

Redwood Creek Coho Salmon Emergency Rear and Release Validation Monitoring in Marin County, California

Contract P1630403-00, 2017 Annual Report





ON THIS PAGE

Adult male hatchery reared coho swimming upstream on Redwood Creek
Photo by: Sarah Carlisle

ON THE COVER

Juvenile coho salmon tissue sample collected from Redwood Creek
Photo by: Martha Ture

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Contract P1630403-00, 2017 Annual Report

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April, 2018

The following manuscripts received the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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This report was prepared for the Golden Gate National Parks Conservancy through funding from California Department of Fish and Wildlife Fisheries Restoration Grants Program Contract P1630403-00. This report is available by sending a request via email to **Michael_Reichmuth@nps.gov**.

Please cite this publication as:

Reichmuth M., S. Carlisle, B. McNeill, and E.A. Gilbert-Horvath. 2018. Redwood Creek Coho Salmon Emergency Rear and Release Validation Monitoring in Marin County, California: Contract P1630403-00, 2017 Annual Report. Golden Gate National Parks Conservancy, San Francisco, California.

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Executive Summary

The National Park Service (NPS) monitors populations of coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) in Golden Gate National Recreation Area (GOGA), and Muir Woods National Monument. The Redwood Creek watershed, located in Marin County, California, is the only coho bearing stream managed by GOGA. Critically low population levels of coho salmon within Redwood Creek triggered further action to save the species from local extirpation. In December of 2016, 106 adult coho salmon were released into Redwood Creek to prevent extirpation of the population and ensure continued persistence of the species within the stream. The NPS Inventory and Monitoring Program and California Department of Fish and Wildlife have supported monitoring of multiple coho salmon life stages in Redwood Creek since 1997. This report focuses on the summer juvenile coho surveys, which seek to quantify the number of juveniles occupying the watershed during the summer months and validate the success of the adult coho salmon release.

The 2017 juvenile coho population estimate for Redwood Creek was 911, 95% CI [669; 1,153] which is an increase when compared to the 2014 estimate of 51, 95% CI [21; 93]. Juvenile coho were widely distributed throughout the mainstem of Redwood Creek with only a few observations in tributaries. However, the juvenile population was smaller than anticipated given the adult coho release. Genetic sampling confirmed that at least 22% of the released adult female coho successfully spawned and constructed viable redds. The success rate was lower than anticipated for this program but did match survival rates from nearby streams, suggesting season-specific environmental factors may have impacted spawning success. Additional field collection of coho smolt tissues in spring 2018 from this same cohort will determine if there are additional unique parents.

Acknowledgments

We thank all the volunteers who hiked equipment to sampling locations and assisted in field activities. We also thank partner organizations including the U.S. Army Corps of Engineers, Friends of Lake Sonoma, and Golden Gate National Recreation Area. We thank Elizabeth Edson for GIS support. Finally, we are grateful for the generous contributions from the California Department of Fish and Wildlife, Golden Gate National Parks Conservancy, and the San Francisco Bay Area Inventory and Monitoring Program. Without all of the above partners, this project would not have been feasible.

1 Introduction

Prior to 2014, Redwood Creek (Marin County, California) was the southernmost coho salmon population with consistent annual coho spawning. It is also a genetically distinct population within the Central California Coast Evolutionary Significant Unit (CCCESU) (Bjorkstedt et al. 2005, Gilbert-Horvath et al. 2016). Until December of 2015, Redwood Creek remained one of the few existing coho salmon populations in California with no documentation of hatchery augmentation. Due to the low number of returning spawners over the past ten years (Figure 1)(Carlisle et al. 2018), captive rearing of Redwood Creek coho salmon was recommended by the collaborative California Department of Fish and Wildlife (CDFW) / National Oceanic and Atmospheric Administration (NOAA) Priority Action Coho Team (PACT) in 2012. Rescue rearing activities were initiated by the CDFW during the summer of 2014 with the first significant adult release occurring during the winter of 2016-2017. The Redwood Creek Coho Salmon Rescue and Captive Rearing Project (Redwood Creek RCRP) is anticipated to run through the winter of 2018-2019, with adult releases anticipated during each spawning season. The primary goal of the Redwood Creek RCRP is to prevent extirpation of any of the three brood years during the three consecutive years of the project. In addition to this main objective, the Redwood Creek RCRP hopes to increase the population size with the objective of increasing the population viability (please refer to the [Redwood Creek RCRP](#) for more information). The results of this report will focus on work funded by CDFW Contract P1630403-00 to the Golden Gate National Parks Conservancy (GGNPC). The funding provides for summer juvenile validation monitoring to assess the short term impacts of the Redwood Creek RCRP.

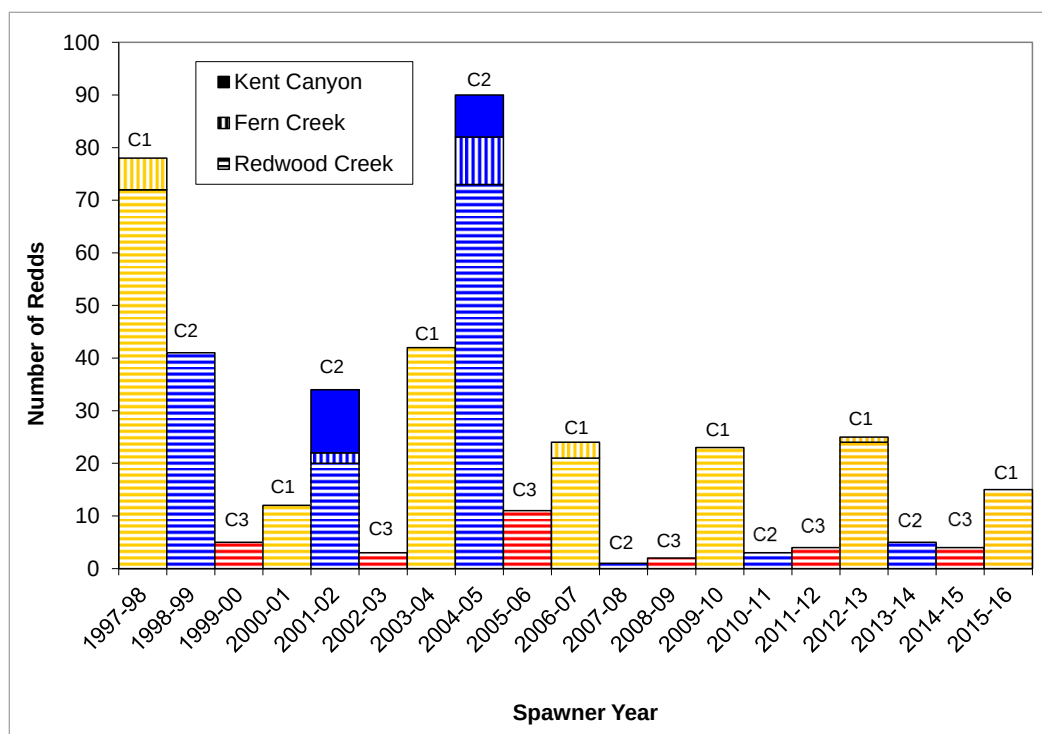


Figure 1. Coho salmon redd numbers in the Redwood Creek watershed by cohort for winter 1997-1998 through winter 2015-2016. Cohorts are designated by color (cohort 1 shown in yellow, cohort 2 shown in blue, cohort 3 shown in red), and creeks are designated by pattern (Redwood Creek in horizontal lines, Fern Creek in vertical, and Kent Creek in a solid color).

The validation monitoring for the Redwood Creek RCRP is performed by the San Francisco Bay Area Network Inventory and Monitoring Program (SFAN). Salmonids were identified by SFAN as one of the network’s vital signs, or indicators of ecosystem health. Monitoring a balanced and integrated set of vital signs meets the scientific monitoring needs of current park management, but will also help detect unanticipated environmental conditions in the future. Salmonids represent a particularly high priority vital sign for SFAN, because coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) are important indicators of ecosystem health, provide important links between marine and freshwater ecosystems, have endangered or threatened status, and garner high public interest. For these reasons, SFAN developed a robust long-term monitoring program in coho salmon bearing streams within National Park Service (NPS) lands (Figure 2).

The summer monitoring performed follows protocols established in the SFAN Salmonid Monitoring Protocol v4.0 (Reichmuth et al. 2010). Any deviations or additions in methodology specific to this validation study are highlighted in the Methods section. This report includes summary results of juvenile surveys performed in the Redwood Creek watershed conducted during 2017 and analyzed using results from a parentage analysis provided by the NOAA Fisheries Southwest Fisheries Science Center (SWFSC) Molecular Ecology and Genetic Analysis Team.

1.1 Background

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

Dramatic declines in salmonid populations throughout coastal watersheds have occurred with changes in watershed condition as a result of land use and development. Salmonids require connected surface flow for migration and dispersal (dams and culverts typically are barriers), cold temperatures (<70°F) and high dissolved oxygen levels (>4.5 mg/l) (Moyle 2002, Brett and Blackburn 1981). While most salmonids have been affected by watershed development, coho salmon are particularly susceptible due to their semelparous (spawning only a single time prior to death) three year life cycle, requiring an entire year of residence in freshwater prior to smolting and migrating to the ocean.

Based on historic regional accounts, numbers of coho salmon have been severely depleted. Redwood Creek is one of the few remaining coastal Marin County streams that still support populations of coho salmon (Lagunitas Creek [including Olema Creek tributary], Redwood Creek, Pine Gulch Creek, and Walker Creek). Some of the factors believed to have contributed to the declines in anadromous fish runs within these streams include (NMFS 2012):

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

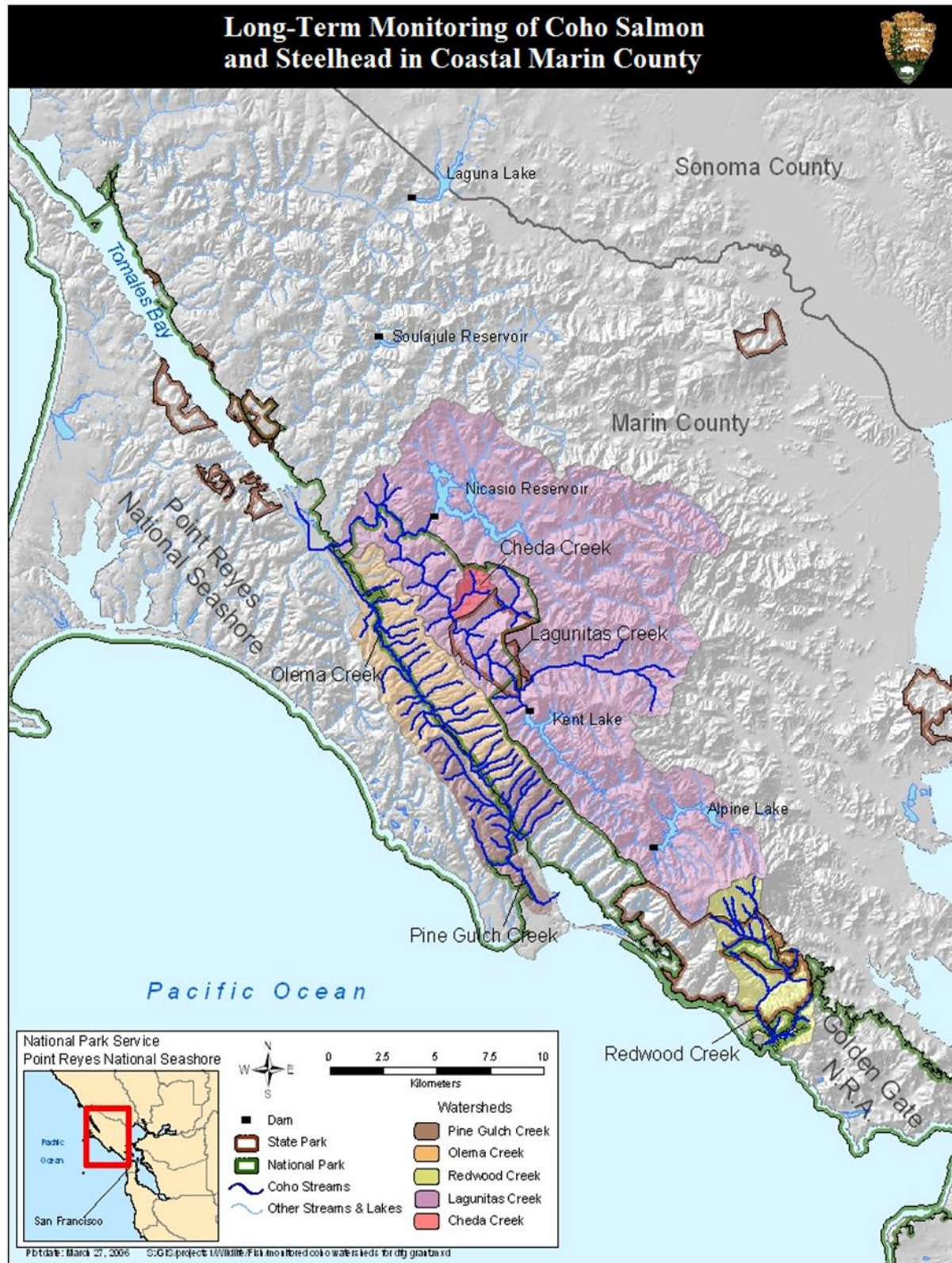


Figure 2. Streams within National Park Service (NPS) lands supporting coho salmon and steelhead in coastal Marin County, California. The NPS monitors streams in Point Reyes National Seashore (Olema and Pine Gulch Creeks) and Golden Gate National Recreational Area (Redwood and Cheda Creeks).

1.2 Coho Salmon

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

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

1.3 Monitoring Rationale

Until the winter of 2015-2016, Redwood Creek remained one of the few existing coho salmon populations in California with no documentation of hatchery augmentation. Due to the low number of returning spawners over the past ten years (Carlisle et al. 2018), captive rearing of Redwood Creek coho salmon was recommended by the collaborative CDFW / NOAA PACT in 2012 and listed as a recovery action step in the CCC ESU federal recovery plan (NMFS 2012). With funding provided by GGNPC, a three year coho collection and rearing program was established by CDFW for the Redwood Creek coho population starting in 2014 with 129 juvenile coho collected.

Rescue rearing activities were initiated by the CDFW during the summer of 2014 with planned adult releases anticipated during the winter of 2016-2017. Subsequent juvenile coho collections occurred during the summers of 2015 and 2016 with anticipated releases during the winters of 2017-2018 and 2018-2019. Up to 200 juveniles were collected from throughout the watershed, and taken to the Don Clausen/Warm Spring Hatchery to be reared to adulthood. Salmonids produce high numbers of offspring per individual— a life history strategy that offsets high rates of mortality that occur throughout their life-cycle. In freshwater systems, there is a large range of mortality rates experienced by coho juveniles during early development due to annual variations in stream condition and habitat quality (Moyle 2002). However, the highest mortality is usually experienced during the ocean phase of the salmonids life with typically less than 3% of the outmigrating smolts surviving to return as adults (Peterson et al. 2015). Raising the collected juveniles to adulthood increases this survival rate to near 100%. This ensures a substantial adult coho effective spawning population for the winters in which adult coho out-planting occurs. Once out-planted, it has been theorized that the

released coho will present natural courtship behavior and spawn in the natural streambed creating a more robust juvenile population than has been documented over the last 10 years (Carlisle et al. 2018).

Our monitoring of the spawning activity and juvenile coho population on Redwood Creek during the summers of 2017 through 2019 will be used to validate the success of hatchery reared coho spawning within Redwood Creek and help guide adaptive management of future rear and release programs. Spawner surveys are performed during the winter and can be used to validate the success rate of the released adults, but environmental conditions and observer efficiencies can be extremely variable. In addition, female fecundity of hatchery reared coho and the successful deposition of viable fertilized eggs in habitat conducive for egg incubation remains unknown. Juvenile surveys are performed during the summer season, when environmental conditions are fairly stable. Juvenile population estimates combined with a parentage analysis provides an accurate assessment of the success of the adult release in relation to the program goals.

1.3.1 Monitoring Objectives

The objectives of this project include monitoring juvenile coho abundance and distribution data. These data can be combined with genetic sampling and parentage analysis, to evaluate the success of the Redwood Creek RCRP and inform future actions.

Utilizing a combination of survey techniques (habitat type surveys, juvenile snorkel surveys, electrofishing, and seining), data will be collected to determine current juvenile coho distribution, densities, condition, and abundance.

1.4 Watershed Background

Redwood Creek is a 23.1 square km (8.9 square mile) coastal watershed (Jones and Stokes 2007) in southern Marin County, California (Figure 2). Redwood Creek flows southwest from the flanks of Mt. Tamalpais, through Muir Woods National Monument (MUWO), discharging to the Pacific Ocean at Muir Beach. Protected from development, the watershed is primarily contained within the boundaries of Mt. Tamalpais State Park, Golden Gate National Recreation Area, and MUWO. The watershed provides habitat to three federally protected aquatic species (coho salmon – endangered; steelhead – threatened; and the California red-legged frog – threatened). In 2005, Bjorkstedt et al. described the coho salmon residing in Redwood Creek as a genetic outlier within the CCCESU with genetic distance from all other samples collected within the CCCESU. However, a more recent study of 30 populations spanning the state, found that while Redwood Creek is genetically differentiated from other populations, it also retains some similarity to nearby southern CCCESU populations (Gilbert-Horvath et al. 2016).

2 Sampling Design and Methods

This project focuses on monitoring juvenile salmon within the Redwood Creek watershed as part of the rescue-rearing project initiated in the summer of 2014 by CDFW. Field methodologies follow those utilized by the NPS SFAN Coho and Steelhead Monitoring Program, which includes salmonid surveys for adult, smolt, and juvenile life stages (Figure 2). All Standard Operating Procedures (SOPs) summer juvenile coho basinwide surveys are documented in the SFAN Salmonid Monitoring Protocol version 4.0 ([Reichmuth et al. 2010](#)). The methods described in this report are provided as a summary of detailed methods within the SFAN Salmonid Monitoring Protocol used for this validation project.

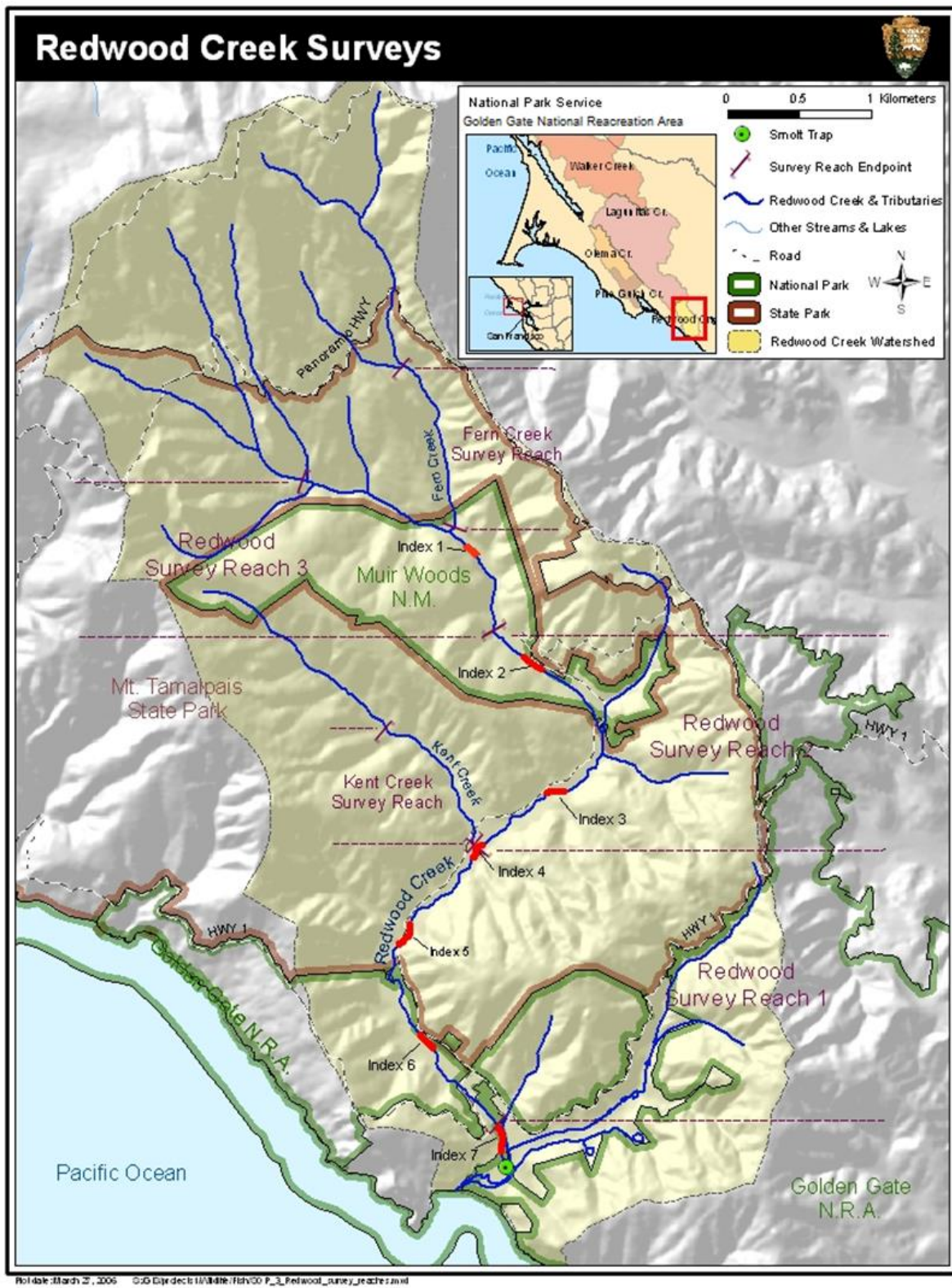


Figure 3. Redwood Creek survey locations. Adult spawner reaches, summer index reaches, and smolt trap locations are shown.

2.1 Juvenile Coho Surveys

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

The primary activity conducted in the watersheds is basinwide general systematic survey (GSS) monitoring during the summer/fall sampling period. Complete published field methods are documented in SOPs 1, 3, 6, and 9 in [Reichmuth et al. 2010](#). The descriptions of field methods for summer juvenile coho and steelhead monitoring are organized by survey type, since a variety of techniques are utilized during the season. Although multiple survey techniques may be deployed within the same sampling period, the basinwide GSS monitoring is treated as a standalone survey.

2.1.1 Basinwide General Systematic Surveys

Basinwide survey techniques, developed by Hankin and Reeves (Dollof et al. 1993), provide statistically valid estimates of stream habitat type and salmonid population size for a broad area or entire stream. Basinwide surveys involve a two-stage sampling design using both snorkeling and electrofishing. This two-stage sampling combines labor-intensive data collection for a randomly selected subsample of units correlated with data from a less labor-intensive sampling technique to achieve representation while reducing effort. Sampling units are classified as pool (scour pool, plunge pool, or mid-channel pool), flatwater, or riffle using level III of the CDFW classification system (Flosi et al. 1998). Every fifth pool unit is flagged for snorkeling, and several measured widths are taken for the purpose of calibrating the estimated width. All large woody debris, live or dead, providing in-stream shelter during summer base flow conditions are counted and recorded within each habitat unit. Program staff survey each of the previously determined pools with a single-to triple-pass snorkel count, using dive lights to search under vegetation, woody debris, and undercut banks. Only coho are counted, but the presence of steelhead and non-salmonid fish is also noted. Typically, snorkeling is calibrated by follow-up electrofishing of randomly selected dive pools to provide an unbiased calibration method. When electrofishing is not feasible, units may be calibrated using a repeat snorkeling method.

2.1.2 Changes to Methodology

During snorkel surveys, a handheld GPS device is used to record the location of each snorkeled habitat unit. The GPS device saves each location as a waypoint, and all waypoints are downloaded in-office immediately following a survey. In recent years, the lower densities of juveniles within the stream have precipitated an increase in sampling frequency. Every fourth pool and tenth flatwater is flagged for snorkel surveys. During summer juvenile surveys on Redwood Creek, pools that could not be electrofished due to the abundance of wood or depth greater than the height of the electrofisher shutoff sensor are re-snorkeled using repeat snorkel passes for calibration. Fish in these units are later seined for biotic information and tissue collection. Sampled pools are *either* seined or electrofished, not both. Juvenile coho tissue samples are collected using the similar field methods as Gilbert-Horvath et al. 2016.

2.2 Juvenile Coho Genetic Analysis

DNA was extracted from fin tissue samples using Qiagen DNeasy 96 Tissue Kits (Qiagen, Inc.), as described in Gilbert-Horvath et al. (2016). A panel consisting of 95 single nucleotide polymorphism, or SNP, loci developed for coho salmon (Starks et al. 2016) was genotyped using a Fluidigm EP1 system (Fluidigm Corp.). Genotype data were analyzed using Colony v2.0.2.2 software (Jones and Wang 2010) to infer sibling relationships and parentage of the juveniles. The candidate parents included not only the adults released directly into Redwood Creek in winters 2015-2016 and 2016-2017 (n=72 females and 41 males), but also excess Warm Springs Hatchery broodstock adults released in winter 2016-2017 into Salmon Creek (n=136 females and 178 males), and 4 unreleased individuals. The latter groups were included for two reasons: 1) released adults have been found to occasionally switch basins following release into freshwater, hence it is unlikely but not out of the question that these released adults could have entered Redwood Creek to spawn, and 2) including unlikely parents among the candidate parents provides a test of the robustness of the parentage inference. Separate infiles were created for candidate fathers (n=222), mothers (n=209) and offspring (n=189 successfully genotyped). At the timing of writing, for reasons related to laboratory logistics, the four remaining juvenile samples had been added to the genotyping queue but had not yet been genotyped. The probability of the true father of an offspring being among the genotyped, released males was set to 0.20, and the probability of a true mother being among the genotyped, released females was the same. Both sexes were assumed to have the potential to be polygamous, i.e., to mate with multiple members of the opposite sex.

3 Monitoring Results

3.1 Redwood Creek Juvenile Coho Basinwide 2017 Results

The 2017 summer habitat and basinwide snorkel surveys of Redwood Creek were initiated at the confluence of Redwood Creek and the Pacific Ocean, and continued upstream to monument tag 74, within Mt. Tamalpais State Park. The measured basinwide survey length for the main channel was 8.6 km. An additional 0.8 km was surveyed on Fern Creek, a tributary to Redwood Creek. Historical results were collected as part of long-term monitoring, and are presented for comparison. Although information on steelhead and index reaches was collected during the summer of 2017, only basinwide coho sampling results are presented in this report.

3.1.1 Habitat Survey

A total of 662 mainstem habitat units were identified within the 8,626 m Redwood Creek survey reach. Pool units were the primary habitat type accounting for 5,349 m and 62% of the total mainstem length. Dry units were not observed on the mainstem during surveys. Habitat composition data for Redwood Creek can be found below in Table 1. Overall, 615 m of side channel habitat and 219 m of backwater habitat units were measured during the basinwide survey. Riffle units accounted for 35% of the side channel habitat length.

An additional 824 m were surveyed in Fern Creek, a tributary to Redwood Creek. Riffle units accounted for the majority (54%) of the length. Pool units represented 24% of the length, while flatwater units accounted for the remaining 21%.

The total mainstem survey length was used to calculate the density of side channel and backwater habitat, 7.3 m per 100 m and 2.6 m per 100 m, respectively. The density of side channel and backwater habitats in 2017 were considerably higher than the historical averages (2004 to 2016 side channel average of 4.3 m per 100 m, 2004 to 2016 backwater average of 1.7 m per 100 m).

Table 1. Habitat composition of Redwood Creek coho survey reach, summer 2017. Measured length is used to calculate percentages of length per habitat type.

	Total length (m)	% of length	# of units	% of units
Pool	5,349	62	286	43
Flatwater	1,026	12	112	17
Riffle	2,251	26	264	40
Dry	0	0	0	0
Total	8,626	100	662	100

Woody debris information collected during the basinwide habitat survey is summarized for 2005 to 2017 (Table 2) and may be used to identify trends in woody debris availability and recruitment. The only two categories of woody debris to exceed the historical averages were the categories of root wads and 20-50 cm wood.

Table 2. Summary of mainstem Redwood Creek basinwide in-stream woody debris (WD) per 100 m during summer base flow conditions. Average 2005-2016 compared to 2017.

Field season	Survey length (# 100 m sections)	Root Wads per 100 m	LWD Jams per 100 m	SWD Jams per 100 m	10-20cm WD per 100 m	20-50cm WD per 100 m	>50cm WD per 100 m
2005-2016 Average	81.4	1.1	0.4	0.8	3.4	2.7	1.3
2017	86.3	1.4	0.4	0.6	3.4	4.0	1.1

LWD Jams= 10 or more pieces of large woody debris

SWD Jams= 10 or more pieces of small woody debris

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

Woody debris information was also collected on Fern Creek. The category of 20-50 cm woody debris had the highest density at 3.3 per 100 m. Root wad density was the lowest at 0.5 per 100 m.

3.1.2 Coho Snorkel Counts

Snorkel surveys were conducted on 24% of the delineated pools with coho observed in 62% (43 out of 69) of the sampled pools. A total of 253 coho were counted in the 69 snorkeled pools, giving a raw average of 3.7 coho per snorkel pool. An additional six pools were snorkeled on Fern Creek. No coho juveniles were observed on Fern Creek pools during the snorkel surveys. Fourteen of the 69 snorkeled pools (20%) were electrofished within a day following the snorkel counts. *Microfish* population estimates for the electrofished pools were used to calibrate the snorkel counts. On Fern Creek, two pools with snorkel counts of zero coho were subsequently electrofished for calibration, and no coho were captured. The 2017 basinwide estimate for juvenile coho was 911, 95% CI [669; 1,153]. Summer coho population estimates with 95% confidence interval were calculated for the basinwide survey reach from 2005 through 2017 (Figure 4). For the summer 2017 basinwide surveys, genetic analysis of juvenile coho tissue samples (presented in section 3.2) allowed for estimates of progeny abundance based on parent group type (ocean-reared, hatchery-reared, or mix of hatchery- and ocean-reared). This resulted in a coho ocean-reared progeny estimate of 70, 95% CI [40; 100], a coho hatchery-reared progeny estimate of 385, 95% CI [230; 540], and a coho hatchery- and ocean-reared progeny estimate of 391, 95% CI [296; 486].

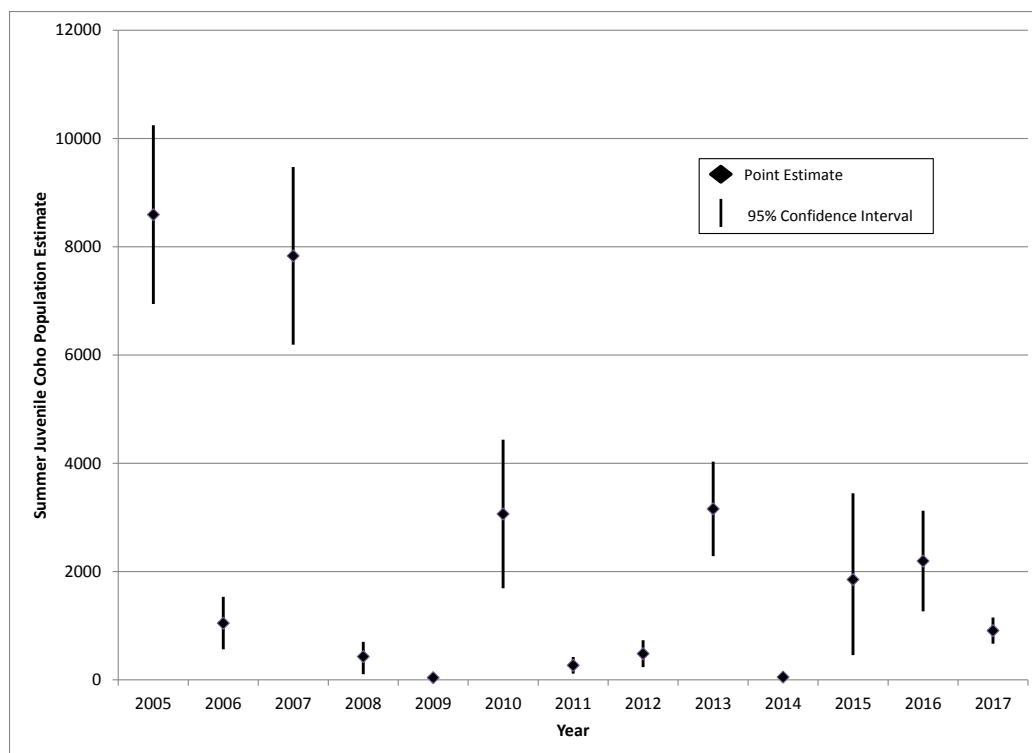


Figure 4. Summer juvenile coho basinwide population estimates for Redwood Creek, 2005-2017.

3.1.3 Summer Coho and Steelhead Measurement Information

A total of 62 juvenile coho were measured for fork length (mm) and weighed (0.01 g). Coho fork lengths measured during 2017 summer monitoring of Redwood Creek ranged from 50 mm to 83 mm. The highest fork length frequencies for coho occurred within the 61 to 65 mm length interval, representing 21% of the sample, and within the 76 to 80 mm length interval, representing 29% of the sample. The Redwood Creek mean and median coho weight was 4.3 g (SD 1.30 g). Coho juvenile length (a) and weight (b) information collected from Redwood Creek during basinwide sampling is represented in Figure 5.

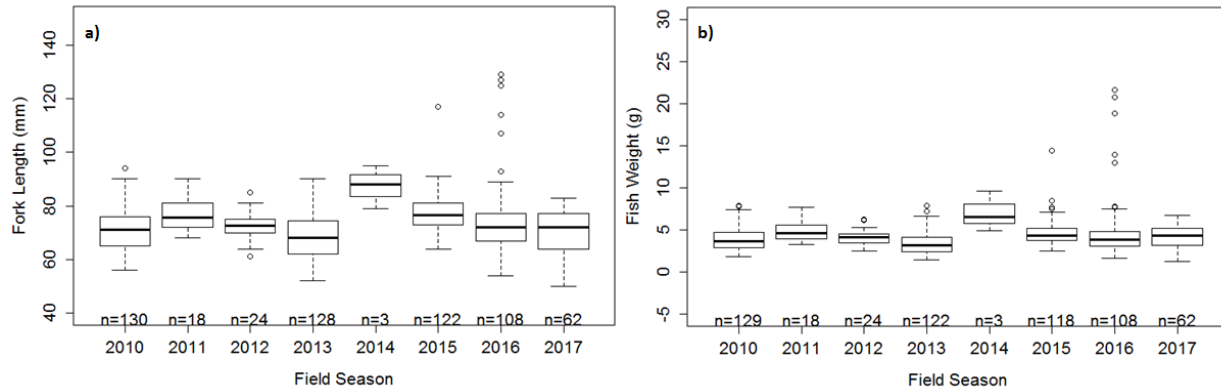


Figure 5. Box and whisker plots for juvenile coho lengths (a) and weights (b) for basinwide Redwood Creek, summer 2010-2017 (no coho captured in 2009). Dark Lines represent medians, circles represent outliers.

3.1.4 Coho and Steelhead Fulton's Condition Factor

Length is the principal factor affecting the weight of fishes. In spite of this, there can be significant differences in weight distribution among similar size fish of the same species within a particular watershed. In order to compare length-weight relationships, we applied the Fulton's condition factor (K-factor) to establish comparable indices of condition (Murphy and Willis 1996). Fulton's condition factor is a ratio relating fish length to fish weight, allowing for the measurement of the relative biomass of a fish. Table 3 shows length, weight, and K-factor for coho captured during basinwide sampling on Redwood Creek in summer 2017.

Table 3. Mean and median fork length, weight, and K-factor for coho measured and weighed in the basinwide and complex calibration pools on Redwood Creek mainstem, 2017.

Species	Sample Size	Mean Fork Length (mm)	Fork Length Standard Deviation	Median Fork Length (mm)	Mean Weight (g)	Weight Standard Deviation	Median Weight (g)	Mean K-Factor	K-Factor Standard Deviation
Coho	62	71	7.6	72	4.3	1.30	4.3	1.16	0.07

3.1.5 Juvenile distributions based on heritage

Wild to hatchery juvenile distribution was determined by using a parentage analysis of juvenile coho salmon tissue samples collected during the summer of 2017. Tissue samples were analyzed by the NOAA Fisheries Southwest Fisheries Science Center (SWFSC) Molecular Ecology and Genetic Analysis Team. These samples were then associated with collection locations to determine distribution of hatchery and wild progeny within Redwood Creek during the summer of 2017 (Figure 6). Samples were also used to show the distribution of family groups within Redwood Creek during the summer of 2017 (Figure 7). Family groups were dispersed throughout Redwood Creek with an average distribution of sibling groups of 2.9 km.

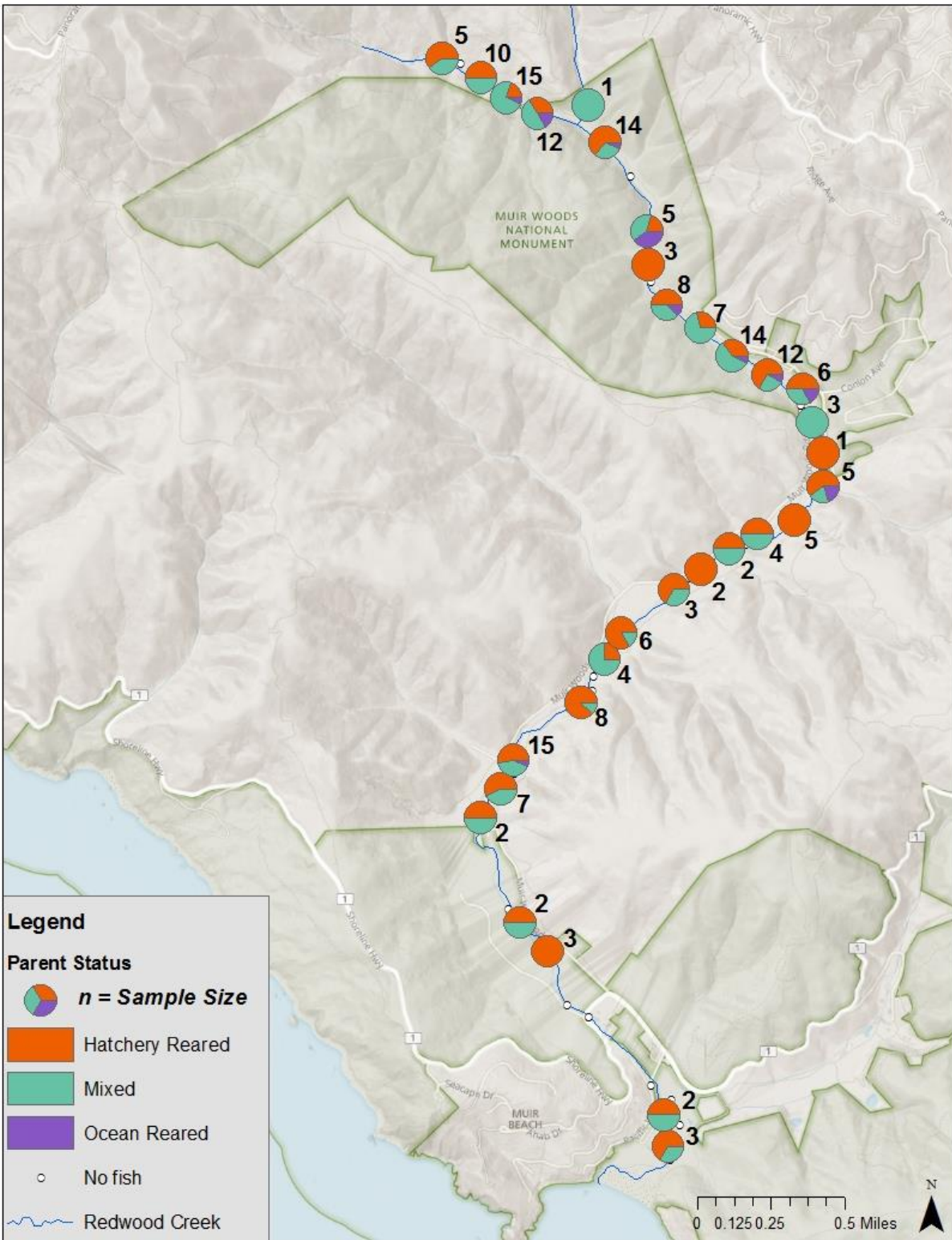


Figure 6. Juvenile coho salmon distribution based on ocean-reared and hatchery-reared parentage in the Redwood Creek watershed, summer 2017 (n refers to the total number of tissue samples collected at each location). Open circles without annotations represent sample locations in with no coho captured.

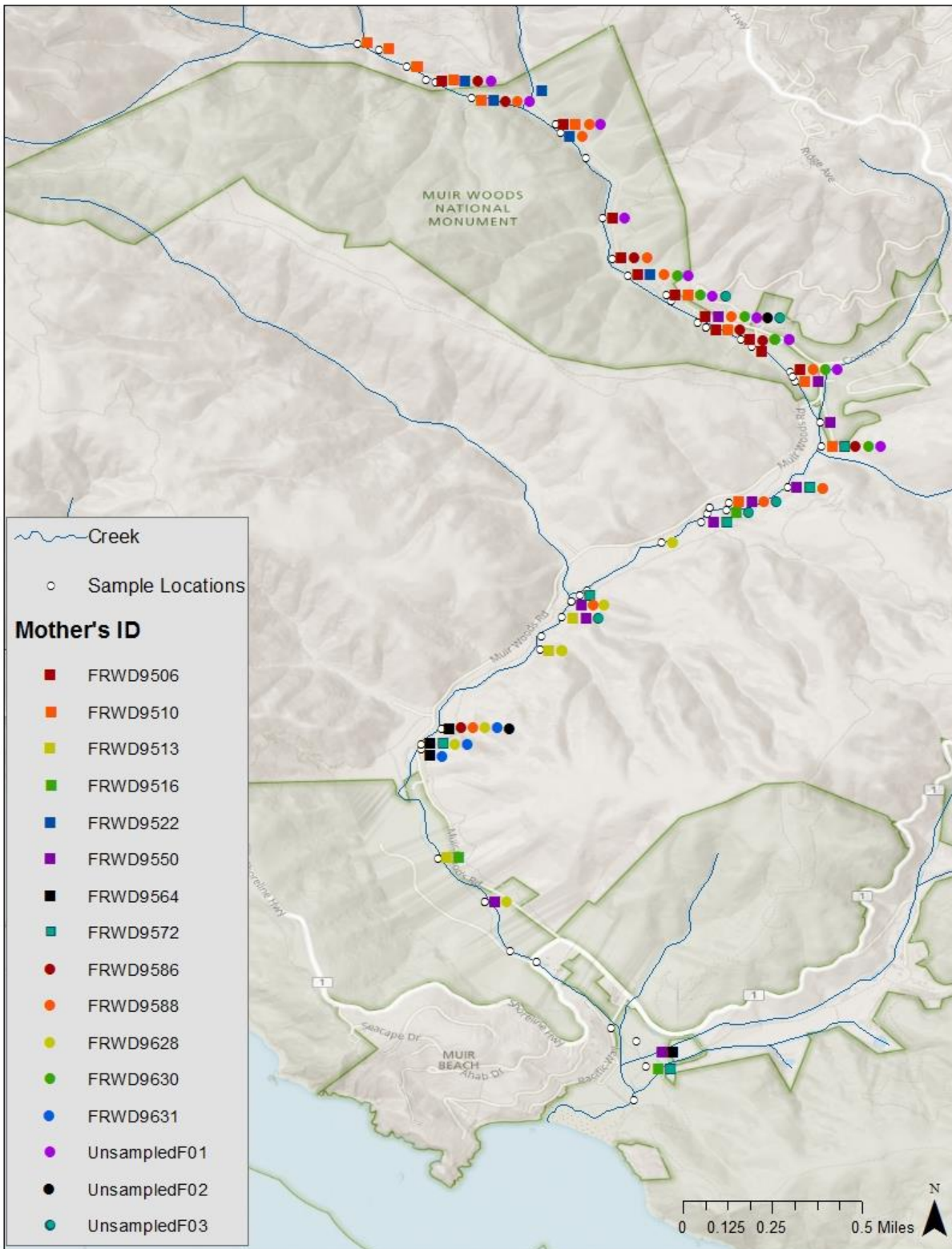


Figure 7. Distribution of juvenile coho in the Redwood Creek watershed by family group, summer 2017. Only coho with at least one sibling are shown above. Open circles without annotations represent sample locations in with no coho captured.

3.1.7 Survival rates

As part of an effort to gage the effectiveness of the Redwood Creek RCRP, the juvenile production estimate is used to create survival rates between the egg (redd) and juvenile life stages. Adult spawner surveys are performed on Redwood Creek as part of the long-term monitoring performed by the NPS. The spawner survey results in combination with the summer juvenile survey and genetic analysis reported are used to validate the success of each cohort.

During the winter of 2016-2017, 106 adult coho spawners taken as juveniles from Redwood Creek and raised to maturity at Don Clausen Fish Hatchery, were released at various sites in the lower 2 km of Redwood Creek. Sixty-nine were females, 34 were males, and three were jacks (precocious males). The release coincided with a rain event (2.48 inches in 3 days), which allowed access to all portions of the watershed for spawning. Forty-seven live adult coho were subsequently observed on the mainstem of Redwood Creek during the 2016-2017 spawner season, with 37 of those observed fish displaying hatchery floy-tags (19 pink [female] and 18 green [male] tags).

Higher than average rainfall during the winter of 2016-2017 limited stream access and ability of observers to discern new redds. Both January and February were some of the wettest months on record (11.34 inches and 10.06 inches, respectively). Due to the high flow conditions, fewer surveys were conducted during the season. This may, in part, explain why a majority of redds could not be positively identified as coho. Only four confirmed coho redds were observed during the 2016-2017 spawner season. The total density of redds was 0.55 redds/km in the approximately 7.8 km of mainstem stream surveyed. No confirmed coho redds were observed on any of the tributaries surveyed.

Twelve unknown redds were observed on the mainstem, and three unidentified redds were observed on Kent Canyon. A logistic regression model developed by Gallagher and Gallagher (2005) uses redd surface area and date of redd observation to assign species. The Gallagher model classified 9 of the 12 unidentified mainstem redds as coho resulting in a total count of 13 coho redds. The Gallagher model also classified the three unknown redds on Kent Canyon as coho resulting in a total of 16 coho redds for the Redwood Creek watershed.

The unknown redds were also classified using the K-nearest neighbor algorithm (kNN) which relies on temporal and spatial data of known redds. Species designation for an unknown redd is based on the three closest known neighbors (Garwood and Larson 2014). The kNN algorithm classified all unknown redds as coho, resulting in 19 coho redds for the Redwood Creek watershed.

Survival rates based on observed redds will be presented as a range based on the two estimation methods described above and the juvenile population estimate CI. Estimated number of coho eggs were determined using the average female fork length and egg estimator found in Shapovalov and Taft 1954. Survival rates for the coho juveniles from egg to juvenile ranged from 1.6% (with 19 redds and lower juvenile CI) to 3.2% (with 16 redds and upper juvenile CI). These survival rates fall within the lower observed range of survival rates documented in previous years. Survival rates historically range from 0.9% calculated for summer of 2004 to 22.6% for the summer of 2016.

3.2 Redwood Creek Juvenile Coho Genetic Results

Based upon reconstructed sibling groups (sibships) and their inferred parents, the 189 genotyped juveniles were produced by 50 unique spawning adults: 31 males and 19 females. Of these 50 adults, 46 were inferred to have spawned in winter 2016-2017, and four in winter 2015-2016. A total of 45 full sibships were found, 18 of which were not groups but singletons; two-thirds of the sibships contained three or fewer individuals. Each full sibship represents a unique female-male spawn pair. All sibships except one had inclusion and exclusion probabilities of > 0.99 , indicating strong support for the inferred relationships. The three largest full sibships contained 19, 17 and 12 individuals, and the mean number of members per full sibship was 4.2.

Released adults accounted for the majority (36 of 50) of parents associated with the sampled juveniles (Figure 8). Of 19 mothers, 16 were released adults, contributing to 38 of the 45 full sibships, including the largest ones, and producing 163 of 189 juveniles. Twenty of the 31 fathers, including two jacks, were released adults, producing 113 juveniles. Released adults spawned with each other as well as with presumptive ocean returning (unsampled) adults (Figure 9). Crosses involving released females were responsible for a larger number of both sibships and offspring than those involving unsampled females. No released Salmon Creek parents were detected through the parentage analysis.

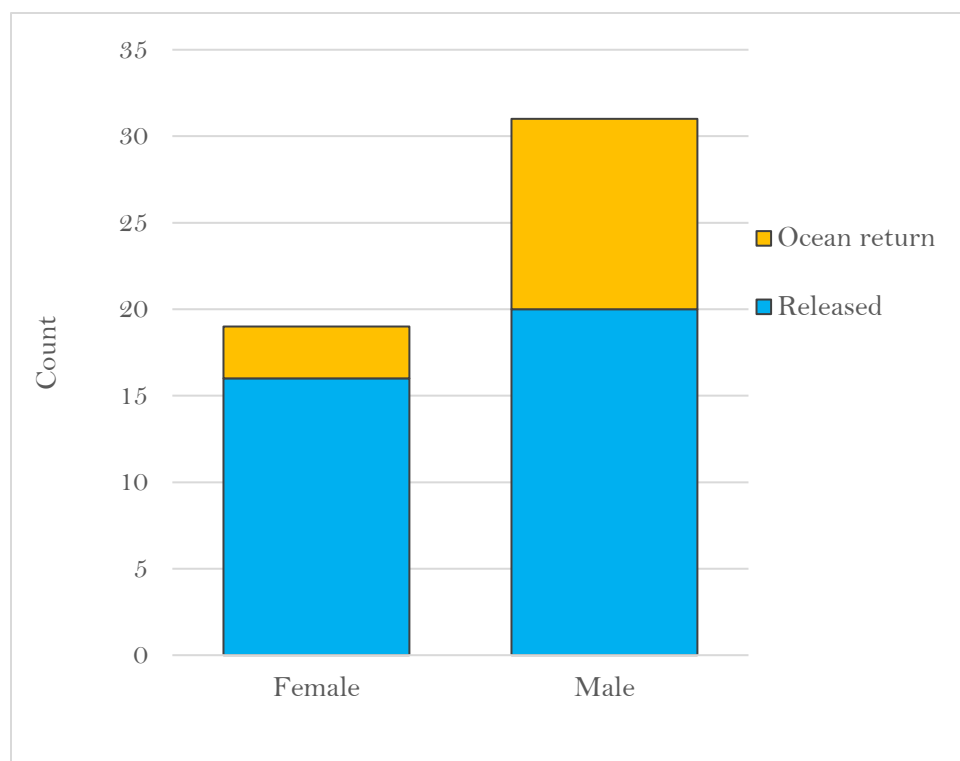


Figure 8. Source of 50 adults spawning in Redwood Creek, inferred from parentage analysis of juveniles sampled in 2017. Released females and males (blue) were rescued as juveniles from Redwood Creek, reared at WSH, and then released as adults back into the creek. *Ocean returning* adults (yellow) were unsampled, their sex and genotypes were reconstructed during the parentage analysis.

Not all of the juveniles sampled in 2017 were born to adults spawning the previous winter. Four juveniles were noted by Michael Reichmuth as possibly being 2015-2016 brood year holdovers (envelope IDs 2017-285, 321, 366 and 390), based on their length and weight. The parentage analysis confirmed that this was the case and these samples represent approximately 2% of the total samples collected. Three adult males released in winter 2015-2016 spawned with the same unsampled female that winter, producing the four holdover juveniles. Two of the holdover juveniles were found to be full siblings, while the others were half-siblings, all sharing the same mother. A comprehensive, multi-year parentage analysis is currently in progress to determine whether there were additional holdovers among the young-of-year and/or smolts sampled by NPS and CDFW in Redwood Creek in 2016.

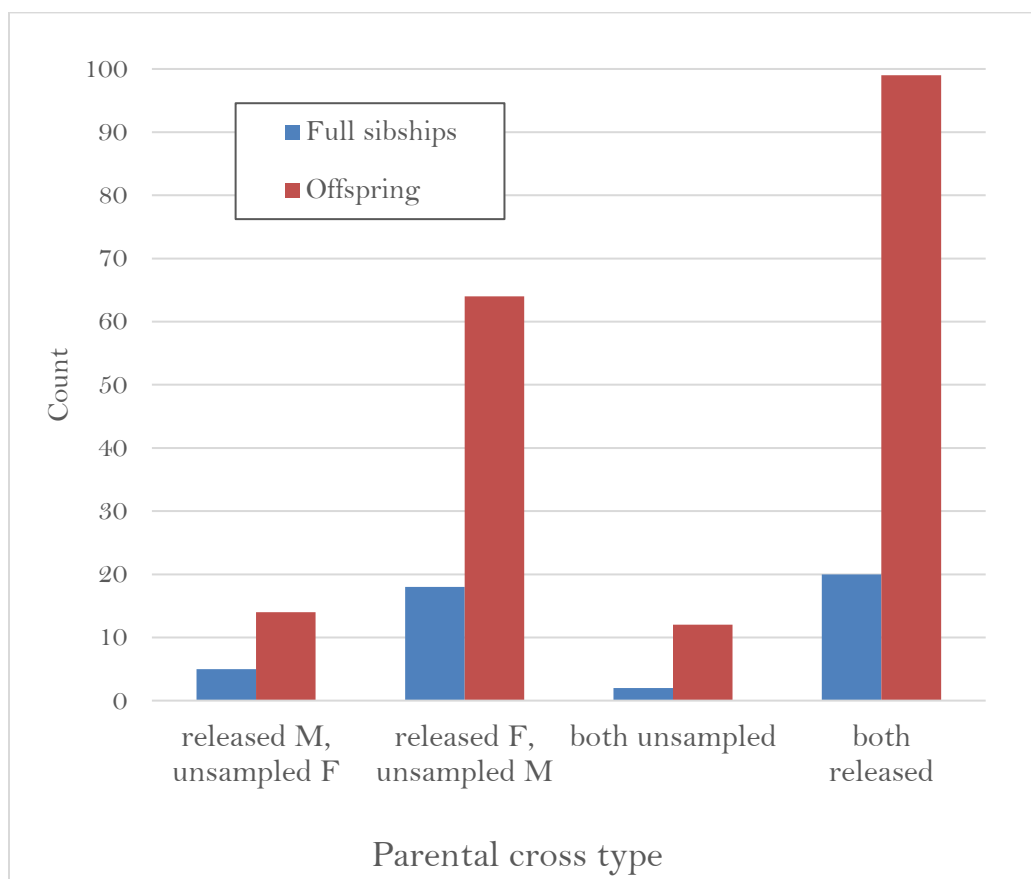


Figure 9. Number of full sibships (blue) and number of offspring (red) produced by each parental cross type, as defined above; unsampled parents are presumptive ocean returns.

The majority of released adults did not produce offspring that were sampled during monitoring (Figure 10); it is not known whether this was due to incomplete juvenile sampling, or to unsuccessful reproduction. Approximately 22% of released females and 45% of released males were identified as parents of the sampled juveniles. If juvenile sampling was incomplete, it is likely we have underestimated the total number of spawners, and, potentially, the proportion of released adults

contributing to the 2016-2017 brood year. Additional sampling during outmigration of smolts during the spring of 2018 could help determine whether juvenile sampling was incomplete.

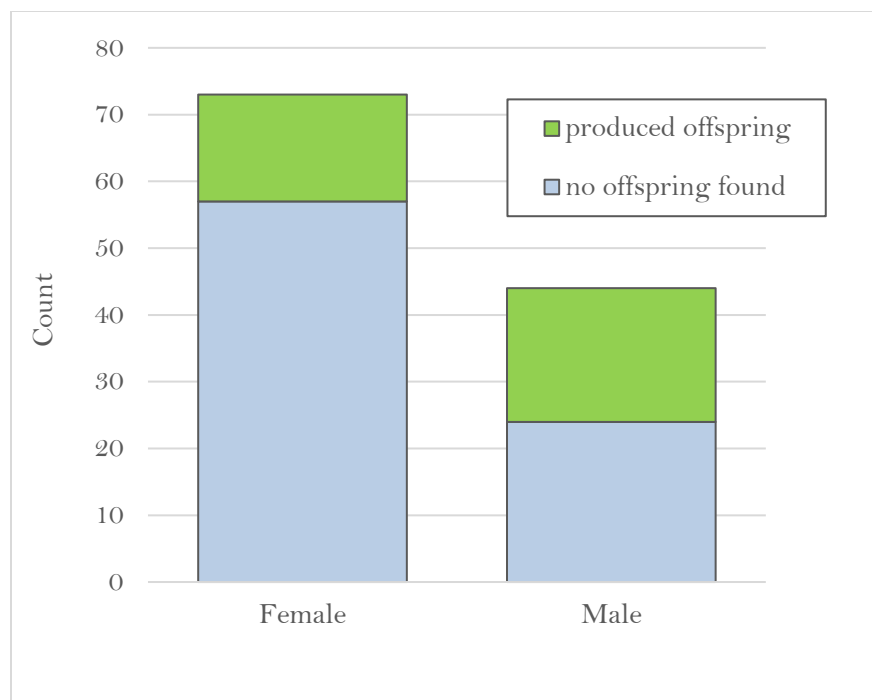


Figure 10. Proportion of adult females and males released into Redwood Creek in winters 2015-2016 and 2016-2017 that were found to have produced offspring sampled in 2017.

4 Discussion

The goal of the Redwood Creek RCRP is to prevent the extirpation of the three brood years of coho salmon in Redwood Creek by temporarily increasing spawner abundance, and to preserve the remaining genetic diversity of the population. With a complete collapse in coho production documented for the 2013-2014 spawning season (Carlisle et al. 2016), the hope of a substantial return of ocean-reared adults to sustain the population was not anticipated. Of the 106 adult coho released, 97% (103 adults) were born in 2013 and were thus released at age four. This is an atypical adult age for coho spawners which usually return at age three or return early as “jacks” at age 1.5. At the time of the release, 13% of the hatchery reared adults were noted as immature with no or very little gonad development. The adult spawner surveys combined with the juvenile coho genetic analysis was able to validate the assumption that four year old hatchery reared coho can produce viable offspring. Although ocean-reared adults did contribute to the 2017 brood year, ocean-reared females only contributed to 8% of the summer juvenile population. Juvenile tissue sample analysis suggests a minimum of 18 successful redds which is higher than reported in winter spawner survey results but consistent with the estimated number of redds calculated using the KNN model. Additional tissue

samples to be collected during the 2018 spring outmigrant smolt trapping can be used to determine the existence of additional parent groups for the 2017 brood year.

The juvenile sampling confirmed that four year old coho salmon can produce viable redds and contribute to the wild population. Hatchery- and ocean-reared coho salmon did not show affinity towards one group as all four possible progeny groups were recorded (ocean female/ocean male, ocean female/hatchery male, hatchery female/ocean male, hatchery female/hatchery male). No progeny from the released immature coho were detected from juvenile tissue sample analysis. However, of the three released jacks (born in 2015), two contributed to the 2017 juvenile coho population, and one spawned with two females. Most females were promiscuous with 63% spawning with more than one male, and one female, in particular, spawned with five unique males.

During the adult coho release on 8 December 2016, fish were released into pools at three locations; Muir Beach pedestrian bridge, Pacific Way Bridge, and Santos Meadow. Seventy-five adult coho were released under the Muir Beach pedestrian bridge approximately 350 meters upstream of the Pacific Ocean. Twelve adults were released under the Pacific Way Bridge approximately 800 meters upstream of the Pacific Ocean. Nineteen adults were released into three pools adjacent to Santos Meadow approximately 2.7 km upstream of the Pacific Ocean. Of the three release groups, the most upstream group had the highest spawning success rate at 42% based on juvenile tissue sample analysis, followed by the Pacific Way Bridge release group at 33%. The Muir Beach release group, with the highest number of coho spawners, had the lowest spawning success rate with only 25% of the released adults contributing to the 2017 summer juvenile coho population. Spawning success rates for release groups during the winter of 2017-2018 and 2018-2019 will be used to determine the relevancy of release locations to spawning success.

Juvenile coho were found utilizing most of the available habitat within Redwood Creek. Average distribution of family groups within the stream was 2.4 km. Tissue samples were collected from approximately 8 km of stream, beginning at the Muir Beach pedestrian bridge and extending to 0.5 km upstream of MUWO, including portions of Green Gulch and Fern Creek. Based on tissue analysis, the majority (75%) of pure ocean-reared progeny resided within MUWO during the summer of 2017. This was also the case for mixed progeny (ocean- and hatchery- reared parents) with 48% residing within MUWO. It is also important to note that 25% of the mixed progeny resided downstream of MUWO while 24% were sampled upstream of MUWO. The majority (42%) of the progeny with pure hatchery-reared parents resided in the Mt. Tamalpais State Park reach between Santos Meadow and MUWO while 40% resided in MUWO. During summer surveys, the majority of juvenile tissue samples (46%) were collected within MUWO.

Survival rates based on spawner survey results, number of female parents from percentage analysis of juvenile tissue samples, and juvenile population estimates indicate that stream conditions were not conducive for coho survival from egg deposition to summer juvenile rearing. Based on spawner survey observations, coho salmon eggs were likely incubating from mid-December through mid-March. During this time period two storm events produced flows in Redwood Creek that exceeded the two year reoccurrence interval (Northern Hydrology and Engineering 2010) during this critical incubation period. It is feasible that the two events, the first on 10 January 2018 and the second on 2

February 2018, caused coho egg mortality due to redd scour. The overall survival rate for coho from redd deposition to summer juvenile is estimated to be between 1.6% and 3.2%. This is below the historic average of 7.8% but comparable to other watersheds in the region. Olema Creek is the closest coho-bearing stream in proximity to Redwood Creek, and a range of survival rates was calculated using the same methodology. On Olema Creek, survival rate ranged from 0.6% to 2.2%. The similar low survival rates observed on both streams, regardless of hatchery augmentation, indicates that environmental conditions such as high flow events likely resulted in decreased egg to juvenile survival.

The juvenile coho population estimate for Redwood Creek was 911, 95% CI [669; 1,153]. The Redwood Creek juvenile coho population estimate is higher than the previous cohort (51, 95% CI [21; 42]). With only three adult females of the 19 females identified through the genetic tissue analysis reared in the ocean, the juvenile population estimate would be much lower if hatchery reared coho were not released into Redwood Creek. However, the juvenile coho estimate represents a small population in the context of population viability, and future rear and release measures may be needed to increase the population to a sustainable level. Downstream migrant traps will be operated during the spring of 2018 to help determine survival and growth from the summer to spring outmigration.

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