, nine coho redds on John West Fork, 20 steelhead redds on the mainstem, and nine steelhead redds on John West Fork. The resulting estimated coho redd density was 3.9 redds/km, and steelhead redd density was 1.4 redds/km for Olema Creek mainstem. The 2018–2019 coho redd estimate was only slightly lower than the estimate for 2015–2016 (Figure 6), which was the last time we observed this cohort returning to spawn. Since spawner surveys began in the winter of 1997, cohort 1 generally has shown the strongest returns in Olema Creek.

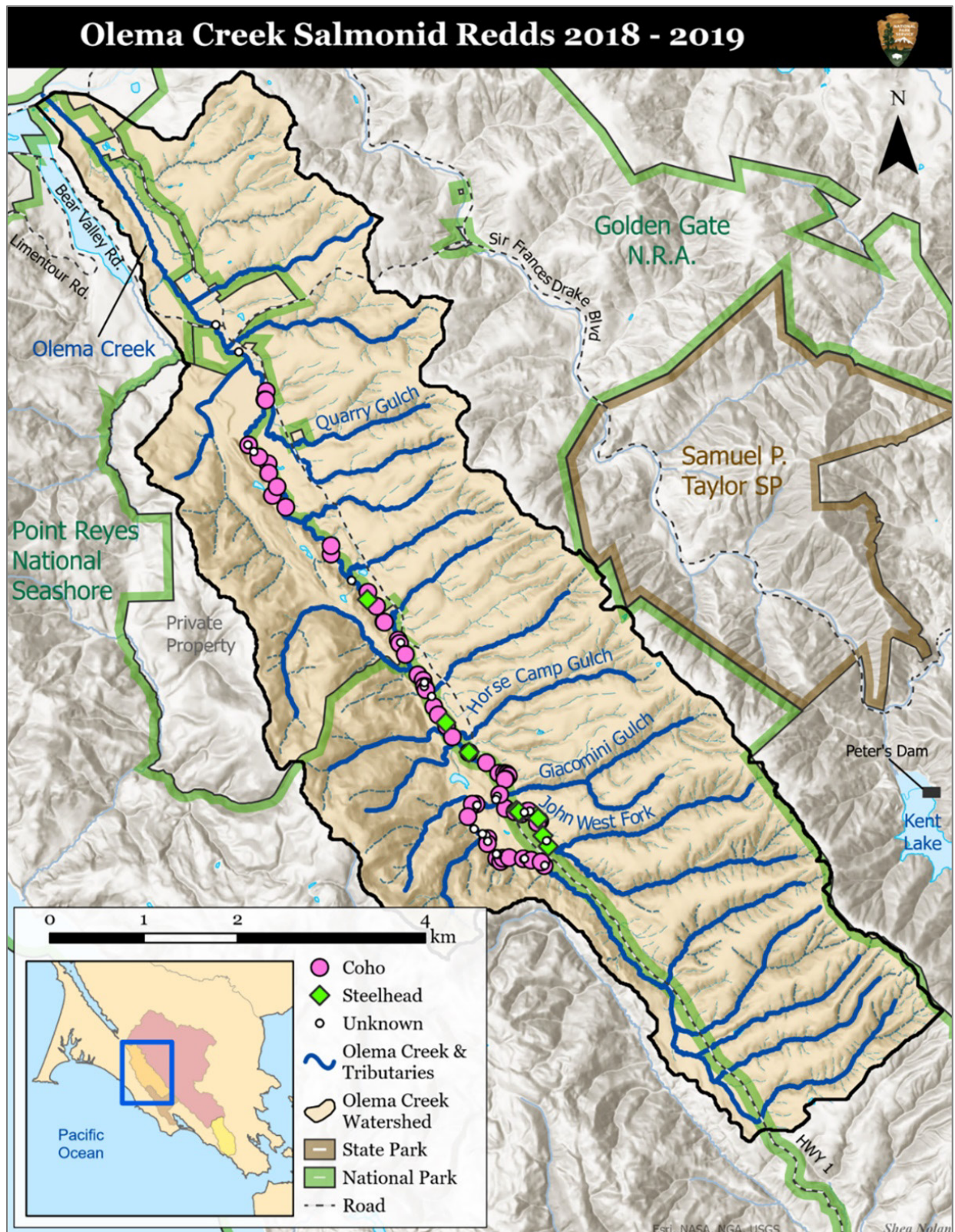


Figure 5. Coho salmon, steelhead, and undetermined salmonid species redd locations recorded in the Olema Creek watershed during the 2018–2019 spawning season.

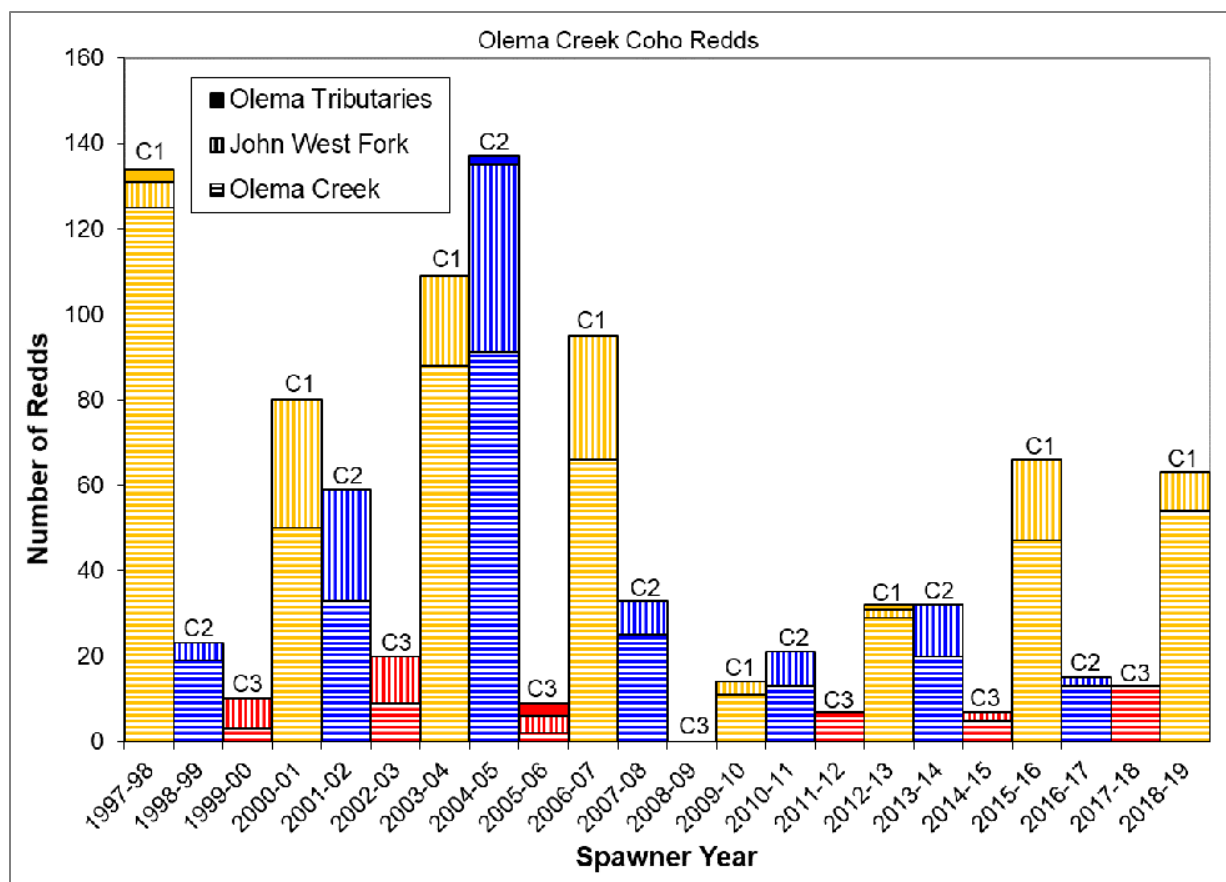


Figure 6. Coho salmon redd results for the Olema Creek watershed by cohort for winter 1997–1998 through winter 2018–2019. Cohorts are designated by color (cohort 1 in yellow, cohort 2 in blue, cohort 3 in red) and creeks are designated by pattern (Olema Creek in horizontal lines, John West Fork in vertical, and other Olema tributaries in a solid color).

Live Coho and Coho Carcass Biotics

We collected data on live adult coho and coho carcasses during each field survey. In Olema Creek, sex ratios and mean FL of captured live coho during 2018–2019 were comparable to the 21-year averages since 1997 (Table 1). We did not encounter many coho carcasses (n=8) in 2018–2019 (Table 2) likely due to the truncated field season caused by the government shutdown.

Table 1. Sex ratio percentages and mean fork length (FL) of live coho within Olema Creek watershed for the period 1997–2018 compared to 2018–2019.

Period	Type ^A	Year	Live Coho				
			Sample Size	Sex Ratio %	n ^B for FL	Mean FL (cm)	FL SD ^C (cm)
Cumulative	M	1997–2018	748	36	715	63	7.3
	F	1997–2018	887	43	864	61	6.0
	J	1997–2018	326	16	326	39	5.1
	Unk	1997–2018	100	5	58	56	7.2
	All	–	2,061	100	–	–	–
Current	M	2018–2019	43	39	43	65	5.9
	F	2018–2019	48	43	48	65	4.5
	J	2018–2019	7	6	7	44	2.4
	Unk	2018–2019	13	12	13	63	8.1
	All	–	111	100	–	–	–

^A M = Male, F = Female, J = Jack, Unk = Unknown.

^B n = Number of fish measured for FL.

^C SD = Standard Deviation.

Table 2. Sex ratio percentages and mean fork length (FL) of coho carcasses within Olema Creek watershed for the period 1997–2018 compared to 2018–2019.

Period	Type ^A	Year	Carcasses				
			Sample Size	Sex Ratio %	n ^B for FL	Mean FL (cm)	FL SD ^C (cm)
Cumulative	M	1997–2018	157	33	114	66	8.0
	F	1997–2018	196	41	152	65	5.1
	J	1997–2018	45	9	45	43	3.6
	Unk	1997–2018	80	17	11	65	7.1
	All	–	478	100	–	–	–
Current	M	2018–2019	4	50	2	63	0
	F	2018–2019	3	37.5	3	62	2.1
	J	2018–2019	0	0	0	–	–
	Unk	2018–2019	1	12.5	0	–	–
	All	–	8 ^D	100	–	–	–

^A M = Male, F = Female, J = Jack, Unk = Unknown.

^B n = Number of fish measured for FL.

^C SD = Standard Deviation.

^D Survey frequency during the peak coho spawning period between 22 December and 25 January was severely limited due to a partial federal government shutdown that likely caused reduced carcass detection.

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 along 1.4 km of its length starting at the confluence with Lagunitas Creek.

Survey Timing and Environmental Conditions

Field crews completed three surveys on Cheda Creek between 21 December 2018 and 8 February 2019. Average water clarity during surveys ranged from 50 cm to 70 cm.

Live Coho and Steelhead

We observed five live adult coho and one steelhead during Cheda Creek surveys.

Coho and Steelhead Carcasses

We recovered one confirmed coho carcass on 8 February 2019.

Coho and Steelhead Redds

Field crews observed two confirmed coho redds within Cheda Creek during the 2018–2019 season. Crews did not measure either redd due to active spawning. Seven redds could not be classified to species in the field. The kNN algorithm reclassified all seven unknown redds as coho, yielding a total estimate of nine coho redds for Cheda Creek. Average surface area for the reclassified redds was 1.91 (SD 1.32) m². The estimated coho redd density, including kNN redds, was 6.0 redds/km.

The team observed two steelhead redds on 8 February 2019. Both redds were measured, and the average surface area was 2.46 (SD 0.65) m². The estimated steelhead redd density for Cheda Creek was 1.4 redds/km.

3.2.3 Redwood Creek Coho and Steelhead Escapement

We included spawner data collected on 8.1 km of Redwood Creek mainstem, primarily Reaches 1 through 3, and Fern Creek, the largest tributary (Figure 3). Crews also conducted spawner surveys on two smaller tributaries, Green Gulch and Kent Canyon. When possible, we combined the mainstem of Redwood Creek and its tributaries for data summaries and analysis.

Survey Timing and Environmental Conditions

The team conducted twelve surveys in Redwood Creek between 27 November 2018 and 9 April 2019. The mean interval between surveys during the primary coho spawning season (November–February) was 8.6 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 week 4 to a high of 3.61 inches during Julian week 3. Average water clarity during surveys ranged from 50 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 Table 4 of McNeill and Reichmuth (2024).

Green Gulch, Fern Creek, and Kent Canyon are the three main tributaries to Redwood Creek. We surveyed Fern Creek five times this season on days when mainstem surveys were also performed to eliminate the possibility of inflating adult spawner numbers by double counting fish. Average water

clarity on Fern Creek ranged from 65 cm to over 100 cm. Surveys of Green Gulch and Kent Canyon were dependent on flow. Field crews surveyed lower Green Gulch and Kent Canyon tributaries on 29 January 2019. Water clarity was 50 cm on Green Gulch and 95 cm on Kent Canyon at time of survey.

Live Coho and Steelhead

On 18 December 2018, the California Department of Fish and Wildlife and partner agencies released 165 adult coho spawners back into Redwood Creek as part of an emergency project. These adults were originally captured as juveniles and reared to maturity at Don Clausen Fish Hatchery in Sonoma County, CA. Eighty-seven of the released fish were females, and 76 were males. The remaining two fish were immature, as sex could not be determined. During the 2018–2019 spawner season, we observed 98 live coho on the mainstem of Redwood Creek, with 92 of those fish displaying neon-colored hatchery floy-tags (46 pink [female] and 46 green [male]). Crews also observed 64 adult steelhead and five unknown salmonids this season. No adult coho were observed in tributaries. Of the 64 adult steelhead recorded, we documented four in Fern Creek.

Coho and Steelhead Carcasses

Crews recovered four coho carcasses on Redwood Creek mainstem during spawner surveys in 2018–2019. Of those four carcasses, staff confirmed one as a hatchery-reared male. We also recovered four steelhead carcasses this season. Three carcasses recovered on the mainstem could not be identified to species. We did not observe any carcasses on the tributaries.

Coho and Steelhead Redds

Field teams documented 55 confirmed coho redds during the 2018–2019 spawner season. Redds were observed in all three reaches of the mainstem. Of the 55 confirmed coho redds, crew members measured pit and tailspill dimensions for 50 redds. The average surface area for coho redds was 2.28 (SD 1.34) m². We did not observe coho redds in Fern Creek, Green Gulch, or Kent Canyon tributaries.

We also documented 28 confirmed steelhead redds on Redwood Creek mainstem and measured 22 of the 28 redds. The average surface area for steelhead redds was 3.03 (SD 1.22) m². Field teams observed three confirmed steelhead redds in Fern Creek and another three steelhead redds in Kent Canyon. No steelhead redds were seen in Green Gulch.

During 2018–2019 surveys on Redwood Creek, crews were unable to classify 19 redds to species due to absence of fish or stream conditions (i.e., high turbidity, water depth, and habitat complexity). We documented a majority of the coho redds throughout the lower three kilometers of Redwood Creek with some spawning observed in the Muir Woods section. Most steelhead spawning occurred upstream of the confluence with Kent Canyon (Figure 7).



Figure 7. Coho salmon, steelhead, and undetermined salmonid species redd locations recorded in the Redwood Creek watershed during the 2018–2019 spawner season.

After kNN analysis, we reclassified six of the 19 unknown redds as coho and the remaining 13 as steelhead, yielding total estimates of 61 coho redds and 47 steelhead redds. The resulting estimated coho redd density was 7.5 redds/km, and the estimated steelhead redd density was 5.1 redds/km for Redwood Creek mainstem. The 2018–2019 coho redd estimate was higher than all but one year for this cohort (Figure 8). However, given the release of 165 hatchery-reared adult coho into Redwood Creek, we expected the dramatic increase in redds.

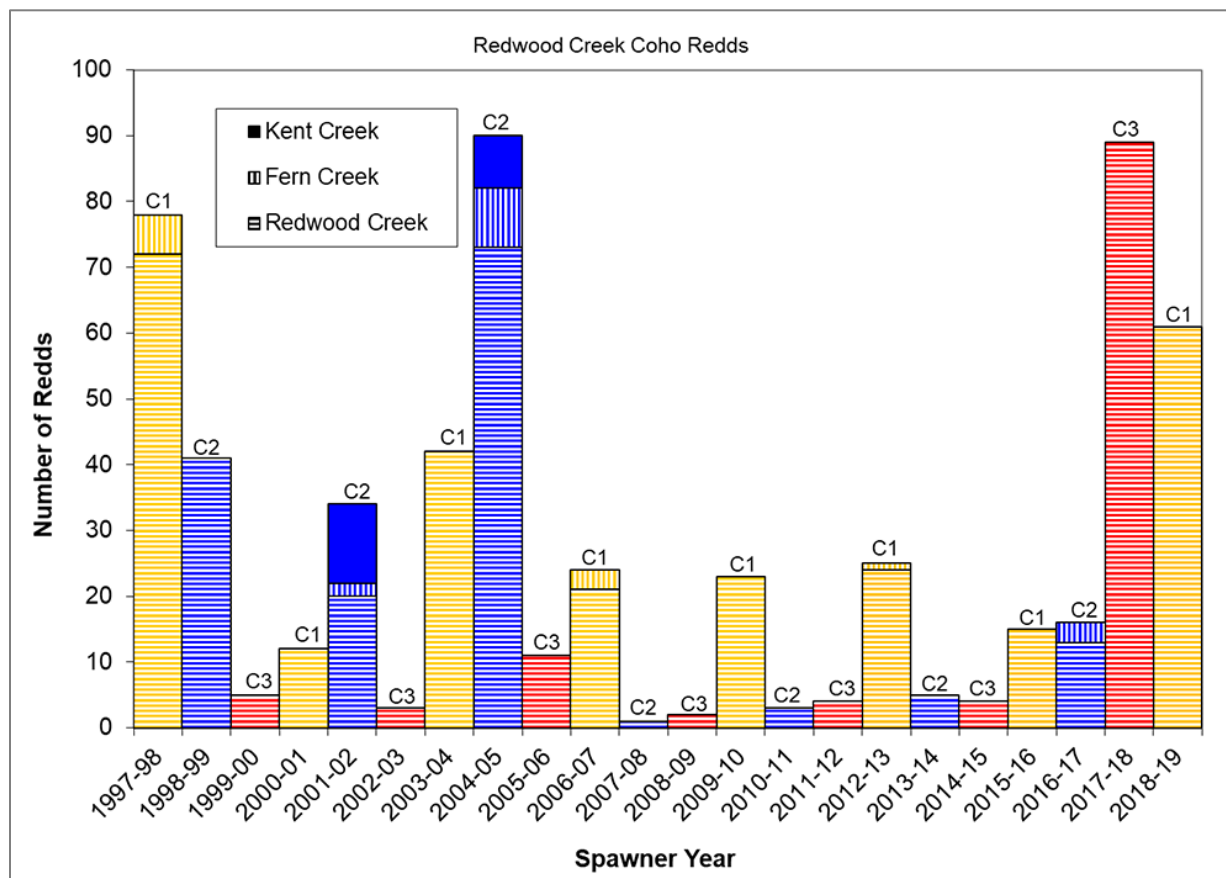


Figure 8. Coho salmon redd results in the Redwood Creek watershed by cohort for winter 1997–1998 through winter 2018–2019. Cohorts are designated by color (cohort 1 in yellow, cohort 2 in blue, cohort 3 in red), and creeks are designated by pattern (Redwood Creek in horizontal lines, Fern Creek in vertical, and Kent Creek in a solid color). The natural coho run was augmented by hatchery reared adult coho during the 2016–2017, 2017–2018, and 2018–2019 spawning seasons.

Live Coho and Coho Carcass Biotics

The program collected data on live coho and coho carcasses during each field survey. In Redwood Creek, sex ratios and mean FL of captured live coho during 2018–2019 were comparable to the 21-year averages since 1997 (Table 3). We did not measure many coho carcasses (n=4) in 2018–2019 due to the truncated field season, therefore the sex ratios for 2018–2019 carcasses are not comparable to the running 21-year averages (Table 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 1997–2018 compared to 2018–2019.

Period	Type ^A	Year	Live Coho				
			Sample Size	Sex Ratio %	n ^B for FL	Mean FL (cm)	FL SD ^C (cm)
Cumulative	M	1997–2018	440	33	433	62	8.0
	F	1997–2018	564	42	546	59	6.3
	J	1997–2018	200	15	200	41	7.2
	Unk	1997–2018	137	10	108	56	5.9
	All	–	1,341	100	–	–	–
Current	M	2018–2019	44	45	26	59	6.7
	F	2018–2019	46	47	27	59	5.8
	J	2018–2019	7	7	7	43	2.7
	Unk	2018–2019	1	1	1	50	–
	All	–	98	100	–	–	–

^A M = Male, F = Female, J = Jack, Unk = Unknown.

^B n = Number of fish measured for FL.

^C SD = Standard Deviation.

Table 4. Sex ratio percentages and mean fork length (FL) of coho carcasses within the Redwood Creek watershed for the period 1997–2018 compared to 2018–2019.

Period	Type ^A	Year	Carcasses				
			Sample Size	Sex Ratio %	n ^B for FL	Mean FL (cm)	FL SD ^C (cm)
Cumulative	M	1997–2018	61	24	54	65	7.7
	F	1997–2018	122	48	102	63	5.7
	J	1997–2018	26	10	26	41	5.0
	Unk	1997–2018	47	18	14	64	4.6
	All	–	256	100	–	–	–
Current	M	2018–2019	1	25	1	56	–
	F	2018–2019	0	0	0	0	–
	J	2018–2019	1	25	1	25	–
	Unk	2018–2019	2	50	1	60	–
	All	–	4 ^D	100	–	–	–

^A M = Male, F = Female, J = Jack, Unk = Unknown.

^B n = Number of fish measured for FL.

^C SD = Standard Deviation.

^D Survey frequency during the peak coho spawning period between 22 December and 25 January was severely limited due to a partial federal government shutdown that likely caused reduced carcass detection.

3.2.4 Pine Gulch Creek Coho and Steelhead Escapement

Survey Timing and Environmental Conditions

Field crews conducted surveys on 7 km of Pine Gulch Creek on 31 January 2019 and 11 April 2019. Seven-day rainfall totals for Julian weeks within peak spawning months (December and January) ranged from a low of 0.01 inches during Julian week 4 to a high of 4.30 inches during Julian week 3. Average water clarity at the time of surveys ranged from 65 cm to 90 cm.

Live Salmonids and Salmonid Carcasses

Field staff did not observe live adult coho in Pine Gulch Creek during the 2018–2019 season. Three live steelhead adults and five steelhead carcasses were observed on 31 January 2019.

Coho and Steelhead Redds

Crew members did not observe coho redds in Pine Gulch Creek during the 2018–2019 season. However, the crew observed 30 steelhead redds and three unknown redds. We reclassified the three unknown redds as steelhead after verifying the absence of juvenile coho during summer basinwide surveys. Field crews measured 30 of the 33 redds which had an average surface area of 2.64 (SD 1.09) m². Steelhead redd density on the mainstem of Pine Gulch was 4.7 redds/km. The redds were distributed throughout a 5-kilometer section of the stream (Figure 9).

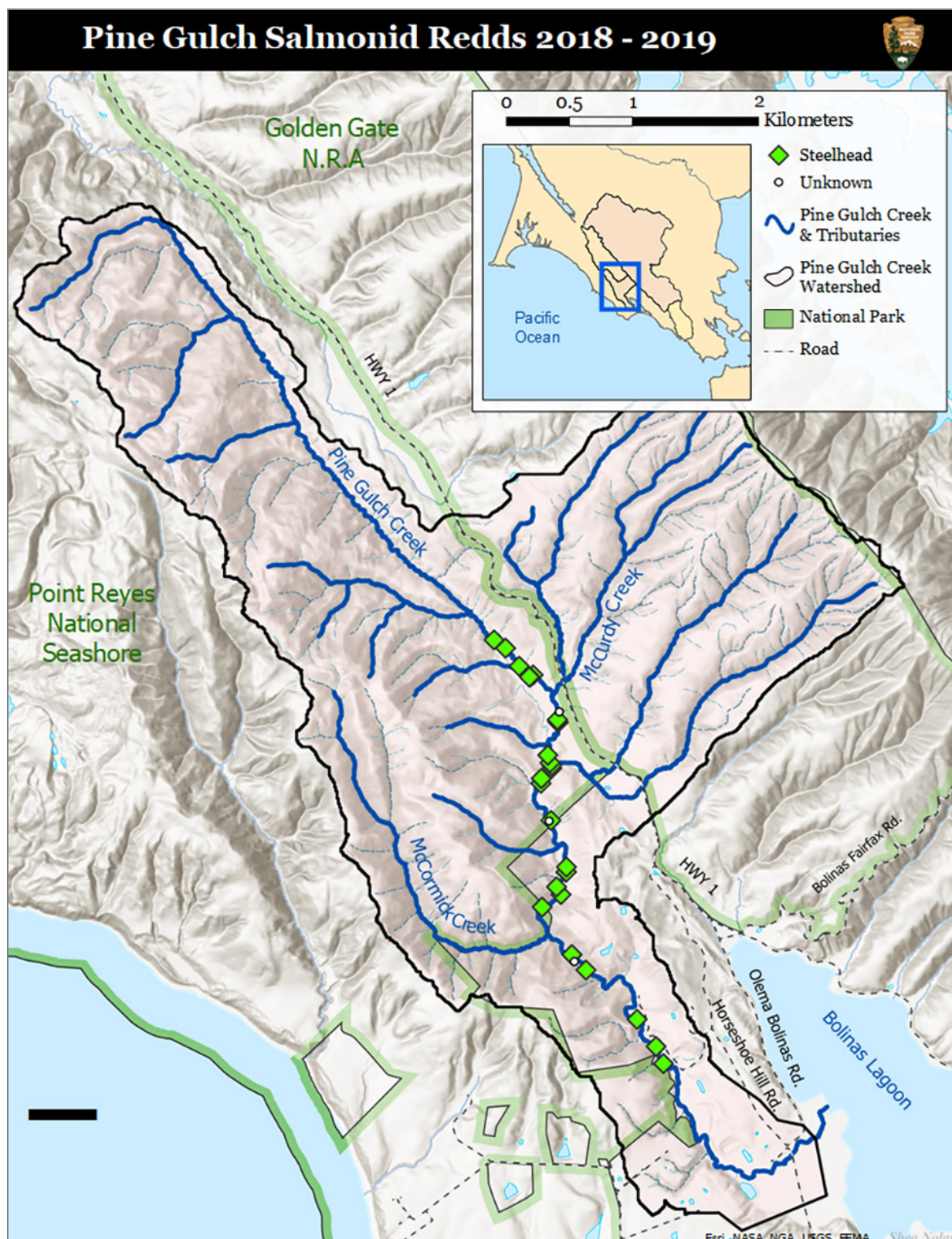


Figure 9. Steelhead redd locations recorded in the Pine Gulch Creek watershed during the 2018–2019 spawner season. Undetermined salmonid species redd locations were reclassified as steelhead after summer basinwide surveys verified the absence of juvenile coho.

3.3 Spring 2019 Outmigrant Coho Smolt-Trapping Results

We reported results for smolt trapping by Julian week (McNeill and Reichmuth 2024) to support analysis between monitoring years and watersheds. For the 2019 season, our program installed traps during Julian week 14 due to sustained high flows into early April. Since juvenile coho were not observed in Pine Gulch Creek during summer 2018 surveys, we did not monitor the stream for smolt outmigration in 2019. We only included data for Olema Creek and Redwood Creek in the report. Smolt-abundance estimates were calculated for coho only due to differences in outmigration timing between coho and steelhead smolts. We summarize anecdotal information collected on steelhead smolts, steelhead 1+, steelhead YoY, and coho YoY 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). Downstream migration of coho smolts occurs from March through early June in Marin County, CA. Historically, Olema Creek coho smolt outmigration peaked during Julian weeks 16–18, and Redwood Creek outmigration peaked during Julian weeks 17–19 (Figures 10 and 11). In 2019, the majority of coho smolts captured on Olema Creek migrated downstream prior to and after, rather than during, the typical peak outmigration window, with Julian weeks 15, 19, and 20 having the highest single-week capture percentages. For Olema Creek, downstream movement of coho smolts during Julian weeks 19 and 20 coincided with uncommonly late spring-storm events. Conversely, timing of coho smolt outmigration on Redwood Creek was earlier than usual, as the highest single-week capture rate occurred during Julian week 16 and was more than four times the historical average. The proportion of smolts captured during Julian weeks 13, 14, and 15 was more than triple the historical weekly average. A second peak was captured during Julian weeks 18 and 19 which is about 1 week later than the historical outmigration peak period.

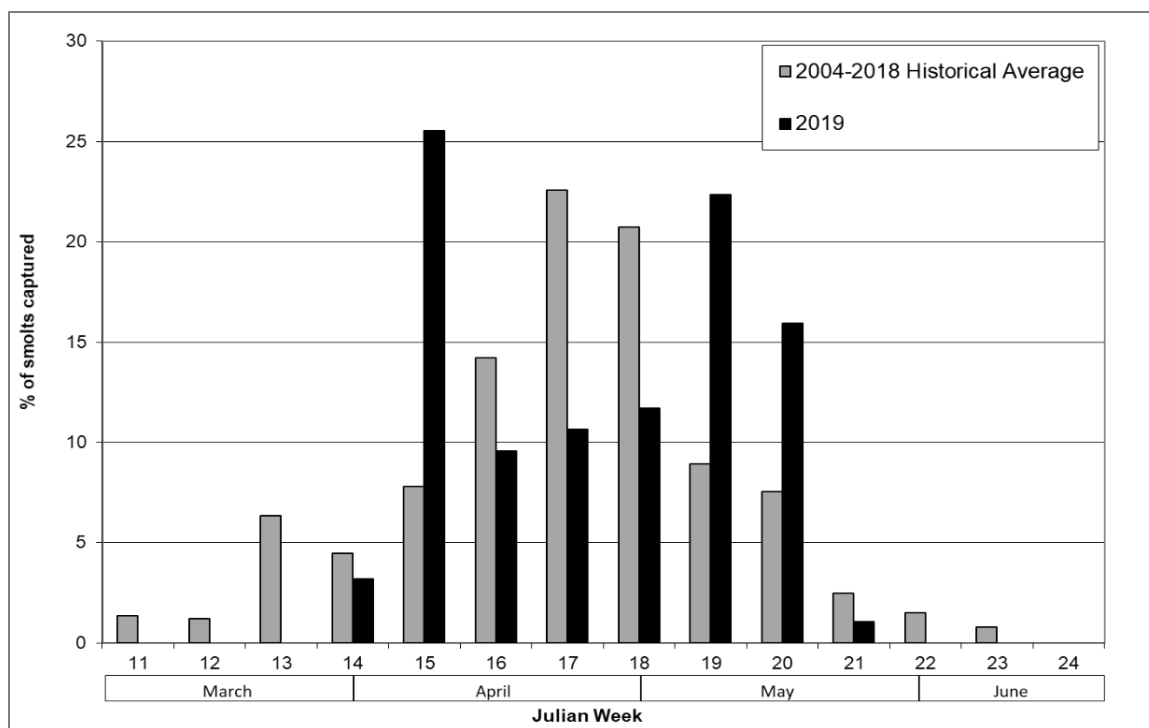


Figure 10. Percent of total coho smolts captured in the trap by Julian week for Olema Creek in 2019 compared to the historical average, 2004–2018.

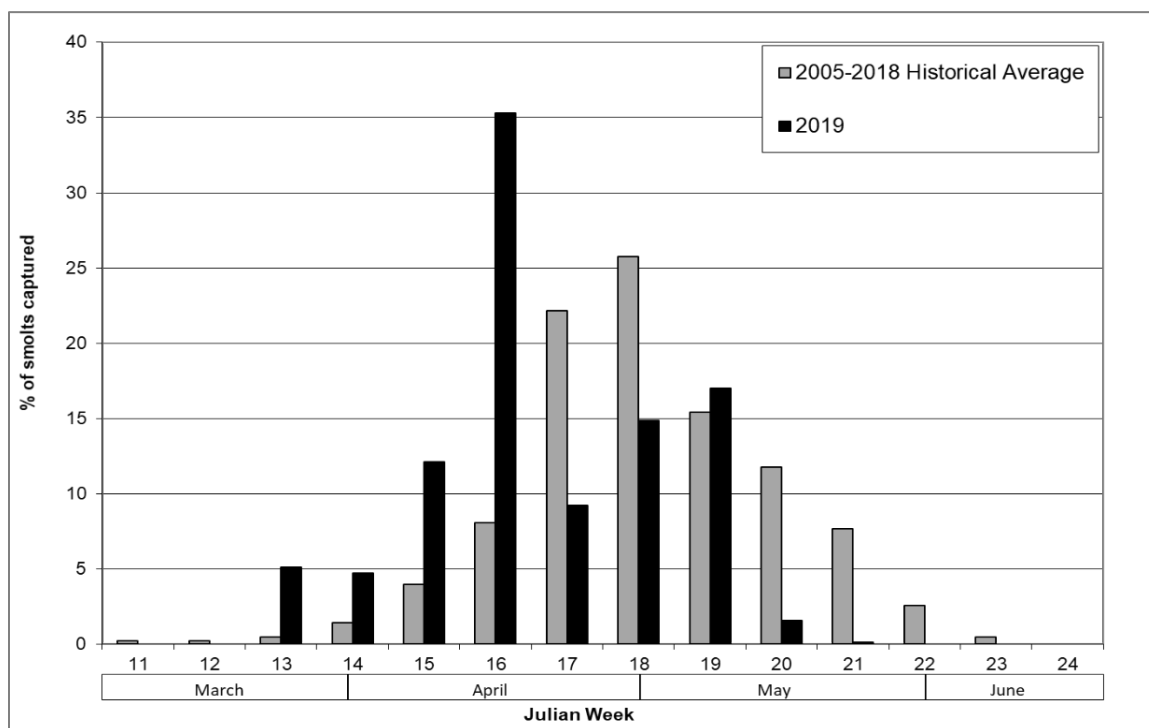


Figure 11. Percent of total coho smolts captured in the trap by Julian week for Redwood Creek in 2019 compared to the historical average, 2005–2018.

Spring Coho Outmigration Rainfall

Rainfall data were collected from gauges located at the Olema Valley Weather Station near Olema Creek and at the Highway 1 Bridge on Redwood Creek. The Olema Valley Weather Station recorded 12.94 inches of precipitation during the 2019 smolt-trapping season (March through May). The rain gauge at the Highway 1 Bridge on Redwood Creek recorded 10.72 inches of precipitation during the same period. For the 2019 trapping season, rainfall amounts at both Olema Creek and Redwood Creek were much higher than the historical averages, which were 8.79 inches and 6.83 inches, respectively.

Spring Coho Smolt Trap Water Temperature

Onset HOBO® data loggers recorded water temperatures in each trap in fifteen-minute intervals. Temperatures within the mainstem smolt traps on Olema Creek and Redwood Creek were within the tolerable range (less than 22 °C) for coho salmon (Moyle 2002) throughout the season. During trapping operations, Olema Creek had an average temperature of 13.5 (SD 1.24) °C, a maximum of 16.8 °C, and a minimum of 9.2 °C. Redwood Creek had an average temperature of 12.7 (SD 0.85) °C, a maximum of 15.0 °C, and a minimum of 10.1 °C.

3.3.2 Olema Creek Smolt Trapping Coho and Steelhead Results

For the 2019 outmigrant trapping study on Olema Creek, crews operated a smolt trap for 52 days from 2 April to 29 May 2019. The trap was fully operational for 46 days and partially operational for six days. We suspended trapping operations on April 5 and May 19–23 due to storm events.

The trap captured a total of 94 coho smolts, and field staff marked 54 of these individuals with PIT tags. The overall recapture rate for marked coho smolts was 24% (13 out of 54). DARR analysis of the coho smolt data stratified by day estimated a capture probability of 23% for the first 41 days and 25% for the final 11 days. We estimated 407, 95% CI [94, 930] coho smolts in Olema Creek for the 2019 season. This abundance estimate was lower than most previous smolt-trapping seasons (Figure 12).

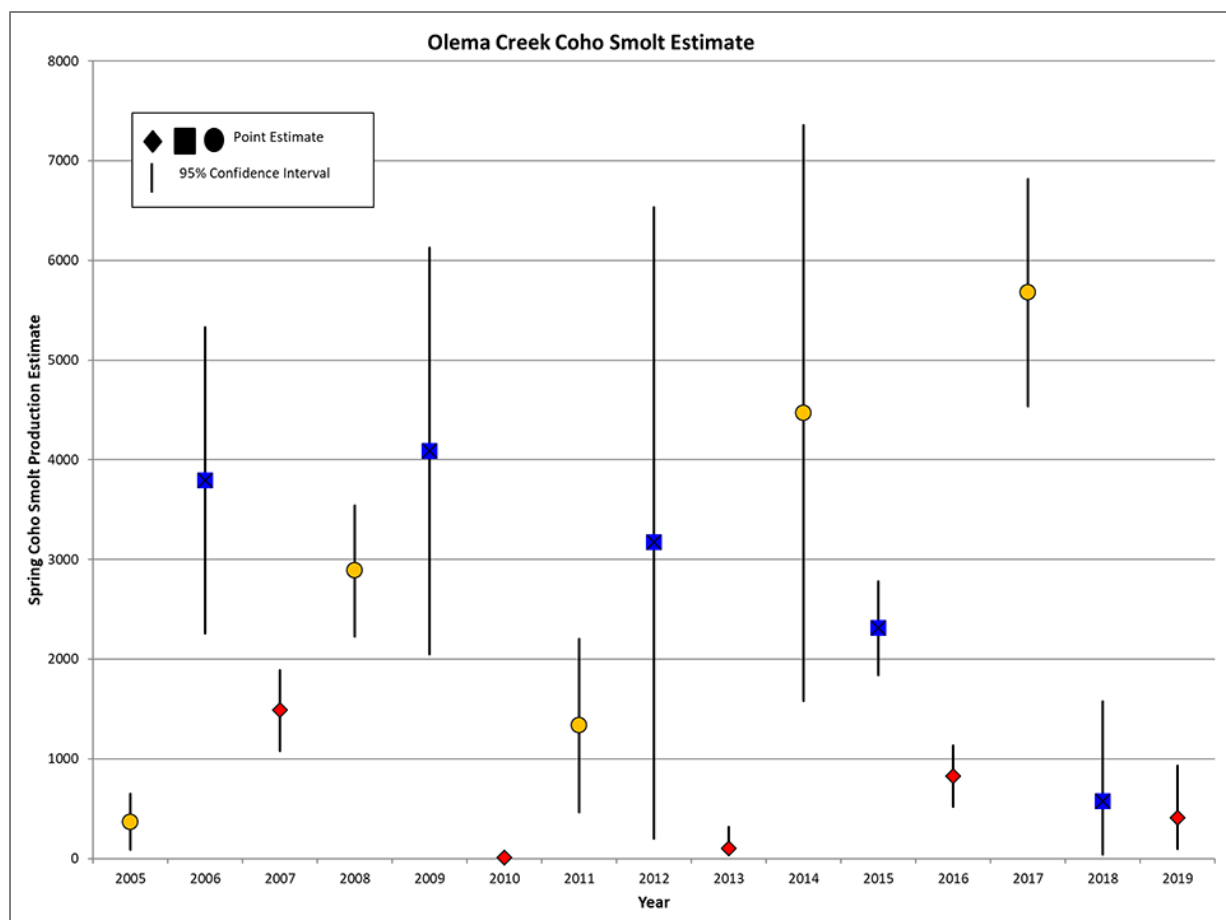


Figure 12. Coho smolt-abundance estimates for Olema Creek, spring 2005–2019. The 2005 and 2013 estimates were calculated using the Chapman modification of the Petersen estimate equation, rather than the DARR program. The 2010 estimate is the raw count. Cohorts are designated by color (cohort 1 in yellow circles, cohort 2 in blue squares, cohort 3 in red diamonds).

Field staff measured all 54 PIT-tagged coho smolts for FL and weighed 52 of these fish. Average FL of tagged smolts was 126 (SD 10) mm, and median FL was 127 mm. The average weight of tagged smolts was 19.7 (SD 4.9) g, and the median weight was 19.9 g. We recaptured 13 of the tagged smolts; these fish spent an average of nine days in the system prior to recapture. Time spent upstream of the trap ranged from one to 24 days, with a median of five days. During the 2018 summer basinwide surveys, we implanted 21 juvenile coho with PIT tags; none of these fish were recaptured or detected during the 2019 smolt-trapping season.

Additionally, the trap captured six coho YoY, 51 steelhead smolts, 30 steelhead 1+, and 76 steelhead YoY. We were unable to identify one salmonid YoY carcass found in the trap to species due to the level of decomposition.

3.3.3 Redwood Creek Smolt Trapping Coho and Steelhead Results

Field crews installed and operated the Redwood Creek smolt trap for 59 days during the period 28 March to 29 May 2019. The trap was fully operational for 58 days and partially operational for one day. We suspended operations on April 5 and May 19–21 due to storm events.

The Redwood Creek trap captured 957 coho smolts, and crews marked 445 of these fish with PIT tags. The overall recapture rate for marked coho smolts was 30% (132 out of 445). DARR analysis of the coho smolt data stratified by day estimated capture probability at 45% for the first 26 days and 23% for the remainder of the season (33 days). We estimated 2,983, 95% CI [2,511, 3,455] coho smolts in Redwood Creek for the 2019 season. This estimate was higher than most prior years of trapping (Figure 13).

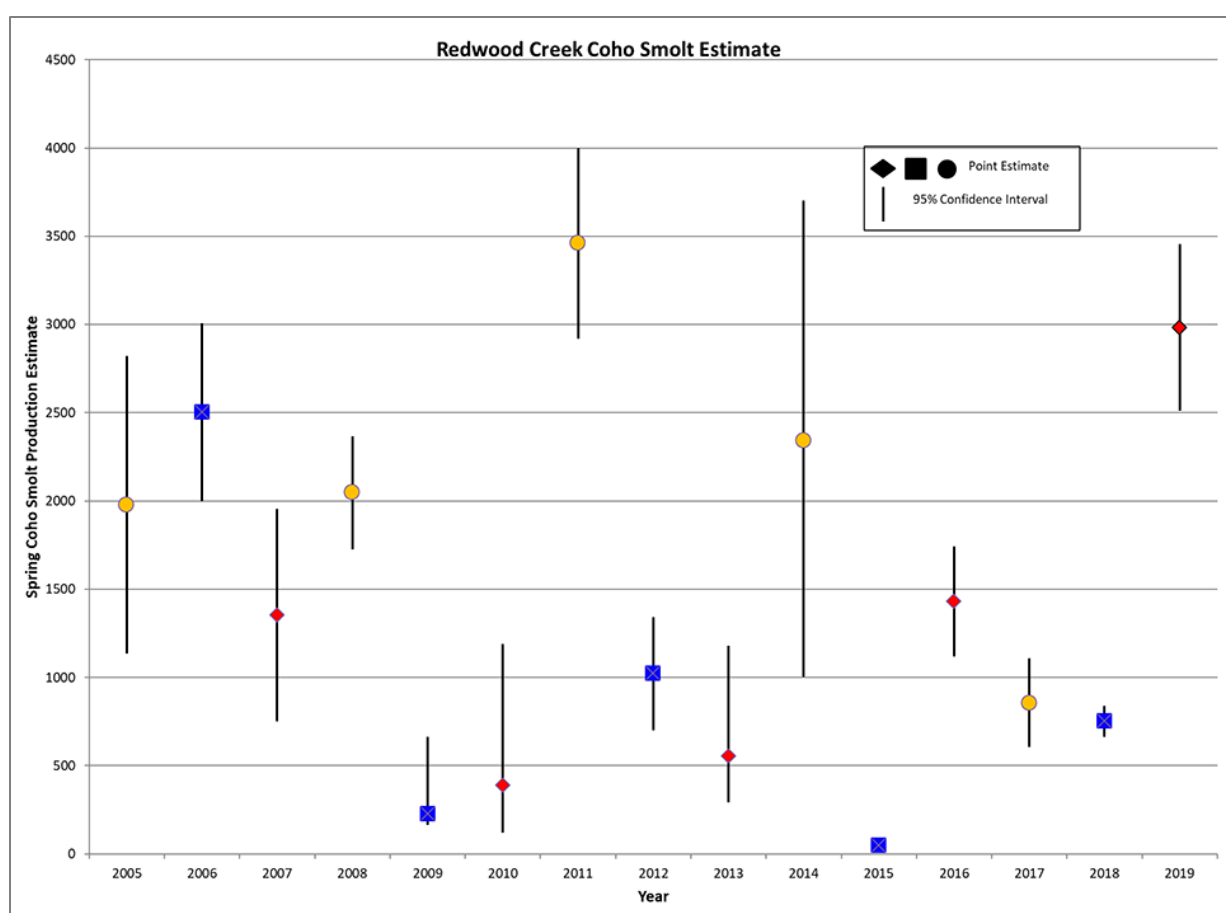


Figure 13. Coho smolt-abundance estimates for Redwood creek, spring 2005–2019. The 2009 estimate was calculated using the Chapman modification of the Petersen estimate equation, rather than the DARR program. The 2015 estimate is the raw count. Cohorts are designated by color (cohort 1 in yellow circles, cohort 2 in blue squares, cohort 3 in red diamonds).

Program staff measured all 445 coho smolts used in the mark/recapture study for FL and weighed 441 of these individuals. Tagged individuals had an average FL of 105 (SD 9) mm; median FL was also 105 mm. The average weight of marked fish was 11.7 (SD 2.93) g, and the median weight was

11.6 g. We subsequently recaptured 132 of the 445 tagged coho smolts and observed an average residence time of six days between date of tagging and recapture. Time spent upstream of the trap ranged from one to 36 days, with a median of four days. During the 2018 summer basinwide surveys on Redwood Creek, we marked 67 juvenile coho with PIT tags and recaptured 23 of these tagged juveniles during 2019 smolt-trapping operations. We measured FL and weighed 22 of the previously tagged smolts which showed an average increase in length of 35 (SD 10) mm and an average increase in weight of 7.5 (SD 2.57) g from summer tagging to spring recapture.

Additionally, 15 coho YoY, 47 steelhead smolts, 48 steelhead 1+, and 682 steelhead YoY were captured. We were unable to identify one salmonid YoY mortality found in the trap to species as a result of decomposition.

3.3.4 Coho and Steelhead Smolt Size and Condition

Length and weight data provide critical information that contributes to an understanding of salmonid health, survival, and condition factors. In addition, length and weight data allow for estimating FL frequency, growth rates, K-factor, and biomass abundance. Throughout the 2019 smolt-trapping operations, staff recorded FL to the nearest mm and weights to within 0.01 g for a subsample of coho and steelhead smolts caught in each trap. Although we reported length, weight, and K-factor for steelhead smolts, these data should be treated as anecdotal since our trapping effort is targeted towards the coho smolt outmigration period.

Olema Creek Coho and Steelhead Smolt Fork Length, Weight, and K-factor

Of the 94 coho smolts captured on Olema Creek, field crews measured 93 for FL and weighed 89. Coho smolt FL measured throughout the spring 2019 monitoring efforts on Olema Creek ranged from 88 mm to 150 mm. The mean FL for coho smolts was 125 (SD 11) mm. The highest frequency of FL occurred within the 126- to 130-mm length interval, representing 20% of the coho smolts measured. The mean coho smolt weight for the 2019 Olema trapping season was 19.4 (SD 4.70) g, and the median weight was 19.8 g. As a measure of coho smolt condition, we calculated mean K-factor to within 0.01 ($100 \times W/L^3$). The mean coho smolt K-factor for Olema Creek was 0.98 (SD 0.07). Coho smolts migrating out of Olema Creek in 2019 were, on average, longer and heavier than in most of the previous years (Figures 14 and 15).

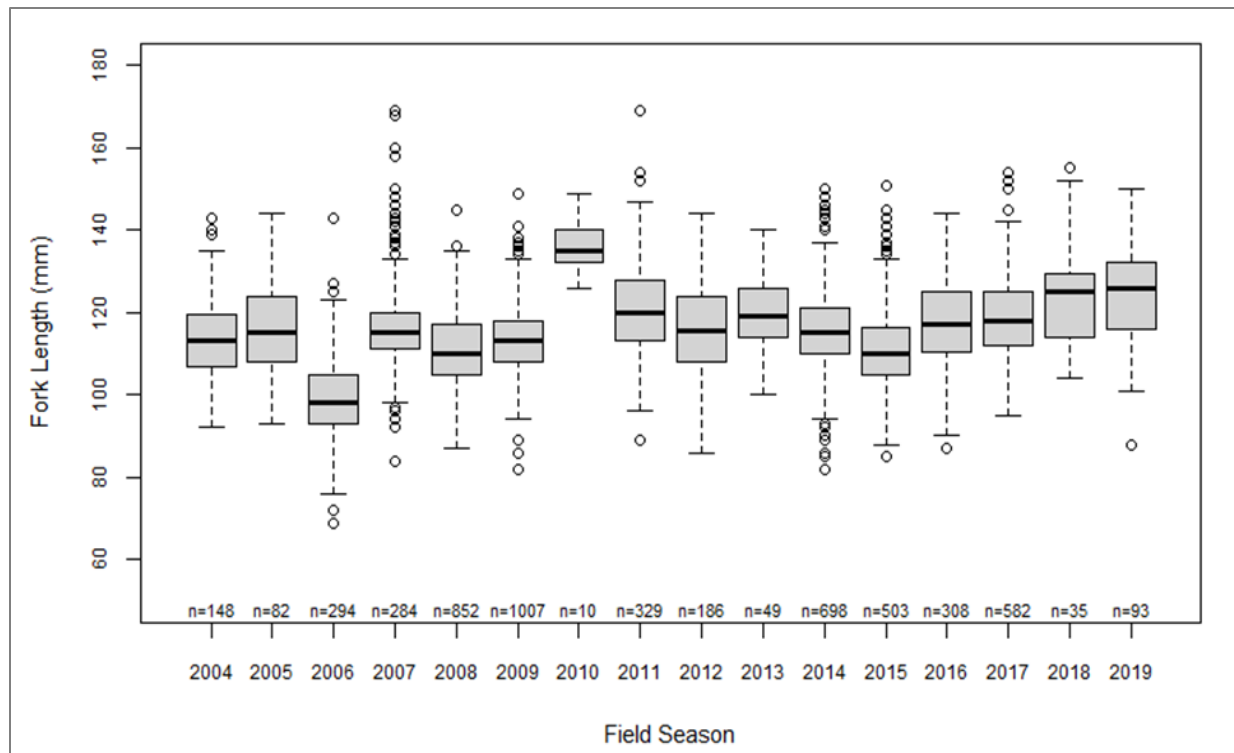


Figure 14. Box plots of coho salmon smolt fork length data for Olema Creek, 2004–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

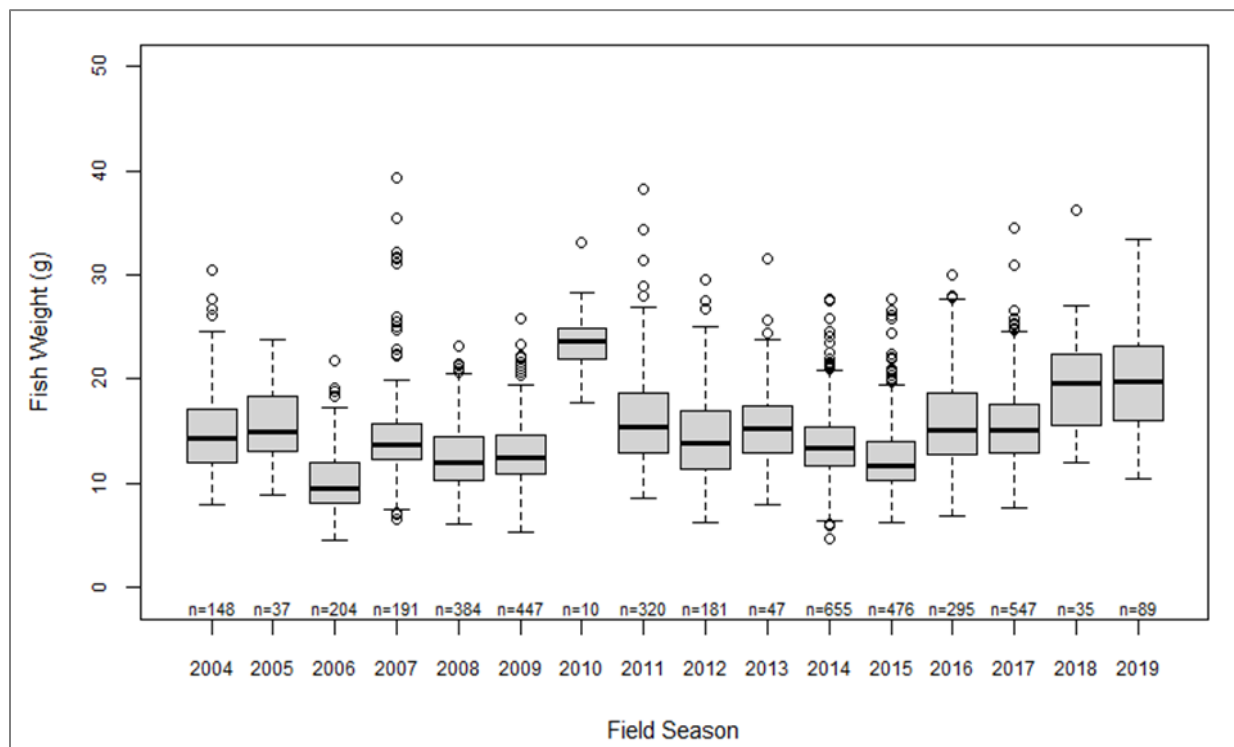


Figure 15. Box plots of coho salmon smolt weight data for Olema Creek, 2004–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

Staff measured all 51 steelhead smolts captured on Olema Creek in 2019 for FL and weighed 49 of the fish. Steelhead smolt FL ranged from 88 mm to 187 mm, and the mean FL was 136 (SD 21) mm. The highest frequency of steelhead smolt FL occurred within the 126- to 130-mm and 136- to 140-mm length intervals, with each representing 12% of the measured population. Steelhead smolts had an average weight of 26.5 (SD 12.61) g and a median weight of 24.5 g. On average, steelhead smolts migrating out of Olema Creek were smaller when compared to recent monitoring years (Table 7 in McNeill and Reichmuth 2024). The 2019 mean steelhead smolt K-factor for Olema Creek was 1.02 (SD 0.09).

Redwood Creek Coho and Steelhead Smolt Fork Length, Weight, and K-factor

During 2019 Redwood Creek smolt trapping, we measured 649 coho smolts for FL and weighed 631 of these fish. Coho smolt FL measured throughout the 2019 outmigrant trapping season ranged from 69 mm to 147 mm, and the mean FL was 104 (SD 10) mm. The highest frequency of FL occurred within the 101- to 105-mm length interval, representing 21% of the coho smolts measured. The mean coho smolt weight for the duration of the 2019 trapping season was 11.4 (SD 3.11) g, and the median weight was 11.3 g. As a measure of coho smolt condition, we calculated mean K-factor to within 0.01 ($100 \times W/L^3$). The mean coho smolt K-factor for Redwood Creek was 1.00 (SD 0.07). Coho smolts migrating out of Redwood Creek in 2019, on average, were shorter and lighter than in most of the previous years (Figures 16 and 17).

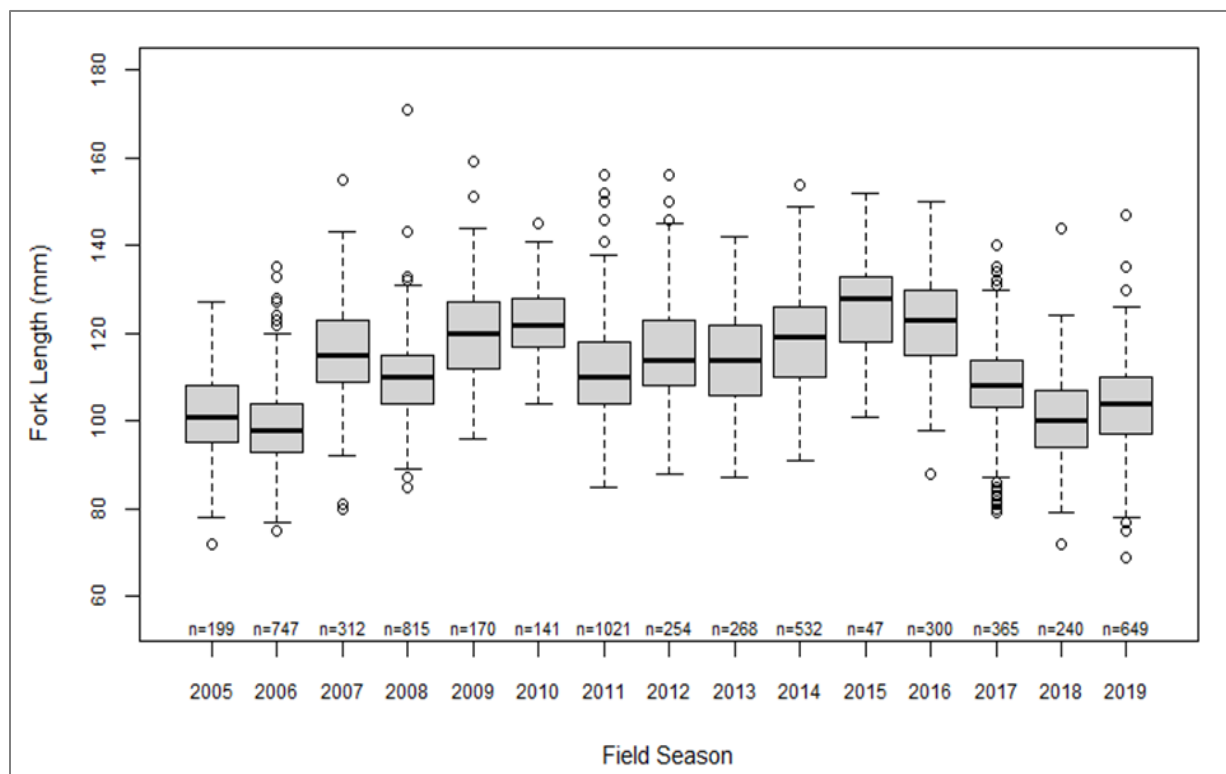


Figure 16. Box plots of coho salmon smolt fork length data for Redwood Creek, 2005–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

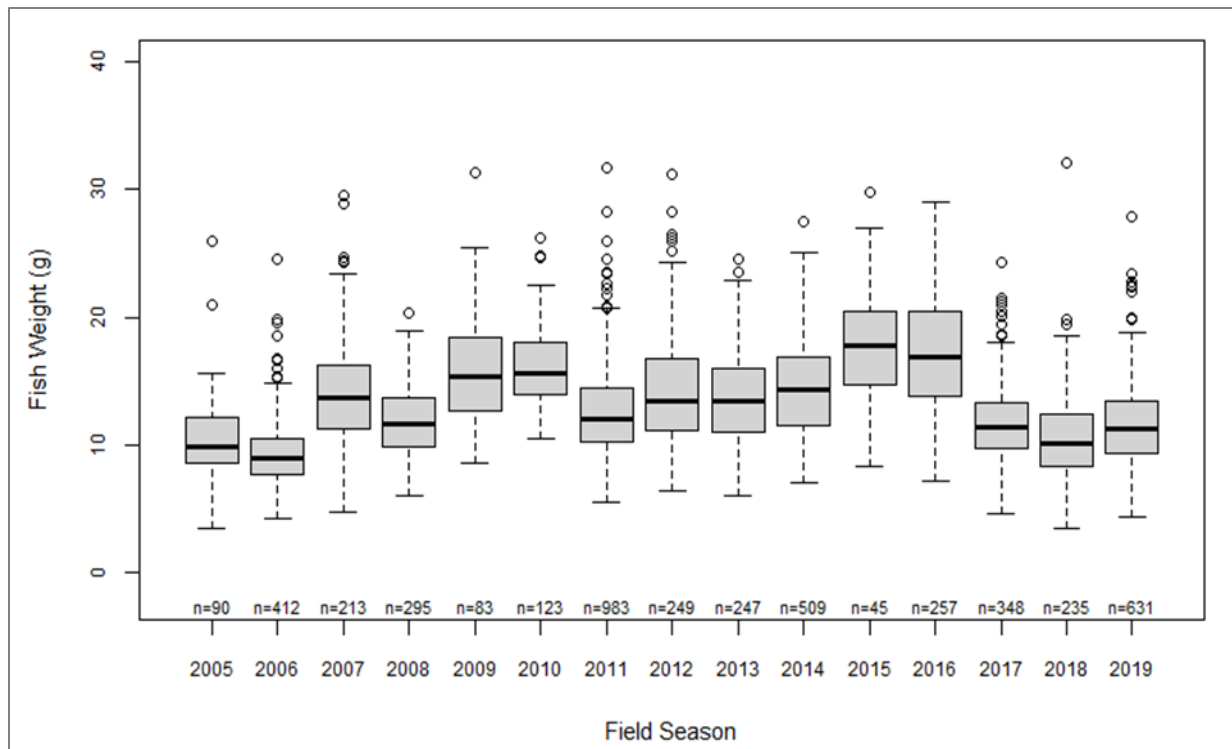


Figure 17. Box plots of coho salmon smolt weight data for Redwood Creek, 2005–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

Of the 47 steelhead smolts captured on Redwood Creek in 2019, crews measured 46 for FL and weighed 42. Steelhead smolt FL ranged from 87 to 188 mm, and the mean FL was 149 (SD 24) mm. The highest frequency of FL occurred within the 161- to 165-mm length interval, accounting for 15% of the steelhead smolts measured. The mean steelhead smolt weight was 31.3 (SD 11.50) g, with a median weight of 34.2 g. On average, steelhead smolts migrating out of Redwood Creek this season were similar in length to those captured in previous years (Table 9 in McNeill and Reichmuth 2024). The 2019 mean steelhead smolt K-factor for Redwood Creek was 0.93 (SD 0.07).

3.3.5 Smolt Trap Summary of Non-salmonid Total Catch

On Olema Creek, we captured 654 non-salmonid aquatic vertebrates during the 2019 trapping season. Stickleback (40%) and sculpin (33%) mainly comprised the non-salmonid catch. Staff captured one California freshwater shrimp (*Syncaris pacifica*) in the Olema Creek smolt trap on the final day of the season. Seven California red-legged frog (*Rana draytonii*) tadpoles and one juvenile frog were also captured. Of the 957 non-salmonid aquatic vertebrates captured in the mainstem Redwood Creek trap, 738 (77%) were three-spined stickleback. Field crews also captured five California red-legged frog tadpoles during smolt-trapping operations on Redwood Creek. Signal crayfish (*Pacifastacus leniusculus*) and bullfrogs (*Rana catesbeiana*) were the only two non-native taxa captured. Staff captured signal crayfish in both Olema and Redwood Creeks while bullfrogs were only captured in Olema Creek. Overall, fewer non-salmonids were captured during 2019 smolt trapping than in previous trapping seasons (Tables 10 and 11 in McNeill and Reichmuth 2024).

3.4 Juvenile Coho and Steelhead Basinwide 2019 Results

The following describes summer juvenile-monitoring results for Olema Creek, Redwood Creek, and Pine Gulch Creek.

3.4.1 Olema Creek

Field crews initiated 2019 summer habitat and basinwide snorkel surveys of Olema Creek 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 13.0 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) deemed unsafe because of potentially high concentrations of fecal coliform.

Habitat Survey

We identified 1,217 mainstem habitat units in the 12,989.7 m Olema Creek survey reach. Pool units were the dominant habitat type available to fish, measuring 7,917 m and accounting for 61% of the total mainstem length (Table 5), up 3% from the previous year. Dry sections of streambed accounted for 6% of the total length surveyed (Table 5), a 50% decrease compared to 2018. Survey crews recorded 98 meters of dry habitat length between monument-tags 15 and 17 during the 2019 summer basinwide habitat survey, which is the most ever recorded in this lower section of Olema Creek. However, a significant portion of mainstem Olema Creek streamflow avulsed into a new side channel that shunted water away from this section of stream, resulting in a higher frequency of dry habitat. Side channel and backwater units were also measured but not incorporated into the basinwide habitat analysis. Overall, the team measured 1,171.1 m of side channel habitat and 402.6 m of backwater habitat during the survey. Flatwater and riffle habitat units accounted for 81% of the total side channel habitat length.

Table 5. Habitat composition of Olema Creek coho survey reach, summer 2019. Measured mainstem total length is used to calculate percentages of length per habitat type.

Unit Type	Total length (m)	% of length	# of units	% of units
Pool	7,917.0	61	454	37
Flatwater	2,116.0	16	324	27
Riffle	2201.3	17	349	29
Dry	755.4	6	90	7
Total	12,989.7	100	1,217	100

Total wetted mainstem-survey length was 12,234.3 m, which we used to calculate side channel and backwater density, 9.6 m per 100 m and 3.3 m per 100 m, respectively. For the 2019 season, both side channel and backwater density were higher than the historical averages of 6.2 m per 100 m and 2.3 m per 100 m. Side channel density was the second highest on record for Olema Creek.

We used total wetted mainstem survey length to calculate wood densities. Only the 10–20 cm and 20–50 cm woody debris categories had higher densities in 2019 when compared to their respective historical averages (Table 6).

Table 6. Summary of basinwide instream woody debris (WD) per 100 m during summer base-flow conditions in Olema Creek. Average 2005–2018 compared to 2019.

Field season	Survey length (# 100 m sections)	Root Wads per 100 m	LWD Jams ^A per 100 m	SWD Jams ^B per 100 m	10–20 cm WD ^C per 100 m	20–50 cm WD ^C per 100 m	>50 cm WD ^C per 100 m
2005–2018 Average	114.7	1.3	0.5	0.6	2.8	2.6	0.8
2019	122.3	1.1	0.3	0.3	4.3	2.8	0.5

^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 refers to diameter of individual pieces of woody debris.

Coho Snorkel Counts and Basinwide Estimate

We conducted snorkel surveys on 20% of the delineated pools and 17% of flatwaters with a depth of 0.2 m or greater. Snorkel crews observed coho YoY in 74% (67 of 91) of pools and 29% (9 of 31) of flatwaters. The raw count of juvenile coho was 1,402, producing an average estimate of 11.5 coho per snorkel unit. Field teams electrofished seventeen (14%) of the 122 snorkel units within a day of snorkeling. Two (2%) of the 122 units were re-snorkeled immediately following the initial pass using the method of bounded counts (Murphy and Willis 1996). We used Microfish and bounded count abundance estimators for the resampled pools to calibrate snorkel counts. The 2019 basinwide abundance estimate for juvenile coho was 8,978, 95% CI [5,373, 12,583]. After rebounding in 2013, this cohort’s juvenile population declined during the last two generations (Figure 18).

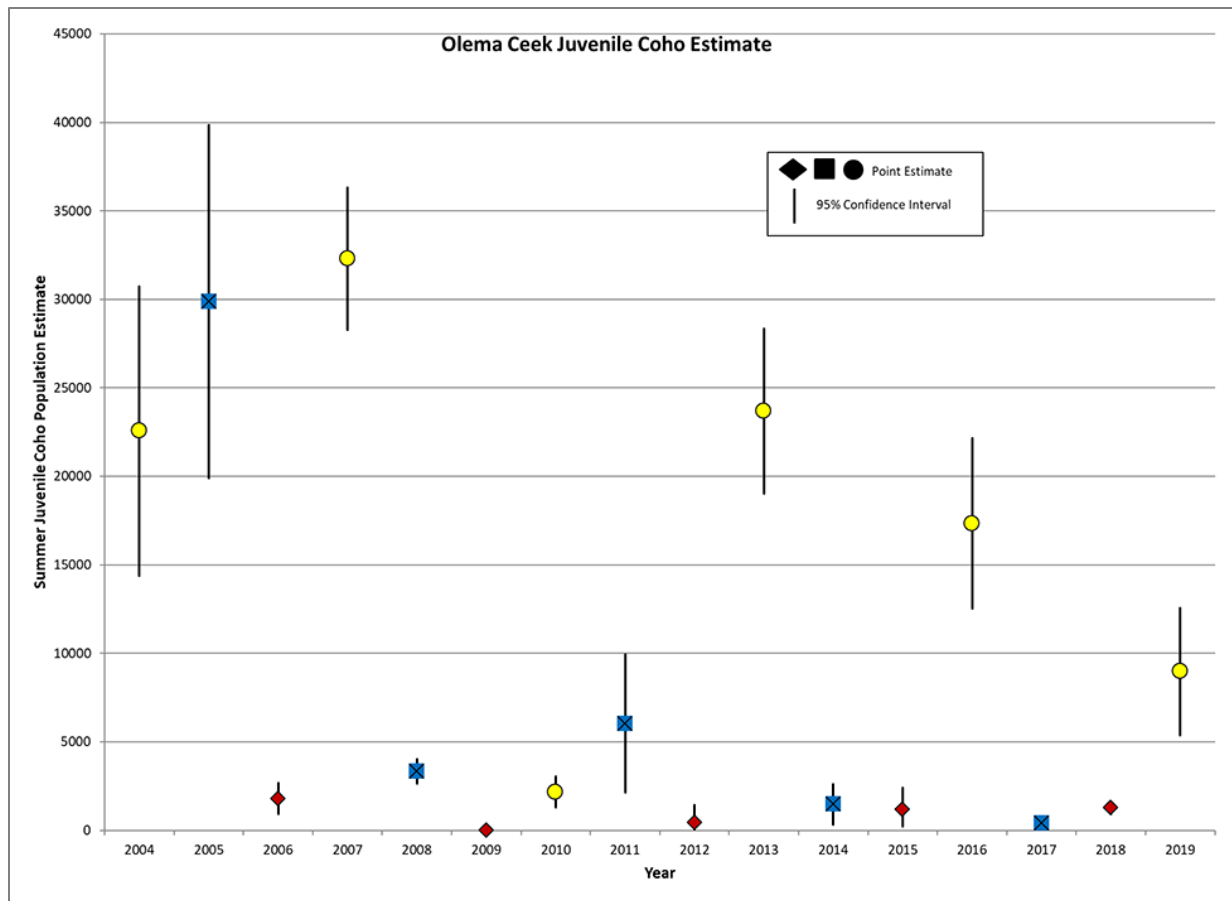


Figure 18. Summer juvenile coho basinwide abundance estimates for Olema Creek, 2004 through 2019. Cohorts are designated by color (cohort 1 in yellow circles, cohort 2 in blue squares, cohort 3 in red diamonds).

Summer Coho and Steelhead Measurement Information

As part of summer basinwide monitoring, we randomly selected a subsample of coho and steelhead juveniles to measure for FL and weight within each electrofished unit. Field crews captured 343 juvenile coho on Olema Creek and measured and weighed 212 of these fish. Coho measured throughout the summer 2019 monitoring efforts on Olema Creek ranged in FL from 52 mm to 94 mm, with a mean FL of 69 (SD 6) mm. The highest frequency of FL for coho YoY occurred within the 66 to 70-mm length interval, representing 34% of the subsample of coho measured in 2019. The Olema Creek mean coho juvenile weight was 3.6 (SD 0.98) g, and the median weight was 3.5 g. Summer 2019 juvenile coho lengths and weights were similar to those in previous years for Olema Creek (Figures 19 and 20). As a measure of juvenile coho condition, we calculated mean K-factor to within 0.01 ($100 \times W/L^3$). The mean coho K-factor for Olema Creek during summer 2019 was 1.08 (SD 0.07).

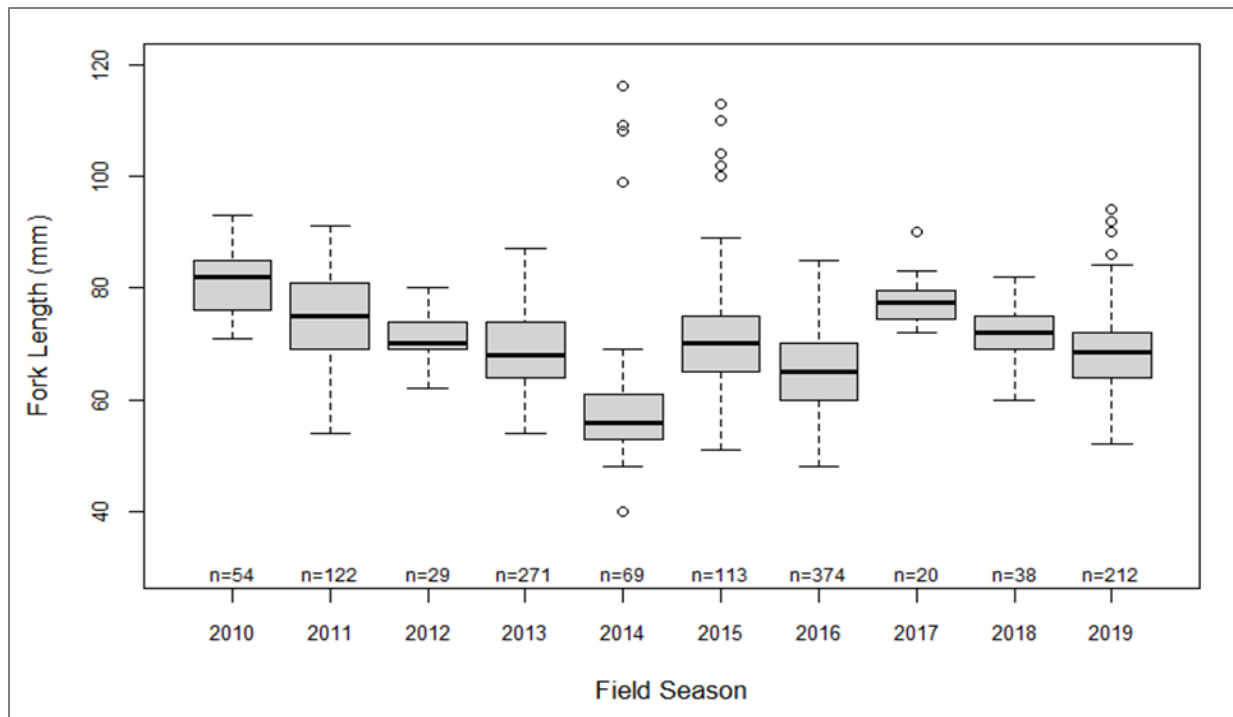


Figure 19. Box plots of juvenile coho fork length data for basinwide surveys of Olema Creek, summer 2010–2019 (no coho captured in 2009). Dark lines represent medians, circles represent outliers, and n is sample size.

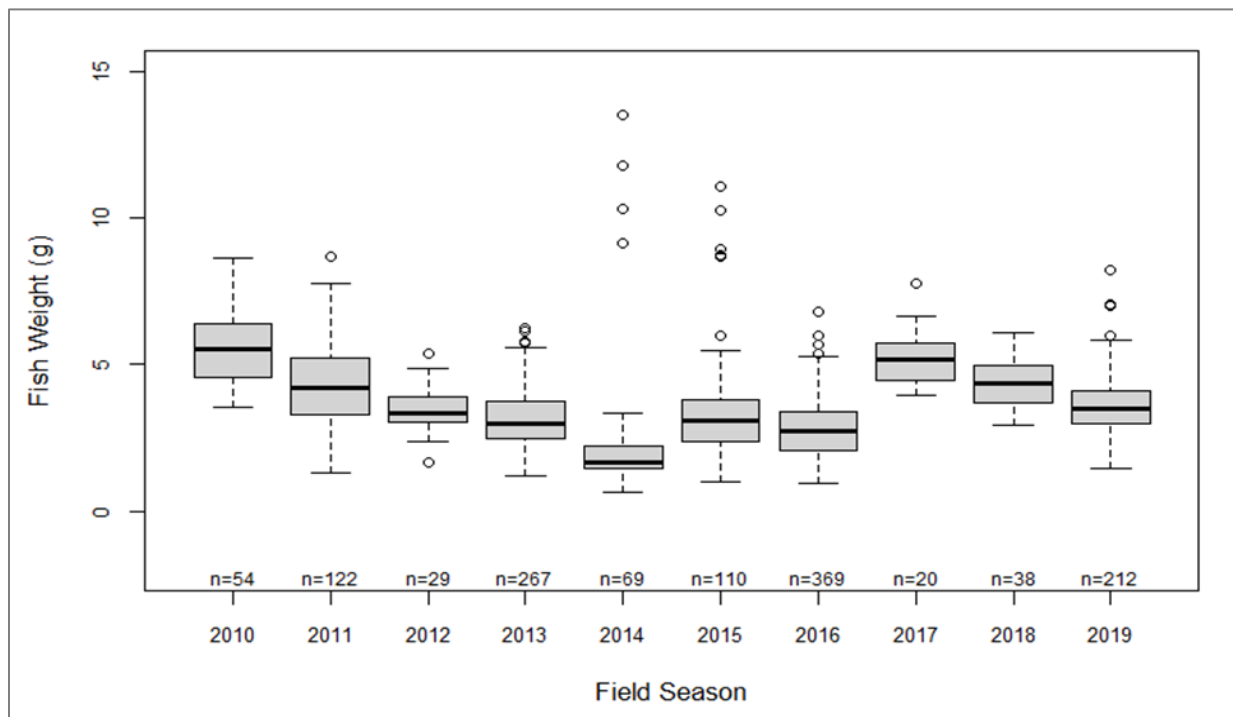


Figure 20. Box plots of juvenile coho weight data for basinwide surveys of Olema Creek, summer 2010–2019 (no coho captured in 2009). Dark lines represent medians, circles represent outliers, and n is sample size.

During 2019 basinwide surveys on Olema Creek, field crews also measured 362 steelhead for FL. The size range for steelhead was 37 mm to 194 mm, and the highest frequency of FL occurred within the 61- to 65-mm length interval, representing 24% of the sample. Based on FL frequencies, we binned all steelhead less than 96 mm as YoY and all steelhead 96 mm and greater as 1+. Of the 362 measured steelhead, we binned 316 fish as steelhead YoY and the remaining 46 as steelhead one year or older (1+). The mean FL for Olema Creek steelhead YoY in summer 2019 was 66 (SD 10) mm. We weighed 305 steelhead YoY and calculated a mean weight of 3.3 (SD 1.64) g, and median weight of 2.9 g. The steelhead YoY mean FL and weight for 2019 summer monitoring were similar to those in previous years (Figures 21 and 22). The mean FL for steelhead 1+ in summer 2019 was 128 (SD 23) mm. We weighed 43 steelhead 1+ which had a mean weight of 21.1 (SD 10.59) g and a median weight of 18.0 g. Again, the mean FL and weight for steelhead 1+ in summer 2019 were comparable to those in prior seasons (Figures 23 and 24). The mean steelhead YoY and 1+ K-factors for Olema Creek during summer 2019 were 1.11 (SD 0.11) and 1.01 (SD 0.07), respectively.

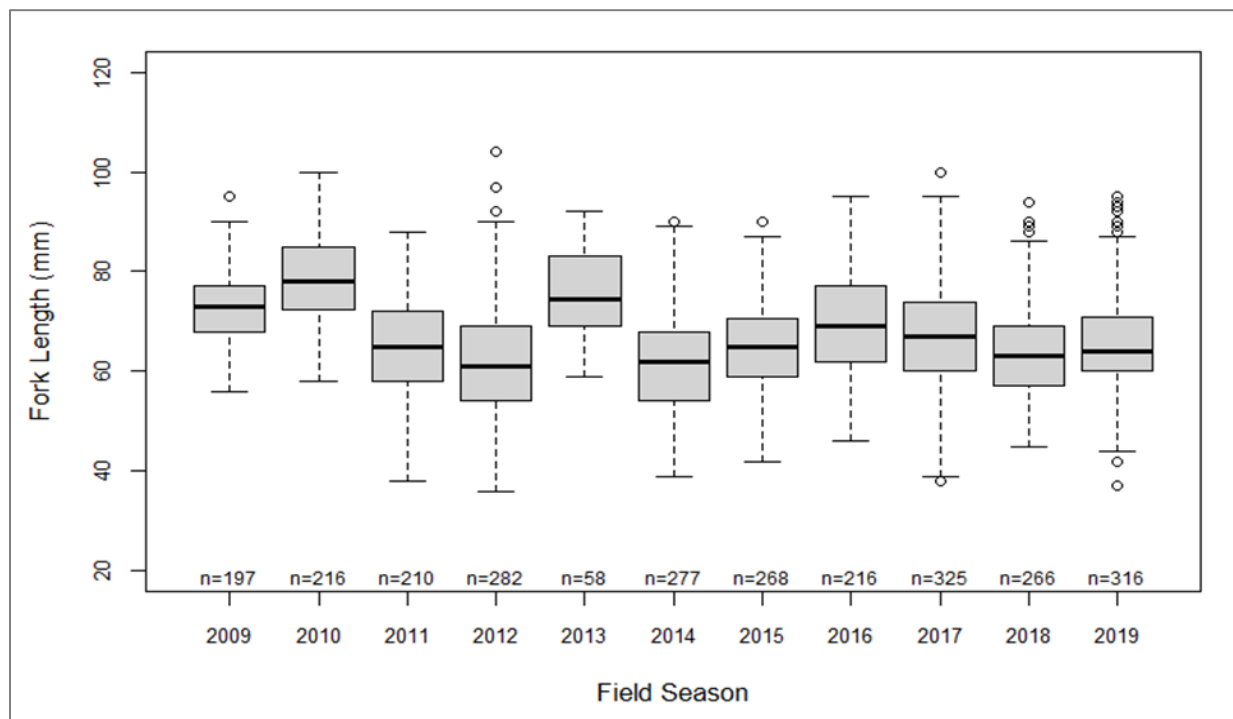


Figure 21. Box plots of young-of-year steelhead fork length data for basinwide surveys of Olema Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

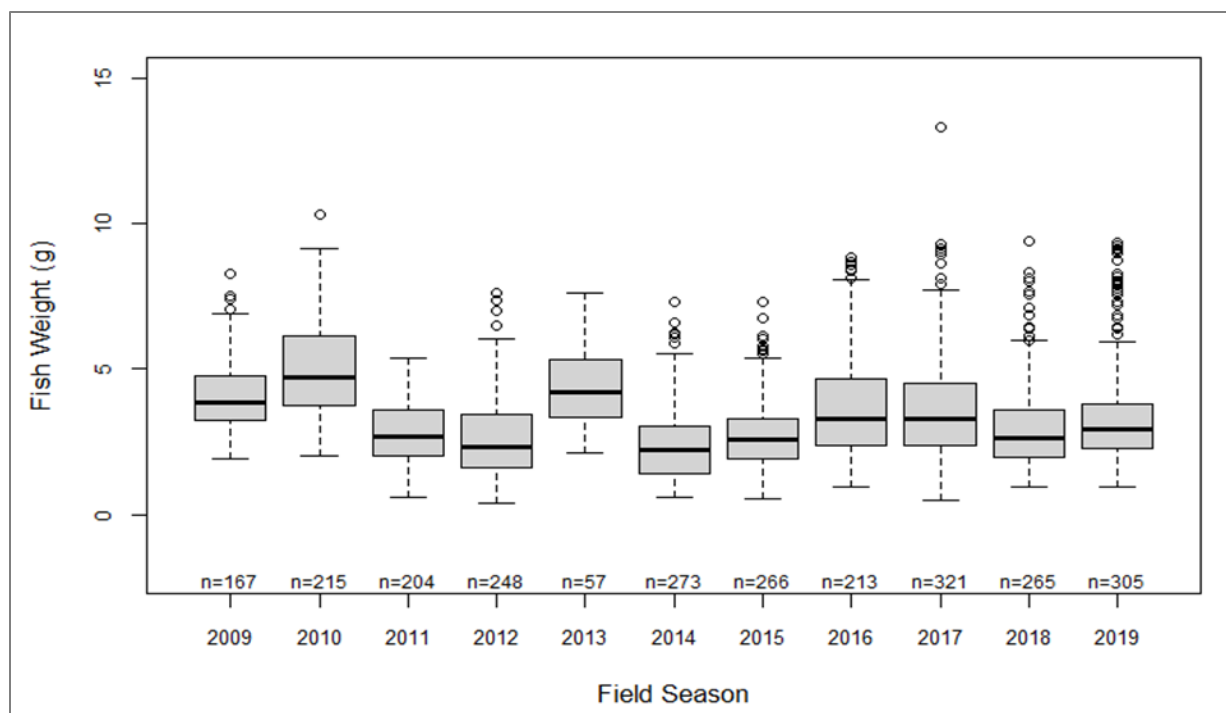


Figure 22. Box plots of young-of-year steelhead weight data for basinwide surveys of Olema Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

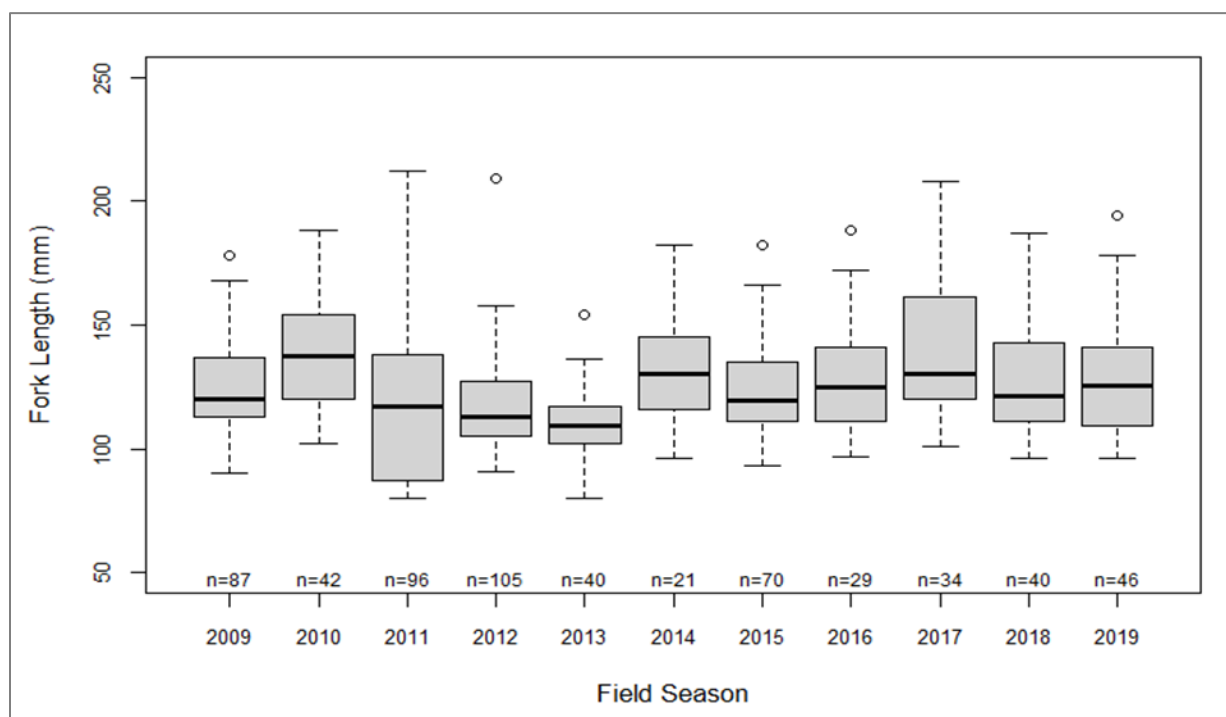


Figure 23. Box plots of 1+ steelhead fork length data for basinwide surveys of Olema Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

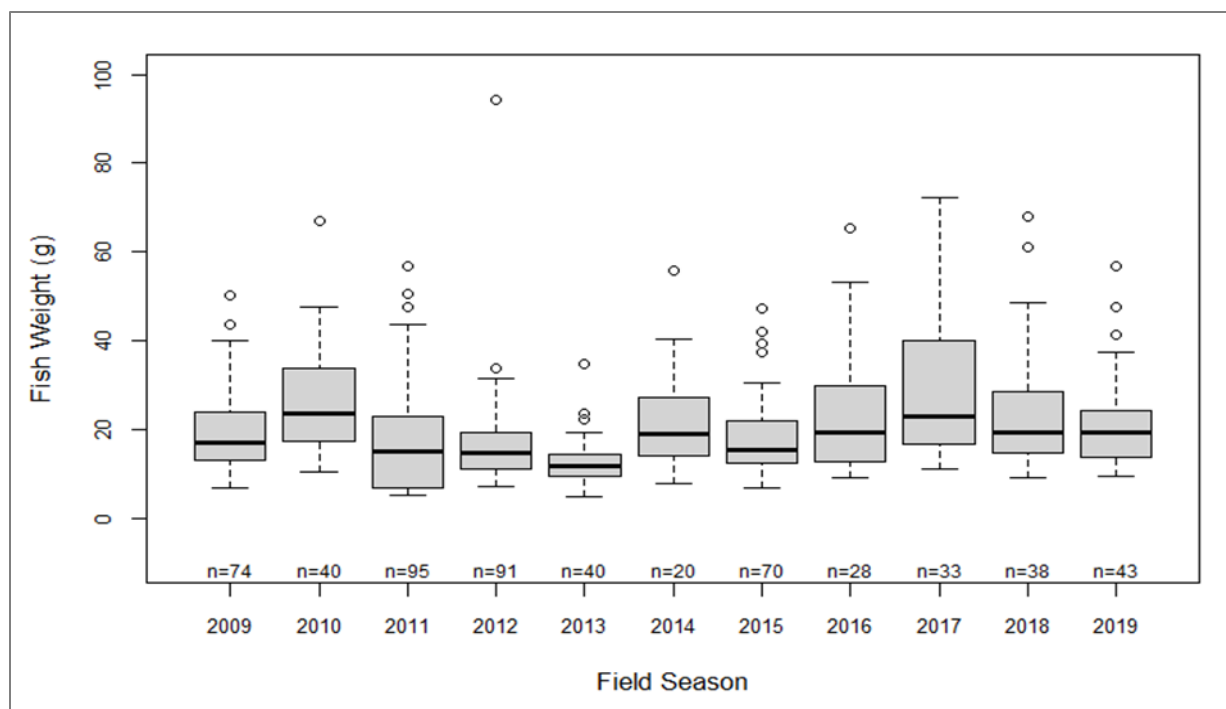


Figure 24. Box plots of 1+ steelhead weight data for basinwide surveys of Olema Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

3.4.2 Redwood Creek

Field crews initiated 2019 Redwood Creek summer habitat and basinwide snorkel surveys approximately 500 meters upstream of the confluence of Redwood Creek and the Pacific Ocean. From there, surveys continued upstream approximately eight km to monument-tag 74, within Mt. Tamalpais State Park. The team surveyed an additional 776 m on Fern Creek, a major tributary to Redwood Creek.

Habitat Survey

Field crews identified 674 mainstem habitat units within the 8,017.7 m Redwood Creek survey reach. Pool units were the primary habitat type, accounting for 5,023.6 m and 63% of the total mainstem length (Table 7). The team did not observe any dry units on the mainstem. Side channel and backwater units were also measured but not incorporated into the basinwide habitat calculations. Overall, crews measured 554.5 m of side channel habitat and 207.8 m of backwater habitat during the basinwide survey. Riffle units accounted for 62% of the side channel habitat length.

On Fern Creek, riffle units accounted for the majority (71%) of the length. Pool units represented 23% of the length, while flatwater units accounted for the remaining 6%.

Table 7. Habitat composition of Redwood Creek coho survey reach, summer 2019. Measured mainstem total length is used to calculate percentages of length per habitat type.

Unit Type	Total length (m)	% of length	# of units	% of units
Pool	5,023.6	63	316	47
Flatwater	861.8	11	105	16
Riffle	2,132.3	26	253	37
Dry	0	0	0	0
Total	8,017.7	100	674	100

We used total mainstem-survey length to calculate the density of side channel and backwater habitat, 6.9 m per 100 m and 2.6 m per 100 m, respectively. Side channel density was considerably higher in 2019 when compared to the 2004 to 2018 average of 4.6 m per 100 m. Backwater density was also slightly higher in 2019 when compared to the historical average of 2.1 m per 100 m.

Since no dry units were documented on the mainstem, we used the total mainstem length to calculate wood densities. In 2019, density of small woody debris jams was lower than the historical average while wood densities in the 10–20-cm and 20–50-cm size categories were higher than average (Table 8).

Table 8. Summary of basinwide instream woody debris (WD) per 100 m during summer base-flow conditions in Redwood Creek. Average 2005–2018 compared to 2019.

Field season	Survey length (# 100 m sections)	Root Wads per 100 m	LWD Jams ^A per 100 m	SWD Jams ^B per 100 m	10–20 cm WD ^C per 100 m	20–50 cm WD ^C per 100 m	>50 cm WD ^C per 100 m
2005–2018 Average	81.2	1.0	0.4	0.8	3.4	2.7	1.3
2019	80.2	1.3	0.4	0.4	5.0	3.8	1.2

^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 refers to diameter of individual pieces of woody debris.

Field crews also collected woody debris information on Fern Creek. The category of 10–20 cm woody debris had the highest density at 4.0 per 100 m. Small woody debris jams and root wads each had a density of 0.4 per 100 m, which was the lowest for all categories of woody debris in Fern Creek.

Coho Snorkel Counts

Field crews conducted snorkel surveys on 25% of the delineated pools and 10% of flatwaters. Snorkel crews observed coho in 74% (n=80) of the sampled pools and 20% (n=10) of sampled flatwater units. We documented 497 coho YoY in the 90 snorkeled units, yielding a raw average of 5.5 coho per snorkel unit. Field crews electrofished 18 of the 90 (20%) snorkeled units on the mainstem within a day of snorkeling. We used abundance estimates for the electrofished units to

calibrate the snorkel counts. The 2019 basinwide estimate for juvenile coho was 1,594, 95% CI [989, 2,199]. The 2019 abundance estimate decreased for this cohort compared to the summer coho abundance estimates from summers 2004 to 2018 (Figure 25).

Crews snorkeled an additional seven pools and one flatwater on Fern Creek and did not observe any coho YoY. Two pools with a snorkel count of zero coho were subsequently electrofished for calibration, and no coho were captured.

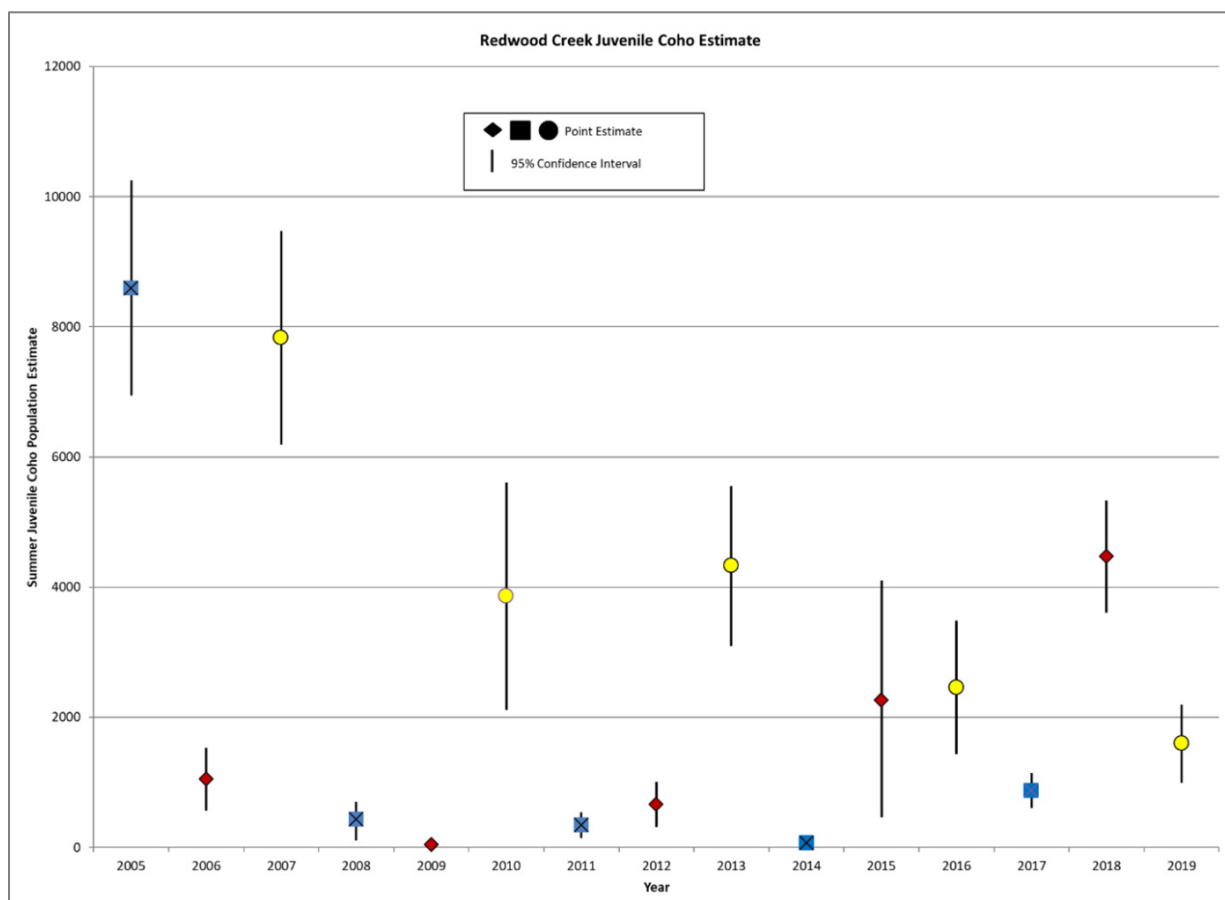


Figure 25. Summer juvenile coho basinwide abundance estimates for Redwood Creek, 2005–2019. Cohorts are designated by color (cohort 1 in yellow circles, cohort 2 in blue squares, cohort 3 in red diamonds).

Summer Coho and Steelhead Measurement Information

During the summer 2019 basinwide surveys of Redwood Creek, we measured 86 juvenile coho for FL and weighed 85 of those fish. Coho FL ranged from 46 mm to 84 mm, with a mean of 70 (SD 7) mm. The highest FL frequencies for coho occurred within the 61- to 65-mm and 66- to 70-mm length intervals, representing a combined 52% of the sample. The Redwood Creek mean coho weight was 4.1 (SD 1.18) g, and the median weight was 4.0 g. Summer 2019 juvenile coho measured lengths and weights for Redwood Creek were similar to those in previous years (Figures 26 and 27). As a

measure of juvenile coho condition, we calculated mean K-factor to within 0.01 ($100 \times W/L^3$). The mean coho K-factor for Redwood Creek during summer 2019 was 1.14 (SD 0.07).

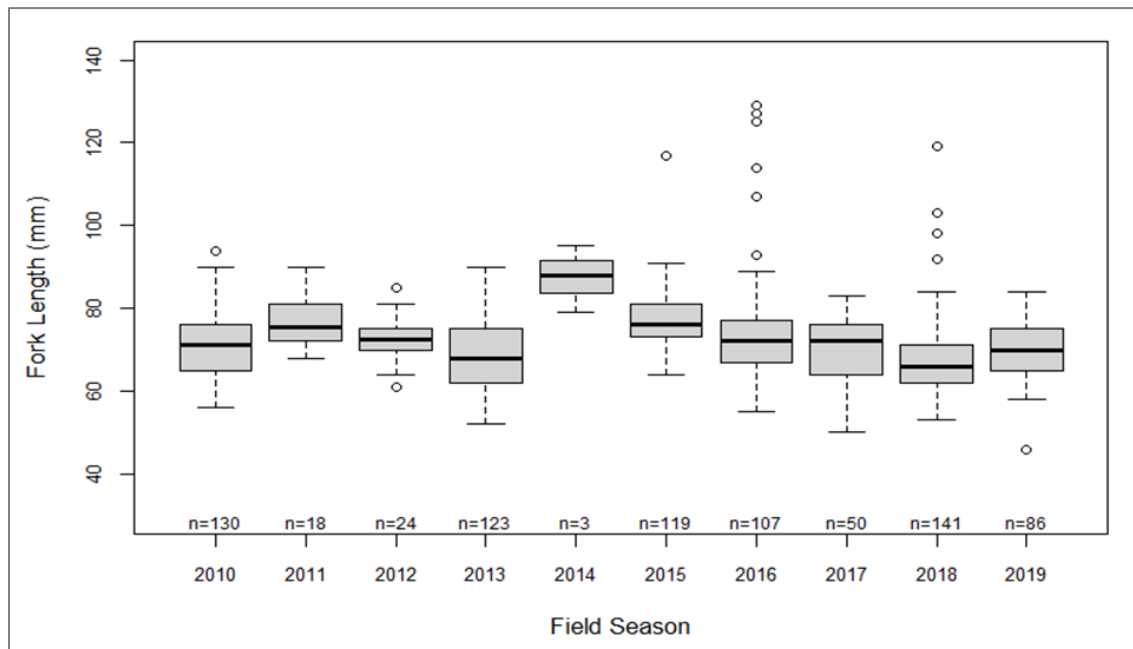


Figure 26. Box plots of juvenile coho fork length data for basinwide surveys of Redwood Creek, summer 2010–2019 (no coho captured in 2009). Dark lines represent medians, circles represent outliers, and n is sample size.

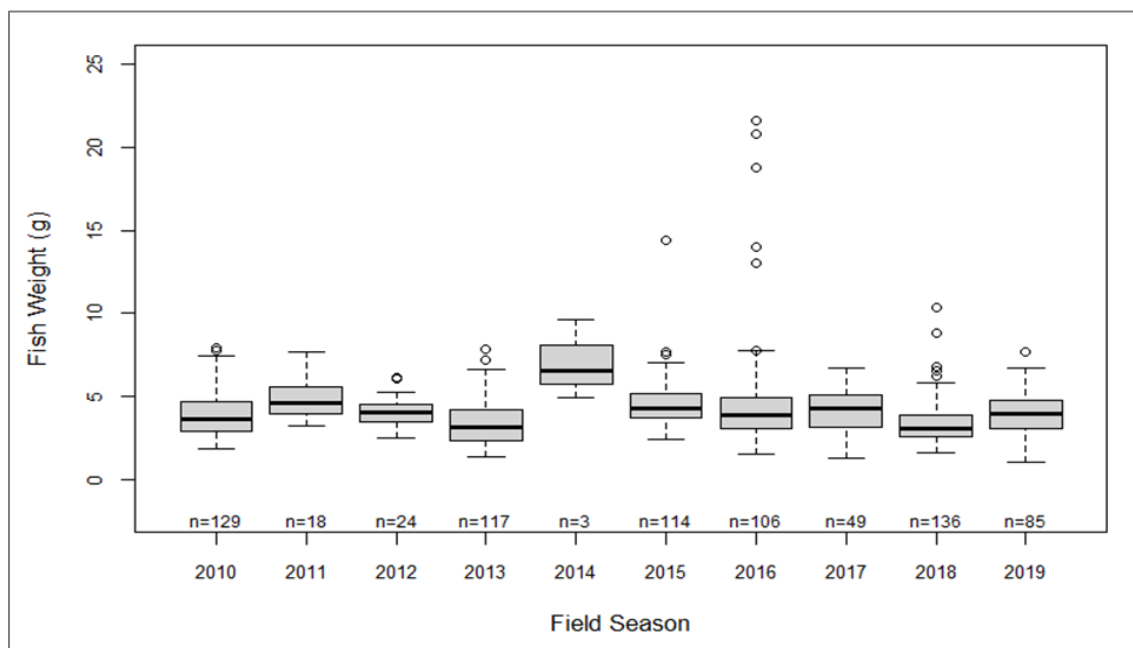
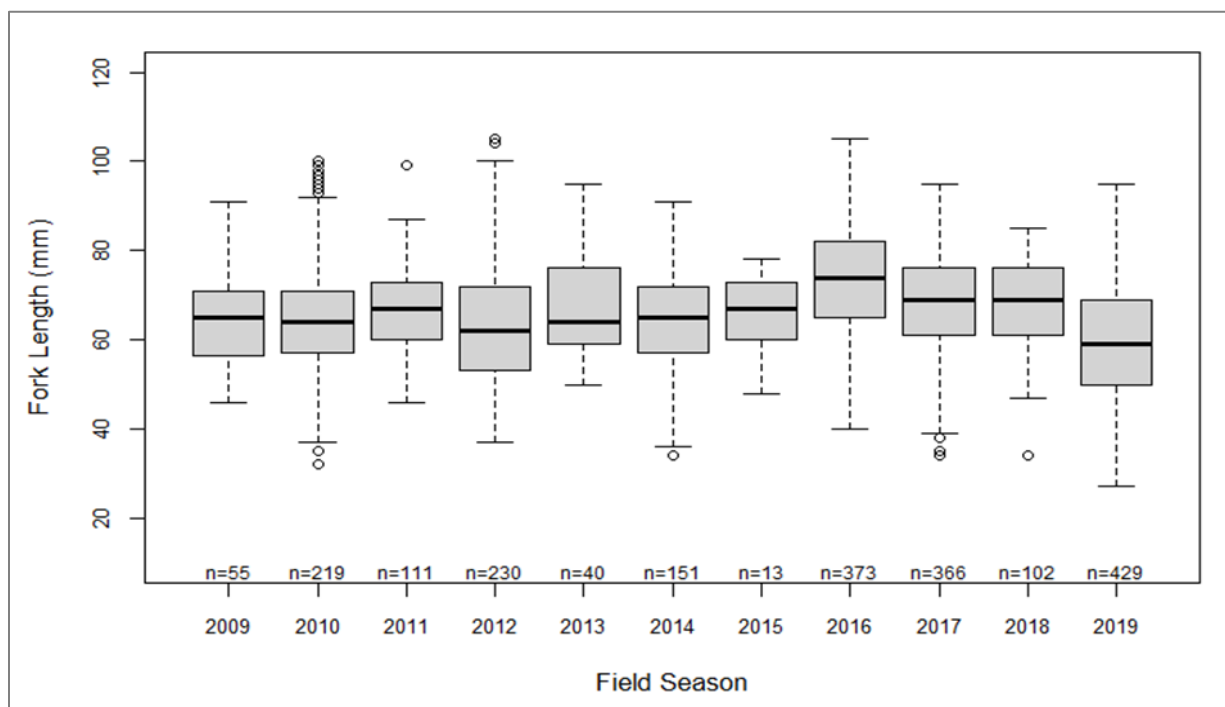


Figure 27. Box plots of juvenile coho weight data for basinwide surveys of Redwood Creek, summer 2010–2019 (no coho captured in 2009). Dark lines represent medians, circles represent outliers and n is sample size.

During 2019 Redwood Creek basinwide sampling, field crews also measured 517 steelhead for FL. The size range for steelhead was 27 mm to 221 mm, and the highest FL frequencies occurred within the 51- to 55-mm and 56- to 60-mm length intervals, with each interval representing 12% of the total sample. Based on FL frequencies, we binned all steelhead less than 91 mm as YoY and all steelhead 91 mm and greater as 1+. Of the 517 steelhead measured, 429 fish were classified as steelhead YoY and the remaining 88 as steelhead 1+. The Redwood Creek summer 2019 mean FL for steelhead YoY was 60 (SD 13) mm. We weighed 398 steelhead YoY and calculated a mean weight of 2.9 (SD 1.74) g, and a median weight of 2.3 g. The steelhead YoY mean FL for 2019 was the lowest on record, while the mean weight was similar to those in previous years (Figures 28 and 29). Steelhead 1+ measured during 2019 basinwide surveys had an average FL of 132 (SD 25) mm. We weighed 81 steelhead 1+ which had a mean weight of 24.1 (SD 11.08) g and a median weight of 21.6 g. Summer 2019 steelhead 1+ average FL and weight were similar to observations from previous years (Figures 30 and 31). The mean steelhead YoY and 1+ K-factors for Redwood Creek during summer 2019 were 1.08 (SD 0.09) and 1.08 (SD 0.08), respectively.



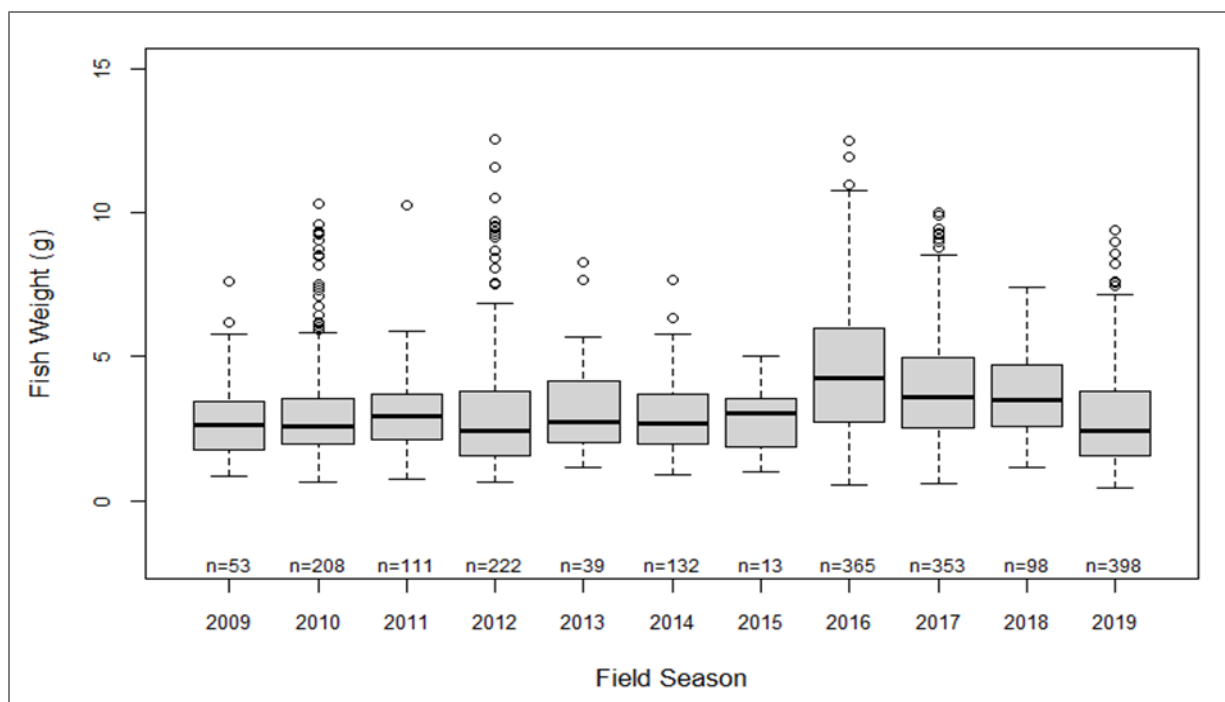


Figure 29. Box plots of young-of-year steelhead weight data for basinwide surveys of Redwood Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

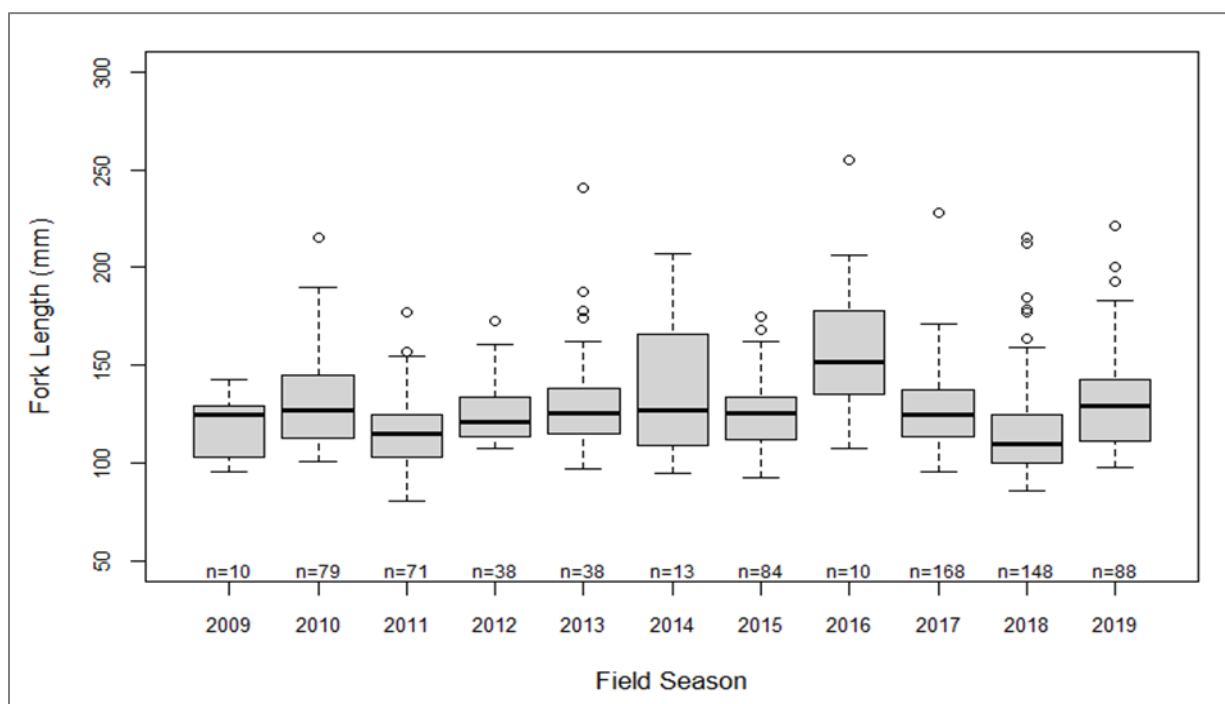


Figure 30. Box plots of 1+ steelhead fork length data for basinwide surveys of Redwood Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

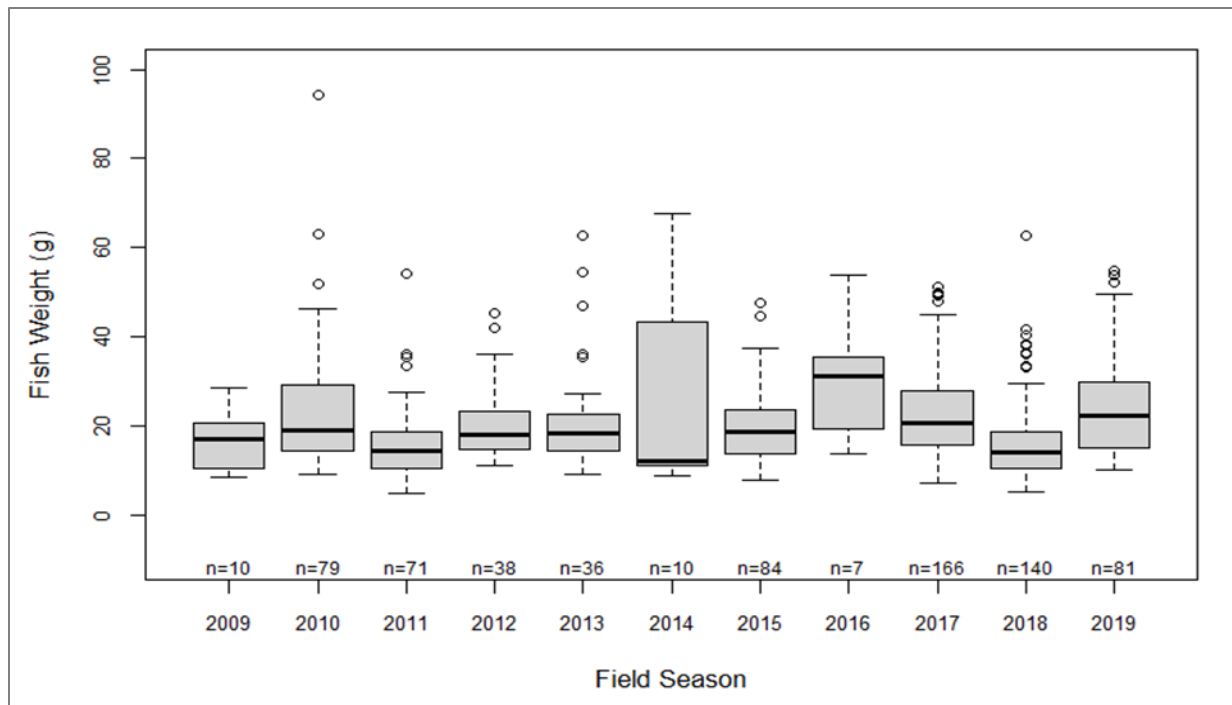


Figure 31. Box plots of 1+ steelhead weight data for basinwide surveys of Redwood Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

3.4.3 Pine Gulch Creek

SFAN crews initiated 2019 summer habitat and basinwide snorkel surveys of Pine Gulch Creek at monument-tag 15 and continued upstream approximately 8.1 km to monument-tag 90, above the Teixeira Ranch within PORE.

Habitat Survey

Field teams identified 727 mainstem habitat units in the 8,055.9 m Pine Gulch Creek survey reach. Pool and riffle units represented the majority of mainstem habitat length, measuring a total of 7,456.7 m (Table 9). Survey crews did not observe dry units this season. Side channel and backwater units were also measured but not incorporated into the basinwide habitat calculations. Overall, field staff measured 819.7 m of side channel habitat and 292 m of backwater habitat during the basinwide survey. Riffle habitat units represented 64% of the total side channel habitat length.

Table 9. Habitat composition of Pine Gulch Creek coho survey reach, summer 2019. Measured mainstem total length is used to calculate percentages of length per habitat type.

Unit Type	Total length (m)	% of length	# of units	% of units
Pool	4,483.3	56	369	51
Flatwater	599.2	7	75	10
Riffle	2,973.4	37	283	39
Dry	0	0	0	0
Total	8,055.9	100	727	100

We used total survey length to calculate the densities of side channel and backwater habitat, 10.2 m per 100 m and 3.6 m per 100 m, respectively. Both side channel and backwater densities were higher in 2019 when compared to their historical averages (2005 to 2018 side channel average of 8.3 m per 100 m, 2005 to 2018 backwater average of 2.1 m per 100 m).

Since no dry units were observed, SFAN crews used total mainstem survey length to calculate instream wood debris densities. For summer 2019, the only woody debris category with a density less than its historical average was small woody debris jams. The 10–20 cm and 20–50 cm woody debris categories had densities considerably higher than their respective historical averages (Table 10).

Table 10. Summary of basinwide instream woody debris (WD) per 100 m during summer base-flow conditions in Pine Gulch Creek. Average 2005–2018 compared to 2019.

Field season	Survey length (# 100 m sections)	Root Wads per 100 m	LWD Jams ^A per 100 m	SWD Jams ^B per 100 m	10–20 cm WD ^C per 100 m	20–50 cm WD ^C per 100 m	>50 cm WD ^C per 100 m
2005–2018 Average	89.6	0.9	0.4	0.7	3.5	3.0	1.2
2019	80.6	1.4	0.4	0.5	5.3	5.1	1.3

^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 refers to diameter of individual pieces of woody debris.

Coho Snorkel Counts

We conducted snorkel surveys on 24% of the delineated pools (87 of 369) and 11% of flatwaters (8 of 75), with no coho observations in any of the 95 snorkeled units. Field crews electrofished 15 of the snorkeled units (16%) within a day following the snorkel counts and did not capture any coho YoY. Four units (4%) were re-snorkeled immediately following the initial pass using the method of bounded counts (Murphy and Willis 1996). SFAN staff have not calculated a population estimate for Pine Gulch Creek since 2009 due to the apparent extirpation of the species from the watershed.

Summer Steelhead Measurement Information

Field crews measured 204 steelhead for FL during the 2019 summer basinwide surveys on Pine Gulch Creek. The size range for steelhead was 25 mm to 186 mm, and the highest frequency of fork lengths for steelhead occurred within the 41- to 45-mm and 46- to 50-mm length intervals, representing a combined 28% of the sample. Based on FL frequencies, we binned all steelhead less than 91 mm as YoY and all steelhead 91 mm and greater as 1+. Of the 204 measured steelhead, we binned 169 fish as steelhead YoY and the remaining 35 as steelhead 1+. The Pine Gulch Creek steelhead YoY mean FL was 51 (SD 12) mm. We weighed 135 steelhead YoY and calculated a mean weight of 2.0 (SD 1.18) g, and a median weight of 1.3 g. Mean FL for 2019 steelhead YoY was the lowest on record, while mean weight was comparable to prior seasons (Figures 32 and 33). The Pine Gulch Creek steelhead 1+ mean FL for summer 2019 was 136 (SD 25) mm. We weighed 33 steelhead 1+ which had a mean weight of 27.8 (SD 14.70) g and a median weight of 23.8 g. Steelhead 1+ mean FL and weight for summer 2019 were the highest on record (Figures 34 and 35).

As a measure of juvenile coho condition, we calculated mean K-factor to within 0.01 ($100 \times W/L^3$). The mean steelhead YoY and 1+ K-factors for Pine Gulch Creek during summer 2019 were 1.09 (SD 0.12) and 1.06 (SD 0.05), respectively.

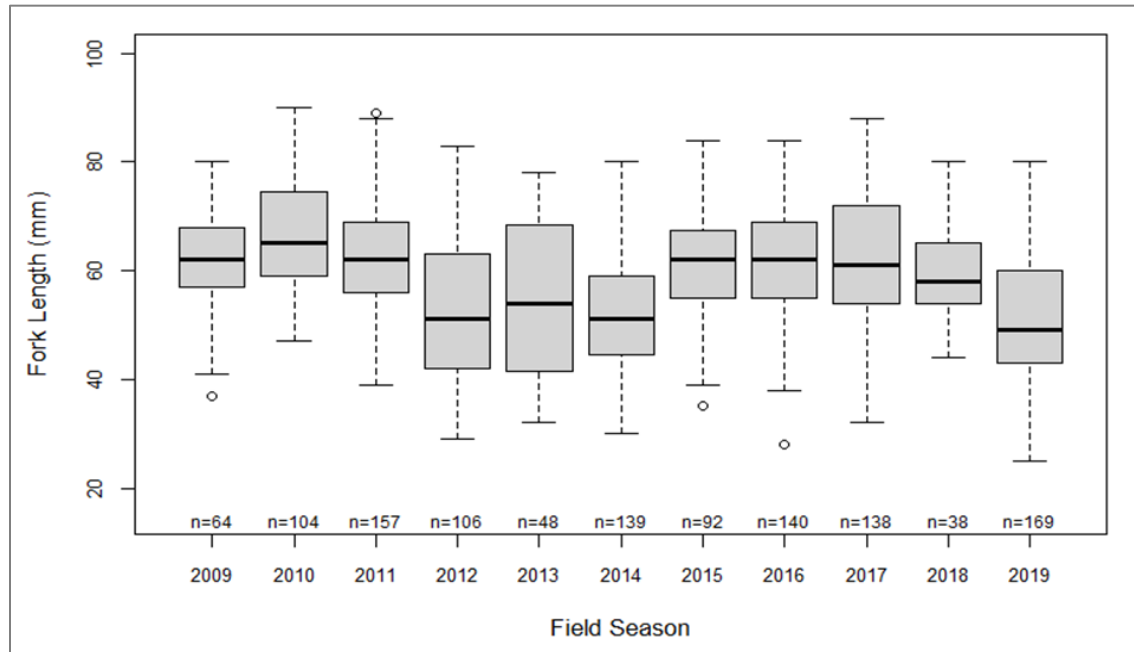


Figure 32. Box plots of young-of-year steelhead fork length data for basinwide surveys of Pine Gulch Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

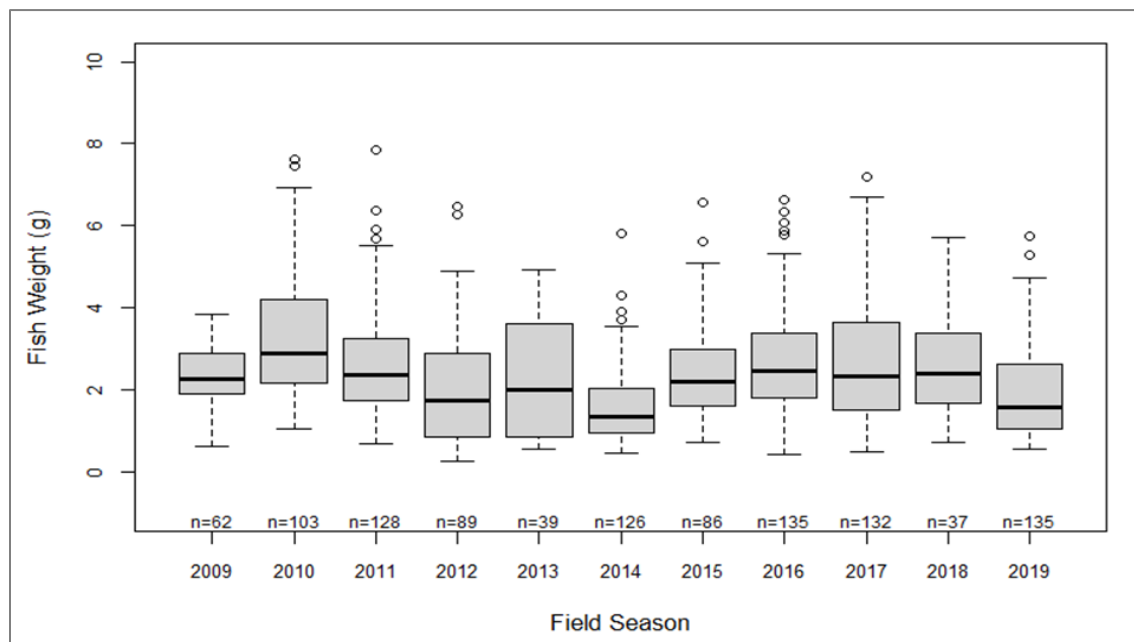


Figure 33. Box plots of young-of-year steelhead weight data for basinwide surveys of Pine Gulch Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

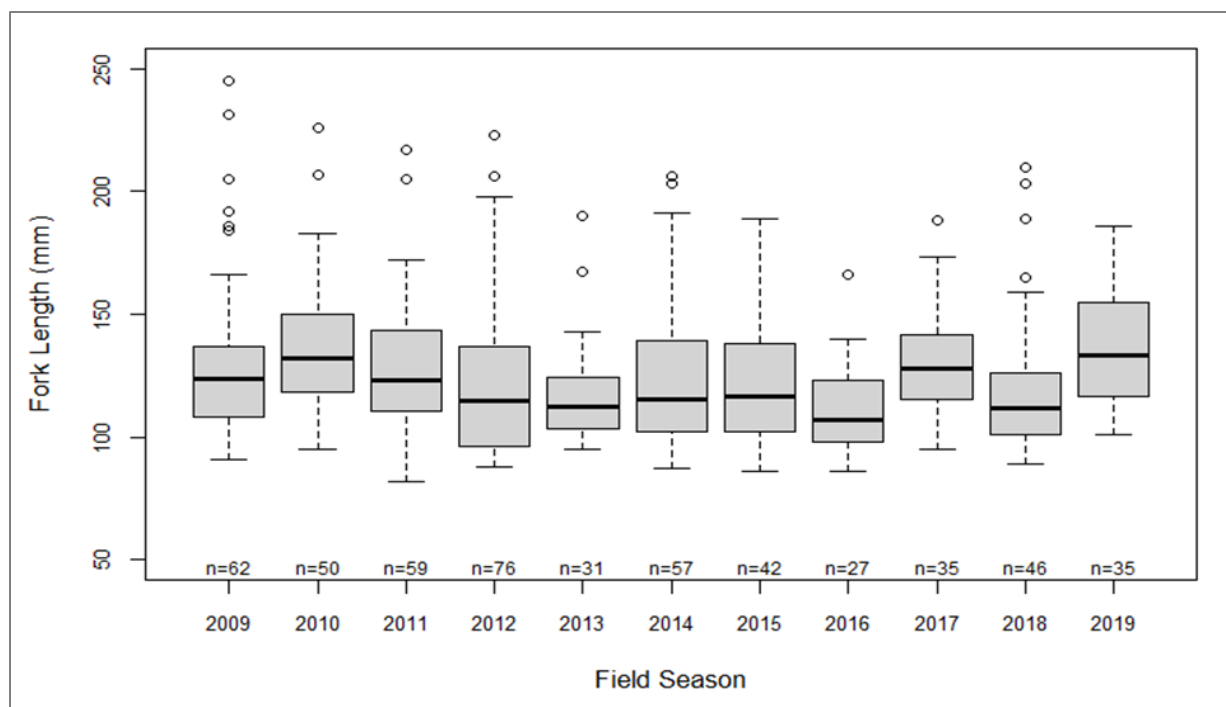


Figure 34. Box plots of 1+ steelhead fork length data for basinwide surveys of Pine Gulch Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

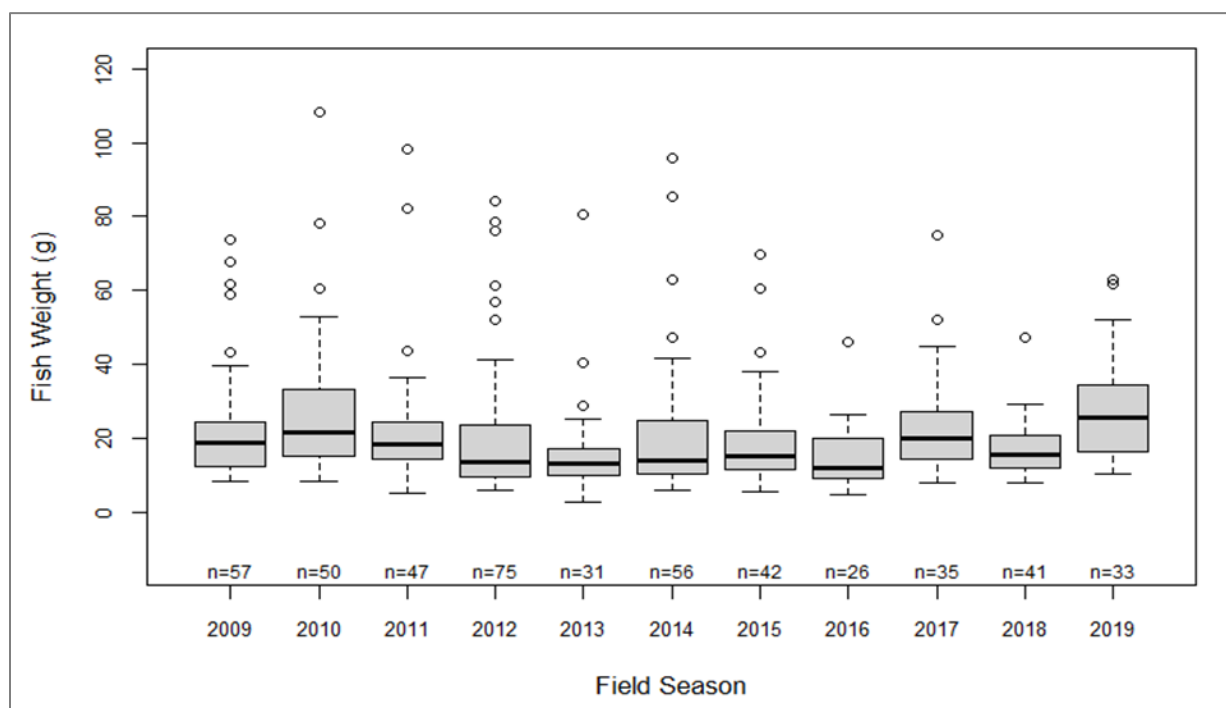


Figure 35. Box plots of 1+ steelhead weight data for basinwide surveys of Pine Gulch Creek, summer 2009–2019. Dark lines represent medians, circles represent outliers, and n is sample size.

3.5 Coho and Steelhead 2019 Index-Reach Monitoring Results

We provided juvenile coho salmon and steelhead index-reach monitoring results for Olema Creek and Redwood Creek. SFAN crews discontinued index-reach sampling on Pine Gulch Creek in 2018 due to the absence of coho YoY during basinwide monitoring for the ninth consecutive season, inconsistency in sampled reaches, and resources needed to complete the surveys.

3.5.1 Olema Creek Legacy Index-Reach Sampling

SFAN crews have not sampled Index Reach 1 since the summer of 2002 due to the creek avulsing into a new channel. In 2009, Index Reaches 4 and 8 were removed from the sampling regime due to access and staffing considerations. We did not sample Index 6 in 2019 due to time constraints and lack of available resources.

Index-Reach Habitat Information

In 2019, pools accounted for the highest percentage of habitat surface area within all sampled index reaches. Field crews did not observe riffle habitat in Index Reach 2 or flatwater habitat in Index Reach 5. Apart from Index Reach 7, flatwater and riffle habitat each represented less than 21% of the total surface area in all sample reaches. We provided Olema Creek index-reach habitat information in Table 20 in McNeill and Reichmuth (2024).

Index-Reach Total Salmonid Catch

We found juvenile coho and steelhead (YoY and 1+) present within all sampled index reaches (Table 11) during the summer 2019 index-reach electrofishing activities in Olema Creek. SFAN staff used total salmonid catch and habitat information described in the next section for additional density calculations in this report. The 2019 total catch for coho within Olema Creek index reaches was lower than the last time this cohort was sampled (Table 21 in McNeill and Reichmuth 2024).

Table 11. Summary of total catch by species for Olema Creek mainstem index reaches, summer 2019. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older. NS = not sampled.

Species/age	Index Reach								Total
	1	2	3	4	5	6	7	8	
CO	NS	42	110	NS	23	NS	43	NS	218
SH YoY	NS	52	123	NS	178	NS	48	NS	401
SH 1+	NS	13	25	NS	7	NS	4	NS	49

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. We calculated number of fish per meter using total catch from electrofishing surveys. Crews captured coho YoY, steelhead YoY, and steelhead 1+ in all four index reaches. Steelhead YoY per meter was considerably higher in Index Reach 5 compared to the other index reaches in summer 2019 (Figure 36; and Table 22 in McNeill and Reichmuth 2024).

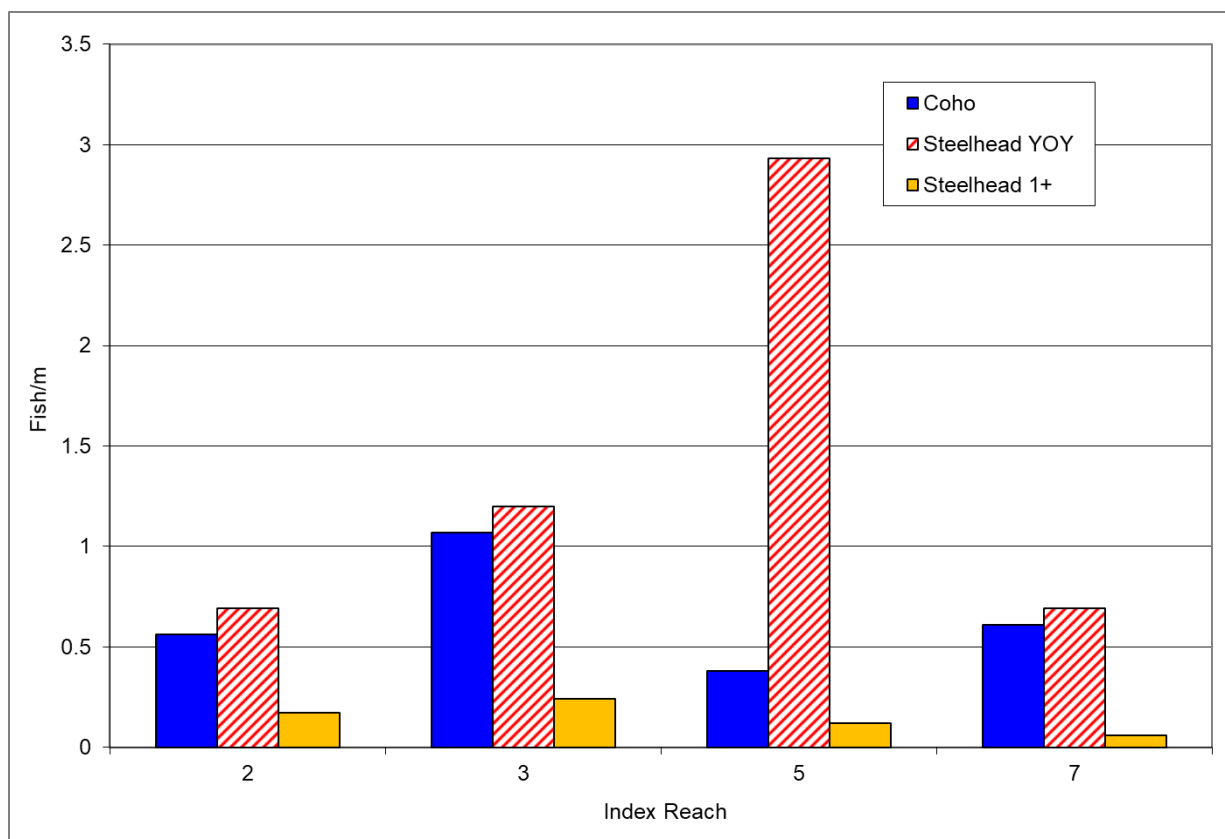


Figure 36. Coho and steelhead juvenile fish per meter according to index reach on Olema Creek, 2019.

Juvenile Coho and Steelhead Measurements

As part of summer index-reach monitoring, field crews measured a random subsample of coho YoY and steelhead for FL and weight. The team measured 138 juvenile coho for FL and weighed 137 of those during 2019 index-reach electrofishing activities on Olema Creek. The size range for coho YoY was 58 mm to 90 mm with a mean of 70 (SD 5.9) mm and median FL of 70 mm. Mean coho YoY weight was 3.9 (SD 0.97) g, and the median weight was 3.7 g.

Crews also measured 260 steelhead for FL and weighed 251 of those fish. Based on FL frequencies, we binned all steelhead less than 96 mm as YoY and all steelhead 96 mm and greater as 1+. The size range for steelhead (YoY) was 46 to 95 mm (n=213), while the size range for steelhead one year or older (1+) was 96 to 283 mm (n=47). Mean FL for steelhead YoY was 67 (SD 10.4) mm, and median FL was 65 mm. The mean steelhead YoY weight was 3.5 (SD 1.75) g, and median weight was 3.0 g. Mean FL for steelhead 1+ was 130 (SD 31.7) mm, with a median FL of 122 mm. The mean steelhead 1+ weight was 19.5 (SD 8.05) g, and the median weight was 16.8 g.

3.5.2 Redwood Creek Legacy Index-Reach Sampling

In 2019, SFAN crews surveyed six of the seven index reaches. Index Reach 7 no longer exists due to restoration activities.

Index-Reach Habitat Information

In 2019, the index-reach habitat composition revealed that pool habitat was the dominant habitat type by length and surface area in Index Reaches 3 through 6. Riffle habitat was the main habitat type by length in Index Reaches 1 and 2, while pool habitat accounted for the majority of surface area in Index 2. We did not observe flatwater habitat in Index Reaches 3, 5, and 6. We provided index-reach habitat data for Redwood Creek in Table 23 in McNeill and Reichmuth (2024).

Index-Reach Total Salmonid Catch

We found juvenile coho and steelhead (YoY and 1+) present within all sampled index reaches (Table 12) during the summer 2019 index-reach electrofishing activities in Redwood Creek. Field crews captured coho in all sampled index reaches this season. The steelhead YoY capture total was the highest since 2007 (Table 24 in McNeill and Reichmuth 2024).

Table 12. Summary of total catch by species for Redwood Creek mainstem index reaches, summer 2019. CO = coho salmon, SH = steelhead, YoY = young-of-year, 1+ = one year or older. NS = not sampled.

Species/age	Index Reach							Total
	1	2	3	4	5	6	7	
CO	2	27	22	24	30	16	NS	121
SH YoY	163	282	117	187	409	181	NS	1,339
SH 1+	12	41	38	52	14	12	NS	169

Salmonid per meter by Index Reach

We calculated number of fish per meter using the total catch from index-reach electrofishing surveys. During the summer of 2019, we captured higher densities of steelhead YoY at all six index reaches than both coho YoY and steelhead 1+. Furthermore, Index Reach 1 had the lowest density of salmonids per meter across species and age class while Index Reach 5 had the highest density of YoY salmonids (Figure 37; and Table 25 in McNeill and Reichmuth 2024).

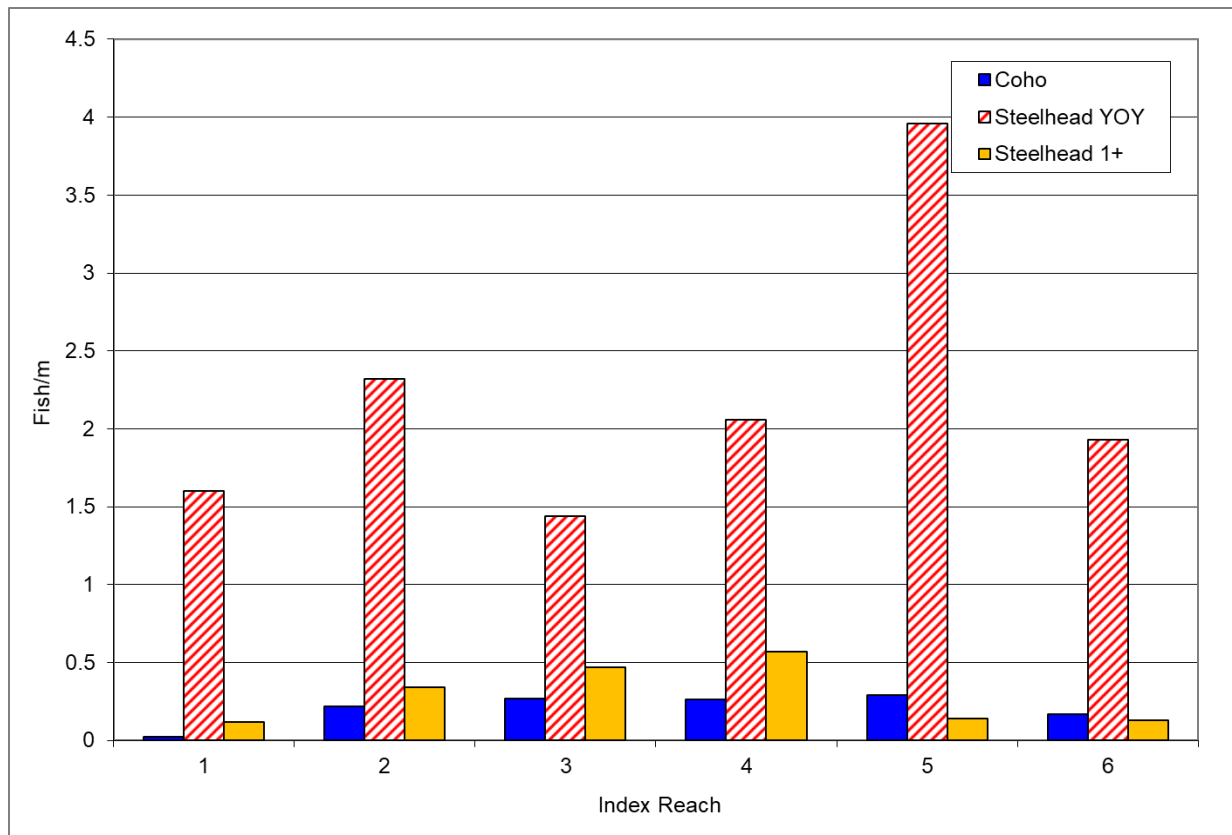


Figure 37. Coho and steelhead juvenile fish per meter according to index reach on Redwood Creek, 2019.

Juvenile Coho and Steelhead Measurements

During summer index-reach sampling, field teams randomly selected fish to measure for FL and weight at each sampled habitat unit. Within the 2019 Redwood Creek sample, 119 coho YoY were measured for FL, and 109 of those were weighed. The size range for coho YoY was 52 to 90 mm with a mean FL of 71 (SD 7.1) mm and median FL of 71 mm. The mean coho YoY weight was 4.2 (SD 1.19) g, and the median weight was 4.1 g.

Crews measured 783 steelhead for FL and weighed 701 of these fish. Based on FL frequencies, we binned all steelhead less than 91 mm as YoY and all steelhead 91 mm and greater as 1+. The size range for steelhead YoY was 29 to 95 mm (n=643), while the size range for steelhead 1+ was 96 mm to 263 mm (n=140). Mean FL for steelhead YoY was 60 (SD 12.4) mm and median FL was also 60 mm. The mean weight for steelhead YoY was 2.8 (SD 1.66) g, and the median weight was 2.2 g. Mean FL for steelhead 1+ was 131 (SD 26.13) mm, with a median FL of 128 mm. The mean steelhead 1+ weight was 23.6 (SD 10.60) g, and the median weight was 19.9 g.

Discussion

Coastal Marin County watersheds are some of the most intensely monitored watersheds within the CCCESU. In addition to SFAN/CDFW funded monitoring of coho salmon on Olema Creek, Redwood Creek, Pine Gulch Creek, and Cheda Creek, MMWD monitors Lagunitas Creek, Devils Gulch, and the mainstem of San Geronimo Creek, while SPAWN monitors tributaries of San Geronimo Creek. Through extensive monitoring efforts, SFAN documents coho salmon behavior, life history, distribution, and population trends. Although 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.

Coho escapement data for Olema Creek show that the timing of spawner runs is highly dependent on the quantity of rainfall within the watershed. More specifically, 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 (ESA 2021). Unlike Lagunitas Creek, Olema Creek is an unregulated stream, so flows during the spawning season are entirely dependent on natural weather patterns.

Our monitoring efforts have documented certain years when migration flows, the flows necessary to allow adult salmonids entry into the watershed, did not occur until mid-January. In those years, SFAN crews observed coho adults in the estuary apparently awaiting migration flows from Olema Creek. In other years, rains in November generated flows that would allow coho early migration to the watershed. Even when this early-entry opportunity was available, crews observed few coho adults 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 for a season and watershed followed a large flow event, as fish waiting at the mouth of the watershed are able to enter the system.

The estimated total of 63 coho salmon redds for Olema Creek during the 2018–2019 spawner season was comparable to the 2015–2016 estimate of 66 redds. This cohort experienced a sharp decline in redd abundance during the 2009–2010 spawner season when survey crews only observed 14 redds, whereas the prior four generations averaged 105 redds per season (Table 2 in McNeill and Reichmuth 2024). Following the collapse in 2009–2010, redd abundance increased two consecutive generations for cohort 1 and remained relatively stable for 2018–2019.

Similar to Olema Creek, the past 21 years of coho salmon escapement monitoring data for Redwood Creek suggest that run timing is highly dependent on rainfall. Redwood Creek is an unregulated stream with variable environmental conditions that limit flows in the winter. 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.

The Redwood Creek estimate of 61 coho redds for the 2018–2019 spawner season was substantially higher than the estimate of 15 redds for 2015–2016, when this cohort (cohort 1) last spawned. We primarily attribute this increase in redd abundance to the release of 165 adult coho salmon on 18 December 2018 as part of the Coho Salmon Rescue and Captive Rearing Project led by CDFW. Project collaborators captured juvenile coho in Redwood Creek during summer 2016 and reared the fish to adulthood at Don Clausen Fish Hatchery in Sonoma County, CA before releasing them back into Redwood Creek this season. Cohort 1 spawning had been relatively consistent since 2006–2007 until a slight decline in redd production occurred during the 2015–2016 season (Table 4 in McNeill and Reichmuth 2024). For all years, most spawning occurred on the mainstem of Redwood Creek, with limited spawning observed on Fern Creek and Kent Canyon during years with higher abundance. We have not documented coho spawning in the Green Gulch tributary.

SFAN also conducted spawner surveys in Cheda Creek and Pine Gulch Creek but at a much lower frequency compared to Olema and Redwood Creeks. We conducted fewer surveys in these creeks due to limited program capacity and minimal use of these streams by coho salmon. For both streams, we still described adult coho use and estimated abundance. 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. Coho salmon redds were detected in Cheda Creek in 15 of the last 20 years, including the past eight consecutive years (Table 3 in McNeill and Reichmuth 2024). The dataset for adult escapement within Pine Gulch Creek includes 19 years of survey information following the discovery of one adult coho salmon during 2000–2001. Since this discovery, SFAN has documented live adult coho and/or coho spawning activity in the watershed seven of the last 19 years (Table 5 in McNeill and Reichmuth 2024). Successful coho spawning on Pine Gulch Creek last occurred during the 2008–2009 season, and we did not detect spawning activity during the 2018–2019 spawner season.

To estimate the number of juvenile coho migrating from freshwater to the ocean during the 2019 spring months and evaluate overwinter survival in Olema and Redwood Creeks, we operated fyke-net smolt traps from late March through May. The 2019 season marked the 16th consecutive season of smolt trapping in Olema Creek by SFAN. We estimated a record high smolt abundance of 5,677, 95% CI [4,538, 6,816] in 2017 and captured a record low of only 10 coho smolts in 2010. The 2019 Olema Creek coho smolt-abundance estimate of 407, 95% CI [94, 930] may be lower than the true outmigration abundance for 2019. We speculate that the primary contributing factor to this lower estimate was imperfect detection of smolts due to a secondary channel bypassing the trap. The secondary channel had an inflow located approximately 700 meters upstream of the trap location and an outflow almost 900 meters downstream of the trap and was discovered during a survey in May 2019. Crews estimated that approximately 40% of the mainstem flow was being captured by the channel. Consequently, the Olema Creek 2019 coho smolt-abundance estimate was approximately half that of the 2016 estimate, which was the last time cohort 3 smolts were in the system. Although the 2019 estimate was likely substantially lower than the true outmigration, it is still a reasonable estimate given the summer 2018 juvenile estimate of 1,301, 95% CI [963, 1,619] when applying an average survival of around 30% between these life stages.

The 2019 smolt-trapping season was the 15th consecutive season in the Redwood Creek watershed, and coho smolt-abundance estimates ranged from a high of 3,459, 95% CI [2,918, 4,000] in 2011 to a low of 226, 95% CI [163, 664] in 2009. The 2019 smolt estimate of 2,983, 95% CI [2,511, 3,455] was more than double the 2016 estimate and exceeded expectations after a summer 2018 juvenile estimate of 4,475, 95% CI [3,613, 5,337]. Given the abundance estimate at both the juvenile and smolt life stage, overwinter survival was more than 60% for this cohort. This is also the largest smolt abundance estimated for this cohort since smolt trapping was initiated on Redwood Creek during the spring of 2005.

Ocean survival is directly related to smolt size (Miller and Sandros 2003), with smolts of larger size at the time of ocean entrance demonstrating a higher probability of returning to source streams as adults. For Olema Creek, the 2019 coho smolt mean FL of 125 (SD 10.5) mm was the second highest since trapping operations began in 2004. Mean weight was also one of the highest on record (Table 6 in McNeill and Reichmuth 2024). When evaluating K-factor for salmonid smolts, it is important to review FL in relation to the K-factor. During the transition to smolt, the salmonid body becomes longer and narrower. This transition causes a decrease in K-factor, as fish with longer FL typically have lower K-factors than shorter fish. With this in mind, smolt K-factor was evaluated by comparing historic mean K-factors of coho smolts with similar mean FL. The 2019 mean coho smolt K-factor of 0.98 (SD 0.07) was higher than the historic average and, more importantly, the third highest K-factor on record for years in which the mean FL was greater than or equal to 115 mm (Table 6 in McNeill and Reichmuth 2024). We also captured steelhead smolts in good condition with a mean K-factor of 1.02 (SD 0.09) which is the third highest on record (Table 7 in McNeill and Reichmuth 2024).

The 2019 coho smolt mean FL of 104 (SD 9.8) mm and mean weight of 11.4 (SD 3.11) g for Redwood Creek were lower than their respective historical averages, while the mean K-factor of 1.00 (SD 0.07) was similar to years in which mean FL was 100–109 mm (Table 8 in McNeill and Reichmuth 2024). When comparing coho smolt condition between Redwood and Olema Creeks, Redwood Creek smolts were much shorter and had a lower mean K-factor. This means Redwood Creek coho smolts migrated to the ocean at an average smaller size (shorter and skinnier) during the spring of 2019 than coho smolts emigrating from Redwood Creek in previous years. Hopefully, with a continued focus on habitat restoration in the Redwood Creek watershed, coho smolt condition will improve. On average, steelhead smolts captured in Redwood Creek had a FL within one standard deviation of the historic average but had a higher mean K-factor when comparing steelhead smolts of similar FL from previous years (Table 9 in McNeill and Reichmuth 2024). Continued collection of smolt data will help refine our understanding of variation and size range of smolts leaving these coastal Marin County watersheds.

The 2019 summer season marked the 11th consecutive season of basinwide sampling in Olema Creek by SFAN following the approved protocol. Although we collected data using a basinwide method from summer 2004 through summer 2008, we did not use a statistically valid technique for calibrating snorkel counts and, therefore, did not include pre-2009 data in the analysis. Juvenile coho abundance fluctuated drastically from one season to the next, and our estimates ranged from a high of

23,695, 95% CI [19,042, 28,348] in 2018 to a low of just one coho counted during the summer of 2009. For Olema Creek, we calculated a 2019 juvenile coho abundance estimate of 8,978, 95% CI [5,373, 12,583]. This estimate is substantially lower than the analogous estimate of 17,337, 95% CI [12,527, 22,147] for 2016 when this cohort was last in the system. This is also the second consecutive season in which we have observed a decline in the juvenile coho abundance for this cohort.

This was also the 11th consecutive season of summer basinwide sampling in Redwood Creek. Juvenile coho abundance estimates ranged from a high of 4,475, 95% CI [3,613, 5,337] in 2018 to a low of just 41 coho counted during the summer of 2009. The 2019 abundance estimate for Redwood Creek was 1,594, 95% CI [989, 2,199] coho YoY, which was less than the estimate calculated for 2016 (2,459, 95% CI [1,435, 3,483]) but within the CI. Like Olema Creek, this is the third consecutive year in which we have observed a decline in the juvenile coho abundance for this cohort. Both the Olema Creek and Redwood Creek basinwide juvenile coho estimates were lower than expected given the number of redds documented in each watershed for this cohort. These estimates suggest poor survival from egg to summer juvenile life stages, and survival was the lowest in Redwood Creek. Despite similar redd estimates for both creeks during the winter of 2018–2019, the Redwood Creek juvenile abundance estimate was less than 20% of what was calculated for Olema Creek. Decreased fitness of the hatchery-reared adults, non-typical placement of redds in the streambed, and high-flow storm events after redd creation may, in combination, have contributed to the unexpectedly low juvenile abundance in Redwood Creek.

Indirect estimates of peak flow were computed by the U.S. Geological Survey's National Streamflow Statistics computer program (Vers. 6.1, Ries III 2007, Gotvald et al. 2012), which uses regression equations based on prior regional investigations of the relationships between environmental parameters and streamflow. Olema and Redwood Creek watersheds are in USGS Hydrologic Region 1 North Coast. In Olema Creek, four storm events exceeded the estimated bankfull flow in January and February 2019. Of those four events, two occurred at a recurrence interval of 5-years and the other one was at or above the 25-year recurrence interval. These high-flow events in Olema Creek likely resulted in mortality of coho eggs due to redd scour and mortality of early-emergent fry (Woodward et al 2014). In Redwood Creek, the high flows were less intense than those recorded in Olema Creek, suggesting that decreased fitness of hatchery-reared adults rather than egg scour may explain the low abundance estimate there. However, one storm event in February 2019 exceeded the estimated bankfull flow.

To characterize the general health of the population, we measured a random sample of both coho and steelhead juveniles during 2019 basinwide electrofishing surveys in Olema, Redwood, and Pine Gulch Creeks. For Olema Creek, the summer 2019 juvenile coho mean FL was shorter than the historical average while mean K-factor was the third highest since 2010 (Table 12 in McNeill and Reichmuth 2024), indicating that although juvenile coho were shorter they were plumper than fish of similar lengths in previous years. Steelhead YoY had the highest mean K-factor compared to historic means despite having a similar mean FL when compared to past seasons (Table 13 in McNeill and Reichmuth 2024). Like juvenile coho, this indicates that YoY steelhead were plumper than those

captured in previous summers of similar lengths. The calculated mean FL and K-factor for steelhead 1+ during the summer of 2019 in Olema Creek were above the historic averages (Table 14 in McNeill and Reichmuth 2024), indicating that the overall size of steelhead 1+ was greater during the summer of 2019 than in previous years.

Both juvenile coho and steelhead YoY measured in Redwood Creek during summer 2019 were shorter than average (Tables 15 and 16 in McNeill and Reichmuth 2024). In fact, the mean steelhead YoY length was the shortest on record. However, both coho and steelhead YoY had a mean K-factor that was higher than the historical average. This means that both coho and steelhead YoY were plumper on average during the summer of 2019 than was recorded in previous summers. Mean length and K-factor calculated for steelhead 1+ in Redwood Creek during the summer of 2019 were higher than the historic average (Table 17 in McNeill and Reichmuth 2024). Similar to Olema Creek, this indicates that the overall size of steelhead 1+ was greater during the summer of 2019 than in previous years. The mean K-factor calculated for steelhead 1+ was the highest K-factor recorded in Redwood Creek.

Mean K-factor for steelhead YoY and 1+ in Pine Gulch Creek during the summer of 2019 were both higher than the historic average (Tables 18 and 19 in McNeill and Reichmuth 2024). However, the mean FL for steelhead YoY was the shortest on record while mean FL for steelhead 1+ tied the highest mean FL on record. The collective size information suggests lower-than-average growth for coho and steelhead YoY measured in Olema, Pine Gulch, and Redwood Creeks from early spring to summer. However, the calculated mean K-factor for all three creeks, and the higher average steelhead 1+ size, suggests favorable food availability during this same period.

Literature Cited

- Adams, P. B., L. B. Boydstun, S. P. Gallagher, M. K. Lacy, T. McDonald, and K. E. Shaffer. 2011. California coastal salmonid population monitoring: strategy, design, and methods. California Department of Fish and Game, Fish Bulletin no. 180. 82 p.
- Bjorkstedt, E. P. 2005. DARR 2.0: Updated Software for Estimating Abundance from Stratified Mark-Recapture Data. Available from [NOAA-TM-NMFS-SWFSC-368.PDF](#) (accessed 12 April 2010).
- Bjorkstedt, E. P., B. C. Spence, J. C. Garza, D. G. Hankin, D. Fuller, W. E. Jones, J. J. Smith, and R. Marcedo. 2005. An analysis of historic population structure for evolutionarily significant units of chinook salmon, coho salmon, and steelhead in the North-Central California Coast recovery domain. NOAA Technical Memorandum NMFS NOAA-TM-NMFS-SWFSC-382. NOAA National Marine Fisheries Service, Southwest Fisheries Science Center, Fisheries Ecology Division, Santa Cruz, California.
- Bohlin, T., S. Hamrin, T. G. Heggeberget, G. Rasmussen, and S. J. Saltveit. 1989. Electrofishing—theory and practice with special emphasis on salmonids. *Hydrobiologia* 173: 9–43.
- Brett, J. R., and J. M. Blackburn. 1981. Oxygen requirements for growth of young coho (*Oncorhynchus kisutch*) and sockeye (*O. nerka*) salmon at 15°C. *Canadian Journal of Fisheries Aquatic Science* 38: 399–404.
- Brown, G. G., and B. J. Ketcham. 2002. Documentation of coho salmon (*Oncorhynchus kisutch*) in Pine Gulch Creek, Marin County, CA. Coho Salmon and Steelhead Trout Restoration Project. PORE-NR-WR-02/02. Point Reyes National Seashore, Point Reyes, California.
- Brown, L. R., P. B. Moyle, and R. M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. *North American Journal of Fishery Management* 14: 237–261.
- Dollof, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. General Technical Report SE-83. USDA Forest Service Southeastern Forest Experiment Station, Asheville, North Carolina. Available at https://www.srs.fs.usda.gov/pubs/gtr/gtr_se083.pdf
- ESA. 2021. Lagunitas Creek Instream Flow Study. Final Report prepared for Marin Water. ESA Oakland, California. 71p.
- Federal Register. 1996. Final rule. Endangered and threatened species: Threatened status for Central California Coast Coho salmon Evolutionarily Significant Unit (ESU). *Federal Register* 61 (212): 56138–56149.

- Federal Register. 1997. Final rule. Endangered and threatened species: Listing of several evolutionarily significant units (ESUs) of west coast steelhead. Federal Register 62(159): 43937–43954.
- Federal Register. 2005. Final rule. Endangered and threatened species: Final listing determinations for 16 ESUs of west coast salmon, and final 4(d) protective regulations for threatened salmonid ESUs. Federal Register 70(123): 37160–37204.
- Federal Register. 2006. Final rule. Endangered and threatened species: Final listing determinations for 10 distinct population segments of west coast steelhead. Federal Register 71(3): 834–862.
- Flosi, G., S. Downie, J. Hopelain., M. Bird, R. Coey, and B. Collins. 1998. California salmonid stream habitat restoration manual. 1998. 3rd edition. California Department of Fish and Game, Sacramento, California. 495 p.
- Gallagher, S., and C. Gallagher. 2005. Discrimination of Chinook and coho salmon and steelhead redds and evaluation of the use of redd data for estimating escapement in several unregulated streams in Northern California. North American Journal of Fisheries Management. 25: 284–300.
- Garwood, J., and M. Larson. 2014. Reconnaissance of salmonid redd abundance and juvenile spatial structure in the Smith River with emphasis on coho salmon. Final report to the California Department of Fish and Wildlife, Fisheries Restoration Grants Program, Contract: P1010504. Smith River Alliance, Crescent City, California. 63p.
- Garza, C., and E. Gilbert-Horvath. 2003. Report on the genetics of coho salmon (*Oncorhynchus kisutch*) held at the Warm Springs (Don Clausen) Hatchery for recovery efforts in the Russian River. NOAA Southwest Fisheries Science Center. Santa Cruz Laboratory. Santa Cruz, California.
- Gotvald, A. J., N. A. Barth, A. G. Veilleux, and C. Parrett. 2012. Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012–5113, 38 p.
- Hassler, T. J. 1987. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) – Coho. U.S. Fish and Wildlife Service Biological Report 82 (11.70). U.S. Army Corps of Engineers, TR EL-82-4.
- Ketcham B. J., and G. G. Brown. 2003. Coho salmon (*Oncorhynchus kisutch*) in Pine Gulch Creek, Marin County, CA. 2002 Monitoring Report. Coho Salmon and Steelhead Trout Restoration Program. PORE-NR-WR-03/01. 18pp. Plus appendices.
- Lestelle, L. C. 2007. Coho salmon (*Oncorhynchus kisutch*) life history patterns in the Pacific Northwest and California. Prepared by Biostream Environmental, Poulsbo, Washington for the U.S. Bureau of Reclamation Klamath Area Office.

- Manning, D. J. 2001. Carrying capacity and limiting habitat analysis for coho salmon (*Oncorhynchus kisutch*) in streams of northwestern California. Masters Thesis. Humboldt State University, Arcata, California.
- Manning, D. J., and T. D. Roelofs. 1996. Coho carrying capacity and limiting habitats analysis – 1996 smolt trapping protocol. Department of Fisheries, Humboldt State University, Arcata, California.
- McNeill, B., and M. Reichmuth. 2024. Long-term monitoring of coho salmon and steelhead during freshwater life stages in coastal Marin County: 2019 Historic data tables. Data Report. San Francisco Bay Area Network, National Park Service, Point Reyes Station, California. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2303822>
- Miller, B. A., and S. Sandros. 2003 Residence time and seasonal movement of juvenile coho salmon in the ecotones and lower estuary of Winchester Creek, South Slough, Oregon. Transactions of the American Fisheries Society 132: 546–559.
- Moyle, P. B. 2002. Inland fishes of California. University of California Press, Berkeley, California.
- Murphy, B. R., and D. W. Willis. 1996. Fisheries techniques. Second Edition. American Fisheries Society, Bethesda, Maryland.
- National Marine Fisheries Service (NMFS). 2012. Final recovery plan for Central California Coast coho salmon evolutionarily significant unit. National Marine Fisheries Service, Southwest Region, Santa Rosa, California.
- Nickelson, T. E., and P. W. Lawson. 1998. Population viability of coho salmon, *Oncorhynchus kisutch*, in Oregon coastal basins: Application of a habitat-based life cycle model. Journal of Fisheries and Aquatic Science 55: 2383–2392.
- Reichmuth, M., B. J. Ketcham, D. Fong, S. Carlisle, E. Brown, and M. Koenen. 2010. Salmonid monitoring protocol for the San Francisco Bay Area Network. Natural Resource Report NPS/SFAN/NRR—2010/202. National Park Service, Fort Collins, Colorado. Available at <https://irma.nps.gov/DataStore/Reference/Profile/2124828>
- Ricker, S. J., Ferreira, S. P. Gallagher, D. McCanne, and S.A. Hayes. 2013. Methods for classifying anadromous salmonid redds to species. Coastal Salmonid Population Monitoring Technical Team Report. California Department of Fish and Wildlife, Arcata, California. 24p.
- Ries III, K. G. 2007. The national streamflow statistics program: A computer program for estimating streamflow statistics for ungaged sites: U.S. Geological Survey Techniques and Methods 4-A6, 37 p.

- Sandercock, F. K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pages 395–446 in C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, British Columbia.
- Schneider, J. C. (ed.). 2000. Manual of fisheries survey methods II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor, Michigan.
- Smith, J. J. 2001. Distribution and abundance of coho and steelhead in Redwood Creek in fall 2001. Report to Golden Gate National Recreation Area, National Park Service.
- Spence, B. C., and J. D. Hall. 2010. Spatiotemporal patterns in migration timing of coho salmon (*Oncorhynchus kisutch*) smolts in North America. Canadian Journal of Fisheries and Aquatic Sciences 67: 1316–1334.
- Stillwater Sciences. 2008. Lagunitas limiting factors analysis; limiting factors for coho salmon and steelhead. Final report. Prepared by Stillwater Sciences, Berkeley, California for Marin Resource Conservation District, Point Reyes Station, California.
- Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-24.
- Woodward, A., A. Torregrosa, M. A. Madej, M. Reichmuth, and D. Fong. 2014. Users' guide to system dynamics model describing Coho salmon survival in Olema Creek, Point Reyes National Seashore, Marin County, California: U.S. Geological Survey Open-File Report 2014–1131, 58 p., <https://doi.org/10.3133/ofr20141131>

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